

**ENCYCLOPAEDIA
OF BREWING**

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CHRIS BOULTON

 **WILEY-BLACKWELL**

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Writing a book is most suited to solitary hermits and not those with responsibilities to family and friends. This is particularly the case where work has to be fitted in the spaces that the day job doesn't fill. I am indebted to my wife, Wendy, to whom this book is dedicated, for her forbearance, not to mention many hours of sub-editorship in putting it together.

INTRODUCTION

The *Shorter Oxford Dictionary* defines encyclopaedia as ‘a work containing information on all branches of knowledge usually arranged alphabetically or a work containing exhaustive information on some one art or branch of knowledge arranged systematically’. An author who seeks to deliver a product that tries to fulfil these definitions knows that it will be a Sisyphean task. This is especially the case with a subject such as brewing, with its long and rich history, its diversity of processes and products, not to mention the usually strong opinions of its practitioners. In this respect I am well aware that this book will contain errors and omissions and probably an overemphasis on my own particular enthusiasms. For all of these shortcomings I apologise and take full responsibility.

With regard to content, I have tried with each alphabetic entry to give a short initial definition which should provide the reader with all the essential information necessary for understanding such that further time need not be wasted. The remainder of the entry is aimed at those who might wish to have further knowledge. Hopefully, the system of cross referencing will provide greater context. If there is a related entry the linking word is in **bold**.

Brewing and mainstream science have been inextricably intertwined for much of its history as an organised undertaking. Indeed in its first industrial heyday many fundamental discoveries were made by brewers. For this we should be justifiably proud, although it makes for some difficult decisions when deciding what should be included in a book such as this and what should be omitted. This is all the more so when current scientific advances underpin many of the new processes and plants being introduced into brewing. I have tried to steer a course which I am sure many will disagree with but one in which I hope that additional descriptions will serve to help with better understanding.

Finally, I have tried to encompass all parts of our industry, large and small, traditional and modern. For this I do not offer any apology. I see no distinctions.



Abbey beers

Abbey beers are those produced commercially, largely in Belgium, and by statute solely within monasteries either directly or under the supervision of monks. The popularity of Trappist beers in the period following the Second World War provided the impetus for arrangements under which commercial breweries produced beers that used the names of existing, or in some cases fictitious, abbeys as a marketing tool. Commonly the use of a real abbey name involved a licensing agreement. These products are collectively termed Belgian abbey beers. Typically the beers ape the stronger *dubbel* and *tripel* true Trappist beers and in consequence are strong in alcohol, very flavoursome and made by top fermentation prior to bottling and a period of lengthy secondary conditioning.

See **Trappist beers**.

ABD medium

Microbiological growth medium (advanced beer-spoiler detection medium) designed by Asahi Brewers of Japan, for the cultivation of difficult-to-grow lactic acid bacteria. The medium comprises **MRS** broth supplemented with beer (to inhibit non-beer spoilers) cycloheximide (to prevent the growth of yeast) and sodium acetate (shown to be stimulatory to many lactic acid bacteria).

Aber yeast biomass monitor

Apparatus used for the automatic determination of viable yeast concentration (<http://www.aber-instruments.co.uk>; last accessed 7 February 2013). The device depends on the dielectrical properties of microbial cells when suspended in fluids that are conducting because of the presence of charged species. When the cells, in this case yeast, are subjected to electrical fields, the charged species in the suspending medium (wort or beer) and those which are intracellular migrate towards the electrode bearing the opposite charge. Since the cell membrane is non-conductive the cells function as capacitors and the magnitude of this can be measured. The total yeast cell membrane area, or biovolume, within the operating field of the electrode can be related to yeast biomass. Providing the sample is well-mixed the derived value of capacitance measured by the instrument can be expressed in the usual units of yeast concentration

such as viable cells per millilitre or viable yeast mass per unit mass or volume. Dead cells, which have a disrupted cell membrane, do not function as capacitors and are therefore not detected. In this respect the measured capacitance correlates strongly with the fraction of a yeast sample scored as viable by a conventional vital staining approach such as methylene blue. Similarly gas bubbles and non-yeast solids do not generate capacitance and are not detected. A corollary is since dead cells are not detected it does not provide any indication of viability.

Calibration involves setting zero and then determining the relationship between derived capacitance and viable biomass concentration. Strain-dependent differences in electrical properties require calibrations to be made for each individual strain. Once these are entered into the memory of the machine they do not need to be repeated. The linear range of the instrument is approximately 1×10^5 to 1×10^9 cells per millilitre. Since the calibration requires comparison of results with yeast concentrations measured using conventional yeast analyses such as methylene blue staining and microscopic cell counting, the absolute precision cannot be better than these relatively crude methods. However, the machine provides excellent repeatability.

Versions of the instrument are sold that are suitable for both laboratory and in-line analyses. The instrument comprises a probe bearing four electrodes, two of which generate the electrical signal and two of which measure the magnitude of the resultant capacitance due to viable cells. All living cells respond in this way and the magnitude of the measured capacitance is frequency-dependent. In the case of yeast cells a value of 0.3 MHz has been found to provide an appropriate response. The probe is inert and resistant to all brewery cleaning regimes. Via a system of electronics the signal can be used to generate a signal which can be integrated with output from a flow meter or load cell such that automatic systems for control of pitching and cropping can be used. In complex in-line systems several probes can be multiplexed via a single controller allowing outputs to be taken from combinations of multiple pitching and cropping mains. Integration of all outputs allows the concentrations of all yeast within the brewery at any given time to be monitored. Apart from control of yeast pitching and cropping the device can be used to control other processes such as krausening, cask beer re-seeding, yeast propagation and continuous centrifuge operation.

The laboratory version makes use of exactly the same technology, but the electrode is placed within an attenuated stirred chamber.

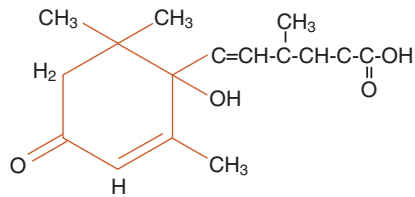
Abrasion

A treatment applied to barley grains in which the husk is damaged (but not totally disrupted) by the application of mild mechanical treatments; for example, the use of rotating wire brushes. The treatment enhances rates of germination either by allowing the more rapid entry into the grain of additives such as gibberellic acid but more likely via the increased efficiency of wetting and oxygenation. Abraded grains can be malted at relatively low moisture contents and thereby allow shorter steeping times and lower steeping temperatures.

See **gibberellic acid**.

Abscisic acid

Abscisic acid is a plant hormone with the structure indicated in the following figure.



It exerts global effects on plants; for example, it is implicated in stress tolerance, stomatal opening, response to pathogens, seed development, apoptosis and the maintenance of dormancy. Its involvement in the latter process is of the most direct relevance to brewing via the control of dormancy in grains that require to be germinated during malting.

The mechanisms by which it exerts its effects are at present not fully characterised, although it appears to have short-term effects as an effector of various cellular processes. In addition, it seems capable of exerting longer-term effects via the modulation of gene activity. Gibberellic acid has an antagonistic effect to abscisic acid.

See **dormancy** and **gibberellic acid**.

ABV

ABV is an acronym that stands for *alcohol by volume*. It is the usual method of denoting the alcohol concentration of beers. The value is provided on packaging as $x\%$ abv. Most beers fall within the ranges of 3–10% abv with the vast majority being between 4 and 6%. There are outliers. The Samuel Adams Brewery in the United States produces the beer *Utopias*, which boasts an alcohol concentration of 25% abv. In most countries there are legal definitions, expressed in terms of ABV, for low- and zero-alcohol beers.

Most countries use the ABV of beers as the mechanism for collecting excise duty. In this regard, it is usual to have bandings such that all beers falling within a certain range of concentrations will attract the same rate of excise duty. This reflects the fact that for many brewers precise control of alcohol content is difficult, and therefore a degree of latitude is given. Naturally, given this situation most brewers will seek to ensure that the actual mean alcohol concentration of any given beer is as close as possible to the middle point of the band. This avoids paying excessive taxation but also ensures that on average the product satisfies the legal requirements.

Since most excise payments are based on self-assessment and, bearing in mind the pivotal role of ABV, the analytical methods used must have suitable precision and repeatability. This has resulted in the adoption of so-called reference methods of analysis which have legal status. Many other methods may be used for routine analyses, based on factors such as rapidity or ease of automation; however, at some stage analyses must be performed using a standard reference method.

Accelerated batch fermentation

Accelerated batch fermentation is an umbrella term that covers a wide variety of approaches which have been developed with the aim of increasing the productivity of batch fermentations by shortening cycle times. For any commercial brewer the capital costs of fermenters and associated plant represent a major investment. This is particularly so in the case of the very-large-capacity vessels used by many of the major world brewers. In addition to capital

expenditure the revenue costs associated with running fermentations must also be taken into account.

Shortening total cycle times for individual batch fermentations is a useful method for increasing the productivity of fermenting vessels. The following example illustrates potential gains.

Assume a tank farm of 30×2000 hL fermenters with a total cycle time from fill to empty of 14 days:

$$\text{Total annual productivity} = (365/14 \times 30 \times 2000) = 1.56 \text{ million hL per annum.}$$

Assume a reduction in cycle time from 14 to 12 days:

$$\text{Total annual productivity} = (365/12 \times 30 \times 2000) = 1.8 \text{ million hL per annum.}$$

The change in productivity can be viewed in several different ways. The increase in productivity of the existing tank farm is equal to 15%. This would mean the current annual output could be achieved with five fewer fermenters representing a saving in revenue costs. Alternatively, if it were wished to increase volume output this could be achieved without needing to expend the capital costs of five new fermenters. Of course, the latter viewpoint assumes that the rest of the brewery could support the additional volume; however, it is commonly the case that fermentation is the rate-limiting step in the process.

Fermentations can be accelerated in several ways. The usual method is to increase the temperature of primary fermentation and, in so doing, to reduce the time taken to achieve attenuation gravity. All brewing yeast strains have optimum growth temperatures of at least 30°C and therefore considerably higher than the temperatures actually used for fermentation. However, this approach must be followed with care since higher fermentation temperatures can adversely perturb the concentrations of many important beer flavour components produced by yeast during fermentation. Nevertheless, many pilsner-type lagers that historically were fermented at low temperatures ($5\text{--}10^\circ\text{C}$) are now produced at temperatures more associated with ales ($15\text{--}20^\circ\text{C}$).

The use of relatively high fermentation temperatures for the production of pale lagers is somewhat controversial. Many brewers claim that the delicate nuances associated with traditional lager beers are lost when high-temperature rapid regimes are used. Indeed, the long fermentation times used in the brewing of such beers, which may extend to several weeks, are used as a mark of excellence. Appellations such as 'slow brewed' are used as marketing tools and adherents of this ideology would argue that many of the major brewers are willing to sacrifice quality for financial gain. The high quality of the traditional lagers cannot be gainsaid; on the other hand, the majority of scientific advances that have been made with regard to elucidating relationships between yeast metabolism and beer flavour have been carried out using model systems based on the high-temperature rapid method. These have shown that with knowledge of the appropriate metabolic triggers and responses it is possible to make beers with acceptable flavour profiles and in a predictable manner.

Predictability is another important consideration. The benefits obtained by shortening fermentation cycle times are much reduced in value if there is much variability. The latter is not uncommon in many breweries; thus, a nominal cycle time of, say, 14 days can quite easily in practice mean 12–16 days, or even worse. In this situation capacity planning is difficult. In order to obtain more constant cycle times it is necessary to regulate with the best achievable

accuracy and repeatability all those parameters that influence fermentation performance. In this regard, advances in control of basic parameters such as temperature, pitching rate and wort oxygenation have eliminated a great deal of variability. Undoubtedly variability in the composition of raw materials such as malts will always present some uncertainties. However, these can often be compensated for by adjusting parameters such as pitching rate and/or wort oxygenation. Further work remains to be done regarding the influences and causes of variability in pitching yeast physiology.

The whole of the cycle time must be considered when looking at ways of shortening it as only times for filling, emptying and cleaning in place (CIP) are generally immutable. Where practised reduction in the duration of VDK stand times is possible. The use of enzyme preparations, where permitted, containing α -acetolactate decarboxylase (see **Maturex**[®]) will eliminate the need for a warm rest as will removal of diacetyl via the use of immobilised yeast technology. A significant portion of the cycle time for many fermentations is taken up by crash cooling. With very large fermenters this can account for up to 24 hours. It is possible to reduce this by half by introducing a method of agitating the vessel contents during the cooling phase. Alternatively, vessels may be racked warm and beers chilled in-line during transfer to the next stage of brewing.

Acetic acid bacteria

Gram-negative beer spoilage bacteria that are able to oxidise ethanol to acetic acid. This ability is exploited for the industrial manufacture of vinegar. Two genera are recognised, *Acetobacter* and *Gluconobacter*. Both are pleomorphic occurring as straight or curved rods or spheres or stages in between and may be motile or non-motile. They are tolerant of hop acids and ethanol but are obligate aerobes; therefore, spoilage occurs in finished beer where there is inadvertent ingress of air, such as may happen during dispense of cask ales. Spoilage is characterised by sour acid flavours as a result of the formation of acetic acid. Growth is evident in the form of ropes, slimes and surface pellicles.

Acetobacter

See **acetic acid bacteria**.

α -Acetohydroxybutyric acid

α -Acetohydroxybutyrate is an α -acetohydroxy acid which is an intermediate in the pathway that leads to the synthesis of the amino acid isoleucine by yeast. Its greater significance in brewing is that it is the immediate precursor of the important vicinal diketone 2,3-pentanedione.

The structure is $\text{CH}_3\cdot\text{CO}\cdot\text{COH}\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{COOH}$.

See **diacetyl cycle**.

α -Acetolactate decarboxylase

α -Acetolactate decarboxylase (ALDC) (EC 4.1.1.5) is an enzyme that catalyses the decarboxylation of its substrate to yield acetoin and CO_2 . It occurs in several bacteria including strains of *Bacillus* and *Lactobacillus*.

Commercial preparations of the enzyme are available and these are used, where permitted, as additives in fermentation (Maturex[®], Novozymes, brewing@novozymes.com). The presence of the enzyme in fermenting worts converts the substrate directly to the relatively non-flavour

active compound acetoin and, in so doing, prevents or reduces the formation of the vicinal diketone diacetyl. The net effect of this is to shorten fermentation times.

Commercial preparations of the ALDC enzyme are obtained from a recombinant strain of *Bacillus subtilis* in which the responsible gene *AldB* was isolated from a strain of *Bacillus brevis* using a plasmid initially cloned into *E. coli*, B12.

The enzyme has also been cloned directly into brewing yeast strains such that these have a reduced ability to produce diacetyl during fermentation. The utility of these transgenic strains has been demonstrated successfully, although owing to the perceived reluctance of the public to accept beers made in this way none of these yeast strains are currently used in commercial brewing.

See **diacetyl cycle**.

α -Acetolactic acid

α -Acetolactate is an acetohydroxy acid that is an intermediate in the pathway leading to the synthesis of the amino acid valine by yeast. Its greater significance in brewing is that it is the immediate precursor of the important vicinal diketone diacetyl.

The structure is $\text{CH}_3\text{-CO-COH-CH}_3\text{-COOH}$.

See **diacetyl cycle**.

Achel

One of the Trappist monasteries of Belgium producing Trappist beers.

See **Trappist beers**.

Acidification power test (AP test)

Name given to a test used to assess **yeast vitality** in which the ability of a suspension of brewing yeast to acidify the external medium is assessed and which produces results that can be used to predict subsequent fermentation performance. Acidification occurs as a result of the proton exclusion via the activity of the membrane-bound H^+ ATPase. The classical test has two components: firstly, the spontaneous acidification when yeast is initially suspended in the test medium (AP1), and secondly, acidification in response to added sugar, usually glucose or maltose (AP2). Typically each component is measured over 10 minutes at a defined temperature and with a known yeast concentration. Both parts of the test are related to membrane functionality. The magnitude of AP1 is related to the availability of endogenous glycogen stores (which is reflective of prior yeast handling); whereas AP2 provides a measure of glycolytic flux.

Several modifications to the basic test have been made. The cumulative acidification test measures the change in absolute proton concentration with respect to time, which allows consideration of both transient increases and decreases in pH, which has been observed for some yeast samples, and, in addition, it avoids the problems associated with detecting comparatively small changes and the logarithmic nature of the pH scale. In the titratable AP test the pH is held at a constant value and the amount of NaOH that is required to be added to accomplish this is measured. The **vitaltitration yeast vitality test [acidification power test (AP test)]** test uses a procedure in which the initial pH is adjusted to pH 10.0 and the time taken for a yeast sample to reduce this to pH 6.5 (the usual intracellular pH of yeast cells) is determined.

See **yeast vitality**.

Acid malt

Acid malts are those which are manufactured in such a way that they contain lactic acid. The acid component is used to control the pH of the wort. This may be necessary where the brewing liquor does not contain the appropriate balance of minerals to ensure that the pH is sufficiently acid to ensure good rates of saccharification and proteolysis. This can be the case where very soft brewing liquor is used as in traditional lager brewing. The advantage of controlling wort pH in this manner is that it does not impinge on the restrictions of the *Reinheitsgebot*.

Acid malts typically contain high nitrogen levels and have high cold water extracts. They are used at rates in the region of 3–10% of the grist. The malts contain in the region of 2.0–2.5% lactic acid. The malts do not break the rules of the *Reinheitsgebot* since the lactic acid is produced naturally via the action of lactic acid bacteria. Several processes may be used to encourage the growth of the bacteria. Grains may be macerated, which releases grain sugars, followed by an anaerobic rest during which the bacteria multiply and acid production ensues. Alternatively the natural bacterial flora may be enhanced by spraying cultures of lactic acid onto green malt suspended in water followed by incubation at 50°C for up to 36 hours and prior to kilning. In another procedure kilned malt is steeped in water during which lactic acid bacteria grow and acidify the medium. The mass is then kilned such that the lactic acid remains associated with the dried grains. Where the rules do not prohibit the practice lactic acid may be added directly to steep water.

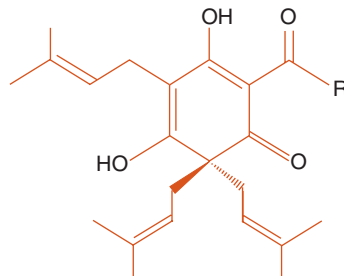
α-Acids

α-Acids are the precursors of the principal hop-derived bittering components of beers. They are isomerised during the kettle boil to yield the bitter iso-α-acids.

See **hop isomerisation**.

β-Acids

Beta (β-) acids, together with α-acids and the uncharacterised fraction, form the soft fraction of hop resins. Typically they comprise between 3 and 10% of the total dry weight of baled hops. Chemically the β-acids comprise mainly lupulone, colupulone and adlupulone (see diagram for structures).



Structure of hop β-acids, where $R = \text{CH}_2\text{CH}(\text{CH}_3)_2$, lupulone; $R = \text{CH}(\text{CH}_3)_2$, colupulone; $R = \text{CH}(\text{CH}_3)_2\text{CH}_2\text{CH}_3$, adlupulone

β -Acids are of little value in brewing, although they can be modified chemically to produce bitter compounds; however, owing to the presence of the three isoprenyl groups they are potent antibacterial agents.

β -Acids are subject to oxidation during prolonged storage of hops, the principal products being hulupones. The latter are intensely bitter and may contribute to overall bitterness in some beers. A multitude of other products of auto-oxidation have been isolated, the effects of which on stored hops, and beers made from them, are probably negative.

See **hop resins**.

Acid washing

Treatment used for the disinfection of pitching yeast based on the relative acid tolerance of brewing yeast compared to many common bacterial contaminants (but by definition not wild yeast).

Best practice requires a treatment using a food-grade acidulant, usually phosphoric acid but occasionally sulphuric, in which the yeast slurry is held at pH 2.2 (± 0.1) at 3°C (± 1) for at least 1 hour but no longer than 2 hours. Care must be exercised to ensure that the acid is dosed in a manner that ensures that the pH of all of the slurry is gradually reduced without the formation of 'hot spots'. Yeast with a viability less than 90% should not be acid washed. Commonly the process terminates when the slurry is pitched. If this is delayed the slurry pH must be increased to around pH 4.0 using sterile NaOH. Ammonium persulphate, a powerful oxidising agent, is sometimes incorporated into the acid at a concentration of around 0.75% w/v. This reportedly increases the potency of the treatment against bacteria such that a higher pH (up to pH 2.8) may be used, thereby reducing the risk to yeast viability.

AC Metcalfe

A two-row variety of malting barley which was placed on the US approved list in 2005 originally bred in Canada, hence, AC, Agriculture Canada, and registered in 1994. It was the most successful of a batch of new varieties that included CDC Kendall, CDC Stratus and CDC Copeland, which were viewed as replacements for the popular but fading Harrington variety.

Acridine orange

A fluorescent dye (Systematic name: 3-N, 3-N, 6-N,6-N-tetramethylacridine-3,6-diamine) that binds to nucleic acids. DNA and RNA can be distinguished based on the colour of fluorescence following excitation with light of an appropriate wavelength. It has been suggested, probably incorrectly, that it can be used as a viability dye based on the assumption that nucleic acids are rapidly degraded after death. More commonly it is used in a double staining technique with a dye such as **propidium iodide**, where the latter is used to stain viable cells.

See **yeast viability**.

Acrospire

In brewing terminology the acrospire is the name given to the leaf sheath or coleoptile of barley. Together with the scutellum, rootlets and coleorhizae it forms the embryo. During germination of the grain the acrospire grows under the husk along the dorsal side of the grain. Assessment of the length of the acrospire is used to gauge the progress and uniformity of

modification during the malting process. Where acrospire lengths are not uniform this is indicative of uneven germination or possibly mixing of grains of differing quality. For the purpose of the assessment the length of the acrospire is judged relative to the length of the grain. In the system used in North America where the grain length is 1, the acrospire length is classified as being within the ranges 0.0–0.25, 0.25–0.5, 0.5–0.75, 0.75–1.0 and >1. This is also referred to as the **acrospire profile**. In good quality malts a high proportion, typically more than 85%, of the acrospires should fall within the 0.75–1.0 range. Some grains produce acrospires that are greater in length than the grain. These are referred to as being **overgrown corns** or **huzzars**, **cockspurs** or **bolters**. From a malting standpoint these are undesirable since they are usually rich in enzyme content but deficient in extract. When the acrospire length has reached 0.75–0.88 of the relative length of the grain the hot and cold water extract values and concentration of total soluble nitrogen substances cease to increase with further germination time.

Acrospire profile

An assessment of malt quality based on an assessment of the length of the **acrospire** relative to that of the grain.

See **acrospire**.

Actidione

Synonym for **cycloheximide**.

Activated carbon

Activated carbon, also known as **activated charcoal** (or active carbon, charcoal) is used as a filtration medium, particularly as one of usually many steps used in the purification of water destined for use in brewing. In particular, treatment with this material is used to remove organic impurities (see **water** for more details). The process is usually referred to as **carbon filtration**.

The material relies on surface adsorption for operation. The term activation refers to the treatments used in its preparation in which it is rendered into a form in which the ratio of surface area to mass is very large.

Activated carbons are prepared from a variety of starting materials including various coals or coal derivatives or plant materials such as woods or the kernels of seeds. The preparation involves pyrolysis of the raw material at high temperature under anaerobic conditions followed by activation in which the carbonised material is oxidised by heating in the presence of oxygen or another oxidising atmosphere. In addition, various chemical treatments may also be incorporated into the production process. A range of chemical additives can also be incorporated into the carbon to provide additional functionalities. For example, silver nanoparticles can be added to impart antiseptic properties.

The activated carbons are supplied as granules, powders or extruded forms. Each of these forms is tailored towards specific applications. For water treatments powdered types can be used in the form of columns where the process flow passes through a bed of carbon. In other applications the carbon may be supplied in the form of impregnated sheets through which the liquid to be treated is passed.

After use the carbon must be regenerated, typically via a heat treatment.

Activated charcoal

See **activated carbon**.

Active dried yeast

See **dried brewing yeast**.

Adhulupone

A product of the auto-oxidation of hop β -acids.

See **hulupones**.

 α -Adhumulone

α -Adhumulone is one of the principal hop-derived α -acids which are the precursors of the bittering components of beer.

See **hop isomerisation**.

Adjunct mill

Adjunct mills are those that are set up specifically to process certain types of solid adjunct. They are used where the solid adjuncts require a very different milling treatment to that which is applied to malts. Examples of these adjuncts are various whole grains of sorghum, wheat or oats, or derivatives of these. The mills may be hammer or roller types (see the relevant entries for details); however, they are set up to suit the nature of the particular adjunct being used. Of course, the same mills may be used for the production of all grists, but many brewers find that better overall process efficiencies can be obtained if separate mills, sometimes of different types, are used, for example, a hammer mill for the treatment of adjuncts and a roller mill for the treatment of malts.

Adjuncts

Adjuncts are defined simply as sources of extract other than malt. A wide variety of materials may be used. They may be employed purely on the basis of cost or because they impart desirable properties to the beer which may not be achieved by the use of malt alone. Commonly particular adjuncts may be used in certain geographical locations where they are plentiful and therefore by inference inexpensive, for example, the use of rice in many North American beers. In countries subject to the strictures of the *Reinheitsgebot* the use of adjuncts is prohibited. In some countries the use of adjuncts provides tax advantages, for example, the **happoshu**-type beverages of Japan.

Adjuncts are typically derived from various cereals. These may be relatively unprocessed raw cereals or semi-purified extracts. Adjuncts may be liquid or solid. In the case of liquid types they take the form of various sugar syrups. Typically these may be added to wort during the boiling stage, and for this reason these are often referred to as **copper** (kettle) **adjuncts**. The reason for addition at this stage is a convenience since it bypasses the solid handling wort preparation stages and the heat treatment ensures sterility. Addition of these materials to the copper does come at some financial cost owing to the proportion of energy used to heat it. Since this heat treatment serves no purpose other than sterilisation there is no reason why the syrup adjuncts cannot be added after wort cooling and pre-fermenter fill (providing that

the microbiological standard of the syrup is adequate). Liquid adjuncts are commonly used as a convenient method of producing highly concentrated worts required for high-gravity brewing. Liquid adjuncts may also be added post-fermentation, for example, as priming sugars, added to adjust the flavour and/or colour of finished beer or as a source of fermentable extract in those beers which are subjected to a secondary conditioning process.

Solid cereal adjuncts require some form of processing in order to release the starch and render it available and susceptible to the activity amylases. At their simplest they take the form of relatively pure solid sugars, which are dissolved in water prior to use. In the case of most solid adjuncts the pretreatment entails milling and mashing, either as an admixture to the malt grist or via a separate treatment in plants dedicated to this purpose. For this reason such materials are referred to as **mash tun adjuncts**. Some solid mash tun adjuncts such as flaked maize and torrefied wheat have been pre-cooked and do not require to be mashed, while others require to be cooked. The treatment that is required to release the sugars from solid adjuncts is dependent upon the gelatinisation temperature of the starch grains. If similar to malted barley the adjunct may be processed with the malt in the mash tun. If the gelatinisation temperature is higher than that of malt a separate dedicated cereal cooker is required (see **cereal cooker, gelatinisation** for more details). Depending on the nature of the adjunct it may be entirely devoid of hydrolytic enzymes. In this case exogenous enzymes may be required to release the extract or those present in the malt must be used. The option chosen has an influence on the nature of the mashing regime and plant employed.

Liquid adjuncts	Comments
Cane sugar syrup	Sucrose syrup obtained from cane or beet
Invert sugar	Syrup obtained via inversion of sucrose and containing equal mixtures of glucose and fructose
Starch-based syrups	Generic name for a variety of syrups produced by acid or enzyme hydrolysis of cereal starches. The precise composition can be controlled to produce syrups with desired properties such as fermentability. For example, high-dextrin syrups are of limited fermentability and are used to impart body to beer; conversely, high-maltose syrups are highly fermentable and are used purely as sources of extract. Depending on the purity some starch-based syrups also contain significant concentrations of nitrogenous compounds as well as other components.
Dextrose syrup	Glucose syrup, also known as corn sugar, prepared via the hydrolysis of corn starch.
High-fructose corn syrup	Also known as HFCS, isoglucose, or glucose–fructose syrup. It is prepared from corn starch glucose via treatment with glucose isomerase to produce a mixture primarily of glucose and fructose. The product of the enzymic treatment is blended with glucose in varying proportions to produce a syrup with desired properties. Different grades of the syrup are denoted by the acronym HFCS followed by a number that indicates the relative proportions of fructose and glucose; for example, HFCS-55 contains 55% fructose, 45% glucose. HFCS is used as a priming sugar since it is sweeter than pure glucose syrup, it is liquid, and in some markets less expensive than sucrose syrup.

(continued)

Liquid adjuncts	Comments
Malt extract	A liquid syrup made via the hydrolysis of cereal grains, clarified and concentrated by vacuum evaporation. The composition of the extract is complex and uncharacterised. Various sugars are present together with nitrogenous and other compounds derived from the cereal grains. The precise composition depends upon the grist and the mashing conditions; thus, the activities of hydrolytic enzymes may be retained or destroyed. The use of exogenous enzymes may be used to manipulate the sugar content and spectrum. Malt extracts are widely used by micro- and home brewers.
Liquid malt	Sometimes used as a synonym for malt extract (see above). Also, a product used in German brewing made by mashing unkilned green barley followed by concentration and removal of undesirable flavour components. Although the material is used as an adjunct its use for the production of beers subject to the restrictions of the <i>Reinheitsgebot</i> is permitted. As such it can be used as an additional source of enzymes.
Caramels	Usually electropositive type III caramels prepared via heating pure sugar syrups with ammonia to give a range of highly coloured and flavoured liquid products used for adjusting colour and/or taste. Used as copper (kettle) adjuncts or added to finished beer.
Miscellaneous syrups	Syrups prepared from hydrolysed potato starch are used by some brewers; in addition syrups made from honey or maple are used in certain beers.
Solid adjuncts	
Coloured malts	Speciality malts that have been produced under conditions which impart changes in colour and flavour are used widely as adjuncts to adjust colour and flavor, in particular, where the use of other process aids is subject to regulation.
Malted cereals	Several cereals may be malted to produce a product analogous to malted barley grains. These include true cereals such as wheat, oats, rye and sorghum; in addition, pseudo-cereals such as buckwheat and quinoa.
Raw cereal grains	<p>Raw barley grains may be used as adjuncts. The grains are hard and require hammer milling; however, the starch granules have the same gelatinisation temperature of malted barley grains and no separate cooker is required. The hard husks assist with wort clarification in lauter tuns. Low endogenous enzyme levels usually require the use of exogenous enzymes and worts may be viscous owing to the presence of high β-glucan levels. Problems with beer hazes may also arise from overuse.</p> <p>The germs of maize grains contain appreciable lipid, and in order to avoid deleterious effects on beer foams degerming is required before use as adjuncts. For this reason maize grains require some processing before use (see grits, flaked cereals).</p> <p>Rice adjuncts are supplied in the form of milled products that comprise almost pure endosperm made from short-grain varieties and have a low nitrogen content. The starch gelatinisation temperature is high and a separate dedicated cereal cooker is required. In addition, fine pre-milling is needed. Varieties must be low lipid types in order to prevent problems with flavour stability and depression of ester formation during fermentation.</p> <p>Sorghum starch granules have high gelatinisation temperatures (71–80°C) and, as with rice, require a dedicated mill and cereal cooler. When used at too high a proportion problems with low pH, high viscosity (poor run-off) and low free amino nitrogen (FAN) can occur. The use of exogenous hydrolytic enzymes is also required.</p>

Liquid adjuncts	Comments
Raw cereal grains	<p>Unmalted wheat, blended with malted barley is used in the production of many traditional white beers. Used at high proportions it causes problems with wort viscosity and wort fermentability but it does have the advantage of conferring excellent beer head properties. For the latter reason small amounts are commonly incorporated into the grists of lager beers.</p> <p>Raw grains of <i>Triticale</i> are attracting interest as a source of adjunct. They contain high endogenous levels of amylases; the starch granules have low gelatinisation temperatures and contribute significant FAN.</p>
Grits	<p>Grits are derived from cereal grains from which the hull and germ have been removed and thus they comprise more or less pure starch. As such they require to be cooked. Grits of maize, rice, sorghum and barley are used as adjuncts.</p>
Flaked cereal grains	<p>Flaked cereal grains of maize, rice, pearl barley and oats may be incorporated into grists as solid adjuncts. They are pre-cooked as part of their preparation and thus do not require to be gelatinised.</p>
Torrefied grains	<p>Torrefied whole unmalted grains, usually of wheat or barley, are prepared by heating such that the kernels split and they increase in volume. The heating process gelatinises the starch grains. Torrefied grains may be used as a source of extract, but they are also a good source of head retaining proteins.</p>
Micronised grains	<p>Micronised grains (maize, barley or wheat) are similar to torrefied types. They are produced by applying heat to ceramic tiles such that they emit radiant heat. The grains are arranged in thin layers and allowed to pass below the heated tiles such that they achieve a temperature of approximately 140°C. The heating process dries the grains and causes them to swell and rupture. During the heat treatment the starch grains gelatinise.</p>
Extruded grains	<p>Raw sorghum grains can be extruded in a treatment in which they are subjected to a heat treatment of 150–200°C (optimum 175°C for the most efficient filtration). This causes the starch granules to gelatinise.</p>
Flours and refined starches	<p>Refined starches are purified from a variety of plant sources including wheat, barley, corn, cassava or potato. They represent the purest form of mash tun adjunct. They may be sold as flours or used to make syrups. Where they have low gelatinisation temperatures they may be incorporated directly into mashes; otherwise they require pre-cooking. The purer forms cause no problems with run-off and do not contribute significant flavour; however, they are generally low in nitrogen. Flours, especially wheat, may be used as adjuncts. Wheat flour is essentially pure endosperm. It is produced by a process of milling and sieving, which separates the endosperm material from other contaminating materials. Most often, for brewing, the flour is further purified to produce a product that is low in nitrogen. For brewing, flours are combined with a binding material that increases the average particle size and reduces dust formation. The product has the same advantage and disadvantages of raw wheat, that is, good head formation but high wort viscosity.</p>

The use of adjuncts is very common, and indeed very few brewers produce beers from all-malt grists. Much dedicated plant is required for the use of individual adjuncts. Apart from storage and handling facilities many solid adjuncts require dedicated adjunct mills and cereal cookers. Most concentrated liquid syrups do not require microbiological precautions

to be taken since the low water activity prevents growth. However, many of these syrups are highly viscous, making them difficult to pump; in addition many have a tendency to set when cooled, and consequently holding tanks and transfer mains must be heated (usually 45–55°C).

All adjuncts must be used with great care. Many impart desirable properties such as good head retention in beers (wheat flour) or neutral clean flavours (rice). Conversely, some may be associated with haze problems or poor run-off owing to high β -glucans (raw barley). Relatively pure sources of starch or refined sugars are good sources of fermentable extract but tend to have low nitrogen contents such that injudicious use may lead to low-FAN worts with concomitant effects on yeast growth and the formation of yeast-derived flavour compounds.

Adlupulone

Adlupulone is one of the principal components of the β -acid fraction of the soft fractions of hop resins.

See **β -acids, hop resins**.

Admiral

A UK-bred hop variety. It is wilt-tolerant, contains 13–16% α -acids, and is generally used for bittering in UK-style ales.

Ageing

The term ageing as applied to the brewing process is principally of US usage and is used to describe the period of storage of green beer during which secondary fermentation and other changes occur which are associated with the maturation of green beer. It is a synonym for **beer maturation, conditioning** or **lagering**.

In another sense the term may also be encountered with respect to the changes in beer quality which occur after packaging. In this case the ageing processes are undesirable and associated with degenerative staling changes which define beer flavour stability.

See **secondary fermentation**.

Agnus

Agnus is a relatively new high alpha Czech hop variety registered in 2000. Its family tree contains **Northern Brewer, Saaz hop, Fuggles** and **Sladek** varieties. It contains 11.9–16.1% total α -acids (29.4–36.3% cohumulone), 3–6% β -acids. Total oils are 1.99–2.84% (10.2–11.6% caryophyllene, 0.05–0.1% farnesene, 16.2–20.0% humulene, 45.6–50.51% myrcene).

Ahil

Ahil is a hop variety, one of the four original Super Styrian high alpha varieties, together with Atlas, Apolon and Aurora, bred in the 1970s at the Hop Research Institute at Zalec, Slovenia. It derives from Brewer's Gold and a Slovenian male. It contains 10–12% total α -acids of which 25% is cohumulone. Total β -acids and oils are 4–5% and 1.8–2.2%, respectively. Storage properties are fair.

Ahtanum

US-bred aroma hop variety containing 5.7–6.3% α -acids.

Air-dried malt

See **wind malts**.

Air rest

An air rest is a stage in the steeping process of malting in which the bed of grains is drained of water and replaced by a stream of air. This removes oxygen-depleted steep water and exhausts CO₂ whilst replenishing the supply of oxygen. Usually one or two air rests are performed during a typical steeping process. The aim is to ensure that the grains are not deprived of oxygen, which would prevent rapid and even germination. The process is necessary since aeration of steep water alone is insufficient to ensure continuous aerobiosis.

See **steeping**.

Ajon

A beer native to Uganda made from malted millet.

See **native African beers**.

Akcent

See **Valtický**.

Albumin

Albumin is the collective term for a group of **proteins**. They occur in all living cells. They are distinguished from globulins, the other major class of soluble protein, based on the fact that they are soluble in salt solutions but not in pure water. They are coagulable by heat.

In beers they derive from malts and other sources of extract with significant nitrogen content. Along with globulins they are major contributors to beer foams.

Alcohol

Alcohol is a term used within the brewing and beverage industries and colloquially for ethyl alcohol. The term is used incorrectly in that alcohol is, of course, a generic name for organic compounds in which aliphatic types have the general formula C_nH_{2n+1}OH. Alcohols may be defined as organic compounds in which one, or more, hydroxyl groups are substituted for a hydrogen atom that was attached to a carbon atom. Ethyl alcohol (CH₃CH₂OH), the component of beers which has mind-altering properties, has several synonyms; ethanol, ethyl hydrate, fermentation alcohol, grain alcohol, grain spirit, pure grain alcohol, grain neutral spirit, neutral spirit. It may be noted that some of these terms refer to the source from which the alcohol was obtained. For example, grain spirit refers to the bland, colourless preparation of virtually pure ethyl alcohol which is obtained from the distillation of fermented preparations of grains.

The etymology of the word is unknown. The prefix *al*, the definite article in Arabic suggests a Middle Eastern source. Indeed, the process of distillation was obtained by the early European

alchemists from Islamic scientists. It has been suggested that the second part of the word derives from Arabic *al-kuhl*, pertaining to the preparations of antimony sulphide used for cosmetic purposes. In this case the term derives from the Arabic name for stibnite, the mineral from which the cosmetic was produced. This seems unlikely other than the fact that the cosmetic was produced by a process of sublimation, and by inference this might have had usage as a general term for distillation. Further weight is added to the unlikely link between alcohol and antimony by virtue of the fact that the modern Arabic term for alcohol is *alkhwil*. This appears to derive from *al-ghawl*, meaning a spirit. This would appear to be a more satisfactory route for the modern English word.

Alcohol chill haze test

The alcohol chill haze test, also known as a Chapon test, is used to assess the colloidal shelf life of beer. It is intended to be applied to bright beer and can be used to predict shelf life or as an indicative method of the effectiveness of stabilisation treatments.

A 200 mL sample of degassed beer is attemperated to 20°C and the haze is measured using a nephelometric haze meter. Pure absolute ethanol (6 mL) is added, and after mixing, the beer is attemperated to -5°C. After exactly 40 minutes the haze is again measured. The increase in haze provides a measure of chill haze. The magnitude is inversely related to the expected shelf life of the beer.

Alcoholic proof

Alcoholic proof is an archaic system used to define the alcoholic concentration present in beverages. It was usually applied to distilled spirits. Different scales of alcoholic proof are used in the United Kingdom and in the United States, respectively. In the United States alcoholic proof is twice the concentration of alcohol measured as ABV (% abv). In the United Kingdom the alcohol proof value is obtained by multiplying the value in % abv by 1.75. In the majority of countries alcoholic strength is now expressed as ABV (% abv).

The system of alcoholic proof arose in the United Kingdom at a time when precise analyses were not possible. In order to gauge alcoholic strength in concentrated form, such as distilled beverages, a test was performed in which gun powder was placed in the liquid. If the mixture was capable of sustaining combustion, it was declared to be 'proof'. The scales derived from the fact that it was subsequently shown that this required the liquid to have an alcoholic content of at least 57.15% abv. An alcoholic solution containing this proportion of ethanol was therefore defined as being 100° proof.

Alcolyzer

Alcolyzers are devices designed for the rapid and automatic analysis of the concentration of ethanol in beers and other alcoholic beverages. The instruments use near infrared spectroscopy as the basis of analysis. Commonly the instrument may also incorporate a digital density meter of the oscillating U-tube variety (see **density meter** for more details). The combined instrument is capable of determining ethanol concentration and specific gravity and, by calculation, original extract (original gravity). More complex combinations of these instruments are also available which are capable of even more multiple analyses, for example, pH, colour and dissolved oxygen.

ALDC

Acronym for the enzyme with significance for diacetyl management, α -acetolactate decarboxylase.

See **α -acetolactate decarboxylase**.

Ale

Ale is the term used to describe a specific class of beer. The word apparently derives from Scandinavia as in the Norse, *oel* or *aul*. In current usage the term ale refers to beers that are produced by a fermentation that is characterised by the use of a yeast strain that during the growth phase separates from the green beer by rising to the surface. Hence, such ale strains are referred to as being top fermenting; the beers are described as being produced via top fermentation, and the fermentation vessels are designed to accommodate the formation and collection of a top crop.

In general, ale fermentations are performed at a relatively high temperature, typically 18–22°C, using worts that are made by infusion mashing and employing a **mash tun**. There is an enormous variety of ales. As a group they tend to be moderately to strongly hopped and they are often classified on the basis of colour. Thus, pale ales are golden in colour and are usually quite bitter in taste (hence ‘**bitter**’ as a descriptor for this category). **Mild ale** and **brown ale** are darker in colour and are usually sweeter than pale types. Very dark types include **stouts** and **porters**.

The combination of specific ale yeast strains and comparatively high fermentation temperatures favours the formation of higher alcohols, and in consequence ales tend to have more robust flavours and aromas in comparison with paler lager beers.

Ales predate pale lager-type beers and in this regard the latter tend to have a more traditional image. Thus, many traditional UK-style ales, also termed **real ales**, are made using a process in which the fermentation stage is completed in the cask (or bottle) from which the beer is dispensed.

The long provenance of ales explains the use of the high fermentation temperature. These products were originally produced in parts of the world where, prior to the introduction of refrigeration, it was not possible to control the fermentation and storage stages at the low temperatures generally considered to be essential for lager production. This explains the schism between UK-style ales and mainland European lagers in that only in brewing of the former was the climate lent amenable to low-temperature beer production. This suggestion is further evidenced by the *altbier* beers of Germany, literally ‘old’ beers that are clearly of the ale type. Similarly, majority of early US beers were produced by the first waves of UK immigrants and were of the ale variety. It was only later when European immigrants in the Milwaukee area realised that, during the winter months, access to ice from the nearby Great Lakes would allow low-temperature fermentation and lagering to be performed.

In more historical times in the United Kingdom the term ale was used for an un-hopped product and therefore could be distinguished from a hopped ‘beer’. Since the introduction of hops into the United Kingdom was a comparatively late development in brewing, probably in the fifteenth century, the term ale later acquired a sense of being older and more traditional. For example, the products derived from early commercial breweries were often referred to as

beers, whereas those from contemporary domestic breweries were called ales. Similarly, beer acquired an urban dimension, whilst ale had more rural connotations.

Several qualifying terms may be used in conjunction with the word ale, which add other layers of meaning. Frequently these are now of historical interest only; nevertheless some are mentioned here for the sake of interest. An **ale-wife** was a female brewer (or sometimes just a beer retailer). The product was sold in an **alehouse**.

In the medieval period ale was the principal beverage that was consumed on celebratory occasions. For this reason the word ale was often appended to a term that indicated when, where or to whom the celebration was to be dedicated. There are many examples; to whit, **leet-ales** (appertaining to the days during which manorial courts sat), **lamb-ale** (a celebration of the spring sheep shearing), **bid-ale** (the name given to feasts at which the invitees were expected to raise funds, or 'bids', for specific causes). **Church-ales** were ecclesiastical events at which the sale of beer by church wardens raised funds for the upkeep of the church and provide alms for the poor. Commonly these ecclesiastical feasts were held at specific times of the year and the name might be associated with this, for example, **Whitsun-ales**. **Clerk's-ale** was a feast associated with Easter and, as the name suggests, was aimed at fundraising for parish clerks. **Cuckoos-ale** was simply a period of celebration associated with rural areas of England and was held after hearing the first cuckoo of spring. **College-ales** were festivals held at specific times at universities which had their own on-site breweries. **Bridal-ales** refer to the practice of a bride selling beer to the guests at her own wedding with the intention of raising funds to pay for the celebration and the future life of the married couple.

Ale-conner

An ale-conner was an official in the United Kingdom who was charged with assessing the quality of beer. In medieval England, supposedly, the ale-conner had a uniform that included a pair of leather trousers. The assessment was carried out by pouring a small puddle of the beer under test onto a wooden seat. The ale-conner would sit in the beer for a defined period of time after which he would attempt to stand up. If the leather breeches had stuck to the by now dried residue of beer, it was considered to be 'strong' and of good quality. The veracity of this version of the ale-conner's craft seems rather far-fetched since presumably, if the beer was sticky and by inference high in sugar, it might not be strong in the alcoholic sense. Whilst it is true that brewers of this era, or the consumers of their products, would have few, if any, methods of measuring beer strength, it seems far more likely that rather than adopt this time-consuming approach they would simply taste the beer and, in so doing, use the more accepted and reliable method of quality assessment. By way of interest it may be noted that the father of William Shakespeare was recorded as being made an ale-conner for Stratford-on-Avon in 1557.

Irrespective of the methods used for testing beers these officials had much power as this extract dated 1464 taken from the records of the *Ancient Trade Guilds and Companies of Salisbury*

Touching the quality and price of ale and beer brewed within the said city. First, every brewer is to make a good wholesome brew of sufficient strength, and every flagon of the better ale is to be sold for one penny, and of the second ale three flagons shall sell for one penny, until a new Assize be

ordained by the officers, and thirteen flagons of the better ale shall sell as a dozen, and six flagons of the said ale with a pottle shall sell as a half dozen, and likewise of the second ale according to its price. Item, there are to be four tasters, to wit one to each ward, to taste and assay the ale brewed from time to time in their several wards within the house of every inn-keeper when the ale shall be in a certain vessel called the Kyse, as well in respect of its soundness as of its strength and flavour; and if by them, or any of them, it shall be found defective in point of brew, to wit, in soundness or strength or flavour, forthwith within twenty-four hours they shall be bound to bestir themselves and present the defect or defects found by them to the Mayor, Seneschal and bailiff, or two of them, to the effect that the tavern in which the said ale was found be forfeited to the Lord Bishop without fine and redemption. And every inn-keeper aforesaid shall carry or cause to be carried his ale to his customers and other men without taking any portage therefor (*sic*), provided the ale exceed not four flagons, and in case any inn-keeper being so required by the Mayor or his deputy, shall refuse to do his office, he shall be excluded ipso facto from brewing, and be compelled by the Mayor, Seneschal or bailiff (*sic*) to make oath not to brew within the City for a certain time to be by them or one of them limited. And furthermore it is ordained and agreed that every inn-keeper who shall be found culpable and in default in respect of his brewing, and by the Mayor, Seneschal or bailiff (*sic*) or one of them shall be so convict, shall for the first offence be in grave mercy, for the second offence in graver mercy, and for the third offence shall be punished with imprisonment of the body at the discretion of the Lord Bishop, if he be present, and if he be absent, at the discretion of the Mayor, Seneschal or bailiff if they be present, and otherwise at the discretion of the Mayor; and for the fourth offence, he shall suffer the penalty of the tumbrel on the first or second Market-day next after the defect was discovered.

Ale extractor

See **vertical stillage**.

Ale founder

Archaic term for an official appointed to inspect beer to ensure standards of quality and quantity; an alternative to **ale-conner**.

Alehouse

A place where ale is served for consumption on the premises. In the original UK sense by implication the alehouse was also the site of the brewery.

Ale kenner

Alternative name for an **ale-conner**.

Ale mead

See **braggot**.

Aleurone body

Cellular components of barley grains which function as storage bodies and which contain proteins, polysaccharides and phytic acid. Also known as aleurone grains or aleurone granules.

See **barley grain**, **aleurone layer**.

Aleurone granules

See **aleurone layer**.

Aleurone layer

The aleurone layer (from the Greek, *aleuron*, or flour) is a cellular component of the cereal grains lying beneath the **testa** and forming the outer layer of the endosperm tissue (see **barley grain** entry for diagrammatic view of localisation of aleurone layer). The bulk of scientific literature regarding this tissue refers to the aleurone layer of barley grains, and for this reason, as well as its relevance to brewing, the following discussion is restricted to this plant. The aleurone layer is distinguished from the rest of the endosperm in that it consists of living cells. During germination the cells of the barley grain aleurone layer produce hydrolytic enzymes such as **α -amylase**, **β -glucanase** and **proteases**. These enzymes are transported into the endosperm proper where they are responsible for the degradation of storage polymers such as starch and proteins to form relatively simple molecules that are used to provide carbon and energy for the growth of the embryonic plant.

On a dry weight basis the aleurone layer accounts for approximately 5% of the total dry weight of a barley grain. It comprises a layer of relatively thick-walled cuboid cells that surround the starchy **endosperm**. Plasmodesmata are also prominent. On average the aleurone layer of barley grains is three cells thick except for the portion that partly covers the embryo where it is reduced to a single layer of flattened cells. Unlike the endosperm proper the cells in the aleurone layer do not contain **starch granules**; however, they do have functional sub-cellular organelles and deposits of reserve materials including lipids and protein. Some of these storage reserves are located in membrane-bound sub-cellular structures termed **aleurone granules** (or grains).

In **malting** growth of the embryo is arrested during the **kilning** stage, thereby preserving the hydrolytic enzymes, together with the barley reserve materials so that they are available for use during the **mashing** stage of wort production to generate the spectrum of sugars and amino nitrogen required for growth of yeast during **fermentation**.

The production of hydrolytic enzymes by cells of the aleurone layer is regulated by the intermediary of the plant hormone **gibberellins** (see **gibberellic acid**). The latter promotes the expression of the genes within aleurone cells which encode the hydrolytic enzymes. Gibberellin is produced naturally by the barley grain embryo in which role it serves to break the dormancy of the grain. This action has been recognised by maltsters and commercial preparations of the hormone may be added to **steep waters** to improve the efficiency and consistency of germination.

The mechanism by which gibberellin exerts its effect on cells of the aleurone layer is complex and is still not entirely characterised. However, the evidence suggests that it serves as an initiator of two distinct signal transduction pathways. The first of these is a calcium-independent pathway that involves several components including cyclic guanosine monophosphate (**cGMP**). In this pathway, activation occurs, of an F-box protein that forms part of an Skp, Cullin, F-box containing (SCF)-ubiquitin ligase complex. The F-box protein binds to a repressor that is blocking the transcription of a gene whose product is required for expression of the genes encoding the hydrolytic enzymes. After degradation of the repressor via the SCF ubiquitin ligase transcription of the hydrolytic enzyme genes can proceed. The second signal transduction involves the calcium-binding protein calmodulin and one or more protein kinases. Activation of this pathway by gibberellin results in the up-regulation of a golgi body

secretory system in which the newly synthesised hydrolytic enzymes are transported from the aleurone layer cells into the endoplasm.

Ale-wife

In the United Kingdom in the medieval period brewing was commonly performed by women. These were termed ale-wives. In addition, the terms **brewess** and **brewster** were used to describe female brewers. Generally ale-wives were also responsible for selling the beer at the same location as its manufacture. The domination of the brewing trade at this time also extended to retailers who sold beer that they had purchased from ale-wives. These latter were also predominantly women and were called **huksters**.

This female dominance of brewing, which was also common in Ireland, persisted in the United Kingdom until the seventeenth century after which the business gradually passed into male hands.

Alexis

A spring malting barley variety.

Ale yeast

Name used to describe those yeast strains that are used to produce those beers defined as **ales**. Taxonomically ale yeasts are classified as members of the species, *Saccharomyces cerevisiae*. They are associated with fermentations in which the yeast crop separates from the green beer by rising to the surface and forming a surface pellicle. For this reason these strains are also referred to as **top-cropping** types, although this is an imprecise descriptor since many ale strains can be made to form bottom crops in an appropriate fermenter.

See **yeast**.

Algoroba

A native beer produced in South America and made via the fermentation of extracts of the fruits of various leguminous plants, in particular, various species of *Prosopis* such as *Prosopis juliflora*, the mesquite plant.

Alkaline steeping

Alkaline steeping describes one of a raft of methods that have been applied during the production of malts with the aim of improving the colloidal stability of beers made from them. The effect is made possible via the increased solubility of the testinic acid fraction of the husk, in other words, that which contains some of the phenolic haze precursors. Beers made from malts treated in this way may also be perceived to be less astringent, presumably also as a result of the removal of phenolic material. In addition, making the steep liquor alkaline has been used as a method of reducing the microbial flora present on the surface of grains and of removing mouldy or musty taints.

Typically the steep water may be made alkaline by the addition of lime (0.05–0.1% w/v) or by the use of NaOH. Since the alkali will eventually lead to severe damage to the grains the treatments must be limited to a few hours of exposure after which time the steep liquor must

be removed and replaced with fresh non-alkaline water. Alternatively, milder treatments can be accomplished by the use of sodium carbonate.

Alkaline steeping is not favoured by UK maltsters but has been used on continental Europe. It has found some favour in sorghum malting. Leyyedi & Taylor (*Journal of the Institute of Brewing*, **112**, 108–116, 2006) reported that steeping sorghum grains in water supplemented with 0.2% w/v NaOH was not cytotoxic but was effective at reducing levels of coliforms and moulds. The diastatic power of a red tannin-free sorghum cultivar was increased from 16.2 to 26.9 sorghum diastatic units (SDU)/g.

Alpha

A shorthand term used as an abbreviation of alpha (α -) acids, the components of hops from which the bitter character of beers are derived.

See **α -acids**.

Alsterwasser

Alsterwasser is the name of a pre-mixed canned shandy-type product made in northern Germany.

See *Radlermass*.

Altbier

Altbier is a German style of beer that originated in the Westphalia region of Germany. They are particularly associated with the German city of Düsseldorf and for this reason they were often referred to as **Düssel**. The *Alt* part of the name translates as 'old'. This is a reference to the fact that the beer is a top-fermented type made at a comparatively warm temperature. In this regard the beers are similar in nature to UK-style ales, and from a German perspective they predate the now more common lager beers. Hence, these beers, frequently simply referred to by the diminutive *alt*, are classed as old style types.

Altbiers arose in Düsseldorf in the nineteenth century and in effect, by a process of new product development, became hybrids between ales and lagers. Thus, the fermentation stage is carried out at a comparatively warm temperature using a top-fermenting ale yeast. This is followed by a period of low-temperature lagering. The resultant beers are pale to dark golden in colour with a moderately dry flavour. The latter is imparted by the period of lagering; however, this is offset by fruity warming notes introduced by the comparatively high concentrations of higher alcohols produced by the ale yeast.

Altbiers are now produced in several countries; however, although there is some variability, they all share the characteristics described earlier. The beers are produced throughout the year and indeed the Westphalia region of Germany escaped the Bavarian legislation which limited brewing to the winter months. There are some seasonal specialities. The *Sticke alts*, which translates as 'secret', is a stronger seasonal variant produced by some of the Düsseldorf brewers.

Amadori rearrangement

The Amadori rearrangement describes chemical reactions in which an N-glycoside undergoes an isomerisation reaction to yield the corresponding 1-amino, 1-deoxy-ketose, also termed a ketosamine.

Amadori rearrangement reactions are intermediate steps in the **Maillard reactions** that underpin the browning steps and formation of various flavour and aroma compounds during the malt kilning and roasting and wort boiling.

Amarillo

A US hop variety bred in the Yakima Valley in Washington State. It contains 8–11% α -acids, 21–24% cohumulone and 0.9–1.9% mL oils/100 g dry material. It is a dual-purpose hop similar to Cascade, Centennial, Columbus and Nugget.

Amber ale

Amber ale is a generic name given to ales produced by top fermentation and using comparatively pale malts. In this sense the name is synonymous with **pale ale**; however, the name is primarily associated with the United States as opposed to the former, which originates in the United Kingdom.

Unlike the majority of UK-style pale ales, amber ales obtain their dominant character from the malts used in their production and not from hops which commonly impart the major flavour to the former. Colours range from pale to reddish hues depending upon the blend of malts used in the grist.

Amber malt

Amber malt is a variant of roasted malt in which the heat treatment is very mild such that although all enzyme activity is completely or virtually destroyed, the grains acquire a pale golden colour but none of the very burnt astringent characters associated with more highly roasted **chocolate malt** and **black malt**. Modern amber malts are made using a roasting drum (see **roasted barley** and **chocolate malt** for more details). A top temperature of approximately 170°C is used. The resultant product has a colour of approximately 60 (50–100) EBC units and gives beers made using a proportion of it in their grists a dry biscuity flavour. It is used mainly for UK-type brown and mild ales.

Historically, amber malts were roasted over open wooden fires and this practice gave the product a smoky character similar to those malts used for the production of German **Rauchbier**. This practice has been discontinued in the United Kingdom and now closed roasting drums are used.

American Malting Barley Association Inc. (AMBA)

US non-profit trade association that is charged with ensuring the supply and quality of malting barley to the US malting and brewing industry, in particular, the development of new varieties with improved agronomic and malting properties. The AMBA [<http://www.ambainc.org> (last accessed 30 January 2013)] was formed in 1982. An earlier incarnation of a similar body was the Malt Research Institute (MRI) founded in 1938 in Madison, Wisconsin. This body funded relevant research programmes at the United States Department of Agriculture Agricultural Research Service (USDA-ARS) Cereal Crop Research Unit (formerly known as the Barley and Malt Laboratory) and also based in Wisconsin.

In 1945, a related organisation, the Midwest Barley Improvement Association (MBIA), with aims similar to the AMBA was formed in Milwaukee, Wisconsin. Initially the scope of this

body was dedicated to the local malting barley industry, but in 1954 this was broadened to encompass the whole of the United States. The MRI and MBIA merged and after the combined organisation was dissolved in 1982, the AMBA was formed.

The AMBA provides a list of recommended malting varieties for use in brewing based on procedures similar to those described in **malting barley – recommended varieties**.

As of 2011 recommended varieties are as follows. The year of their recommendation is given in parenthesis.

Two-row: AC Metcalfe (2005), CDC Copeland (2007), Charles (a winter variety) (2009), Conlon (2000), Conrad (2007), Harrington (1989), Hockett (2010), Merit (2000), Merit 57 (2010), Moravian 37 (2010), Moravian 69 (2010), Pinnacle (2011) and Scarlet (2008)

Six-row: Celebration (2011), Lacey (2000), Legacy (2001), Quest (2011), Rasmusson (2009), Robust (1984), Stellar-ND (2006) and Tradition (2004)

American Pale Ale

Beer of the United States based on similar and older beer styles associated with the United Kingdom. The American versions typically use pale malts and are fermented with ale yeast strains. They can be comparatively strong (5.5–6.0% abv). The most significant character is that of being quite highly bittered and commonly use late kettle hop additions or dry hopping. Native hop varieties (Amarillo, Cascade, Centennial and Columbus) are used to impart the citrus and resinous tastes and aromas characteristic of these types. Unlike United Kingdom pale ales these versions may be sold unfiltered.

Ametyst

See *Valtický*.

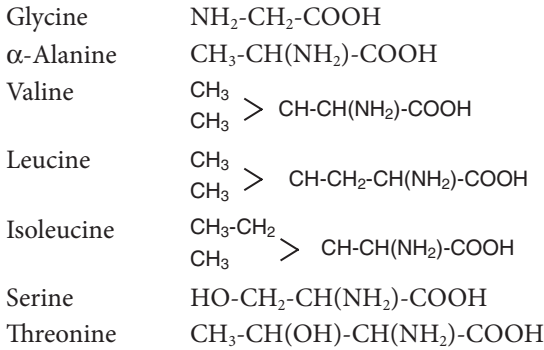
Amino acids

Amino acids are nitrogen-containing organic compounds that occur in all living cells. They are the basic building blocks of **polypeptides** and **proteins**. Some 20 standard amino acids are commonly found in proteins. These are coded for in the triplet code of DNA. In addition, a number of non-standard amino acids occur all but a very small number of which are not encoded for in DNA. The majority of these non-standard amino acids are intermediates in amino acid catabolic and anabolic pathways.

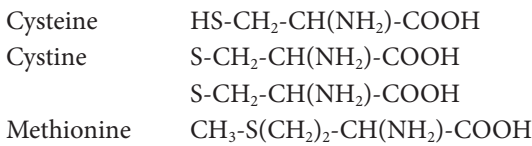
In worts amino acids are mainly derived from malts and nitrogen-containing adjuncts. The amino acid content of worts is expressed as **free amino nitrogen (FAN)**. This measure includes all compounds with free amino groups and so polypeptides and proteins will also feature. However, the bulk of FAN is free amino acids and short peptides containing two or three amino acid residues. Most amino acids are extracted in a preformed state from malt during wort production. The remainder (30–50% of total FAN) is formed via protein and polypeptide degradation during mashing. FAN in wort is the major source of assimilable nitrogen which is utilised by yeast to support growth during fermentation.

Amino acid molecules contain both amino and carboxyl groups. The general formula is $H_2NCHRCOOH$. The amino and carboxyl groups are both attached to the same carbon atom, the α -carbon atom. R is a substituent also attached to the α -carbon atom. Amino acids are classified based on the nature of the substituent group:

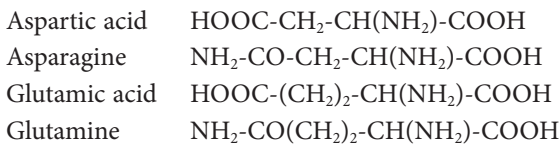
(1) *Aliphatic amino acids with a single amino and carboxylic group:*



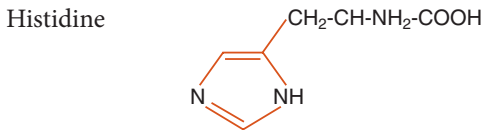
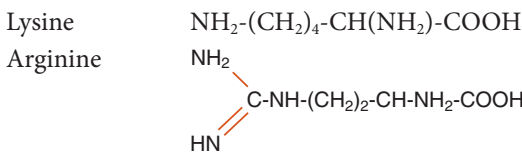
(2) *Aliphatic sulphur-containing amino acids:*



(3) *Aliphatic amino acids with dicarboxylic groups:*



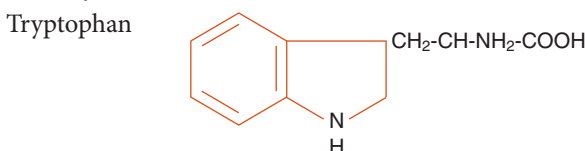
(4) *Aliphatic basic amino acids:*



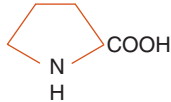
(5) *Aromatic amino acids:*



(6) *Heterocyclic amino acids*



Proline



See **free amino nitrogen (FAN)**, **nitrogen**, **proteins**.

Aminopeptidase

See **exopeptidase**, **proteases**.

Amitraz

Amitraz (N,N'-[(methylimino)dimethylidene]di-2,4-xylylidine) is a triazapentadiene compound that may be used as an acaricide in the treatment of infestations of red spider mite of hop plants.

Ammonium persulphate

See **acid washing**.

Amos's Early Bird Goldings

A variety of one of the group of Goldings, traditional UK-style aroma hops originally selected in 1887 from a crop of Bramling Goldings by Alfred Amos of Wye.

See **Goldings**.

α -Amylase

α -Amylase (α -1,4-glucan 4-glucanohydrolase; EC 3.2.1.1) is an enzyme which hydrolyses α -(1,4) linkages in starch polypeptides. It is a component of malt diastase, which, in conjunction with other hydrolytic enzymes, β -amylase, limit dextrinase, α -glucosidase and phosphorylase, is responsible for the degradation of starch and the subsequent liberation of fermentable sugars during the mashing phase of wort production. Depending on where the glucan chains are cleaved a range of products can be formed. These include glucose, maltose and a range of branched and unbranched oligosaccharides and dextrans.

Several amylase isozymes occur in malt but not in barley. Three classes of α -amylases are recognised. Type I is poorly abundant in malt. These bind calcium and are resistant to acid and chelating agents. Heavy metals such as copper are inhibitory. Type II α -amylases, in the presence of excess calcium, are resistant to heat and the inhibitory effects of heavy metal ions. They are, however, inhibited by calcium chelating agents such as phytic acid. Type II enzymes are unstable at pH values below 4.9 and exhibit maximal activity at pH 5.3. Type III α -amylases are complexes of α -amylase II and another protein termed **barley amylase/subtilisin inhibitor (BASI)**. The latter is a small protein originally isolated from barley but subsequently identified in several other cereals. Its physiological role is uncertain. Its ability to inhibit type III α -amylases suggests that might serve as a regulator of starch deposition and degradation. However, as its name suggests, it is also able to inhibit the bacterial protease subtilisin. This suggests that BASI might have an additional role possibly in the prevention of attack by plant pathogenic bacteria.

α -Amylases are most active at temperatures of approximately 48–60°C. They are more resistant to high temperatures than β -amylases and in consequence they retain activity for longer in temperature-programmed mashes.

β -Amylase

β -Amylase (α -1,4-glucan maltohydrolase; EC 3.2.1.2) is an enzyme that hydrolyses α -(1,4) linkages in starch polypeptides. It is a component of malt diastase, which, in conjunction with other hydrolytic enzymes, β -amylase, limit dextrinase, α -glucosidase and phosphorylase, is responsible for the degradation of starch and the subsequent liberation of fermentable sugars during the mashing phase of wort production. β -Amylases hydrolyse the penultimate α -(1,4) linkages of amylose and amylopectin to liberate maltose. β -Amylases cannot hydrolyse α -(1,4) linkages that are close to α -(1,6) branch points; consequently when acting alone they degrade amylose molecules to the point where α -(1,6) linkages are encountered. Similarly, amylopectins are shortened until the residues consist of dextrans where all the non-reducing ends are within a couple of residues of a branch point.

β -Amylases in barley occur in two forms: an insoluble latently active form and a soluble active form. Both bound and free form appear to be the same protein. During malting the proportion and ease of extraction of the soluble form of the enzyme increase. Two or more forms of the soluble enzyme have been shown to occur. These are genetically distinct. One of these occurs as an aggregate with another inactive protein. These aggregates can be separated by treatment with proteases such as papain and with agents that break disulphide bonds such as β -mercaptoethanol. It must be assumed that the distribution between bound and free form represents a mechanism for controlling activity during starch formation and breakdown.

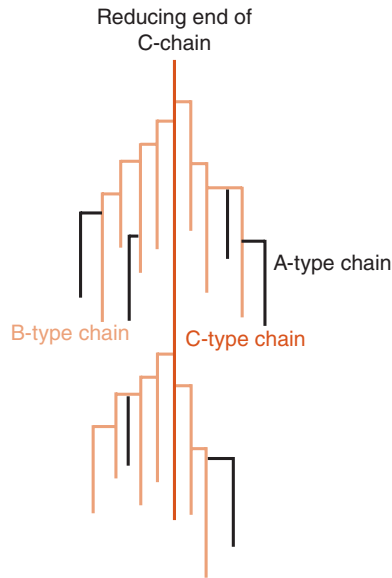
In general β -amylases are less thermotolerant and are more susceptible to inhibition by heavy metals compared to α -amylases. They are relatively unaffected by mild acidity and chelating agents. They have broad pH optima within the range pH 5.0–5.3.

The thermotolerance of β -amylases from individual barley cultivars is variable. Predictably those with the greatest ability to withstand high temperatures yield the most fermentable worts.

Amylopectin

Amylopectin is a condensation polymer of glucose. It forms the major component, typically approximately 75–80%, of starch granules. The remainder consists of amylose. By virtue of its relative abundance in malted barley it is the major raw material for the production of fermentable sugar during the mashing phase of wort production. Chemically, amylopectin consists of glucose units connected by α -(1,4) linkages. Branch points with α -(1,6) linkages occur at intervals of approximately 26 units. The molecular weight of amylopectin molecules is of the order 2×10^6 to 4×10^8 . The branch points account for approximately 6% of the total bonds. Each molecule has a single reducing end where the terminal chain end has a free C-1 position. In addition and because of the branched nature of the molecule, there are numerous non-reducing chain ends in which the terminal glucose residue is unsubstituted on position C-4.

The chains of linear α -(1,4) linked glucose molecules are classified into types A, B or C depending on their disposition within the amylopectin molecule. The A-type chains are attached to another chain by α -(1,6) linkages via its potential non-reducing end. The B- and C-type chains carry one or more A- or B-type chains. The C-type chain forms the backbone of the molecule and is distinguished by being the only one that has a free non-reducing end. Branch points occur on the C-chain approximately every 20–40 glucose units.



Idealised structure of molecule of amylopectin showing linear glucan chains linked by α -(1,4) bonds and branchpoints where α -(1,6) bonds occur

Amylopectin molecules from different plant sources are characterised on the basis of the number of individual glucose units in each chain and the ratio of A : B-type chains.

Amylose

Amylose is mainly a linear molecule consisting of α -(1,4) linked glucose units with occasional branch points where α -(1,6) linkages occur. Together with amylopectin it constitutes the major component of starch. In malted barley, the degradation of amylose and amylopectin by diastatic enzymes during the mashing phase of wort production yields fermentable sugars.

Amylose is a minor component of most starches compared to amylopectin and typically accounts for 20–30% of the total glucose content of starch grains. There are some natural variations to this pattern. High-amylose variants of maize and barley occur in which the starch grains of the endosperm contain up to 70% amylose. Conversely, some other mutants of barley, wheat, maize and rice, termed ‘waxy’ because of the appearance of the endosperm, may contain little or no amylose. In barley amylose molecules typically contain 1600–1900 sugar residues. The linear nature and relative lack of branch points means that each molecule has a free reducing and non-reducing end.

Anaerobic respiration

Anaerobic respiration is a term used occasionally as a synonym for fermentation. It is defined as the generation of energy by living organisms by catabolic reactions which do not involve the consumption of oxygen. In the case of brewery fermentations it is a misleading term since in the presence of sugars even under aerobic conditions, the phenomenon of catabolite repression means that energy generation is via substrate-level phosphorylation and ethanol and CO_2 are the major end products.

See **fermentation, catabolite repression**.

Anthocyanin

Name given to a class of flavonoid compounds which are found in most plants, including barley, and which serve as pigments.

See **polyphenols**.

Anthocyanogen

Anthocyanogens are a class of polyphenols, namely, flavan-3-ols, which after acidic cleavage and oxidation yield anthocyanin pigments. They are important precursors of beer hazes. The terminology is incorrect but has persisted in the brewing community. The name arose because early investigators thought they are colourless flavan-3,4-diols, which were also given the name leucoanthocyanins. This has since been shown to be not the case and the more appropriate term used in the wider chemical community is proanthocyanidin.

See **polyphenols, colloidal stability**.

Anti-foam

Anti-foams are chemical processing agents that are used to reduce the tendency of some process liquids to develop uncontrollable foams. This may occur particularly in the kettle and in fermentation. It is undesirable since it leads to losses. In the case of fermentation it increases the risks of contamination; hop iso- α -acids preferentially bind to gas bubbles and may be lost, resulting in the need to increase hopping rates. Excessive foaming in fermenters can affect adversely the foaming ability of finished beer since some of the proteins involved may be either lost or denatured. The ability to suppress foaming in fermenters allows over-filling of vessels and therefore increases batch productivity.

Several anti-foaming agents, also known as **defoamers**, can be used in brewing operations. They must be of food grade and must not exert any negative effects on finished beer. The suspicion that they may affect the head-forming ability of beers has caused some brewers to eschew their use entirely or at least to limit the quantity that can be used. This approach is probably overcautious since anti-foams are designed to be removed during the brewing process and should not persist into beer.

Anti-foams are either natural products or they may be synthetic in origin. Examples of the former include corn flour which has been sprayed over the surface of fermenting wort to suppress foam. Various extracts of grains rich in fatty acids have been shown to be effective, although the use of these materials appears rare or non-existent. Synthetic anti-foams can be split into silicone and non-silicone types based on mineral oils. The latter group encompasses a wide range of compounds that have a non-polar structure. These include esters of fatty acids (diglycol stearate, sorbitan trioleate), phosphate esters (sodium octyl phosphate), alcohols (polyalkaline glycols) and soaps (metallic ions of stearic or palmitic acids). Silicone anti-foams are emulsions of dimethylpolysiloxane and an ester of a long-chain alcohol.

The silicone anti-foams are most commonly used in brewing. Concentrations are of the order of a few parts per million. The agent may be added directly to worts before boiling in the kettle or after cooling and collection in the fermenter. Alternatively, in the case of fermentation, they may be sprayed directly into the foam head as needed. This method of addition is most effective but requires care with sterility.

Anti-foams act on the structure of the bubbles in foams. They displace bubble wall stabilising components causing them to burst and coalesce. They achieve this by virtue of the fact

that a thin film of anti-foam material which is formed in the bubbles has a lower surface tension than the materials present in the untreated bubble walls.

Anti-foam materials can be removed from beers in several ways. Their non-polar nature means that they naturally accumulate at liquid surfaces and thus they tend to remain bound to the walls of vessels after removal of the liquid. They readily attach themselves to yeast cell walls and, indeed, they have been reported in some instances to stimulate yeast growth. The materials bind to other processing aids such as silica gels or filtration media such as kieselguhr and perlite.

Antigen I

Antigen I is the major protein component in beers based on antibody reactivity. Structurally and compositionally it is very similar in structure to protein Z found in barley and other cereals. It is an important contributor to beer foam stability.

See **protein Z**.

Anti-vacuum valve

Anti-vacuum valves, also known as anti-vac valves or vacuum-relief valves, are fitted to fermenting vessels with the aim of preventing situations that, if not avoided, can lead to disastrous collapse and damage of expensive brewery plants. Thus, a partial vacuum can be created in vessels under several circumstances, for example, where caustic cleaning reagents react with gaseous CO₂, where vessels are emptied from the base or where cold liquids are admitted to vessels that have been heated during cleaning.

Anti-vacuum valves are fitted to the top plates of vessels. They take the form of a hinged cylindrical plate fitted with an o-ring that forms a seal with the lower inside surface of the top plate. The valve opens inwards and has an arm mounted on the top surface. The arm is attached to a bracket that forms a pivot allowing the valve to be opened and closed. The arm is fitted with an adjustable weight which in normal operation ensures that the valve remains shut. Sliding the weight up and down the arm provides a means of adjusting the pressure needed to open the valve and thereby prevents vacuum formation during sensitive operations.

Anti-vac valve

See **anti-vacuum valve**.

APCV-Portugal

The association of Portuguese brewers [*Associação Portuguesa Dos Productores de Cerveja*; <http://www.apcv.pt> (last accessed 30 January 2013) (Portuguese)].

API 20C test kit

A rapid method based on the API test strip approach and specially designed for yeast.

See **API test strips**.

API® test strips

A commercial system [<http://www.biomerieux-usa.com> (last accessed 30 January 2013)] designed for the rapid identification of microorganisms. Individual kits are available for bac-

teria and yeast, and these may be used to identify common brewery contaminants. They comprise small strips that contain a number of small wells, usually 20, containing dried medium. Aliquots of a saline suspension of a pure culture of the test organism are introduced into each well and the strips are incubated in a chamber. Growth on specific substrates can be detected by changes in colour due to the presence of suitable indicator dyes or via colour changes after reagents are added which detect the presence of specific products of metabolic activity.

Apollo

Apollo is a US-bred super alpha hop variety containing 15–19% α -acids. It is resistant to powdery mildew.

Apolon

Apolon is a hop variety bred in the 1970s at the Hop Research Institute in Zalec, Slovenia. It is related to **Ahil**, **Atlas** and **Aurora** which together constitute the original **Super Styrian** high alpha varieties.

The analytical profile is 10.0–12.05% total α -acids of which 26.0% is cohumulone. Total β -acids are 4.0%. Total oils are 1.3–1.6%.

See **Super Styrian hops**.

Apparent attenuation limit gravity

The apparent attenuation limit is the specific gravity measured at the end of fermentation. It is the limit gravity in the sense that addition of further yeast or longer residence time has no further effect. The adjective apparent is appended where the gravity measurement is made in the presence of ethanol. The latter is less dense than water and therefore has a depressing effect on measurements of specific gravity. The real attenuation limit is the measure of specific gravity made after the removal of ethanol and correction for volume and temperature. The real attenuation limit gravity is approximately $0.8 \times$ the apparent attenuation limit gravity.

Apparent extract

See **original extract**.

Apparent final gravity

The wort concentration measured as specific gravity or some other derived unit measured at the end of fermentation and not corrected for the depressing effect of the presence of ethanol.

See **original gravity (OG)**.

Apparent gravity

See **original extract**.

Apparent total N-nitroso compounds (ATNCs)

A potentially carcinogenic group of compounds that may arise in beer as a result of the growth of the beer spoilage bacterium *Obesumbacterium proteus*. This organism, sometimes found in pitching yeast, can grow in early fermentation and reduce nitrates, present in wort, to

nitrites. The latter can react with wort amines to generate ATNCs. Current voluntary agreements limit ATNC contents of beer to no more than 20 µg/L.

Apparent wet density

See **specific bed volume**.

APV continuous fermenter

See **tower continuous fermenter**.

APV continuous mashing system

This device was devised by the APV Company for continuous mashing and lautering and was intended to be used as part of a continuous brewhouse and fermentation system. It comprises a mill and feeder system in which grist is suspended in liquor in a mash mixer prior to feeding into stainless steel tubes held in attemperated water tanks. The mash flows through the tubes without back-mixing (plug flow) at a rate and temperature designed to provide the desired mashing regime. At the end of this process the converted mash is loaded into one of a series of eight buckets each taking the form of a small mash tun. The buckets are located on a rotating table. Each bucket is allowed to rotate such that when particular positions in the orbit are occupied, the usual steps of lautering (fill, wort collection and recycling, wort collection, sparging, spent grain discharge and cleaning) are carried out.

Aquifer

An aquifer is a geological term describing a source of underground water. Aquifers are tapped by some brewers in the form of boreholes or wells for the abstraction of brewing liquor.

Aquifers occur where surface water percolates through permeable rock strata until it reaches an impermeable layer on the surface of which the water accumulates.

See **water**.

Arabinoxylan

Arabinoxylans are non-starch polysaccharides that form part of the pentosan components of the hemicellulose fraction of plant cell walls.

See **hemicellulose**.

Arabis Mosaic Nepovirus (ArMV)

A virus that is capable of producing disease in hop plants. Infected plants are slow growing and have shorter than normal internodes with the result that the plant appears short and bushy. Yields of cones are significantly reduced (up to 50%). The leaves develop pale yellow-green spots and some leaf blades become thin and transparent, eventually splitting. The latter symptoms result in the disease also being referred to as hop split leaf blotch virus.

Arnold of Soissons

Belgian monk and patron saint of brewing born in Brabant in the eleventh century and often confused with **Arnulf of Metz** and **Arnou of Oudenaarde**. His association with brewing and subsequent canonisation is reputedly a result of his exhortation of the local populace to drink

beer as opposed to the more dangerous supplies of water, presumably not a difficult argument to win.

Arnoldus Group

An initiative of the association of Belgian Brewers that seeks to promote the benefits of moderate alcohol consumption and to warn of the dangers of alcohol misuse. The group [<http://www.beerparadise.be> (last accessed 30 January 2013)] has produced guidelines regarding the responsible marketing of alcoholic beverages that are binding to all members of the group.

Arnou of Oudenaarde

A saint often associated with brewing based on a story involving the provision of a miraculous supply of beer to thirsty soldiery. It appears that there is some confusion between this personage and **Arnulf of Metz** and **Arnold of Soissons**.

Arnulf of Metz

A Frank born sometime towards the end of the sixth century, also known as Arnoul or Arnouf. He became bishop of Metz in AD 612 and later adopted a monastic lifestyle. He is often confused with Arnould of Soissons, a patron saint of brewing.

Aroma hops

Aroma hops are those, as the name suggests, that are added to impart desired hop-derived aroma and flavours to beers other than bitterness. The active components are those that are found in the volatile hop oil fractions of the lupulin glands of hops (see **hop oils** for more details).

Of course, all hops contain both hop oils and the precursors of bittering compounds (iso- α -acids); however, the proportions of each differ with hop variety. Those that are used principally as sources of bitterness, termed high alpha varieties or kettle hops, have been selected because they contain a high proportion of iso- α -acids. Aroma varieties that are used to impart characteristics such as floral, spice and citrus are added towards the end of the kettle boil (late hopping mainly associated with continental lager beers) to preserve as much as possible of the volatile oil fraction. Alternatively they may be added directly to packaged beer (dry hopping associated with UK-style cask ales). In both cases the content of iso- α -acids is not relevant since most or all will not be isomerised. The bittering components of such beers are obtained from other hops (or hop preparations) selected for this purpose.

Arsenic-beer drinkers' disease

The name given to an epidemic that occurred in 1900 in the Northwest of the United Kingdom and which was attributed to the accidental contamination of beer with arsenic. More than 6000 cases were recorded and these included over 70 fatalities.

The source of the contamination was identified as being a batch of sulphuric acid used in the preparation of cane sugar; however, it was calculated that this would have resulted in levels of arsenic in beer of 0.2–0.4 mg/L, which is insufficient to produce the symptoms. The effects could not be ascribed to simple very heavy beer consumption. The majority of the victims suffered from symptoms of heart failure and it was suggested that this could imply

that ethanol consumption predisposed some individuals to arsenic poisoning. It is now suggested that the reverse may be true and that arsenic may predispose some individuals to alcoholic cardiomyopathy. This suggestion is supported by a later event that occurred in some of the northern states of the United States and Quebec. In this episode predominantly heavy beer drinkers developed similar, and often fatal, cardiac disease, which was shown to be linked to the use of cobalt chloride as a beer heading agent. This became known as '**Quebec beer drinkers' cardiomyopathy**'. All symptoms disappeared when the use of the cobalt was discontinued.

In both of these cases it was concluded that the diseases were induced by a combination of cobalt or arsenic, heavy alcohol consumption and other predisposing factors.

Artesian well

Name given to a deep water supply which may be tapped to provide a source of brewing water. The name derives from that of the historical French province of *Artois*, which has such sources of water. An artesian well comprises a natural aquifer located between two impermeable rock strata. The aquifer contains an inclined element such that fresh water enters from the sides and, in so doing, generates a hydrostatic pressure. If a borehole is sunk into the lower regions of such an aquifer this hydrostatic pressure is sufficient to drive the water to the surface without the need for pumping.

Asahi premature yeast flocculation (PYF) Test

Procedure used to assess whether or not a batch of malt shows PYF activity based on measurement of suspended cell count after 2 days in a 50 mL laboratory fermentation performed at 21°C.

See **premature yeast flocculation (PYF)**.

Asahi vessel

Asahi vessels, developed by the Japanese brewing company of the same name, are combined fermenting and conditioning tanks. They are now rare but were a popular choice of many US brewers in the 1960s and 1970s when there was a need to produce large volumes of beer using a process with a comparatively short cycle time.

They comprise cylindrical tanks, made from stainless steel with a dished top an aspect ratio close to 1:1. Capacities are large, typically 5000 hL, although examples greater than 10,000 hL have been used. Vessels are insulated and fitted with an outer weatherproof coat to allow them to be sited in the open air.

The unique features of the vessels (see accompanying figure) are that they have a flat base, the inner surface of which is inclined towards an exit main in order to facilitate collection and removal of the bottom yeast crop. The vessels are fitted with an external wall and bottom-mounted cooling jacket. In addition, there is a circulation system, which incorporates an in-line plate and frame heat exchanger and a continuous centrifuge. The set-up of the recirculation loop is complex. Both the take-off and re-entry points are at the base of the vessel; however, the latter is attached to an internal arm, pivoted at the base and attached to a float at the top. It is claimed that this arrangement gives improved control of dissolved CO₂ levels. The external part of the loop is constructed in a way that allows the in-line chiller and centrifuge to be bypassed.

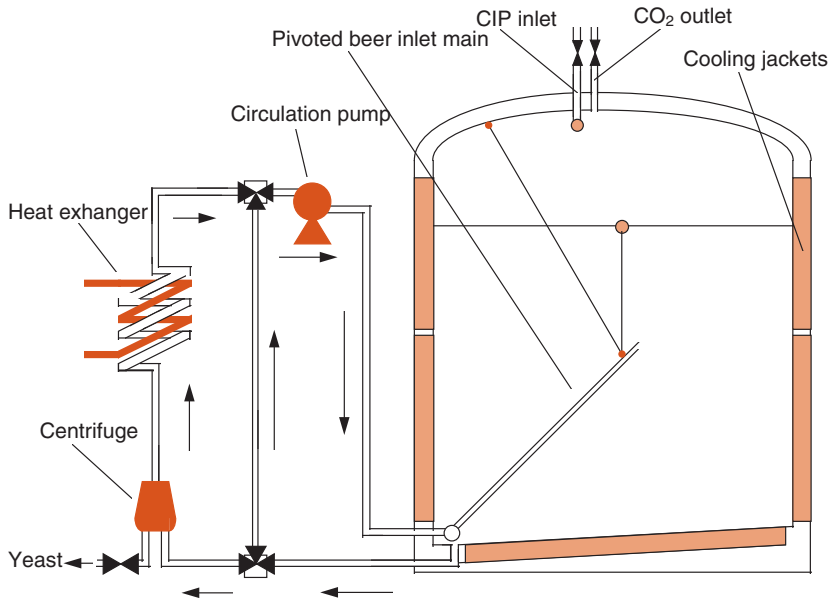


Diagram showing the key features of an Asahi fermentation vessel

A typical operation was as follows. As is common with many breweries, several batches of wort were usually required to fill the fermenters and filling times could be as long as 20 hours. The wort was clarified using a trub flotation technique prior to pitching and transfer. After a relatively long cool primary fermentation (*ca.* 8 days at 5–9°C) the fully attenuated green beer was chilled to approximately 2°C by continuous circulation through the external chiller. During this period of 5–10 hours the green beer was also passed through the centrifuge and yeast counts decreased by approximately half. Following this period the beer was lagered and cold conditioned in the same vessel for a further 30 days. Throughout this period the beer was circulated through the loop bypassing the chiller and centrifuge. Using just the vessel cooling jackets at the end of this phase the temperature was reduced to –1°C and the majority of the yeast had formed a compact sediment at the base of the vessel.

Aspergillus oryzae

The mould used in the initial amyolytic step in the production of saké.

See **saké**.

Assimilation tank

Vessel used for yeast propagation at brewery scale in a semi-continuous process where part of the culture is removed for pitching-on but leaving a small residue which is mixed with fresh wort to seed a further propagation phase.

See **yeast propagation**.

Assobirra

An organisation representing the Italian brewing industry [*Associazione Degli Industriali Della Birra E Del Malto*; <http://www.assobirra.it> (last accessed 30 January 2013)]. The organisation seeks to promote a positive image of beer consumption and ensures that member companies abide by current European guidelines regarding the responsible marketing of beer.

ATP bioluminescence

Phenomenon used as the basis of several tests which are used for the rapid detection of low levels of microbial contamination or as a means of post-CIP hygiene testing of brewery plants. ATP occurs in all living cells but is rapidly degraded after cell death; therefore, its presence is indicative of the presence of viable organisms. In addition, the technique has been used as a means of assessing **yeast vitality**.

ATP can be detected using the luciferin–luciferase enzyme system which is extracted from the North American firefly *Photinus pyralis*. In the presence of Mg^{2+} ions and molecular oxygen the enzyme complex reacts with ATP to yield AMP, pyrophosphate and light. The light, the intensity of which is directly related to the concentration of ATP, can be detected and quantified using a luminometer.

Several commercial instruments have been developed which rely on this reaction for their mode of action. These may be laboratory based or small portable instruments which can be used for routine field testing. For hygiene testing the cleaned surface is swabbed and any ATP present, which is indicative of lack of cleanliness, is extracted and quantified in the luminometer. Many commercial instruments used in routine brewing QC hygiene testing use proprietary dipsticks which contain all the reagents necessary for the test to be performed.

Systems aimed at detecting viable microorganisms in beer streams may use a pre-culture step in order to increase possibly very low cell counts. This extends the time required for results to be obtained. Alternatively, membrane filters can be used to concentrate samples and thereby increase detection limits. Current systems are capable of detecting, without prior enrichment, roughly 1000 bacterial cells or 10 yeast cells.

Asua

A native beer originating from South America and made via the fermentation of extracts of boiled and crushed maize or cassava (manioc).

Atlas

Atlas is a hop variety, one of the four original Super Styrian high alpha varieties, together with Ahil, Apolon and Aurora, bred in the 1970s at the Hop Research Institute at Zalec, Slovenia. It derives from Brewer's Gold and a Slovenian male. It contains 9–11% total α -acids of which 36% is cohumulone. Total β -acids and oils are 4 and 1.3–1.6%, respectively. Storage properties are poor.

ATTC

American Type Culture Collection.

See **yeast culture collections**.

Attenuation

The term attenuation is used to describe the decrease in wort concentration, measured in the units which relate to density such as **present gravity** or **degree Plato**, which occurs during fermentation as a result of yeast growth and metabolism. The term is usually modified to indicate some aspect of fermentation performance; for example, the rate of decrease in wort concentration can be described as the **attenuation rate**. Similarly, the desired end gravity may be described as the **attenuation gravity**. These parameters provide useful means of checking that the fermentation is proceeding as normal. A beer that contains no residual fermentable extract would be described as being fully attenuated.

See **super-attenuation**.

Attenuation gravity

Attenuation gravity is the wort concentration, measured during fermentation as a derived unit of wort density such as present gravity (PG) or degree Plato (°P) at which all the fermentable extract has been utilised by the yeast. It is also referred to as the **end gravity**, **racking gravity** (RG) or **final gravity** (FG).

In some cases the fermentation may have been made to cease prematurely; for example, by the application of chilling, when some residual fermentable extract remains as it may be required to fuel a subsequent secondary fermentation. Although in this latter case the wort is not fully attenuated, the terms given here may still be used since the desired end point has been reached.

Attenuation limit

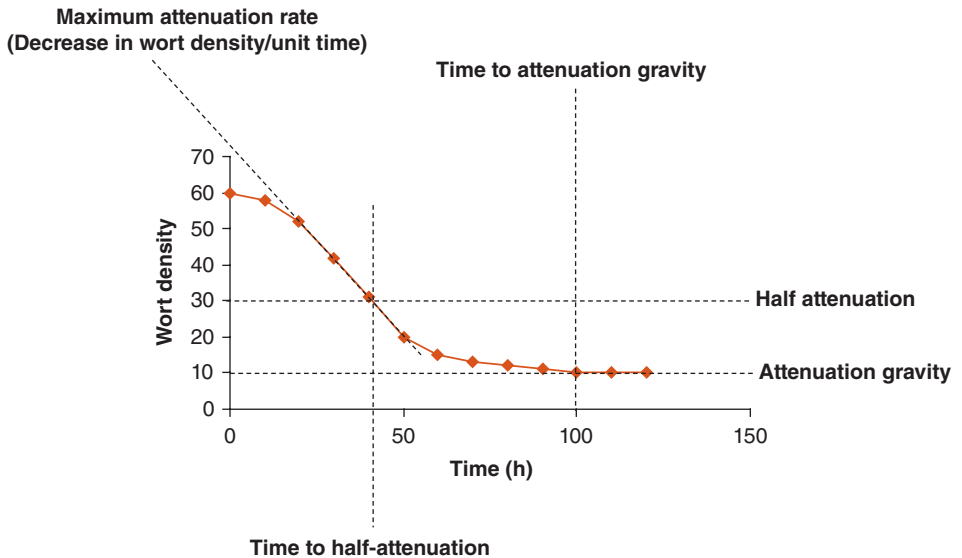
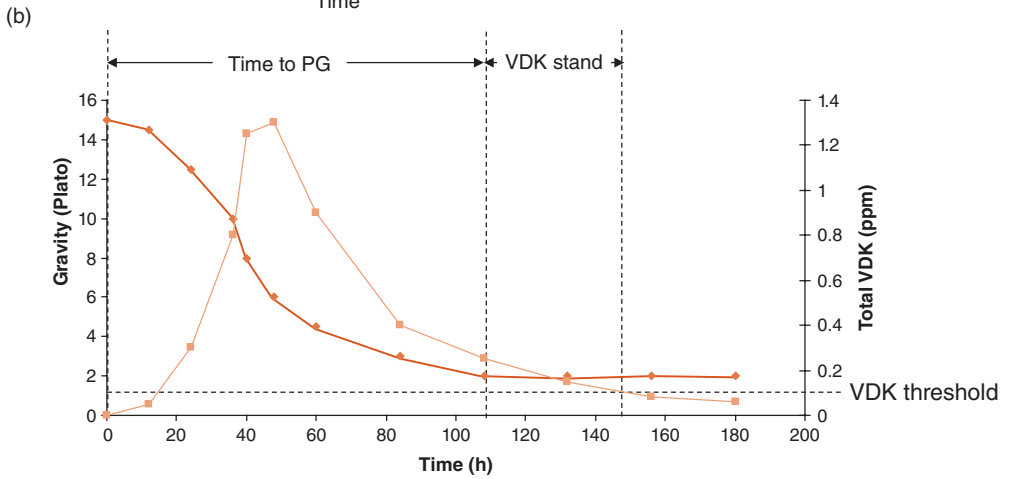
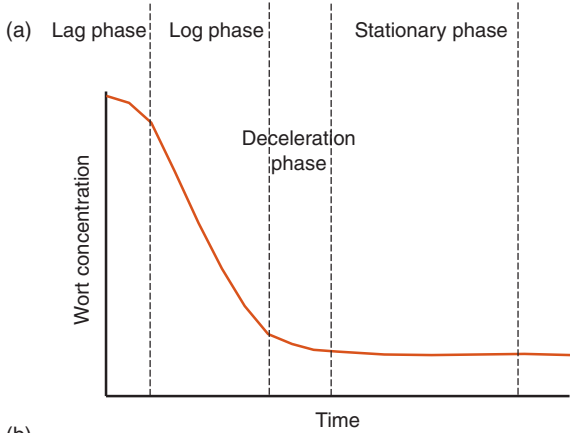
The attenuation limit of a wort is the measure of specific gravity of the non-fermentable residue which is left after fermentation is completed. It is usually measured via a laboratory test in which pitching yeast is mixed with a sample of filtered aerated wort and the mixture incubated at 25°C. The specific gravity is measured daily and the process monitored until no further reduction in specific gravity is observed. The terminal specific gravity is a measure of the minimum specific gravity achievable in fermentation. The presence of ethanol, which is less dense than water, exerts a depressing effect on the measured gravity. For this reason the result would be referred to as the apparent attenuation limit.

The attenuation limit is a theoretical value and may not be the same as the actual final gravity achieved in real fermentations. Thus, in commercial fermentations, either by design or via non-ideal performance, the process may end when some fermentable residue remains owing to premature separation of yeast from wort.

Attenuation rate

The term attenuation rate is used to describe the rate of decrease in wort concentration during fermentation with respect to time. It is used to assess how well (or not) fermentation is proceeding. Since the rate is not linear other measures of fermentation rate that relate to attenuation are commonly used, as shown in the figure.

A



Attenuation time

Term used as a measure of fermentation performance defined as the time taken from the commencement of fermentation (usually the time the vessel is completely filled) to the point at which the minimum desired wort concentration (measured as specific gravity or °Plato) is achieved.

Aubry test

The Aubry test is one of several methods that are used to assess the germinative energy of grains.

See **germinative energy**.

Augustine of Hippo

Augustine of Hippo (AD 354–430) was a philosopher and theologian who lived in the Roman provinces of North Africa. He was canonised by the Catholic Church in the thirteenth century and is recognised as the patron saint of brewers, printers, theologians and sore eyes. His association with brewing is somewhat surprisingly claimed to reflect the fact that he famously grew out of a somewhat dissolute youth to adopt a decidedly more ascetic lifestyle in middle age. His struggles in this regard are summed up by his often quoted remark, ‘grant me chastity and continence, but not yet’.

Aurora

Aurora is a hop variety, one of the four original Super Styrian high alpha varieties, together with Atlas, Apolon and Ahil, bred in the 1970s at the Hop Research Institute at Zalec, Slovenia. Unlike the other three, which are seedlings of Brewer’s Gold and a Slovenian male, it derives from Northern Brewer. It contains 10–12% total α -acids of which 22% is cohumulone. Total β -acids and oils are 4–5% and 1.1–1.8%, respectively. Storage properties are very good.

Australasian Associated Brewers Inc. (AAB)

The AAB can be contacted at ausbrew@aab.org.au (last accessed 31 January 2013)] was founded in 1967 and is a trade organisation representing the interest of the Australian and New Zealand brewing industry. Its membership includes most of the major brewers in these countries. Its stated aim is to promote public debate on issues such as advertising, responsible consumption of alcohol and taxation.

Automated yeast slurry analysis

See **yeast slurry analysis**.

Auto-tilting stillage

See **stillage**.

AutoTrack™

Proprietary hygiene testing system made by Biotrace International [now part of the 3M Company; <http://www.3M.com> (last accessed 31 January 2013)] based on ATP bioluminescence.

It is an in-line system that continuously measures total ATP (microbial + non-microbial) and free ATP (non-microbial) levels, in liquid or gas streams.

See **ATP bioluminescence**.

Autumn beer

Autumn beer is a historic and generic term given to seasonal beers that are brewed in the United Kingdom during the autumn months and thence stored throughout the winter for consumption the following spring. The beers are primarily associated with country house brewing.

See **seasonal beers**.

Avenin

Avenins are **prolamin** proteins that occur in the grains of the oat (*Avena sativa*). They are the equivalent of the hordeins in barley.

Awn

The awn is a part of the seed head of certain cereals. It is a hair-like projection formed on the tip of the lemma. It is characteristic of many grasses and contributes to the overall bristle-like appearance of the plant. In the case of the barley plant it is synonymous with **beard**. Some barley varieties are awnless, but when present, they are of variable length, in some cases reaching up to 30 cm. The fine structures of awns where present are variable. Those of some varieties are smooth, whereas others bear teeth at the base and along their length barbs or hair-like extensions. These differences are used for varietal identification purposes.

Awns are provided with vascular bundles and numerous stomata. These features are in accord with their presumed function. The presence of stomata allows high rates of transpiration thereby implicating the awns as organs of plant temperature control. The vascular tissue, together with a supply of chloroplasts, suggests that awns increase the photosynthetic capacity of the plant and by implication the potential yield of grains.

In mature barley plants the awn dries and becomes brittle, and during threshing it is usually broken off close to the lemma.

Bacillus

Gram-positive bacteria which comprise large motile spore-forming rods. The ability to form endospores makes them thermophilic such that they can survive wort boiling and they are capable of growth at comparatively high temperatures (up to 70°C). They are not tolerant of low pH or hop acids and so they cannot cause spoilage of beers or bittered worts; however, growth is possible in sweet wort. The major product of growth is lactic acid and this ability has been used as a method of **biological acidification**. Where this is not an intentional it represents spoilage.

Backa

Backa is a hop variety selected from a landrace growing in the region of the same name in the former Yugoslavia. It is an aroma type with low α -acid and, as a result of low yields, it has been largely replaced by superior varieties.

Bacterial diseases of hop

Several bacterial species are able to cause diseases in hops. The symptoms are various and include the appearance of spots and necrotic lesions on infected tissue. Systemic infections lead to stunting, wilting and general weakening of plants with concomitant reductions in yield.

Examples of recognised diseases and the causative agents include bacterial blight disease, which is caused by *Pseudomonas syringae* pv. *cannabina*. Crown gall disease is caused by the soil bacterium *Agrobacterium tumefaciens*, which, as suggested, results in the formation of tumour like growths that cause damage to the roots and a consequent lack of vigour and reduced yield. In the case of *Xanthomonas* leaf spot disease caused by *Xanthomonas campestris* pv. *Cannabina*, the production of extracellular gums by the bacterium can cause blockage of plant phloem tissue such that wilting occurs. Hop shoot proliferation disease is caused by systemic phytoplasma infections of phloem tissue. These organisms are transmitted by insect vectors and in severe cases can result in general weakening and even wilting of infected plants.

Bactometer®

Commercial apparatus [<http://www.biomerieux.ch> (last accessed 4 February 2013)] for the rapid detection of microbial growth.

See **impedimetry**.

Bakers' yeast

Name given to yeast, which, as the name suggests, is produced commercially for the purpose of leavening dough in baking. Bakers' yeast strains are classified as *Saccharomyces cerevisiae*, the same taxonomic group as **ale yeasts**.

Yeast destined for use in baking is produced in commercial quantities using a **fed-batch fermentation** in which the propagation is performed under highly aerobic and catabolite derepressing conditions. This ensures that yields are very high, compared to a brewing fermentation, and the yeast has a fully respiratory physiology. The latter state favours the high rates of CO₂ evolution and low ethanol yields which are the most appropriate for leavening.

Bakers' yeast is sold either in the form of a dewatered wet cake or as an active dried preparation.

Bakhar

See **pachwai**.

Balché

Balché is the name given to a comparatively weak native mead-like alcoholic beverage made via the spontaneous fermentation of honey and extracts of the bark of the tree of the same name (*Lonchocarpus violaceus*). The product has its origins in the Mayan civilisation.

Balling, Carl Joseph Napoleon von (1805–1868)

Scientist and Professor of Technical Chemistry based at the Polytechnical Institute in Prague who, in response to requests by officials in Bohemia and Austria responsible for excise payments, made a study of brewing fermentation. In order to quantify sugar concentration and the amount of the same consumed by yeast during fermentation he devised the eponymous scale for which he is now best known.

See **degree Balling**.

Balling (of grist)

Balling is the term applied to dry grist materials which have been handled incorrectly such that they have become moistened. Such material tends to be hygroscopic and any absorption of moisture causes the grist materials to adhere and form 'balls'. The presence of the latter can adversely affect the efficiency of the mashing process.

Ball mills

Ball mills are those in which the material to be broken up is placed within a cylindrical chamber that can be made to rotate. The dry goods that are to be milled are supplemented with a number of balls made from hardened steel. As the chamber rotates the balls are thrown around and impact with the dry goods thereby bringing about disruption and reduction in particle size.

Ball mills have no use in commercial brewing but may be encountered for use in some laboratory analyses.

Ball valve

Ball valves are those in which a sphere made of stainless steel is located within pipework. The sphere is pierced by a hole the orientation of which is parallel to the direction of flow. An inert elastomer cradle forms a seal between the walls of the sphere and the wall of the pipe. The ball can be rotated by 90° to restrict or permit flow, as required.

The characteristics of this type of valve are that they provide a good seal and have excellent shut-off properties, but they are not good for controlling rates of flow. They have little effect on pressure when fully open and they are not susceptible to blocking and, hence, they may be used in situations where the fluid has a high solid content. However, they are not hygienic since the parts of the sphere may not be fully accessible to CIP fluids. They are resistant to high pressures and for this reason are commonly used to control the supply of gases and other utilities.

Baltic porter

See **porter**.

Bantu beer

A pejorative term for beer of native African origin.

See **native African beers**.

Bar hugger

See **lowliner**.

Barley

Cultivated barley is a cereal crop plant the seeds of which provide the raw material used in the manufacture of malt. Its botanical name is *Hordeum vulgare* and it is a member of the grass family (Poaceae or Gramineae) and the tribe Triticeae. It is considered to be a subspecies of wild barley (*H. vulgare* var. *spontaneum*).

It appears to have been domesticated in the Fertile Crescent in the Middle East probably in Neolithic times. Evidence exists for barley cultivation in Iran in 8000 BC. In ancient Egypt it was an important foodstuff being used widely for baking and brewing.

It is an important cereal food crop ranking fourth in the world in terms of the area of land devoted to its cultivation. It is cultivated mainly in temperate zones of the northern hemisphere, especially Europe and North America. In the southern hemisphere Australia is the major producer. Spring varieties are sown in early spring and harvested in late summer/autumn. Winter varieties are sown in the autumn/early winter and are harvested in late spring of the following year. The plant is relatively tolerant to cold, salinity, alkaline conditions and periods of drought. It is able to compete well with other grasses and it reaches maturity sooner than wheat. All of these factors, no doubt, contribute to its success as a feed crop. It is intolerant of very acid and wet conditions. Optimum conditions are a temperature range of 15–30°C and an annual rainfall of 500–1000mm. All varieties exhibit a photoperiod response and require long days to flower. In addition, winter types require a vernalisation period of two to

several weeks where the average temperature is less than 10°C (50°F). Soils should be of moderate fertility especially with regard to nitrogen. Elevated levels of the latter result in reduced grain yields. Nitrogen fertilisers must also be used sparingly since high protein levels render grains less useful for malting.

Most barley is used for animal feed where high nitrogen varieties are preferred. The largest proportion of the remainder is used in the manufacture of alcoholic beverages such as beer and distilled spirits. In this case low-nitrogen high extract-yielding varieties are preferred.

Barley varieties are classified on the basis of the disposition of the rows of seed kernels on the spike. These may be two-rowed or six-rowed. All are now classified as *H. vulgare*, although the former types are sometimes referred to as *Hordeum distichon*. All wild barleys are two-rowed.

Both two- and six-rowed barleys are used for brewing. Traditionally the two-rowed types were predominant in Europe, whereas six-rowed varieties were favoured by North American producers. Barley kernels of two-rowed varieties are on average larger and more uniform compared with those from six-rowed types. In addition there are other biochemical differences that have importance in terms of malt quality. In general it is preferable to use malts with a relatively low total nitrogen content. Two-rowed varieties fulfil this need. Furthermore, they contain more extract and α -amylase but less β -glucan and diastatic power.

Many different and individually named cultivars exist. Many of these are suited to particular climatic and soil conditions and, in this respect, individual cultivars of barley are often adapted to particular ecological niches.

Genetically the cultivated barley plant is diploid and contains 14 chromosomes. This differs from wild varieties, which may be diploid, tetraploid or hexaploid.

Barley amylase/Subtilisin inhibitor (BASI)

BASI is a small protein originally isolated from barley but later found in several other cereals. It binds to and inhibits barley type III α -amylases, suggesting a role in the regulation of starch metabolism in those plants that possess it. In addition it also binds to and inhibits bacterial subtilisin. This apparent dual function has resulted in the suggestion that it might have a defence role in the prevention of bacterial infection. The content of BASI in various barley cultivars has indicated that it is relatively more abundant in malting varieties compared with feed types.

The accumulation of BASI mRNA in barley has been shown to be tissue-specific and to vary in concentration consistent with it having a developmental role. The mRNA was identified in endosperm tissue and the aleurone tissue of germinating seeds. The accumulation of BASI mRNA in these tissues was shown to be enhanced by abscisic acid and abolished by gibberellic acid. These responses are consistent with the putative role of BASI as a regulator of α -amylase activity during starch breakdown.

Barley Australia Ltd.

A non-profit-making organisation [<http://www.barleyaustralia.com> (last accessed 25 March 2013)] formed in 2005 by a group of companies with an interest in the cultivation of malting barley in Australia. The organisation seeks to look after the interests of barley growers, brewers and maltsters, funds appropriate research and produces annual lists of accredited malting varieties.

The process of accreditation is overseen by the Malting and Brewing Industry Technical Committee, which is made up members with appropriate expertise and interests. Decisions are based on breeding, field, malting and brewing trials.

As of 2011 the list of accredited varieties (together with the dates of recommendation) was

Baudin (2003)
 Buloke (2008)
 Commander (2009)
 Fitzroy (2005)
 Flagship (2008)
 Gairdner (1998)
 Grimmet (1982)
 Hamelin (2004)
 Schooner (1983)
 Stirling (1982)
 Vlamingh (2006)

Barley bushel

A non-decimal measure used for quantifying batches of malt. The precise weights vary in different countries. All are given as fresh weights:

United Kingdom, South Africa = 56 lb, 25.4 kg

Australia and New Zealand = 50 lb, 22.7 kg

United States, Canada = 48 lb, 21.8 kg

Barley grain

The barley grain, or corn, is the fruit of the cereal grain plant, **barley** (*H. vulgare* and related species). It consists of a package that contains an embryonic barley plant together with reserve materials, principally carbohydrates and proteins, which when mobilised provide fuel for germination of the embryo. The barley grain is the raw material for the preparation of **malting barley**, the most common ingredient used for the manufacture of wort.

Botanically the grain is a **caryopsis**, that is, a dry indehiscent, one-seeded fruit, in which the seed coat, or **testa**, is fused to the **pericarp**, the tissue surrounding the fruit which develops from the ovary wall of the flower.

Barley grains are variable with regard to their physical dimensions but typically lie within the range 6–12 mm in length. The weight of grains is usually expressed in the form of ‘**one thousand corn (kernel) weight (TCW)**’ value since this allows for variability between individual grains. TCW values are in the range of 30–45 g. In general, grains of two-rowed barley varieties are slightly larger and plumper compared to six-rowed types.

The barley grain has an elongated bulbous form with tapering ends. The outer coat or **husk (hull, glume)** comprises two leaf-like structures or bracts, termed the **lemma** and the **palea**. The first of these is rounded and covers the dorsal part of the grain. The latter is more flattened in form and covers the ventral portion of the grain. In huskless (or naked) varieties of barley the husk is relatively easily detached and it is absent in threshed corns. Both lemma and palea bear longitudinal ridges or veins, two in the case of the palea and five in the lemma. These veins mark the location of vascular bundles which run beneath their surfaces. In addition to

the veins the palea has a relatively deep central groove. The husk serves to protect the grain from damage, and in mature grains it consists entirely of multiple layers of dead cells. Vascular bundles run through an inner layer that comprises parenchyma cells. In immature grains these cells are capable of photosynthesis and in part provide sugar molecules used for the formation of starch granules, which constitute the major reserve material of the mature grain. In brewing the husk may be of significance since it forms part of the filtration bed in **lauter tuns**.

The tip of the lemma is extended to form a long bristle-like appendage termed the **awn** or **beard**. During the threshing of grain the awn is broken off. At the base of the grain at the point of attachment to the stalk, or **pedicel**, is a basal bristle termed the **rachilla**. This lies within the central dorsal groove of the palea. The rachilla is the axis of the spikelet by which the grain is attached to the barley plant. The form taken by the rachilla is variable and it can be of varietal taxonomic significance.

Barley grains have characteristic colours. In the absence of the husk, the presence or absence of **anthocyanin** and other pigments in the **aleurone layer** and/or pericarp can impart white (colourless), blue, purple, black or green colours to the naked grain. Colours within the husk can further modify the hue of the grain. Thus, husked grains may appear green in colour when there is a combination of yellow husk and blue grain. The husk is typically a shade of yellow to orange, but colourless, black, red and grey varieties occur. In addition, the presence of anthocyanins may confer purple colouration to the veins in the lemma and palea. Lying beneath the palea and overlaying the embryo are small leaf-like structures termed **lodicules**. These are variable in morphology and of use in varietal identification. Most bear hair-like projections which are thought to assist in supplying the embryo with moisture.

The internal structures of barley corns are complex. The major features are shown in the accompanying diagram. The combined testa and pericarp form the outer boundary layer of the grain. These serve to protect the embryo and other internal structures from damage. The testa also controls the passage of gases and dissolved metabolites into and out of the interior of the grain. The latter is made up of crushed cells which take the form of an inner and outer cuticle which enclose a central layer of cellulose and crushed hyaline. The latter is derived from the nucellar tissue of the original ovule. The central tissue of the testa is the location for much of the pool of **proanthocyanidins**, barley constituents which are important in the formation of **beer hazes**. The testa covers the entire surface of the grain except at the **micropyle** where it may be thinned or even absent. In the central ventral groove the testa is fused to the **pigment strand**. This structure is derived from the chalazal tissue or the basal region of the original ovule.

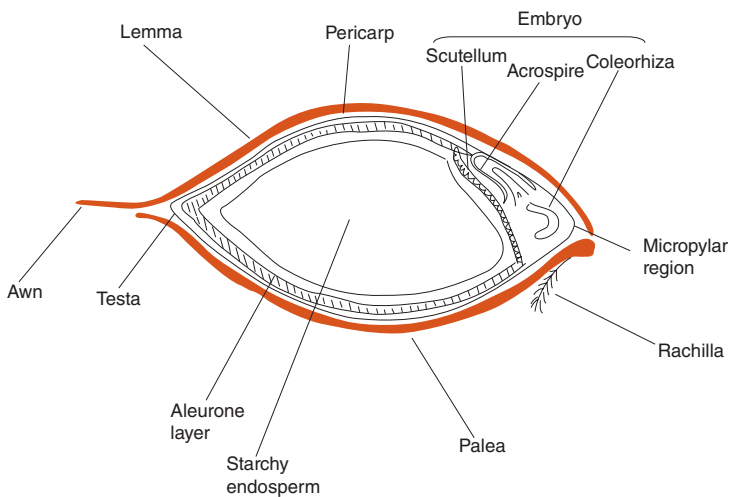
The pericarp lies between the testa and the husk. Like the testa the pericarp also consists of multiple layers of dead cells. Two outer layers of cells, the epidermis and hypodermis, comprise elongated cells aligned with the longitudinal axis of the grain. Beneath these is a further double row of cells that are orientated 90° to those in the outer layer. For this reason these are termed **cross cells** and had primarily a photosynthetic role in the ovary from which the grain was derived. In the central furrow of the paleal region the pericarp is thickened and contains the vestiges of a vascular bundle.

The bulk of the interior of the barley grain consists of the **endosperm**. This is also multi-layered and, with the exception of the embryo, it fills all the interior of the grain. At the central ventral furrow the testa is fused with a column of **sheaf cells** which projects into the interior

of the grain. Endosperm cells radiate out from this column. At the periphery of the endosperm and directly beneath the testa is the aleurone layer. This is a thin layer of living cells encompassing most of the endosperm. The cells are thick-walled and cuboid in form and are traversed by plasmodesmata. They contain prominent nuclei and functional organelles but no starch. Two types of storage body are present, lipid-containing **spherosomes** and **aleurone bodies**. The latter have a protein matrix in which are inclusions of either salts of **phytic acid** (inositol hexahydrate) or complexes of proteins and polysaccharides.

The cells of the endosperm proper are all dead. Those within the central part are densely packed with large and small starch granules which are embedded in a matrix of protein as shown in the accompanying illustration. In addition, protein-containing storage bodies are present. The cell walls are composed principally of **β -glucans**. The cells immediately below the aleurone layer (**sub-aleurone**) contain relatively few and small starch grains and are more abundant in protein content, including β -amylase. In grains with an abundance of starch granules the endosperm takes on a soft floury white appearance. In contrast, where there is a relatively high protein and lower starch content, as is the case in immature grains and some high-protein barley varieties, the endosperm takes on a steely or glassy appearance.

The embryo lies towards the dorsal end of the grain beneath the testa and away from the awn. It is separated from the endosperm by the **scutellum**, derived from the Latin word meaning 'little shield'. This is part of the embryo and contains a layer of epithelial cells which abut the endosperm. In this region of the endosperm, termed the depleted or crushed layer, the cells are devoid of content and the walls are pressed closely together. The axis of the embryo is fitted into a recess in the scutellum. It consists of the coleoptile (the leaf sheath of a monocotyledonous seedling, also in brewing known as the **acrosipire**), which points towards the apex of the grain. The coleoptile encloses the apical meristem, bud primordia and a small number of embryonic leaves. Directed towards the base of the barley grain is the coleorhiza. The latter is the sheath surrounding the embryonic roots and appears during germination from the tip of the developing grain when it is known as the **chit**.



Transverse section through a barley grain

Barley mosaic virus

Barley yellow mosaic virus and mild mosaic virus are the causative agents of mosaic disease in barley. The virus is transmitted by soil-borne spores of the fungus *Polymyxa graminis*. The symptoms are the appearance of elongated leaves which bear pale green or yellow flecks and which may take on a curled form. Diseased plants may be stunted, bear fewer tillers and have smaller and reduced numbers of grains. Infected crops show reductions in yield of up to 80%. Resistance to mosaic virus is an important required characteristic of modern malting varieties of barley.

Barley plant

The aerial part of mature barley plants is from 30 to 120 cm tall. For reasons of ease of harvesting and subsequent handling modern varieties tend to be shorter and have more robust stems compared with older types. Plants have main stems and usually one or more secondary shoots which arise from a shared crown. The main and secondary shoots are termed culms. Stems are cylindrical and hollow. The stems have a number of nodes, usually five to seven per stem, each of which bears a leaf. The leaves are elongated and the bases form a sheath that is wrapped around the stem. In most varieties the leaves have a waxy covering. The shape, size and number of leaves are characteristic of particular varieties. In winter varieties and, to a lesser extent, spring types, the main stem may be augmented by secondary shoots termed tillers. Apart from varietal differences, the number of tillers that are formed is also dependent upon the planting conditions. In crop fields where competition is fierce one or two tillers would be typical. The base of the main stem and tillers, if present, is swollen to form a crown. The latter bears a secondary system of adventitious roots. In addition, there is a primary, or seminal root system that is formed during germination of the barley grain. The root system extends to a depth of 1–2 m.

The flowers and later the mature seed kernels are borne on spikes which develop at the tips of the main stem and fertile tillers. The spike, also known as the ear or head, consists of a number of individual spikelets. Each spikelet is attached to a stalk which is called the rachis. The rachis is a structure with bilateral symmetry. Lengths vary between approximately 3 and 15 cm. Individual spikelets are attached to nodes distributed along the length of the rachis. The distance between the nodes is characteristic of individual cultivars and, depending on the actual length, gives a compact bushy or loose open appearance to the ear. Three spikelets develop at each rachis node. In two-rowed varieties only the central one is fertile and leads to the formation of a flower and eventually a seed. Lateral spikelets are either male (flowers containing palea, lemma and reduced sexual parts) or have a total lack of sexual organs (deficiens group). In six-rowed types all of the spikelets are fertile.

Barley kernels arise within fertile spikelets. For a detailed description of the structure of these see **barley grain**. In general the kernels are spindle shaped and they vary in size and plumpness between individual varieties. In two-rowed types they are symmetrical, whereas in six-rowed varieties those borne on the lateral spikelets tend to be twisted and smaller than those arising within the central spikelet. In these types the central kernels are symmetrical, and the lateral ones have either a right- or left-handed bias.

The kernels are surrounded by the glume, comprising the palea and the lemma. These are lanceolate in form and usually terminate in extended hair-like structures termed awns. The size, number, colour and fine structure of the awn are of significance for varietal identification.

Awns may be coloured, short or long, borne singly or in multiples and may be smooth or dentate.

Plant growth and development

The first visible signs of germination of the seed are the emergence of the radicle or primary root. This grows into the soil and eventually gives rise to a branched primary root system. Following radicle formation the first shoot appears. Initially this is surrounded by the coleoptile, which provides protection during passage through the soil. Where planting is shallow further growth of the coleoptile is inhibited by light when it emerges from the soil. The first true leaf is then formed at the tip of the coleoptile. Where the seed has been more deeply planted an underground rhizomatous stem arises from the coleoptile. This may develop adventitious roots. Leaves begin to develop when this stem reaches the surface. These arise in the form of tubes rolled around the stem. The blades unfurl and emerge. New leaves develop every 3–5 days. The base of the stem, near to the soil surface where leaf bases are borne, swells to form the crown and the secondary adventitious root system begins to develop. At the point at which the seedling has developed around three leaves, the secondary stems or tillers begin to develop from adventitious buds on the crown. The number of tillers that form is dependent upon the barley variety, the density of planting and climatic conditions. Favourable growth conditions, namely, sparse planting, high soil nitrogen and cool temperatures, favour profuse tillering in those varieties that are capable of so doing. Tillers develop adventitious roots and may go on to form heads. In some cases, particularly where competition is fierce, a proportion of the tillers may die back before reaching maturity. This represents a stress response.

The stem elongates during the shooting or jointing stage. Growth occurs in the internodal regions, which become hollow. The nodes, which remain solid, carry the leaf bases. The flowers develop at the tips of the main stem and fertile tillers. Initially these take the form of swellings which are covered by the apical or flag leaf. This is termed the boot stage.

The terminal internode continues to lengthen such that the awns and eventually the whole ears become clear of the boot. Pollination of the flowers occurs just before the head emerges, typically around 6 weeks after the first emergence of the visible crop. As the head begins to mature the leaves lose their green colour and eventually wither and die. This process occurs first at the base and gradually moves upwards through the whole plant. Development and retention of sufficient leaf area is important to ensure that there is sufficient photosynthetic potential to support the plant and the maturing grains. Complete drying of the whole plant coincides with the achievement of complete maturity of the grains.

Following flower formation and pollination the kernels develop within the ripening ear. In the early stages the kernel elongates and reaches its final mature length. This is followed by a period of kernel fattening. Starvation of the plant during this phase results in kernels of normal length but characteristic 'thinness'. During the maturation, or ripening phase, the kernels undergo a series of gradual changes in which the endosperm is formed. Initially this has a watery, or milky, character. As the starch grains are synthesised and laid down the kernels gradually become more solid. The gradual loss of water is associated with changes in the outward appearance of the grain. When immature the glumes of the grains are thin and green. As the grains swell and dry the green colour gradually disappears and they take on a golden brown appearance.

The appearance, moisture content and relative hardness of grains are all used as markers of maturity. Accumulation of starch and other solids in the endosperm ceases when the moisture content has decreased to approximately 35%. Subsequently the moisture content falls to below 15% and at this point the grains are ready for harvesting.

Barley quarter

A pre-decimal measure used in the United Kingdom and in South Africa for quantifying batches of barley. It is equal to a fresh weight of 400 weights (203.2 kg).

Barmigen

One of many substances that have been described as causes of premature yeast flocculation (PYF). Barmigen is reported to be a form of humic acid which can be isolated from an acid hydrolysate of malt bran.

See **premature yeast flocculation (PYF)**.

Barnes bush

The name given to the fitting welded to the central aperture of a beer keg that carries the spear; also known as a Barnes neck. The name derives from the Australian inventor Roy Barnes.

See **keg**.

Barney Miller medium

Microbiological medium developed by the Miller Brewing Company for the detection of lactic acid bacteria, now superseded by more popular and readily available commercial formulations. It contains tomato juice broth, peptone, beef extract, maltose, glucose, potassium acetate, L-malate, L-cysteine HCL and Tween 80.

Barrel

In brewing the term barrel refers to a container for holding beer, typically made from wooden staves held together by iron hoops, the whole being made by a cooper. However, these containers might more properly be referred to as casks and the barrel as a unit of volume. Indeed, the barrel is a primary unit that is used for expressing large volumes such as the capacity of brewery vessels or even the total output of whole breweries. The UK barrel is equal to 36 imperial gallons or 163.65 L. The US barrel is slightly smaller, being equal to 31.5 US gallons or 119.34 L. Understandably this can lead to confusion and for this reason it is becoming increasingly common for beer volumes to be quoted in hectolitres.

The difference between the UK and US barrel measures is accidents of history. In historical times a multitude of units were used for quantifying and defining particular weights and measures. In the United Kingdom, with regard to capacity, an early unit was named as the gallon. However, this term was applied to both wet and dry goods and furthermore, the actual capacity of the gallon varied depending upon the nature of the goods. This was a reflection of the practice of using common receptacles such as baskets and pails as the primary measure. Eventually steps were taken to standardise these measures and to define their precise dimensions. With respect to the gallon three distinct measures were codified in various UK legal systems of weights and measure:

- (1) *The corn gallon.* This was used primarily for dry goods and is also known as the Winchester gallon or dry gallon. In 1696 this was defined as being equal to 268.8 in.³, 4.405 L.
- (2) *The ale gallon.* This was used for measuring the volume of beer and was defined as being equal to 282 in.³ In 1824 the Weights and Measures Act established the imperial gallon as the single measure of capacity. This was defined as being the volume equal to 10 lb of distilled water weighed in air using brass weights with the barometer standing at 30 in. and a temperature of 62°F. This was subject to further revision in 1963 and 1985 to give the current definition of the space occupied by 10 lb of distilled water with a density of 0.998859 g/mL measured using weights with a density of 8.136 g/mL. This works out as 277.420 in.³ or 4.545964591 L.
- (3) *The wine gallon.* This was used for measuring the volume of wine. It was defined in 1706 and is also known as the Queen Anne gallon. It is equal to 231 in.³ or 3.785 L. This version of the gallon was adopted by the United States and this explains the current difference between the UK and US barrels.

Most, if not all, countries have their own peculiar naming systems for units of weights and measures. The story of the gallon, as described here, is illustrative of these in that common terms may be applied to different commodities with the actual value of the unit being dependent upon the actual commodity. In the United Kingdom several measures of beer volume have been used and some of these still persist to the present. These may be used as measures of capacity or for the containers in which the particular volumes of beer are placed. The names for these and the volumes of each are shown in the following table. The volumes shown are those that were standardised after 1803.

Name	Volume (imperial gallon)	Volume (L)
Pin	4.5	20.48
Firkin	9.0	40.96
Kilderkin	18.0	81.92
Barrel	36.0	163.84
Hogshead	54	245.76
Puncheon	72	327.68
Butt	108	491.52
Tun	216	983.04

Base extract

Base extract is the residue that remains when the α -acid fraction of hops has been extracted. It contains the β -acids, hop aroma compounds and other resins impurities. It is used as a kettle addition in conjunction with other post-fermentation bitterings.

See **hop extracts**.

Base malts

Base malts are those that are used primarily to generate the fermentable sugars and soluble nitrogen components of worts. Thus, they are those malts that in the mashing phase of brewing possess the appropriate complement of active saccharifying and proteolytic enzymes. During the mashing phase these enzymes are responsible for the conversion of the starch in the

endosperm into simpler soluble sugars and also for the breakdown of proteins into simpler amino acids and shorter peptides. The substrates for these enzymes are mainly derived from the grains of the base malts. In addition, some substrates may derive from other malts which do not themselves possess any active enzymes or other sources of extract present in the grist such as adjuncts.

Base malts are distinct from speciality malts. The latter are primarily used to impart flavour and colour to beers and as such are not required to possess active enzymes.

Basi

Basi is the name given to a type of beer that is native to the Philippines. It is made from a boiled aqueous extract of crushed sugar cane flavoured with rice and extracts made from the barks and fruits of various indigenous trees.

Baudin

An Australian semi-dwarf two-rowed spring barley variety accredited for use in malting in 2003. It is a cross of Stirling and Franklin parental types. It is susceptible to several leaf diseases and for this reason is considered most suitable for low- to medium-rainfall areas.

BBT

Acronym that stands for **bright beer tank**.

BCCM

Belgian Co-ordinated Collections of Micro-organisms.

See **yeast culture collections**.

Beading

Term descriptive of the desirable appearance of columns of ascending gas bubbles which appear within the body of beer after it has been dispensed into a glass and contribute to the foam head.

See **beer foam**.

Beard

Hair-like structures attached to the seed heads of grasses including some varieties of barley (see **awn**).

Bed voidage

Bed voidage describes the proportion of a filter bed that is not occupied by solid material. It follows that it provides a rough measure of the capacity for a filtration medium to entrap particles. In practice the real capacity of a filter bed is less than this. This is because there may be spaces in the bed that are not accessible to particles. With regard to brewing applications an example of this latter effect is kieselguhr. Kieselguhr particles, as used in powder filters, have a porous structure; however, these pores are smaller than the average size of the solids present in unfiltered beer. Therefore, the internal spaces of the kieselguhr particles are inaccessible to these particles.

The real bed voidage is described as the **effective bed voidage**. It can be determined experimentally by preparing mixtures containing defined and varying proportions of filter powder and a filler material that is free flowing, insoluble and with a pore size of approximately $2\ \mu\text{m}$. The mixtures are placed into calibrated cylinders in which the bottom comprises a perforated metal grid sealed with a gasket and overlaid with a sheet of filter paper. Pressure is applied to the top of the cylinder and this compresses and forces the entrained water out of the bed. The volume occupied by the drained solid material is recorded. A graph is prepared in which the x -axis is the percentage of filler present in the mixture and the y -axis is the corresponding increase in bed volume. The plot is linear and the intercept on the x -axis gives the measure of effective bed voidage expressed as a percentage.

Beer

The name derives from the Latin word *bibere* meaning to drink. This vague etymology provides a clue to the fact that precise definitions of beer that may be applied universally are difficult to arrive at. Beer is defined as a beverage, usually alcoholic, which is made by fermentation of an aqueous medium that contains sugars derived mainly from cereals and which is commonly flavoured with hops. The fermentation step is catalysed principally by yeast.

In some countries, for example, Germany, this definition is satisfactory since by law, beers can only be made from malted barley, yeast, hops and water (see *Reinheitsgebot* for more details). Most other countries are much less proscriptive and examples may be found where beverages called beers fail to meet one or more of the defining characteristics given earlier. Thus, not all beers contain hops and indeed, many other flavouring agents are used. Not all beers contain alcohol, although many countries have legal definitions that stipulate a minimum alcohol concentration that a beverage must contain for it to be labelled as being a beer. Not all beers use pure yeast cultures as the agent of fermentation. Mixed cultures of one or more yeast strains are common as are mixtures of yeast and bacteria.

The sugar component is commonly obtained from malted barley, but many beverages that are called beers use other sources of fermentable sugar. In this regard it is common for alcoholic beverages to be defined in terms of the source of fermentable sugar, for example, wine (grapes), perry (pears), cider/applejack (apples), mead (honey). All other remaining alcoholic beverages, excluding those in which distillation is used in their manufacture, are called beers. This allows for those countries that have indigenous 'native beers' that might be made from a variety of sources of fermentable sugar.

The alcohol content of the beer is often used as the basis of levying duty. The majority of countries raise tax revenue on alcoholic beverages. Typically, different types of alcoholic beverage attract different rates of excise duty. Many countries use the presence of a given proportion of malt in the beverage as a means of classifying the product as a beer and this is liable to duty at beer rates. These subtle characteristics have become important owing to the development of the so-called ready-to-drink (RTD) category of beverages. These are compounded products that use a wide variety of colouring and flavours mixed with an alcoholic base. The source of this alcoholic base, in many countries, has importance in that it is this that defines the basis upon which the product will be taxed. Thus, if neutral (grain) alcohol is used the product might be defined as a spirit, and in some legislation this may be taxed at a higher rate compared with, say, an alcoholic base derived from fermentation of a malt-based extract. In this

situation it is to the benefit of the manufacturer if the RTD is classified as a beer. From another but similar standpoint the *happoshu* products of Japan manage to attract a reduced excise levy compared to standard beers by being made from wort which contains less malt than that stipulated by the current Japanese legal definition of beer (see *happoshu* for more details). It seems likely that the current cat-and-mouse situation where the manufacturers try to stay one step ahead of the taxing authorities with regard to minimisation of excise liability will continue and that this will involve the former pushing the legal boundaries as to what does or does not constitute a beer.

See **ale**. Other specific beer styles are described elsewhere.

Beer analysis

Beers contain similar classes of compounds since they use, more or less, common ingredients that are subjected to a similar series of process steps to make wort followed by conversion via yeast growth and metabolism to make beer. However, the individual members of these classes and the concentrations in which they are found vary enormously reflecting the differences in choice and proportions of classes of raw materials and the detail of the process steps used to make varying beer styles.

Raw materials and water contribute a wide range of inorganic constituents (see **beer – inorganic constituents**).

The major products of yeast metabolism in fermentation are ethanol and CO₂. Typical concentrations for each are 4–6% v/v (32–48 g/L) and 5.0–6.0 g/L, respectively. Much of the carbohydrate fraction of worts are utilised by yeast in fermentation; the residues are those compounds that brewing yeast cannot assimilate. These include some of the longer-chain hexose sugar polymers such as maltotriose, maltotetraose and dextrans. Traces may be found of sugars such as D-ribose, L-arabinose, D-xylose, D-mannose and D-galactose. Di- and trisaccharides include isomaltose, cellobiose, kojibiose, panose and isopanose. Traces of β-glucans and arabinoxylans also occur. High concentrations of these indicate a lack of process control.

A huge range of nitrogenous compounds occur. There are few intact proteins, although protein Z and lipid transfer protein from malt appear to survive the brewing process and to be implicated in beer foaming potential. Yeast proteinases may be found in non-pasteurised beers. Most wort free amino acids are assimilated by yeast, but a variety of peptides of varying molecular sizes are found. Proline is not usually utilised by yeast and persists into beer. Break-down products of nucleic acids persist. Guanosine, uridine and cytosine are the most abundant. Both nucleosides and nucleotides are found. Beer contains the B vitamin nicotinic acid (5–10 mg/L). A range of amides are found which are formed in wort boiling and are most common in dark beers. The most abundant is N-furfurylacetamide. Trace quantities of various amines may be found.

Lipids occur in trace amounts. Fatty acids either free or esterified as mono-, di- or triacylglycerides can all be found generally at less than 0.5 mL/L. Sterol esters are present at very low levels (<0.02 mg/L). Hydroxy acids of medium-chain-length fatty acids are thought to be the precursors of beer staling aldehydes such as *trans*-2-nonenal. Elevated levels of free fatty acids usually indicate significant yeast lysis either in fermentation or in subsequent ageing processes and can be a cause of poor foam performance.

Many phenolic compounds are present, deriving from malt and hops, and these contribute to beer astringency but also participate in the formation of beer hazes with proteins (see **polyphenols**).

Hop resins contribute to bitterness and comprise mainly *cis* and *trans* isomers of isochumulone, isohumulone and isoadhumulone.

Sulphur-containing compounds include small amounts of cysteine and methionine, either free or as constituents of polypeptides. Dimethyl sulphide, formed from malt S-methylmethionine, is present at varying concentrations depending on the beer style where it may have positive or negative connotations. Other sulphur-containing component may occur in small concentrations as sulphides, mercaptans and thiols. Most have very low flavour thresholds and objectionable odours and tastes.

Various vitamins can be found, at low concentrations.

An enormous range of mainly volatile beer components are formed by yeast in fermentation. They include organic acids, aldehydes, ketones, higher alcohols and other polyols and esters, volatile sulphur compounds.

See **yeast-derived flavour compounds** and associated links.

Beerandhealth.com

A Belgian-based website [<http://www.beerandhealth.com.be> (last accessed 25 March 2013)] devoted to answering questions relating to health and the consumption of beer specifically and other alcoholic beverages in general. The site provides a service in which summaries of relevant papers from the scientific press are produced in a form in which they may be understood by the interested lay person. In addition, an interactive question and answer service is provided. The information database covers both positive and negative aspects on health of beer and alcohol consumption. The site is independent but is sponsored by the Belgian Brewers' Association.

Beer bitter substances

The mixture of compounds derived from hops which collectively contribute to the bitter taste of beer.

See **bitterness**.

Beer colour

Beer colour is influenced by the nature of the raw ingredients and the conditions of the brewing process. Darker colours derive mainly from melanoidins formed in **Maillard reactions** and caramelisation browning reactions in wort boiling. Caramels may also be added as colouring agents. Darker colours can also arise from oxidised polyphenols in tanning reactions mediated by metal ions. Light beers can arise in part from the use of pale malts and very high levels of adjuncts such as rice which do not contribute much colour. In such pale beers the characteristic golden appearance is in part due to the presence of riboflavin. Some loss of colour can occur during filtration, especially with fine pore membrane filters.

Beer colour is measured spectrophotometrically. In older methods a series of coloured discs of glass were used for comparison purposes (see **Lovibond tintometer**). Spectrophotometric methods were introduced in order to make them independent of the human operator. A

standardised wavelength of 430 nm and a path length of 1 cm have now been agreed by all codes of analysis. Multipliers are used in order to give a reasonable scale of numbers, unfortunately with no standardisation.

The original Standard Reference Method (SRM), adopted by the American Society of Brewing Chemists (ASBC) for colour, was introduced to be a spectrophotometric equivalent of the Lovibond scale. It was taken to be $10 \times A_{430}$ using cuvettes with a path length of 0.5 in. Later the multiplier was changed to 12.5 to allow for 1-cm-path length cells. Beer should be degassed and filtered, if necessary, before making measurements.

The relationship between Lovibond and SRM units is given as

$$\text{SRM} = \text{Lovibond} - 0.76 \times 1.3546.$$

The European Brewing Convention (EBC) method uses a multiplier of 25 and so units are approximately double the SRM values:

$$\text{SRM} = \text{EBC} \times 0.508.$$

On the EBC scale a pale lager scores around 4 units, a pale ale, *ca.* 20 and a dark stout, 138.

It is now recognised that assessment of beer colour based on measurement at a single wavelength is only partially successful. More recently, the use of tristimulus measurements has been recommended by the ASBC. This approach takes a more rounded view of colour and uses three parameters for quantification. These are hue (h°), the predominant colour; L^* , a measure of lightness or darkness; and chroma (C^*), dullness or vividness. Instruments are available for making tristimulus measurements. These are able to discriminate between beers with identical spectrophotometric-based colour properties.

Beer dispense

Term used to describe all the activities and associated equipment used to deliver draught beers from the container in which it is stored to the glass from which it will be consumed. There are many levels of sophistication. At its simplest, beer may be dispensed directly from a tap in a cask, either into a glass or via a secondary container such as a jug. At its most complex, in very large licensed premises such as pubs and bars, several different beer qualities, each using different types of dispense equipment, are required to deliver beer at the appropriate temperature and dissolved gas content and with high standards of hygiene. In this situation the bulk beer will usually be stored at some distance from the point at which it is dispensed into a glass. This requires the use of long lengths of connecting tubing, a means of transporting the beer either with a pump or using compressed gas (of appropriate composition) and a tap which is appropriate for the type of beer. In addition, primary and secondary chillers may be needed and appropriate non-return valves in order to ensure the correct temperature at dispense and correct foam generation.

Beer engine

Name given to the device used to dispense draught cask beers. It consists of a cylinder, traditionally made from brass but now usually stainless steel or plastic, which is mounted below the bar. The capacity of the cylinder is usually a quarter or a half of an imperial pint. The

cylinder contains a piston the vertical movement of which is controlled by a handle, the hand pump, which sits on top of the bar. The cylinder is connected to the tap of a beer cask via suitable tubing. The cylinder contains a bottom-mounted non-return valve, the cylinder valve, and a top-mounted piston valve.

In traditional systems the beer engine operates as a simple lift pump. Pulling the pump handle causes the piston to rise and beer is drawn into the cylinder via the cylinder valve. As the handle is returned to the vertical position the cylinder valve closes and the piston valve opens. The movement causes the piston to pass through the beer and this pushes the beer out of the piston valve to a spout through which it is dispensed into the glass. Several designs of spout are in use. They may be straight or of a swan-neck design which allows the beer to be dispensed though the liquid as the glass fills. In most cases the end of the spout terminates in a device, termed the **sparkler**, designed to generate a foam head.

Modern beer engines and the associated beer lines are designed to be easily cleaned and thereby ensure good hygiene. In larger installations a pump may be used to move the beer from cellar to tap. The cylinder may be fitted with a water jacket to provide additional cooling in order to meet the preferences of some consumers for dispense temperatures less than the traditional 10–15°C.

See **cask beer**.

Beer flavour

The flavour of beer and its perception by the consumer is predictably complex and by inference difficult to quantify and analyse in a satisfactory manner. With regard to the consumer, the combination of flavour, aroma and appearance are all influential. For any particular style preconceptions of how the beer should taste are strongly influenced by appearance. A pale pilsener-type lager would be expected to be served at a relatively cold temperature, to have the correct colour but also to have brilliant clarity, an appropriate level of carbonation, and to possess a substantial and stable foam head. If any of these parameters are deficient comments regarding poor taste would be expected. Conversely, if beer is served in an opaque glass, untrained tasters find it difficult to discriminate between very different beer styles.

The particular attributes of any beer are defined by the brewer and the *modus operandi* is to control the process so as to ensure that for every individual batch, these attributes are adhered to as closely as possible. In part this relies on setting physical and chemical specifications which describe parameters that are amenable to analysis. The brewery quality system provides the framework that ensures that these specifications are achieved. However, with regard to flavour these analyses are totally inadequate since two beers that adhere to all specifications may have very different sensory attributes. For this reason commercial brewers employ trained taste testers who as a group are able to discern the subtleties of beer flavour and to identify deficiencies. Typically all batches of beer are tasted and are not released until passed as being true to type.

Beer flavour is very complex. At least a thousand components are known, but this is probably an underestimate. Many of these are present at relatively low concentrations but close to their flavour threshold values such that small perturbations can have a large impact on overall sensory perception. The situation is made more complex since synergistic and antagonistic effects also occur.

Final beer flavour is influenced by the nature and quantities of raw material used and the conditions employed in the brewing process. With regard to raw materials the composition of the grist and the hop components are obviously major influences. Brewhouse regimes have a major impact as do the conditions employed in fermentation and the subsequent processing of green beers. Of particular note is the influence of yeast. Apart from the obvious changes that accompany the yeast-catalysed transformation of wort into beer in terms of the conversion of wort sugars into ethanol and CO₂, the results of yeast metabolism produce a multitude of compounds many of which have a profound effect on beer flavour (see **yeast** and **beer flavour**).

The relative importance of malts, hops and yeast on beer flavour is difficult to quantify. Certainly, each is responsible for the appearance of many hundreds of individual beer components. Perhaps it may be said that flavour-active components derived from malts and hops are the major building blocks, whereas, aside from ethanol and carbonation, the influence of yeast is to impart more subtle characters.

The flavour of beer is in a state of continual change. The desired characteristics of any beer are defined at the completion of the brewing process, whether this be in the brewery or, in the case of a cask- or bottle-conditioned product, at the optimum point for consumption after release to trade. After this time a process of deterioration occurs, which takes the form of the development of stale characters. These processes are not related to microbial spoilage (see **beer flavour stability**).

The influences on beer flavour and aroma of some of the major classes of beer components are shown in the accompanying table. This by no means is an exhaustive list and there is considerable diversity between individual members of each group.

Influence of classes of major beer constituents on sensory properties

Component	Effect on sensory properties of beer
CO ₂	Mouth tingle
Ethanol	Warming
Higher alcohols	Warming, solvent-like, mouthfeel, fullness
Esters	Fruity, floral
Organic acids	Sour, acid
Hop iso-acids	Bitterness
Inorganic chlorides	Salty
Sugars	Sweetness
Polyphenols	Astringency
Sulphur compounds	Struck match, rotten, bad egg, sweetcorn
Fatty acids	Soapy, goat, cheesy, rancid
Short-chain aldehydes	Catty, green apple
Longer-chain aldehydes	Stale

Beer flavour stability

The property of a beer that defines the time period after finishing during which the sensory attributes of a beer are deemed acceptable and within specification (see **beer shelf life**). This property is independent of spoilage via microbial infection. Implicit in the definition is that beer flavour is in a state of continual change and that the changes that occur in the interval

between packaging and consumption are, for most beers, undesirable. The optimum sensory character of any beer is based on assessment after the completion of manufacture. In effect this is an arbitrary line in the sand since it represents a point in a continuum of change and, depending on the length of the supply chain, perhaps, one that may be relevant to the brewer but not the consumer.

In addition to undesirable changes in sensory characteristics, beers that are designed to be clear are subject to haze formation. This is normal and reflects the colloidal stability of the beer, a function of the content of haze-forming proteins and polyphenols (see **colloidal stability**). In the majority of chilled and filtered beers this parameter is controlled by treatments performed in the brewery in which the precursors of hazes are removed in order to give a desired level of colloidal stability.

Flavour changes associated with ageing are complex. They reflect chemical changes in the nature of those components that are considered to be desirable. In addition, compounds are formed, which impart stale characters. The changes can be made only with reference to one beer since some attributes might be considered positive in one beer but negative in another. It is generally agreed that as beer ages the bitterness notes gradually decrease and this is a result of degradation of hop iso-acids. In addition, an increase in sweet and toffee characters develop as do papery, cardboard flavours which are associated with staling. Transient increases in the flavour note usually described as 'catty' is also usually noted.

Undesirable changes in flavour during ageing are, at least in part, the result of oxidation reactions, although the precise chemistry that underlies beer staling remains to be fully elucidated. However, it is this reason that brewers strive to exclude oxygen from all stages of the process where it is not necessary. Whether this is strictly necessary in the brewhouse is controversial; nevertheless plants have been developed where operations such as lautering can be carried out under a blanket of inert gas. Certainly, after the initial stages of fermentation, great care is taken to minimise exposure to oxygen, and steps are taken, for example, to purge empty tanks and pipework with CO₂ or de-aerated liquor prior to filling with anaerobic beer. Well-managed breweries can now achieve dissolved oxygen concentrations of 100–150 µg/mL. The deleterious effects of oxygen are made worse when in combination with heat. Low temperatures (<3°C) are maintained throughout all process stages after fermentation. It is known that undesirable flavour changes occur if beers are subjected to pasteurisation. These effects are exacerbated by the presence of high dissolved oxygen levels. Conversely, avoidance of these negative effects has been a major driver for many brewers to adopt cold sterile filtration as a means of providing microbial stability in packaged beers.

Some key aspects of staling of beers via oxidation reactions are mediated by highly reactive oxygen radicals (see **free oxygen radicals**). Unsaturated fatty acids are particularly susceptible to reactions with unsaturated fatty acids, and it seems likely that these may be the precursors of at least some staling compounds. The products are a range of carbonyls such as C9, C10 and C11-alka,2,4-dienals, which have stale characters and low flavour thresholds (0.5, 0.3 and 0.01 µL, respectively). Of particular note is **trans-2-nonenal**, which has the characteristic cardboard flavour and aroma associated with stale beer and a flavour threshold of 0.1 µg/L.

A large range of compounds have been shown to change in concentration during ageing; many of these are strongly flavour-active and may be involved in beer staling. They include many carbonyls, including linear aldehydes, Strecker aldehydes such as 2-methyl-butanal,

3-methyl-butanal, 2-phenylacetaldehyde and 3-(methylthio)propionaldehyde. Others are ketones, cyclic acetals, heterocyclic compounds such as derivatives of furfural, ethyl esters of substituted medium-chain-length fatty acids and lactones.

There is a second element to beer flavour stability. Several beer components, notably polyphenols, exhibit antioxidant activity. These can ameliorate the damaging effects of free oxygen radicals. In effect, these react with the latter and prevent the damaging staling reactions already described. The concentration of these is dependent on the nature of the raw materials used to make the beer and the degree of processing which influences the concentrations of natural beer antioxidants.

Beer flavour stability can be assessed in several ways. Forcing tests in which finished beers are subjected to storage at elevated temperatures, typically 50–60°C, attempt to shorten the natural ageing process. Treated beers are subject to taste tests by expert panels and the results are considered predictive of natural ageing. Such tests still take many hours to complete and therefore are not suitable for routine QC testing. Since they require assessment of finished beers forcing tests cannot be used to assess the influence on the individual stages of the brewing process. Alternative approaches are to determine the concentrations of precursors or products of staling. In most cases these have measured the products of staling; for example, see **thiobarbituric acid value**, which, it may be argued, is of limited importance.

Currently, it is considered that an assessment of the antioxidant properties of beer provides the most practical method of determining the staling potential of finished beer and stages in its production. This is achieved using **electron spin resonance (ESR)**. Although the apparatus required for these analyses is expensive it is being used by major brewers as a routine quality control tool for ensuring that the staling potential of beer is under control. Undoubtedly, as more brewers take up the approach, costs will fall.

Beer foam

The majority of beers on dispense into glass form a creamy head. With a few exceptions, for example, in the case of traditional ales in some geographical locations in the United Kingdom where foam is considered a poor substitute for liquid beer, the quantity and quality of the foam is a major positive attribute. In consequence much effort is made to ensure that the raw materials used to make beer and the conditions employed in its manufacture combine to provide a product with desired foaming characteristics. In support of these goals much work has been performed to elucidate the underlying physics and chemistry of foam formation and foam stability, and a raft of methods has been developed which attempt to quantify beer foaming ability.

Foams are defined as being colloidal systems that possess a continuous liquid phase and a discontinuous gas phase. Foam formation has a number of distinct elements. It is initiated by bubble formation. Within a carbonated liquid gas bubbles form spontaneously within the body of the liquid at nucleation sites where a minute fissure in the glass container or a particle of dust in the liquid provides a site for localised gas breakout. This is termed heterogeneous bubble formation and generates micro-bubbles the buoyancy of which causes them to rise to the surface where they collect and generate the foam head. Predictably the level of carbonation is influential as is the presence of other gases, such as nitrogen. Gas breakout and bubble formation is encouraged within the body of beer when a pressurised bottle is opened and bubble formation takes place at nucleation sites in the liquid. The same events occur when

draught beer is forcibly dispensed into a glass. In the case of **widgerts** a gas stream is forcibly expelled into the beer to generate bubbles.

The gas bubbles rise and collect at the surface of the liquid to generate the foam head. This is highly dynamic. The solubility of the gas in the liquid phase is important. Gas moves from smaller bubbles into larger ones via a process termed disproportionation. Where the gas is relatively soluble in the liquid, as is the case with CO₂, movement is rapid and bubble size increases rapidly. Where the gas phase is less soluble in the liquid phase, as with nitrogen, passage is slower and the bubble size remains small, hence the stable creamy foams characteristic of **cream flow beers**. A process of coalescence occurs where the walls of adjacent bubbles collapse and form a single larger bubble. This tendency can be accelerated by the presence of hydrophobic contaminants such as lipids. These may arise from oily or greasy contaminants either introduced by the consumer or via poorly cleaned glassware. Where this occurs the rate of coalescence is very rapid and beer heads may very quickly dissipate, leaving a bare unattractive beer.

Within the foam excess beer drains from the bubbles and passes back into the liquid phase to leave a relatively dry network of gas filled bubbles. This accumulates on the surface of the head as it floats on the surface of newly forming wetter foam. A proportion of the dry foam is left on the inner wall of the glass as the beer is consumed, and the deposit, which is considered a mark of quality, is referred to as **cling** or **lacing**. The drainage effect is inversely related to the viscosity of the beer.

The longevity of the foam is a function of its continued rate of formation during consumption and the counter rate of collapse. Continuous gas breakout in the body of the beer preferably continues throughout consumption. The appearance of vertical columns of gas bubbles passing from the nucleation site into the head is considered desirable and is referred to as **beading**. The continued formation of the head is termed creaming.

Materials are present in beers which are able to generate foams and others exert stabilising effects. Working against these are other constituents which have an inhibitory effect. Several beer proteins and polypeptides, arising from malt and hops, have been isolated from foams. Of particular note are lipid transfer protein 1 (LTP1), protein Z and a group of hordein-derived polypeptides. These species are involved in both bubble formation and stabilisation. The degree of hydrophobicity appears important and structural changes occur in the boil, which enhances their foam-positive nature. Various polyphenols may also play minor roles, possibly via their effect on beer viscosity, as related to foam drainage. Hop iso- α -acids preferentially migrate into beer foams where it appears that they have a role in stabilizing the walls of foam bubbles. These interactions require the presence of di- or trivalent metal ions. Hop-derived products such as tetrahydroiso- α -acids have the most potent activity. The most potent foam negatives are lipids, although their effects can be lessened by the ability of some proteins to bind these compounds such that foaming potential may improve with time. High ethanol concentrations and basic amino acids are also foam negative.

The source of raw materials and the conditions employed in brewing are all influential. Good heads are promoted by the use of wheat adjuncts, probably via the provision of additional polypeptides but also possibly as a result of high arabinoxylans giving more viscous beers. Malt-derived fatty acid hydroperoxides are potent foam-negative lipids and the use of malts with low lipoxygenase activity has been advocated. From a process perspective, extensive proteolysis in the mash and prolonged boiling at elevated temperatures exert negative effects.

In fermentation, excessive foaming causes the loss of foam-active proteins as does the injudicious use of anti-foam. Yeast health is of prime importance. Conditions that cause yeast stress such as very-high gravity brewing may result in the release of foam-negative proteases. In the event of extensive yeast lysis the release of short-chain fatty acids can destroy foams. In conditioning and finishing the use of protease stabilisers such as papain, particularly in conjunction with cold sterile filtration, may be a cause of foam polypeptide degradation. There have been some reports describing the loss of foam-active beer components during membrane filtration.

Since beer foaming is such a major quality parameter several methods of assessment are used. The attributes of beer foams have been described as quantity, strength, stability, whiteness, lacing performance and bubble size (creaminess). There is no single method capable of assessing all of these apart from direct observation. This can be quantified by the use of image analysis techniques; however, in practice it is beset with difficulties because of inconsistencies introduced by the method of dispense. The majority of methods rely on assessing foam stability. This is measured as **foam collapse time** or **head retention value**. Some of these methods are **Blom**, **Ross and Clark**, **NIBEM meter**, **Sigma head value** and **Rudin**. Of these, Rudin and NIBEM are most commonly used. These are criticised in that they involve the artificial generation of foam to a much greater volume than seen in actual dispense and, as such, it is argued that this is not representative of the behaviour of the beer during real dispense and consumption. This is true, although since the methods do seem to give some degree of correlation with subsequent trade performance, they will continue to be used for routine QC testing purposes.

Beer hazes

The majority of beers are designed to be brilliantly clear at the time of consumption. In practical terms this requires that beers should not contain suspended particles with a mean diameter greater than approximately 1 μm . For the majority of beers a sizeable and costly proportion of the brewing process is directed towards ensuring that the final product is brilliantly clear at the point of packaging and that this clarity is maintained throughout its intended shelf life.

In order to be able to assess beer clarity it is necessary to have methods for measurement of beer hazes and a standardised system of units by which their magnitude can be expressed. Current methods are based on light scattering (nephelometry) and use standards comprising particles with defined light scattering characteristics (see **haze standards**). The following table indicates ranges of values, expressed in two standard units (ASBC and EBC), which would be expected for beers containing various levels of haze.

Relationship between the visual appearance of beer and the magnitude of haze value expressed in ASBC and EBC haze units

Visual appearance	Haze value (ASBC)	Haze value (EBC)
Brilliant	0–34.5	0–0.5
Bright	34.5–69.0	0.5–1.0
Slightly hazy	69.0–138.0	1.0–2.0
Hazy	138.0–276.0	2.0–4.0
Distinctly hazy	276.0–552.0	4.0–8.0
Very hazy	>552.0	>8.0

The size of the particles that contribute to hazes has an impact on visual perception. In particular, the presence of very small particles (less than approximately $0.5\mu\text{m}$ in diameter) is important. These very small particles are not visible to the naked eye; nevertheless they do cause some light scattering with the result that when present in beers they give a dull appearance, often termed a **cast**. In technical parlance such hazes are also referred to as **invisible hazes** or the more acceptable **pseudo-hazes**.

Hazes are detected using nephelometry (turbidometric) devices. These so-called haze meters are used to assess the clarity of beers, or other process liquids, at appropriate stages in the brewing process. They may take the form of an offline laboratory apparatus or may use sensors which can be located in-line or in-tank. The latter types can be integrated into automatic control systems in which the output is used to regulate some aspect of the process. The appropriate type of haze meter must be used (see **haze meters** for more details).

Beer hazes can arise in several ways. Some are inevitable; others are avoidable. They may be divided into biological and non-biological hazes.

Biological hazes are those that arise as a result of microbial spoilage. In these cases the haze may be due directly to the presence of microbial cells suspended in spoiled beer or as a result of solid slimes, ropes, and so on, which are formed as a consequence of microbial growth.

Non-biological hazes, as implied in the name, are those hazes that arise in beer by any means other than by direct microbial growth. Predictably they are diverse in their nature and source.

There are three major sources of non-biological haze:

- (1) accidental contamination
- (2) from raw materials or process aids as a consequence of poor management of the brewing process or selection of raw materials
- (3) colloidal hazes.

Accidental contamination describes any solid material that is inadvertently introduced into beer at any stage in the process. There are many examples and opportunities for this type of contamination to occur. Examples include lubricants, process aids such as filter powders, waterborne solids, residues from cleaning agents and solids introduced with process gases. Poor control of raw materials and the brewing process can produce hazes in the form of pentosans from wheat adjuncts, un-degraded starch granules arising from poor brewhouse practice, β -glucans via the use of poorly modified malt, oxalate crystals via the use of calcium-deficient worts, and particles of carbohydrates or proteins which are fragments of yeast cells and arise via poor yeast husbandry. Dead microorganisms can be introduced with contaminated raw materials. For example, hazes have been detected in filtered beers, which have been shown to be caused by very small dead bacilli that are capable of passing through conventional powder filters and are introduced into beer with heavily contaminated malt.

Essentially these categories of beer haze are preventable. The use of appropriate brewing plant and raw materials and proper management of the process should prevent their occurrence.

Colloidal hazes are those that are formed via reactions between wort or beer proteins and polyphenols which result in the formation of visible precipitates. The proteins are mainly derived from malts and the polyphenols from both malts and hops (see **colloidal stability** for a full discussion of the chemical species involved in haze formation).

The formation of colloidal hazes in beers is inevitable. Much of the brewing process is directed towards ensuring that a proportion of the precursor protein and polyphenols is removed before the beer is packaged. Thus, material is removed as cold and hot break during wort boiling and cooling. Further material is removed during fermentation and particularly in the conditioning phase. The use of low temperatures facilitates the formation of solid temporary **chill hazes**. Most beers are filtered at low temperatures before packaging and this provides the last opportunity to remove chill haze material and other suspended solids. These various separation steps are augmented by the use of various process aids, such as fining and stabilisation agents, which are designed to precipitate, sediment or adsorb polyphenol or protein haze precursors.

Despite these treatments some haze-forming materials persist in packaged beer and, with time, these will lead to the formation of permanent haze. An essential part of the management of the brewing process is to ensure that the packaged beer exhibits a lag time that is sufficiently long so that haze levels remain at acceptable levels throughout the intended shelf life of the beer. In order to ensure that this is the case a number of techniques have been developed which assess beer colloidal stability. These are of two types. In the first analytical methods are used to determine the concentrations of haze precursors. Since these values will vary as a result of natural variation within different batches of raw materials, it is useful to monitor protein and polyphenol concentration in beers and, if necessary, to adjust stabilisation regimes. Several methods are available for the determination of both beer proteins and polyphenols (e.g. see **SASPL**, **sensitive proteins**, **alcohol chill haze test**, **Folin–Ciocalteu method for protein**, **tannometer**).

An alternative is the more direct approach which uses haze meters to assess colloidal stability in packaged beer. These tests can be carried out in real time in which samples of beer are stored under conditions that simulate those under which the beer is expected to be exposed to in the trade. Of course, this is a very time-consuming procedure and shorter predictive **forcing tests** are perhaps more common. In these cases the beer is subjected to cycles of storage at relatively high (typically around 50°C) and then low (around 4°C) temperature. The haze is monitored throughout. The assumption is that each cycle of storage, measured in days, in the forcing test is equivalent to a number of weeks or months of storage under 'normal' in-trade conditions.

Beer – inorganic constituents

Inorganic constituents derive mainly from the water used to make the beer. Others find entry from other raw materials. A wide variety of cations are found. Levels vary greatly between individual beers, reflecting the degree to which brewing liquor is treated prior to brewing and the nature of the raw liquor used. The concentrations of inorganic constituents of beer differ from those present in raw materials and wort as a consequence of the fraction lost in various solid breaks and that taken up or adsorbed by yeast. The concentrations of several heavy metal ions are subject to regulation and methods are available for their determination. The most abundant cations are K (330–1000 mg/L), P (90–400 mg/L), Na (40–230 mg/L), Mg (30–250 mg/L), Ca (40–150 mg/L) and Si (10–22 mg/L). Traces of many others are found including Al, As, Cd, Cr, Co, Fe, Pb, Mn, Hg, Ni, Se, Sn and Zn. Anions include chloride (140–1000 mg/L), nitrate (1–100 mg/L), phosphate (100–1000 mg/L) and sulphate (100–400 mg/L).

Many of the inorganic constituents of worts are essential trace nutrients for yeast growth. Those that persist into beers may have desirable or undesirable flavour attributes. These include salty, sweet, metallic characters. Some may be precursors for other reactions. For example, high levels of sulphate can lead to elevated levels of H₂S and SO₂ in beers. Nitrates are to be avoided since in the event of microbial spoilage they can be a source of nitrosamines.

See **apparent total N-nitroso compounds (ATNC)**.

Beer Institute of the USA

The Beer Institute of the USA [<http://www.beerinstitute.org> (last accessed 4 February 2013)] is an organisation founded in 1986 to represent the interests of the US brewing industry in state and national legislatures and other pertinent public bodies. As well as its lobbying activities it produces an annual statistical report detailing beer production in the United States. Its membership includes over a hundred US brewers and allied traders.

Beer maturation

Beer maturation refers to the changes that occur during the transformation of beer from its green state, at the end of primary fermentation, to its finished form in which it is deemed suitable for consumption. The changes in beer which occur during maturation are loss of undesirable flavour and aroma components, development of desirable flavour and aroma components, adjustment of carbonation, clarification and the removal of components, which have the potential to cause the development of hazes in packaged beers.

The type of maturation process that is used depends on the type of beer. The vast majority of beers are termed brewery conditioned. These are those beers for which all of the maturation stages occur within the brewery. In the cases of such products the beer is ready for consumption as soon as it is released from the brewery. No further desirable changes occur in the interval between release and consumption; indeed, since all such beers are inherently unstable, they will eventually acquire stale characters and possibly hazes. For this reason most beers of this type will have a stated shelf life and a declared 'best before date'.

Several options are available depending upon the type of beer. In traditional bottom-fermented lager brewing the green beer issuing from primary fermentation is transferred to a dedicated **ageing** or **lagering tank** in which it undergoes a secondary fermentation that may last for several weeks, or even months. The fermentation may use residual yeast and extract from primary fermentation; alternatively, additional sugar may be added, termed **priming**, or yeast and sugar in the form of actively fermenting wort, termed **krausening**. The secondary fermentation is conducted at relatively cool temperatures, typically a gradual reduction from a fermentation temperature of 5–10°C to 0–1°C. In the initial phases the yeast takes up the residual sugar, and ethanol and CO₂ (condition) are formed. In the initial stages the vessels are vented and undesirable components such as acetaldehyde and H₂S are allowed to escape. In the later stages the vessels are sealed to allow the formation of carbonation. During the lagering phase the undesirable flavour compound **diacetyl** is reduced by yeast to much less flavour-active products (see **vicinal diketones** and **VDK** for more details). A multitude of other changes in beer flavour and aroma occur in this phase, which are relatively uncharacterised, but which together result in the development of the desired flavour and aroma. In the

very end stages the beer may be cooled further, and during this stage solid materials derived from primary fermentation form a sediment at the base of the storage tanks. In addition, aggregates of proteins and polyphenols form, which, if not removed at this stage, would have the potential to form hazes in packaged beer. The proportion of proteins and polyphenols so removed correlates positively with the subsequent colloidal stability of the finished beer. This proportion also correlates positively with the time of storage and lowers the temperature of storage.

Processes such as lagering are very time-consuming and extravagant in the usage of tanks. In efforts to reduce costs several approaches are used, which reduce the storage period needed to achieve beer maturation. In these approaches the flavour and aroma change, which are associated with secondary fermentation are allowed to occur in fermenter at the completion of primary fermentation. This period of maturation is termed **warm conditioning**. The principal aim of this stage, particularly for pilsener-type lagers, is to ensure that diacetyl is removed by yeast. For this reason the period of warm storage in fermenter is referred to as a **warm rest/stand** or **VDK (diacetyl) rest/stand**.

Once the diacetyl is reduced to a specified low concentration the green beer is separated from yeast and then subjected to a brief storage period at low temperature. A typical regime would be 1–3 days at -1 to -3°C . This process is termed **cold conditioning** and serves the sole function of the precipitation of complexed proteins and polysaccharides and subsequent sedimentation and removal of solids. Cold conditioning may be carried out in the same vessels as primary fermentation, termed **uni-tanking** (see **uni-tanks**), or in separate dedicated **conditioning tanks**. Commonly the removal of proteins and/or polysaccharides is promoted by the use of processing (stabilizing) agents which are able to form complexes with and precipitate out these haze precursors. These materials may be added directly to conditioning tanks, dosed in during transfer of beer to or from conditioning tanks or combined with other processes such as filtration. In order to reduce solids loadings on filters and thereby to promote long filtration runs it is also common to use high-speed continuous centrifuges located in between the fermenter and the conditioning tank or between conditioning tanks and filters. Where beer clarification is via sedimentation under the influence of gravity a variety of **fining agents** may be used which promote aggregation of particles. Adjustment of carbonation is achieved post-filtration in **bright beer tanks** (BBTs).

A few beers are designed to undergo a period of maturation after packaging. These are **cask beers** (large pack) or **bottle-conditioned beers** (small pack). In these cases the beer is packaged with a low concentration of viable yeast and a small quantity of fermentable sugar. This allows a secondary fermentation to occur in the final package with the formation of ethanol, some changes in beer flavour and aroma, and the development of carbonation (condition). See **cask beer** for more details.

Beer ropiness

A symptom of bacterial spoilage of beers, often of draught cask beers in public houses, which appears, with other symptoms such as turbidity and surface pellicles, in the form of 'strings'. The latter are a consequence of the ability of some bacterial spoilage bacteria, for example, some acetic acid bacteria, *Pediococcus* spp. and *Lactobacilli* spp., to produce extracellular polysaccharides.

Beer shelf life

The time interval between beer finishing and consumption during which it is considered to retain flavour and aroma within specification. This assumes no spoilage due to microbial contamination and that beers have been stored and handled in an appropriate manner. The latter is a broad assumption since whilst in extended supply chains, as might apply to export beers, conditions may be far from ideal, especially with regard to temperature. Vigorous agitation of packaged beer can result in the formation of hazes. With regard to large-pack beers the shelf life after broaching is considerably shortened particularly if significant air ingress occurs.

Shelf life

Cask beer. Around 72 hours after broaching, providing storage at 12°C (54°F).

Unpasteurised keg beers. 30–50 days.

Pasteurised keg beers. 90–120 days.

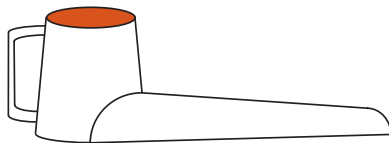
Small-pack glass bottle and canned beer. 4–12 months, depending on the beer style.

Polyethylene terephthalate (PET) bottles. Dependent on the oxygen barrier properties but typically up to 6 months.

Bottle-conditioned beers. Ageing is complex and usually the flavour undergoes radical changes throughout long periods of storage. The expected flavour typical of the beer style in the first phase of storage persists for 6–12 months. After this time some staling may become evident. After this (after 1 year) beers usually acquire a vinous, fortified wine character which is far from unpleasant. In the experience of the author this can persist for over 100 years.

Beer slipper

An antique drinking vessel associated with the United Kingdom and used for preparing and consuming heated (mulled) beer. The vessel was fabricated from copper and took the form of a tankard the base of which was extended so that the whole took on the appearance of a shoe (see figure). In use the tankard was filled with beer, often a highly alcoholic barley wine-type product, and the pointed part was embedded into the ashes of a hot coal or wood fire. When the beer had reached the desired temperature the vessel was removed and the beer consumed.



Beer spoilage

Beer is inherently resistant to microbial spoilage and the brewing process removes many potential microorganisms including pathogens, hence the truism that, in days of yore, drinking beer carried much less risk than consuming the then untreated water supply. Thus, beer is relatively low in nutrients and those that are present cannot be used by obligate aerobes because of the absence of oxygen. Ethanol, CO₂ and low pH prevent the growth of many organisms and further protection is provided by the antiseptic properties of hops. The brewing

process serves to reduce microbial loadings since it incorporates a sterilizing boiling stage, and after the initial stages of fermentation anaerobic conditions prevail preventing the growth of aerobic contaminants. Maintaining temperatures at low values for most stages of processing after fermentation up to the point of consumption further lowers the risk of the growth of contaminants.

Although no pathogens, including viruses, are found in beer, a small number of microorganisms can grow and as a result cause undesirable changes in products and processes. A wider range can grow in process liquids at intermediary stages in the brewing process. Additional undesirable effects can result from growth on or in raw materials, and process aids and taints may arise in beers as a result of microbial activities found on utensils and items of process plants. The risks of unwanted microbial activities are further increased where there is a loss of process control, for example, the inadvertent ingress of oxygen or failure to control temperature at desired values. For all of these reasons great care must be exercised to ensure that unwanted microorganisms are excluded from brewing streams, and the proper design and operation of brewing plants is a vital and costly activity. All breweries require careful selection and handling of all raw materials, rigorous control of process conditions, use of hygienically designed plant, use of appropriate cleaning systems and a carefully designed underpinning system of sampling and microbial analysis.

The risks of spoilage must be subject to constant appraisal since products and processes are subject to continuous evolution. There are several examples of process or product changes that have an impact on the risks of microbial spoilage. Typically these reduce the inherent resistance to spoilage discussed already. Low- and zero-alcohol beers fall into this category as does the practice of some brewers of only adding hops, in the form of speciality modified forms to bright beer. Similarly, the trend towards reducing in-pack oxygen concentration to very low levels has resulted in an increased incidence in spoilage by obligate anaerobes such as *Megasphaera* spp. Until comparatively recently the vast majority of beers were subjected to a terminal pasteurisation step in order to provide microbial stability throughout the intended shelf life. Currently, in the interests of flavour stability, there is an upsurge in the use of cold sterile filtration in place of pasteurisation. Clearly this raises the bar in terms of risk, and quality assurance techniques are required to be sufficiently robust.

Microbial testing of processes and products requires a risk analysis, the use of a suitable sample plan and a suite of tests capable of detecting potential spoilers. Classical microbial tests are used routinely, although most of these require a few to several days to complete and therefore produce results only of historical value. In order to support the current desire for rapid processes and minimal stockholding much effort has been devoted to devising rapid microbial testing. Techniques now exist, at high cost, which allow automatic in-line sampling and analysis which provide both detection and positive identification, without the need for an enriching pre-incubation step, resulting in results being obtained within minutes.

The range of problematic microorganisms is small.

Beer stabilisation

Beer stabilisation is the collective term given to treatments that are used during the brewing process to ensure that packaged beer has an appropriate colloidal stability.

See **colloidal stability**.

Beer staling

Deteriorative changes, not linked to microbial spoilage, which occur after beer has been finished. They are chemical changes that result in changes in the effects of beer components which have positive properties and the formation of new compounds which have undesirable stale tastes and aromas.

See **beer flavour stability**.

Beerstone

Beerstone is the name given to a deposit of calcium oxalate which forms on the surface of vessels which come into contact with beer. It is commonly found in fermenters, tanks containing beer and the inner surfaces of associated pipework, including beer dispense lines. Once it is formed it is difficult to remove. Treatments with nitric acid (0.5–1.0% v/v) or caustic detergents containing metal ion sequesterants such as ethylenediaminetetraacetic acid (EDTA) are able to dissolve it.

Beer tap

General term applied to any device used to dispense draught beer.

Beer vitamin content

Several vitamins are found in beers, usually at low concentrations; see accompanying table.

Vitamin	Typical range in beer (mg/L)	Recommended daily intake (mg)
Thiamine (B ₁)	0.002–0.14	0.8–1.2
Riboflavin (B ₂)	0.07–1.3	1–2
Niacin (B ₃)	3–20	15
Pantothenate (B ₅)	0.5–2.7	5–7
Pyridoxine (B ₆)	0.3–1.7	1.7–2.0
Folic acid (B ₉)	0.03–0.10	0.5
B ₁₂	0.09–0.14	0.001–0.003
Biotin (vitamin H)	0.007–0.018	Not applicable

Belgian biscuit malt

A variety of malt also sometimes referred to as simply biscuit malt. As the name suggests, when used as a component in grists, it imparts a dry biscuit-like character to the resultant beers. It is primarily used to impart colour to beers without also adding very strong malty or roasted flavours. It is produced by roasting the malt (see **chocolate malt** and **roasted malts** for more details). It has limited or no enzyme activity and a colour of 45–50 EBC units.

Belgian blond ale

Belgian blond ales are made predominantly with pale Belgian Pils malts together with other speciality malts and some sugar adjuncts. The beers are produced by top fermentation, using aromatic hops. Commonly the beers are aged in bottles for several months prior to sale either with or without a secondary bottle fermentation. They have a golden appearance and typically contain 6.5–7.0% abv. The flavours are described as being spicy and fruity flavours deriving largely from the activities of yeast and reinforced by the hops. The most well-known example

is *Duvel* (literally the Devil), produced by the Duvel Moortgat Brewery in the town of Breendonk.

B

Belgian candi sugar

Belgian candi sugar is used in many traditional Belgian beers as a priming sugar. It is an invert sugar, a mixture of fructose and glucose, produced from sucrose. The raw material is molasses syrup and the inverted product retains some of the caramel notes of the raw material. It is used in many **abbey beers** and **Trappist beers** where in secondary conditioned beers it is used by the yeast to generate additional alcohol. The material imparts some sweetness and caramel flavours to beers, but since it has been inverted it does not add body.

Bentonite

Bentonite is a mineral clay of volcanic origin. Several forms occur. They are described as being aluminium silicates of the montmorillonite group. Generally they are impure, containing various oxides and sulphates of aluminium, sodium and iron. The principal component is given by the formula $(\text{Si}_4\text{O}_{10})(\text{AlOH})_2n\text{H}_2\text{O}$.

Sodium bentonite, in which the former metal constitutes the major exchangeable ion, has the property of being able to absorb up to six times its weight of water to form a gel-like material that is able to adsorb proteins. It is used (now rarely) as a colloidal stabilising agent in brewing. It is more commonly used for the same purpose in winemaking.

Berliner Programm

See **Braugersten-Gemeinschaft e.V.**

Berliner Weisse

Berliner Weisse is a speciality beer that by law can be produced only in Berlin. It is a low-alcohol (2.5–2.7% abv) highly carbonated pale brown bottled beer made from a combination of malted wheat and pale malted barley. It is associated with summer and is often drunk in combination with a measure of raspberry or woodruff-flavoured syrup.

Unlike true German wheat beers the proportion of wheat is less than the customary 60–70%, and for this reason *Berliner Weisse* is not considered a true *Weissbier*. The fermentation is reminiscent of Belgian *gueuze* in that a mixed culture of yeast and *Lactobacillus* sp. is used. The presence of the bacteria imparts an acidic sour character to the beer and this explains the predilection for adding the sweet syrups.

Bev-trace®

Proprietary system [made by Biotrace International, now part of 3M; <http://www.3M.com> (last accessed 26 March 2013)] for rapid microbiological testing based on ATP bioluminescence, which uses a membrane enrichment system and a portable luminometer.

See **ATP bioluminescence**.

Bid-ales

Medieval feasts held in the United Kingdom at which the invitees were expected to raise funds, or ‘bids,’ for particular causes.

See **ale**.

Bière de garde

Bière de garde is a style of beer associated with rural regions of the Pas de Calais region of France. It is a **seasonal beer** that is brewed during the autumn and stored throughout the winter for consumption the following year. The name reflects this heritage since it translates as 'beer for keeping'. Original examples were farmhouse produced. Following a relatively warm fermentation of worts often made from pale malts (although darker varieties were also used) and using ale-type yeast strains the beers were bottled and stored at a cool temperature. Commonly the bottles were of the champagne type and the beers were **bottle-conditioned beers**, thereby producing carbonation, an increase in ethanol content and flavour maturation during the storage period.

The beer style has persisted and, apart from examples brewed commercially in France, several American craft brewers produce examples bearing this name. Many of these are comparatively strong in alcohol, 7–9% abv being not uncommon.

BierIG Österreich (BierIG)

This is the name of an Austrian consumer group founded in 2002 with the intention of championing for what are perceived as traditional beers and campaigning against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Contact details are <http://www.bierig.org> (last accessed 4 February 2013).

Bifenthrin

Bifenthrin (2-methyl-3-phenylphenylmethyl (1S,3S)-3-[(Z)-2-chloro-3,3,3-trifluoroprop-1-enyl]-2,2-dimethylcyclopropane-1-carboxylate) is a natural pyrethroid insecticide which may be used for the treatment of **red spider mite** infections of hop plants.

Big bag

Format used for the supply of kieselguhr filter powder suitable for use in larger breweries which have automated powder handling systems. Each unit is made up of disposable polypropylene sacks containing 500 kg of powder.

See **kieselguhr**.

Bil-bil

Name given to an opaque beer made from sorghum native to Cameroon.

See **native African beers**.

Bine

The name used for the climbing stem of the hop plant. See **hop plants**.

Biobeer

Biobeer is a German nomenclature that indicates that a beer has satisfied the requirements that allow it to be described as 'organic'. Such beers can be so certificated if it can be demonstrated that all raw materials and subsequent handling procedures render the beer totally free from any 'non-organic' contaminants. This requires that all suppliers also adhere to these rules. The German authorities operate a strict system of inspection which guarantees that these rules

are adhered to. Beers that meet these guidelines are entitled to bear the European Biobeer logo.

B

Biofilms

Biofilms are aggregates of microorganisms and extracellular materials which together form an adherent film on surfaces. They are a persistent source of viable organisms that can detach from the biofilm and contaminate liquid media which come into contact with it and, once formed, they are difficult to remove by conventional CIP regimes.

Wherever a solid surface is in contact with a liquid the potential exists for biofilm formation. The process begins with organic and inorganic constituents of the liquid medium forming a priming layer on the surface. It is considered that for many microorganisms a solid substrate is the preferred habitat for growth. For many it may be essential. Microorganisms colonise the priming layer and multiply. Extracellular polysaccharides and glycoproteins accumulate and provide a presumably stable and sheltered environment which favours survival of the entrapped microbial cells. The microbial flora may include many different genera and species.

Biofilms are highly organised. They may be up to 40 mm in thickness and contain microbial colonies interspersed amongst extracellular materials. Channels provide means for dispersal of organisms and metabolic waste products and the inflow of fresh nutrients from the liquid medium. The extracellular materials are hydrophilic, which is considered to provide protection from desiccation since water becomes trapped within the solid matrix. The mixed populations exist in symbiotic or commensal relationships. This can be highly significant from the perspective of beer spoilage because aerobic members of mixed populations can, by exhausting local supplies of oxygen, provide anaerobic niches which allow the survival of obligate anaerobic species. Occurrences of beer spoilage by anaerobes such as *Pectinatus* spp. have been traced to biofilms in areas of breweries where it might be suspected that they could not survive. Once established in biofilms many bacteria undergo adaptations such that they often become more resistant to otherwise lethal doses of disinfectants.

Biofilms form in areas that are difficult to clean. Once formed relatively large portions become detached and provide irregular sources of contamination. Their formation is favoured where other solid deposits are allowed to accumulate, for example, where cleaning regimes and water treatments result in scales or beerstone. For obvious reasons these should be avoided. Apart from acting as sources of contamination they can be sites for corrosion and they impair the function of plants such as heat exchanging surfaces.

Biofilms have been found in breweries especially in locations where heavy and continuous contamination occurs, for example, in packaging halls on conveyors and associated with parts of fillers. They are particularly associated with dispense lines in licensed premises. Remedies are twofold and both aim to avoid conditions that prevent the initial colonisation. Firstly, good design of the plant is an essential prerequisite. Dead legs and other areas that are not subject to proper scouring, cleaning and rinsing must be avoided. Secondly, cleaning regimes must be sufficiently rigorous to remove soils efficiently. The aim is to avoid the sets of circumstances that are required for colonisation of surfaces to occur.

Biogenic amines

Nitrogen-containing compounds derived from amino acids and which in mammalian systems serve as bio-signalling molecules. Examples include histamine, tyramine, tryptamine and

cadaverine. They are implicated in several human diseases including immune responses, carcinogenesis and many neurological disorders. High levels in some foodstuffs have been associated with undesirable physiological reactions. Levels in most beers are too low to present concerns; however, some cases of abnormal reactions to beer consumption have implicated interactions between tyramine and monamine oxidase inhibitors taken as medication for depressive conditions. Beer tyramine levels are normally low but can be elevated, together with other biogenic amines, as a result of infections with *Pediococcus*. This bacterium has been shown to be able to form tyramine from tyrosine. Elevations in tyramine levels have been most associated with draught beers, suggesting that infection via poor dispense hygiene might be the cause.

Bio-Gro hops

Bio-Gro is the trade name of the New Zealand Biological Producers and Consumers Council. It has the power to certify crops and their products as being organic. Currently five varieties of New Zealand hops have this accreditation. These are Hallertau Aroma, Pacific Gem, Motueka, Riwaka and NZ Cascade.

New Zealand is ideally placed to produce organic hops since the majority of pests, found elsewhere in the world, are not native to this country and, hence, pesticides are not required. The isolated geographical location has no doubt played a significant role in this fact.

Biological acidification

Procedure used to control pH during wort production involving lactic acid produced by the activity of bacteria, usually *Lactobacillus delbrückii*. It is a benefit to maintain pH at low values during mashing in order to control the activity of key enzymes which have low pH optima and to have a relatively acidic wort since this provides hostile conditions for many common spoilage bacteria and favours rapid diacetyl removal. Of course, pH can be manipulated by the addition of food-grade acids, but this is not permitted in many countries. In addition, the use of a naturally produced source of acid is viewed as being preferable by many brewers and consumers. Acidification is useful where high proportions of adjuncts such as unmalted barley are used or where the water supply makes the control of mash pH difficult. In addition, it is claimed that the organoleptic quality of beers is improved.

Lactic acid is produced in dedicated plants in which a culture of *L. delbrückii* is allowed to grow on sweet wort, usually the first worts, at an elevated temperature (typically *ca.* 45°C) for several hours. The acidified wort is then used to make adjustments, as required.

See also **acid malt**.

Biological haze

A haze that arises in beer as a result of microbial spoilage.

See **beer hazes**.

Birth scar

The circular structure which occurs on the surfaces of the cell walls of budding yeasts and which marks the point where a newly emerging daughter cell is attached to the mother.

See also **yeast**, **yeast cell cycle**.

Bishop continuous fermentation system

A continuous fermentation process introduced in the 1960s into four of the then Watney breweries in the United Kingdom.

Wort was produced in a conventional brewhouse and transferred for temporary storage in one of three holding vessels. The vessels were chilled and of good hygienic design such that storage times of up to 2 weeks were achieved without spoilage. Wort was transferred from the storage vessels and sterilised by passage through an in-line heat exchanger. Oxygen was then introduced into the wort by passage through a U-shaped column designed for this purpose. The cooled and oxygenated wort was then transferred into the first of two stirred and attenuated fermentation vessels. Yeast was pitched into the first vessel, and subsequent yeast growth and fermentation rate and extent were regulated by controlling the temperature, supply of oxygen and wort feed rate. Beer issuing from the second fermentation vessel was transferred into a cylindrical chilled separation tank. Here the provision of an internal attenuator cooled with brine caused yeast to settle into a conical bottom. Green beer was removed from the upper part of the tank. Recovered yeast was sent to a press from which entrained beer was recovered and returned to the beer stream.

In commercial use the system was shown to be suitable for both ale and lager production. Productivities of individual fermentation systems were quoted as 6500 hL/week, giving a total combined annual output of the four breweries of 1.6 million hL. On one occasion one of the systems operated without a break for 13 months, a remarkable achievement.

Bitter

A name popularly used in the United Kingdom for a pale ale sold either in bottle or draught. The name makes reference to the fact that these beers tend to be quite highly hopped and, hence, the name bitter was commonly used to distinguish this type of ale from the sweeter mild ales. Before the widespread introduction of draught pale lager beers in the 1960s draught bitter had the majority share of the UK on-trade market (>70% of the total). The word bitter was commonly qualified with other terms to denote various categories, for example, 'ordinary' bitter, 'best bitter', 'export bitter' and 'special bitter'. The qualifying terms gave an indication of the alcoholic strength (and cost) of the beer.

See **ale**.

Bittered wort

Description applied to wort after it has been boiled in the kettle. This makes reference to the usual practice of adding hops to the wort during boiling, and as a result of the application of heat, **hop isomerisation** occurs and bitter hop iso- α -acids are formed.

Bitterness

Bitterness of beer is imparted principally by the presence of iso- α -acids derived from hops (isohumulone, isochumulone and isoadhumulone) (see **hop isomerisation**). A smaller contribution in some beers is made by **hulupones**, oxidation products of β -acids (see **α -acids**, **β -acids**, **hop isomerisation** and **hop resins** for more details). Collectively these compounds are referred to as **beer bitter substances**.

The bittering principles of beer are routinely determined using spectrophotometry. A sample of degassed acidified beer is shaken with isooctane into which the bitter components

are extracted. The UV absorbance (275 nm) is read against a blank of pure isooctane. The resulting absorbance is related to the dissolved concentrations of the mixture of iso- α -acids present. Since it is not possible using this method to resolve individual components the result is described as **bitterness units** (BU) using the following equation:

$$\text{BU} = 50 \times A_{275}$$

This method has received widespread adoption and, to reflect this development, the unit is now more usually described as **International Bitterness Unit** (IBU). Beers with bitterness values of up to approximately 100 IBU are produced, although this is an extreme value and most fall within the range 10–50 IBU. The total concentrations of iso- α -acids found in beers lie with the range of approximately 20–50 mg/L.

The method of analysis is non-specific and non-isomerised α -acids interfere. In the case of beers made from whole hops or non-isomerised extracts this is not a problem since little of these survive the brewing process; however, isomerised extracts may contain these precursors of iso- α -acids, and where these are added post-boil they may be present in the finished beer. In such cases, in order to determine the true concentrations of iso- α -acids, it is necessary to perform an initial purification step, typically using high pressure liquid chromatography to effect the separation.

Bitterness unit

See **bitterness**.

Blackjack

A term of UK origin describing a large vessel made from tar-coated leather and used for drinking beer.

Black malt

See **chocolate malt** and **roasted barley**.

Blato

A Czech aroma hop variety which is a clone of Saaz.

See **Zatecky Chmel**.

Blisk

Blisk is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with Bobek and Buket it is one of the 'B' series of Slovenian hops which were released in 1980 and were bred with the intention of possessing high α -acid contents, as in the **Super Styrian hops**, but with good aroma properties. It is a triploid variety derived from a tetraploid **Atlas** and a Slovenian male.

It contains 10–14% total α -acids of which 33% is cohumulone. Total β -acids and oils are 3–5% and 1.2–3.2%, respectively. Storage properties are poor.

Block and bleed valve

A block and bleed valve is one in which part of a system of pipework or associated plant can be isolated and drained in order to allow maintenance work to be carried out. It takes the

form of an isolating valve, usually of the ball type, which stops process flow when closed. Linked to this and on the downside of the isolation valve is an additional bleed valve which is used to drain the isolated part of the system.

B

Blom method for foam assessment

A method for assessing the foaming ability of beer or other process liquids now not used. It is based on generating foam in a measuring cylinder by sparging with CO₂. Beer is allowed to run off at fixed time intervals and the residual weight of foam is determined. From these weights a foam collapse time can be calculated. The mathematic equations used in the Blom method have been used to develop related methods, notably the **Ross and Clarke method of beer foam assessment**, and subsequent iterations.

Blown malt

This is a synonym for **porter malt**.

Blsanka

Czech aroma hop variety which is a clone of Saaz.

See **Zatecky Chmel**.

Boadicea

Boadicea is a UK dwarf high alpha hop variety that is reportedly aphid resistant and so can be cultivated with a minimum use of pesticides. It contains 8–11% α -acids.

Bobek

Bobek is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with **Blisk** and **Buket** it is one of the 'B' series of Slovenian hops which were released in 1980 and were bred with the intention of possessing high α -acid contents, as in the **Super Styrian hops**, but with good aroma properties. It is a seedling derived from a cross with a **Northern Brewer** and a Slovenian male. It is moderately disease resistant, but the yield is poor. The latter probably accounts for its general lack of take-up.

It contains 6–9% total α -acids of which 26% is cohumulone. Total β -acids and oils are 4–6.6% and 1.4%, respectively, humulene (12%), caryophyllene (4%), farnesene (3.0%). Storage properties are fair.

Boby drum maltings

A type of drum malting of the decked variety.

See **drum malting**, **pneumatic malting**.

Bock

Bock is a style of beer which has its origin in Germany. Bocks are strong bottom-fermented lagers (5–10% abv or greater) with colours ranging from pale through golden to dark. The beers are lightly hopped and they have sweet malty and very flavoursome characters which derive from the toasted **Vienna malt** and **Munich malt** used in their production.

The beers originate from the German town of Eisbeck in Lower Saxony and the name may derive from a corruption of this place name. However, it is also claimed that the name may

also derive from the German for 'buck', the male deer, presumably a reference to strength. Bocks beers have a very long history. They were commonly brewed for special occasions and often had ecclesiastical associations and usually had a very dark colour. With regard to the latter it has been suggested that they provided a valuable source of nutrients to monks during Lenten fasts. Bock beers are now commonly brewed in many countries both as a consequence of renewed interest in traditional beer styles and earlier as a result of the diaspora of German brewers.

Several variants of bock beers are brewed. Typically these are prefaced with another word which is descriptive of the particular variant.

Urbock is the originator of the bock style. The prefix *Ur* translates as 'original' and reflects this heritage. The original beer was strong in alcohol and was a brown-coloured ale finished off by a process of cold conditioning as in a lager. This was the original bock beer, which was developed in Einbeck. These brewers were amongst the first to use hops as flavouring and preservative. In the Middle Ages this beer was transported from Eisbeck and was sold in Bavaria. The beers proved popular and the resultant fierce competition with local brewers prompted the then ruler, Duke Willhelm V, to develop a similar product. This resulted in 1612 in a new Bavarian brewery which is now the site of the Hofbräuhaus. Eventually, with the help of imported Einbeck brewers, these beers became dominant and gave rise to the now more familiar *bock* style of beer.

Doppelbock (literally double bock) is a strong (5–12% abv) lightly hopped variant of bock beer and is a speciality of Bavaria. *Doppelbocks* are very flavoursome with strong sweet, malty and toasted notes. Most have a dark brown golden colour and thick creamy head, although some variants are pale. Commonly the brand names are given the suffix '. . .ator' to indicate that they are of the *doppelbock* style.

Eisbock beers are of the bock style but are generally smoother and more alcoholic. They are the original **ice beers** in which during production the immature beer is frozen. When the ice is removed the alcoholic content of the residue is increased. In addition, some harsh flavour compounds may also be removed. Eisbock beers originate in the northern Bavarian city of Kulmbach.

Maibock, literally 'May bock', is a lighter style of bock. The beer is lighter in colour and character compared with a traditional bock and tends to have a lesser alcoholic content (6.5–7.5% abv). Although *Maibocks* still have the low bitterness characteristic of the bock style, they are drier, lighter and less full. This lighter character reflects the name and the intended association with spring. Similar, perhaps identical, beers are also sold under the general name **Hellesbock**, literally pale bock.

Weizenbock beer is made in a similar fashion to standard Bock beer in that Vienna and Munch malts are used; however, the grist also contains between 60 and 70% wheat. The beer is not filtered and, in consequence, it has an opaque golden brown colour. Unlike standard bocks an ale yeast is used, which is a type that possesses the *POF* gene. As a result the beers develop the characteristic clove/spice flavours and aromas that are associated with fermentations performed with such yeast strains.

Weizendoppelbock beer is analogous to the doppelbock version of bock. In other words it is a wheat beer made with a *pof*⁺ top-fermenting ale yeast, but it is stronger, darker and more highly flavoured than the standard *weizenbock* type. Typical alcoholic strengths are 7–9% abv.

Weizeneisbock is a speciality beer, typically brewed for special occasions. As the name suggests it is a combination wheat and ice beer made using the dark Vienna and Munich malts that are associated with traditional bock beers. It is made from a **Weizendoppelbock** base beer, which, although already strong, is further concentrated by partial freezing and filtration of ice. The alcohol concentration pre-freezing is around 8.0% abv and this is increased to 12.0% abv after the freeze concentration. The beer has the dark malty notes of standard bock beers, but the taste is smoother, very warming and with raisin-like characters.

Body feed

Body feed is the term used to describe filter powder, usually kieselguhr or perlite, which is dosed with rough beer before filtration. The function of body feed is to prevent premature blocking of the filter. It does this by continually renewing the surface of the filter through which the un-clarified beer is passed.

See **powder filter**.

Boerner grain divider

This is a device designed to produce a randomised mixture of grains from a sample such that the fraction that is used for analyses is representative of the whole.

See **grain samplers**.

Bog myrtle

Bog myrtle is the common name for the plant *Myrica gale*, a resinous shrub the extracts of which have been used as an alternative to hops.

See **gruit**.

Bolter

A term used in malting which describes grains in which the acrospire has grown to a length greater than the overall length of the whole grain. These are generally undesirable since the grains may be rich in enzymes but low in extract.

See **acrospire**.

Bombard

A large receptacle or jug made from leather and coated in tar used for dispensing beer.

See also **blackjack**.

Bomb filter

A device used in the laboratory to assess the filterability of beer.

See **filterability of beer**.

Boot stage

The boot stage refers to the stage in the growth cycle of cereal crops such as barley. It is descriptive of the stages in which the spike begins to form. During this phase the sheath of the flag leaf gradually extends and the base becomes swollen. This swelling, known as the boot, comprises the developing spike, which is covered by the sheath of the flag leaf. The boot stage is completed when the head of the spike begins to emerge.

See **barley plant**.

Bor

Bor is a relatively new high alpha hop variety produced in the Žatec region of the Czech Republic. It was released in 1994 and was produced by open pollination in the region with **Northern Brewer**. It is relatively disease resistant and is aimed at bittering or dual-purpose use. It contains 7.5–11% total α -acids of which 24% is cohumulone. Total oils are 1.0–1.5% (9–14% caryophyllene, 0.5–0.9% farnesene, 26–40% humulene, 35% myrcene).

Bordeaux mixture

An aqueous solution, typically 1% w/v made with equal quantities of copper sulphate and hydrated lime. It is used as a fungicide by virtue of the toxic effects of copper ions on the spores of the latter. The hydrated lime component assists with adherence to leaves of the infected plants. Historically it has been associated with the treatment of fungal infections of grape vines, particularly in France, hence the name. It has been used for the treatment of downy mildew infections in hops. Use of this preparation has declined because it tends to leave stains on plants and it is somewhat phytotoxic. Another copper-containing preparation that is less toxic and effective against fungi is **copper oxychloride**.

Boreholes

Boreholes were traditionally used by many brewers as a means of accessing water from subterranean aquifers for brewing or malting purposes. The use of well or borehole water is attractive since it is usually less costly than municipal supplies; the supply is dependable; it is free from undesirable additives, which may be present in the latter; it is of a constant temperature and composition and is usually (at the point of source) free from microbial contamination. The nature of the water with regard to its composition and brewing properties is characteristic of its geographical location and this may make it particularly suitable for the production of certain beers. Thus, the water that could be extracted from boreholes and the association of specific geographical locations as centres of excellence for particular beer styles are inextricably entwined. For these reasons many brewers continue to use boreholes as their principal supply of brewing water. The majority of countries have legislation regarding water abstraction and a levy will normally be charged.

In order to access the aquifer boreholes may be up to 200 m in depth and must have an impermeable lining to prevent contamination from the intervening strata. A submerged pump is required to provide the motive force to transport the water to the surface. Before use and depending on the quality, the water requires treatment of the types described in the entry on **water**. These will be of greater complexity compared with those that are applied to municipal water supplies.

Bottle conditioning

The process of conducting a secondary fermentation, and by inference the formation of CO₂, in a bottled beer.

See **bottle-conditioned beer**.

Bottle-conditioned beer

Beers, usually ales, which are bottled in the presence of fermentable sugar and viable yeast such that a secondary fermentation occurs in the interval between packaging and consumption.

The processes are similar to those employed in the manufacture of cask-conditioned beers except that it is common to perform a certain amount of clarification before bottling in order to avoid overlarge sediments. Primary fermentations may be arrested before full attenuation, by chilling, in order to leave residual extracts for the secondary fermentation. In larger-scale commercial processes the source beer is fully fermented to remove all fermentable residues and priming sugar, usually sucrose, is added immediately before bottling. This is not essential but makes the calculation and control of the secondary fermentation easier. Similarly, the yeast concentration can be controlled by leaving sufficient suspended cells in the green beer after primary fermentation. Alternatively, the beer may be filtered and a defined cell count added at bottling. The filtration step removes unwanted non-yeast solids and this approach provides an opportunity to use different yeast strains for primary and secondary fermentation. The dual yeast strain approach is useful as a means of introducing new yeast-derived flavour notes and it allows the use of strains that form compact sediments and readily adhere to glass. The latter behaviour is desirable in bottle-conditioned beers but perhaps not in primary fermentation.

Newly bottled beer should contain a viable yeast count of the order of 10^3 – 10^4 cells per millilitre and fermentable extract of around 5–7 g/L, as sucrose. It is not usually necessary to admit air or oxygen at packaging and certainly not if active dried yeast is used.

Bottles are stored at a cool temperature (10–15°C) for 2–4 weeks to allow development of condition. For high-alcohol variants much longer storage times (6 months to 2 years) are claimed to be necessary, although presumably this is a question of personal preference. During the conditioning period for a moderate-strength beer (4–5% abv) the CO₂ content increases to around 3 vol (6 g/L) and the total yeast count to 2 – 3×10^6 cells per millilitre.

Bottle fermentation

Term used to describe a fermentation in which the yeast crop separates from the green beer and settles at the bottom of the fermentation vessel.

See **fermentation**.

Bottling

Packaging beer into bottles in a state in which it meets all legal and quality specifications. In many countries the trend from large pack to small pack continues such that in the United Kingdom in 2008 the proportions were roughly equal. The majority of bottles are made from glass and are secured with crown enclosures. PET has a small but significant proportion of the market but suffers from a general perception that it is used solely for low-quality beers. From a technical perspective its oxygen barrier properties are inferior to glass; however, advances are being made and undoubtedly this sector of the market will become increasingly important. Although in many countries packaging of beer into returnable bottles accounts for a sizeable fraction of total sales, in others, such as the United Kingdom, this has fallen to less than 1% and the remainder is sold in one-trip bottles. The realisation that the bottle can be used as an important marketing tool has resulted in a major increase in bespoke bottle designs. Typically this requires the purchase of unique packaging **change parts**. The tendency towards using clear or green glass makes the beers susceptible to **light-struck character**, which has resulted in an increased use of hop products that are not susceptible such as tetra-isohop. After filling and capping the majority of bottled beers are rendered microbiologically stable via **tunnel pasteurisation**. A smaller proportion is treated by **cold sterile filtration** (see **cold**

sterilization) or flash pasteurisation. Since the majority of PET bottles are not sufficiently heat stable to withstand pasteurisation they must be filled in aseptically.

Before bottling the bulk beer must meet all specifications. In most cases the beer will be bright and yeast free. Modern high-speed bottling lines are costly both in terms of capital and revenue. Filling rates may be more than 1500 bottles per minute. Bottling lines comprise a number of individual units which, depending on the type of operation, will include some of the following steps: clean bottle intake (de-palletiser), empty bottle inspection (EBI), cold sterile filtration, flash pasteurisation, filling, crowning, tunnel pasteurisation, full bottle inspection, labelling, secondary packaging, palletisation, tertiary packaging and warehousing. Empty bottles may be new or washed pre-used containers. In the latter case the bottles require to be sorted, washed, de-labelled and sanitised. Where the bulk beer is sterilised all subsequent operations up to crowning must be conducted under aseptic conditions. Bottles are transported through the packaging steps on conveyor belts. These require careful design in order to prevent toppling. In areas where hold-ups may occur, accumulation tables allow surplus containers to be held temporarily and so avoid having line stoppages. Modern bottling lines are highly automated and in consequence require relatively few manual operations. Bottle flow through individual stages requires careful management to ensure smooth and efficient packaging.

Bottle washers operate continuously and various steps occur as the bottles pass through. After soaking in warm water bottles are treated with hot caustic soda followed by a series of rinses. A complex series of jet ensures that all are properly treated and the remains of labels and other solid residues are removed automatically. New bottles are rinsed, sanitised and inspected for integrity and absence of any inclusions prior to filling. Empty bottle inspectors are complex and costly. Typical machines perform several checks including base inspection (camera), residual liquids (optical, infrared or radiofrequency permittivity), inspection of inner and outer wall sealing surfaces and presence of solid inclusions (image analysis).

The bottle filler must deliver (at high speed) the correct volume to each bottle, prevent oxygen pickup, prevent entry of microbial contamination (in sterile fill operations), prevent loss of carbonation and deliver the bottle to the crowner. Bottle fillers are rotary devices that have multiple filling heads to provide the necessary speed. Bottles are moved on individual platforms which transport them into the filler, raise them up to the filling heads and pass them onto the crowner. Operations are performed against a counter-pressure. Before filling the bottles are pre-evacuated and counter-pressured with CO₂. Filling is either to a pre-set level or via volumetric displacement. The beer is usually supplied cold and is transported to a central filler bowl which is pressurised to 1 bar, to prevent gas breakout, from where it passes to the individual filler heads. The bowl is supplied continuously with fresh beer from the BBT. Filler heads are attached directly to the base of the bowl to minimise pipe runs. After filling the still open bottles pass under a jetter, which directs a very small volume of high-pressure sterile water into the neck of each bottle. This causes the beer to foam and thus dispels air from the headspace. After this the bottles are fitted with a crown. A key line check is to ensure that these are applied correctly and at the appropriate force to provide a gas-tight seal. Aseptic filling operations are essentially the same as described but with greater attention to hygiene. In the case of sterile filtration the necessary equipment is located close to the filler and the latter may be placed within a secondary 'clean room' enclosure fitted with positive pressured air supply. Frequent automatic sanitizing foam treatments ensure that the external surfaces of the filler are kept clean and as far as possible microbe free.

In non-aseptic filling operations the filled and capped bottles are passed into a tunnel pasteuriser (see **tunnel pasteurization**). Full bottle inspectors check fill levels and can detect the presence of any inclusions such as shards of broken glass. Typically these use optical detection systems or via the use of high frequency, infrared, X-ray or gamma-ray irradiation which are capable of discriminating between the gas and liquid phases in the bottle. Inclusions can be detected by spinning and suddenly stopping the motion of bottles so that the continued movement of solid objects allows detection. Out-of-specification bottles are automatically rejected.

Bottles are then transported to a labeller where the bottles are dressed. Labellers are complex rotary devices that are supplied with a number of stations, one for each label (back, front, neck). As the bottles pass these stations, labels with adhesive are pressed onto the appropriate part of the bottle. Rollers ensure proper and smooth attachment. Increasingly bottles are supplied ready decorated, which generally provides superior appearance to paper labels. Lot and date codes are commonly applied directly to the glass of the bottle neck using laser ink jetters. Filled bottles are placed into secondary packaging, which may take many forms, such as crates, cardboard cases and shrink wrap. Palletisers group individual packs and after shrink wrapping deliver these to the warehouse for storage and onward distribution.

Bottom cropping

Bottom cropping describes the practice, associated with lager yeast strains, of removing yeast crops which form at the bottom of fermenting vessels during fermentation.

See **crop**.

Bottom-cropping yeast

Term used to define a group of brewing yeast strains which during fermentation have a tendency to separate from green beer and settle at the bottom of fermenting vessels and form a sediment. The term **bottom fermentation** is also used, although this is somewhat nonsensical since obviously at some period of the fermentation the yeast cells should be uniformly dispersed throughout the wort. Bottom cropping is a characteristic of many brewing yeast strains that are classified as being lager types, and these terms may also be used interchangeably. This is also factually incorrect since many yeast strains classified as top-cropping ale types can be made to form bottom crops providing an appropriate fermenting vessel is used.

See **yeast**.

Bottom fermentation

Term used to describe a fermentation in which the yeast crop separates from the green beer and settles at the bottom of the fermentation vessel.

See **fermentation**.

Bottom trough

Component of a Burton union fermentation system used for the collection of green beer for transfer to a racking tank.

See **Burton Union system**.

Bouza

Bouza is a native alcoholic beverage associated with Egypt and Sudan. It is one of the earliest and most ancient recognised beers and is reputedly the origin of the English word *booze* and

its derivatives, generic slang words for alcoholic beverages and those who consume them. In ancient Egypt supposedly baking for bread and for production of bouza were highly organised and related undertakings.

It is made from coarsely ground wheat or millet grains which are formed into a dough and lightly baked. The resultant loaves are mixed with water and a further aliquot of grain which has first been steeped in water for 2 or 3 days to allow germination before drying in the sun and grinding. The mixture is inoculated with a reserved portion of a preceding batch of bouza. After 24 hours the product is sieved and consumed whilst still fermenting. The beverage is viscous, opaque and yellowish in colour. It has a pH of approximately 4.0 and an alcoholic strength in the region of 4% abv.

Box fermenter

See **closed square**.

Box maltings

See **compartment maltings**.

Brackling

An undesirable characteristic of some cereal crops, including malting varieties of barley, where the upper regions of the straw are liable to buckling.

Bractwo Piwne

This is the name of a Polish consumer group founded in 1997 with the intention of championing for what are perceived as traditional beers and campaigning against the globalisation of the world brewing industry. It is a member of the EBCU.

Contact details are at <http://www.bractopiwne.pl> (last accessed 4 February 2013).

Braga

A beer made in Romania via the spontaneous fermentation of an extract of millet or wheat. It is unfiltered, has a low ethanol content of approximately 1% by volume and an acidic taste.

Braggot

Braggot, also known as ale mead, is a beverage associated with the United Kingdom which is essentially a combination of top-fermented ale and mead. Historically it may have been made by blending of mead and ale immediately before dispense. Alternatively, it may be made by fermentation of a mixture of a conventional ale wort and honey. Hops and other spices may or may not be added. The alcoholic strength is usually high, typically up to 12% abv.

Bramah, Joseph

Prolific inventor born in Stainborough, Yorkshire, UK in 1748 and credited, along with many other innovations, with the introduction of an 'unpickable' lock, an improved flushing water closet and the **beer engine** used for the dispense of draught cask ales.

Bramling goldings

A variety of one of the group of Goldings, traditional UK-style aroma hops.

See **Goldings**.

Branded glassware

Branded glassware is seen as engaging directly with the consumer and is becoming increasingly popular in the **on-trade** and as promotional items in the **off-trade**. Coloured brand logos or other communications are applied using ceramic screen printing after which the glass is fired at high temperature. Other techniques include sand blasting and relief printing. Coloured printing – which can fade over time – has been challenged by embossing where the non-coloured branding is integrated into the glass design itself. Branded glassware is often nucleated (see **nucleation**) to enhance visual presentation. Thermochromic inks have been explored in branded glassware but with less success than in can or bottle labels. The latter feature labels parts of which change colour at particular (usually cool) temperatures. In busy accounts with many brands, branded glassware can add complexity to glassware management.

Braugersten-Gemeinschaft e.V

German organisation [<http://www.brauerstengemeinschaft.de> (last accessed 4 February 2013)] charged with providing data regarding malting barley, in particular, the evaluation of new varieties. Since 1995 these activities of the group have been formalised under the guise of the **Berliner Programm**, which is controlled by the advisory council of the *Braugersten-Gemeinschaft e.V* and seeks to integrate the activities of farmers, breeders, maltsters and brewers in order to provide speedy information following accreditation of individual varieties. Results of evaluations of malting and brewing performance of varieties are published in the *Braugerstenjahrbuch* (Annual Malting Barley Manual). Formal approval of varieties is governed by the **Bundessortenamt**, the government organisation that provides lists of German accredited varieties and grants rights to plant breeders.

Bravo

Bravo is a high alpha hop variety (14–17% α -acids, 1.6–2.4% oil) bred in Washington State in the United States from Zeus and Nugget parental strains. It is resistant to downy mildew and has good storage properties.

Brem

Brem is a traditional fermented foodstuff made from rice and native to Indonesia. It is associated particularly with Bali. It may be consumed as a non-alcoholic solid product. In addition, an alcoholic beverage form also exists which is made from steamed glutinous rice and a starter (called *ragi*) which contains rice and a mixture of moulds, yeasts and bacteria. The process of manufacture is reminiscent of saké and involves an initial amyolytic phase in which the rice is mixed with the *ragi* starter. A sugar-rich syrup is collected from this initial phase and this is mixed with a yeast culture, and an alcoholic fermentation ensues. The final beverage may be honey or red coloured depending on the nature of the rice.

Brettanomyces

Literally ‘British fungus’, a genus of yeast which, as the name suggests, was first isolated as a causative agent of spoilage in English ales. The genus *Dekkera* is a teleomorph. Growth is stimulated by oxygen and growth on glucose produces copious amounts of acetic acid. This is a positive feature in some beers, such as Belgian lambics and gueuze, or negative, where growth has occurred in UK-style ales. The craft brewing segment of the industry, particularly

in the United States, has resulted in a resurgence of interest in Belgian-style beers, and various strains of *Brettanomyces* are now available commercially. They may be used for primary fermentation, with or without *Saccharomyces*, or they may be used in a secondary fermentation in which the yeast is commonly introduced via infected wooden casks.

Brewers Association of Canada

The Brewers Association of Canada (*L'Association des Brasseurs du Canada*) [<http://www.brewers.ca> (last accessed 5 February 2013)] represents the Canadian brewing industry. It was founded in 1943. Its membership is responsible for more than 98% of the annual Canadian beer production. As well as producing an annual statistical bulletin it seeks to promote responsibility in beer production and the environment, advertising and consumption.

Brewers Association of Japan

The Brewers Association of Japan [<http://www.brewers.or.jp> (last accessed 5 February 2013)] was founded in 1953 as a non-profit-making organisation that represents the interests of the Japanese brewing industry. Its membership includes all of the major Japanese brewing companies. It is a member of the **Worldwide Brewing Alliance**.

Its aims are to promote a positive image of responsible beer consumption. It lobbies on behalf of the Japanese brewing industry on matters such as advertising and taxation. In addition, it is a source of technical literature and seeks to coordinate research into the brewing process, raw materials and environmental issues.

Brewer's gold

A hop variety developed in the United Kingdom in the early twentieth century. It is a dual-purpose variety that contains medium concentrations of α -acids (5.5–8.5%, 38% cohumulone) and 1.5% hop oil. It is similar to bullion and is a parent of many modern high alpha varieties, for example, Nugget.

Brewers of Europe

The Brewers of Europe is an umbrella organisation whose stated aim is to represent the interest of European brewing companies. It was founded in 1958 and is based in Brussels [<http://www.brewersofeurope.org> (last accessed 4 February 2013)]. It seeks to promote the interests of the brewing industry by providing advice and lobbying within the legislature of the European Union on subjects such as responsible beer consumption, beer consumption and health, competition matters, beer and excise liability, beer quality and product safety and environmental matters. The organisation represents European brewing interests within the **Worldwide Brewing Alliance**. EBC is a technical arm of the Brewers of Europe.

The national brewing associations of some 23 countries are members of the Brewers of Europe. These are

Verband der Brauereien Österreichs (Austria)

Belgian Brewers (Belgium)

Cyprus Brewers Association (Cyprus)

Czech Beer and Malt Association (Czech Republic)

Bryggeriforeningen (Denmark)

Panimolitto (Finland)

Brasseurs de France (France)
Deutcher Brauer-Bund e.V. (Germany)
Greek Brewers' Association (Greece)
Association of Hungarian Brewers (Hungary)
The Irish Brewers Association (Eire)
Associazione degli Industriali della Birra e del malto (Italy)
Lithuanian Breweries Association (Lithuania)
Fédération des Brasseurs Luxembourgeois (Luxembourg)
The Malta Federation of Industry (Malta)
Centraal Brouwerij Kantoor – CBK (the Netherlands)
Norwegian Brewers (Norway)*
The Union of Brewing Industry Employers in Poland – Polish Brewers (Poland)
APCV – Associação Portuguesa dos Produtores de Cerveja (Portugal)
Brewers of Romania (Romania)
Cerveceros de España (Spain)
Sveriges Bryggerier AB (Sweden)
Swiss Breweries Federation (Switzerland)*
Beer and Malt Producers Association of Turkey (Turkey)*
British Beer and Pub Association (BBPA) (United Kingdom)

Brewers' pound

A now largely archaic system of UK origin used for measuring extract concentration applied to worts or the beers made from them. A brewers' pound is defined as the weight of a barrel of beer minus the weight of a barrel of water (measured at 60°F, 15.5°C). The term 'pounds gravity' is a synonym. In historical parlance a beer made from a 10-lb wort would be described as a '10-lb beer'.

See **extract**.

Brewer's yeast

The term used to describe those species of yeast that are used in brewing.

See **yeast**.

Brewery conditioning

The vast majority of beers may be described as being brewery conditioned. It refers to those beers that are matured within the brewery and therefore are ready for immediate consumption when despatched from the brewery to the point of sale. Thus, the various processes associated with beer maturation in which green beer is treated such that it acquires mature flavour, specified levels of carbonation and an appropriate colloidal stability are all performed within the confines of the brewery. Collectively these processes are termed brewery conditioning. The beers are distinct from those beers as **cask-conditioned beer** and **bottle-conditioned beer** in which a secondary fermentation which results in the formation of CO₂ and some additional ethanol, as well as clarification, occurs in the container from which the beer is dispensed and after despatch from the brewery.

See **beer maturation**.

* These countries are associate members of the Brewers of Europe by virtue of not being members of the European Union.

Brewery Convention of Japan

An organisation founded in 1982 by the **Brewers Association of Japan** [<http://www.brewers.or.jp>] (last accessed 5 February 2013)]. The aims of the organisation are to standardise brewing analytical methods (published as the Methods of Analysis of the Brewers' Association of Japan in 1990) and to formalise links with other international groups such as the ASBC and EBC. The organizing committee runs an annual meeting in which oral and poster presentations already delivered at ASBC and EBC meetings are given, in English.

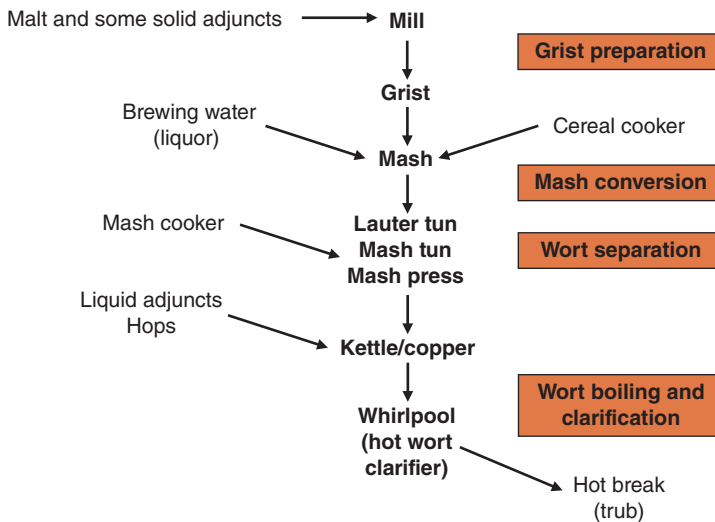
Brewess

A historic term used in the United Kingdom for a female brewer. See **ale-wife**.

Brewhouse

The brewhouse is the name given to the part of the brewery that is responsible for the production of wort. The sub-processes that occur are grist preparation, mashing in, mash conversion, spent grain separation, wort boiling and hot wort clarification. These process steps and the equipment associated with them are described elsewhere under their respective headings. Although distinct sub-processes can be defined, as indicated, many different pieces of brewery plant can be used to undertake them. These variations are derived from different brewing traditions and may be associated with particular beer styles. A particular plant is required in order to process certain types of raw materials. In addition, some newer plant has been introduced, which has perceived benefits in terms of process efficiency or process costs.

The division between the brewhouse and the areas where other parts of the brewing process are performed is somewhat arbitrary. Thus, the brewhouse would usually be considered to end at the point where hot wort is separated from hot break (or trub) typically using a whirlpool (hot wort separator). The subsequent cooling and oxygenation of wort is usually considered as part of fermentation.



Brewing processes that are performed within the brewhouse together with terms used for some of the associated brewery plants. Note that this is a generic representation and no single brewery would generally possess all of the equipment noted in the figure. Similarly, many different variations to the general process flow diagram depicted are possible.

Brewing yeast

Specific strains of yeast, the growth and metabolic activities of which result in the conversion of wort into beer.

See **yeast**.

Brew length

The term brew length is used to describe the volume of wort that can be made in a single batch by the brewhouse. The actual size may vary greatly depending upon the capacity of the brewery. In a typical craft brewers set-up a size of 1–10 UK barrels (1.6–16 hL) would be usual. In commercial breweries the batch size might range between 50 and 1000 bbl (80–1600 hL).

The choice of brew length is obviously made based upon the requirements of the brewery. In this regard it makes sense that the productivity of the brewhouse matches the requirements of the rest of the brewery. Commonly this ideal is not adhered to. In many modern commercial breweries the fermenters are too big to be filled by a single batch of wort. In this situation several batches of wort must be made to fill a single fermenter and this requires more time than would be the case where brewhouse and fermenters are in balance. This can be a source of unexpected variability in terms of both fermentation performance and beer analysis. In order to minimise these effects much effort has been directed towards reducing the time required to produce a single batch of wort and, in consequence, minimising the effects of this mismatch. For example, moves from lauter tuns to the modern generation of mash filters are commonly made since the cycle times for the latter are generally shorter than the former. For example, a cycle time of 2–3 hours is possible with a modern mash filter as compared to approximately 3–4 hours for a lauter tun.

The brew length may not necessarily correlate with batch volumes of finished beer. Many modern commercial breweries use the practice of high-gravity brewing in which very concentrated worts are produced by the brewhouse which are diluted with water post-fermentation to a required sales strength. In this regard, therefore, the brew length should be characterised in terms of volume and concentration. Thus, the productivity of the brewhouse would be measured in terms of the total extract generated per batch of wort and the time taken to produce it.

In another sense, in archaic brewing practice it was usual to separate and treat differently the first and stronger runnings of wort from the second and weaker runnings. These worts were fermented separately to produce two distinct types of beers. In some cases after removal of the first strong worts the grains were re-mashed to produce a second weaker wort. This practice was referred to as **parti-gyling**.

Brewpub

Combined microbrewery and licensed premises. Typically a small brewery, usually with a brew length of around 5–8 hL and making a range of traditional beers that are all sold on the premises where they are made. The simplicity of the supply chain is a clear advantage. Commonly the brewery may be made prominently visible to the consumer as a means of emphasizing the immediacy between production and sale. The development of the brewpub is part of the international wave of interest in craft brewing seen by many as a backlash against the dominance of the market by a few large brewers making products which many consumers

view as being made with an eye focussed on cost as opposed to quality. Many brewpubs are new start-ups and may simply be a stage in the development of a more conventional brewery business with a distribution chain to other premises. Conversely, chains of brewpubs have been launched by major brewers, perhaps viewed by some, as a cynical attempt to capitalise on the underlying sentiments of the trend. These may range from traditional craft brewery operations through to facilities where a centrally produced wort concentrate is provided for dilution, fermentation and finishing in the brewpub.

Brewster

A historic term used in the United Kingdom for a female brewer.

See **ale-wife**.

Bridal-ales

The term used in medieval England for the practice of a bride selling beer to her guests at her own wedding. The aim was to pay for the celebrations and to raise funds for the married couple. It is the origin of the term 'bridal'.

Bright beer

Bright beer is beer that has been processed such that it has a desired degree of clarity and composition. Thus, in this sense brightness is used to describe brilliance or clarity. In the case of beers that are conditioned in the brewery (see **brewery conditioning**), such as those that are packaged into kegs, cans and most bottled beers, the final stage in the brewing process is **filtration**, where suspended solids are removed to give a beer which meets predetermined specifications regarding haze content (see **beer hazes**). This beer, post-filtration, is termed bright beer and is stored in tanks designed for this use called **bright beer tanks** (BBTs).

In addition to clarity, brewery-conditioned bright beer has a defined composition and is usually required to meet a number of predetermined specifications. Typically these would include alcohol content, specific gravity (or related unit), carbonation, colour and dissolved oxygen content. Usually the beer is stored chilled (*ca.* 4°C). It may be required to meet various flavour quality specifications and those associated with head performance. Usually the beer will not be sterile since microbiological stability will be dealt with in subsequent processing steps in the form of pasteurisation or sterile filtration. Nevertheless, the microbiological status of beer in BBTs may be monitored in order to monitor the general hygiene of the process. The specifications of bright beer may be the same as those for the packaged beer. In some cases the beer may be diluted before packaging and other additions for adjustment of flavour may be made; however, caution must be exercised in order to ensure that the clarity is not compromised.

In the case of those beers that are not finished in the brewery, such as cask or bottle-conditioned ales, the desired degree of clarity is achieved in the final package. These beers are much less 'bright' than their brewery-conditioned counterparts; however, similar terms are used. Clarification of these beers is via simple sedimentation, either natural or with the assistance of **fining agents**; and when this has occurred the beer would be described as having 'dropped bright'.

See **filtration**.

Bright beer tank

Bright beer tanks (BBTs) are those in which beer is held after filtration and immediately before packaging. The name alludes to the fact that the beer has been treated to remove a desired proportion of suspended particles to give a clear 'bright' product.

BBTs require a capacity appropriate to the scale of the brewing operation. Typically in a large modern brewery they take the form of stainless steel cylindroconical vessels with external cooling jackets similar to fermentation or conditioning tanks; however, many other configurations are used. Essential features are good hygienic design and ability to hold beer at a cold temperature under a controlled atmosphere.

For the majority of beers it is essential that the beer dissolved oxygen concentration is as low as can be achieved. In addition, a specified level of carbonation and possibly nitrogenation must be achieved. In order to meet these specifications BBTs should be designed to permit a degree of top pressurization, and provision may be made for adjustment of gas levels, as required. A hygienic means of removing samples for analysis is required, and many users might require a means of making and dispersing liquid additions.

See also **filtration**.

BRI mashing bath

Laboratory-scale apparatus that allows 25×500 mL batches of grist to be mashed in a controlled manner. The apparatus is used mainly to assess the performance of malt.

Brink rate

US usage, a synonym for pitching rate. Literally a measure of the viable yeast count suspended in wort at the onset of fermentation. As with other measures of pitching rate, other indirect measures of yeast concentration, such as weight of yeast added per unit volume of wort, may be used.

See **pitching rate**.

Brink yeast

See **pitching yeast**.

British Beer and Pub Association (BBPA)

A UK-based organisation [<http://www.beerandpub.com> (last accessed 5 February 2013)] devoted to serving the needs of the beer industry. Originally the Brewers' Society, which was itself formed in 1904 via the amalgamation of the Country Brewers' Society, the London Brewers' Society and the Burton Brewers' Society. Its aim was to promote the interests of the brewing trade. In 1994 it became the Brewers' and Licensed Retailers' Association (BLRA) and altered its focus to represent the pub and beer retailing trades. In 2004 it was renamed as the BBPA. It is an excellent source of statistics regarding the brewing and beer industry.

Brix meter

Brix meters are digital refractometers used to calculate the dissolved solids concentrations of solutions. Typically they are hand-held devices that are used to determine the concentration of sugar solutions. The Brix concentration is inferred based on the measurement of the refractive index of the sample.

BRi yeast vitality apparatus

A device developed by the Brewing Research Institute of the United Kingdom (now the Brewing Division of Campden BRi) which comprises an attemperated chamber containing a dissolved oxygen probe linked to a recording device. A suspension of yeast of known concentration is placed in the chamber and oxygen is introduced. The rate at which the yeast consumes the oxygen (specific rate of oxygen uptake) is computed and this can be related to predictive fermentation performance.

See **yeast vitality**.

Bromate

The sodium and potassium salts of bromine have been used as additives to malt steep liquor. Bromate ions are able to penetrate the whole surface of grains but especially at the embryo end. Once inside the grain they are efficient inhibitors of a number of enzymes, especially those that catalyse proteolysis. The bromate ions are reduced to bromide. Bromate does not persist in beer.

The treatment has multiple benefits. Bromate reduces heat output via inhibition of respiration. This reduces the need for refrigeration (where available) and lessens the tendency to bolt due to overheating in more traditional maltings not provided with refrigeration. Rootlets in treated grains are smaller and take on a twisted thickened appearance. The reduction in size improves overall yields and the smaller bulk improves the capacity of germination vessels. Predictably treatment with bromate reduces the concentration of soluble nitrogen in malts.

Bromate may be applied at any stage in the steeping process but is usually added at the end of steeping, often in conjunction with gibberellic acid. The ratio of these two additives can be varied in order to manipulate the hot water extract and total soluble nitrogen ratio.

An effect of bromine treatment is to reduce the amount of proline that is released into wort during the mashing phase of brewing. Since proline is not assimilated by yeast under the conditions of brewery fermentation the effect is to reduce the nitrogen content of beers. Such beers should have an enhanced colloidal stability. Bromate salts reduce levels of S-methylmethionine, a precursor of the important beer flavour compound dimethyl sulphide.

Bromelain

Bromelain is a generic term given to preparations of proteolytic enzymes derived from the pineapple plant (*Ananas* sp.) or other members of the family Bromeliaceae. The enzyme is used as a meat tenderiser and has medical applications, particularly as an anti-inflammatory

drug. In brewing it is used, albeit rarely, as a method of improving beer colloidal stability via reducing the concentration of protein available for interactions with polyphenols in beer hazes.

It is relatively inexpensive, hence its use; however, it is a potentially risky strategy in that the enzymes are non-specific and may also degrade potentially desirable foam-enhancing proteins. As with any enzyme added to beer there is a further potential risk in that activity may persist after packaging in unpasteurised beers.

Bromopyrogallol red

Bromopyrogallol Red (5'5"-dibromopyrogallolsulphonephthalein) is a dye that reacts with proteins to form a coloured complex. It has been shown that, in worts or beers, it binds preferentially to the protein fraction that is involved in interactions with polyphenols in the formation of beer hazes.

See **colloidal stability**.

Brown ale

Beer style originating in the United Kingdom which takes its name from the brown malt used in its manufacture. Bitterness and hop aroma character is usually quite low and modern versions have sweet or nutty tastes. The beers are similar to **mild ales**. Early versions dating to the eighteenth century had original gravities ranging from 1060 to 1090. Brewing of these was largely discontinued in favour of beers based on pale malts or dark porters. A few brands have persisted or have been revived, albeit usually at much lower strengths, typically 3–4% abv. Several modern craft brewers in various countries produce brown ales.

Brown Betty

Drink made from a mixture of spices, sugar, brandy and ale, which may be served in the form of a hot punch.

Brown malt

Brown malt is a coloured malt produced in a roasting drum. It is treated at a relatively low temperature such that it is roasted to give a colour of approximately 120–130 EBC units. This colour is similar to that of amber malt; however, brown malt has a drier and less sweet flavour.

Brown malts are used in UK-style brown ales and some sweet stouts. Originally the heating step has been carried out over wooden fires. As would be expected this has imparted smoky characters to the malt. This practice has been discontinued and the adoption of the roasting drum approach to manufacture has resulted in the sometimes encountered name of **drum brown malt** for this product.

Bryggeriforeningen

This is the name of the Danish Brewers' Association [<http://www.bryggeriforeningen.dk> (last accessed 5 February 2013)]. It is based in Copenhagen, founded in 1899 and represents the interests of all the major producers in Denmark of beers and other products including cider,

bottled water and soft drinks. It is a part owner of the Scandinavian Brewing School, an establishment which is a major contributor to the education and training of Danish and other brewers.

With the Danish Distilleries Association and the Wine and Spirits Organisation in (VSOD) Denmark it was responsible for the formation of Fereningen Gode Alkheldninger [GODA; <http://www.goda.dk> (last accessed 5 February 2013)], the major Danish initiative seeking to promote the benefits of responsible alcohol consumption.

Bud scar

The name given to the roughly circular structures which are features of the cell wall of yeast cells that proliferate via budding. They mark the point on the wall where buds were formed and which remain after the emerging daughter cell has become detached from its mother. In this regard the number of visible bud scars correlates with the age of the cell. The bud scar is rich in the carbohydrate chitin, and therefore fluorescent stains such as **calcofluor** can be used to determine the ages of individual cells within yeast populations. When a yeast cell forms a bud the point of separation on the newly emerged and virgin daughter cell which corresponds with the parental bud scar is termed the birth scar.

See **yeast**.

Buffer tank

A buffer tank is one that is located in a process stream for the temporary holding of process fluids. Its use, as the name suggests, is to serve as a means of balancing flows and preventing sudden changes in pressure. Thus, buffer tanks are used where the rate of forward flows of fluids into and out of individual pieces of process plant might be different.

An example would be where a stream of beer is being delivered from a conditioning vessel to a filter and thence to a BBT. In this arrangement it would be usual to have buffer tanks immediately before and after the filter. This allows the filter, which is sensitive to changes in inlet pressure and flow rate, to be operated independently to the rates of addition of fresh beer from the storage tank and the removal of bright beer issuing from the filter for delivery to the BBT.

Bühler-Miag disc mill

A Bühler-Miag disc mill is a mill used for producing grists at laboratory scale. It is the mill recommended by both the EBC and the Institute of Brewing and Distilling as the basis of those methods that require the production of grists under defined conditions [<http://buhlergroup.com> (last accessed 5 February 2013)].

The device is electrically driven and the grinding action is derived from a single rotating disc acting against a second fixed disc. Grains are fed into the chamber formed by the two discs where and after grinding the grist is forced to the periphery from where it is collected. The fineness of the grind is set by adjusting the gaps between the two discs. Recommended methods of analysis stipulate particular gap settings for the production of extracts based on fine or coarse ground grists.

Laboratory mills are calibrated using 'standard check malts', for example, the ASBC standard malt 4.

Buket

Buket is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with **Bobek** and **Blisk** it is one of the 'B' series of Slovenian hops which were released in 1980 and were bred with the intention of possessing high α -acid contents, as in the **Super Styrian hops**, but with good aroma properties. It is derived from a cross between a **Northern Brewer** and a Slovenian male.

It contains 8.7–13.5% total α -acids of which 24% is cohumulone. Total β -acids and oils are 4–6% and 1.2–2.9%, respectively. Storage properties are fair.

Bullion

Bullion is a hop variety that was bred at Wye College in the United Kingdom. It was one of the earliest high α -acid cultivars (6–9%) and was bred from a parental wild male Canadian hop from Manitoba and a UK-female variety. Aside from its good bittering potential the hop has a blackcurrant character said to be characteristic of wild American hops. This aroma character made the variety unpopular in the United Kingdom. Other varieties developed at the same time were **Northern Brewer** and **Brewer's Gold**. These hops once accounted for approximately 30% of the total world crop production. They have been superseded by newer varieties in some part, at least, based on better disease resistance; however, these varieties are the forebears of most of the current high α -acid cultivars.

Buloke

Buloke is a variety of malting barley that appears on the Australian list of recommended varieties as being most suitable for export as malt into the markets of Southeast Asia, or as barley grain into China.

Bundessortenamt

See *Braugersten-Gemeinschaft e.V.*

Burn's test

Method used to assess **yeast flocculence** developed in the 1930s and a forebear of many current procedures (see **Helm's test**). In Burn's test a fixed quantity of yeast (5 g pressed yeast cake) is suspended in acetate buffer, and after mixing, the proportion which settled after 10 minutes is assessed. In later tests the protocol has been modified by the introduction of a preliminary washing step with or without EDTA to remove metal ions and substituting water with a buffer of defined pH and containing Ca^{2+} ion to promote flocculation.

Burnt sugars

See **caramels**.

Burr

Name given to the young inflorescences of female hop plants.

See **hop plants**.

Burtonisation

Treatment of softened water with a cocktail of minerals in order to adjust the ionic composition so that it simulates the natural hard water which can be recovered from the aquifers underlying the UK town of Burton on Trent and suitable for producing UK-style pale ales.

See **water**.

Burton Pale Ale

Burton pale ale is a name given to a style of beer of the type made from pale malts by top fermentation using ale yeast strains but which are usually less highly bittered than India pale ales. It is, as the name indicates, a type of pale ale which historically was associated with Burton on Trent and was therefore made with the hard water found in the aquifers of that UK town. The term Burton is commonly applied to similar beers brewed in other parts of the world in which the water has been treated to resemble the natural Burton on Trent variety.

Burton snatch

A somewhat whimsical term that has perhaps suffered from the tendency over time of some words to acquire additional meanings. In the brewing sense it refers to the sulphury nose characteristic of many Burton ales formed as a result of the high sulphate content of the natural brewing waters associated with that town.

Burton union set

The name given to an entire Burton Union fermentation system.

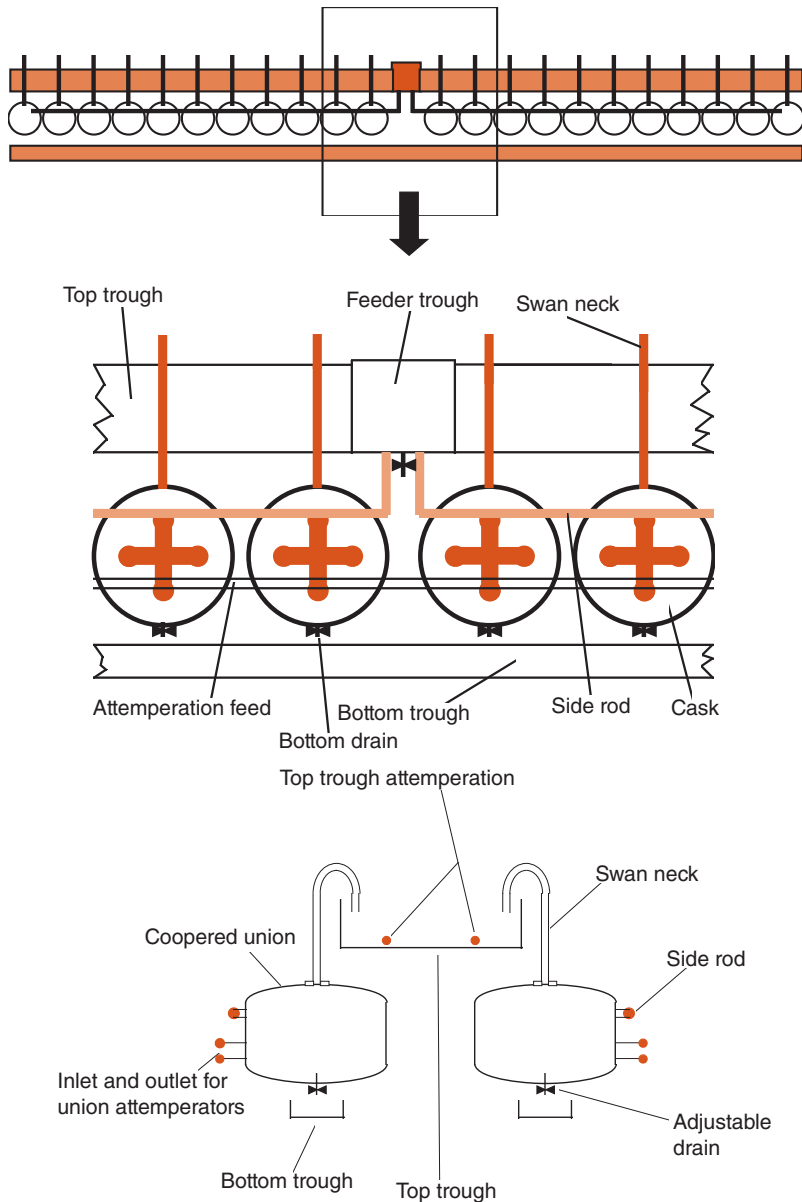
See **Burton Union system**.

Burton union system

The Burton Union system describes plants used to conduct primary fermentation. It was devised in central United Kingdom and derives its name from Burton on Trent, the erstwhile brewing capital of England. It is a highly complex system developed for use with non-flocculent top-cropping ales. Although now largely relegated to historical curiosity it was responsible for the production of much of the pale ale for which this region is justly famous. The Burton on Trent brewer, Marston's, continues to use the system for a proportion of its beers.

In some ways the system is a development of the more common ale **dropping system**. Fermentation is started in a conventional square fermenter. After 24–36 hours when the fermentation has reached a vigorous state of activity, it is transferred from square to Burton Union system. The latter consists of a number of pairs of coopered casks, each with a capacity of approximately 150 imperial gallons (*ca.* 7 hL) into which the fermenting wort is introduced. These casks are termed 'unions' and each is fitted with an internal attenuator linked to a central coolant fluid feed and return point. Each pair of union casks, arranged in a horizontal orientation, is suspended below a central stainless steel trough, termed the **top trough**. Each union and the top trough are connected by a series of vertically arranged stainless steel tubes, termed swan necks. These protrude from the central opening of each union and empty into the top trough via their curved tops (see the accompanying illustrations).

B



Diagrams showing the key features of a Burton Union system

As the fermentation proceeds in each union cask a mixture of yeast and beer is forced up the swan necks and is transferred into the top trough. This is cooled with an internal attemperation system that causes the yeast to settle at the base of the trough. This is slightly inclined, which allows the barm ale to flow back into a feeder trough, and from there it is returned into the casks by a series of tubes termed feeder rods. When fermentation is judged complete the beer is removed from each union cask via drains which exit into the **bottom trough** from whence it is transferred into a racking tank.

The capacity of each Burton Union system is controlled by the number of pairs of casks. Each complete unit is referred to as a **Burton Union set**. In large sets up to 60 might be used, giving a total capacity per set of *ca.* 350 hL. At their peak major Burton brewers such as Bass had many hundreds of these large union sets in constant use. The system has many drawbacks, notably, complexity, difficulty of cleaning, high degree of manual operation, requirement for skilled coopers and high beer losses, to name a few. Nevertheless it is capable of producing very high-quality beers.

Burukutu

Name given to a native African beer of Nigerian origin made from sorghum.

See **native African beers**.

Busaa

Name of a native African beer associated with Kenya, Tanzania and Uganda. It is usually made from a mixture of extracts of maize and malted finger millet (*Elusine coracana*), although in some countries malted sorghum is used. A two-stage process is used in which the maize grits are made into a dough and are allowed to stand for a souring process via the action of lactic acid bacteria. A portion of dough is then mixed with water and ground malted finger millet is added after which a spontaneous alcoholic fermentation takes place. The product is opaque and sour (0.5–1.0% lactic acid) and contains 2–4% ethanol by volume. The product is unstable and must be consumed soon after the initial mixture is made. In domestic operations fatalities have been reported as a result of aflatoxin poisoning from infected grains. Commercial operations have been developed in which the product is bottled and pasteurised.

Butt

A butt is measure of capacity or the name of the container used for the storage of a particular volume of beer, or other liquids. The precise volume depends upon the country of origin and the nature of the liquid contained within. In the United Kingdom a butt of beer is now generally equivalent to 108 imperial gallons (491.52 L) or 129.70 US gallons. Different volumes are used where the liquid is wine. The name derives from the medieval French, *botte*, meaning *pipe*. The term was descriptive of the elongated coopered casks traditionally used to store large volumes of wine.

Butterfly valve

Butterfly valves are relatively inexpensive types in which fluid flow is regulated by a disc, usually constructed from stainless steel, which is located within a pipe and attached to a vertical shaft. Rotation of the shaft allows the disc to be rotated such that it is parallel to the fluid flow (open) or at 90° to the fluid flow (closed). When closed the disc is pressed against a rubber o-ring, which provides an excellent seal. The valves are less useful for regulating flow in a controlled manner since throttling does not occur to any appreciable degree until the valve is almost closed. Better control can be achieved if the vertical shaft is slightly offset from the centre point of the disc.

Butterfly valves have excellent hygienic properties and are used in many situations in brewing where pressures are relatively low, for example, in pipeline feeding tanks used for beer and for associated CIP and utility services.

Caffeic acid

A simple phenolic compound, one of a series of substituted cinnamic acid derivatives, which are found in worts. Concentrations in an unboiled lager wort are reported to be of the order of 0.1 mg/L.

See **polyphenols**, **tannic acid**.

Cagniard-Latour, Charles

French noble and scientist (1777–1859) who, independent of other contemporary investigators, notably the Germans Theodor Schwann and Friedrich Trautgott Kützing, was responsible for elucidating the role of yeast in fermentation.

Cake density

See **specific bed volume**.

Calandria

Calandria is the term used for the tube and shell heat exchange unit used in wort kettles fitted with external heaters.

See **wort kettle**.

Calcium alginate

The salt of alginic acid, a gel used in brewing applications for entrapping yeast cells, for use in the form of beads in immobilised yeast reactors. The beads are made by mixing solutions of calcium chloride and sodium alginate. Alginic acid is obtained from the cell walls of brown algae.

Calcofluor

Calcofluor (4-methyl,1-7-diethylaminocoumarin) is a fluorimetric dye that absorbs light in the yellow region of the visible spectrum and emits light in the near ultraviolet. Calcofluor binds to β -glucan. These properties allow it to be used in industry as a whitening agent for fabrics and paper. The same properties are exploited in brewing applications. The dye is used

as the basis of the methods used for the quantification of β -glucans in barley, malt, wort and beer (see **β -glucans** for more details). In addition, the dye also binds to chitin in the cell walls of yeast and other fungi. Since in yeast cells the chitin is concentrated within the **bud scars**, formed when daughter cells are released from mothers, treatment of yeast cells with calcofluor and subsequent examination under a fluorescence microscope allow visualisation of bud scars. The number of bud scars present provides an indication of the age of individual yeast cells.

Calcofluor Carlsberg sanded slab test

A test that is used to assess the extent and homogeneity of modification of malt grains.

See **sanded slab tests**.

Cali

Cali is the name of a hop cultivar grown historically in New Zealand. It was the US variety, Late Cluster, imported into New Zealand in 1897 from Northern California (from which the name derives). This cultivar largely replaced the earlier UK imports, Fuggle and English Golding, which did not flourish in New Zealand. Cali was susceptible to black root rot (causative agent, *Phytophthora citricola*). Losses due to this disease provided the impetus for the development of a New Zealand government-sponsored hop breeding programme. Crosses between Cali and males derived from black root rot-resistant Fuggle resulted in the mid-twentieth century in the release of the varieties **First Choice**, **Calicross** (1960) and **Smooth-cone** (1961). These resistant varieties, which contained high α -acid contents (8–10%), became popular in New Zealand in which position they remained until the release of triploid types with more desirable properties.

Calicross

A New Zealand-bred disease-resistant hop variety released in 1960.

See **Cali**.

California common beer

California common beers are those that are the modern variant of the earlier **steam beer**. The beers are characterised by being produced with lager yeast strains at warm fermentation temperatures.

See **steam beer**.

Caminant

A variety of proanthocyanidin-free barley.

Campden brewing research international (BRI)

UK-based brewing research organisation [<http://www.camdenbri.co.uk> (last accessed 6 February 2013)] originally founded in 1948 by the Brewers' Society as the British International Research Foundation (BIRF) under the leadership of Sir Ian Heilbron. It is a membership-based organisation that performs research work and training on behalf of the brewing industry. It is a renowned centre for work on food safety of relevance to brewing and its associated

legislation. It has passed through several incarnations, becoming the Brewing research Foundation (BRF) then BRi. In 2008, it merged with the Campden and Chorleywood Food Research Association (CCFRA). The latter is the largest organisation in the world devoted solely to food research.

C

CAMRA

CAMRA is an acronym that stands for the Campaign for Real Ale. It is a consumer group and was founded in the United Kingdom in 1971 with the aim of promoting traditional cask ales. The impetus to found the organisation was provided by the then perception that the major UK brewers were promoting brewery-conditioned, chilled, filtered and pasteurised keg ales at the expense of the cask-conditioned 'real' alternatives.

The organisation has proven to be a powerful pressure group and now has something like 100,000 members. The organisation promotes the consumption of traditional ales and other alcoholic beverages with a similar heritage such as some ciders and perries. It does this via the organisation of beer festivals and publications such as *The Good Beer Guide* and *What's Brewing*. In addition, it provides recognition for trade outlets that CAMRA identifies as sharing the ideals of the founders. It lobbies on behalf of public houses and issues such as liability to excise duty. The growth of CAMRA since its inception in the United Kingdom has mirrored the rise in the numbers of craft brewers.

Canadian Malting Barley Technical Centre

A centre for research into barley that publishes lists of recommended varieties of malting barley.

As of 2011 the list of recommended varieties was

Two-row: AC Metcalfe, CDC Copeland, Newdale, CDC Kendall, CDC Polarstar

Six-row: Legacy, Tradition, Stellar-ND

Candle filter

Candle filters are **powder filters** that are used for primary filtration of beer. They comprise a vertical cylindrical stainless steel body that has a conical base. A rigid plate mounted horizontally and located at the top of the interior of the tank acts as a support from which a number of vertically mounted filter elements are suspended. These elements, which are also fabricated from stainless steel, are the candles from which the filter takes its name.

The candles are roughly 30cm in diameter, 1000–2000mm in length and are mounted approximately 80 cm apart. They are hollow and cylindrical in section and contain perforations through which beer flows. They serve as supports on which the filter powder accumulates. In order to provide a large surface area the candles take the form of dimpled washers clamped face to face, wound wire wedges or meshes. Designs are proprietary to individual companies, but in each case, the spacing and arrangement of these elements is carefully arranged to ensure an even flow of beer.

Before filtration commences the filter housing is flushed with de-aerated water to remove oxygen. Powder pre-coats are applied to the outside of each candle by pumping in a slurry of filter powder via an inlet located in the conical part of the base of the filter. After pre-

coating is completed the rough beer plus body feed powder is pumped into the filter. Powder accumulates on the candles and clarified beer passes into the central cavity of each candle and from there out of the filter via a top-mounted outlet. As the powder accumulates on the surfaces of the candles the effect is to increase the total surface area available for filtration. Eventually the space between the candles becomes filled or the trans-filter pressure increases to the maximum permitted value. Either of these conditions signals the end of the filtration run.

Beer still entrained in the filter is forced out by flushing with de-aerated water. Since this dilutes the beer this last portion may be retained in a separate tank and blended back into a subsequent batch of beer. The filter is emptied by reversing the fluid flow which lifts the powder cake of the candles and forces it back out of a bottom-mounted drain. After emptying the filter is cleaned automatically.

Productivities of candle filters are of the order of 3–6 hL/m²/h. This is slightly greater than a large plate and frame-type powder filter but less than a horizontal leaf type. Generally, if it is necessary to switch beer quality within a run, it is necessary to first flush with de-aerated water in order to prevent back-mixing; however, with careful operation some brewers manage to avoid this.

Canning

Process of packaging beer into cans, either aluminium or steel, to meet all legal and quality specifications. The majority of operations are similar to those described for **bottling** (see entry for details). Compared with bottling lines maximum filling speeds are approximately double and may be more than 2000 cans per minute. Modern beer cans comprise two pieces: the body base and walls and a separate top. Beer is filled into the empty can and then the end is applied and secured by the formation of a mechanical seam. The joint is made by the presence of a sealing compound, made from synthetic rubber or latex, which fills the space between the metal surfaces of the body and lid. The interior of the cans is coated in an inert lacquer to prevent metallic taints in beer.

The properties of cans mean that they must be handled differently from bottles. They are light and high-speed conveyors must be designed and operated to prevent their falling over. Unlike bottles they lack the mechanical strength to be pre-evacuated and the comparatively wide neck provides a large surface area for air ingress. Empty cans are delivered to a multi-head rotary filling machine where the filling head is lowered onto the top of the can and makes a gas-tight seal. The settings are such that the seal is maintained with the application of little pressure to avoid damage by crushing. The fill volume can be controlled volumetrically or via filling tubes. In all cases the can is first flushed and pressurised with CO₂ and then filled in a way that prevents fobbing. After filling the cans are released from the head and the gas space may be sprayed with CO₂ to displace any air. The lid is placed onto the top of the filled can as quickly as possible and then pushed upwards onto a seaming head. The latter locks the can in place and forms a gas-tight seal. Air ingress is prevented by blowing a stream of CO₂ over the surface as the lid is slid into place. An essential quality check is to ensure that the seams are formed correctly. Since optical devices cannot be used fill heights are checked with sensors that subject the filled cans to gamma irradiation. Cans are usually tunnel pasteurised to ensure microbial integrity.

Canterbury Goldings

A variety of UK aroma hop, probably the original forebear of all of the Goldings hop varieties. Also known as **Old Golding**.

See **Goldings**.

C

Caramel malt

Caramel malts are speciality types during the preparation of which the grains are kilned whilst still wet. The resultant stewing of the grains causes the endosperm to mash and liquefy and to be transformed into a syrupy liquid. When the grains are cooled the syrup crystallises to form a hard sugary mass. For this reason these products are also known as **crystal malts**. The precise conditions of time and temperature used in the manufacture control the nature of the final product. Caramel malts are prepared from green malt, the heating process being applied immediately after germination.

Caramel malts are produced using roasting drums. In the early stages of the heating process water may be added to ensure that the grains are stewed. In the first part of the process the temperature is held at approximately 65–70°C. During this saccharification phase the endosperm liquefies to produce a clear sweet syrup. After this phase, when the water has been driven off, the heating is continued and may be increased until the desired flavour and aroma have developed. In the case of Carapils a relatively low temperature of 55–60°C is used. For more highly coloured varieties the temperature may be allowed to increase up to 160°C. The more prolonged the treatment and the higher the temperature that is used the greater the extent of melanoidin formation. The finished grains take on a smooth swollen appearance that when sectioned have a hard glassy endosperm. In general, the darker the colour of the malt the lower the extract yield and the lower the pH of resultant worts.

Caramel malts produce characteristic flavours and colours in beers made from them. The heat treatment induces many chemical changes. One of the products is maltol (2-methyl 3-hydroxypyrrone). This had a sweet caramel flavour but, in addition, is a powerful reductone. The latter property is characteristic of caramel malts. In addition, some caramel malts provide enhanced foaming properties.

Different types of caramel malts are commonly given a numerical suffix followed by the letter L. This refers to the colour in Lovibond units that the malt imparts to beers. Those with low numbers (10–60L) are pale in colour and impart a caramel flavour. Both of these are enhanced with an increase in number. Caramel 60L, also known as medium crystal, is most commonly used for UK-style pale ales, porters and stouts. Caramel 80L and above are increasingly coloured and have more intense caramel flavours. These malts impart burnt sugary flavours.

Caramel malts may be subdivided on the basis of colour as follows:

Crystal 10L, light crystal

Crystal 20L, crystal malt

Crystal 40L, pale crystal

Crystal 60L and 80L, medium crystal

Crystal 120L, dark crystal

Caramels

Caramels are preparations made by heating sugar syrups, which are used as brewing adjuncts. The heating process causes the development of dark-coloured products and sharp, dry and acidic flavours, and thus these preparations are used for adjusting colour and to impart flavour in certain beers. Caramels are used as copper (kettle) adjuncts or they may be added to finished beers. In the latter case they may be added pre- or post-filtration. In this application in some beers caramels that have been produced using a comparatively mild heat treatment (products sometimes termed burnt sugars) may be used as primings.

Several classes of caramels are manufactured. Those used in brewing are typically class III types (also known as electropositive ammonia caramels). These are used in brewing for the purpose of adjusting flavour and colour. They are prepared by heating relatively pure sugar syrups (usually glucose) with ammonia. Temperature programmes are complex and are carefully controlled in order to give products with desirable characteristics. Stock preparations are blended, together with water, to give standardised ranges of caramels with predetermined colours and flavours. In addition, the caramelised products can be fractionated using ultrafiltration, allowing the manufacture of products aimed at either flavour or colour adjustment.

Typically colours are within the range 32,000–500,000 EBC units. They contain 65–75% solids and 2.5–5% nitrogen. They have isoelectric points in the range of pH 6.0–pH 6.5 and they carry a positive charge, hence the name. The chemical changes that occur during the heating step are complex and involve caramelisation (dehydration and polymerisation of sugar molecules) and the formation of coloured Maillard compounds via the reactions of sugar molecules with ammonia.

Caramels are associated with some health hazards owing to the presence of 4-methyl imidazole and 2-acetyl-4-tetrahydroxybutyl imidazole, which have been shown to be toxic to small mammals such as rabbits and mice. The concentrations of these compounds in caramels destined for use in brewing are controlled and are guaranteed to be at safe levels when used in beers at normal dosage rates.

Carapils malt®

Carapils (Cara Pils) is a registered trademark of the Briess Malt and Ingredients Company (a subsidiary of Briess Industries, USA). It is a **caramel malt** produced from two-rowed barley that has been treated to make it fully crystalline but without allowing the malt to develop colour (approximately 1.5L) or aroma. It contains no enzyme activity. The production process results in a malt that when used in worts produces low fermentability owing to the high dextrin content. For this reason it is also referred to as **dextrin malt**. It is used in making worts at a concentration of 1–5% of the grist. It is used as an enhancer of beer body and to improve beer head retention.

See **caramel malt**.

Carbon dioxide volumes

Carbon dioxide in beer is typically measured in volumes of gas per volume of beer. This is defined as the volume that carbon dioxide gas would occupy if it were removed from the beer at atmospheric pressure and 0°C, compared to the original volume of beer. Generally ales tend

C to be carbonated at the lower end at about 1–1.3 volumes with European lagers at around 2.2–2.7 and American/Japanese lagers and wheat beers at around 2.7–3.0. ‘Volumes’ of carbon dioxide in beer broadly equate to $2 \times$ concentration (g/L) such that 1 vol is 2 g/L. Key factors that impact on gas levels (both carbon dioxide and nitrogen) include pressure and temperature. Gases increase in solubility with an increase in pressure or a decrease in temperature (see **Henry’s law**). Accordingly care should be taken with draught beer to ensure that the top pressure on the container balances the dissolved gas and that the storage temperature (and container residence time) is correct. Over-carbonated beer results in **fobbing**, which increases beer losses and dispense time. Tables are widely available that relate volumes of carbon dioxide in beer to gas pressure and temperature.

See **mixed gas dispense**.

Carbon filtration

See **activated carbon**.

Carbonyl compounds, yeast and beer flavour

Yeast influences beer flavour in respect of carbonyls by being the agent for some of their removal from wort and the formation of others in fermentation.

The conversion of wort into beer is accompanied by the loss of characters that are described as ‘worty’ and are considered to be undesirable. The compounds that have been implicated are aldehydes, 2-methylbutanal, 3-methylbutanal and especially 3-methylpropionaldehyde. The latter would appear to be of most significance since it has the lowest flavour threshold. In normal fermentations these are removed by yeast via the action of NADH or NADPH-linked aldehyde dehydrogenases and aldoketoreductases with varying substrate specificities. Some zero-alcohol beers, made by the cold contact fermentation process, retain a proportion of these aldehydes, which explains why they often have this characteristic. Several other aldehydes are formed in fermentation as intermediates in the biosyntheses of higher alcohols from oxoacids, and in general these make negative contributions to beer flavour. The same range of enzymes alluded to already are responsible for their elimination from beer.

Of special note are acetaldehyde and the vicinal diketones (VDKs) diacetyl and 2,3-pentanedione. The role of yeast in VDK formation and removal during fermentation is described in the **VDK cycle**. Acetaldehyde is formed from pyruvate via the action of pyruvate decarboxylase. It has a green apple grassy flavour, which is considered undesirable in beer. Acetaldehyde accumulates in mid- to late fermentation and its concentration may rise to levels above the flavour threshold. In late fermentation where warm conditioning is practised levels decline. Similar changes occur where beers are subjected to traditional lengthy cool conditioning, in the presence of yeast. Under some circumstances where fermentation has been managed inappropriately acetaldehyde concentrations remain high. Typical causes are the use of pitching yeast with low vitality. Very high pitching rates, excessive wort oxygenation and a very high fermentation temperature have also been cited as causes. Where beer is handled inappropriately the inadvertent admission of air can result in oxidation of ethanol to form acetaldehyde.

Relatively high concentrations of SO_2 can arise in fermentation (see **sulphur compounds, yeast and beer flavour**). SO_2 binds to aldehydes and forms adducts. In this form the aldehydes

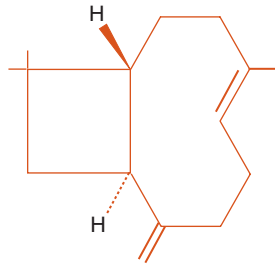
are not available for enzymatic reactions during fermentation, and so they may persist at elevated levels in beer. It follows that where elevated aldehyde concentrations are observed both sulphur and carbohydrate metabolism may be implicated.

carboxypeptidase

See **exo**peptidase, **proteases**.

β -Caryophyllene

β -Caryophyllene is a sesquiterpene that, together with **humulene**, comprises one of the major components of **hop oil**.



Structure of β -caryophyllene

During storage β -caryophyllene undergoes oxidation and hydrolysis to yield a number of products that contribute to the pleasant odours associated with hops.

Carlsberg flask

Proprietary apparatus used for propagation of new cultures of brewing yeast (see **yeast propagation**). The device is used for the growth phase of the terminal laboratory phase of yeast propagation and as a receptacle for transporting the new culture from laboratory to brewery. The flask is constructed from stainless steel with a good internal polish and has an operating volume of around 20L. The top plate is detachable to facilitate cleaning and is fitted with a number of ports that allow attachment of lines for addition of air, removal of CO₂, removal of samples, inoculation and transfer of culture. The latter can be facilitated by using the gas venting main in reverse to blow the culture out using CO₂ as a transporter gas. All fittings are made to a high standard of hygiene and gas ports are fitted with sterile filters.

In use the flask is filled with wort or a nutrient medium and is sterilised by autoclaving. After cooling the medium is inoculated with a suitable culture. During incubation cell yields can be enhanced by continuous aeration. Rates of oxygen transfer can be increased by the use of a magnetic stirrer.

Carlsberg gushing test

See **gushing**.

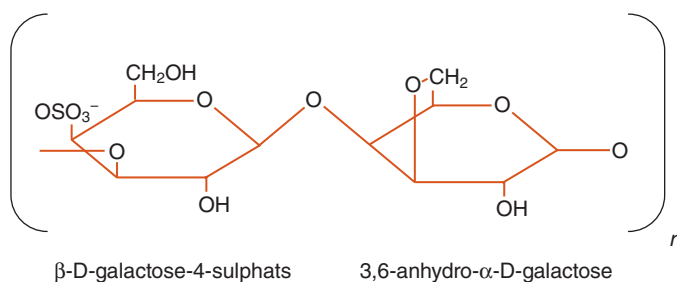
Carlsberg Laboratory

Centre for research in brewing and biotechnology based in Copenhagen, Denmark [<http://www.carlsberglab.dk> (last accessed 6 February 2013)]. Founded in 1875 by the founder of the Carlsberg brewing company, J.C. Jacobsen, to study chemistry and physiology with an emphasis on the scientific examination of yeast and grains and their relation to brewing. Unusually, a year later, it was made part of the Carlsberg Foundation where results were made freely available to all. Many incumbents were pioneers of chemistry, genetics and brewing, for example, Kjeldahl (quantification of nitrogen content of organic samples), Sørensen (concept of pH), Hansen (first pure yeast culture), Winge (life cycle of budding yeast). In 1972 the Carlsberg research laboratory was merged with that of Tuborg and a new Carlsberg Research Laboratory was built adjacent to the old building. The foundation status remains in place.

κ -Carrageenan

κ -Carrageenan is a polysaccharide obtained from various marine algae which is used as a kettle fining agent. It is used to remove a proportion of wort protein that, if left, would have the potential to form haze in the finished beer. It is the most commonly used kettle fining agent.

Three isomers of carrageenan occur in algae, termed kappa, lambda and iota. All have use in various industries, but the kappa form is the only form that gives strong gels and that is useful as a wort clarification agent. Structurally κ -carrageenan is a linear polymer that consists of alternating repeating units of β -D-galactose-4-sulphate and 3,6-anhydro- α -D-galactose.



Structure of the repeating unit of κ -carrageenan

The sulphate moieties confer a negative charge to the polymer and provide the site of interaction with positively charged protein molecules. At the relatively high temperatures of the kettle the molecules have a random coil structure; as the wort is cooled the structure changes to form ordered and compact helices. It is believed that it is in this latter conformational state that the κ -carrageenan and protein aggregates form relatively large particles that promote sedimentation when wort is cooled. This explains why κ -carrageenan must be added to hot wort but has no effect until subsequent cooling has taken place. The optimum pH for reaction with proteins is pH 5.3.

κ -Carrageenan is supplied in several grades of varying purity as either granules, tablets or powders. Of these powders are least favoured because of handling difficulties. Granules are the least pure preparation and tend to be used where batch sizes are large. Tablets are the most

pure and easily used preparations. In order to prevent thermal degradation the finings are not added until close to the end of the boil, typically 5–10 minutes before the completion of boiling, the actual time being dependent on purity. The dosage rate is critical for effective action. At too low a concentration no effect at all is observed. At increasing concentration, above a minimum critical value, an increasing proportion of protein is removed. There is no effect on the polyphenol constituents of wort.

κ -Carrageenan is obtained from several marine algae, notably the Atlantic red alga, *Chondrus crispus*. Commonly this is referred to as **Irish moss**, and historically relatively impure preparations of κ -carrageenan were sold under this name. More recently another alga, *Eucheema cottonii*, which is a richer source of κ -carrageenan, has become dominant. This alga is farmed in a sustainable manner in regions of the Pacific, where it is native.

Carter dockage tester

Apparatus used to obtain samples of barley and other grains that are free from contaminating materials. It comprises an apparatus which contains a number of sieves or riddles and a motor driven fan. A representative weighed sample of the uncleaned grain to be assessed is placed into a top hopper from which it is aspirated into the body of the machine. Various fractions are separated and collected in different sections of the apparatus on the basis of size and weight from where they may be recovered, examined and weighed.

Cartridge filter

Cartridge filters are those that comprise a preformed unit usually made of polypropylene, which fits into a housing, typically made of stainless steel. The housing is attached to the line that carries the process fluid. When in position the end of the cartridge, which is supplied with suitable O-rings, makes a tight seal with the housing. The process fluid enters the housing and is forced into the body of the cartridge. The filtrate, which has passed through the filtration medium, exits the housing via a second aperture at the base of the housing.

Cartridges are supplied in standard sizes, typically 250 mm in length. In order to accommodate different flow rates several cartridges can be mounted within a single housing; alternatively, multiple housings can be used in parallel or serial arrangements.

Cartridge filters can be of depth or absolute type and can be used singly or in combination. The former comprises a single bed that is made up of multiple concentric layers in which the effective pore size decreases from the outer to inner surfaces. This allows larger particles to be removed first leaving the smaller-pored, and, by implication, more easily blocked inner layers, to remove the finer particles. Materials used for depth filtration include porous polypropylene, nylon, polyester, glass fibre, cellulose and cellulose acetate.

Absolute cartridge filters have a defined pore size, typically 0.45–0.8 μm in diameter. They are made from materials such as polytetrafluoroethylene (PTFE), polyethersulphone (PES), nylon or polypropylene. In order to maximise the available surface area of filter the membranes are made such that they are folded or pleated.

Cartridge filters are used for several purposes. They may be used as trap or polishing filters or for cold sterilisation of beer. For all of these duties they are typically located after the primary filter since they are not tolerant of high solids loadings. For purposes such as cold sterilisation a sequence of multiple cartridge filters may be used. A typical arrangement would

be an initial depth filter with a nominal cut-off of 10–20 µm used as a trap filter to remove breakthroughs of filter powder or other solids. This is followed by an absolute filter with a cut-off of *ca.* 1 µm and a second absolute filter with a cut-off of 0.45 µm. This arrangement safeguards the integrity of the two absolute filters. The gradation in pore size of the latter prevents the terminal sterilizing stage from being overloaded with solids.

Caryopsis

A caryopsis is a dry indehiscent one-seeded fruit in which the seed coat (testa) is fused with the seed coat wall (pericarp). It is the characteristic fruiting form of members of the grass family (Poaceae, formerly Graminae). Members important to brewing include barley, wheat, oats, rice, maize and sorghum.

See **barley grain**.

Cascade

Cascade is a hop cultivar of the aroma variety bred in the United States in the mid-twentieth century. It was released in 1972 but originated in 1956 as part of the American programme to produce disease-resistant hop varieties. Parents include the UK variety **Fuggles** and a Russian type, **Serebrianka**. It contains 4.5–7% α-acids and 1.2% oils. Storage properties are poor.

Casella mill

The Casella mill is a laboratory mill designed for the determination of controlled coarse and fine-grind extracts performed as standard malt analyses. It was adopted in 1963 as the milling method used in the standard EBC recommended method. It has now been superseded by the **Bühler-Miag disc mill**.

The Casella mill comprises a cylindrical chamber in which a rotor fitted with a series of knives is placed. All parts that may come into contact with the charge are made from stainless steel. The charge is fed into the chamber via a top-mounted funnel where they are broken and ground by the action of the rotating knives. At the base of the chamber the wall takes the form of a sieve through which grist particles of the appropriate size can pass into a receiver from where they may be recovered. The sieves can be changed in order to obtain grists with a different fineness of grind.

Cask

Name given to the container used for beers of the type associated with draught traditional UK-style **ale**. These are beers in which the final phase of maturation takes the form of a secondary fermentation that is carried out in the container, or cask, from which it will eventually be dispensed. Casks of various capacities (see **barrel** for more details) are made now rarely from wood and, more usually, aluminium or stainless steel. Less expensive types are also available made from plastic.

Casks are much more complex than kegs since they are required to be fitted with apertures for filling, gas exchange and beer dispense. The features of a cask are shown in the accompanying figure.

See **cask beer**.

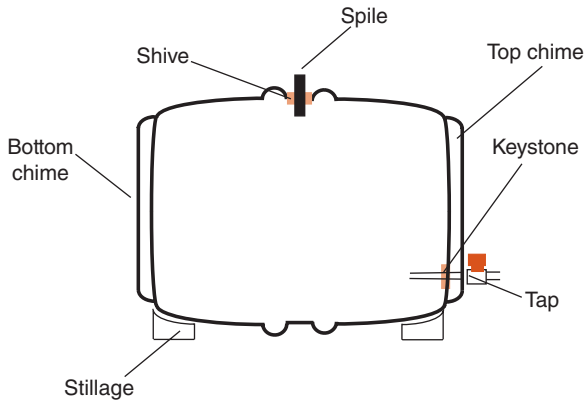


Diagram showing the features of a cask

Cask aspirator

See **cask breather**.

Cask beer

A cask beer is a UK-style draught ale in which the final stages of maturation are performed in the container, or **cask**, from which the beer is eventually dispensed. Such beers are not filtered or pasteurised, but in the final stages of processing they are placed into the cask with a residue of fermentable sugar and a viable yeast count of the order of 1×10^5 to 1×10^6 cells per millilitre. This process is termed **cask racking**. The fermentable sugar may obtain from a partially fermented primary fermentation or it may be added to a fully fermented beer in the form of a syrup, usually of sucrose. In this case the added sugar is referred to as primings or **priming sugar** and the process as **priming**. The secondary fermentation is allowed to proceed in the brewery but is completed in the premises from which the beer is eventually dispensed and consumed. Although there is some change in flavour and formation of a small amount of additional ethanol, the primary function of the secondary fermentation is to allow the development of a suitable level of carbonation, termed **condition**, and the term **cask-conditioned beer** is also used for these beers to reflect the fact that the secondary fermentation is carried out in the cask. These beers are beloved of traditionalists and for this reason may be referred to as **real ales**, to distinguish them from their brewery-conditioned, pasteurised counterparts.

Cask breather

A cask breather, also called a **cask aspirator** or **cask spigot**, is a device that is fitted to the shive of a cask to which a supply of carbon dioxide is connected. As the beer is dispensed a counter-flow of carbon dioxide replaces the liquid in the cask. Since this prevents air entering the cask, as is the usual method for dispense of cask-conditioned beers, hygiene is improved and the shelf life of the beer can be extended by a day or so. In the case of a **vertical stillage** connection of a carbon dioxide supply to the venting valve allows the same role to be fulfilled. This approach is useful in periods where beer sales are slow; however, some purist aficionados of cask beers claim that it can lead to over- (and artificial) carbonation.

Cask-conditioned beer

A synonym for **cask beer**.

Cask racking

Process of transferring a UK-style ale from storage tank to beer cask.

See **cask beer**.

Cask spigot

See **cask breather**.

Cassata

A variety of winter malting barley that has received full approval of the UK Institute for Brewing and Distilling. It has good yields and is resistant to barley mosaic virus.

Cast

Cast (n.) is used as a descriptor for beers that have a slight haze in which the causative particle size is sufficiently small to be not directly visible to the naked eye but nonetheless to cause a lack of brilliant clarity.

See **beer hazes**.

Casting

Casting is the term, mainly associated with the United Kingdom, which describes the act of emptying a vessel. In particular it is applied to the transfer of boiled wort for the kettle to a whirlpool, known as a copper cast, or casting the copper.

Catabolite inactivation

Metabolic control system in which the presence of a particular nutrient results in the inactivation of enzymes required for the assimilation of other related nutrients.

See **yeast growth and metabolism**.

Catabolite repression

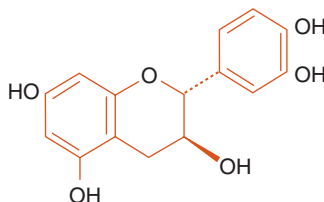
System of metabolic control in which the presence of particular nutrients causes the repression of genes that are unnecessary for the existing mode of growth.

See **yeast growth and metabolism**.

Catechin

Catechin is a monomeric polyphenol of the flavanol type (see accompanying diagram for structure). It has importance in brewing since it is an important precursor of beer hazes.

See **polyphenols, colloidal stability**.



Structure of catechin

Caum

Caum is the name given to native beers made by various indigenous tribes in Brazil. The source of fermentable sugars is manioc, maize or plantains. Other flavourings, including fruit juices, may be used. Production of all the beverages shares in common a preliminary stage in which the source of starch is macerated by chewing. In addition to breaking down the plant material, this introduces human amylases from the saliva which breakdown the starches to produce fermentable sugars.

Cauliflower head

See **rocky yeast head**.

Caustic soda

See **detergents**.

Caviar beer

Caviar beer dates back to a period in the history of North America in the late nineteenth and early twentieth centuries during which caviar was provided in some bars as a free snack food. The snack food was made freely available since it was assumed that its salty character would promote increased beer consumption. It seems that some consumers would actually add the caviar to beer, hence the name. The largesse was a consequence of the fact that caviar was inexpensive and readily available since the sturgeon, the source of the caviar, was a very common native of the River Hudson. Caviar was available in this region and during this period in such abundance that it was given the name *Albany beef*.

CBS

Centraalbureau voor Schimmelcultures.

See **yeast culture collections**.

CDC Copeland

A two-rowed variety of malting barley developed at the Crop Development Centre at the University of Saskatchewan in Saskatoon, Canada, hence CDC. It was one of a batch of new varieties which included CDC Metcalfe, CDC Stratus and CDC Kendall which were viewed as replacements for the popular but fading Harrington variety. It was placed on the American recommended list of brewing malting varieties of barley in 2005.

CDC Harrington

A two-rowed variety of malting barley developed at the Crop Development Centre at the University of Saskatchewan in Saskatoon, Canada, hence CDC. It was originally registered in 1981 and was very popular in Canada, accounting in 1993 for 38% of the total acreage of malting barley. Subsequently it has been superseded by other varieties with superior properties. These include CDC Metcalfe, CDC Stratus and CDC Copeland.

CDC Kendall

A two-rowed variety of malting barley developed at the Crop Development Centre at the University of Saskatchewan in Saskatoon, Canada, hence CDC. It was one of a batch of new varieties that included CDC Metcalfe, CDC Stratus and CDC Copeland, which were viewed as replacements for the popular but fading Harrington variety.

CDC Polar Star

A two-rowed variety of malting barley bred at the University of Saskatchewan, Canada, and which appears on the 2010/2012 list of Canadian recommended malting varieties.

CDC Stratus

A two-rowed variety of malting barley developed at the Crop Development Centre at the University of Saskatchewan in Saskatoon, Canada, hence CDC. It was one of a batch of new varieties that included CDC Metcalfe, CDC Kendall and CDC Copeland, which were viewed as replacements for the popular but fading Harrington variety.

Cekin

Cekin is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with the varieties Celeia, Cerera, Cicero and Chmelja it constitutes one of the 'C'-series of varieties of **Super Styrian hops** released in 1990 with the intention of combining high α -acids and good aroma properties. It is a seedless triploid type derived from **Aurora** and a tetraploid Slovenian male.

The analytical profile is 6.0–8.0% total α -acids of which 24.0% is cohumulone. Total β -acids are 2.0–3.0%. Total oils are 1.0% of which 6% is caryophyllene, 7.0% farnesene, 16.5% is humulene and 48.0% is myrcene.

Celeia

Celeia is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with the varieties Cerera, Cekin, Cicero and Chmelja it constitutes one of the 'C'-series of varieties of **Super Styrian hops** released in 1990 with the intention of combining high α -acids and good aroma properties. It is a seedless triploid type derived from a tetraploid **Savinja Goldings** and a diploid Slovenian male.

The analytical profile is 5.0–6.0% total α -acids of which 25.0% is cohumulone. Total β -acids are 3.5%. Total oils are 1.3% of which 7% is caryophyllene, 5.6% farnesene, 17.6% is humulene and 49.0% is myrcene.

Cellar

The cellar is the term used to describe a room in which beer is stored or processed under controlled conditions of temperature. The cellar may be within a brewery and associated with parts of the brewing process or the same term is used to describe the area within a bar or public house where the containers for draught beers are stored and from which the beer is dispensed. As the name suggests traditional cellars were located underground where the temperature was naturally cool and not subject to much seasonal variation. In more modern installations the room may be fitted with a refrigeration system or a method of attemperation supplied directly to the beer storage vessels.

Within a brewery the cellar is usually used to describe the areas where green beer is stored for the purpose of maturation (see **beer maturation** for more details). In the case of many traditional beers, such as some lagers, this storage phase can last for several weeks or months. Originally this would have been performed in naturally occurring caves and later in purpose-built underground cellars possibly fitted with refrigeration units. Other related or synonymous terms are used to describe the process and the room used, such as **cellaring**, ageing cellar or

conditioning cellar. The vessels in which the beer is contained may be called **cellar tanks**. In modern ageing processes, where the process temperatures are usually much lower than those that can be achieved naturally and, in consequence, the storage times are much reduced, it is usual to supply a suitable coolant directly to jackets surrounding the storage tanks. The term **filter cellar** is used by some to describe the area in which beer filtration is performed.

Within the context of the dispense of UK-style ales the cellars in a bar are traditionally kept at a temperature of 11–12°C (52–53°F) since this would be typical of that seen in a deep cellar. In modern installations a refrigeration system and controlling thermostat are used to ensure that these conditions are adhered to. A thermometer should be fitted with a visible read-out to allow regular checking of the cellar temperature. In some premises a heating system may be required during the winter months to avoid too low temperatures. Bar cellars should be designed to good standards of hygiene and so the walls should be lined with ceramic tiles or a similar non-absorbent cleanable surface. The floor should be well draining. A suitable stillage is required for casks and kegs from which beer is to be dispensed together with associated beer lines, gas supplies, pumps, fob traps and any additional cooling equipment. Beer and gas supply lines must be labelled properly to avoid the risk of incorrect dispense. A holding area is required for the storage of untapped containers. The size of this area must be appropriate for the volumes of beer which are sold in the particular outlet and allow proper stock control and rotation. Apart from the containers and the essential equipment required for draught beer dispense, no other items should be stored in the cellar, in particular, nothing that might be a source of contamination or taint.

Cellarbuoy

See **fob detector**.

Cellaring

A term used to describe the part of the brewing process in which green beer is stored for a period at low temperature (see **beer maturation** for more details). Synonyms are **ageing** and **cold conditioning**.

Cellar tanks

A vessel used for the storage and maturation of green beer.

See **cold conditioning** and **secondary fermentation**.

Cellobiase

Cellobiase is a hydrolase enzyme that breaks β -(1-4) linkages, which join the two glucose residues in the disaccharide cellobiose to yield β -D-glucose. It is a β -glucosidase (β -D-glucoside glucohydrolase, EC 3.2.1.21). It occurs as part of the complex of enzymes that are responsible for the degradation of β -glucans. The occurrence of cellobiase in malt has been assumed since the oligosaccharide substrates, which themselves are formed by the degradation of larger β -glucan polymers, do not accumulate in malts. However, their presence in malts has not been demonstrated definitively. It is possible that these activities may arise in brewery mashes from the contamination of malts with enzymes of microbial origin. With regard to the latter, cellobiases, which constitute part of the activities of microbial **cellulases**, may be

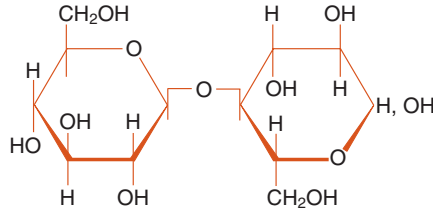
added to mashes to reduce β -glucan concentrations as part of a strategy to regulate wort viscosity.

See **β -glucans, β -glucanase, cellulase.**

C

Cellulose

Cellulose (β -D-glucopyranosyl-(1-4)-D-glucopyranose) is a disaccharide consisting of two molecules of glucose joined by a β -(1-4) linkage.



Cellulose is a product of the hydrolysis of β -glucans which is formed when *exo*- β -(1-4) glucanases attack at the non-reducing chain ends. The presence of these enzymes in malt has not been confirmed; however, they are present in preparations of microbial β -glucanases, which may be added to mashes to reduce wort viscosity. Cellulose, albeit at low concentration, has been found in beer.

See **β -glucans and β -glucanase.**

Cellulase

Cellulase (EC 3.2.1.4) is the trivial name for a complex of enzymes whose activity results in the hydrolysis of cellulose with the concomitant formation of glucose. The majority of cellulases are of microbial origin. Preparations of cellulases are available commercially and are used in brewing during mashing, where permitted, to catalyse the degradation of β -glucans.

Several enzymes are thought to be involved in the conversion of crystalline cellulose to glucose. These are β -1,4-glucan cellobiohydrolase, *endo*-1,4- β -glucanases and β -glucosidase. Acting in concert these enzymes breakdown the ordered crystalline structure of cellulose such that the molecules become accessible to attack by hydrolytic β -glucanases. Both *endo*- and *exo*- β -glucanases occur and the activities of these result in the fragmentation of the linear glucan molecules. The products, which include disaccharides such as cellulose and the tetrasaccharide cellotetraose, are further hydrolysed to glucose via the action of β -glucosidase.

See **β -glucanase.**

Cellulose filter aid

Cellulose may be used as a filter aid in the form of a fibrous material that is made from wood pulp. In brewing applications it is used exclusively as a first pre-coating material (see **powder filter** for more details). It is particularly useful for this purpose since the long cellulose fibres are particularly good for bridging the gaps in the septa of powder filters. In addition, the fibres are relatively pliant such that they are able to provide an efficient cushioning effect in the event of sudden pressure changes in the filter bed.

Cellulose filter aids are more expensive than kieselguhr and perlites, although they have the advantage of being non-toxic and biodegradable.

Centennial

Centennial is a US dual-purpose aroma and bittering hop (9–11.5% α -acids, 1.5–2.3 mL/100 mL hop oils), bred in 1974 in Washington State and released in 1990. It was bred from Brewer's Gold and a US male variety. It is sometimes known as Super Cascade. It is claimed that it can be replaced by a blend of Cascade and Columbus (70:30).

Centibrew continuous wort production system

The Centibrew continuous wort production system was devised during the 1970s when there was much interest in continuous brewing processes. As its name suggests it was intended for continuous mashing, separation of sweet wort from spent grains, boiling and hot wort clarification. It consisted of a continuous hammer mill, associated malt and adjunct silos and grist transporting system. After mashing in, the mash was pumped through a series of spiral heat exchangers such that a temperature-programmed conversion regime could be performed. The separation step was carried out in three stages, each of which used a rotating conical sieve and associated holding tank. At each stage the recovered spent grains were washed with a countercurrent of sparge liquor. After three sparge treatments the wort streams were combined and clarified by continuous centrifugation. The centrifugate was fed into a tank where hops (or hop extracts) were added. After this the hopped wort was pumped into a further tank in which the application of steam at high pressure allowed rapid increase to 150°C. After treatment for 2 minutes the boiled wort was transferred to a vacuum vessel such that the temperature was rapidly decreased to 90°C before clarification using a second continuous centrifuge to remove trub and, finally, cooling.

Centraal Brewerij Kantoor

Amsterdam-based Dutch brewers' association [<http://www.cbk.nl> (last accessed 5 February 2013); in Dutch only].

Central Institute for Supervising and Testing in Agriculture (CISTA)

CISTA [<http://www.ukzuz.cz> (last accessed 5 February 2013)] is an organisation located in Brno founded by the Ministry of Agriculture in the Czech Republic charged with administering all activities with regard to the testing and assessment of all matters regarding agricultural products within the Czech Republic including administering the accreditation of malting barley varieties.

Centre for Bioenergy and Brewing Science, University of Nottingham

Centre for teaching and research in brewing and bioenergy located at the Sutton Bonington Campus of the University of Nottingham, UK. Brewing science was established at the university in 2005 by the arrival of Professor Katherine Smart.

Centrifuges

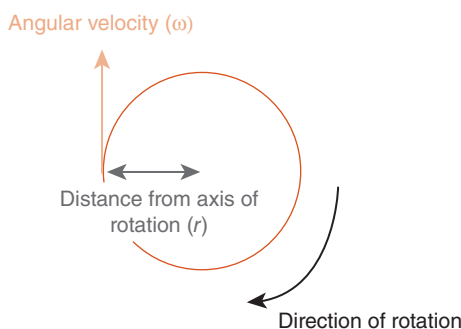
Centrifuges are devices used for performing solid–liquid separations. They rely on manipulation of gravitational force to effect the separation. Centrifuges are used widely in brewing, most commonly for the removal of yeast and other non-yeast solids after conditioning and

prior to beer filtration and also for the recovery of beer from waste yeast. Less common applications of centrifugation may be for duties such as hot wort clarification. Different types of centrifuge may be used depending on the task. The majority are designed to be operated continuously.

C

In centrifuges, rates of sedimentation of particles are increased by subjecting the suspension to a rapid spinning motion. This imposes a centrifugal force on the particles and in response they are forced outwards. Since the suspension is contained within a rapidly rotating centrifuge bowl the particles are directed towards the extremity from where they may be collected.

In a centrifuge, particles of mass, M , are subjected to a force, the centrifugal force, which is described by the angular velocity (ω) and the radius, or the distance from the axis of rotation (r) as illustrated in the following diagram.



The force that is exerted on particles, the centrifugal force, is described in the following equation:

$$\text{Centrifugal force} = M\omega^2 r.$$

Thus, the larger the mass of the molecule, the faster the rotational speed, and the longer the axis of rotation, the greater will be the force exerted on the particle. When a suspension is subjected to centrifugation, two other forces are also present: the buoyant force and the frictional force. The buoyant force is related to the relative densities of the particles and the suspending medium. The frictional force describes the force that resists sedimentation and is generated by the friction of the particles as they migrate through the suspending liquid. This is dependent upon the viscosity of the suspending medium and the radius of the particles. When a particle is subjected to a centrifugal field it will move at an accelerating velocity until the centrifugal force is equal to the buoyant force plus the frictional force. In practice, for a given rotational speed and with a given particle the centrifugal force and buoyant forces are constants. The balancing of forces occurs rapidly and the result is that particles sediment at a constant rate. This is described as the sedimentation coefficient (S):

$$S = v/\omega^2 r,$$

Where, v is the velocity and the other terms are as described already.

The centrifugal force is most commonly described in terms of the earth's gravitational force (g). This is termed the relative centrifugal force, (RCF). For ease of use it can be expressed in terms of the rotational speed (rpm).

$$\text{RCF} = 11.17r(\text{rpm}/1000)^2$$

where r = radius in cm.

Relatively small centrifuges, intended for laboratory use, are capable of generating many hundreds of thousands of g and can sediment very small particles such as sub-cellular organelles and larger molecules. The devices used for separations in commercial-scale brewing generate approximately $5000\text{--}6000 \times g$. This reduces the sedimentation times of particles such as yeast cells suspended in beer from days to a few seconds.

Cereal cooker

Cereal cookers are brewery process vessels in which **adjuncts**, which contain starches that have relatively high **gelatinisation temperatures**, are preheated prior to cooling and adding to the mash.

Modern cereal cookers are fabricated from stainless steel and are similar in construction to mash mixing vessels and mash cookers. Early vessels were made from copper and were commonly horizontally mounted cylinders fitted with a means of stirring the contents. Modern cereal cookers are vertically mounted cylinders fitted with dished ends. Heat is supplied by steam, which is either injected directly or more usually via wall-mounted jackets. In order to ensure efficient heat transfer the contents are stirred using a variable speed agitator. If the latter is centrally mounted baffles are fitted to the walls of cylindrical vessels to improve the efficiency of mixing. Modern cereal cookers are frequently designed to be pressurised in order to promote starch gelatinisation.

The load of material to be treated is added via a hopper fitted with load cells. The hopper may be equipped with a vibrating system to ensure ease of emptying. When the process is completed the heated material is returned to the main grist via a bottom-located exit point. A sparge ring located near the top of the cooker is used as part of a cleaning in place (CIP) system and for ensuring that transfer of the charge to the mash vessel proceeds efficiently.

In operation the material, grits and small proportion of ground malt, possibly supplemented with an enzyme preparation, is mixed with water to give approximately $8\text{--}10\text{ kg/hL}$. Cereal cookers are designed to increase the temperature of the contents at approximately $1^\circ\text{C}/\text{min}$. Holding temperatures are within the range $70\text{--}100^\circ\text{C}$. After an appropriate time, which depends on the nature of the adjunct material used, the contents of the cereal cooker are transferred into the main mash. The relatively high temperature of the adjunct is used to increase the temperature of the main mash.

Cerera

Cerera is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with the varieties Celeia, Cekin, Cicero and Chmelja, it constitutes one of the 'C'-series of varieties of **Super Styrian hops** released in 1990 with the intention of combining high α -acids and good aroma properties. It is a seedless triploid type derived from a tetraploid **Savinja Goldings** and a diploid Slovenian male.

The analytical profile is $5.0\text{--}6.0\%$ total α -acids of which 25.0% is cohumulone. Total β -acids are $4.0\text{--}4.5\%$. Total oils are 1.5% of which 6% is caryophyllene, 3.0% is farnesene, 13.2% is humulene and 58.0% is myrcene.

Cerveceros Latinoamericanos

Cerveceros Latinoamericanos [<http://www.cerveceroslatinoamericanos.com> (last accessed 5 February 2013)] is a trade organisation representing the interests of brewers in Latin America. It was founded in 1959 in Lima, Peru. It is a member of the **Worldwide Brewing Alliance**. Its aims are to promote a positive image of beer production and consumption via, and to lobby with, legislatures on issues such as taxation, environmental matters and advertising.

Chalconaringenin

Chalconaringenin is a polyphenolic chalcone intermediate in the pathway leading to the formation of hop flavonols (see diagram for structure).

See **polyphenols**.

Chalcones

Class of flavonoid polyphenol based on the molecule, chalcone (1,3-diphenyl-2-propen-1-one).

Chalice glass

A wide mouth bowl footed with a long stem, typically half-pint or 333 mL, and popular for Trappist and Abbey ales.

See **glassware**.

Challenger

Challenger is an English hop variety bred at Wye College and introduced in 1972. It has both **Northern Brewer** and **Northdown** varieties in its pedigree. It is a dual-purpose hop with good aroma characteristics and relatively high bitterness levels (5–9% α -acids, 1.0–1.5% hop oils).

Chamant

A variety of proanthocyanidin-free barley.

Change parts

Components of packaging lines that are required specifically for given packaging types, sizes and designs. During changeovers between packaging runs they are the parts that require to be in place, hence the name. An example would be a star wheel which is sized to grab a particular container and transport it onto the next stage of processing. Change parts are costly and sharing between pack types, where possible, is an obvious advantage.

Chapon test

See **alcohol chill haze test**.

Chariot

A spring variety of malting barley particularly suitable for making UK-style ales.

Charles

A two-row winter variety of malting barley developed by the United States Department of Agriculture (USDA) Agriculture Research Service Small Grains Germplasm Research Facility based in Idaho, USA. It was added to the recommended list of the **American Malting Barley Association Inc. (AMBA)** in 2009.

Chelan hop

Chelan is a US-bred high alpha hop, released in 1994. It was bred from **Galena** to which it bears some resemblance. The analytical profile is 12.0–14.5% total α -acids of which 33.0–35.0% is cohumulone. Total β -acids are 8.5–9.8%. Total oils are 1.5–1.9% of which 9.0–12.0% is caryophyllene, <1.0% farnesene, 12.0–15.0% is humulene and 45.0–55.0% is myrcene.

Chemchrome Y

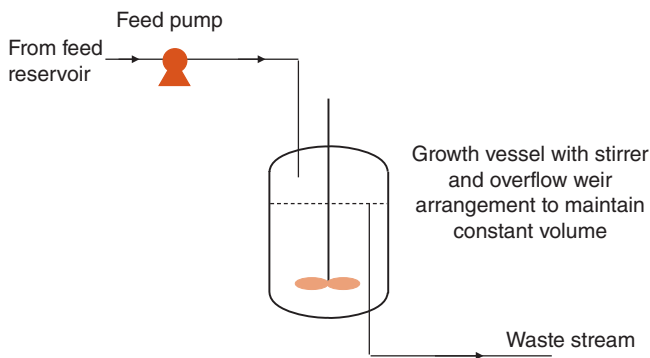
One of a series of dyes produced by the French company Chemunex [<http://www.aeschemunex.com> (last accessed 6 February 2013)], which can be used to determine cell viability, including yeast. The dye is an esterified form of fluorescein, which is taken up by all cells. In the viable fraction, endogenous esterases release free fluorescein and produce a visible fluorescence. Dead cells remain unstained.

See **yeast viability**.

Chemostat

A chemostat is a method of conducting the cultivation of microorganisms, which forms the basis of continuous cultures. Implicit in the name is the suggestion that the conditions within a chemostat regarding the composition of the medium and the biomass concentration, rate of growth and physiological state of the microbial population are all constant. It forms the basis of the continuous systems of fermentation used in brewing.

All microbial cultures can be classified as open or closed depending on the method by which nutrients are supplied. A batch culture is a closed system since all available nutrients are present at the time of inoculation. Such systems are in a constant state of transition, and growth rates eventually tend to zero as either an essential nutrient becomes depleted or a metabolite builds up to toxic levels. Continuous systems are open in that there is a constant supply of fresh medium introduced into a reactor, the contents of which are held at a constant volume by displacing an equivalent volume of culture (see diagram). Provided the temperature and all other environmental conditions are kept constant, the growth rate of the microorganism and the composition of the exhausted medium should also be constant and conditions of steady state can in theory be maintained indefinitely.



Schematic showing the essential features of a chemostat

The growth of an organism in a chemostat is influenced by two factors. These are the removal of nutrients from the medium as a result of growth and the dilution effect of the continual addition of fresh medium. The rate of growth of the cell population is expressed mathematically by the general growth equation

$$N_t = e^{\mu t} N,$$

where N is the cell concentration at time t ; N is the cell concentration at time zero and μ is a parameter termed the specific growth rate. This is the rate of increase in the size of the population as regulated by the conditions (temperature, nutrient availability, etc.) established in the growth vessel.

By rearrangement of the general growth equation, the growth rate at any time is given as

$$\frac{dN}{dt} = \mu N.$$

In a chemostat the continuous addition of fresh medium displaces an equal volume of culture medium. The rate of loss of cells is defined as:

$$\frac{dN}{dt} = DN,$$

where D is defined as the dilution rate and is equal to the rate of addition of fresh medium divided by the volume of the culture. It has the unit of the reciprocal of time.

In a chemostat the net change in population size at any instant is given as the difference between the last two equations. Every organism has a maximum growth rate which is determined by the genome of the organism and which cannot be exceeded. This is given by the symbol μ_{\max} . In a chemostat an increase in dilution rate increases the availability of nutrients and the population size increases in response. The increased population results in the depletion of an essential nutrient, and eventually the concentration of this falls to zero and becomes growth limiting. At this point the values of the last two equations are equal and a steady state is established. Thus, under these conditions, $\mu = D$ and the growth rate is determined by the rate of addition of fresh medium. However, if the dilution rate is increased to a value above μ_{\max} , further increases in growth rate are not possible and the population density will eventually decrease to zero. This is termed wash-out.

ChemScan RDI™

System for rapid microbiological analysis in filterable samples made by the Chemunex company [<http://www.aeschemunex.com> (last accessed 6 February 2013)]. It uses a combination of antibody-based markers for specific organisms, fluorescence microscopy and laser scanning. Results are available within 3 minutes of sampling and a single cell can be isolated, identified and, if required, recovered for further analysis. Predictably it is costly but has seen used in the pharmaceutical industry. It has yet to find use in brewing, but should suitable markers become available, it offers a route to real-time microbial testing in high-speed packaging lines, albeit at a cost.

Cheongju

See **takju**.

Chhaang

An alcoholic beer-like beverage popular in Sikkim, Tibet, Nepal and Bhutan. It is prepared from barley, millet or rice and may be flavoured with other ingredients such as ginger. The latter imparts a warming quality which, together with alcohol, is prized as a method of warding off the extreme cold associated with these mountainous regions.

Chibuku

Name given to a native African opaque beer made from sorghum or millet. It is associated with Zimbabwe and other southern African countries. Modern versions of the beer are sold in waxed cartons. The name 'shake shake' is used in conjunction with the beer and refers to the need to resuspend the sediment in the cartons before consumption.

See **Native African beers**.

Chibuku process

A method used for the industrial production of native African beers made from sorghum and maize. It differs from other similar processes in that starch degradation is performed using enzymes derived from sorghum malts supplemented with an amyloglucosidase of fungal origin.

See **Native African beers**.

Chicha

A generic term used in Latin America to describe fermented native beers. It is particularly associated with beers made by the fermentation of an extract of maize, but other sources of starch such as the manioc plant (*Manihot esculenta*) may also be used.

The product made from maize is pale straw coloured, cloudy with an ethanol content of up to 3% by volume. In modern versions the maize is allowed to germinate to allow starch breakdown and sugar formation. The germinated grains are ground, suspended in water and allowed to ferment in earthenware jars. In more traditional processes the un-germinated grains are macerated by chewing, thereby introducing salivary amylases to promote starch degradation.

Chill haze

Chill haze is defined as the haze that is formed when beer is cooled to 0°C and that redissolves when the beer is warmed up to 20°C or greater. It is caused by the binding via comparatively weak hydrogen bonds between the proline groups of sensitive proteins and polypeptides and hydroxyl groups in oxidised polyphenol tannoid molecules.

The precise mechanism remains a subject for discussion; however, it seems agreed that polyphenol molecules, which in beer are in excess of sensitive proteins, each have multiple binding sites and are able to bind to multiple polypeptides and thereby form bridges to give large networked complexes. In the case of chill haze the weak hydrogen bonds are disrupted when the beer is warmed up and the haze redissolves.

Permanent haze is that which does not redissolve when the beer is warmed up to 20°C. This occurs when the bound protein polyphenol complexes undergo further oxidation and polymerisation with the formation of much stronger covalent bonds. These are not disrupted when the beer is warmed up.

See **colloidal stability**.

Chill proofing

Collective term for steps carried out with the aim of removing colloidal haze materials and their precursors.

See **chill haze, colloidal stability**.

Chill-proofing agents

Process aids used to remove the precursors of beer colloidal hazes

See **colloidal stability**.

Chimay

One of the Trappist monasteries of Belgium producing Trappist beers.

See **Trappist beers**.

Chimb

A variant of **chime**.

Chime

The name given to the ends of a coopered cask, which consists of a metal hoop that secures the ends of the staves. In modern metallic casks and kegs, the chime is part of the structure of the container and may include branding and apertures for ease of manual handling.

See **cask**.

Chinaman's hat

A colloquial name, associated with the United Kingdom, and used to describe the inverted conical wort spreaders that may be seen mounted above the surface of the boiling wort in some wort kettles.

See **wort spreader**.

Chinook

Chinook is a US hop variety produced from a cross with a US male and **Petham Goldings**. It contains high bitterness levels (11–13% α -acids) and is therefore used primarily for bittering; nevertheless it imparts a smoky character when used for late hopping.

Chit

A chit describes the first signs of the appearance of the root sheath or coleorhiza on a germinating grain. In barley it marks the first visible manifestation of germination and takes the form of a small white structure at one end of the grain. The process is termed chitting. The term can also be used in the sense of processes or treatments which induce germination and hence lead to the formation of chits (see **germination**).

Eventually the visible coleorhiza splits and the first rootlets appear and take the form of a tuft at the end of the grain.

Chitin

A polymer consisting of a linearly arranged β -1,4 linked groups of N-acetyl-glucosamine. It is found in the cell walls of yeast cells, accounting for up to 5% of the dry weight of the wall.

The majority of the chitin is found in the **bud scar** and may be visualised by the use of appropriate stains such as the fluorophore **calcofluor**.

Chit malts

Chit malts and **short grown malts** are under-modified types in which the total malting time is curtailed such that the product is generated quickly and with low losses. The reduced production time and lower loss rates incur a much reduced cost compared with standard malts. The use of these products is popular where legislation forbids the use of adjuncts and raw grains, for example, where the *Reinheitsgebot* holds sway.

Chit malts are produced by germinating for approximately 2 days when chitting occurs and, at this stage, arresting further modification by gentle kilning. The mild heat treatment ensures high enzyme survival rates. Under these conditions malt losses are only 1–2%. In the case of short grown malts steeping is curtailed such that the grains achieve 40% moisture content. After allowing the grains to germinate a light kilning is performed. In this case costs are reduced since the moisture content is low and therefore kilning costs are commensurately less.

These types of malts are cheaper than conventional malts and therefore reduce overall brewing costs when incorporated into grists. They produce dry flavours and beers with good head retention. They contain relatively high levels of enzymes; in particular, short grown malts possess greater than usual α -amylase activity. However, the relatively short malting time means that they retain many of the characters of raw grains and, for this reason, their use is limited to no more than about 10% of the total grist.

Chlorination of water

Chlorine is used as a means of sterilizing water intended for use in the brewery. It is also used in similar fashion as a means of reducing levels of iron and manganese in water. The approach has now been largely discontinued based largely on the toxicity of the gas and the fact that chlorine can react with organic components of water, leading to the formation of chlorophenols and trihalomethanes. These are potentially toxic and may cause taints.

Chlorine is used either as free gas or in the form of hypochlorites or hypochlorous acid. Suggested dosage rates and contact times are 5 mg/L available chlorine and 30 minutes. Conversely, based on the initial loading rates, dosage rates should be sufficient to ensure that residual chlorine levels are of the order of 1 mg/L.

After the treatment residual chlorine should be removed by aeration, filtration through active carbon or by addition of sulphite or bisulphite.

Chlorine dioxide

Chlorine dioxide is (ClO_2) is a powerful disinfectant which is used in brewing primarily for water treatment. It is a powerful oxidizing agent and it is via this property that it exerts its biocidal effects, probably via denaturation of membrane proteins. Dilute aqueous solutions are relatively stable and contain chlorine dioxide in gaseous form. After decomposition it yields mixtures of chlorite (*ca.* 70%) and a mixture of chlorate and chloride (*ca.* 30%). Chlorine dioxide does not chlorinate organic contaminants and will not form trihalomethanes.

In concentrated form chlorine dioxide is hazardous and it is not supplied in bulk; instead on-site generators are used. Several types of generator are available, the most commonly used being those in which a solution of sodium chlorite is treated with hydrochloric acid:



Compared with other methods of generation, of which there are several, this method is relatively low yielding; however, it produces chlorine dioxide, which is free from chlorine. This is advantageous for brewery application since there is no risk of chlorination of organic contaminants and the consequent threat of tainting or generation of hazardous chlorinated by-products.

Typical dosage rates are of the order of 0.3–0.5 mg/L. A minimum contact time of 10 minutes is necessary to ensure good kill rates. It is effective over a wide range of pH values. Chlorine dioxide exerts biocidal activity against bacteria and, providing sufficient contact time and concentration, it will also kill yeast, both brewing and non-brewing strains. However, it has been reported that with careful control of concentration and time, it may be used as a means of selectively reducing the count of potential beer spoilage in pitching yeast slurries without damage to the yeast (see **yeast washing**)

Typical applications are as a primary water disinfection, particularly for borehole water. In addition it may be used as a surface sanitiser. In pure form it is non-corrosive against stainless steels of the grades commonly used in brewing applications. It is available in other 'stabilised' forms where other additives such as chlorides and chlorates can occur in combination with a low pH due to the presence of acids. These preparations are very corrosive.

Chlorothalonin

Chlorothalonin (2,4,5,6-tetrachloroisophthalonitrile) is a broad-spectrum non-systemic fungicide that is used for the treatment and prevention of downy mildew infection in hops.

Chmel

Czech word for hop.

Chocolate malt

Chocolate malts, as the name suggests, are dark products used in brewing to impart colour and flavour to beers. They are commonly used in recipes for stouts and other dark beers. They are produced by roasting the grains after pretreating with gentle heat to reduce the moisture content to approximately 5%. The process is similar to that described for the production of **roasted barley** and further details can be obtained by referring to the entry bearing this title. The heating process destroys all enzyme activity.

The dried grain is transferred to a roasting drum. A two-stage ramped temperature-controlled programme is used, which typically ranges from 75 to 175°C in the first stage and up to 225°C in the second stage. The duration and top temperature used in the second stage determines the final colour of the malt. Amber malt is the most mildly roasted chocolate malt. Chocolate malt is one of the least roasted black malt and typically uses a top temperature of 215°C. **Black malt** uses a higher temperature in the region of 225°C. When the final heating step is completed the process culminates in the discontinuation of heating and sprinkling with

water. This cools the grains and causes them to swell and stops any further colour development. In section the grains take on a dark floury appearance. Colours of finished malts are in the region of 50–100 EBC units for amber malts, 500–600 EBC units for pale chocolate, 900–1100 EBC units for standard chocolate and >1200 EBC units for black malts. The darkest black malts are sometimes referred to as **patent black malt** or just **patent malts**.

Chocolate malt imparts a dark or deep red colour, depending on the usage rate, and a dry roast, astringent flavour. Black malts provide more roast and burnt character. Usage rates for each are typically 3–12% for chocolate malts and 1–3% for very dark black malts. These malts have no enzyme activity.

Chondrus crispus

Chondrus crispus is the scientific name for the marine alga colloquially known as Irish moss or carageen. It is the source of the kettle fining agent κ -carrageenan.

See **kettle finings**, **κ -carrageenan**.

Church-ales

The name of an ecclesiastical feast associated with medieval England at which the sale of beer by church officials to the attendees helped raise funds for the local church.

See **ale**.

Cicero

Cicero is a hop variety bred at the Hop Research Institute at Zalec in Slovenia. Together with the varieties Cerera, Celeia, Cekin and Chmelja it constitutes one of the 'C'-series of varieties of **Super Styrian** hops released in 1990 with the intention of combining high α -acids and good aroma properties. It is a seedless triploid type derived from **Aurora** and a tetraploid Slovenian male.

The analytical profile is 6.0–7.0% total α -acids, of which 29.0% is cohumulone. Total β -acids are 2.5%. Total oils are 1.0–1.1%, of which 6.7% is caryophyllene, 3.0% farnesene, 17.7% is humulene and 51.0% is myrcene.

CIP

The acronym that stands for cleaning in place and is descriptive of systems incorporated into a plant which allow cleaning and sanitation without the need to dismantle. Typically, specific items of a brewery plant are fitted with devices that assure desired standards of cleanliness and hygiene. They are connected to an external supply of cleaning and associated fluids and these are circulated through the equipment in a CIP circuit. The pipework, valves and pumps necessary to operate the circuit may be permanently plumbed in providing a fully automatic cleaning system or it may require manual setting up of the supply and return legs. A CIP system comprises a supply of cleaning and rinsing fluids, a pump to deliver them and a return leg to drain the fluids from the cleaned plant. The latter step is usually carried out using a second smaller scavenging pump. The whole is described as a **CIP set**.

CIP accounts for a significant proportion of total brewery running costs both in terms of capital and revenue, and inevitably there may be some necessary compromises to be made. The key is that it must be effective; however, allowing for this prerequisite there are several

options. The self-contained nature of the CIP circuits means that there is a choice as to what is included. The equation is cost versus flexibility. Many dedicated CIP systems provide excellent flexibility since individual items of plants may be isolated, cleaned and quickly returned for duty. It is even better if the pipework and the plant linking items of the brewery plant can be isolated and cleaned separately. In practice some flexibility may be sacrificed by linking several items of plant and pipework in common circuits. This limits the number of costly pumps and associated CIP plants required to support the process.

The design of CIP systems is of critical importance for proper function. In complex systems cleaning fluids and beer streams may require to flow through common valve blocks in close proximity. Any failure may have catastrophic consequences as would the inadvertent addition of CIP reagents to beer by an incorrect route being set up. These possibilities are avoided by a combination of good design and rigorous control. Complex automatic systems are computer controlled, which do not allow inappropriate and conflicting routes to be established and automatic valves have fail-safe arrangements in the event of malfunction.

For effective cleaning it is essential that all surfaces are wetted and CIP cleaning agents are designed to do this. The CIP system must deliver the fluid to the surface in an effective manner. CIP supply pumps must be powerful enough to provide the motive force both to ensure all plants and pipeworks are completely flooded. In addition, the fluid flow must be sufficiently vigorous to provide the scouring action necessary to efficiently remove soils. Pulsed addition increases the energy of the cleaning process. With regard to vessels, **spray balls** ensure that all the internal surfaces of tanks are cleaned. In pipework the velocity of fluid flow requires to be matched to the diameter. For horizontal pipes with a diameter of 7.62 cm a flow rate of at least 2.2 m/s is needed to ensure complete flooding; however, for vertical pipes with downward flow this must be increased by fourfold.

The type of CIP regime is chosen to suit the nature of the soil and the sensitivity of the process step. For relatively low risk parts of the process, cleaning agents may be used more than once. All or part of the cleaning agent may be recovered, in which case these are referred to as total or partial recovery CIP system, respectively. The recovered fluids may be actual cleaning agents such as caustic soda or rinse water. In the case of recovered caustic soda the strength is monitored by the use of in-line conductivity probes and, where necessary, fresh reagent is added automatically from a separate supply tank. Water recovered from a final rinse may be recovered and used as the pre-rinse in the next cleaning cycle. In sensitive areas such as a yeast propagation plant or similar, where there is an enhanced risk if sterilisation is not achieved, the cleaning reagents are only used once. A similar approach may be used where there is a high concentration of CO₂, which is likely to result in high loss rates of caustic soda.

CIP treatments may be hot or cold. In brewing lore hot processes should be cleaned hot. There is a cost relationship between cleaning temperature, strength of the reagent, the mechanical energy expended and the duration of the clean. Generally water pre-rinses are applied cold. Caustic soda-based cleans in the brewhouse, wort paraflows, flash pasteurisers and areas with high soils such as fermentation yeast storage vessels are usually hot. Acid pre-rinses are applied cold because of the risk of corrosion to stainless steel.

Before commencing tanks and pipework must be empty, and similarly, at the end of individual stages, the rates of addition and scavenging must ensure total drainage so that there is no mixing of reagents; otherwise impaired performance may result. The sequences of events

are usually a pre-rinse to remove heavy soil, and after draining the circuit this is followed by a hot caustic detergent clean, which is allowed to circulate for up to 60 minutes. Alkali-based cleans may be neutralised by a short cold acid rinse. Finally a final cold rinse is applied. Where necessary this incorporates a **terminal sterilant**. In very sensitive areas total sterilisation may be guaranteed by a final treatment with anaerobic culinary steam.

Microbiological status may be checked at the end of cleans via conventional sampling and plating techniques.

CIP set

See **CIP**.

Citrobacter

Facultative anaerobic member of the Enterobacteriaceae and occasional contaminant and spoiler of worts. The name refers to the fact that some strains can grow on citrate as a sole source of carbon. The bacteria are motile rods, often borne in pairs, tolerant of hop acids but rapidly killed by high ethanol concentrations and therefore do not survive into beer. They ferment glucose via the mixed acid route and yield isocitrate, lactate, pyruvate and succinate. In addition, dimethyl sulphide is formed.

Clarity

A variety of proanthocyanidin-free barley.

Clark haze meter

Apparatus, now superseded, used for the detection and quantification of beer hazes and based on light scattering. Results were compared with standards based on suspensions of fuller's earth.

Clark unit

A unit used to quantify the hardness of water in the United Kingdom and equivalent to a mineral content of 1 grain of calcium carbonate per imperial gallon of water.

See **water hardness**.

Clay-coloured weevil

The clay-coloured weevil (*Otiorrhynchus singularis*) is a pest of hop plants and of many commercial fruit crops. Larval forms of the weevil can cause damage to the roots of plants, but the adult form is the most serious pest. The weevils shelter during the day in the soil at the base of plants. They emerge during the night to feed, and in the case of hops they can cause severe damage to young plants by checking growth as a result of the destruction of growing tips. Insecticide treatments are used to check numbers.

Cleansing system

See **dropping system**.

Cleansing tank

See **dropping system**.

Clean-Trace®

Proprietary system [made by Biotrace International, now part of 3M; <http://www.3M.com> (last accessed 25 March 2013)] for surface hygiene testing based on ATP bioluminescence, which uses disposable swabs that contain the necessary reagents and a portable luminometer.

See **ATP bioluminescence**.

CLEN medium

A selective medium for differentiating wild from culture yeast. The medium is similar to lysine agar, in which a nitrogen source is provided that the majority of brewing yeast cannot utilise. Multi-nitrogen sources are provided, cadaverine, lysine, ethylamine and nitrate, which in theory none of which can be utilised by brewing yeast but can be assimilated by a wider range of wild yeast compared to lysine alone.

Clerk's-ale

The name of a period of feasting, held in medieval England, usually held at Easter and associated with fund raising for parish clerks.

See **ale**.

Cling

The phenomenon, considered by most but not all to be desirable, in which a portion of the foam head of a beer attaches itself to the inner wall of the glass as the liquid level falls as the beer is consumed. It is also known as **lacing**. Approaches to quantifying cling are given in **lacing index** and **NIBEM-CLM cling meter**.

Clipper

A two-rowed variety of malting barley released for use in Australia in 1969/1970. It rapidly became a very successful cultivar based on crop yields and good malting properties. It has now been phased out in Australia but is still important in South Africa, the climate of which it is particularly suited to.

Closed square

Closed squares, in the United States often known as **box fermenters**, are fermentation vessels that were developed from the earlier open variety (see **open fermenter** for details). Essentially they are of similar design to open squares with the addition of an enclosing hood and a man-way door for access. They are bigger than open square fermenters, typically up to 500 hL, but very large examples up to 12,000 hL may also be found. They are usually made from stainless steel and are fitted with automatic CIP systems for good hygiene.

Attemperation is via external wall-mounted cooling jackets and usually an in-tank thermometer is fitted, the output of which can be used to regulate the supply of coolants in an automatic attemperation system. The vessels are conveniently grouped together in rooms separated by corridors into which the man-way doors and fittings for filling and emptying are located.

Closed squares can be used for both top- and bottom-cropping yeast strains. When used with the former yeast crops are removed via suction pumps. Gas jets may be played over the surface of the green beer with the effect of pushing the yeast head into the outlet point. When

used with bottom-cropping yeasts it is necessary to use a standpipe located in the base, which allows the removal of green beer without disturbing the yeast. The latter is then removed after the beer, either manually or via rinsing away with jets of water. The base may be inclined to facilitate yeast removal.

Clusters

Clusters is the name given to a popular US hop variety. As a group cluster hops are probably the oldest cultivars. The earliest varieties probably derived from hybrids between indigenous male plants and European imported types. They are divided into types, early and late Clusters. The former matures 10–14 days earlier, hence the name. Both types are vigorous, high yielding and have relatively high α -acid contents (5.5–8.5%) but low oil content (0.4–0.8%). Apart from some differences in susceptibility to disease both types are very similar. It is thought that Early Clusters are clonal selections of the Late Clusters variety. Modern types derive from a clonal selection programme that dates back to 1957. From 41 selections four clones were selected based on α -acid content and time to achieve maturity. By 1972 these four clonal types accounted for 80% of the total hop crop in Washington State.

Coagulable nitrogen

See **permanently soluble nitrogen (PSN)**.

Cobbs Goldings

One of the varieties of Goldings UK aroma hops selected in 1881 from a garden of Canterbury Whitebine on a farm owned by one John Cobb in Kent, UK.

See **Goldings**.

Cocculus indicus

The fruit of the plant *Anamirta cocculus*, also known as India Berry. The fruits are drupes approximately 1–2 cm in diameter and contain a sesquiterpene termed picrotoxin. The latter has a bitter taste and narcotic properties. Preparations of the crushed fruit, termed *hard multum*, were occasionally used as a beer adulterant and hop substitute.

Cockspur

A term used in malting which describes grains in which the acrospire has grown to a length greater than the overall length of the whole grain. These are generally undesirable since the grains may be rich in enzymes but low in extract.

Cocktail

A spring variety of malting barley that appears on the fully approved for brewing list of the UK-based Institute of Brewing and Distilling.

Coefficient of modification

See **index of protein modification**.

Coeliac disease

Coeliac disease (also known as gluten sensitive enteropathy [GSE]) is a genetically determined autoimmune disease of humans that is associated with intolerance to **gluten**. Symptoms are

diverse but most commonly are associated with malabsorption of nutrients in susceptible individuals. The reaction is most strongly elicited by the wheat **prolamin** gliadin, but other prolamins such as barley **hordein** may also cause a response. The condition is managed by adopting a lifelong gluten-free diet. For this reason most coeliacs are advised to avoid all beers. Whether or not this is entirely necessary is a question of dispute (see **gluten** and **gluten-free beers** for more details).

Cohobation

Cohobation is the process by which hop oils are extracted using steam distillation. The process is carried out such that the oil fraction, which is volatilised with the steam, is retained in a trap. The aqueous fraction, together with any uncondensed soluble components, is returned to the reservoir boiler.

See **hop extracts**.

Cohulupone

A products of the autoxidation of hop β -acids.

See **hulupones**.

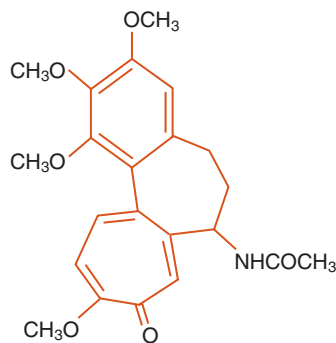
α -Cohumulone

α -Cohumulone is one of the principal hop-derived α -acids, which are the precursors of the bittering components of beer.

See **hop isomerisation**.

Colchicine

Colchicine ((S)-N-(5,6,7,9-tetrahydro-1,2,3,10-tetramethoxy-9-oxobenzo[*a*]heptalen-70yl)acetamide) is an alkaloid that is obtained from the corn and seed of the meadow saffron, *Colchicum autumnale*. It is used in medicine as a treatment for gout. Its relevance to brewing is that it disrupts mitosis in plants via binding to tubulin proteins and hence inhibiting microtubule assembly. For this effect it is used to induce the formation of tetraploid variants of hop plants. These are used as parents in crosses with normal diploid types to produce seedless **triploid hop varieties**.



Structure of colchicine

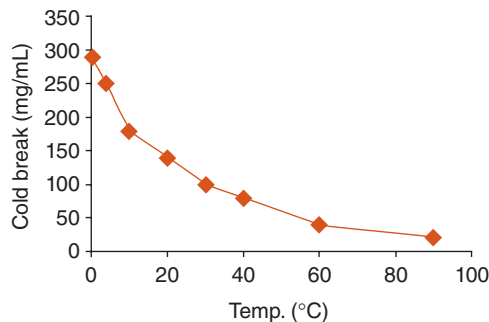
Cold break

Cold break is the solid material which is precipitated when wort, or beer, is cooled. It is similar but distinct from the **hot break**, or **trub**, which forms when wort is boiled. The gross composition of cold break is given in the following table:

Mean particle size (mm)	0.5–1.0
Protein (%)	45–75
Polyphenol (%)	10–30
Carbohydrates (%)	20–30
Ash (%)	2–3

Compared with hot break, the average diameter of the particles of cold break is much finer (0.5–1.0 mm compared with 30–80 mm). This is a consequence of the fact that cold break forms slowly as a finely divided precipitate as opposed to the relatively large flocs of hot break which form rapidly during wort boiling. The cold break contains significantly more polyphenols compared with hot break (10–30% compared with 5–10%). This is predictable since the hydrogen bond formed between the latter and proteins are unstable at temperatures greater than 80°C. Cold break does not contain appreciable quantities of lipid.

In terms of total quantities hot break is much more abundant than cold break (150–400 h/L compared with 5–30 g/hL); however, the quantity of cold break formed is dependent on the temperature, as shown in the following figure.



Graph showing the relationship between the quantity of cold break formed during wort cooling and the temperature

The quantity of cold break formed is influenced by the use of **kettle finings** such as κ -carrageenan. Although the latter is added to the wort in the later stages of the boil, it exerts its effects as an agent for protein removal during subsequent wort cooling.

The formation of cold break is a slow process and although its appearance is primarily associated with cooling hot wort, the process of precipitation continues throughout fermentation and into maturation. In this sense the formations of cold break and **chill haze** and **permanent haze** are intimately related.

In order to ensure that the finished beer has whatever is the specified degree of colloidal stability, it is necessary to remove a proportion of either (or both of) the protein or the polyphenol component present in the initial wort and which, if left, will contribute to hazes.

This may be achieved via simple cold storage and filtration or via the use of specific colloidal stabilizing agents. The cold break that forms during wort cooling contains a proportion of this material which must be removed at some stage in the brewing process. Whether or not it is desirable to remove cold break prior to fermentation is disputed. As with trub it is claimed by some that the presence of some break material in wort is desirable either as a source of yeast nutrition or to provide nucleation sites for CO₂ bubble formation and dissipation. Others insist that break confers no positive benefits and may be a source of off-flavours. In any case the uncontrolled addition of yeast nutrients, especially lipids from hot break, is likely to be a source of inconsistency in yeast growth during fermentation. The consensus view is that the absence of break produces beer with cleaner taste and the presence of excessive break leads to pitching rate errors, especially where it is removed selectively at the end of fermentation with bottom-cropped yeast. It is difficult to distinguish between the relative impacts on fermentation performance of hot and cold breaks, both of which may be present in variable amounts dependent on the processes adopted by individual breweries.

It is, of course, impossible to eliminate all cold break since, as discussed, it continues to form during fermentation. For this reason many brewers do not attempt to remove it. Others seek to remove as much as possible before transfer to the fermenter. Several processes may be used including filtration, sedimentation, centrifugation or flotation. Filtration, using kieselguhr or perlite is made more efficient by reducing the wort temperature to sub-zero values. This not only maximises the total quantity of cold break but also results in the formation of a slush which is easier to eliminate by filtration. Nevertheless, filtration is costly in terms of use of filtration media and leads to high wort loss rates. Simple sedimentation is the process used in a **coolship** (see entry for more detail). Probably flotation devices are most commonly used, at least by those brewers who seek to remove cold break. These comprise holding tanks located prior to the fermenter in which the cold wort is pumped. Commonly the wort is pitched with yeast, during or immediately after transfer to the tank as a precaution against microbial spoilage. A fine stream of air bubbles is admitted into the base of the tank. This generates a surface layer of foam into which the cold break collects. The layer of wort is carefully decanted, leaving the cold break behind in the tank. Aside from ensuring that the pitching yeast is evenly distributed throughout the wort, the process also provides a convenient means of aerating the wort.

Cold conditioning

A term used in relation to brewery-conditioned beers which are subjected to a period of storage at low temperature, typically -1 to -3°C . The aim of this is to allow complexes to form between potentially haze-forming proteins and polyphenols. Additional processing aids may also be added to promote precipitation of proteins and/or polyphenols. These complexes, together with any other solid materials, can be separated from beer to give a clarified product with an increased colloidal stability.

See **beer maturation**, **beer stabilisation**.

Cold contact process

This is a parented process used for the production of zero-alcohol beers. It relies on the restriction of fermentation by the use of a sub-zero fermentation temperature.

See **reduced-alcohol beer**.

Coldewe test

The Coldewe test is now a largely discontinued method used to determine the **germinative energy** of grains. It uses a piece of apparatus specifically designed for the purpose. This comprises a circular porcelain plate that contains regularly spaced perforations in which the grains may be placed. The plate fits into the upper part of a jar. The jar can be sealed with a lid. The grains are placed on the plate and the whole is located within the sealed jar. The top of the grains is covered with sand. Water is poured over the sand, which percolates through the plate and collects at the base of the jar. The lid and water reservoir help to keep the grains moist. The jar is held at a constant temperature (20°C) by placing it within a suitable incubator.

The number of grains that germinate during the course of the test can be assessed by examining the rootlets that grow and, in so doing, protrude through the base of the plate. In addition to enumerating the proportion of germinated grains the size of the rootlets gives some indication of vigour.

Cold sterile filtration

Procedure for rendering beer microbiologically stable by passing through a membrane with an absolute pore size, usually 0.45 µm. Implicit in the term is the fact that potential spoilage microorganisms are eliminated without the need for potentially flavour-damaging heat treatments. The process can be applied to any beer and packaging format. All process steps after the filtration step must be performed under aseptic conditions.

See **cold sterilisation**.

Cold sterilisation

Cold sterilisation is the process by which beer is rendered microbiologically stable by passage through a membrane, or a series of membranes, with pore sizes sufficiently small to exclude beer spoilage organisms. As the name suggests it is an alternative to processes such as pasteurisation, in which contaminating microorganisms are inactivated by the application of heat. As in the case of pasteurisation cold sterilisation does not guarantee absolute sterility; instead when conducted according to specification it reduces microbial loadings to an extent that it produces beer that will not spoil throughout its intended shelf life.

Cold sterilisation is considered beneficial in terms of beer quality since it avoids beer staling reactions which are promoted by the application of heat. However, by the same token it does not inactivate beer components such as proteases, which might derive accidentally via yeast autolysis or by design in the form of process aids. Proteases that retain activity in packaged beer have the potential to damage foam positive proteins. Cold sterilisation is technically challenging in that the brewer must have total confidence in the integrity of the filters. An essential part of their design and operation is to ensure that this confidence is well founded. Of course, once filtered the beer is susceptible to re-contamination in the subsequent process steps. It follows that the design and operation of the filling line must ensure that this does not happen.

Cold sterilisation of beer via filtration has been practised for some considerable time. Historically the process was performed using asbestos filters. Understandably the use of this dangerous material for this purpose has been discontinued. A few brewers use sterilizing sheet or depth filters; however, modern systems are usually based on cartridges where the filter elements are either depth types or membranes with defined pore sizes. Depth types are made

C from media such as cellulose, cellulose acetate, glass fibre, nylon, polyester and polypropylene. In the case of absolute filters a pore size of $0.45\mu\text{m}$ is usual. Membranes with smaller pore sizes would provide greater security; however, these may affect beer quality by removing a proportion of those components responsible for colour, foaming potential or even gravity. Membranes are made from materials such as PES or PTFE.

The cartridges take the form of cylindrical rigid plastic supports that contain the filter material. The dimensions of typical cartridge filter elements are 250 mm in length and 70 mm in diameter. The filter surface takes several forms, depending on the type of medium. For absolute types the sheet filter is folded or pleated to provide a large surface area. Depth types contain layers of filter medium often of varying porosity from the outer to inner core. This arrangement serves to sieve out larger particles first, which protects the finer inner portion, which is required for the sterilisation duty.

The cartridges are fitted with 'o' rings that seal the connection with process pipework. Cartridges are placed in stainless steel enclosures either singly or in multiples, depending on the required flow rate. The enclosures protect the cartridges and provide routing and a sterilisable environment.

In practice the sterilizing process is carried out after primary filtration and, possibly, in-filter colloidal stabilisation. The primary filter may be a powder type of possible crossflow. In either case, as already discussed, cold sterilisation does not guarantee total removal of microorganisms, and a well-managed process should ensure that microbial loadings pre-sterilisation are as low as possible. Typically sterilisation filters are used in series. A common arrangement would be an initial trap filter to prevent forward flow of larger particles such as filter powder. This would be followed by two absolute filters with cut-off values of 1 and $0.45\mu\text{m}$, respectively. Possibly a depth-type polishing filter might be located between the trap and the first sterilizing filter.

Failure of the sterilizing system at any stage in production would carry potentially catastrophic consequences. It is essential, therefore, that the brewer must be able to guarantee correct operation at all times. This requires a combination of careful installation, preparatory checks, correct operation and proper cleaning and maintenance. After correct installation of the cartridges, paying particular attention to the condition of the sealing 'o' rings, the system must be sterilised. The latter is achieved by treatment with hot water, steam or chemical sterilants. After rinsing with sterile water, or draining the system depending on the sterilisation regime, integrity tests are performed. These involve sealing the inlets and outlets of the system followed by pressurisation of the system of cartridges. Pressure gauges are fitted before and after each element of the filtration system. These are used during the filtration process to check on proper operation. If the pressure differential between the inlet and the outlet exceeds a specified value, this indicates a malfunction and the cartridge should be replaced. In the initial integrity testing phase the rate at which the pressure decays over a specified time period is monitored. If the pressure decay curve is greater than specified this is indicative of a leak and highlights a potential point of entry for microbial contamination, which requires attention before filtration can proceed.

After use the filters are cleaned according to the instructions of the manufacturer. This might be simple flushing with hot water with or without the addition of chemical agents such as hydrogen peroxide, peracetic acid or sodium hypochlorite. In some instances periodic treatments with dilute alkalis and acids are recommended.

In addition to monitoring trans-filter pressure differentials during filtration runs, samples should also be taken pre- and post-filter and checks made of microbial loadings. In both cases, if values exceed specifications, this would prompt remedial actions to be taken. Of course, because of time constraints the results of these tests are likely to be of historical interest only. It would be considered prudent therefore to carry out further microbial testing on packaged products. This might take the form of keeping batches of the product on hold before release to trade in order to give time for microbial results to be obtained. In addition, further microbial testing of packaged product would also be undertaken. This has the advantage that the microbial integrity of the whole of the filling and packaging operation is assessed.

Cold water extract

The cold water extract is a parameter used to assess the quality of malt. It is most commonly used by UK ale brewers. It is also referred to as the **preformed solubles (preformed sugars)** or **matters soluble**. It is a measure of the pool of soluble substances that can be extracted from samples of ground malt by treatment with cold water. It follows, therefore, that it provides a measure of the water soluble pools of compounds that were present in the original barley and more significantly, those compounds that were liberated by the processes associated with germination that occur during the malting process. As such it is taken to be a measure of **malt modification**.

The method involves subjecting a sample of ground malt of known weight to an extraction process using a fixed volume of water at a temperature of 20°C and for a controlled period of time. The water is made alkaline to inactivate malt enzymes. The specific gravity of the aqueous extract is measured and this is used to calculate the cold water extract, expressed as a percentage of the total weight of malt.

The use of cold water extract values is now rare since correlations with other measures of malt modification are poor. The hot water extract value is of much greater significance in judging malt quality. However, the cold water test is relatively easy to perform and it is used by some maltsters to select malt for the production of high-colour varieties. In this case a high cold water extract value is indicative of high amino acid and sugar content, which in turn favours the formation of melanoidins during kilning.

Cold wort clarification

Methods that are used (if practised) to remove solid break materials from wort prior to fermentation. Several approaches can be taken. A relatively crude procedure where cylindrical fermenters are used is to wait until approximately 24 hours after pitching and take off and discard the solid material which forms as a sediment in the cone. Other methods are applied to cooled wort before pitching, for example, **cold wort flotation**. Apparatus such as **continuous centrifuges** and **cross flow filtration** can be used to recover the wort entrained in break materials.

Cold wort flotation

Cold wort flotation is a technique used by some brewers (probably now rarely) as a means of combined aeration and cold break removal.

See **cold break**.

Collection gravity

Wort concentration measured at the completion of fermenter fill.

See **wort collection**.

C

Collection time

See **wort collection**.

College-ales

College-ales were festivals held at particular colleges of English universities which had their own on-site breweries. The tradition was particularly associated with the Universities of Oxford and Cambridge.

Colloidal stability

The colloidal stability of beer refers to its propensity to form non-biological hazes as a consequence of interactions between beer components, particularly polyphenols and proteins, leading to the formation of visible precipitates.

The majority of beers are required by the consumer to be free from suspended solids and to have a brilliant and clear appearance. Beer clarity is dependent upon a number of factors. Microbial spoilage can lead to the formation of visible hazes or other manifestations of growth. These are biological hazes and are considered elsewhere in this book. Suspended solids can also arise from raw materials used in the brewhouse, from process aids used in the brewing process or via accidental contamination. Proper management of the brewing process should ensure that the risk of accidental contamination is minimised. Various other non-biological hazes other than those derived from proteins and polyphenols can arise during the brewing process. These include hazes due to the formation of precipitates of calcium oxalate and those that are derived from cereal carbohydrates such as pentosans and α - and β -glucans.

Apart from these sources of haze, which are essentially preventable, the formation of solid material during the brewing process and in finished beer is inevitable. It is this property of beer that is described by the term colloidal stability and which is described here. A proportion of the solid material suspended in worts or beers which is already present or formed as a result of brewing processes is removed at various stages which incorporate separation steps. These include lautering or mash filtration, whirlpooling and the formation of tank bottoms. The fraction that persists to the end is removed in the terminal filtration step. Nevertheless, beers are inherently unstable and the formation of non-biological haze material continues after packaging. The colloidal stability of packaged beer is dependent upon the concentration of haze precursors in the raw materials, the proportion that is extracted into the wort minus the fraction that is removed during the brewing process. With regard to the latter the nature of the plant used and its method of operation are influential. Factors that promote haze formation include heavy metals ions, excessive agitation of beer, exposure to oxygen, exposure to light and exposure to heat (pasteurisation).

The protein and polypeptide fraction of worts or beers that are involved in haze reactions with polyphenols are referred to as **sensitive proteins**. These can be determined by measuring the proportion of protein which is precipitated with the polyphenolic material tannic acid, hence the term sensitive. With regard to the polyphenol component of hazes both concentra-

tion and the degree of polymerisation are important. When beer is chilled to below 0°C a haze forms as a result of binding between small polymerised polyphenols and proteins. The binding is via weak hydrogen bonding, and when the beer is warmed up again (to 20°C) the aggregates dissociate and the haze disappears. This haze is referred to as **chill haze** or **temporary haze**. When the beer is stored for a longer period further polymerisation of polyphenols occurs, and these much larger molecules form stronger covalent bonds with sensitive proteins and the resultant hazes do not dissolve when the beer is warmed up. These are referred to as **permanent haze**, and it is these which form in packaged beer over relatively long time periods.

The precise chemistry of haze formation remains a subject for debate. Haze composition is complex. The protein content is approximately 45–65%. The hydrolysate of this fraction contains a high proportion of proline, arginine, aspartic and glutamic acids. The phenolic fraction contains ferulic, sinapic, vanillic, syringic, gallic, protocatechuic and caffeic acids. Since ferulic, vanillic, sinapic and syringic acids do not occur in malt or hops it is assumed that these must derive from the lignin component of barley straw (6–8% of the total haze complex). The ash component of haze material (total 0.5–3.5%) is rich in metals such as aluminium, copper and iron. There are also traces of pentoses, arabinose and xylose and up to 4% glucose.

Haze active proteins and polypeptides that persist through the brewing process from wort to beer are derived from barely hordeins and prolamins. They are rich in proline. The evidence suggests that proline is required for haze formation. The propensity of proteins to form hazes correlates positively with proline content. An important practical consideration is that stabilisation treatments designed to remove haze-forming proteins must not produce collateral damage by also removing those proteins that are required for foam formation. Antibody studies have shown that those raised against foam-active proteins have shown no cross-reaction with other protein fractions. However, antibodies raised against haze proteins show some cross-reaction with foam proteins. This reflects the possibility that foam-active globulins and albumins might form loose associations with the high proline-containing fraction derived from malt hordeins.

With regard to the polyphenolic component of hazes the degree of polymerisation is important; thus, dimers and trimers are much more haze-active compared with monomers. Thus, the so-called proanthocyanidins and other flavanols are important precursors (see **wort composition, polyphenols**). Polymers greater than trimers do not survive the brewing process, but they can form during beer storage as a result of oxidation reactions and this explains why hazes can develop with age in otherwise clear beer.

The chemical nature and the total and relative concentrations of both proteins and polyphenols are influential in haze formation. This has been ascribed to the numbers of binding sites available for cross-linking and consequent formation of large complexes. An excess of either protein or polyphenols produces an imbalance in binding sites such that extensive binding and agglomeration formation is not favoured. Where both components are present in roughly equal concentrations the numbers of respective binding sites are balanced and cross-linking continues to proceed and very large complexes are formed.

An essential part of brewing is to ensure that the precursors of colloidal hazes, polyphenols and/or proteins are reduced in concentration such that the clarity of the beer remains within a desired specification throughout its intended shelf life. The treatment, which can be used to remove haze precursors, is collectively termed **beer stabilisation**. Stabilisation processes incur

a cost and therefore, the extent of the treatment correlates positively with the desired shelf life. In the case of large-pack keg beers where the desired shelf life is measured in weeks the treatment can be comparatively slight. In the case of small-pack bottled or canned beers where a shelf life of several months is required the extent of stabilisation treatments needs to be commensurately greater.

Several stabilisation treatments are possible. The formation of insoluble complexes between polyphenols and proteins occurs spontaneously, albeit slowly, at low temperatures. In traditional brewing practice beer may simply be stored in the brewery at a low temperature for a period which may extend from a few days to several months, for example, the practice of lagering by which lager beer obtains its name (see **lager**, **secondary fermentation** for more details). In this case, provided the beer is kept cold during subsequent filtration, the haze material formed during the storage phase is removed and the clarified beer has acceptable colloidal stability.

In order to shorten this storage phase and to avoid some of the costs associated with it more proactive strategies are employed. These involve the treatment of beers with process aids that are designed to remove the proteins or polyphenols which are responsible for haze formation and colloidal instability. Collectively these are known as beer stabilizing agents. Several are in common use and these are described in more detail elsewhere in this book (see individual entries). In the case of proteins and polypeptides, proteases such as **papain** can be used to degrade them or they may be adsorbed onto **silica gel** or precipitated with **tannic acid**. Polyphenols can be adsorbed onto polyvinylpyrrolidone (**PVPP**).

The formation of colloidal hazes at low temperatures is made reference to in the term **chill haze**. By inference the period of storage at low temperature and cold filtration to remove chill haze is referred to as **chill-proofing**. This terminology has now been extended to include treatments with the process aids described in the last paragraph, and collectively these are referred to as **chill-proofing agents**.

The protein precursors of hazes are derived largely from barley, whereas the polyphenol components are derived from both barley and hops. In both cases it follows that the haze precursors are present from the start of the brewing process; thus, they may be removed at any stage and, indeed, they are. A proportion of the total polyphenols and proteins are precipitated during the wort boil as trub or **hot break**. More of the material is lost at wort cooling in the form of **cold break**. Proper management of the brewing process should ensure that as much as is possible of this break material is separated from the wort before fermentation. Process aids such as the kettle fining agent, **κ-carrageenan**, assist in the formation of cold break. Further cold break material is deposited throughout fermentation. The greatest proportion is formed in the conditioning phase where the temperature is reduced to a low value. In this regard the lower the temperature, the more colloidal material is removed. Thus, in conventional lagering processes temperatures close to 0°C are usual. For modern rapid cold conditioning temperatures of -1 to -3°C are used with a total exposure time of 1-3 days. Stabilisation agents can be added to conditioning tanks; alternatively, they can be added immediately before or during filtration.

Colony

An agglomeration of microbial cells growing on the surface of solid media. Microbial cell suspensions, such as those of yeast, are streaked onto the surface of a nutrient medium solidi-

fied with agar in such a way that individual cells are separated. After incubation the cells proliferate to form a colony. Since the colony developed from a single cell it can be assumed that all individual cells within it are clones of the original. This provides a convenient method for obtaining and handling pure cultures. The shapes and colours of yeast colonies may differ between individual strains and colonial morphology can have diagnostic significance.

Colony-forming unit (CFU)

See **yeast viability**.

Columbanus of Ghent

A patron saint of brewers associated with Belgium. Columbanus was a seventh century Irish monk who travelled and settled in continental Europe possibly as a result of Norse encroachments in his native country. As with many such patron saints he is credited with many miracles in which water was turned into beer. In a historical sense it has been argued by some that monks such as Columbanus possessed much knowledge of organised brewing and, as a result of their evangelizing perambulations, were responsible for the dissemination of these skills in the locations in which they founded new monasteries.

Columbus

Columbus is a US hop variety bittering hop (14–16% α -acids). It is sold under the trade name of **Tomahawk**. It has a good aromatic character (1.5–2.0 mL/100 mL total hop oil), which makes it attractive to some brewers for use in dry hopping. Together with **Cascade** and **Centennial** it forms one of the ‘3 Cs’ of US hops.

Colupulone

Colupulone is one of the principal components of the β -acid fraction of the soft fractions of hop resins.

See **β -acids, hop resins**.

Combrune, Michael

Michael Combrune was an eighteenth century UK brewer. He was remarkable at that time for his desire to introduce scientific principles to brewing. His publications, *An Essay on Brewing* (1758) and *Theory and Practice of Brewing* (1762), describe this early scientific endeavour. In particular, chapter 5 of the second of these publications, entitled ‘On the Thermometer’, provides the evidence as to why he is largely credited with the realisation that accurate control and measurement of temperature is a vital prerequisite for the proper control of the brewing process.

Comité Bière Malt Orge (CBMO)

French Barley Malt and Beer Committee, the organisation that oversees the accreditation of new malting barley varieties for use in France.

Commander

An Australian malting barley variety developed by the University of Adelaide barley breeding programme and accredited in 2009. It is mid- to late-season maturing and is described as very high yielding and producing very plump grains.

Comparamill

The Comparamill is a small-scale laboratory mill designed to determine the energy required to be expended in order to mill a sample of barley or other cereal. The device consists of a small milling chamber in which rotating knives provide the methods of disruption. The mill is activated and when a flywheel attached to the drive shaft of the motor has reached a pre-determined rotational speed, the motor is switched off and the charge of dry goods allowed to enter the mill chamber via a top-mounted hopper. A microprocessor measured the rotational speed of the flywheel. This is measured and recorded at the time when the charge is added to the mill and subsequently at two further known times after the deactivation of the motor.

The time intervals are set such that after completion of the second period, the grist has been reduced to a fine powder. The microprocessor determines the loss of energy at each time period. The resistance to grinding is taken as the energy needed to achieve the grind. It is claimed that there is a positive correlation between milling energy, grain nitrogen content and hot water extracts.

Compartment maltings

A generic name given to a vessel used for the germination stage of malting which has a rectangular or circular configuration and is provided with a means of loading, automatically turning the grains, forcing a flow of conditioned air through the bed and emptying the grain, termed stripping, prior to transfer to the kilning stage. The term box malting is also used for those with rectangular geometry. The typical representative of vessel of this type is the **Saladin box**.

Compatible solutes

Compounds produced by cells, including yeast during fermentation, as a response to osmotic shock. Examples are neutral polyols including arabinol, mannitol, erythritol, sorbitol and **glycerol**. The latter is of importance in brewing since it may accumulate in concentrations of up to 2 g/L and makes a significant contribution to beer sweetness and mouthfeel.

When cells are suspended in hyper-osmotic media a stress response is initiated, which results in the intracellular accumulation of compatible solutes. In effect these balance the internal and external osmotic forces and prevent water passing into cells and possible lysis. This phenomenon is well recognised in xerotolerant organisms such as *Saccharomyces rouxii*, the potential spoiler of sugar syrups. Brewing yeast strains are less well adapted to these stresses and are unable to retain all glycerol in the cell, and for this reason a proportion arises in beer. Concentrations increase with an increase in wort gravity.

Compression hop jack

See **hop separator**.

Concerto

A spring variety of malting barley which, as of 2011, appears on the provisionally approved for brewing list of the UK-based Institute of Brewing and Distilling.

Condensed tannin

Condensed tannins are polymers of **flavanols**. They are also termed **proanthocyanidins** (or **anthocyanogens** in brewing literature). They are distinguished from hydrolysable tannins in

that they are made up of flavonoid monomers, the bonds of which are not susceptible to cleavage by acid hydrolysis. They form the polyphenol components of beer hazes via reaction with proteins.

See **colloidal stability, polyphenols**.

Condensing font

A font for dispensing beer which, when in operation, is designed to develop beads of condensation on the visible metal surfaces. The intention is to enhance the aesthetic appeal of the branded font and thereby to entice consumers. The units depend on the circulation of a coolant such as glycol supplied by an external chiller.

Condition

The term condition is used as a noun to describe the degree of carbonation of a beer. The term is also used as a verb to describe processes that are applied during the maturation of beer. Since these latter processes incorporate, at some stage, the adjustment of carbonation, the linkage between these usages should be apparent.

From a maturation standpoint additional qualifying terms provide more detail of the processes that may be applied. Thus beers may be matured within the brewery, termed **brewery conditioning**, or they may be matured in the final large- or small-pack container from which they are dispensed, termed **cask** or **bottle conditioning**, respectively. In the latter two examples the utilisation of fermentable sugars by yeast in the container generates CO₂, or condition, in the beer.

In the case of brewery-conditioned beers, **warm conditioning** describes the period at the end of primary fermentation where green beers are held for a period of time in the presence of yeast. The aim is to ensure that essential yeast-catalysed beer flavour maturation steps are given the time and appropriate conditions to occur. In particular, the reduction to sub-flavour threshold levels of the undesirable flavour component diacetyl.

Cold conditioning describes the period of storage at cold temperatures which has the aim of allowing potential haze-forming compounds, proteins and polyphenols to form complexes and, together with other solid materials, to form sediments at the base of tanks. The cold-conditioned beer, which has less tendency to form hazes, may be separated from the sediment by decantation.

Conditioned dry milling

Conditioned dry milling is the name given to the process in which malt and other cereal grains are subjected to a controlled wetting process, termed conditioning, immediately before **milling**. The intention is to increase the pliability of the husk but to ensure that the interior remains dry and brittle. This arrangement allows the milling process to abrade and degrade the interior structures of the grain so as to ensure adequate yield in the subsequent mashing process; however, it leaves the separated husks relatively intact and hence provide a good bed through which the sweet wort may be filtered in the mash separation step.

The controlled wetting process is performed using either steam or warm water. Exposure times are short, usually 1–2 minutes, which results in an increase in the moisture content of the husks by no more than 1.5–2%. The wetting treatment is carried out as the grain is

delivered to the mill. The transporting step is accomplished using a mechanical conveyor, termed a conditioning screw, which is located within a heated casing.

Compared with conventional dry milling the conditioned material requires a finer setting on roller mills. On the basis of sieve tests the conditioned husk fraction is increased by approximately 30%. Understandably the spent grain fraction increases in volume, but this is set against claimed improvements in yield, faster saccharification and increased attenuation.

See **milling**.

Conditioning

Term used in relation to maturation processes applied to green beer, usually a period of storage at cold temperature, with the aim of improving colloidal stability.

See **beer maturation**.

Conditioning screw

See **conditioned dry milling**.

Conditioning tank

A vessel used for holding green beer for a period of time at low temperature primarily to allow the formation of protein, polyphenol precipitates and thereby improve the colloidal stability of the beer.

See **colloidal stability**.

Conduit

See **python**.

Congress mash

The congress mash describes a standardised programmed temperature rise mashing procedure defined by the EBC (*EBC Analytica*, Method 4.5.1 Extract of Malt: Congress Mash). It is used for the assessment of the potential of malt to produce wort solubles using a standardised mashing procedure. The method is used as the basis of other assessments of malt quality such as saccharification rate, odour, wort viscosity, total soluble nitrogen and free amino nitrogen.

Duplicate samples (55 g) of malt are subjected to a standardised grind using a Bühler–Miag disc mill and a gap of 0.2 mm. The ground malt is suspended in 200 mL water at 45°C. After holding for 30 minutes the temperature is raised at 1°C/min for 25 minutes. After this time when the temperature has reached 70°C, a further 100 mL of water, previously attemperated to 70°C, is added. The mash is held at this temperature, and at intervals of 5 minutes samples are removed and the degree of saccharification assessed. This is accomplished by mixing a drop of the mash with a drop of iodine on a porcelain spot plate. The appearance of a yellow colour indicates that saccharification is complete. The time at which this occurs is noted. If this has not occurred after 60 minutes the test is discontinued and the result noted.

After holding for 1 hour at 70°C the mash is cooled to room temperature and water added to give a total mash weight of 450 g. The diluted mash is filtered through a specified standard paper. The first 100 mL of filtrate is recovered and returned to the filter funnel. The total

filtration time (when the cake appears dry) is noted and recorded as being 'normal' (completed within 1 hour) or slow (>1 hour). The colour and aroma of the filtered mash are noted. The specific gravity of the wort is determined using a pyknometer or a density meter.

Conical divider

Device used for obtaining representative samples of cereal grains.

See **grain samplers**.

Coning and quartering

Coning and quartering is a method used to obtain a sample of grains that is representative of the whole.

See **quartering iron**.

Conlon

A two-rowed variety of malting barley which was added to the recommended list of the **American Malting Barley Association Inc.** in 2000.

Conrad

A two-rowed variety of malting barley which was added to the recommended list of the **American Malting Barley Association Inc.** in 2007.

Continuous centrifuge

Two types of continuous centrifuge are commonly used in brewing clarification operations. These are the **self-clarifying disc stack** type and the **decanter centrifuge**. The former consists of a bowl that contains a number of parallel rotating discs – the disc stack. The beer is fed in via a point located at the top of the bowl. The large number of rotating discs increases the total surface area available for separation and presents a very short path length, typically 0.5–2.0 mm, for sedimentation of suspended particles. The latter accumulates on the plates and is forced to the periphery where it collects on the inside of the bowl. Clarified beer moves inwards towards the centre of the bowl where it is collected and pumped out of the centrifuge. In self-clarifying centrifuges the bowl is constructed so that it contains a join around the rim. At intervals the join is opened and the accumulated solids are discharged from whence they can be collected for further processing. The ejection of solids may be a simple time-based operation or there may be a more sophisticated automatic solids sensing system fitted. These may use optical sensors that monitor the clarity of the out-flowing beer and in response adjust automatically the solids discharge. Alternatively, they may use a differential pressure sensor that measures the accumulation of solids in the bowl and activates the discharge cycle when a predetermined value is reached.

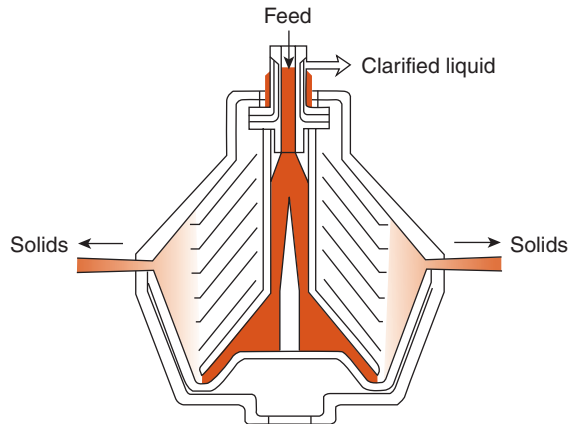


Diagram showing a section through a continuous disc stack centrifuge

Continuous disc stack centrifuges are useful for clarification operations which may be carried out in-line during tank-to-tank transfers. A typical application is the removal of yeast and other solids during transfer from the fermenter to the conditioning vessel. In this application it would usually be referred to as a **green beer centrifuge**. Alternatively, continuous centrifuges that are capable of generating much higher g forces might be used in-line between conditioning vessels and filtration. These are used to reduce solids loadings with the aim of extending filtration runs. In comparison to green beer centrifuges the particle sizes required to be removed post-conditioning and pre-filtration are relatively small non-yeast particles. For this reason these high-speed devices are commonly referred to as **protein centrifuges**.

Depending on their size, speed and the nature of the solids loadings, continuous disc stack centrifuges are operated at flow rates of approximately 50–750 hL/h. They are particularly suited to clarification operations where the feed contains a relatively low and consistent solid content. Modern versions are capable of producing a fairly dry discharge which is relatively easy to process and which minimises beer losses. They are of all stainless steel construction and they are easily cleaned and can be sterilised.

They do have some disadvantages. There is some heat pickup during centrifugation due to the frictional forces involved. Consequently, it is necessary to cool the in-flowing beer to 1–2°C below the desired post-centrifugation set-point. Alternatively, a post-centrifugation trim chiller may be used. Centrifuges are very noisy and appropriate ear defenders must be worn by operators. In order to help with noise insulation, the centrifuges are usually located within a dedicated room. Older centrifuges were not well sealed and this was a common source of oxygen pickup. More modern designs are hermetically sealed and this should not now be a problem. They have a very high energy demand. Loads on motors are very high during initial start-up because of the need to overcome inertia. Similarly, after discharge the relatively large volume of in-flowing beer required to replace that occupied by the solids produces a heavy load on the motor. Energy requirements for centrifuges are typically 0.32 MJ/h.

Decanter centrifuges are designed for clarifying liquid feeds with relatively high solid contents such as might be found in tank bottoms. The decanter centrifuge consists of a rotating bowl into which the unclarified liquid is fed. The centrifugal force separates the heavier solids

from the liquid. A rotating scroll conveys the separated solids to the tapered end of the centrifuge where they are discharged. The clarified liquid flows out at the other end of the bowl. Decanter centrifuges are not capable of handling the high flow rates associated with decanter centrifuges. Typically they operate at flow rates of 30–50 hL/h. However, they can clarify liquids with solid contents of up to 60% by volume.

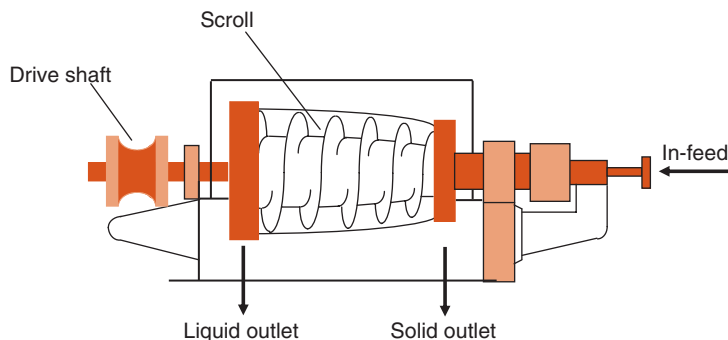


Diagram showing the essential features of a decanter centrifuge

Continuous fermentation

Continuous fermentation is an alternative to the more usual batch method and, as the name suggests, one that generates a constant supply of product (green beer) in response to a constant supply of feedstock (sterile aerated wort). The transforming microorganism, yeast in the case of brewing, is confined within the reactor, usually at a higher concentration than that used in batch fermentations, and is not allowed to escape with the product stream. The constant supply of fresh growth medium ensures that there is no lag phase, the organism remains in a state of exponential growth, and conversion to product is rapid and efficient.

Continuous fermentation in brewing has a long history and indeed patents describing such processes date back to the end of the nineteenth century and the first decades of the twentieth century; however, it became very popular during the 1960s and 1970s when it was seen by many of the then major brewers as an excellent response to the need to supply very large volumes of big brand beers. During those years several brewing continuous fermentation systems were designed, built and used in commercial brewing. Very few of these are still in existence.

For most brewers the disadvantages outweigh the supposed gains and batch fermentation remains predominant. The advantages are that there is always a constant supply of green beer available for finishing. Conversion times from wort to green beer are short since it is possible to use a high yeast concentration and the product shows a high degree of consistency. The unit costs associated with batch fermentations (emptying, cleaning, etc.) are much reduced as are beer losses. The costs of the continuous fermenters are more than offset by those associated with the purchase and management of large complex tank farms. On the debit side, continuous systems are technically complex and require 24-hour skilled technical assistance. Start-up times are long as are downtimes in the event of failure. A continuous supply of wort is difficult in most batch brewhouses and the necessary storage of sterile wort is difficult and high risk. Although the rate of green beer production can be adjusted by the regulation of the rate of

wort supply, the practical achievable range is small and therefore large changes in demand are difficult to cope with. Continuous fermentation does not fit into the common scenario where a brewery at any given time needs to produce simultaneously several different beer qualities in varying proportions.

C

For a discussion of the theoretical aspects of continuous cultures see **chemostat, plug-flow fermenter**. From a brewing perspective the changes that occur during batch fermentation, when yeast grows on wort and beer is produced as a by-product, are essentially linear and time related. Nutrients are taken up in an ordered fashion. This is difficult to accomplish in a single growth vessel, and for this reason the majority of commercial continuous beer fermenters employ multiple tanks arranged in a cascade. In this way the linear processes are encouraged to proceed in subsequent tanks. An example of this approach is that devised by Morton Coutts in the 1950s and which is the only current system still in commercial use in what were the Dominion Breweries (DB) in New Zealand (see **Coutts, Morton W.** for details).

In recent years there has been a renaissance of interest in continuous fermentation processes largely as a result of the development of immobilised yeast technology. These comprise reactors that contain an inert support to which live yeast cells adhere. These are ideally suited to continuous processes since very high biomass loadings are achievable and no special provisions are needed to ensure that the cells are retained in the reactor. Although no full-scale commercial systems are currently in use for primary fermentation, a few reactor types are used in commercial brewing for rapid removal of diacetyl.

See **immobilised yeast**.

Continuous high-pressure wort boiling

These are systems of wort boiling which takes advantage of the fact that energy savings and better hop acid utilisation can be achieved by the comparatively high temperatures that can be achieved by increasing the pressure at which wort is heated. In continuous systems wort is allowed to pass through a series of heat exchangers which operate at progressively higher temperatures, typically up to 140°C. Total residence time in the hottest stage is approximately 3 minutes. The wort is subsequently cooled in expansion chambers during which volatiles are flashed off and the recovered heat may be used to offset the cost of heating the initial stages.

See **wort kettle**.

Continuous wort production

The majority of brewers use a process based upon distinct batches. This is considered advantageous since for most brewers there is some seasonal variation in demand. In addition, many brewers produce a portfolio of different beer types and, therefore, the batch approach is deemed most appropriate. In the latter part of the twentieth century, particularly during the 1970s and 1980s, the development of large national beer brands and relatively short conditioning and finishing times has led to considerable interest in the concept of continuous fermentation (see **continuous fermentation** for more details).

In order to support this concept it was considered desirable to develop continuous brew-houses. Bearing in mind the complexity of the nature and number of stages involved in the production of cooled bittered wort production it may be appreciated that fulfilling the requirements of a continuous brewhouse was by no means a trivial task. In particular, the

mashing, mash separation and boiling steps provided considerable technical challenges. Nevertheless, several designs have been proposed, patented and in some cases put into commercial breweries.

Continuous mashing systems are described in the entries for **APV continuous mashing system** and **Ullmann continuous mashing system**. A complete continuous brewhouse is described in the entry **Centibrew continuous wort production system**. Typically these rely on the replacement of conventional mash separation devices such as lauter tuns or mash presses with novel approaches featuring devices such as continuous centrifuges which by their nature lend themselves to continuous operations. Similarly in the case of wort boiling the usual method is to introduce a very rapid flash process using high temperatures followed by rapid cooling.

Despite the apparent suitability of some of these approaches to continuous wort production the concept has not seen much, if any, take-up. This has been due to several factors. The inherent complexity of the plant and consequent high purchase and maintenance costs compared with the supposed gains attracted few brewers. The need to store un-pitched wort represents a considerable hygiene hazard. In most cases the need to produce single brands does not arise, and therefore for most brewers the batch process remains the obvious choice. Indeed the only long-standing practitioner of continuous fermentation, DB Breweries of New Zealand (currently part of the Asia Pacific Breweries group), chose from the outset to use a batch brewhouse.

In recent years there has been something of a resurgence of interest in continuous fermentation and maturation fuelled by developments in the use of immobilised yeast. It is possible that this will be mirrored by a resurgence in interest in continuous wort production.

Contract brewing

Brewing beer on behalf of another company. The commissioning company will usually supply details of the ingredients, process conditions and specifications and deal with marketing issues. The contract brewer might supply bulk beer for packaging by the commissioning company or carry out this stage as well. Contract brewing is commonly carried out where volumes are such that they would not easily fit into the usually much bigger batch sizes used by the commissioning company or where the latter has closed its own facilities suitable for brewing more traditional brands.

Coolship

Coolships are shallow open cylindrical vessels used for cooling hot wort. In commercial breweries they have been superseded by closed wort cooling systems.

See **wort cooling**.

Coombes

An alternative term for **culms**.

Coping-up

Term used for the sealing of traditional hop pockets by sewing-up with strong twine.

See **hop pocket**.

Copper

Copper is the term used, particularly in the United Kingdom, for the kettle; the piece of brewery plant in which wort is subjected to a controlled process of boiling. The name reflects the fact that early manifestations were fabricated from copper. This metal was chosen because of its excellent durability, thermal conduction properties and the ability of the Cu^{2+} ions to take part in some desirable reactions such as the oxidation of thiols leading to the elimination of some sulphur compounds from wort and concomitant improvements in beer flavour.

The use of copper has been largely superseded by stainless steel. The latter has greater strength allowing thinner sheets to be used, and the appropriate grades are more resistant to caustic cleaning agents. Compared with copper, stainless steel has a smaller thermal conductivity and is less wettable and, in consequence, nucleated boiling is less favoured; however, the ability to use thinner sheets to some extent offsets the former disadvantage.

See **wort kettle**.

Copper adjunct

Copper adjuncts are sources of fermentable extract, other than malt, which are supplied in the form of liquid sugar syrups. They do not require any form of preprocessing other than sterilisation, and for this reason they may bypass the mashing stage of wort production and be added directly to the copper (kettle).

See **adjuncts**.

Copperas

See **green vitriol**.

Copper finings

See **kettle finings**.

Copper oxychloride

Copper oxychloride ($\text{CuCl}_2 \cdot 3(\text{CuOH})_2$) is a copper-containing fungicide used for the treatment of diseases of plants including downy mildew in hops. It is less phytotoxic than the more common **Bordeaux mixture**, for which it is often used as a substitute.

Coriolis flow meter

See **flow meter**.

Corn cutter

See **farinator**.

Corn sugar

A synonym for glucose (dextrose). Corn sugar syrups are used as liquid adjuncts and are preparations of glucose prepared via the hydrolysis of corn starch.

See **adjuncts**.

Couch frame

A rectangular flat-bottomed structure used in nineteenth century UK floor malting to contain a piece of steeped grains. The use of the couch frame was a mandatory requirement since it was used to assist in gauging quantities for tax purposes. Their use was discontinued in 1880 following changes in legislation.

Couching

Term used in traditional floor malting where the grains are manually moved into heaps after steeping is completed. The packing together of the grains allows an increase in temperature and thereby promotes germination. The heaps of grains are referred to as couches.

See **floor malting**.

Coulter counter

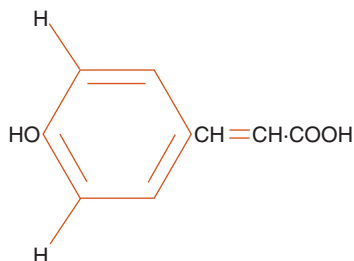
A counting device used for the automatic enumeration and sizing of particles. In brewing applications it is commonly used for determining the concentrations of suspended yeast cells in process fluids where precision and assessment of viability is not critical. Typically the device comprises a chamber into which the sample suspended in an electrolyte is introduced. The chamber contains a partition which is pierced by microscopic orifices. As particles are forced through the orifices they cause a momentary change in electrical resistance that allows a count to be made and the magnitude of which allows an evaluation of size.

Coulter counters are useful for routine analysis of yeast counts in green beer where numbers are small and viability is not important. They are not capable of discriminating between live and dead cells, and non-yeast particles of similar size to yeast cells can interfere.

p-coumaric acid

A simple phenolic compound, one of the series of substituted cinnamic acid derivatives, which is found in worts (see accompanying diagram for structure). Concentrations in an unboiled lager wort are reported to be of the order of 0.6 mg/L.

See **polyphenols, tannic acid**.



Structure of p-coumaric acid

Counter mount

A generic expression in the retail industry used in the **on-trade** to describe an unbranded (often stainless steel or plastic) unit attached, usually with a clamp, to the bar top, containing a beer line to a single **dispense tap** and often a plastic drainer or **drip tray**. Counter mounts are typically branded via a tap marker or counter mount surface which faces the consumer.

Coutts continuous fermentation system

See **Coutts, Morton W.**

Coutts, Morton W.

Morton Coutts (1904–2004) was a New Zealand-born brewer most noted as a pioneer of continuous brewery fermentation. Coutts took over the running of a family owned brewing business in Taihape, New Zealand after his father became permanently incapacitated in the 1918 influenza pandemic. The company eventually became part of Dominion Breweries and from 2004 part of Asia Pacific Breweries.

The Coutts continuous method was developed during the 1950s and is the only extant complete continuous beer fermentation system at the time of writing. It comprises a multistage cascade of tanks. Wort is boiled and clarified by storage at 0°C followed by removal of the resultant cold break. The low temperature prevents the growth of many chance microbial contaminants. Clarified wort is pumped into the first holding tank where it is oxygenated and pitched with actively growing yeast recycled from later in the process. The strain is a flocculent type that assists with clarification at the end of the process; however, in order to ensure it remains in suspension and has intimate contact with wort all fermentation vessels are provided with mechanical agitators. From the hold-up tank the mixture of fermenting wort and yeast is pumped into the main fermentation vessel. This occupies 60% of the total volume of the whole system and it is where the bulk of the primary fermentation takes place. Some of the contents of this vessel are recycled into the holding tank, a procedure said to reduce the stress applied to the recycled yeast when first exposed to fresh wort.

The nearly fermented beer then passes into a third vessel that occupies around 30% of the total system volume. Here the primary fermentation is completed. The green beer now passes into a smaller separation vessel. This is unstirred and has a conical bottom into which the flocculent yeast forms a sediment. Some of this yeast is recycled, as described, the excess is removed and the entrained beer recovered and returned to the process stream. The partially clarified green beer is then transferred to maturation tanks for diacetyl reduction and finishing. Relative retention times in each vessel are 3–4 hours (hold-up tank), 30 hours (fermentation vessel 1) and 12 hours (fermentation vessel 2).

In order to cope with the demand for different beer qualities a single base beer is produced and a degree of differentiation introduced by treatments applied during the finishing stages.

The fermenters have been highly successful based on the number of awards accrued by the company. Individual fermentation runs can last for more than 1 year without the need for shutdown.

Crabtree effect

An effect first observed and described by Herbert Grace Crabtree in 1928 working with cancer cells in which the addition of a pulse of glucose resulted in a reduction in rates of respiration. It is of relevance to brewing since it also occurs in *Saccharomyces* yeast strains. Thus, when yeast is growing on a medium with high sugar concentration, such as wort, ethanol is always a major end product of metabolism irrespective of whether the conditions are aerobic or anaerobic. This would apply, for example, in the initial aerobic phases of fermentation or during propagation using wort as a feedstock. It follows that under these conditions metabolism is never respiratory and energy transduction via oxidative phosphorylation does not occur.

Two underpinning mechanisms have been implicated. In the first, the 'short-term Crabtree effect', which most closely relates to the Crabtree effect proper, it is considered, in yeast at least, that control is at the enzyme level such that pyruvate dehydrogenase has a higher affinity for

pyruvate compared with pyruvate decarboxylase. At low glucose concentrations pyruvate concentrations are also low and the route via pyruvate dehydrogenase is favoured. At high carbon flux rates pyruvate concentrations increase and acetaldehyde formation is favoured over acetyl-CoA. In other words a type of overflow mechanism is operative.

The so-called long-term Crabtree effect operates at the gene level such that glucose and other simple sugars at given exogenous concentrations trigger responses such that the genes that code for respiratory and other pathways associated with aerobic metabolism are repressed and metabolism is always fermentative. This effect, more properly called glucose (sugar) repression and (catabolite) inactivation (see **yeast growth and metabolism**), is explainable in that when growing on a sugar-rich medium such as wort, yeast can fulfil its requirements for energy via glycolysis without the need for the much more metabolically expensive and complex fully respiratory system. Indeed, in brewing so much ATP is available via glycolysis that the excess is expended via heat generation, hence the exothermic nature of brewing fermentation.

In facultative anaerobic yeasts as a whole there is a continuum of Crabtree responses. Respiratory types (*Candida*, *Hansenula*, *Kluyveromyces*, *Pichia*) metabolise more than 70% sugars via respiratory pathways under aerobic conditions. Strongly Crabtree-positive types, which include *Brettanomyces*, *Schizosaccharomyces* and *Saccharomyces*, catabolise less than 10% of sugars using respiratory pathways.

Craft brewing

There is no precise definition, although the usual descriptors are small, independent, traditional, brewing beers based on historic styles and using ingredients such as adjuncts only as a means of introducing novel characters. In many mature beer markets beer volumes and the number of brewing companies have been in decline. As a result of growth and acquisition a large proportion of the modern market is dominated by a small number of monolithic brewing companies often producing very large international brands; usually variants on the theme of pale pilsener-type lagers. Counter to this has been a rise in the number of new start-ups of brewers who meet the criteria listed above. In the United Kingdom, the total number of breweries declined dramatically throughout most of the twentieth century. This trend was reversed by the growth of the craft brewer segment. In the 1970s, when it is considered that the first UK craft operations began, the total number of UK registered breweries increased from around 180 to more than 800 in 2010. At the time of writing (2012) more than 1000 craft breweries are in operation. This trend has been repeated in other countries, particularly in the United States, Canada, Australia, New Zealand, Europe in general and Japan.

The majority of craft brewers are small. In the United Kingdom the **progressive beer duty** laws provide for a 50% discount on annual volumes less than 5000 hL and most craft operations fall into this category. In other countries volumes may be considerably greater. In Japan, up until 1994, brewers had to produce annual volumes of at least 20,000 hL to gain a license to make beer. After this date a relaxation of these rules allowed *ji-biiru* 'local beers' to be produced by craft brewers with annual volumes less than 600 hL [see <http://www.craftbeerassociation.jp> (last accessed 7 February 2013)]. In the United States [see <http://www.brewersassociation.org> (last accessed 7 February 2013)], similar trends have been followed. In 1980 only 44 brewing companies were registered. As a result of up-scaling of essentially a few home brewing hobbyist brewers and subsequent emulation the craft segment increased from a low

initial base to more than 1980 independent brewing companies in 2011. The US craft segment accounted for around 5.7% of total beer sales and 11.5 million US bbl (*ca.* 13.4 million hL) in volume terms, in 2011. The United States has a codified system of definitions for the purposes of gathering statistics. Large breweries are considered to produce annual volumes greater than 6 million US bbl (7.02 million hL). A regional brewer produces volumes within the range 15,000 to 6 million US bbl (17,550–7.02 million hL). A microbrewery produces less than 15,000 US bbl (17,550 hL). A brewpub must sell at least 25% of its output in the premises where it is produced. In all cases, to qualify as a craft brewer, the company must be independent of large brewing companies and must have a flagship beer which is all-malt. Adjuncts can be used to enhance beer styles.

In the United Kingdom the vast majority of craft brewers produce cask ales for a local market. Batch sizes are of the order of 1–10 UK bbls (1.6–16 hL). A simple isothermal mash infusion system is used. As with many craft brewers throughout the world there is considerable interest in the use of speciality malts and hops. In the case of the latter, perhaps overenthusiasm may occasionally be to the detriment of balance. **Dried brewing yeast** is used by many in a single trip operation to avoid the complications of yeast handling associated with serial re-pitching. In the UK bottled beers, especially bottle-conditioned types, are becoming more popular since this route affords easy opportunities to gain entry into more distant markets without the problems of large-pack container distribution and recovery.

As a group craft brewers offer a bewildering variety of products. These may be traditional beer styles or more novel products. No doubt it has been made easier to take distinctive beer styles away from their traditional homes to other geographical locations by better understanding of the underlying science which has elucidated the relationships between raw materials, process and product has made the much easier. In this regard the craft brewers have in many ways served as pioneers in adapting brewing processes to allow the production of excellent simulacra of long-existing beer styles. In addition, they have been at the forefront of development of new beers using a wide variety of non-traditional ingredients which perhaps belies the essentially conservative attitudes espoused by many. Whether or not some of these beers eventually develop into accepted new beer styles remains to be seen; however, evolution has always been a vital part of brewing tradition.

Cran

Scottish dialect word meaning a tap or valve. In brewing parlance the word is used to describe a valve, particularly of the type used to seal the bottom of a tank, such as a fermenter.

Crash cooling

Crash cooling refers to the last stage in some fermentations where the process is considered complete and the separation of yeast from green beer is encouraged by the application of cooling. The term is used particularly in respect to large-capacity fermentation vessels, usually of the cylindroconical variety. Commonly these are supplied with several external cooling jackets (see **cylindroconical fermenter** for more details).

When fermentation is complete a coolant is supplied to all available jackets at the maximum rate available such that the beer is chilled in the shortest possible time. As a result convection currents are reduced to a minimum and sedimentation of yeast ensues. Although the term

crash cooling implies a rapid process, in reality a decrease in temperature of no more than 1°C/h is common and thus it may take 12–24 hours to attain the desired end point (usually 2–4°C).

Creamer

See **orifice plate**.

Cream flow beers

See **smooth flow beers**.

Cristobalite

A crystalline form of silica that occurs in heat-treated kieselguhr. It is carcinogenic and kieselguhr filter powders, which contain these materials, must be handled in a way in which the inhalation of airborne dusts by operatives is prevented.

See **kieselguhr**.

Crop

When used as a noun the term crop refers to the yeast which forms during fermentation as a consequence of growth and which is removed during and/or at the completion of fermentation. It may also be used as a verb to describe the action of removing yeast from the fermenter.

During the course of a typical brewing fermentation the concentration of yeast in the fermenter increases by three- to fivefold and thus, surplus yeast is always generated. Usually a proportion of this yeast is retained and used to inoculate (pitch) a subsequent fermentation. In this case the retained yeast is referred to as **pitching yeast**. The manner by which yeast separates from the green beer during the course of fermentation depends on the nature of the yeast and on the type of fermenting vessel. Ale strains typically rise to the surface of fermenting wort to form a thick surface pellicle which may be removed from the beer layer. Conversely, lager strains sediment to the base of the vessel during fermentation from whence the crop may be removed prior to the green beer. For these reasons ale strains of brewing yeast are referred to as **top cropping** and lager strains as **bottom cropping**. The reasons for the differences in behaviour are a consequence of differences in the hydrophobicity of the cell surfaces of the respective strains. In addition, the aggregates of ale strains appear to be able to trap bubbles of CO₂ and this also promotes top cropping.

Separation of yeast from fermented wort is influenced by the flocculent nature of the yeast strain. **Yeast flocculation** is defined as the non-sexual binding of yeast cells to form loose aggregates which, owing to their size, more easily separate from beer under the influence of gravity. The ability of yeast cells to flocculate is genetically determined. Those strains that lack the requisite genes will not form flocs and therefore tend to crop poorly. In this case the suspended yeast counts in green beers tend to be high and it may be necessary to use strategies such as continuous centrifugation in order to reduce loadings and to avoid short beer filtration runs. Conversely, heavily flocculent strains tend to form very large and stable flocs and may separate from wort before fermentation is completed. In this situation it may be necessary to employ some form of mixing in order to prevent yeast from separating from wort prematurely

and so to ensure that the desired degree of attenuation is achieved. The expression of flocculation is a regulated phenomenon. The presence of fermentable sugars inhibits the formation of flocs. This is obviously desirable since it ensures that yeast remains in suspension during primary fermentation. The exhaustion of fermentable sugars triggers the formation of flocs (in those strains capable of doing so) and separation of the yeast crop ensues. This may be promoted by the application of chilling, which reduces convection currents and encourages yeast separation. Subsequent re-pitching into fresh wort exposes the yeast to a fresh source of fermentable sugar and the flocs are dispersed.

The formation of the crop is influenced by the configuration of the fermenting vessel. Traditionally the design and operation of the vessel mirrored the type of cropping operation that was employed. Thus, traditional ale fermenters are open-topped in order to provide access for both observing the formation of the top crop and for its removal. Skilled managers of such fermentations were able to judge progress by the appearance of the **yeast head**. When the time was considered appropriate top crops were removed by the application of suction via a pump or simply by pulling a wooden plank (or similar device) over the surface of the vessel and thereby pushing the yeast head into a chute for removal. This process is referred to as **skimming**. The initial head that forms is heavily contaminated with trub and usually this is removed and discarded. A further proportion of the yeast in the fermenter drops out in the base of the vessel. These cells are considered to be in less than prime condition and are discarded when the fermenter is emptied. The second top crop consists of relatively clean and healthy yeast and this is removed and retained for re-pitching. In this sense the top-cropping procedure is self-cleansing and the recovered yeast is of high quality.

In the case of bottom-cropping yeast strains fermentations are commonly performed in closed vessels. Since there is no provision for direct observation it is necessary to gauge when the crop has formed by indirect means, typically based on time and wort concentration. Modern vessels usually have a cylindroconical configuration. The combination of the cone and high degree of internal polishing facilitate collection and movement of sedimented yeast with a minimum of friction. Although such vessels are associated with lager fermentations, many ale yeasts will also form a substantial bottom crop. The reasons for this are unclear but maybe due to a combination of the relatively small surface area and the high hydrostatic head; whatever the truth it is possible to use cylindroconical vessels for both lager and ale fermentations. Of course it is often the case that with ale yeasts much of the crop may still form at the surface. In this case this is commonly ignored since it is not seen!

The yeast crop is removed by opening the valve at the base of the vessel. Flow may be under the influence of gravity or using a pump. The latter should be a low shear type in order to avoid damage to yeast cells (although the susceptibility of yeast to damage via shear forces is not proven). Flow rates during cropping should be controlled in order to prevent the core of the crop being 'sucked' out before the outer parts.

One of the disadvantages of bottom cropping is that the yeast is always contaminated with dead cells and non-yeast solids. It is undesirable if this material is allowed to contaminate retained cropped yeast since, amongst other sources of inconsistency in fermentation performance and beer quality, it may be a cause of errors in pitching rate control in subsequent fermentations. Fortunately, much of the trub and non-yeast solids are the first material to sediment in the cone of the fermenter. Most cropping regimes allow for this and the first run-

nings are usually discarded. Nevertheless, some contamination of bottom-cropped yeast with non-yeast solids is inevitable and this is one of the factors that limits the number of times yeast may be cropped and re-pitched. Top-cropped yeast is less susceptible to such problems and tends to be cleaner and can be re-pitched a greater number of times; indeed many traditional ale brewers crop and re-pitch indefinitely. Cropping is finished when the interface between yeast and beer is detected. The detection may be via visual observation using a sight glass located in the cropping main or via the use of a suitable turbidometric sensor.

In modern breweries, where the capacity warrants the cost, cropping may be controlled using an **Aber biomass monitor**. This device provides an instantaneous measure of viable yeast concentration. Locating a sensor in the cropping main, together with a suitable control system allows the procedure to be automated. Thus, the destination of liquid flow during vessel emptying is regulated in response to threshold values of yeast concentration measured by the monitor. Initially, where the yeast concentration is low, the flow is directed towards waste tanks. As the proportion of viable yeast cells in the crop increases and that of trub declines, the output from the probe increases such that when a predetermined threshold value is reached the flow is directed towards yeast storage vessels. When the interface between yeast and beer is reached the output from the probe falls, and when a given lower value is reached flow is directed towards the next stage of beer processing.

Yeast crops may be treated in several ways depending on the type of plant and the prejudices of individual brewers. Yeast slurries in beer destined for re-pitching may be stored cooled without further treatment. This applies to both top- and bottom-cropped fermentations. In the case of the latter, the yeast is commonly pressed using a plate and frame filter to remove entrained beer. The recovered beer is returned to the batch from which the crop was removed. The pressed yeast may be stored in a cold room in the interval between cropping and re-pitching. Surplus bottom-cropped yeast slurry may also be subjected to a separation procedure using a press, or similar, to recover entrained beer. It is necessary to apply stringent control procedures in order to ensure that the recovered beer does not compromise the quality of the beer stream to which it is returned. Thus, times and conditions of storage of slurry and recovered beer must be controlled in order to prevent deterioration. Despite the potential value of recovered beer many brewers will not accept the risk to quality and eschew the procedure entirely.

The prevalence of high-gravity brewing, the use of very large batch sizes and the trend to increase in fermentation top temperatures has resulted in some changes to cropping procedures (and procedures for storing cropped yeast). The combination of these factors increases the levels of stress to which yeast is exposed. These stresses are maximal in the cone of large fermenters after the yeast has sedimented. If ameliorative procedures are not introduced this can result in unacceptable losses in the viability of cropped yeast. In order to minimise these effects many brewers remove crops during primary fermentation and before any cooling has been applied. This is termed **warm cropping**. Since the yeast crop may still be forming at this time, especially with relatively non-flocculent types, it may be necessary to crop several times. In the case of very high-gravity brewing the ethanol concentration in the barm ale surrounding cropped yeast may be sufficiently high to represent a threat to yeast viability. In order to reduce this threat the yeast may be diluted with sterile chilled de-aerated brewing liquor, a practice known as **pitching yeast dilution**. Of course, storage vessels must have sufficient capacity to accommodate the increased volume.

Crop Evaluation Limited

A London-based subsidiary of the UK Agriculture and Horticulture Development Board (AHB) founded in 2000 and involved in the evaluation of recommended lists of varieties of cereals, including malting varieties.

See **malting barley – recommended varieties**.

Cross cells

See **barley grain**.

Cross-flow filtration

Cross-flow filtration is a technique that may be applied in brewing for a number of tasks. These are purification of water, recovery of beer from excess yeast and primary filtration of beer. In each application the essential features of the process are the same, although different filtration membranes that are appropriate for the task are used.

Cross-flow filtration avoids the problems of blocking and build-up of trans-filter pressure associated with dead-end systems. This is accomplished by the use of a re-circulating loop which is driven by a pump. Within the loop is a membrane that has pores of a known size and appropriate for the filtration duty. The unfiltered material is continually swept across the surface of the membrane and this prevents the build-up of solids which will eventually block dead-end filters. The recirculation loop is fitted with a back-pressurisation valve. This provides a motive force that drives the liquid through the membrane. New unfiltered material is allowed to enter the recirculation loop via an in-feed valve. In cross-flow systems the clarified product is referred to as the permeate. The material within the loop is termed the retentate.

It may be appreciated that as the filtration run proceeds the solids concentration of the retentate gradually increases and the pores of the membrane filter will eventually block. This results in an increase in the pressure required to drive the filtration process. Eventually the maximum safe operating pressure is achieved and the run must be discontinued. The membranes may then be cleaned by reversing the flow of liquid.

The size of the pores, termed the cut-off or reject limit, and the type of material from which the membranes are made and their design vary according to the task to which they are to be put. The guiding principles are the average size and concentration of the solids in the unfiltered feed material. In the case of water purification where total demineralisation is required the membranes act as molecular sieves and have a cut-off of 150–300 Da. Pore sizes within the range 0.2–1.0 μm are used for beer recovery from spent yeast. For primary filtration of beer a pore size of around 0.5 μm is suitable.

Several designs of membranes are used. Ceramic types are used for coarse filtration tasks where the solids loadings are very high such as in beer recovery. For other duties the majority of membranes are made from artificial plastic materials such as PES. For duties such as beer primary filtration the membranes are folded into spirals or other shapes as a means of maximizing the surface area. Membranes are held within stainless steel housings. A typical membrane has a surface area of approximately 10 m² and this is held within a unit that is approximately 1000 mm in length and 100–200 mm in diameter.

Commercial units comprise multiple units of membranes. The number of individual units is chosen to suit the particular batch size and required throughput. For beer filtration a unit

containing 20 membranes with a circulation pump capable of delivering 650 m³/h would be capable of processing beer at a rate of approximately 200 hL/h.

Despite the cleansing effects of the liquid flowing across the membranes in cross-flow systems blockage and pressure build-up will eventually occur. In practice it is usual to have spare banks of membranes since this allows individual units to be taken out of the system and cleaned without having to stop the filtration process. In some designs the tendency to block is reduced by using a regime in which the forward flow of liquid is periodically reversed. This pulse helps to remove any material that has accumulated in the pores and thereby the total run time is prolonged. Nevertheless, cross-flow systems of the types used for beer filtration are not particularly tolerant of high solids loadings and most commercial installations require a high-speed protein centrifuge to be located immediately before the filter.

Cross-flow filtration systems produce beer with a clarity which matches that achievable with powder filters. There is no effect on other beer attributes such as colour or foaming ability. The relatively small pore size removes yeast cells and most other microbial contaminants. In most commercial systems an additional cold sterile filtration system is also provided. This obviates the need for pasteurisation. It is possible to combine beer stabilisation and cross-flow filtration. In one system, the combined stabilisation system (CSS) (Handtmann Company, Biberach, Germany) unfiltered beer is passed through so-called absorber modules, each of which contains cross-linked agarose beads. These beads absorb haze-forming polyphenols and proteins and they are regenerable by treatment with hot caustic soda solution. After passage through the absorbers the beer is filtered using crossflow. This system is now used commercially in at least nine breweries.

The most obvious advantage of cross filtration of beer is that it avoids the use of kieselguhr and other powders required for conventional beer filters. The use of filter powders attracts the costs of their purchase, handling and disposal. There is now an added dimension in that the hazardous nature of kieselguhr (see **kieselguhr**) is likely to provide the spur for the introduction of legislation limiting or even banning its use. In this case the widespread adoption of crossflow for beer filtration seems inevitable. At present take-up has been sporadic, although popularity for new installations continues to grow.

Crude soluble protein

An approximation for the total dissolved protein content of extracts made of brewing raw materials, worts or beers obtained by performing a total nitrogen determination and multiplying the result by 6.25.

Crystal hop

Crystal is a US-bred triploid hop variety that derives from Hallertau, Cascade, Early Green and Brewer's Gold. It is an aroma variety with low bitterness (2.0–4.5% α -acids).

Crystal malt

Crystal malt is a synonym for caramel malts. These are malts that are prepared from high-nitrogen barley grains by heating in the presence of water such that the endosperm liquefies to form a sweet-tasting syrup. On cooling the endosperm crystallises to form a hard glassy mass, hence the name. All enzyme activity is lost during the heating process, and hence, these

malts are used purely to impart flavour and colour. The particular flavour and degree of colouring that any particular grade of crystal malt imparts is regulated by the duration and temperature used in the roasting process.

Crystal malts are common ingredients in the production of many UK-style ales, particularly pale ales and also for ale golden Pilsener-type lager beers. Typically the crystal malt constitutes 5–10% of the total grist.

See **caramel malt**.

CSS filtration system

A combined stabilisation and cross-flow beer filtration system introduced by the Handtmann Company of Biberach, Germany.

See **cross-flow filtration**.

CTZ hop varieties

The terminology CTZ is used to describe the three very high (super) alpha hop varieties **Columbus**, **Tomahawk**[®] and **Zeus**. They were bred in the United States and together account for more than 25% of the total US hop crop.

See the entries for individual varieties for more details.

Cuckoos-ale

Cuckoos-ale was a period of feasting associated with rural areas in medieval England (although apparently persisting until the nineteenth century in some areas) that was held on the day at which the first cuckoo of spring was heard.

Culms

Culms are the seminal roots (rootlets) that appear on the end of grains such as barley during germination. They appear after the chit, the initial visible manifestation of germination, has split. In barley grains the rootlets take the form of a white tuft at the end of the grain. They are also known as **coombes** and **cummins**.

When malting is completed the unwanted rootlets are removed in a process termed **deculming**. The removal of culms and entrained dust from malt is termed **dressing**. Culms are removed since they contain high concentrations of nitrogenous compounds that can impart bitter flavours to beer. In some circumstances they may contain high concentrations of nitrosamines. Culms are highly hygroscopic and it is important to remove them as soon as possible after kilning is completed whilst they are still brittle and relatively easy to detach from the grains. The ability of culms to absorb moisture has been utilised by storing kilned malt under a layer of culms, thereby preventing rehydration of the latter and thereby avoiding the expense of re-kilning.

The amount of rootlets formed during malting contributes to overall malting losses. The total rootlet loss may be quantified as the dry weight of the recovered culms calculated as a percentage of the total decrease in weight as a batch of barley is converted into finished deculmed and dressed malt.

Deculming used to be a manual operation similar in some respects to hand threshing. It is now achieved mechanically using an apparatus designed specifically for the purpose. In pneumatic deculmers the untreated grains are projected into a stream of air within a vertical cylinder. The introduction of the grains is carried out with sufficient force to remove the culms. The malt grains fall under the influence of gravity into the base of the cylinder from where

they are recovered. The rootlets and other light solid materials are transported with the jet of air and are recovered using a series of cyclones. In another deculming device the untreated grains are introduced into a trough, the walls of which consist of perforated screens. The grains are transported into and out of the trough by a rotating beater. The mechanical force that is applied is sufficient to remove the culms that fall through the mesh into an outer chamber from which they are collected via a screw conveyor.

Culms are usually sold as animal feeds. In order to make handling easier they may be pelleted after removal from grains. The yield is approximately 4 g/100 kg malt.

Cummins

An alternative name for **culms**.

Cumulative acidification power test

See **acidification power test (AP test)**.

Curing

Curing is the term used for the final phase in the kilning stage of malting. It is used in the sense of applying the final period of heating at a defined temperature and humidity in which the malt acquires its final characteristics. In general, the higher the temperature used during the curing phase, the greater the colour and the intensity of flavour and aroma. It follows that accurate regulation of the conditions to which grains are exposed to during curing is essential in order to produce malts that are suitable for producing particular beer styles.

See **kilning**.

Custer effect

A phenomenon that occurs in some yeast strains, for example, those belonging to the genus *Brettanomyces* and its teleomorph, *Dekkera*, whereby alcoholic fermentation is inhibited under anaerobic conditions; or the converse, stimulation of rates of glucose fermentation under aerobic conditions. The inhibition seen in anaerobic cells can be relieved by the readmission of oxygen or by supplying proton acceptors such as aliphatic carbonyls. For example, acetoin is reduced to 2,3-butanediol. The metabolic basis for the effect is obscure but may be linked to differences in redox control in that compared with Custer-negative yeasts, these species are less able to use glycerol formation as a balancing mechanism under anaerobic conditions.

Cutting

Name given to the process in which **isinglass** finings are prepared from the source fish swim bladders by treatment with dilute acid.

See **isinglass**.

Cutting liquor

Water used for diluting high-gravity beer, also called dilution liquor.

See **high-gravity brewing**.

Cycloheximide

An antibiotic isolated from cultures of *Streptomyces griseus*. It is added to **WLN medium** to prevent the growth of culture yeast thereby making it selective for bacteria which are not

C inhibited by the presence of this antibiotic. With this addition the medium is called **WLD**, Wallerstein Differential Agar. The compound, 4-[(2*R*)-2-[(1*S*,3*S*,5*S*)-3,5-dimethyl-2-oxocyclohexyl]-2-hydroxyethyl]piperidine-2,6-dione, also commonly known as **actidione**, inhibits protein synthesis in eukaryotes, including yeast. Media supplemented with cycloheximide (added to molten and cooled agar via sterile filtration since it is heat labile) allow the growth of many aerobic bacteria but not yeast cells.

See **WLN medium**.

Cyfluthrin

Cyfluthrin([(R)-cyano-[4-fluoro-3-(phenoxy)phenyl)methyl](1*R*,3*R*)-3(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate) is a synthetic pyrethroid insecticide that may be used for the treatment or prevention of pest infestations on crops such as hops.

Cylindrical fermenter

Cylindrical fermenters are closed vessels which, as the name suggests, have a cylindrical geometry with two dished ends. They are a simplified and therefore less expensive form of the **cyllindroconical fermenter**. They have most of the advantages of the latter in that modern incarnations are built from stainless steel; they have excellent hygienic properties and are suitable for collection of CO₂. Apart from use as fermenters vessels with cylindrical geometry are also commonly used for conditioning.

Two types of cylindrical fermenting vessels are in common use, which are distinguished by being of either vertical or horizontal orientation. Vertical types are broadly similar to **cyllindroconical fermenters** (see relevant entry for more details). They are served by a single bottom-located valve through which pitched oxygenated wort is added; the bottom crop of yeast is removed followed by the green beer. They are attemperated by circulating the coolant through external jackets. They are conveniently grouped together in tank farms serviced by common sets of mains, pumps and utilities. Yeast crops form in the dished bottom from where they are removed, probably with slightly less efficiency and ease compared to cyllindroconical vessels.

Horizontal cylindrical fermenters have been chosen by many brewers based on a prejudice that the high hydrostatic heads generated in tall vertical vessels lead to increased yeast stress and, by implication, deleterious effects on beer quality. Whether or not this belief has any basis in fact remains to be proven definitively. Horizontal cylindrical vessels have some process disadvantages. Like their vertical counterparts they can be grouped together in tank farms although with increased difficulty, a need to occupy a bigger footprint and a much more complex supporting structure. The most significant drawbacks are that the yeast crop forms over the whole surface of the base of the vessel and this makes removal somewhat problematic. Usually vessels are built slightly inclined to the horizontal to facilitate this process. CIP systems are more complex and have several top-mounted entry points to ensure proper distribution of cleaning agents. There is a suspicion, again with little supporting published data, that mixing in horizontal vessels is less vigorous compared with vertical types. Commonly mechanical mixers are provided to remedy this effect. It is certainly the case that fermentation performance is not ideal when highly flocculent yeast strains are used.

No doubt the arguments regarding the theoretical pros and cons of vertical and horizontal vessels will continue to rage. From a practical standpoint it would seem that proponents of

the vertical systems have won the day in that for many years new installations have overwhelmingly been in favour of this type of vessel.

Cylindroconical fermenter

Cylindroconical vessels, as the name indicates, comprise tanks that are made in the form of a closed cylinder the base of which is tapered to form a cone. They are the most commonly used vessels for primary fermentation and cold conditioning by commercial brewers. They are often thought of as being the epitome of modern commercial vessel design, but in fact they have a comparatively long history. Vessels with the characteristic cylindroconical design used for both primary fermentation and cold conditioning were described by a Swiss brewer, L. Nathan, in the early years of the twentieth century. Apart from increases in capacity and the use of stainless steel modern vessels are not very different from their antecedents (see **Nathan vessel** for more details).

The principal features of a cylindroconical are shown in the diagram. They are constructed from stainless steel and have a layer of insulation surrounded by an outer skin, usually made from aluminium. Cooling is provided by a number of wall-mounted jackets through which the coolant is circulated. The nature of the coolant is dependent upon the required cooling duty. Chilled water or brine may be suitable for use with relatively warm ale-type fermentations. For cooler fermentations and cold conditioning glycol or ammonia is required. The number and arrangement of these are dependent upon the duties to which the vessel is used for (see the diagram). Attenuation is controlled automatically by linking the output from one, or more, in-tank thermometers to a controller which actuates the coolant supply valves. There is no provision made for heating.

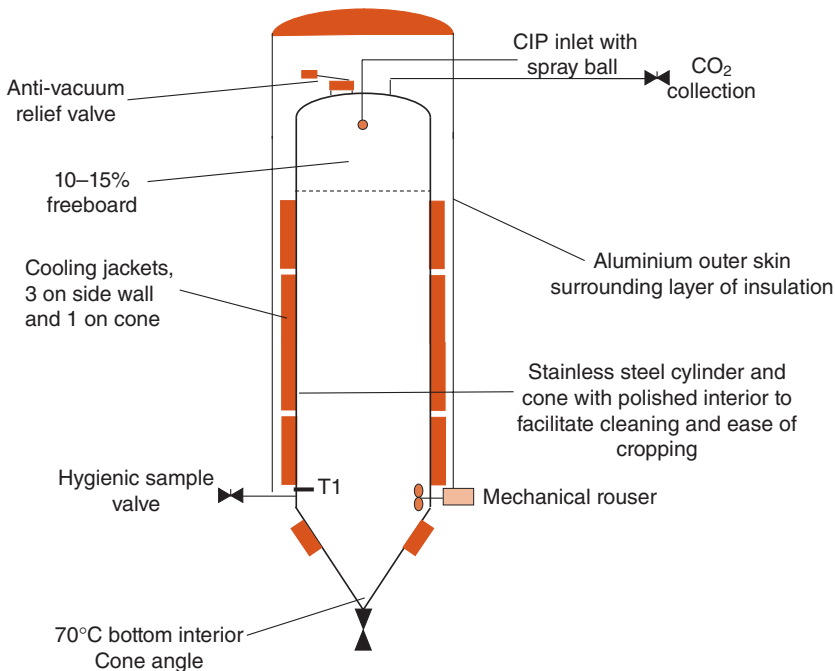


Diagram showing the key features of a cylindroconical fermenting vessel

The capacity of the vessels is very variable and may be as little as a few hundred and up to several thousand hectolitres. The chosen capacity is dependent upon several factors, which include the capability of the brewhouse and the mix of beer qualities required to be made at any given time. A few very large vessels are suitable for a brewery producing a limited range of beer types with little seasonal variation since fewer unit operations are required. On the other hand, where many beer qualities are required and demand is variable, a larger number of smaller vessels is more desirable. The most commonly encountered capacity is in the range 1000–2000 hL. Typically several individual batches of wort are required to fill these vessels and collection times can be commensurately prolonged.

All filling and emptying operations are via the main located at the base of the cone. This is linked to a complex valve block that directs process flow in an appropriate direction depending on which part of the operation is in progress. Possible operations are the following: filling with pitched oxygenated wort, removal of yeast crop, removal of green beer, CIP return and drain. These operations may be automatic using remotely actuated valves or in simpler installations manually made joints using short lengths of pipe of appropriate size and shape to make the desired connections.

Cylindroconicals used solely for primary fermentation tend to have a relatively tall aspect ratio and cones with a steep included angle. Typical dimensions are 3:1 with a cone with an included angle of 70°. This arrangement favours reasonably efficient mixing (at least during primary fermentation, although recent evidence suggests that this is not always the case) via convection currents and the steep cone facilitates yeast cropping. Where vessels are used solely for cold conditioning they tend to be more capacious than those used for fermentation, have smaller aspect ratios and shallower cones.

The top of the vessel takes the form of a shallow dish. This is provided with a number of fittings which are arranged on a removable top plate. These include a man-way door for access and usually a sight glass for making visual observations and addition of anti-foam, as necessary. In order to prevent vessel collapse which might occur during operations such as emptying or treatment with CIP agents that absorb CO₂, a vacuum-relief valve is provided in the top plate as is a means of egress for CO₂. The latter may be via a simple pressure-relief valve or now more commonly where the vessel is used for primary fermentation, the CO₂ outlet is linked to a recovery system.

A sample valve is usually provided and this is typically sited approximately 1 m above the top of the cone in the cylindrical portion of the vessel. Some vessels have a means of mechanical agitation. This may take the form of a mechanically driven impeller usually mounted laterally and located close to the top of the cone. Some designs have a loop system driven by a pump and in which the contents of the vessel are taken off from a point close to the base of the vessel and returned near the top. The loop system may incorporate an addition system and possibly an in-line plate and frame heat exchanger. The provision of a means of mixing the vessel contents is particularly useful for increasing the efficiency of cooling during times when convection currents are weak because of lack of CO₂ evolution owing to low yeast activity, for example, during crash cooling at the end of primary fermentation. More recently it has been demonstrated that the application of mechanical mixing during primary fermentation produces a more rapid and consistent performance. In the absence of an external loop system, an addition point, located close to the base of the vessel, may be fitted to facilitate post-pitching

addition of oxygen or air. The interior of the vessels are polished to a high degree, especially the cone, to ensure that the cropping of sedimented yeast proceeds smoothly with a minimum of adherence and back-mixing.

Apart from recording temperature monitoring of progress of processes such as primary and secondary fermentation is dependent upon offline analysis of samples removed from the vessel via the valve provided for the purpose. Fitting of in-tank devices suitable for automatic analysis and use in control systems is rare but is used by some. A number of devices that provide an in-tank measure of wort specific gravity have been developed. The majority of these rely on measuring the pressure at different and known heights in the vessel. From these measurements the wort specific gravity and total volume of liquid can be inferred. A system for the automatic analysis of VDK via sampling of the headspace and transport to a remotely sited online gas-liquid chromatograph has been described but apparently with limited widespread adoption. Undoubtedly the difficulties of cleaning the long runs of capillary tubing necessary to transport samples to chromatograph have been seen as a major problem. Application of anti-foam on the liquid surface is widely practised, where permitted. This has proven necessary owing to the trend to use higher temperatures during primary fermentation as a means of reducing cycle times and overfilling vessels as a means of increasing the productivity of individual batches. In the former case the increased vigour of fermentation may lead to more foaming, and in the latter case less freeboard is available to contain the foam head. In order to facilitate early identification of uncontrolled foaming to trigger timely remedial action, the use of high-level probes and even video cameras have been advocated.

The majority of modern vessels are designed to withstand pressures of a few bars. Operation with some positive pressure provides a useful safeguard against the entry of contaminating microorganisms. In addition, some brewers use overpressure as a means of regulating yeast activity and by inference the formation of important groups of beer flavour compounds, particularly esters, which are produced by yeast during fermentation.

Multiple cylindroconicals are conveniently grouped together in tank farms where they occupy a small footprint. Where the climate permits vessels may be located outside. More commonly they are located inside a dedicated building or often in a building that encloses the bases of the vessels such that the tops protrude through the roof. A system of stairways and platforms links the vessels and permits access to the exterior parts, as required. In order to minimise external fouling and to protect the external fittings a weatherproof canopy is fitted over the top plates of each vessel.

The operations of individual vessels within the tank farm are linked in order to minimise operating costs. For example, several tanks may be serviced by a single system in order to manage operations such as wort cooling, oxygenation, pitching, cropping, beer removal and CIP. Where more flexibility is required multiple servicing systems are provided. In modern installations management is software driven linked to remotely actuated valves, pumps and other associated plant. A central office houses the controlling computers. These provide mimics of all vessels in the tank farm with details of their status at any given time. Information available includes full or empty, clean or dirty, available or not available. Where active, a unique identifier for each batch is provided, together with details of the beer type and the progress of the operations being performed. The system incorporates controlling software the use of which allows the relevant parameters for each stage of the process to be entered and

acted upon. This has within its memory desired temperature profiles for each beer quality being made within the tank farm. The system monitors the temperatures of all active vessels and produces an alarm if an out-of-specification condition should arise. Typically modern control rooms also include facilities for routine analysis of samples removed from the vessels such that the results can be entered into the same software system. In order to facilitate sampling for laboratory analyses a manifold system may be used where tubes attached to vessel sample taps are routed to a common sampling station. This is a useful labour-saving strategy; however, care has to be taken with hygiene and in order to obtain truly representative samples it is essential to first run off enough liquid to account for the volume of the sampling tubes. The net result of the development of these highly automated systems has been that extremely complex tank farms can be managed by very few operatives. With regard to the design of individual vessels there is no consensus regarding the optimum capacity or aspect ratio. In the majority of cases decisions are made based on the basis of factors such as batch sizes from the brewhouse, availability of space, access to the brewery site or the cost and availability of the cylindrical tubes needed for the construction of the vessels. It may be appreciated that none of these factors relate to the actual operation which needs to be conducted within the vessels. For this reason management tends to be an empirical process. This is perhaps acceptable where a single design of vessel is used; however, it is problematic where several vessels with varying capacities and aspect ratios are used to produce a single beer quality. In these cases it is usual to have to employ unique fermentation management regimes for each vessel. This is not ideal and more work is needed to identify reliable procedures, the use of which will allow the control of fermentation and beer flavour in a predictable manner.

Cymoxanil

Cymoxanil (1-(2-cyano-2-methoxyiminoacetyl)-3-ethylurea) is a fungicide that has been used for the treatment of downy mildew in hops.

Cypermethrin

A synthetic pyrethroid insecticide that may be used for the treatment of insect infestations on crops such as hops.

Czech noble aroma hop

A synonym for **Saaz hop**.

Dadd's and Martin's medium

Medium used for the cultivation and isolation of *Zymomonas* spp. It contains yeast extract and peptone, glucose as the principal carbon source and ethanol to inhibit non-beer spoilers and cycloheximide to inhibit yeast.

Dagger nematode

The dagger nematode (*Xiphinema diversicaudatum*) is an indirect pest of hops. By virtue of its habit of feeding on the root tips of plants it acts as the vector for the **Arabis mosaic nepo-virus**. It is widespread but occurs most commonly in sandy soils. Treatment is difficult, although fumigation of soils can reduce numbers.

Dalex

Freeflow dispense taps in plastic or stainless steel with (or without) flow control.

Dampfbier

Dampfbier is the German name for steam beers.

See **steam beer**.

Damson-hop aphid

The damson-hop aphid (*Phorodon humuli* Schrank) is a pest of hops. It constitutes the most serious threat to hops cultivated in the northern hemisphere. The adult forms of the aphid are winged females, termed alatae, and are 1.4–2.1 mm in length. They have a black patch on the upper surface of the abdomen and a sharp triangular tail. They possess long stylets which are used to penetrate into the phloem of the hop plant and gain nutrients. They are usually found on the leaves at the top of the bine but may also infest the cones. Aside from weakening plants and causing loss of leaves they produce honeydew, which provides a source of nutrition for sooty moulds. Infected cones become brown and brittle and are liable to disintegrate during harvesting. The aphids may be vectors for virus diseases such as hop mosaic carlavirus, hop split leaf blotch virus and hop plum pox virus.

The pest survives winter by colonizing various species of *Prunus*, especially blackthorn, damson and plum. They overwinter as shiny black eggs which in April hatch to produce

wingless female insects. The latter multiply and after about two generations winged females arise in late May. When the temperature exceeds 13°C (May/June) the winged aphids migrate and where possible colonise the hop plants, the summer host. In September and October a reverse migration back to the winter host occurs. This is triggered by the day length falling below 13.5 hours. The females migrate first followed by males after which mating and egg production occurs.

Control is via removal of any likely winter host plant growing close to the hop garden, although since migration distances can be considerable, this is not a very effective measure. More usually chemical control measures are used. Originally these took the form of organophosphorus insecticides. The use of these has declined since most aphids have developed resistance. More commonly synthetic pyrethroids are used such as Cyfluthrin, Cypermethrin, Deltamethrin, Fenpropathrin, Lambda-Cyhalothrin and Imidacloprid. The reluctance to use such chemical treatments has resulted in the development of new aphid-resistant cultivars. In addition, the use of natural aphid predators such as ladybirds is a subject of interest.

Danish Brewers' Association

See *Bryggeriforeningen*.

Danske Ølentusiaster

This is the name of a consumer group located in Denmark. It was founded in 1998 with the intention of promoting traditional Danish beers. It is a member of the European Beer Consumers Union (EBCU). The organisation seeks to educate consumers about the history of brewing; it organises beer festivals, carries out beer tastings and identifies what are considered to be outlets that fulfil the needs of its members. The latter are entitled to advertise the fact that they are accredited bearers of the 'Danish Beer Mark'.

Contact details are at <http://www.ale.dk> (last accessed 7 February 2013).

DAPI

A fluorescent dye, 4',6-diamidino-2-phenylindole, which has been used to determine yeast viability based on its ability to bind with AT-rich portions of double-stranded DNA. Passage through the plasma membrane is impeded in viable cells and therefore these are comparatively more resistant to staining compared with dead cells.

See **yeast viability**.

Daraclar™

Daraclar™ is a generic trade name given to a range of silica gel beer stabilisers produced by the US chemical company Grace.

See **silica gel**.

Darcy's law

The relationships described by Darcy's law can be used to describe the flow of beer through a filter. The law was originally derived by Henry Darcy in 1855–1856 to describe the flow of water through aquifers.

The law in a form applicable to a beer filter is shown as follows:

$$Q = \frac{\phi \Delta P A}{LM},$$

where

Q = flow rate (mL/s)

ϕ = permeability factor

A = area of filter (cm²)

L = thickness of filter medium (cm)

M = viscosity of beer (poise)

ΔP = pressure differential (dyn/cm²)

See **filtration**.

Dead mash

A synonym for **set mash**.

DEAE cellulose

An ion exchange resin (diethylaminoethyl cellulose) in which cellulose is derivatised with an ionisable tertiary amine diethylaminoethyl group. The material carries a positive charge at neutral pH values and thus it functions as an anion exchanger. In brewing it is used as a support material in immobilised yeast reactors (see **immobilised yeast** for more details). It is supplied for commercial use in bioreactors in the form of beads sold under the trade name Spezyme.

De-aerated water

De-aerated water (or liquor) is water that had been treated to reduce the dissolved oxygen concentration to a desired low level. This is necessary to prevent reactions that can result in the formation of the precursors of beer staling compounds. Current standards require dissolved oxygen concentrations to be less than 0.2 mg/L. In addition many modern boiler designs require that water destined for steam generation has a low oxygen content.

Several methods may be used for the deoxygenation of water. The simplest approach is boiling; however, on the basis of high cost, this is not used for the production of de-aerated brewing water, although some manufacturers use a relatively high operating process temperature in order to combine de-aeration and pasteurisation. Removal of dissolved oxygen requires manipulation of partial pressure. Release of oxygen from water is promoted by manipulation of pressure and the use of an inert stripping gas. The latter can be nitrogen but, for brewing applications, is more usually carbon dioxide for obvious reasons. Commonly de-aeration and carbonation can be combined in a single treatment.

In vacuum de-aeration systems the water to be treated is introduced into a chamber via very fine nozzles designed to produce a large surface area for gaseous exchange. The chamber is fitted with pumps which produce a vacuum and this promotes exchange of oxygen from the liquid to the gas phase. Introduction of carbon dioxide further encourages oxygen stripping. In column types the water is passed down a column, typically several metres tall in a large-capacity installation, which is filled with a packing material, usually stainless steel, designed to provide a large surface area. A countercurrent stripping gas is passed upwards against the flow of water. Membrane systems utilise cartridges that contain semipermeable hollow fibre membranes. The water to be treated is passed down one side of the membrane, whilst on the other a partial vacuum and flow of stripping gas produces a large differential in partial pressure which drives oxygen out of the water and across the membrane.

De-alcoholisation

This is a process by which ethanol is removed from beer in order to make it a low- or zero-alcohol product.

See **reduced-alcohol beer**.

D

Debranching enzyme

A synonym for **limit dextrinase**.

Decanter centrifuge

See **continuous centrifuge**.

Decoction mashing

Decoction mashing is the traditional regime used in the production of European lager beers. The grist is comparatively finely ground and uses relatively poorly modified malt. Decoction mashing uses multiple vessels and the thinness of the grist is necessary to allow the mash to be pumped between them. The essence of the process is that three vessels are used to manipulate the temperature of the mash and to effect separation from the spent grains.

The three vessels are a mash mixing vessel, a decoction vessel (or mash cooker) and a lauter tun. Both the mash mixing vessel and the decoction vessel are fitted with agitators. In operation the mash is collected in the mash mixer at a relatively low temperature. At intervals a portion of the mash is removed and pumped into the decoction vessel where it is heated. The heated portion is then returned to the mash mixer and, in so doing, the temperature of the whole mash is raised. After controlled stand times the process may be repeated and in which case this would be referred to as **double decoction mashing** or **triple decoction mashing**, and so on, as appropriate. When mash conversion is completed the mash is pumped into the lauter tun where separation of sweet wort and spent grains is carried out. In some breweries the separation step is carried out using a **mash filter (mash press)**.

Many different regimes may be used depending on the nature of the grist and the beer style that is being brewed as the arrangement of vessels allows for a great deal of versatility. Thus, the size of the portion of decocted mash may be varied, as may the temperature it is raised to and the period of time it is held before return to the main mash. The rate at which it is returned can be used to regulate the rate of increase in the temperature of the main mash. Before making a decoction the mash mixer agitator may be turned off such that the grains are allowed to start to settle out, and thus the solid content of the portion removed can be manipulated. In some set-ups the mash mixer may be fitted with a heater to supplement the effect of decoction. Adjuncts can be added at various points in the process as can enzymes. Whichever regime is chosen the common principle is that the relatively cooler main mash provides the bulk of the enzymes which catalyse the various required degradative reactions, whereas the relatively hotter decoction treatments are responsible for structural degradation and starch gelatinisation.

The decoction regime is complex, and compared to a **simple infusion mashing** system it is costly in terms of the numbers of vessels, associated plant and their operation. The advantages are that it is possible to ensure that the temperature can be manipulated at different stages in the process such that the conditions are optimal for the different classes of enzymes

required for mash conversion (see **mashing** for more details). Thus, in the boiling phase starches are gelatinised and made susceptible to subsequent saccharification; residual grain cells are degraded; colour changes occur; some enzymes are inactivated by heat denaturation; and changes in flavour are brought about. The greater degree of control of mashing conditions permitted by the decoction system allows the use of poorly modified malts that would not be usable in a simple infusion system. Compared with the latter decoction allows a greater yield of extract. However, this is offset by the relatively high operational costs. The use of poorly modified malts is now becoming less common and traditional decoction mashing is tending to be replaced by **temperature-programmed infusion mashing**; nevertheless, many brewers insist that the traditional regime is retained because it is essential for maintaining the quality of their particular beers.

The following diagram shows the steps in a typical double decoction mashing regime. In this instance the initial mash was collected at approximately 35°C. After a short preliminary stand the temperature of the mash is increased to just over 50°C after which the first decoction is made. In this approximately 25% of the mash is withdrawn and boiled and returned to the mash mixer such that the overall mash temperature is increased to around 68°C. After another stand at this temperature a further decoction is made and the main mash temperature increased to around 76–77°C.

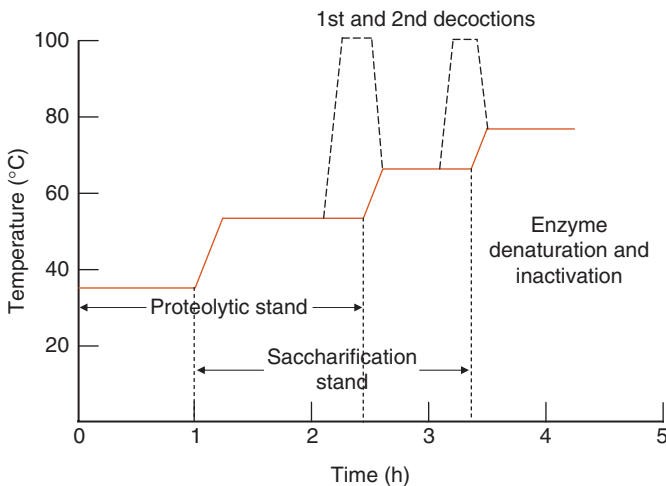


Diagram showing the stages in a typical double decoction mashing regime

Many different variants on the scheme shown in the diagram are possible. Traditionally, dark beers use thick mashes (3–4 hL liquor per 100 kg grist), whereas lighter beers use thinner mashes (4.5–5.5 hL liquor per 100 kg grist). As would be expected in the production of light beers the periods of boiling are shorter compared with those used for dark beers.

Different classes of enzymes show their maximal activities at different phases in the process. In the initial relatively cool stand proteolysis occurs, and in addition enzymes which are

relatively heat-labile such as phytase, maltase and β -glucanase are active. After removal of the first portion of mash and transfer to the decoction vessel the resultant boiling and hot stand at around 70°C allows α -amylases to liquefy starch. The heated portion is returned to the main mash where the increased temperature favours the activity of both proteases and amylases. In second or third decoctions the temperature increases lead to inactivation of proteases but allow continued starch breakdown. For this reason the earlier relatively cool stands are often termed **protein stand**, whereas subsequent hotter treatments are called **saccharification rest**.

The process is terminated when the temperature is allowed to increase to approximately 75–77°C. This inactivates the bulk of the enzymes. At this stage the mash is transferred to the lauter tun (or mash filter) to effect separation of sweet wort from spent grains.

See also **double mashing**, **simple infusion mashing**, **temperature-programmed mashing**, **protein stand** and **saccharification rest**.

Deculming

See **culms**.

Defoamer

Synonym for **anti-foam**.

DE-free beer filtration

An abbreviation for diatomaceous earth-free filtration in which beer is clarified using systems that do not require kieselguhr powder. These powder-free systems are based on **cross-flow filtration**.

Deglutan

Deglutan is a trade name given to a preparation of bentonite designed to be used as a beer stabilisation agent via the adsorption of protein.

See **bentonite**.

Degree Balling

The scale bearing this name was devised by Carl Joseph Napoleon Balling and was published in 1843. It is used as a unit of concentration for worts and sugar solutions based on density measured at 63.5°F (17.5°C). Measurements can be made using a hydrometer calibrated to give sugar concentration as per cent weight. In this case, 1°Balling is equal to 1 g sugar per 100 g liquid measured at 63.5°F. A degree Balling is equal to 3.8° saccharin. Put another way, wort with a specific gravity of 1040 is equivalent to a sucrose solution of 9.95% w/w.

Degree Baumé

The Baumé scale, devised by the chemist Antoine Baumé (1728–1804), is a now largely archaic scale used to measure liquid density. Hydrometers calibrated in degree Baumé were designed to measure the relative density of liquids in two groups either more or less dense than water.

The relation to specific gravity is given as

Less dense than water: degree Baumé ($^{\circ}\text{Bé}$) = $144.3/\text{specific gravity}$

More dense than water: degree Baumé ($^{\circ}\text{Bé}$) = $144.3 - (144.3/\text{specific gravity})$.

Degree Belgian

The degree Belgian ($^{\circ}\text{Be}$), which may be occasionally encountered, is used for the expression of the specific gravity of beers and worts.

It is defined as $(\text{specific gravity} - 1)/100$.

Degree Brix

The degree Brix ($^{\circ}\text{Bx}$) scale is used as a measure of dissolved solids expressed as per cent weight per weight, originally at a temperature of 60°F (15.5°C) but now 20°C . It was devised by Adolph Brix based on a recalculation of the tables of **Balling**.

The scale is used principally for expressing the concentrations of sugar solutions as in the case of the syrups commonly used in brewing. Similarly, fruit juice concentrates may be similarly described.

Degree Gay-Lussac

Degree Gay-Lussac is a description of alcohol content used in some countries and is measured in alcohol by volume (ABV).

Degree of general hardness

A unit used to quantify the hardness of water and equivalent to a mineral content of 10 mg of calcium oxide per litre of water.

See **water hardness**.

Degree Plato

The Plato scale is used to describe the concentration of solutions of worts or sugars. The scale is a revision of that of **Balling** and made by Plato in 1918 since the former was erroneous. As with the **Balling** tables the concentration, usually of wort, is compared to the values of sucrose solutions (w/w) measured at 20°C .

Using the Plato scale, wort with a specific gravity of 1.010, measured at 20°C , is equivalent to a sucrose solution of 2.557% w/w. In other words the concentration in degree Plato is numerically roughly equivalent to a quarter of the present gravity.

Degree Régie

The degree Régie is a French system, now archaic, used to measure liquid density. In the past it has been used for expression of the concentration of worts.

One degree Régie is equal to $(\text{legal density} - 1000 \times 100)$.

Legal density is defined as the mass of 50 cm^3 of liquid, measured at 15°C , divided by the mass of an equal volume of pure water measured at 4°C .

Degree saccharin

Degree saccharin is a synonym for **present gravity**.

Degree Twaddle

The Twaddle scale is used as a measure of the density of liquids, generally those whose density is greater than that of water. The unit is often applied to solutions of materials such as sodium hydroxide (NaOH) as might be used as part of cleaning in place (CIP) regimes.

One degree Twaddle ($^{\circ}T_w$) is equal to a difference in specific gravity of 0.005.

D

Deltamethrin

Deltamethrin([cyano-(3-phenoxyphenyl)-methyl]3-(2,2-dibromoethenyl)2,2-dimethyl-cyclopropane-1-carboxylate) is a synthetic pyrethroid insecticide of the type that may be used for the control of insect infestations on crops such as hops.

Density bottle

A device used for measuring the density of liquids.

See **pycnometer**.

Density meter

As the name suggests density meters are used for the determination of the specific gravity of liquids. In brewing the devices are used for routine quality control for monitoring the specific gravity of worts and beers. Two types of measuring device are in common usage for quality control purposes. Firstly, the vibrating U-tube type relies on the measurement of damping of oscillation which is caused by the presence of the sample of liquid. The degree of damping is compared to that when the tube is filled with distilled water, and from this the specific gravity can be inferred. The devices are attemperated and are capable of very precise and measurements. The second type of device relies on ultrasonics for determination of specific gravity. This latter type is particularly suitable for in-line use. In this role they may be used for duties such as the automatic control of blending high-gravity beers with breakdown liquor or wherever an in-line measure of gravity is needed.

Several designs of density meter have been developed for use for the automatic in-tank measurement of specific gravity in a fermenter. Such devices have the potential advantages of giving an early indication of non-ideal behaviour and also the possibility of using the output from the sensor as part of a bigger fermentation control system.

In an early development the vibrating U-tube type of sensor was used as part of an external loop system, with an inlet and outlet attached to the vessel, through which the fermenting wort was pumped. This attempt at in-line gravity measurement was not particularly successful since errors were caused by gas breakout. In order to prevent this valves were required to control the back-pressure and thereby to prevent gas breakout. Nevertheless these problems, together with concerns of the hygiene of the loop system, have prevented any wide take-up of this approach. Several other gravity sensors have been developed which are located within the fermenter. In the **Gravibeam** system the detector takes the form of a displacer which when immersed in wort experiences an upthrust the magnitude of which is measured using a load cell. Temperature compensation is provided by the presence of a platinum resistance thermometer. The value of the upthrust is related to specific gravity.

Two other devices, the **Platometer** and the **FerMAC system**, rely on the measurement of pressure at different heights in the vessel. Providing the sensors are located at a known vertical distance apart the differential pressure can be used to infer the specific gravity of the surrounding medium. The design of the Platometer is shown in the following figure.

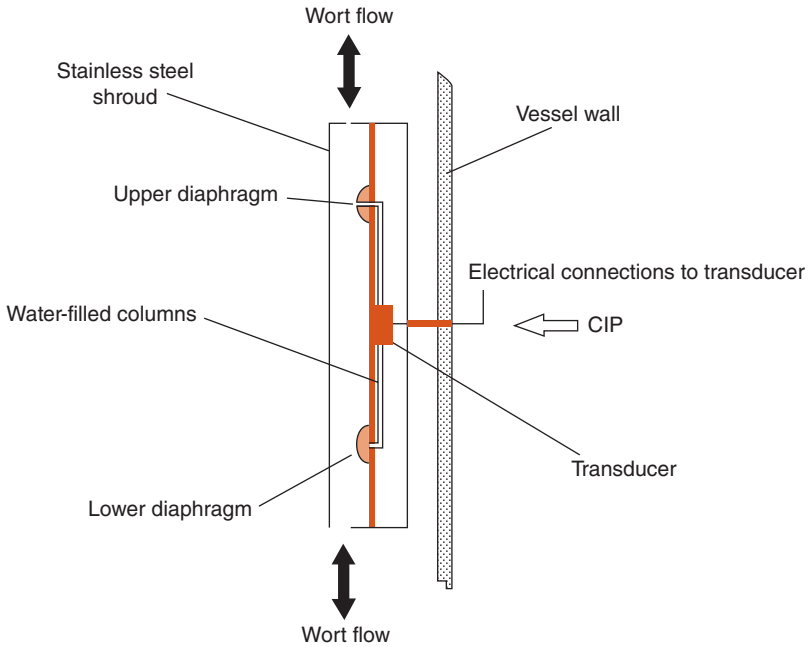
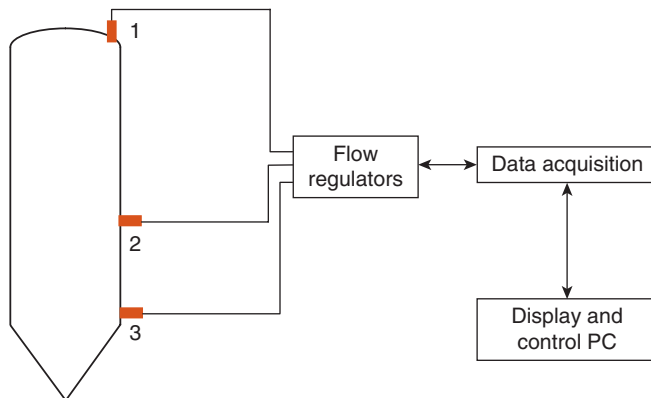


Diagram showing the sensor arrangement used in the Platometer for the automatic in-line measurement of specific gravity

Two stainless steel diaphragms separated by 45 cm are mounted near the wall of the vessel. The diaphragms sense the pressure and this is transmitted to a transducer and converted into an electrical signal. The two sensors are separated by a column filled with water such that the diaphragms and transducer are balanced by equal-sized columns of water and wort at the same temperature. Thus, the electrical output from the transducer provides a temperature-compensated measure of specific gravity. The device reportedly provided continuous measurement of wort gravity with an accuracy of $\pm 0.1^\circ\text{Plato}$.

In the FerMAC system three pneumatic sensors are located within the vessel as shown in the following diagram.



FerMAC system for in-tank measurement of specific gravity

The transmitters take the form of stainless steel diaphragms that are attached to the inner wall of the fermenter. The pressure exerted on the diaphragm by the fermenting wort is detected by a balancing flow of inert gas supplied to the back of each. The pressure value required to achieve the balance provides a measure of the pressure due to the hydrostatic head. The differential between the top and bottom sensors is used to compute the total wort volume and that between the two lower sensors the specific gravity.

Depth filtration

Depth filtration describes the type of process in which the sieving action is achieved using a bed of material through which the fluid to be clarified is passed. It is distinct from surface filters, which rely purely on the cut-off of the pores in the membrane for their sieving action.

Depth filtration relies on a combination of three mechanisms. These are the pore size of the surface of the material, which limits the size of particle that can enter the filter bed, the ability of the interstices within the bed to trap particles, and electrostatic effects, whereby charged particles, which may be smaller than the pore size, become bound to components of the filter bed with an opposite charge. Compared with surface filters depth filters have a greater capacity and are therefore suitable for the clarification of feedstocks with relatively high solids loadings.

Several different types of depth filter are used in brewing. They are used commonly in water treatments in the form of sand filters for solids removal and as deionisation columns for water purification. Depth cartridge filters are used for cold sterilisation of beer and powder filters are used for primary beer filtration and possibly colloidal stabilisation.

See **filtration**.

De-stoner

De-stoners, as the name suggests, are used to remove extraneous objects from solid dry goods such as malts or other solid adjuncts. This is a necessary prerequisite to the processing of such materials in order to prevent damage to brewery plants.

De-stoners take the form of inclined screens over which materials such as malt grains are allowed to enter in the form of a thin stream. A stream of air is blown upwards through the screen, the velocity of which is sufficient to lift the malt grains and to allow them to pass downwards over the screen to be collected at the base. Heavy stones and other extraneous matter are not moved by the air stream and these remain on the screen. The latter is attached to a mechanical oscillator the operation of which causes the trapped stones to be transported up the screen eventually to fall off the end into a collection bin.

Detergents

Chemical cleaning agents used in routine brewery cleaning regimes. They are a type of **surfactant** and rely on their effect by being able to completely wet surfaces and remove adhering soil and via their emulsifying activity where they are able to keep soil particles in suspension and prevent them re-adhering to surfaces. They may be used alone but most often with other additives to enhance their performance in given situations. Alkaline detergents based on sodium hydroxide are most commonly used because of the latter's ability to saponify lipids and to remove heavy soils. Typically it is used hot (70–90°C) at a concentration of around

2–4% w/v. It may be used in combination with hypochlorite, which is useful for removing tannins. It has the major disadvantage that it reacts with CO_2 to give sodium bicarbonate. Unless vessels such as fermenters are first purged with air, there is a risk that the effectiveness of the sodium hydroxide will be decreased and dosing rates must be adjusted to account for the loss. In addition, bulk stores may become increasingly deteriorated if exposure to CO_2 occurs. Alkaline detergents based on NaOH react with soluble salts in water to form calcium carbonate and magnesium hydroxide, and this can form insoluble scales on metal surfaces. The effect is exacerbated at high temperatures. This can be avoided by the use of **sequestering agents**. Alkaline detergents are often supplemented with polyphosphate molecules which act as emulsifiers.

Acid detergents are usually based on phosphoric acid, alone or in combination with nitric acid. They are able to remove scales and calcium oxalate **beerstone**. They are not affected by CO_2 and therefore can be used where levels of this gas might be elevated. The acids are corrosive and, for this reason, they are usually applied at cold temperatures. They are less effective at removing heavy soiling and may be used in a two-stage treatment after first washing with caustic soda.

DeviceNet

DeviceNet is a digital communication system used in automated control and monitoring systems of the type used in many large commercial breweries. It is a relatively inexpensive system which was developed by the US automation and control company Allen-Bradley (part of Rockwell Automation).

Dextrinisation equivalent (DE)

This is a term used to quantify the reducing power of sugar syrups. It is the ratio, expressed as a percentage, of the actual glucose concentration of a syrup compared with the concentration of glucose that would be obtained if all the starch was hydrolysed to glucose.

Dextrinizing units

Dextrinizing units are used to quantify the activity of **α -amylases**. The process, dextrinisation, is descriptive of the ability of these enzymes to hydrolyse starch and to produce relatively smaller dextrin molecules. During the mashing stage of wort production these enzymes, in conjunction with **β -amylases**, convert starch into simpler fermentable sugars. The concerted action of these and other similar enzymes is quantified as malt **diastatic power (DP)**.

Dextrin malt

See **Carapils Malt**.

Dextrinogenic amylase

This is a synonym for **α -amylase**. It refers to the fact that these enzymes show rapid rates of progress when mashing is gauged by the iodine colour test but increases the reducing power of the digest relatively slowly.

See **α -amylase** and **starch**.

Dextrins

Dextrins are polymers of glucose. They are either linear glucose polymers linked by α -(1-4) linkages or branched polymers containing additional α -(1-6) linkages. Their relevance to brewing is that they are formed in worts during the mashing process. They are not fermented by brewing yeast strains and therefore they persist in beer where they contribute to mouthfeel and fullness.

Dextrin concentrations in worts range from 2.5 to 4.5 g/100 mL. The spectra of dextrins in worts and resultant beers are identical. They represent approximately 90% of the non-fermentable residue in beer. Chemically they comprise 4 or more glucose units. Some 40–50% of wort dextrins contain 4–9 glucose units; the remaining dextrins contain 10 or more glucose units. The latter are referred to as **higher dextrins**. The spectrum of dextrins in worts and beers has a characteristic pattern. Those with 4 glucose units are the most abundant. Repeating peaks of higher dextrins are separated by 4–5 glucose units. The degree of branching increases with an increase in molecular size. Those with 4 glucose units contain around 30% branched molecules, whereas the figure rises to 70% of dextrins with 7 glucose units and 100% of dextrins with 10 or more glucose units.

Diacetyl

Diacetyl (syn. biacetyl, 2,3-butanodione, dimethyl ketone, 2,3-diketobutane) is a **vicinal diketone** (VDK) with the structure $\text{CH}_3\text{-CO-CO-CH}_3$. It is produced during fermentation and has a pronounced flavour and aroma of butterscotch or toffee. It has a low flavour threshold (0.07–0.15 mg/L). In some beers, particularly some ales and stouts, the presence of diacetyl at a concentration above the flavour threshold is considered desirable. In the majority of beers, particularly pilsener-type lagers, the presence of diacetyl above the flavour threshold is undesirable and considered to be a major defect.

Diacetyl arises in beer via two routes. Its presence, at very high concentrations, may be a symptom of beer spoilage by bacteria, particularly *Pediococcus* or lactic acid bacteria. In such cases other accompanying symptoms such as the presence of slimes and ropes occur.

Diacetyl is also produced by yeast during the course of normal fermentations. It arises in beer as a breakdown product of an intermediate in the biosynthesis of the amino acid valine. In late fermentation free diacetyl is taken up by yeast and further metabolised to products that have much lower flavour thresholds than diacetyl. An essential part of the management of modern commercial rapid lager fermentations is to ensure that at completion the residual diacetyl concentration is below the flavour threshold.

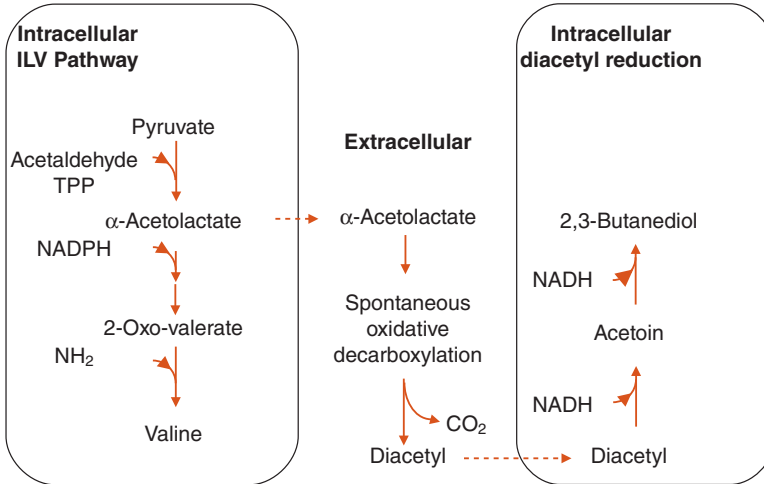
See **diacetyl cycle**, **VDK management**.

Diacetyl cycle

The term diacetyl cycle, also known as the more generic VDK cycle, describes the generally agreed series of reactions which involve the participation of yeast and which lead to the formation of diacetyl (and other VDKs) and its subsequent reduction during the course of fermentation.

Diacetyl, as well as the important beer flavour and aroma VDK, 2,3-pentanedione, is formed by yeast from intermediates of the pathways which lead to the synthesis of valine and iso-

leucine, respectively. Key intermediates in this pathway are the α -acetoxy acids, α -acetylactate and α -acetoxybutyrate. A proportion of these intermediates is excreted by yeast into the external medium during fermentation where they undergo spontaneous oxidative decarboxylation to form free diacetyl and 2,3-pentanedione, respectively. In the latter part of the cycle these compounds are re-assimilated by yeast and are reduced to the less flavour-active 2,3-butanediol and 2,3-pentanediol, respectively (see diagram).

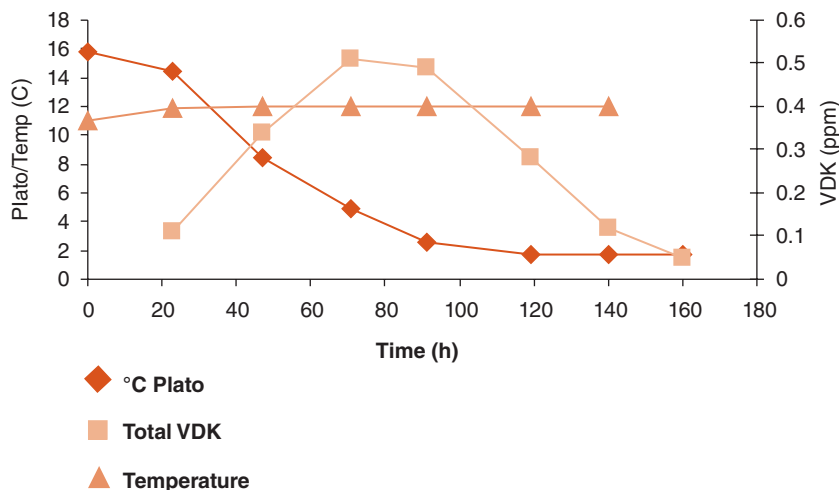


Principal steps in the pathways leading to the synthesis and degradation of diacetyl. The enclosed areas indicate those parts that occur inside yeast cells and the unenclosed areas the parts that occur in the fermenting beer.

Since diacetyl is the most significant VDK with regard to beer flavour the remaining discussion will be restricted to this compound.

The individual rates of the reactions that comprise each stage control the actual concentration of diacetyl that appears in beer. It is generally agreed that the rate-determining step in the whole cycle is the spontaneous oxidative decarboxylation of α -acetylactate to form free diacetyl. From a practical standpoint, this means that in the presence of yeast the concentration of free diacetyl is always low since as soon as it arises it is assimilated and reduced. For this reason, the extracellular concentration of α -acetylactate is always higher than that of free diacetyl and the former can be regarded as a 'potential diacetyl'. Analyses of samples of fermenting worts for diacetyl concentration must reflect this. The procedures used always incorporate an initial heating step in which all α -acetylactate is first converted to diacetyl. For this reason it is usual to refer to analytical results as 'total VDK' or 'total diacetyl', meaning the sum of α -acetylactate and diacetyl.

In early fermentation the rate of formation of α -acetylactate exceeds the rate of decarboxylation and reduction, whereas in the latter stages the reduction stages predominate. In consequence the total VDK measured throughout fermentation takes the form of a peak (see diagram).



Patterns of total VDK appearance and disappearance during a typical all-malt lager fermentation. The line "total VDK" represents the sum of free diacetyl and its precursor, α -acetolactate.

The rate of formation of diacetyl is influenced by the spectrum and total concentration of amino acids present in the wort. In particular the concentration of valine is significant. Valine is a strong inhibitor of the enzyme acetoacetyl synthase, which catalyses the formation of α -acetolactate. Where intracellular concentrations of valine are high this enzyme is inhibited, and accordingly diacetyl formation is restricted. Valine is a group B amino acid that is not taken up until mid-fermentation. For this reason in early fermentation intracellular valine concentrations are low and diacetyl formation proceeds. The uptake of valine restricts the activity of the synthetic pathway, diacetyl reduction predominates and the total VDK peak declines. The specific effect of valine is probably of small practical importance since all worts contain complex mixtures of amino acids. The regulation of uptake of mixtures of amino acids by yeast is complex, being carried out by several permeases, both non-specific and specific. Once inside, the cell transaminases catalyse reactions, leading to interconversions between individual amino acids. In these circumstances it is difficult to predict with any certainty how enzymic reactions, whose activities are modulated by amino acids, might be influenced. In addition, worts made from materials such as malted barley tend to have a fairly constant amino acid spectrum. The factors of most significance, therefore, are the total amino acid concentration and the rates of reaction which utilise amino acids. Where the total amino acid concentration is low or where conditions favour high rates of yeast growth, which produces rapid and extensive utilisation of amino nitrogen, intracellular valine concentrations remain low and VDK accumulation proceeds unhindered. In this circumstance the VDK peak is high and persistent. Conditions that favour high rates of yeast growth and produce a similar effect are high pitching rates and dissolved oxygen concentration.

The spontaneous oxidative decarboxylation of α -acetolactate to give free diacetyl is a purely chemical reaction and, predictably therefore, rates are increased by elevated temperature. For this reason many breweries prefer to allow a slight increase in temperature during the warm diacetyl stand to allow for this possibility. Rates are also enhanced by low pH, the

presence of oxygen and metal ions such as iron, copper and aluminium. With the exception of oxygen, these should not be process variables and are therefore of academic interest only. In the case of oxygen, this should be excluded at all stages after the start of fermentation and, perhaps also, is not relevant. It does provide an explanation as to how a beer ostensibly with no defects can rapidly acquire an obvious diacetyl taint when dispensed into a glass. Thus, if at the point of separation of beer from yeast a high concentration of α -acetolactate was present, in the absence of oxygen and at cold temperatures, spontaneous decomposition to free diacetyl might not occur to any appreciable degree until dispense, exposure to air and warming.

Reduction of diacetyl proceeds in two steps via catalysis by NAD- or NADP-linked reductases to give acetoin and 2,3-butanediol, respectively (see the first diagram under 'Diacetyl Cycle'). Under most circumstances the uptake and reduction is very rapid. Several enzymes have been isolated from brewing yeasts, which are capable of performing these reactions *in vitro*. Which of these catalyses the reactions *in vivo* is not clear. It seems that lager strains contain a specific acetoin reductase and a number of alcohol dehydrogenases that show activity towards diacetyl but not acetoin. All ale strains contain at least one enzyme that shows activity towards acetoin and diacetyl. The ability of lager strains to assimilate and reduce diacetyl is influenced by physiological conditions. Respiratory competent cells which are fully derepressed and capable of aerobic oxidative growth show the activity towards exogenous diacetyl. Presumably this reflects the up-regulation of genes coding for enzymes capable of reducing diacetyl. Yeast of anaerobic repressed physiology, as in the case of cropped pitching yeast, has a comparatively lower ability to assimilate and reduce exogenous diacetyl. This ability increases when such yeast is forcibly exposed to oxygen. Since the latter is accompanied by sterol synthesis and the acquisition of a more competent plasma membrane it is tempting to suggest that this increased activity reflects an increased ability of the cells to take up diacetyl. To some extent this premise is supported by the observation that the ability to assimilate and reduce free diacetyl during fermentation is reduced with residence time. This would be consistent with the suggestion that transport of diacetyl might be limiting at this stage. This remains to be confirmed.

See also **VDK management**.

Diacetyl:2,3-pentanedione ratio

Diacetyl and 2,3-pentanedione, qualitatively the two most important VDKs formed in beers, may arise via the action of yeast during fermentation or via the effects of spoilage by bacteria (see **diacetyl cycle** for a detailed explanation). Where concentrations in finished beers are abnormally high it can be helpful but difficult to ascertain their origin, thus, from abnormal fermentation performance or via spoilage. An indication can be obtained by determining the relative concentrations of each. During the course of a normal brewery fermentation the ratio of diacetyl to 2,3-pentanedione is usually in the range from 2:1 to 3:1. In the case of bacterial contamination much greater concentrations of diacetyl arise, and in consequence the ratio of 5:1 or much higher may occur.

Diacetyl rest

A synonym for **diacetyl stand**.

Diacetyl stand

Diacetyl is a VDK, with a highly objectionable toffee butterscotch flavour and aroma produced by yeast and released into beer during the course of fermentation. It is subsequently taken up and further metabolised by yeast in late fermentation. Diacetyl stand (also known as a **diacetyl rest** or **VDK rest** or **stand**) refers to the period that occurs towards the end of fermentation, usually for lager beers, although it can also be applied to ales, where the contents of the fermenter are held at a warm temperature in the presence of yeast, with the aim of allowing the concentration of diacetyl to fall to a sub-flavour threshold concentration. The process is associated particularly with modern fermentation practice where the subsequent conditioning phase is performed rapidly at very low temperature and in which yeast plays no positive part.

In traditional lager beers diacetyl reduction occurs when the green beer is subject to a slow cool secondary fermentation in the presence of yeast. In this case, time is not an issue and diacetyl analyses would not normally be performed. In more modern rapid processes where time constraints may be more pressing the primary and secondary fermentation is conducted in a single vessel. Reduction of diacetyl is dependent upon the presence of yeast. In the case of these rapid processes beers are chilled immediately after fermentation is completed and the majority of the yeast is removed. This prevents any further opportunity for diacetyl reduction; hence, it is essential to ensure that this occurs before green beers are chilled to conditioning temperatures. For this reason, in such rapid fermentations, diacetyl analyses are routinely performed on samples removed at intervals towards the end of the process. When the diacetyl concentration falls below a specified concentration the fermentation is deemed complete; the diacetyl stand is finished and the beer may be transferred to the next stage of processing.

See **fermentation, diacetyl cycle**.

Diamant

See **Valtický**.

Diaphanoscope

Name given to an optical device, now of purely historical interest, used for the examination of malt grains with the aim of determining the degree of steeliness by visual observation of a number of grains under transmitted light. The instrument, a type of light box, was adapted from similar devices used in medical and photographic applications which make use of intense beams of transmitted light to allow improved visual examination.

Diaphragm valve

Diaphragm valves are those in which process flow is regulated by the operation of a plug mounted on a shaft assembly the height of which can be adjusted by the action of a screw. The plug is shaped to fit into the valve body inside the pipe. A seal is provided by a diaphragm made from a flexible inert material which is mounted over the surface of the plug.

The diaphragms provide a good hygienic cleanable surface and this type of valve can be used safely with beer or any other process stream such as yeast slurries which come into contact with beer. When closed a good seal is formed between the diaphragm and valve seat and this type of valve has excellent shut-off properties. In order to ensure the hygienic integrity of the seal it is essential that the integrity of the diaphragm is not compromised; however, even in the event of failure of the latter, there should be no leakage.

Diastase

Diastase is the collective term for the enzymes which together catalyse the hydrolysis of starch during the mashing phase of brewing to yield fermentable sugars and non-fermentable dextrans. Several distinct activities are involved, and the enzymology is complex and not fully characterised. In the case of malt worts the principal enzymes involved are α - and β -amylases. The former enzyme cleaves starch molecules randomly at internal α -(1,4) bonds to yield dextrans, oligosaccharides and some maltose. β -Amylase exerts its activity at the non-reducing ends of dextrin molecules to produce maltose. It cannot cleave α -(1,6) bonds that occur at branch points.

In barley malts several isozymes of both α - and β -amylases occur. Apart from the amylases several other activities are grouped with diastase. Phosphorylases cleave α -(1,4) bonds at non-reducing chain ends and with the addition of a phosphate molecule yield glucose 1-phosphate. Since worts contain phosphatases the action of these may convert glucose 1-phosphate into free glucose and phosphate. Several forms of α -glucosidase each with differing substrate specificities occur in barley malt, some of which may be active during the early phases of temperature-programmed mashes. The enzymes can hydrolyse maltose and larger molecules such as oligosaccharides, dextrans and starch. Several diastatic enzymes are capable of catalysing other side activities such as the conversion of maltose into isomaltose.

Malted barley also contains debranching enzymes which are capable of cleaving α -(1,6) bonds which form the branch points in amylopectin and starches. These enzymes, also referred to as limit dextrinases, result in the formation of maltose and maltotriose. The role of these malt enzymes in mashing is uncertain. Much of the activity may be destroyed during kilning, and even if this is survived other inhibitory proteins are also known to persist into mashing. Thus, in the absence of exogenous debranching enzymes, many, if not most, of the α -(1,6) bonds may survive the mashing phase.

Diastatic malt extract

Diastatic malt extracts are liquid preparations of malt in which the mashing conditions have been adjusted to ensure that the activities of some or all of the cereal hydrolytic enzymes are retained.

See **malt extract, adjuncts**.

Diastatic power (DP)

The diastatic power or activity is a measure of the starch hydrolysing power of malts. It is a measure of the combined activity of a number of enzyme activities, principally α - and β -amylases, collectively known as **diastase**. For this reason it is also known as the **enzymatic power**. The diastatic power of malt is indicative of the amount of starch hydrolytic activity that is available to produce fermentable sugars during the mashing stage of brewing.

Diastatic power of malt is measured by incubating an extract with a solution of a standardised starch preparation at a controlled temperature. The extent of starch degradation is taken to represent the diastatic power of the particular malt. Different procedures and methods of measurement are used. Extracts are made from infusions of finely ground malt. The precise conditions used to prepare the infusion differ between individual procedures; however, all require the use of controlled quantities of ground malt suspended in an aqueous extraction

medium and held for specified times at a controlled temperature. In the Institute of Brewing (*IOB Methods of Analysis, Vol 1 Analytical*, ISBN 0 900489 10 3) the degradation of starch is assessed by determining the concentration of reducing sugars formed via iodometric titration. The results are compared against a blank prepared without extract. Results are expressed with reference to a known quantity of the original malt, dry or as is.

Three procedures are given in the American Society of Brewing Chemists methods manual (*ASBC Methods of Analysis*, ISBN 1-881696-01-4). The first of these is broadly similar to the IOB method, but the original enzyme extraction is conducted in the presence of sodium chloride and the production of reducing sugars is determined using a ferricyanide procedure. In the rapid procedure reducing sugars are determined using a spectrophotometric procedure after reaction with p-hydroxybenzoic acid hydrazide. In the third procedure the production of reducing sugars is determined using flow injection analysis.

Several units are used to quantify diastatic power. In the United Kingdom (Institute of Brewing) the original unit was the °Lintner (°L). This defined 100°L as being equivalent to the ability of 0.1 mL of a 5% w/v infusion of malt under the defined conditions of the test to produce sufficient reducing sugar to completely reduce 5 mL of Fehling's reagent. This has been superseded by the Windisch–Kolbach (°W-K) unit, which is also used by the European Brewing Congress.

The relation between the two units is given by the following formula:

$$\text{Diastatic power (°L)} = \frac{(\text{°W-K} + 16)}{3.5}$$

The US method uses sodium chloride in the infusion medium. For this reason the resultant diastatic power is different from the European procedures and the units are termed *diastatic power degrees ASBC*.

Values for diastatic power show some correlation with the protein content of the malt, presumably indicating that the higher the protein content, the higher the content of diastatic enzyme. Typical values are 35–40 for a well-modified low-protein UK ale malt, 90–110 for a European lager malt, >125 for an American high-protein two-row malt and >150 for a six-row malt.

Diastatic yeast

Name applied to certain yeast strains (*Saccharomyces diastaticus*, now reclassified with *Saccharomyces cerevisiae*), which possess amyloglucosidase activity and are therefore able to degrade dextrans to yield fermentable sugar. Such yeasts are considered undesirable since contamination of normal brewing yeasts causes super-attenuation of worts. In addition, diastatic yeasts usually carry the *POF* gene, which is responsible for **phenolic off-flavours (POFs)**. The ability to utilise phenols has made these yeast strains an obvious source of DNA for genetic manipulation of brewing strains where super-attenuation might be desirable, for example, in the production of low-carbohydrate beers. Although such yeasts have been constructed, none is in use, as far as the author is aware.

See **wild yeast**.

Diätbier

These are traditional low-carbohydrate beers suitable for consumption by diabetics.

See **diet beers**.

Diatomaceous earth

See **kieselguhr**.

Diatomite

See **kieselguhr**.

Diauxie

Term coined by the French biochemist and geneticist, Jacques Monod, which essentially translates as 'two growth phases'. It is of relevance to brewing in that it describes the growth of yeast, including brewing strains, when growing on sugar under aerobic conditions whereby there is an initial growth phase, where the sugar is consumed and ethanol is a major end product. After disappearance of the sugar there is a period of apparent inactivity after which a second phase of growth takes place, this time at the expense of ethanol. The transition from one growth phase to the next is termed the diauxic shift.

The phenomenon is explainable in that in the initial growth phase the presence of sugar represses the respiratory pathways and this overrides the effects of oxygen such that ethanol is the major end product. Once the sugar is exhausted the repressing signal is alleviated and the cells develop respiratory capacity by up-regulating the appropriate genes and ethanol consumption proceeds.

See **yeast growth and metabolism**, **Crabtree effect**.

DiBAC₄

Shorthand name for the dye bis(1,3-dibutylbarbituric acid) trimethine oxonol [also known simply as oxonol], which has found use as a fluorescent dye useful for determining the viability of cells, including yeast. It is a voltage-sensitive dye which has also been used to measure membrane potential. In viable cells the dye is taken up and then pumped out into the medium and so viable cells remain colourless, whereas dead cells fluoresce.

See **yeast viability**.

Dicofol

Dicofol (2,2,2-trichloro-1,1-bis(4-chlorophenyl)ethanol) is an organochlorine pesticide that is related to dichlorodiphenyltrichloroethane (DDT). It was used widely for the treatment of infestations of hop plants with **red spider mite**. Usage has declined because of the development of resistance in mites and fears over potential toxic effects of pesticide residues in hops.

Diet beer

Diet beers are those that are made in such a way that they have a low carbohydrate content. These are made using worts that are highly fermentable such that the resultant beers contain very low carbohydrate contents. The beers have a long history and have been marketed as being suitable for consumption by diabetics. More recently they have been championed by the health conscious, particularly those who have chosen to adopt a low-carbohydrate, protein-rich diet as a means of achieving weight loss. Several major brewers, particularly from the United States, have marketed such products in a category termed *lite* or light beers. It should be noted that, although these beers may have low carbohydrate contents if the alcohol

concentration falls within the usual range of 4–6% abv, as most do, they cannot be described as low calorie. Indeed beers made from worts of the same original gravity as those made from worts with the usual fermentability will contain greater ethanol contents. In order for the beer to qualify as being genuinely low calorie it must have a low carbohydrate and ethanol content. Some light beers do meet this requirement, but much confusion remains.

Several routes may be used to achieve worts of high fermentability. In traditional types; for example, the German Diätbiers, the grist and mashing regimes are adjusted to ensure that the proportion of non-fermentables is low. These include very prolonged temperature-programmed mashing in which there are several rests. For example, 30 minutes at 50°C, 45 minutes at 62°C, 45 minutes at 65°C, 30 minutes at 68°C, 30 minutes at 70°C, 15 minutes at 72°C and finally mashing off at 74°C. In addition to this protracted regime, which provides considerable time for the malt saccharifying enzymes to act, powdered diastatic malt may also be added to the fermenter. In less traditional processes and, where legislation does not prohibit it, enzymes may be used. Typically these are fungal α -amylases and they are added to cooled wort in fermenter. Where they are used care must be taken to ensure that other beer qualities are not cross-contaminated with active enzymes.

Dihydro-isohumulones

See **rho-isohumulones**.

Dilution rate

The rate of addition of fresh medium to a continuous fermentation system.

See **chemostat**.

Dilution water

Dilution water (or liquor) is that which is used in **high-gravity brewing** in order to dilute the concentrated beer to the required sales concentration. In addition, albeit more rarely, the same term may be used for water that is used by some brewers to reduce the concentration of the suspending beer in yeast slurries cropped from high-gravity fermentations.

Dilution water forms part of the final product and therefore it must have a composition that cannot compromise beer quality. It must be potable, free from all taints, sterile, de-aerated and contain no contaminants that might influence beer taste and aroma or might be a cause of beer hazes either directly by the presence of suspended solids or via subsequent interactions with other beer components.

Dilution of high-gravity beer may occur pre- or post-filter. In the latter case it is essential that it is free from all solid materials. Typically water of brewing quality is used as the starting material. In order to render it into a suitable form for dilution it is usually treated in a plant dedicated to this purpose. Before use the water is passed through a trap filter, de-aerated, usually by a vacuum stripping technique (max. 50 $\mu\text{g/L}$ dissolved oxygen), and carbonated followed by sterilisation by passage through a sterilizing sheet filter or via treatment with ultraviolet radiation.

Dimethylpolysiloxane

Dimethylpolysiloxane is the active ingredient of silicone-based **anti-foams**, which are used for controlling foaming in processes such as wort boiling or fermentation. The generalised

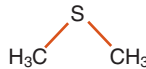
structure is $(\text{CH}_3)_3\text{SiO}[\text{Si}(\text{CH}_3)_2\text{O}]_n\text{Si}(\text{CH}_3)_3$. These polymers have very low surface tensions, in the region of 21 dyn/cm, which accounts for their ability to function as efficient anti-foaming agents. They are relatively insoluble, a property that increases with an increase in the length of the polymer.

See **anti-foam**.

Dimethyl sulphide (DMS)

A sulphur-containing component of beer which has the taste and aroma of cooked sweetcorn. In pilsener-type lager beers, at concentrations in the range 30–100 µg/mL, it produces a desirable flavor; at higher concentrations, its presence is considered a defect. DMS is largely derived from malt and is formed both during malting and in the brewhouse. Therefore, the concentrations of DMS found in beer are largely controlled by the conditions used in malting, the types of malt used to make worts and the conditions used in the brewhouse. Some DMS may arise in fermentation via the action of yeast strains which possess dimethyl sulphoxide (DMSO) reductase activity, and abnormally high levels may appear as a result of contamination of worts with enteric bacteria. Both of these are not usual occurrences.

The precursor of DMS in malt is the compound S-methylmethionine (SMM) and during the finishing kilning stages a proportion of this is converted to DMS and DMSO. At kilning temperatures greater than 60°C a greater proportion of the SMM is converted to DMSO and less to DMS. During wort production heating promotes further conversion of SMM to DMS. Thus, if the whirlpool stand time is prolonged, the greater the concentration of DMS is formed in wort. Both DMS and DMSO persist throughout fermentation and into beer, albeit with some loss due to evaporation and gas purging, unless further modification occurs via the routes described already.



Structure of dimethyl sulphide

Dinkel

Dinkel is a type of spelt, a primitive form of wheat. It was commonly grown in Germany where it was primarily used for baking. It originated in Asia and from here it was imported into the Swabia region of southern Germany. It was a popular grain crop, and in the mid-nineteenth century the area of cultivation in some areas of Germany was more than five times greater than that devoted to wheat. Eventually it was superseded by higher-yielding wheat varieties.

In recent years there has been a resurgence of interest largely based on the fact that the plants require little fertiliser and have high levels of resistance to many diseases, which obviates the need for excessive use of insecticides. In addition, the grain contains relatively high levels of protein and minerals and this, coupled with the ability to grow under chemical-free conditions, has attracted proponents of health foods.

The grains have been used for brewing speciality beers.

See **spelt**.

Diod dail

Diod Dail, in Welsh 'nettle drink', is a type of herb beer made from the fermentation of an infusion of nettle leaves and usually burdock roots. It is also mentioned in the autobiography of H.E. Bates (Methuen, ISBN 13: 978-0-413-77600-6, 2006) as being a popular home-brewed beer in the Northamptonshire region of the United Kingdom.

D

Direct epifluorescence filter technique (DEFT)

Method for the rapid identification and enumeration of microbial cells. The sample is filtered through a membrane filter and cells are stained with a suitable dye. Acridine orange is commonly used since it differentiates between viable (stain orange) and dead (stain green) cells. The conjugates are viewed by fluorescent microscopy, which may be linked to image analysis. Fluorescence techniques provide great sensitivity and very small numbers of cells can be detected in a matter of a few hours without the need for a pre-growth stage. Using fluorescent dyes (antibody-direct epifluorescent filter technique) attached to antibodies strain specific to target organisms, positive identification is possible and very small numbers of contaminants can be distinguished within a large population of non-target cells or at very low levels within a process stream. In another variation conjugates of fluorescent dyes attached to oligonucleotides specific to target organisms can be used to detect and identify specific cells via *in situ* hybridisation on membranes. Undoubtedly, as more and better probes become available, coupled with automatic sampling, analysis and reporting these techniques will prove to be of great value in real-time microbiological testing.

Disc filter

See **pulp filter**.

Disc mill

Disc mills are used to grind grains and other solid adjuncts to produce a grist (see **milling** for further details). They comprise two discs, mounted close together, the inner faces of which are often roughened or fitted with small projections. The material to be ground is fed into the middle of the discs in the gap between each. The gap is adjustable. Various designs of mills may be found in which one disc is stationary and the other rotates; alternatively both may rotate, often in opposite directions. The material to be milled is broken up by the action of the moving discs, the roughened surfaces or projections increase the frictional forces to which the particles are subjected. As the process proceeds the grist is forced outwards and exits from the gap between the discs.

Disc mills are efficient but are not suitable for large-scale commercial brewing and hence they tend to be used for experimental purposes; for example, the Bühler–Miag disc mill is the standard equipment recommended by the brewing laboratory methods manuals for the preparation of standardised extracts. In these applications the process is carried out using dry feedstocks. More recently there has been an interest in this type of mill for use in a combined milling and mashing operation. In this case the process is carried out with the disc mill suspended in water in what eventually becomes the mash.

See **milling**, **pin mill**, **Bühler–Miag disc mill**.

Disinfection

Disinfection is any process which is designed to eliminate the risk of microbial spoilage. This may be accomplished using physical treatments or via exposure to chemical agents with biocidal activity. All of these are employed in brewing. Heat is a very effective sterilizing agent that is capable of killing all microorganisms. The effectiveness is dramatically increased where moist heat is used; hence, the use of culinary steam to sterilise sensitive areas of plants, for example, yeast propagation plant, keg rackers and sample cocks. Steam is particularly useful since it has excellent penetrating power and, providing all the parts of the plant being treated reach the desired temperature, sterility is guaranteed. The killing effect is increased at elevated pressure. Disinfection of beer is accomplished by the application of heat treatments in flash and tunnel pasteurisers.

UV irradiation is used to sterilise water, especially that deriving from boreholes where contamination is possible. It owes its effectiveness to its ability to disrupt nucleic acids. It is not useful where the suspending medium is opaque to UV radiation, which includes beer.

Chemical disinfectants are usually referred to as sanitisers since many have both cleaning and biocidal properties. Alcohol is an example of a simple biocide. It is used in the form of an 80% aqueous solution of methylated spirits either for flooding surfaces or as a spray. It is particularly useful for disinfecting sample taps where the solvent can be ignited to provide additional security.

The ideal properties of chemical disinfectants are that they kill a wide range of organisms, preferably at low concentration, and exert long-lasting effects but have no effect on the media, the fabric of the plant or any other chemicals they come into contact with. Since none possess all of these qualities different types are used for the applications that their properties most closely meet (see table).

Examples of disinfectants used in brewing and their usual applications

Disinfectant	Application
Surface sprays, surface cleaners and foams	Iodophores
	Water-soluble surfactants
	Hypochlorite
	Peracetic acid
Terminal sterilants	Chlorine dioxide
	Hypochlorite
	Ozone
	Iodophores
	Peracetic acid
Soak tanks	Iodophores
	Quaternary ammonium compounds
	Hypochlorite
	Amphoteric surfactants
	Bioguanides
Sanitiser for non-process water	Bromine-based halogen disinfectants
	Non-foaming water-insoluble biosurfactants
CIP additives	Neutral biosurfactants

Dispense

The delivery of beer to (usually) a glass, typically in defined (and geographically appropriate) portion sizes. A process normally performed by bar staff in the **on-trade** from a container to a dispense **tap** and into **glassware**.

D

Dispense data logging

Sensor-based technology used for the remote monitoring and recording of key dispense parameters such as volume, flow rate, throughput, temperature and line cleaning. It is used by many large pub groups to reconcile delivered stock against dispensed volume of beer. Data logging has also found application both in the assurance of dispense temperature to the consumer and in minimising associated volume losses. The technology is also used in trouble shooting and in rationalising the number of branded fonts in a bar.

Dispense pumps

A hardware alternative to **mixed gas dispense** via top pressure which is used to propel beer from container to **beer tap**. Depending on geography, dispense pumps are electric or gas driven.

Dispense tap

Generic name for any of the many types of font used to dispense draught beers from the bulk container to the glass.

See **dispense** and links.

Dispense temperature

The temperature at which beer is dispensed and intended to be drunk by the consumer. Typically, but not always, it varies with the product category and is dependent on the cooling technology and the rate of **dispense**. Key to in-glass temperature is container storage temperature (cellar, cold room), losses between container and tap together with supplementary secondary cooling. Globally, lager dispense temperature varies widely between 0 and 8°C (32–46.4°F). Increasingly lower temperatures 0–4°C (32–39.2°F) are being preferred as ‘the market goes colder’. Some bespoke lager brands are dispensed below 0°C/32°F but require high duty supplementary cooling. Keg and cask ales are dispensed between 8 and 13°C (46.4–55.4°F) but like lagers are being dispensed at ever-cooler temperatures. Likewise stout temperatures range between 4 and 8°C (39.2–46.4°F).

See **remote beer cooler**.

Dispense time

Draught beer **dispense** is affected by a number of factors such as complexity, distance from container to tap, gas pressure and flow restriction. Despite recommended specifications for **dispense** time, the practical reality is that these can vary widely with **dispense** conditions. As a rule of thumb, a standard measure (500 mL or a 568 mL pint) can in a ‘normal’ set-up be dispensed in 20 seconds. Some brands make longer **dispense** times part of the serving ritual. Conversely, for short but intense serving periods in sports stadia, fast **dispense** technologies are increasingly used that deliver 500 mL in 2–6 seconds.

Dispense tubing

Draught beer is typically dispensed via tubing from container to tap. The tubing is most usually made from **medium-density polyethylene (MDP)**, **nylon** or nylon lined MDP (**multilayer barrier dispense tubing**). Although the diameter of the tubing can vary depending on conditions and need, a popular specification used in **pythons** is 6.7 mm (id), 9.5 mm or 3/8 in. (od). **Dispense** lines are colour coded to facilitate identification in the cellar or bar. Rather than using MDP or nylon, small self-contained low-throughput **dispense** systems may use stainless steel tubing for beer transfer.

Dissolved gas measurements

It is necessary at various stages in the brewing process to determine the dissolved contents of gases, usually, CO₂, O₂ and increasingly N₂. These may be checks carried out in bulk liquids or in packaged beers. Concentration ranges can be quite wide; for example, oxygen tensions in cooled wort might be as high as 20–35 mg/L, whereas in bright beer, less than 150 µg/L would be usual. The sensitivity of apparatus must be sufficient to cope with these ranges in an accurate and repeatable manner. It is necessary to be able to measure the concentrations of individual gases in combination such as where mixtures of CO₂ and N₂ are required or where it is necessary to detect low levels of O₂ in the presence of relatively high levels of CO₂. Equipment may be laboratory based, portable for in-plant checks or mounted in-tank or in-line. In the latter case outputs may be suitable for use in control loops. Calibration checks are essential in order to ensure the accuracy of readings, and suitable standards may be available for carrying out such checks. The solubility of gases is influenced by temperature; for example, the solubility of CO₂ increases by 15% for every 5°C drop in temperature. Similarly, gas solubility falls with an increase in the concentration of other dissolved solutes.

Dissolved oxygen concentrations may be measured using electrochemical sensors where the gas diffuses through a membrane and via reaction in an electrochemical cell produces an electric current proportional to the oxygen concentration (typically 0.001–40 mg/L). Optical probes use a sensor which when excited by green light produces a green fluorescence. The intensity of the fluorescence is quenched by oxygen the degree of which allows quantification (typically 0.001–2 mg/L). An early approach for CO₂ measurement was indirectly by measuring the partial pressure in the gas space. In more modern approaches the specific thermal conductivity of individual gases allows independent quantification of both dissolved CO₂ and N₂.

See also **TPO**.

Diverter automatic grain sampler

This is a device that is used to obtain representative samples whilst grains are transported along a conveyor belt.

See **grain samplers**.

Dizythum

See **zythum**.

Dobbel

Dobbel, literally double, is one of the traditional categories of Trappist beers made by top fermentation and usually bottled and subjected to a lengthy secondary fermentation. The

name refers to the quantity of malt used in the grist and is distinguished from the stronger *tripel* (double) and weaker *enkel* (single) varieties.

See **Trappist beers**.

Dockage-free barley

Samples of barley grains may be subjected to several tests in order to assess their quality. As a preliminary to many of these tests it is necessary to obtain samples of barley grains that are free from contaminating material and fragments of damaged kernels. In addition, the quantity of contaminating material is used as a measure of the quality of the barley. Dockage-free barley kernels are those that are retained when uncleaned samples are subjected to a process of sieving through a series of riddles of defined size. The procedure is carried out using a piece of equipment known as a **Carter dockage tester**. This consists of an apparatus for holding the sieves, a compressed air supply to facilitate the separation and a series of containers to collect the various fractions.

The barley kernels are passed over a number 6 riddle, number 6 and 5 buckwheat sieves and a 4.5 round-hole sieve. Grains that are retained are considered to be dockage-free.

Further differentiation of kernels on the basis of size may be performed using additional sieves with known slot sizes. This is known as dockage and assortment.

Dolo

Name given to an opaque beer made from sorghum and native to Burkina Faso.

See **native African beers**.

Dominion continuous fermentation system

See **Coutts, Morton W.**

Dongdongju

See **takju**.

Doornkaat malt steep

The name given to a proprietary design of steeps, either flat- or conical-bottomed, introduced in the early years of the twentieth century. The devices featured a continuously circulating air-lift system which comprised a series of tubes into the bases of which compressed air was introduced. The airflow caused a mixture of grain and aerated water to pass up through the tubes and exit from the top there to be distributed over the surface of the contents of the steep.

See **steeping**.

Doppelbock

A style of beer that originates from Bavaria in Germany.

See **bock**.

Dormancy

Dormancy is a phenomenon associated with all plant seeds. It is defined as the failure of a seed to germinate when the conditions are favourable for this process to occur. Dormancy is

a controlled phenomenon and is a defence mechanism employed by plants to ensure germination does not occur at an inappropriate time, for example, during seed dispersal or when climatic conditions are likely to be unfavourable for the developing plant. It is relevant to malting since it is obviously critical that the grains will germinate a short time after steeping has commenced. From another standpoint, it is important that grains retain dormancy during the period immediately before harvest and throughout the period of storage that precedes malting. It follows that in order for grains to be of acceptable malting quality, they must exhibit a degree of dormancy which ensures that pre-germination has not occurred before delivery but is not so pronounced that steeping does not promote germination within an acceptable time period.

The extent of dormancy is influenced by variety, climatic effects and horticultural practice. Some plant varieties produce seeds that always have very persistent dormancy, whereas in other varieties, it may be transitory or non-existent. The application of fertiliser can shorten dormancy, but weather conditions close to harvest time are probably most influential. In this regard humidity and temperature are important controlling factors. This explains why the same variety of plant grown in different parts of the world will produce seeds that exhibit differing degrees of dormancy. Thus, hot dry conditions favour shorter periods of dormancy. On the other hand, a period of rainfall immediately before harvest can induce what is termed **secondary dormancy**. In addition to these factors there is usually a degree of heterogeneity in dormancy between individual grains of any given batch. Typically smaller grains exhibit greater degrees of dormancy.

With regard to malting barley it is desirable for the grain to have lost its dormancy within 2 months of harvesting, providing it has been stored under optimal conditions. The ability of the grain to germinate is assessed using a variety of standard tests. These are termed **germinative energy** or **germinative capacity**. Further details of these tests can be obtained in the relevant entries.

The testa provides a barrier to oxygen ingress into the embryo and other tissues of the grains. This environmental effect may be a factor that controls dormancy. The effect of very humid conditions in promoting dormancy may also be related to this in that the wet conditions favour the development of a profuse microbial flora on the surface of the grains. This population depletes the oxygen at the surface of the grain and so ensures anaerobiosis within the grains.

Varietal differences in dormancy suggest that genetic factors are influential; however, underlying mechanisms remain poorly characterised. From a biochemical standpoint the plant hormone **abscisic acid** (ABA) has been implicated in the control of dormancy. The mechanisms by which ABA exerts its effects are unknown. It appears to have both short-term effects which involve changes in ion fluxes and, in addition, it modulates gene expression. Both the concentration present in tissues and the sensitivity of the plant to the effects of ABA are of importance. Although the mechanisms are not known, it has been observed that barley cultivars with lower levels of dormancy generally contain less ABA.

The application of various agents to barley grains is able to break dormancy. These agents have been classified on the basis of their ability to influence endogenous levels of ABA. Compounds such as **gibberellic acid**, hydrogen peroxide, ethanol and salicylate are able to break dormancy, and coincidentally they reduce endogenous concentrations of ABA. Provision of

exogenous ABA is capable of reversing the effect. Other agents such as fusicoccin, a fungal toxin and sulphuric acid, n-caproic acid and sodium azide break dormancy but have no effect on the endogenous concentration of ABA. It is thought that the latter exert their effects by reducing the sensitivity of plant tissues to ABA.

Dorothea of Caesarea

A fourth century martyr, probably mythical, who is regarded by some as a patron saint of brewing. The reasons for the association with brewing are unclear, although her myth describes her gift of fruit and flowers to a sceptical lawyer, Theophilus. The gift prompted the conversion to Christianity of the latter and subsequently she has been associated with flowers and produce. Sowing of produce on her feast day on February 6 reputedly guarantees a bountiful harvest.

Dort

See **Dortmunder beer**.

Dortmunder adambier

Historic style of German beer, also known simply as Adambier, which used a grist containing a high proportion of roasted and smoked malts, with or without the addition of wheat, to give a concentrated wort sufficient to yield 10% abv and with commensurately high hopping rates. The wort was fermented using top-cropping ale yeast after which the green beer was aged for between 1 and 4 years in oak casks. In the aging phase sour notes developed owing to a spontaneous secondary mixed yeast and bacterial fermentation.

Dortmunder beer

Dortmunder beers originate from the area in Westphalia, Germany, of the same name. The beer style is also known by the diminutive **Dort**. This area of Germany, which incorporates the Ruhr, has a history of heavy industry, particularly coal and steel, and these beers were developed to satisfy the needs of the workforce.

The beers are of the pale pilsener variety of lager produced by bottom fermentation. Dortmund lagers are described as being full bodied, moderately hopped and having a strength of approximately 5% abv.

Although the Ruhr industrial base has now declined, the brewing output from the area remains buoyant and, in fact, exceeds that of Bavaria. The two remaining major brewers are Dortmund Actien-Brauerei (DAB) and Dortmund Union Brauerei (DUB).

Double decoction mashing

See **decoction mashing**.

Double mashing

Double mashing is a procedure in which sweet wort is produced from a grist that contains a mixture of components which contain starches that have widely different gelatinisation temperatures, for example, as happens where malts and adjuncts such as maize, rice or sorghum are used. In this circumstance the malt and adjunct are mashed separately. The former uses a conventional mashing regime such as **temperature-programmed infusion mashing**; the latter is prepared using a **cereal cooker**.

The adjunct is mashed-in in the cereal cooker at a relatively cool temperature of approximately 35°C. In order to ensure efficient starch breakdown and saccharification a proportion of diastatic malt (up to 10%) and possibly an additional bacterial α -amylase is included. The temperature is allowed to increase to a temperature suitable for starch liquefaction (70°C). It may be held at this temperature for a controlled period of time and then heated to between 85°C and boiling depending on the nature of the grist. Simultaneously the malt mash is carried out in a separate vessel. When this second saccharification is completed the cereal cooker mash is mixed in. This may be in the same vessel as that used for the malt mash or a third vessel. The resultant temperature is determined by the proportions and temperature of each component. After a final stand to allow saccharification to reach completion, heat is applied to inactivate the enzymes and the sweet wort separation step is effected using either a lauter tun or a mash filter.

Double-tube sampling spear

This is a device used for removing samples of grains from a bulk source.

See **samplers for grains**.

Doughing-in

Doughing-in is a synonym for mashing-in.

See **mashing-in**.

Downy mildew

Downy mildew is a disease of hops caused by the fungus *Pseudoperonospora humuli*. Other species cause serious infections of other plants of commercial significance. Commercially it is the most serious disease of hops. Its presence has been recorded in most parts of the world where commercial crops are produced, including Japan, Europe, and North and South America. By the application of strict rules of quarantine it has been excluded from Australia, New Zealand and South Africa.

The fungus is able to overwinter in the rootstocks of infected plants from which it is able to infect the shoots, which develop in the spring at the start of the growing season. Infection is favoured in warm moist conditions. The infected shoots develop abnormally to give so-called stunted basal spikes. These bear deformed down-curved leaves which are pale and have a silvery upper surface. The undersides of infected leaves take on a black colour which is caused by the formation of numerous sporangia borne on branched sporangiophores. These spores are the agents by which other plants become infected. Providing a film of water is present the sporangiospores germinate and produce motile zoospores. These are able to invade plant tissue via open stomata. Infection takes several forms depending upon the site of infection. For example, undersides of leaves and stems develop black spots and leaves adopt a characteristic angular form. Other shoots can be dwarfed, giving secondary basal spikes. If the terminal bud is infected there is increased development of lateral shoots. Where the burr is infected cones fail to form or those that persist become variegated as a result of the browning of some bracts and bracteoles. Overall there is a serious loss of yield.

Control is via the removal and combustion of any infected material. In addition, various chemical treatments can be applied. In earlier times the latter took the form of drenching

or spraying with a solution of copper sulphate (Bordeaux mixture) or copper oxychloride. Latterly various fungicide sprays have been introduced including metalaxyl, fosetyl-aluminium, chlorothalonil, and cymoxanil.

There is considerable variability in the susceptibility of various cultivars to infection by the fungus. Hallertauer Mittelfruh, Brewers Gold, Atlas, Blisk, and Savinjjski Gold are particularly susceptible. A major aim of modern hop breeding programmes has been the development of cultivars that are resistant or tolerant of downy mildew.

DPV

Acronym that stands for dual-purpose vessel and a synonym for **dual-purpose tank**, or **uni-tank**.

Draff

See **spent grains**.

Drauflassen

German term for a brewing practice where wort is added in batches to a fermenter over a period of time with only the first batch being pitched. The procedure is used if there is a mismatch between the batch size of the brew house and the capacity of the fermenters, or if there insufficient yeast available to meet the desired rate for the entire wort volume. Apart from normal brewing practise this can also happen where **propagation** plants generate insufficient yeast to pitch a whole fermenter. Typically the first batch of wort is pitched and after 24 hours, when active growth is evident, more aerated wort is added. The practice is also used as a means of controlling **yeast-derived beer flavour compounds**, particularly esters.

Dray

Dray is the name given in the United Kingdom to a vehicle that is traditionally associated with transporting beer, particularly that are packaged into casks or other similar large containers. Before the advent of motorised transport, such vehicles were characterised as being horse drawn and being low and either having no sides, or with detachable sides, thereby facilitating the removal of heavy containers. The name appears to derive from the Middle English *draie* meaning a sledge or cart or the Old English *dragan*, Norse *draga* meaning to drag or to draw or a vehicle that trails on the ground and moves by dragging.

Heavy horses, typically shires used for this purpose, and their minders are described as dray horses and draymen, respectively.

Dressed malt

Malt grains which have been treated after kilning to remove rootlets and entrained dust.

Dressing

Dressing is the process by which the culms (rootlets) and entrained dust are removed from kilned malt. In addition, any broken grains are separated. The cleaned product of these processes is termed **dressed malt**.

See **culms**.

Dried brewing yeast

Also known as active dried yeast, preparations of pure cultures of brewing yeasts that have been subjected to a drying process to remove metabolic water whilst maintaining relatively high levels of viability. Dried yeast is sold in vacuum packs in various sizes from sachets containing a few grams (suitable for home brewing) up to several kilograms (suitable for commercial brewing operations). Providing no exposure to oxygen and cold storage the yeast has a shelf life of 1–2 years. Once the packaging is broached and air is admitted the yeast should be used within a few days.

Before drying the yeast is cultivated on a salts medium which also contains added vitamins, phosphate and nitrogen (mainly in the form of ammonia). The sugar source is molasses. In order to maximise cell yields the yeast is grown under **fed-batch fermentation** conditions. This highly aerobic process ensures very high yields and cells with a fully respiratory derepressed physiology. Such cells have very high levels of membrane sterols and unsaturated fatty acids which help in maintaining viability during the drying process. In addition, at the end of the growth phase, the yeast is subjected to a mild heat shock which encourages the synthesis of trehalose, which further increases the ability of the cells to withstand the stresses of drying.

The yeast crop is concentrated by passage through a continuous centrifuge, and after washing with water to remove traces of the spent medium, the resultant cream is refrigerated then passed through a rotary vacuum filter to yield a yeast cake. The cake is then passed through an extruder to give small tubular-shaped particles and the remaining water is removed using a fluidised bed dryer. The dried product is placed into vacuum packs under an inert gas.

Dried yeast preparations are tested for viability, microbial purity and confirmation of identity via genetic fingerprinting before release. Typically the cell content is of the order of 5×10^9 viable cells per gram; bacterial and wild yeast contamination is less than 0.0001%; and those bacteria that may be isolated are not usually beer spoilage types. Ale yeasts survive the drying process more successfully compared with lager types, and viabilities are of the order of 70–90% and 60–75%, respectively. The reasons for the differences are not known but could reflect the increased complexity of the genome of the lager strains.

For rehydration for brewing the powder should be sprinkled onto the surface of approximately 10× the weight of sterile tap water. After allowing to stand for 15 minutes at around 30°C, the suspension should be stirred gently, and after a further 15 minutes' stand, the yeast may be pitched. For the very best results, during the second stand, the temperature of the suspension should be slowly reduced to the pitching temperature via the gradual addition of cooled wort. Dried yeast should not be pitched directly into wort as the relatively high permeability of cell membranes in the critical rehydration phase can allow a sudden uncontrolled entry of wort components with consequent loss of viability.

Dried brewing yeast is widely used by craft brewers but, as yet, rarely by large commercial brewers. This may change as more strains become available, even bespoke drying of proprietary strains is possible, and quality improvements are made. Dried yeast is useful for brewing speciality beers where serial re-pitching may not be feasible. It is also useful for contract brewing where propagation facilities are not available.

Drip tray

Typically a square plastic tray located below the **dispense** tap and used to collect fobbing beer and drips. An **Irish coffin box** has a drip trap located on the box top to place filled glasses on.

Dr Lange haze meter

A beer haze meter based on the measurement of light scattering at 90° using incident light with a wavelength of 860 nm.

Drop bright

Term used to indicate that a beer in a tank or cask has achieved a desired level of clarity as a result of the sedimentation of suspended particles such as yeast cells and other solid materials found in beer. The sedimentation process may be entirely natural or more usually is assisted by the addition of **fining agents** which, by virtue of their charged nature, are able to promote aggregation of particles and thereby accelerate settling under the influence of gravity.

An essential component of the correct management of **cask beers** is to ensure that the beer achieves both the desired clarity and level of carbonation before it can be dispensed. This feature is checked by the landlord in his beer cellar by removing a sample of beer from a still-laged cask and checking that it is sufficiently clear (or dropped bright) for sale. Failure to drop bright within the prescribed time would be indicative of a problem such as use of inactive or incorrectly dosed fining agents or possibly the presence of microbial contamination.

Dropping can

A dropping can is a device used for removing liquid samples from brewery vessels, particularly fermenters not fitted with dedicated sample taps. In the case of some dropping cans, provision is made to allow removal of the sample from a desired depth in the vessel. They comprise a cylindrical vessel with an upright tall thin aspect, usually made from stainless steel, with a capacity of approximately a litre. The can has a weighted base to facilitate rapid and easy immersion in deep vessels. A stainless steel chain is attached to the neck of the can.

In use the can is plunged into the vessel taking care to secure the free end of the chain to a convenient support. When full, the can plus the sample is retrieved using the chain. Before use it is essential that the can and the chain have been thoroughly cleaned and sanitised using a suitable soaking fluid.

The neck of some dropping is designed to be sealed with a rubber bung. The latter is fitted with a second stainless steel chain the same length as that attached to the body of the can. When the can is lowered into the vessel the opening is sealed with the bung. When the can is submerged to the required depth the bung is pulled out by tugging the appropriate chain, allowing the can to fill. The can plus the sample is then removed during which, and it is assumed that, no mixing occurs.

Dropping system

The dropping system describes a method of fermentation practised by some traditional ale brewers. Several variations have been practised involving various types of brewing plant and a plethora of terminology. It describes a method in which primary fermentation is initiated in a fermenter, usually of the traditional square variety. After some 10–24 hours the contents of this fermenter are transferred or 'dropped' into a second fermenter, typically located below the initially used vessel. The transfer is controlled in such a fashion that a large proportion of the trub and other undesirable materials are left in the first vessel. Although the process is extravagant in terms of usage of vessels, it has the major advantage of removing wort compo-

nents which might be considered detrimental to future beer quality and clarity. In addition, the transfer would provide a second opportunity to introduce oxygen into the wort and thereby favour a vigorous fermentation. Furthermore, proponents of the method claimed that it was easier to arrest the second fermentation before attenuation was fully completed. This was advantageous for cask beers since it obviated the need for priming. The process has also been termed the ‘**cleansing system**’ of fermentation. The secondary fermenters are also termed ‘cleansing tanks’ and ipso facto contained within a ‘cleansing room’.

The fermentation is allowed to proceed to completion in the second set of tanks and when the time is appropriate the subsequent top crop of yeast is removed by **skimming**. To reflect these operations the vessels are referred to by some as **dropping tanks** or **skimming backs**. The yeast was transferred, via gravity, to storage vessels, termed **yeast backs**, which were usually located on the floor immediately beneath that housing the dropping tanks.

In another variation of the dropping system much favoured by London porter and stout brewers but now discontinued the beer was dropped into a series of cask-like vessels termed **pontos**. The origin of the term is apparently unknown; however, each cask was fitted with a top which incorporated an extended wooden lip from which the yeast head was allowed to overflow into a trough for collection.

Although the ponto system is now nothing more than a historical curiosity, it can be viewed as a less sophisticated forerunner of the Burton Union system, which involves a slightly similar system of continuous yeast cropping and removal (see specific entry for a full description).

Dropping tank

See **dropping system**.

Drum brown malt

Drum brown malt is a synonym for **brown malt**. It alludes to the fact that the modern product is prepared in a drum roaster, as opposed to an open wooden fire associated with traditionally prepared brown malt.

Drum malting

Name given to malting system in which the germination stage is performed in a rotating drum that is fitted with a means of introducing conditioned air of a defined temperature and humidity. The drum allows the grain bed to be turned, thereby reducing the need for manual intervention. The use of forced air streams categorises the plant as being of the pneumatic type. Several designs exist which aim to improve the degree of control of the conditions and homogeneity within the drums and which facilitate automatic filling and discharge. In some cases a single drum is designed to combine steeping, germination and kilning. Historically the introduction of drum malting, in the nineteenth century, is associated with the French brewer Nicholas Galland and later his German collaborator, Julius Henning (see **pneumatic malting** for more details).

Modern designs can accommodate batches of more than 50 tonnes. A relatively large drum capable of holding 45 tonnes of grain has a diameter of approximately 4.5 m and length of 16 m. Commonly such drums are operated in pairs. Typically each drum is fitted with its own dedicated fan and air-conditioning unit. The end of the drum distant from the air-conditioning

unit is fitted with teeth which engage with the drive wheel of an electric motor. In one common design the interior of the drum is fitted with a perforated deck on which the grain bed rests and through which air is circulated from below. The degree of conditioning of the air stream is regulated throughout the malting process to control germination. Provision is made for CIP and often sprinkling bars are present if wetting is required. The grain is transferred into the drum via a loading chute located at one end of the drum. A series of internally mounted spiral blades serve to move the grain as the drum rotates and, in so doing, ensure that the bed is self-levelling. The same blades move the grain during discharge from each end to the middle where it exits from opened doors into a hopper and then to a conveyor belt for transfer to the kiln.

Dry hop essences

See **dry hopping**.

Dry hopping

Dry hopping is the practice of adding hops to cask beers during the transfer of beer from the racking tank to the cask, or occasionally to ageing tanks. The hops are of the aroma variety. They are added as late as possible in the process in order to minimise losses of the delicately flavoured volatile oils. Originally whole hop cones were used, but in current traditional processes the hops are added in the form of pellets. These are lightly pressed to avoid undue damage to the lupulin glands and are added to the filled casks immediately before closure with the shive. Typical addition rates are of the order of 5–50 g/hL. Common hop varieties used are Fuggles, Goldings and Wye Northdown.

In order to ensure greater consistency and to avoid deterioration of hops during storage the pellets may be substituted with various extracts. These are sesquiterpeneless oils produced by fractionation of CO₂ extracts of hops. These are termed dry hop essences. They are supplied as 1% ethanolic solutions and, apart from containing flavour/aroma components at predetermined concentrations and composition, they are totally soluble and so provide 100% utilisation and no risk of haze formation.

Dry milling

Dry milling is the name given to the milling process in which malt grains, other cereals and other solid adjuncts, if used, are subjected to a process of abrasion and degradation such that the resultant grist is rendered into a form suitable for mashing. In the case of dry milling no water is used until the dry grist is mashed-in.

See **milling**.

Dry steeping

A synonym for the **air rest** stage of **steeping**.

Dual-purpose hops

Dual-purpose hops are those varieties that have sufficient content of α -acids to provide bitterness and hop oil in sufficient quantity and composition to provide desirable aroma. Therefore, they may be used to impart in beers both bitterness and hop aroma.

Dual-purpose tank

See **uni-tanks**.

Dublin Principles

A report drawn up in 1998 by the International Centre for Alcohol Studies (ICAP) and the National College of Ireland which describes a consensus policy regarding ethical cooperation between companies involved in the production of alcoholic beverages and the general scientific and public health communities. The report, entitled *Principles of Cooperation among the Beverage Alcohol Industry, Governments, Scientific Researchers and the Public Health Community*, is available as a download at <http://www.icap.org> (last accessed 28 March 2013).

Dumas procedure

The Dumas procedure is used for the determination of total nitrogen content. In brewing it is applied to samples such as malts, adjuncts and worts. It can be used for the determination of total soluble nitrogen when applied to extracts made under defined conditions.

Nitrogen in samples is oxidised by combustion at high temperature in the presence of oxygen. After purification, to remove potentially interfering contaminants, the resultant nitrogen oxides are reduced to pure nitrogen using a catalytic procedure. The concentration of nitrogen is determined using a thermal conductivity detector. After comparison with standards of known nitrogen concentration the result can be related to the nitrogen concentration in the original sample. When performing analyses it is important to use reagents, particularly gases, that are guaranteed to be free from nitrogen.

The procedure had largely replaced the older **Kjeldahl** method, on the basis of safety. However, compared with the latter the Dumas procedure tends to produce a slightly higher result since it also includes inorganic nitrogen.

Dunav

Dunav is a hop cultivar that originated in the late 1960s in the former Yugoslavia. It was one of a group of cultivars (with **Vojvodina** and **Neoplanta**) which were bred with the intention of replacing the poor yielding traditional landrace aroma variety, **Backa**. It derives from a cross with Northern Brewer and a male derived from a cross with **Savinja (Styrian) Goldings** and a wild male.

Analysis is 5.0–11.0% total α -acids of which 30% is cohumulone. Total β -acids are 3.0–5.0%. Total oils are *ca.* 1.2%.

Dunkel

Dunkel is a German beer style. The name comes from the German for 'dark' and is descriptive of the product. *Dunkel* beers are lagers, made with bottom-fermenting lager yeast strains. The beer style originated in Bavaria but is widely imitated elsewhere. The beers have the appearance of dark ales but many of the taste characteristics of paler Bavarian lagers. In other words, they are moderately hopped, derive most of their flavour from malts, and have a clean low ester and higher alcohol character and little aroma. The dark malts introduce pronounced body and nutty, malty, sweet notes. Strengths are typically around 5.0% abv and within the range 4.7–5.6% abv.

The true Bavarian dark *dunkel* lagers predate the, perhaps better known, paler varieties. This is explained by the fact that the ability to make pale malts required control and equipment that were not available to early maltsters. In consequence, all beers made with the products of these early practitioners tended to be dark. Thus, the dictates of the original *Reinheitsgebot* legislation would have been aimed at a *dunkel* style of lager.

The use of *dunkel* as an adjective is also applied to other beer styles merely to indicate the colour, for example, as in *dunkelweizen*, a dark wheat beer. These beers are, of course, distinct from true *dunkel* lagers.

Dunkelweizen

Dunkelweizen is a German wheat beer which, unlike the usual variety, is made with a proportion of dark wheat malt, such that it has a dark golden colour. The name translates as 'dark wheat'.

See *weissbier*.

Dünnbier

Dünnbier literally translates from German as 'thin beer'. It was a traditional product made from a weak wort such that after fermentation the alcohol concentration was approximately 1.5–2.5% abv. The beer was made in Northern Germany and was consumed by workers employed in heavy manual labour.

Düssel

Düssel is an alternative name for *altbier* and is a reference to the fact that this style of beer originated in the German city of Düsseldorf.

See *altbier*.

Dust explosions

The stages in the brewing process, which involve the handling of dry goods, inevitably generate dusts. The latter are defined as particles with a mean diameter smaller than 500 microns. Providing the particles are present in sufficient concentration and in the presence of oxygen (air) and a source of ignition, such dusts can be the source of violent explosions. The apparatus used in brewing, which has the potential to generate dusts, must be designed to ensure that such explosion risks are minimised. Similarly the processes in which such apparatus is used must be conducted such that the generation of dusts is controlled to prevent the generation of the conditions where explosions might occur. Should a dust explosion take place, equipment must be designed such that the destructive forces generated are channelled in a way that minimises potential harm.

The stages in brewing where dust explosions might occur are wherever dry goods are handled, for example, grain silos, conveyors, elevators, screens and dry mills. In commercial breweries a dust extraction system is used, which typically employs cyclones and suitable filters. All appropriate equipment is linked to a central dust collecting system where it may be blended with spent grains and sold. The generation of potential sources of ignition must be avoided. This requires rigorous exclusion of naked flames, such as the use of welding torches in sensitive areas, shielding of electrical appliances and earthing to avoid the generation of

sparks. Where the equipment might generate heat, such as via frictional forces in mechanical bearings, temperatures should be monitored using appropriate sensors. The output of the latter should be linked to automatic shut-down systems in the event of the generation of potentially hazardous conditions. In some cases inert gas blankets may be provided to reduce the available oxygen concentration. Equipment such as dry mills is designed to minimise the risks of dust explosions; however, should one occur, weak areas are provided, which give way and are linked to channels through which the destructive forces are vented in as harmless a way as possible.

D value

A term, decimal reduction value, used to quantify the relationship between time, temperature and the thermal inactivation of microorganisms.

See **pasteurisation**.

Dwarf hops

Conventional hop varieties are very tall plants and require to be supported on a trellis up to 7 m in height. The costs of the trellis-work are considerable as is that of the specialised horticultural machinery needed for the husbandry of the plants. In order to mitigate some of these costs dwarf hop varieties have been bred which require supports that are no more than 3 m in height.

The dwarfing character derives from the possession of a gene the expression of which results in roughly a halving of the intermodal distance compared to standard varieties. Initial crosses contained very low concentrations of hop α -acids (>2%), but subsequent breeding programmes have produced varieties that can be used as sources of both bitterness and aroma. The first commercial dwarf variety, First Gold, was produced at Wye College using a dwarf male plant as the donor of the reduced stature character; others are Herald, Pioneer, Pilot and Summit.

Dynabeads®

Polymeric particles (diameter 2.8 μ M) that have paramagnetic properties [<http://www.invitrogen.com> (last accessed 8 February 2013)]. The beads can be coated with specific ligands which bind to appropriate cell receptors and, by application of a magnetic field, the bead plus bound cells can be separated from a mixture. Beads with an attached lectin have been shown effective at selectively removing brewing yeast cells via attachment to surface mannose receptors as is presumed to underpin the phenomenon of **yeast flocculation**. It has been suggested that beads with a suitable mannose ligand could be of use in assessing yeast flocculence.

Dynamic Disc mash filter

This is a device designed to carry out the separation of sweet wort from spent grains during the mashing phase of wort production. It uses a cross-flow filtration approach to effect the separation step. In order to assist with filtration and to prevent fouling of the membrane a rotating disc located in the mash and close to the membrane surface drives the mash tangentially across the surface of the membrane. In this arrangement the tangential flow can be

regulated in a manner that is independent of the applied pressure, and so it is claimed that this allows the use of thick mashes but retains good yields and high throughputs. In order to increase outputs multiple stacks of units can be used. The unit was designed to be used in conjunction with a novel milling technique in which a fine grind is used and the husks are separated and discarded before mashing-in.

It seems that this approach remains at the concept stage.

D

Dynamic low-pressure wort kettle

Type of wort kettle that employs a system of very rapid fluctuations in pressure as a method of inducing very rapid boiling and highly efficient stripping of wort volatile components.

See **wort kettle**.

East Kent Goldings

See **Goldings**.

Eastwell Goldings

A variety of one of the group of Goldings, traditional UK-style aroma hops selected in 1889 and cultivated at Eastwell Park near Ashford in Kent.

See **Goldings**.

Easy Count yeast analyser

Apparatus and a method for determining yeast concentration based on the use of a hand-held portable fluorimeter and proprietary reagents (GenPrime Inc., Spokane, WA).

EBC colour units

See **beer colour**.

EBC tall tubes

Laboratory-scale fermentation apparatus designed to assess yeast performance under controlled conditions but which, to some extent, mirrors production-scale vessels. The fermenters are made from glass (150 cm high and 5-cm diameter) and with a capacity of around 2 L. Tubes are fitted with external jackets through which water is circulated for attemperation. The base of the tube terminates in a dished end in which the yeast crop collects. Occasionally a tap may be fitted to the base for emptying. Halfway up the straight side of the tube there is a sample port that takes the form of an aperture covered by a silicone rubber septum. Samples are removed by piecing the septum with the needle of a syringe and withdrawing fermenting liquid. The top of each tube is open but fitted with a sterile foam bung when in use to allow exhaust gas to vent. Before use the tubes are cleaned and sterilised by treatment with steam. Wort is collected into a separate sterile flask and oxygenated to a desired concentration. After pitching the mixture is transferred to the tall tube and fermentation performance is monitored by periodic removal of samples followed by offline analysis. The contents of the vessels are not mechanically agitated and, therefore, they may be considered to approximate to a section

through a larger fermenter. The behaviour and flocculence characteristics of the yeast during fermentation may be assessed by visual observation.

Typically tall tubes are used in sets of 10 or more, which allows multiples of fermentations to be performed simultaneously. Several variations have been devised. The Carlsberg Research Centre **multiferm fermentation system** used a bank of 60 all-stainless steel tall tubes fitted onto motorised carousels in two banks of 30. Filling and emptying, oxygenation, pitching, crop removal and weighing were automatic procedures and cleaning was via a dedicated cleaning in place (CIP) system. An automated sample system allowed removal of aliquots of medium at defined times using a motorised syringe and needle system. Samples were delivered to evacuated tubes and stored cold in the presence of preservatives for later analysis.

EBC unit of haze

A unit of haze as defined by the European Brewing Convention and which is based on standards made from formazin. The EBC system uses a scale 1–10 to describe beers as brilliantly clear (<0.5 EBC units) to very hazy (>8.0 EBC units).

See **beer hazes, haze standards, formazin**.

EBI

Empty bottle inspector.

See **bottling**.

Ebulum

An ale associated with the British Isles and originating in the dark ages. It is flavoured with a variety of herbs and spices. A modern version, claimed to be exported from Wales to Scotland by druids in the ninth century, is made from oats, barley, wheat and ripe elderberries.

Ecotherm wort kettle

The Ecotherm system is a wort kettle that utilises an internal boiler but in which wort flow rates are accelerated by the provision of a pump located below the heating chamber. It was designed by the Steineker Company. The name refers to the claim made by the manufacturers that the improved flow rates and heat transfer result in reduced fouling such that the number of heating cycles that may be performed before cleaning is required increases by more than twofold (compared with a standard wort kettle based on an internal heater utilising a thermosyphon).

See **wort kettle**.

Echter Mehltau

German for 'true mildew', a synonym for powdery mildew, a fungal disease of hops.

See **powdery mildew**.

Ecokeg

A proprietary design of keg made as a single trip container for beer. The company [<http://www.ecokeg.com> (last accessed 8 February 2013)] was founded in Australia in 2002 after the purchase of patents for one-way kegs developed by Carlton & United Breweries Ltd.

The keg has a capacity of 30 L and is designed to be capable of filling and handling using (with some modifications) a conventional keg racker. The keg comprises an inner and outer shell. The outer part has the same dimensions as a standard 50-L stainless steel keg and is made from high-density polyethylene. This is recyclable and provides strength such that it is claimed that handling, stacking and ability to withstand a drop test is similar to stainless steel containers. The inner part of the keg is made from polyterphthallate (PET), which is semi-rigid and also recyclable. The liner incorporates oxygen-scavenging technology, which ensures a low dissolved oxygen concentration in the beer and, by inference, good flavour stability. As with a standard keg there is a single point of entry and exit via a valve and spear also made from recyclable plastics. Versions of the Ecokeg are available which can use any of the standard A, D, G or S fittings.

Ecokegs are supplied clean and pre-pressurised at a pressure and with an inert gas chosen by the customer. The claimed advantages are that all kegs are supplied ready to use in an undamaged form and do not require external cleaning or sterilisation. Empty kegs weigh significantly less than stainless steel versions and therefore transport costs are reduced.

Edel-Hell

See *Helles*.

Effective bed voidage

See **bed voidage**.

Ehrlich pathway

See **higher alcohols, yeast and beer flavour**.

Eighty shilling (80/-)

Also 80 shilling, a name commonly applied to Scottish ales of medium alcoholic strength. These beers are also known as **Scotch ales**.

See **shilling system** and **Scottish ales**.

Einfachbier

Einfachbier, in German 'plain beer', describes one of the categories of products by which excise is levied. These beers must be made from a wort between 2.0% and 5.5% extract. This gives an alcoholic strength of 0.5–1.5% abv.

Einkorn

Einkorn is a form of hulled wheat similar to emmer and spelt. It occurs in wild (*Triticum boeoticum*) and domesticated (*Triticum monococcum*) forms. It was one of the earliest forms of cultivated wheat arising in Turkey. Its name derived from the German for 'one corn', which is descriptive of the fact that usually a single kernel develops in each spikelet. This is in contrast to emmer, which usually bears two kernels per spikelet.

Cultivation is now restricted to marginal mountainous areas in parts of North Africa and Europe which are not suitable for more common wheat varieties.

It seems likely that einkorn, together with other primitive hulled wheats, would have been used in the brewing operations of the early civilisations of the Fertile Crescent. Einkorn flour is yellowish in colour. It is used by some modern Belgian brewers where, apart from contributing to colour and good head retention, it is claimed to impart vanilla and honey characters.

Eisbock

Eisbock is a German beer style in which the alcoholic strength of a *doppelbock* is increased by allowing the beer to freeze and removing the ice which forms.

See **bock**.

Electronic nose

Device designed to produce an electronic fingerprint of the spectrum of volatile components of beers. The aim of the device is to provide an objective means of characterising beer aroma, which obviates the need for human tasters and removes the supposed inherent weaknesses of the latter approach to beer analysis. Several potential applications have been suggested. They might be used in routine process control where the output from the instruments could be used to assess process streams and either provide an early alert of non-standard behaviour or, when specification is achieved, automatically move individual batches onto the next stage of processing in a timely fashion. The device could wholly or partially replace human taste panels for trueness-to-type tests and could possibly be capable of identifying precisely the causes of differences. It has been suggested they would be useful tools for studying the chemical basis of beer ageing.

Electronic noses rely on a detection system. Some versions have used an array of polymers which interacted with volatile components of beers to produce changes in conductivity in a complex but repeatable fashion. Other sensing systems are based on mass spectrometry. Artificial neural networks are commonly used as the means of handling the complex data outputs.

No doubt developments in this area will continue as the discriminatory power of analytical techniques and the supporting computational analysis of the results continue to grow and develop.

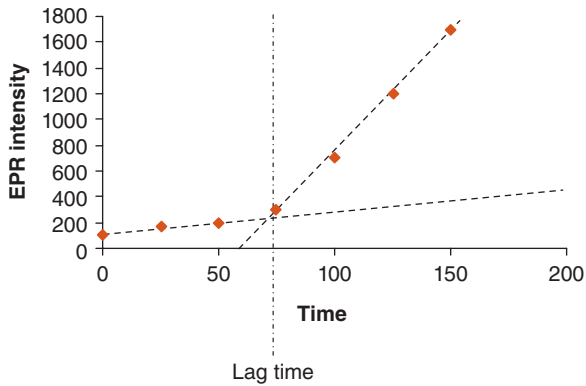
See **sensory analysis**.

Electron spin resonance (ESR)

Technique used to assess the antioxidant properties of beer, or stages in its production, and, by inference, its potential for staling. ESR is a spectroscopic method which allows the detection of free radicals by virtue of their possession of unpaired electrons. The sample is placed in a strong magnetic field and subject to a fixed microwave field at a temperature of 60°C. The latter increases the rate of oxidation of free radicals. This causes the free electrons to align with the magnetic field. The microwave field causes some the free electrons to adopt a configuration against the magnetic field and this is detected as an increase in the electron paramagnetic resonance (EPR) intensity. For measurements made with beer a spin trap is used. The compound *tert*-butyl-phenylnitron reacts with beer free radicals and forms a secondary but more stable free radical, a spin adduct.

Plots of increase in EPR intensity versus time show the rate of free radical formation within the sample and the time course of the resultant spin adduct formation. The antioxidant com-

ponents of beers are more able to react with the generated oxygen radicals compared with the trapping agent. Consequently this produces a lag time in the increase in EPR intensity. The lag time is calculated (see figure) and this is a measure of the antioxidant content of the beer and, by inference, the resistance to staling of the beer.



Plot of electron paramagnetic resonance intensity versus time in a test of beer flavour stability. The lag time is a measure of the endogenous antioxidant activity of the beer.

Electropositive ammonia caramels

These are the type of caramel most used in brewing for the purpose of adjusting flavour and colour. They are prepared by heating relatively pure sugar syrups (usually glucose) with ammonia. Temperature programmes are complex and carefully controlled in order to give products with desirable characteristics. Stock preparations are blended together with water to give standardised ranges of caramels with predetermined colours and flavours. Typically colours are within the range 32,000–500,000 EBC units. They contain 65–75% solids and 2.5–5% nitrogen. They have isoelectric points in the range of pH 6.0–pH 6.5 and they carry a positive charge, hence the name.

Ellis cup grain sampler

This is a device that is used to obtain representative samples whilst grains are transported along a conveyor belt.

See **grain samplers**.

Elsasser

Elsasser is a traditional French aroma hop variety that is now grown to a limited extent in Australia. It forms part of the parentage of the US variety **Glacier**.

Embossed glass

See **branded glassware**.

Emmer

Emmer (*Triticum* sp.) is a form of wheat that occurs in both wild and domesticated forms. It appears to have originated from the Near East where with barley it was used extensively for

both brewing and baking. Archaeological records suggest that it was an important crop in many Near Eastern countries including Israel. It spread from this region to Europe and the Indian subcontinent.

Wild emmer (*Triticum dicoccoides*) is the progenitor of the domesticated variety (*T. dicoccum*).

Like einkorn and spelt, emmer is a hulled variety of wheat. The husk which encloses the grain is very durable and remains attached during threshing. This requires that considerable mechanical force, in the form of milling, must be exerted after threshing to release the grains. No doubt this contributed to the increasing popularity of more tractable cereal crops and the concomitant decrease in the use of hulled wheat varieties.

The use of emmer as both human and animal foodstuff has a long history in the Mediterranean region, particularly Italy. Here, together with einkorn and spelt, collectively termed faro, there has been a resurgence in interest in commercial exploitation for use in baked products and pasta. However, cultivation is restricted to marginal areas of relatively high altitude and poor fertility. Cultivation occurs in Austria, Greece, Albania, Italy, Spain and particularly Turkey.

Emulsifiers

Emulsifiers are surfactant molecules that are used in combination with **detergents** to clean process plant. They comprise molecules that bear both hydrophilic and hydrophobic components. The hydrophobic groups adopt configurations in which they are pointing outwards, and this tends to prevent their adhering to surfaces. At certain concentrations they form micelles in which macromolecules form which have a hydrophobic core and hydrophilic interior. The latter traps soil particles and prevents them from adhering to the surface, which is being cleaned.

End Gravity

See **attenuation gravity**.

Endopeptidase

The term which describes a **protease** enzyme that cleaves peptide bonds located within the constituent chains of polypeptides and proteins. Many enzymes of this type are known and typically they attack peptide bonds within specific sequences of amino acids.

Endosperm

In a general sense the tissue in a plant that is found in the seed and surrounds the embryo the nutrition of which it is responsible for. In barley grains it contains the starch granules the degradation of which during mashing leads to the formation of wort fermentable sugars.

See **barley grain**.

Engerth malting system

See **semi-continuous malting**.

Enkel

Enkel, literally single, is one of the traditional categories of Trappist beers made by top fermentation and usually bottled and subjected to a lengthy secondary fermentation. The name refers to the quantity of malt used in the grist and is distinguished from the stronger *dobbel* (double) and *tripel* (triple) varieties.

See **Trappist beers**.

Enterobacter agglomerans

See *Rhanella aquatilis*.

Entire

Entire is reportedly the forerunner of the style of beer that came to be known as **porter**. The name refers to the fact that the wort was produced and used as a single entire batch, as opposed to the earlier practice where the first and stronger worts were separated from the second and weaker worts, each fraction being used to produce distinct beers.

See **porter**.

Entire butt

See **porter**.

Enzymatic power

A measure of the ability of barley malt or other malted cereals to hydrolyze starch and thereby produce fermentable extract. It is more usually known as **diastatic power (DP)**.

Enzyme

Enzymes are functional **proteins** that are present in all living cells. They function as biochemical catalysts. In other words, they increase the rates of the multitude of reactions that together constitute metabolism. Reaction rates are increased many hundredfold over that which would occur in their absence. They are true catalysts in the sense that they remain unchanged when the reaction is completed. They do not change the equilibrium of the reaction.

Enzymes and brewing

Enzymes exert profound influences on all stages of the brewing process. These may be unwitting in the sense that they underpin the activities of the plants which result in the formation of brewing raw materials such as barley grains. The packages of starch and proteins together with preformed enzymes present in malt grains are responsible for the formation of fermentable extract and protein degradation products during the mashing phase of wort production. During fermentation the enzymes present in yeast cells are responsible for converting simple sugars and other nutrients present in wort into ethanol and the wide range of other yeast metabolites that together constitute beer. Potential deleterious effects include degradation of beer head-forming proteins by **proteases** which may be released by autolysis of yeast cells in stressed populations. Enzymes may be used in the brewing process in a more directed manner. Where permitted they may be used as process aids in brewing and in the manufacture of many liquid adjuncts. The process aids are preparations of one or more enzymes, usually of variable

purity, which are produced commercially. Typically the enzymes are of bacterial, mould or plant origin. Occasionally they are obtained from animal sources. Commercial preparations inevitably contain contaminating enzymes in addition to the stated primary activity. Some of these side activities are desirable; others are not. Enzymes are more or less labile and commercial preparations require storage under appropriate cool conditions. Even when this is done commercial preparations have a finite lifespan and activity is gradually lost. In the case of these complex mixtures, relative activities are lost at variable rates, such that the action of some preparations may change with time. For this reason they must be handled with care, subject to appropriate stock control and generally treated with caution.

Commercial enzyme preparations are used for specific purposes either to augment activities already present in natural raw materials or to bring about specific changes which increase process efficiency, eliminate or reduce process problems, enhance beer properties, or bring about dramatic changes in beer. In addition they may be used in the preparation of liquid adjuncts such as sugar syrups. These are described in detail elsewhere, but examples of enzymes used as process aids and their intended actions are shown in the following table. The list is illustrative and not intended to be exhaustive.

Enzyme	Action	Intended use
Fungal α -amylase	Hydrolysis of endo α -(1,4) links in dextrans, amylose and amylopectin	Addition to mashes to increase fermentability, addition to beer to replace priming sugars
Bacterial α -amylase	Hydrolysis of endo α -(1,4) links in dextrans, amylose and amylopectin	High heat stability favours use in high-temperature mashes for increasing wort fermentability. Side activities of proteases and β -glucanases are beneficial contaminants. Liquefaction of starches in cooked adjuncts Manufacture of liquid adjuncts
Bacterial pullulanase	Hydrolysis of α -(1,6) links in dextrans and amylopectin	Used in conjunction with amyloglucosidase or β -amylase to saccharify dextrans and to produce glucose or maltose-rich syrups, respectively
Amyloglucosidase (glucoamylase)	Hydrolysis of the non-reducing ends of starch chains to release glucose	Increase wort fermentability especially where high levels of starch adjuncts are used
β -Glucanase complex	Degradation of β -glucans	Added to mashes to decrease viscosity and improve run-off
α -Acetolactate decarboxylase	Conversion of α -acetolactate to acetoin	Elimination of diacetyl stands in rapid lager fermentations
Proteases Ficin (from figs) Bromelin (from pineapple) Papain (from pawpaw)	Degradation of potential haze-forming proteins in beer	Enhancements to beer colloidal stability

Enzyme structure and function

Many thousands of enzymes are known. The component amino acid chains which constitute enzymes, as well as other proteins, are the primary product of the transcription of the genetic code. The sequence of bases present in the DNA molecules collectively constitutes the genetic code of living cells. The functional proteins, which are the eventual products of transcription, in effect put into action the information held within the genetic code.

Enzymes are highly specific for the range of reactions that they have influence over. This accounts for the large number of enzymes that occur. By convention, the reactions that collectively constitute biochemistry are conveniently considered in terms of pathways of sequences of related reactions. Each individual reaction is catalyzed by a specific enzyme. These enzymes act in concert. Typically, DNA transcription and the consequent synthesis of enzymes, which underpin the reactions associated with specific pathways, are controlled such that the large numbers of genes responsible are either up- or down-regulated in concert. In this way the gross metabolism of a cell can be shifted to meet specific needs. For example, strains of brewing yeast have to be capable of responding rapidly to sudden changes of oxygen availability as occurs when cells are taken from the anaerobic conditions of storage vessels and pitched into aerated wort. This is accomplished by the controlled switching on and off of many hundreds of genes. The resultant change in the mix of products of the expressed genes allows certain required pathways to be activated and other unnecessary pathways to be switched off. In this way the yeast cell is able to respond to these changes and to shift its metabolism from a relatively quiescent maintenance mode to one of active growth.

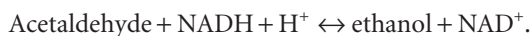
Enzymes function by lowering the activation energy of the reaction(s) that they catalyze. In order for any chemical reaction to occur sufficient energy must be available to drive it. This is termed the activation energy. In the case of most biochemical reactions under the conditions associated with living cells insufficient energy is available. The reactants in enzyme-catalyzed reactions, termed substrates, first bind to the enzyme. Substrates bind to particular sites on the enzyme molecule, termed active sites. They are made up of a unique combination of functional chemical groups with a particular spatial arrangement such that one or a very limited number of reactant substrate molecules are able to bind. The enzyme-substrate complex reduces the activation energy and the particular reaction can proceed. The product is released, returning the enzyme to its initial state and free to catalyze another reaction. The ability of enzymes to bind one or a limited number of substrates, based upon the configuration of the active site, explains enzyme specificity. The underlying mechanism was originally termed the lock and key hypothesis, explained in terms of the substrate being an exact and exclusive fit for the active site on the enzyme. More recently this has been superseded by the induced fit hypothesis. This holds that the binding site has a more fluid and flexible structure which is able to change shape and mould itself to a conformation required for binding the substrate molecule. The net result, in either case, is that individual enzymes show activity towards one or a limited number of substrates. This effect is defined as substrate specificity.

Enzyme activity is influenced by environmental conditions. Individual enzymes are most active under particular defined conditions of temperature, pH and the presence and/or absence of other chemical species. An increase in temperature increases the energy available to drive reactions and, thus, rates of enzyme-catalyzed reactions are also increased. However, at very

elevated temperatures the energy present is sufficient to disrupt protein structures. This is termed denaturation and results in an irreversible loss of enzyme activity. Interaction between enzymes and substrates are dependent on the presence of charged groups; consequently changes in pH result in conformational changes in active sites and a concomitant alteration in the efficiency of substrate binding. This endows individual enzymes with an optimum pH the peak of which may be broad or sharply defined.

Many compounds, either simple chemical species or more complex biochemicals, are capable of influencing enzyme activity. These may reduce or entirely obliterate activity, termed inhibitors, or they may enhance activity, termed activators. These effects may be temporary or permanent. Inhibitors may exert their effects by binding to the enzyme active site in preference to the natural substrate and therefore blocking the reaction. This effect is termed competitive inhibition. Alternatively, other inhibitors or activators may bind to the protein molecule and, in so doing, induce a conformational change in which the active site becomes more or less capable of binding substrate molecules. For many enzymes, regulation by binding of an activator is termed allosteric control. The enzyme is an allosteric enzyme and the activator binds at the allosteric site. The latter is distinct from the active site. Inhibition of the activity of an enzyme which occupies an early position in a pathway by the metabolite that is the ultimate end product of the same pathway is common. In this way, so called end-product inhibition controls the activity of the whole pathway and prevents synthesis of metabolites, which the cell already has a plentiful supply of, with a concomitant conservation of energy and nutrients.

Many enzymes have non-protein components which are required for activity. These may be inorganic or organic and are termed cofactors. The former include sulphur and various metal ions, sulphur proteins and metalloenzymes, respectively. This feature explains the requirements for such simple inorganic components in growth media such as brewers' wort. Organic cofactors may be permanently bound to the enzyme molecules in which case they are termed prosthetic groups. Examples include molecules such as haem, sugars or flavins. This may be indicated in the name of the enzyme as in haemoprotein, glycoprotein, flavoprotein, and so on. Proteins that are composed solely of amino acids are termed simple proteins. Those that contain non-amino acid prosthetic groups are termed conjugated proteins. The complex of cofactor and enzyme is termed a holoenzyme. The enzyme minus cofactor is termed an apoenzyme. With other enzymes, cofactors may be essential for activity but are not permanently bound. These are termed coenzymes. They function as intermediaries by binding particular groups that are subsequently involved in the enzyme-catalyzed reaction. Examples include compounds such as nicotinamide adenine dinucleotide phosphate (NADP) and nicotinamide adenine dinucleotide (NAD), adenosine triphosphate (ATP) and coenzyme A (CoA). Many coenzymes are vitamins. They are a special class of substrates that are used in common by a wide range of enzymes. Typically they undergo chemical changes by virtue of their participation in enzyme-catalyzed reactions. For example, NAD is used in a wide variety of oxido-reduction reactions. An example highly relevant to brewing would be alcohol dehydrogenase:



An important aspect of the regulation of cellular metabolism is to ensure that a supply of coenzymes in the relevant chemical state is always available. In other words, in the reac-

tion shown above, the formation of ethanol from acetaldehyde is accomplished by the oxidation of NADH. The reduced NADH is produced in the preceding reactions of **glycolysis** during which sugars are oxidised to pyruvate. Re-oxidation of NADH during the terminal step of ethanol formation allows the replenishment of the supply of NAD⁺, which is required for the continued flow of carbon through the glycolytic pathway. On its own during the conditions of brewery fermentation the re-oxidation of NAD via ethanol formation is insufficient to balance the needs of glycolysis. Brewing yeast utilises other routes to make up this shortfall. Many of these are important determinants of beer flavour such as higher alcohols. Similar mechanisms apply to other coenzymes and many of these are of importance in the regulation of pathways that underpin the formation of important beer flavour compounds.

Regulation of enzyme activity *in vitro* is obviously vital to cellular function. It is accomplished at two levels. Firstly, at the cellular level, enzyme activity is influenced by the availability of substrates and the ability of inhibitors and activators to modify catalytic properties. In addition, the products of other genes may produce enzymes whose role is to alter the structure and activity of target enzymes. Secondly, regulation occurs at the gene level by which activation or deactivation of the gene results in synthesis or absence of the corresponding enzyme. The former series of mechanisms may be regarded as short-term modulation of enzyme activity, whereas control of enzyme synthesis at the gene level tends to be used in more long-term control strategies.

Enzyme nomenclature

Enzymes are given trivial names which usually incorporate the name of the usual substrate prefixed with *-ase*. In many cases trivial names are not particularly informative. Thus, cellulase, as the name indicates, is the enzyme that catalyses the degradation of cellulose. However, the function of catalase, the generic name for enzymes that convert hydrogen peroxide to water and oxygen, cannot be gleaned from its common name. Historically, the same enzyme might have had more than one name and, furthermore, different enzymes were given the same or similar names. For this reason more precise systems were introduced by the nomenclature committee of the International Union of Biochemistry and Molecular Biology (IUBMB). The current system places all enzymes into one of six groups. These groups are descriptive of the reactions that are catalyzed by member enzymes. They are

- (1) oxidoreductases (oxidation–reductions)
- (2) transferases (transfer of functional groups)
- (3) hydrolases (hydrolysis reactions)
- (4) lyases (addition reactions to double bonds)
- (5) isomerases (reactions involving isomerisations)
- (6) ligases (reactions that result in the formation of bonds at the expense of the cleavage of ATP).

Each of these major groups is further divided into a number of subsections and in some cases sub-subsections. The additional levels of complexity allow a more focussed description of the specific reactions catalyzed by particular enzymes. Each enzyme has a systematic name which is precisely descriptive of its function and a classification number. The latter is always prefaced by EC (for Enzyme Commission). An example given by Lehninger [Lehninger, A.L. (1970) *Biochemistry*, pp. 184–185, Worth Publishers Inc., New York] is for the enzyme with

the common name, creatine kinase, which catalyzes the phosphorylation of creatine at the expense of the hydrolysis of a molecule of ATP:



It has the systematic name ATP : creatine phosphotransferase and the classification number EC 2.7.3.2, where the first digit indicates enzyme class 2, transferases; the 7 for the subclass phosphotransferase; 3 for the sub-subclass phosphotransferase, where a nitrogenous group is the acceptor; and the final 2 the designation for creatine kinase.

E

Enzyme-linked immuno-absorbent assay (ELISA)

Immunological technique used in brewing for the identification of microorganisms. The technique relies on having antibodies to particular antigens specific to the organism being tested. In the case of bacteria and yeast these will typically be cell surface proteins. Specific antibodies are supplied attached to a suitable support. The sample is placed in contact with this, and if the antigen (target organism) is present it will bind to the antibody. The excess is removed by washing and a second antigen-specific antibody preparation is added. The second antibody is conjugated to a suitable enzyme whose activity is linked to a chromagenic dye. In the final step after washing, addition of the enzyme substrate allows visualisation of antigen and antibody complexes and, by inference, a positive identification.

The approach has been used with success for the identification of spoilage bacteria such as strains of *Lactobacillus* and *Pediococcus*. It is of less value with regard to differentiation of brewing strains because of cross-reactivity of closely related strains. Should more specific antisera be developed it may prove to be of greater utility.

Eosin Y

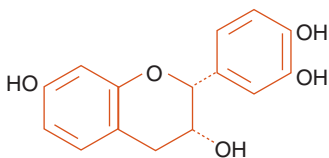
A fluorescent dye (2-(2,4,5,7-tetrabromo-6-oxido-3-oxo-3*H*-xanthen-9-yl)benzoate) which, by virtue of its exclusion from viable cells, has been used as a viability stain for yeast cells.

See **yeast viability**.

Epicatechin

Epicatechin is a monomeric polyphenol of the flavanol type (see accompanying diagram for structure). It has importance in brewing since it is an important precursor of beer hazes.

See **polyphenols, colloidal stability**.

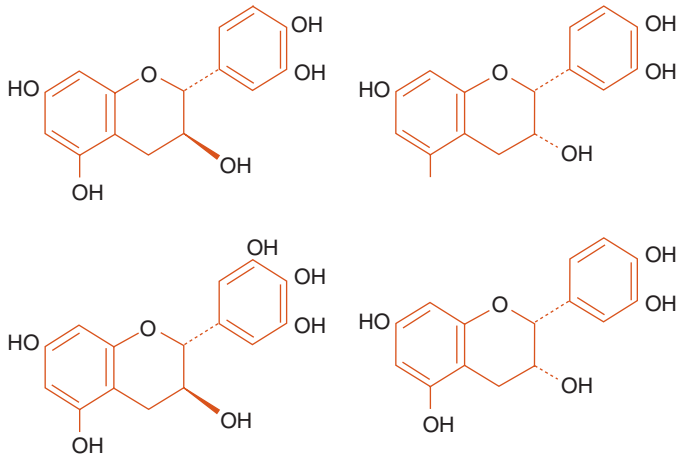


Structure of epicatechin

Epigallocatechin

Epigallocatechin is a monomeric polyphenol of the flavanol type (see accompanying diagram for structure). It has importance in brewing since it is an important precursor of beer hazes.

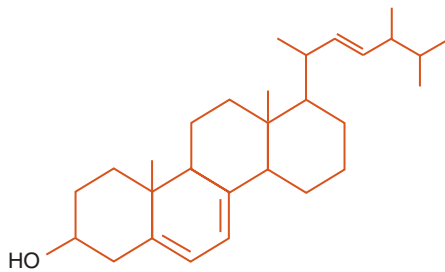
See **polyphenols, colloidal stability**.



Structure of epigallocatechin

Ergosterol

The principal sterol found in yeast cells and which has the following structure shown in the figure.



Structure of ergosterol

See **yeast sterols**.

Erntebier

Erntebier, literally harvest beer, is a product of German origin made from a weak wort and in consequence containing only 1.5–2.5% abv. The traditional product was home-brewed for consumption by farm labourers.

See **reduced-alcohol beers**.

Eroica

Eroica is a US-bred high alpha variety of hop (12.3% α -acids, 3.8–5.2% β -acids, 41% cohumulone) which derives from **Brewer's Gold**. It is very late maturing and gives high yields and is relatively disease resistant.

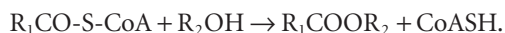
Esters, yeast and beer flavour

Esters, in the brewing sense, refer to the group that is formed by yeast during the course of fermentation. They are important components of beer flavour and aroma and many are

produced at concentrations close to their flavour thresholds. Their flavours are generally described as fruity, floral or solvent-like. An essential part of fermentation control is to ensure that esters are formed in concentrations appropriate for the beer style.

Beer esters are typically considered in two groups: acetate esters, where the acidic component is acetate and the alcohol is ethanol or a higher alcohol, and ethyl esters, where the acidic group is a medium-chain-length fatty acid and the alcohol group is usually ethanol. Examples of the first group are ethyl acetate, isoamyl acetate, isobutyl acetate and phenylethyl acetate, and the second are ethyl butanoate, ethyl hexanoate, ethyl octanoate and ethyl decanoate.

Esters are synthesised by yeast in enzyme-catalyzed reactions involving precursors which are esters of CoA and an alcohol. Acetyl-CoA may derive from pyruvate devolving from glycolysis or via a direct reaction between CoA and acetate via the action of acetyl-CoA synthase. In the case of ethyl esters the preliminary step involves the reaction of CoA and a medium-chain-length fatty acid. The ester is then formed via reaction with an alcohol catalysed by alcohol acyl transferase (AAT):



A number of isozymes show ester-forming activity. In brewing strains, two genes, *ATF1* and *ATF2*, have been identified which code for AATs. A close homologue, Ig-ATF1, is found in lager strains. These enzymes appear responsible for the synthesis of acetyl esters. The *ATF1* gene product appears to be located in yeast lipid particles, which suggests that there may be some linkage between the synthesis of these two groups of metabolites. Deletion studies show that the *ATF1* gene appears to have the greatest importance and is implicated in the formation of a range of acetate esters from ethyl acetate up to octyl-acetate and including phenyl ethyl acetate. Double deletions of *ATF1* and *ATF2* did not produce any isoamyl acetate, although ethyl acetate, propyl acetate and isobutyl acetate were still produced albeit at reduced concentrations, presumably indicating alternative routes for production.

The double deletion mutants still produce ethyl esters and, in consequence, other activities have been proposed which show specificity towards ethanol and medium-chain-length fatty acid CoA esters. Several candidates have been putatively identified and in at least one case, both ester forming and esterase activity were demonstrated. Other esterase activities capable of modulating ester concentrations in beers may also exist.

In order to influence beer flavour the esters must leave yeast cells. They appear to accomplish this via simple diffusion; however, the rates of efflux are markedly slower the longer the chain length of the molecule.

Since over-expression of the *ATF1* and *ATF2* genes results in large increases in acetate ester formation it appears that the availability of substrates is not limiting. By inference, factors which influence expression of these genes are likely to be of importance in acetate ester formation. Both the availability of oxygen and unsaturated fatty acids have been shown to have importance via their ability to repress *ATF1*. From this point of view the availability of both oxygen and unsaturated fatty acids during early fermentation reduce acetate ester formation. Further regulation of the *ATF1* gene occurs via kinases which respond to the availability of glucose, maltose and nitrogen. All of these have the ability to activate transcription of *ATF1*.

With regard to ethyl ester formation the availability of precursors, especially the medium-chain-length fatty acids, appear to be of greater importance compared with acetate esters. In

addition, expression of one of the relevant genes, *EHT1*, which codes for ethanol hexanoyl transferase (eht1), correlates negatively with concentrations of ethyl octanoate and ethyl decanoate. Since this has esterase activity this suggests that this reverse reaction may be of importance. It is suggested that under fermentation conditions long-chain fatty acids accumulate and by feed-back inhibition restrict the activity of acetyl-CoA carboxylase, the first step in fatty acid biosynthesis. The resultant release of medium-chain-length fatty acids provides precursors for ethyl ester formation. Oxygen allows unsaturated fatty acid synthesis to proceed; the inhibition is released and ethyl ester synthesis rates decline because of lack of substrate.

The general trends that can be discerned with regard to total ester formation are that the yeast strain is of importance, presumably due to genomic differences. The medium composition, particularly the total sugar concentration and C:N ratio, are important. Where these are high ester levels are elevated. Pressure reduces ester formation perhaps by influence on transport, and temperature has the reverse effect. Oxygen availability correlates negatively with ester formation for all esters except ethyl hexanoate.

The metabolic basis for ester formation remains obscure and several hypotheses have been advanced. These include the regeneration of free CoA coupled to the detoxification of membrane-damaging medium-chain-length fatty acid-CoA esters. In brewing fermentation the synthesis of unsaturated fatty acid synthesis is restricted to the initial aerobic phase and in this phase ester formation is inhibited. It is suggested that in subsequent anaerobic growth the synthesis of long-chain esters might provide a method of modulating membrane fluidity, which cannot be accomplished by the usual route of regulating the ratio of saturated and unsaturated membrane fatty acids. The *atf2* enzyme has been shown to have high affinity for growth-inhibitory precursors of sterol synthesis. The formation of esters of these compounds could be a preliminary step in their excretion from the cell, thereby preventing their accumulation in the early stages of anaerobic fermentation. Perhaps most interestingly ethyl butyrate has been shown to be attractive to fruit flies and it is suggested that, since the latter feed on yeast on rotting fruits, this might be a ploy by yeast to promote their dissemination to new sources of nutrition.

Ethanol tolerance

All organisms exhibit variable tolerance to ethanol. In brewing this is significant from two standpoints. The degree to which potential beer spoilage organisms tolerate oxygen is a key factor in defining the degree of risk. Secondly, ethanol tolerance of brewing yeast strains is an important factor in deciding what upper limits can be placed on the practice of **high-gravity brewing**.

With regard to beer spoilers many microorganisms are inhibited or killed by the presence of ethanol. Thus, the spectrum of organisms capable of spoiling worts is much greater than the rather more specialised group that can flourish in beer, especially under anaerobic conditions and in the presence of hop products (see **beer spoilage**). Conversely, low- or zero-alcohol beers do not have this natural protection and the risk of spoilage becomes commensurately high. At the other end of this scale, some lactic acid bacteria are highly ethanol tolerant and can cause spoilage in what might be thought of as relatively safe products such as **saké** where ethanol contents may be as high as 20% v/v. This property is highly variable. The majority of

lactic acid bacteria will not grow in beer or other alcoholic beverages. With regard to saké spoilage, a group of lactic acid bacteria that require the presence of mevalonic acid for growth has been recognised. This compound arises in saké via the action of the mould *Aspergillus oryzae*, used on the formation of saké mash in a process analogous to malting in beer, and in Japanese it is referred to as *hiochi acid*. Two groups of ethanol-tolerant lactic acid *hiochi* bacteria have been isolated. Heterofermentative types are strains of *Lactobacillus fructivorans*. Homofermentative types are classified as *Lactobacillus homohiochi*. Representatives of the former group require mevalonate to be present for growth. They are able to ferment sugars and the presence of ethanol is growth stimulatory but cannot tolerate concentrations greater than 25% v/v. Ethanol-tolerant strains exhibit morphological and compositional differences. They tend to have smaller cells compared with ethanol-sensitive types, possibly a response of the latter to compensate for impaired nutrient uptake by increasing membrane surface area. Cell envelopes are thicker, possibly to restrict the entry of ethanol, and the fatty acyl chains in membranes have an unusually high concentration of 18:1 unsaturated and longer-chain-length fatty acids. Beer spoiling lactic acid bacteria are less ethanol tolerant compared to those found in saké; however, they have a much increased tolerance to hop isohumulones. Beer spoiling strains of *Zymomonas mobilis* produce ethanol via fermentation of sugars and can tolerate up to 16% v/v ethanol.

With regard to yeast, a similar variability exists to that described for bacteria. In general, wine strains are more tolerant to ethanol (up to 20% v/v) compared with brewing strains (typically 8–12% v/v). Presumably these reflect genetic differences. The effects due to ethanol alone are difficult to quantify. Generally it has been found that added ethanol is less toxic compared to the same concentration generated via growth and metabolism. This suggests that intermediates in ethanol formation might be important, and in this regard acetaldehyde has been proposed as a possible candidate. It must be remembered that in a batch culture more sugar is required in the medium to generate high ethanol concentrations, and it is possible that osmotic stresses could be contributing to the apparent toxic or inhibitory effects of ethanol. Gradual addition of sugars throughout batch growth can be used as a means of distinguishing between these effects. The cellular targets for ethanol toxicity remain obscure. The outer membrane is freely permeable to ethanol and it is possible that under some circumstances intracellular accumulation could lead to protein denaturation. Exposure to high ethanol concentrations leads to an increased incidence of **petite mutants**, which is a concern for high-gravity brewing. The majority of deleterious effects ascribed to ethanol appear to be related to membrane structure and function. Reported adverse effects of exposure to oxygen include leakage of intracellular components, disruption of transport processes and changes in proton motive potential. Structural changes have been observed which result in altered membrane fluidity and hydrophobicity.

A response to ethanol exposure by yeast, analogous to that of lactic acid bacteria, as described already, is a tendency to increase, where possible, the synthesis of unsaturated fatty acids, presumably as a means of regulating membrane fluidity. This perhaps suggests some routes by which the deleterious effects of very high-gravity brewing might be ameliorated. The genome could be manipulated to increase the natural ability to synthesise unsaturated fatty acids. More simply and directly, synthesis of unsaturated fatty acids can be promoted by increasing the supply of oxygen to wort, or suitable nutritional supplements might be made.

In this regard, the role of metal ions, particularly Mg^{2+} , which many worts appear to be deficient in, appears to play a significant role.

Ethyl acetate

The most abundant ester found in beer and produced via yeast metabolism during fermentation. It has the structure $CH_3-CH_2COO-CH_3$ and is described as having a fruity, solvent-like aroma and taste. Flavour threshold values in beer are of the order of 25–30 mg/L and it occurs within the range of 5–35 mg/L.

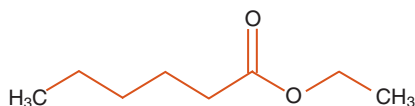
See **esters**.

Ethylene vinyl acetate (EVA)

A copolymer of ethylene and vinyl acetate used in soft drinks **dispense** tubing. It is more flexible than **medium-density polyethylene (MDP)** but is rarely used in beer **dispense** because of concerns with off-flavours, reportedly exacerbated by higher levels of vinyl acetate in the polymer.

Ethyl hexanoate

Ester, also known as ethyl caproate, produced by yeast during fermentation with the structure as shown in the figure. It has the flavour and aroma of apple. It has a flavour threshold in beer of approximately 0.2 mg/L and occurs in beer at concentrations within the range of ca. 0.05–0.2 mg/L.



Structure of ethyl hexanoate

See **esters**.

Ethyl octanoate

Ester, also known as caprylic acid ethyl ester, produced by yeast during fermentation with the structure as shown in the figure. It has the flavour and aroma of aniseed. It has a flavour threshold in beer of approximately 0.9 mg/L and occurs in beer at concentrations within the range of ca. 0.04–0.5 mg/L.



Structure of ethyl octanoate

See **esters, yeast and beer flavour**.

Euchemia cottonii

Euchemia cottonii is a red alga which is found in various parts of the Pacific Ocean. It is a rich source of the kettle fining agent, κ -carrageenan.

See **kettle finings, κ -carrageenan**.

European Beer Consumers Union (EBCU)

The EBCU is a consumer organisation founded in Bruges in 1990. It represents the views of a number of other national consumer groups all of which campaign for what they consider to be traditional beers. They champion the efforts of craft brewers and are opposed to what they see as the increasing globalisation of the world beer market and the consequent loss of regional specialities.

E

Exopeptidase

A category of **protease** enzyme that cleaves the terminal or penultimate peptide bond in a polypeptide chain and in consequence releases either a single amino acid or a dipeptide. Those which attack at the amino terminus of the polypeptide are termed **aminopeptidases**, whereas those which attack at the carboxyl terminus are termed **carboxypeptidases**. In the mashing stage of brewing carboxypeptidases are particularly important in the formation of wort-free amino nitrogen at the expense of the degradation of malt proteins.

See **protease**.

Experimental breweries

Scaled-down versions of breweries which may be used for training, evaluation of raw materials, new process options and new product research. The majority of large brewing companies have at least one of these, sometimes more than one, to allow some specialisation. For example, the requirements for new product development might require concentration on facilities for packaging, whereas the needs for process development would be likely to require flexibility so that the means of carrying out any part of the brewing process can be investigated.

The capacity of an experimental brewery will depend upon the uses to which it is put. Typically, the smaller the batch size, the more likely it is that control of all variables will be precise. However, this will usually be at the expense of the relation that results bear to full-scale commercial brewing. The smallest experimental facilities are laboratory scale. All individual stages of the brewing process are represented from micro-maltings (typically a few kilogram batch size) through to small-scale mills, experimental mashing baths, entire small-scale brew houses (5- to 50-L brew length and offering various levels of sophistication in terms of control), yeast propagation facilities, beer filters and various types of fermentation apparatus. The latter range from simple fermentation bins, through **mini-fermenters**, **EBC tall tubes** to general purpose laboratory fermentation systems of the types used in mainstream scientific research. Laboratory facilities are generally not used to produce finished beer and therefore a micro-packaging plant does not usually feature.

True experimental breweries have all the features of their commercial counterparts. Batch sizes are usually of the order of 1–20 hL. Since it will usually be necessary to assess beers the full range of packaging options, cask, keg, bottle and can, may be provided. The packaging lines are built to achieve the same specifications, including in-pack oxygen levels, as for commercial beers. Commonly a beer of the same quality as one of the brewing companies' mainstream brands will be produced at regular intervals and subjected to a detailed assessment to confirm that it is true to type. This ensures that confidence can be placed in other development works.

Experimental breweries are very costly and their design requires great care. It is important that the diameter of connecting pipework is also scaled down appropriately to avoid large

dead volumes; similarly, the capacities of pumps should be rated in accordance with the size of the plant. Where the major aim is to study the brewing process attempts may be made to mimic full-scale plant, for example, lauter tuns, which have a similar aspect ratio to full-scale versions but performance are very narrow to contain the small batch sizes. Similarly, high aspect ratio cylindrical fermenters may be used. Whether or not the design aspirations are fully achieved is perhaps open to debate. Nevertheless, a well-designed experimental brewery is a very desirable asset as it allows much development work to be performed which otherwise might have to be undertaken at full scale with all of the accompanying disruption to normal production and financial penalties in the event of failure.

External wort boiling systems

External wort boiling systems, also known as calandria, are heat exchange units through which wort is circulated. Typically they consist of bundles of stainless steel pipes, arranged vertically and located within a chamber provided with a steam supply. Wort is withdrawn from the base of the kettle and introduced into the base of the heating unit. It is heated as it passes upwards through the vertical array of tubes after which it is returned into the top of the kettle.

See **wort kettle**.

Extract

The term extract, used on its own and in a brewing sense, is a somewhat imprecise term which refers to the total soluble materials present in brewing materials such as worts or beers. In this sense it is a measure of wort concentration. It encompasses all solutes present and, as such, does not give any indication of the fate or significance of these solutes. However, it is predictable that, using standard raw materials and methods of production, the total extract will relate to the concentration of fermentable extract and, by inference, yields of ethanol in beers. In order to be of value the term extract must be qualified to provide terminology with more precise definitions. These qualifying terms describe defined conditions under which measurements of extract should be made and the units in which the concentration should be expressed.

Extract is used in two senses: firstly, the potential extract that might be obtained from various brewing raw materials, and secondly, real measures of the extract present in worts, beers or other process liquids such as syrups, and so on. The latter category is used to assess the materials themselves as well as the processes and the plant used to make extracts.

The potential extract of brewing raw materials is expressed in terms of the weight of the extract obtained compared to the weight of the raw material used. For example, in archaic UK brewing practice, the **brewers' pound** was defined as the weight of a barrel of wort, measured at 60°F (15.5°C) minus the weight of a pound of water measured at the same temperature. This value was applied to worts and also to the beers made from them, as in a '20 lb beer'. In more modern usage potential extract is referred to in the more usual terms of pounds per barrel or the metric equivalent, kilograms per hectolitre. With regard to the process liquids derived from these raw materials values are related to the more usual measures of wort concentrations such as specific gravity. In this case a wort (or beer derived from it) of, say, 20.7 brewers' lbs would be equivalent to a specific gravity (SG) of 1.0575 (measured at 60°F, 15.5°C), 1.05723 (SG measured at 20°C), 14.097 Brix (equivalent to % w/w cane sugar), 1.05760 Balling (SG measured at 17.5°C), approximately 14.3°Plato (see the respective entries for these units for precise definitions).

In order to be able to assess the yield of extract from raw materials standardised laboratory procedures are used. These methods are theoretical in the sense that they may bear little relation to actual extracts obtained under the conditions of commercial brewing; nevertheless, they are of value in that they provide indicative reference values which describe some aspect of the brewing material under examination. The methods define the quantities of material to be used, the conditions under which the material should be treated, and the method and units by which extract should be measured and expressed.

E

In order to assess commercial-scale brewery operations extract measurements are made at various stages in the brewing process. Providing accurate measures are available of the total quantities of raw materials used, the volume and concentration of extract obtained provide an indication of the efficiency of the process. In any given brewery the standard reference wort for any given product is defined as that which is obtained at the completion of the boil when it is ready for transfer from the kettle. The wort concentration at this point with reference to the total volume is defined as the **original extract**.

With regard to fermentation the total extract present is subdivided into two principal fractions, fermentable and non-fermentable. These describe those wort solids which under the conditions employed are either utilised by yeast or which remain in the beer when fermentation is completed. The presence of yeast and the resultant formation of ethanol have effects on extract measurements that require correction. Since ethanol is less dense than water it exerts a depressing effect, and for this reason uncorrected values are referred to as **apparent extracts**. Predictably measurements made after the removal of ethanol by distillation and correction for volume and temperature are referred to as **real extracts**. As a result of yeast activity during fermentation a proportion of the extract will have been converted to ethanol and the formation of more yeast biomass. The yield of ethanol, new biomass formed and quantity of sugar consumed are loosely predictable, and therefore, providing the ethanol concentration and residual gravity are known, it is possible to calculate the gravity of the wort from which the beer was derived. This is termed the **original gravity (OG)** or **original extract**.

Extract hops

A synonym for **kettle hops**, those varieties which have a high content of α -acids and are therefore suitable for bittering.

Faba amara

Name given to preparations made from the seeds of the plant of the Philippines of the same name. The seeds, also known as bitter beans or St Ignatius beans (from the plant name *Ignatio amara*), are intensely bitter and contain the very toxic alkaloids strychnine and brucine. Ground extracts of the seeds either alone or in combination with other adulterants were reportedly used in eighteenth- and nineteenth-century United Kingdom as hop substitutes in beers.

Falling kräusen

See *kräusen*.

Falling-number test

A procedure used to assess pre-harvest sprouting damage in cereal crops.

See **pre-harvest sprouting damage (PHSD)**.

Falscher Mehltau

German for 'false mildew'; a synonym for downy mildew, a fungal disease of hops.

See **downy mildew**.

Farbebier

Farbebier, as the name suggests, *farbe* being the German for colour, dye or tint, is a beer that is produced specifically for adjusting colour. This practice is a consequence of the beer purity laws that preclude the use of other artificial colourings. The beer is not intended for consumption undiluted and is made by specialist suppliers to the German brewing industry.

Farbebier is produced from a highly concentrated wort (18–20°P) made from a mixture of pale and dark malts. The mixture is boiled and fermented to produce a beer with a colour of approximately 8000 EBC.

Farinator

A farinator is a device that facilitates examination of the internal structure of cereal grains such as wheat or barley. It is also known as a **corn cutter**. It is usually made of stainless steel and consists of a handheld device that contains receptacles for 50 cereal grains. A knife device allows the grains to be cut so as to produce transverse sections. Grains can then be examined visually, and assessments are made of attributes such as mealiness/vitreosity.

Faro

Faro is the name of a beer associated with Belgium. Traditionally it was a relatively low-alcohol table beer for everyday drinking made from a blend of **lambic beer** and *Meerts bier* and sweetened by the addition of brown sugar, molasses or caramel. The traditional faro style of beer has all but disappeared. A few modern versions are still produced in Belgium, which are still sweetened with some form of sugar, but the majority are pasteurised after bottling such that no secondary fermentation takes place.

See **lambic beer**.

Farro

Farro is an Italian name for Emmer wheat. It is still cultivated in Italy and is used primarily for human consumption. It is popular with proponents of 'healthy' foodstuffs. Historically it was a major staple associated particularly with the Roman Empire.

Farro is used as a source of extract by some speciality brewers.

Fast dispense

System for rapid beer dispense designed by the IMI Cornelius (<http://www.corneliusuk.com>; last accessed 17 February 2013). The system is designed for retail outlets where there is a requirement for very rapid service of draught beers, for example, bars with very high throughputs or at events such as festivals or sports stadia. The system uses push-button precise metered dispense of beer, line pressures are very carefully controlled to prevent fobbing and sensors identify when kegs are empty and automatically switch to a new container without the need to disrupt service. Beer volumes of 500 mL can be dispensed in 5 seconds with a precision sufficient to meet weights and measures legislation. Further productivity is obtained by the use of multiple dispense taps.

Fat bine

See *Verticillium wilt disease of hops*.

Favorit

See *Valtický*.

FBI

Full-bottle inspector.

See **bottling**.

Fed-batch fermentation

An aerobic and high-yielding method of cultivating yeast used for the manufacture of active dried brewing and baker's yeast. The key to the method is that conditions are controlled such that metabolism is fully derepressed and respiratory. This ensures that biomass yields are very high, approximately five times greater than that seen in a conventional brewing fermentation, the yeast has very high levels of sterols and unsaturated fatty acids and the products of growth are CO₂ and water. No ethanol is produced.

In order to ensure that metabolism is fully respiratory, it is necessary to control sugar concentrations at low and derepressing levels. This is achieved by feeding the medium into the growth vessel at a rate that ensures that the sugar is immediately assimilated by the growing cells with the result that the effective sugar concentration is always close to zero, and in consequence repression and fermentative metabolism does not occur. The medium is added at an exponential rate in tandem with the increase in biomass concentration. In order to ensure that growth is respiratory, a continuous supply of oxygen is required. This is achieved by providing a continuous supply of air or oxygen and a growth vessel designed to produce very high rates of oxygen transfer.

In the case of the production of active dried brewing yeast, the medium is based on molasses, which contains 45–50% w/v sucrose. Nitrogen is supplied mainly in the form of ammonia, and the other nutrients are various salts, phosphate, amino acids, metal ions and vitamins. Initially growth is allowed to proceed as a conventional batch culture, and this is used to inoculate the fed-batch propagation system. The medium is fed into this at a rate that ensures respiratory metabolism. This is monitored by measuring the ethanol concentration and the relative content of CO₂ and oxygen in the exhaust medium.

See **dried brewing yeast**.

Fenpropathrin

Fenpropathrin[(RS)- α -cyano(3-phenoxybenzyl)2,2,3,3-tetramethylcyclopropanecarboxylate)] is a synthetic pyrethroid insecticide of the type that may be used for the control of insect infestations on crops such as hops.

FerMAC system

The FerMAC system is a method for the automatic in-tank measurement of specific gravity and volume in a fermenter using differential pressures from three sensors located at the top, middle and bottom of the vessel [Sugden, R.E. (1993) In-line monitoring and automated control of the fermentation process. *Brewers' Guardian*, June, 21–32].

See **density meter**.

Fermentable extract

The proportion of extract present within a wort, or other raw material that is used to make wort, which could be utilised by yeast during fermentation. It is a theoretical measure in the sense that not all of the fermentable extract might actually be consumed by yeast. This might be either non-intentional or intentional. In the former case earlier than planned separation of

yeast from wort might occur in the case of the phenomenon such as **premature yeast flocculation (PYF)**. In such a case the sedimentation of yeast prevents fermentation from proceeding to completion. In the latter case the fermentation may be induced to cease via the application of measures that cause separation of yeast when some fermentable sugars remain. An example of this circumstance would be some traditional lager practices where at the end of primary fermentation, the application of cooling encourages yeast separation and a cessation of yeast activity. The remaining sugar, termed the **fermentable residue**, remains available for utilisation during the subsequent secondary fermentation.

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Fermentable residue

The fermentable residue is defined as extract remaining in green beer at the completion of fermentation, which under appropriate conditions would be utilised by yeast. This situation might be desired or it may be a non-intentional and undesirable situation. An example of the former case would be that in which fermentation is brought to completion by the application of measures that cause yeast separation when some fermentable extract remains. This would be the case where residual extract is required in order to fuel a secondary fermentation as in cask-conditioned ales or traditional lagering practice. An example of the latter case would be any event that causes premature separation of yeast and cessation of yeast activity such as accidental application of cooling. In this eventuality fermentation would end sooner than desired with a consequent high final gravity, less than specified ethanol concentration and probably out-of-specification beer flavour and aroma.

In a fully attenuated wort there would be no fermentable residue; however, the ability of yeasts to utilise sugars is dependent on the genome of the individual strain. For example, many lager strains are less efficient at utilising maltotriose compared with ale strains.

Fermentable residue is measured in laboratory forcing tests. A sample of the end wort is obtained and transferred aseptically to a sterile conical flask. The wort is inoculated with culture yeast, and the mixture is incubated on a flask shaker overnight at room temperature. A comparison of the initial and final wort concentrations provides a measure of fermentable residue.

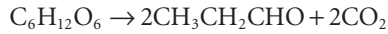
Fermentation

Fermentation is the term used to describe the stage in brewing in which wort is converted into green beer. The process is catalysed by the yeast *Saccharomyces cerevisiae*, usually a pure culture of a selected strain, occasionally a mixture of two or more yeast strains and more rarely a relatively uncharacterised mixture of yeast and bacteria. The term 'fermentation' derives from the Latin *fevere* meaning 'to boil'; a reference to the visible effervescent nature of the process due to the formation of gaseous CO₂.

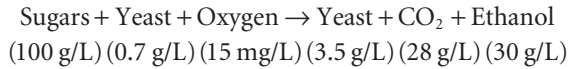
It should be appreciated that brewing fermentation is the manifestation of yeast growth. In this sense green beer is simply the spent growth medium that remains after yeast growth ceases. The art of fermentation management is to regulate yeast growth and metabolism such that the spent medium, or beer, has the desired composition.

During fermentation the yeast grows on the nutrients available in wort typically multiplying between four- and sixfold. As a result of this growth, those sugars that the yeast cells are

capable of assimilating are converted largely into ethanol and CO₂. The gross reactions are described by the **Gay-Lussac equation**, which indicates that for each molecule of glucose fermented, two molecules each of ethanol and CO₂ are formed.



In practice, this equation is an oversimplification that reflects the fact that Gay-Lussac did not appreciate the vital nature of fermentation. Thus, in real fermentation, a proportion of the sugar is utilised by yeast to form new biomass, and consequently, the yield of ethanol is less than the theoretical maximum. A more accurate mass balance of fermentation is given in the following equation.



The yield of ethanol is approximately 86–88% of theoretical maximum. The yield of CO₂ is also less than would be predicted by the Gay-Lussac equation since a proportion of it is fixed by yeast in various carboxylation reactions.

In addition, a wide range of other wort components are utilised by yeast cells and in consequence are either reduced in concentration or totally eliminated. In particular, the concentration of assimilable nitrogen [measured as **total soluble nitrogen (TSN)** or **free amino nitrogen (FAN)**] is an important parameter that influences both yeast growth and the formation of beer flavour constituents.

An equally large number of products of yeast metabolism are released into the external medium. The sum total of these effects is the disappearance of several components that impart undesirable ‘warty’ characters and the formation of many thousands of chemical compounds many of which are important contributors to beer flavour and other desirable beer attributes. An essential feature of fermentation control is regulation of fermentation conditions, which ensure that yeast growth and metabolism proceed in a fashion that occurs at a predictable rate and to a desired extent and results in the formation of products in concentrations that are considered appropriate for the particular style of beer being made.

In a general scientific sense the word fermentation is commonly referred to as ‘anaerobic respiration’. Thus, it is used to describe metabolism in which under anaerobic conditions, energy, in the form of ATP, is generated via substrate level phosphorylation and redox balancing is accomplished principally via the reduction of acetaldehyde to form ethanol. By implication, in the presence of oxygen, energy generation occurs via oxidative phosphorylation and redox balancing via the respiratory electron transport chain. In the case of brewery fermentations catalysed by the yeast *S. cerevisiae*, these assumptions are not true.

In order to obtain adequate growth of yeast during fermentation, it is necessary to add some oxygen, usually as a single dose, during fermenter fill. The requirement for oxygen is a result of the practice of **serial fermentation** in which the yeast used to initiate fermentation is derived from the crop obtained from a previous fermentation. Such yeast is depleted in the lipids, unsaturated fatty acids and sterols, which are essential for proper membrane structure and functionality and for which yeast has an obligate requirement for growth to occur. Synthesis of these lipids by yeast requires molecular oxygen, and these processes occur during the initial

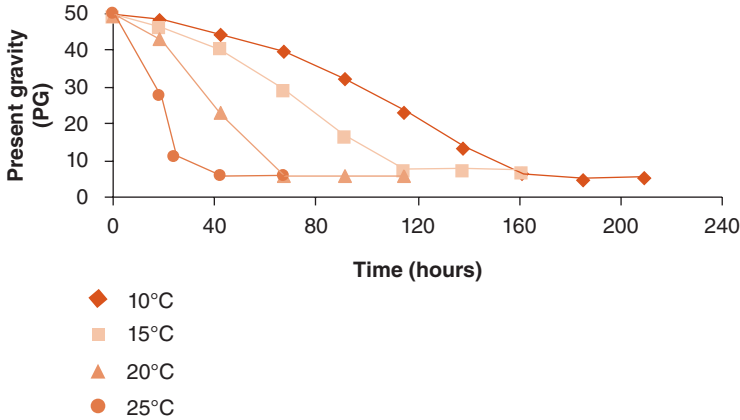
aerobic phase of fermentation. When the initial charge of oxygen is depleted, no further synthesis of these essential compounds can occur. During cellular growth and proliferation in the subsequent anaerobic phase of fermentation, the pools of unsaturated fatty acids and sterols are diluted between mother and daughter cells. Eventually lack of membrane functionality caused by depletion of these essential components causes yeast growth to cease (assuming all other essential nutrients are still present in excess). In many brewery fermentations the concentration of oxygen supplied at the start is the factor that controls the extent of subsequent yeast growth.

Saccharomyces cerevisiae is defined as a heterotrophic facultative anaerobe. The former term refers to the fact that it can utilise a relatively large range of organic compounds to provide carbon skeletons for generating new biomass and for the formation of energy. Bearing in mind the chemically complex nature of wort, this is a useful facility. The latter term refers to the ability of this yeast to grow under both aerobic and anaerobic conditions, provided that the lipid requirements are fulfilled, as discussed already. Brewing yeast strains have a versatile genome that is able to respond rapidly to changes in oxygen availability and the nature of the source of carbohydrate. They are capable of fully oxidative respiratory growth but typically this capacity is limited. Wort provides a medium that is very rich in sugars. The yeast can generate energy sufficient for the relatively modest levels of growth, characteristic of brewery fermentations, via substrate level phosphorylation. This is reflected by the fact that even in the presence of oxygen, relatively low concentrations of fermentable sugars such as glucose and maltose are able to switch off the genes responsible for respiratory oxidative phosphorylation and the bulk of sugars are catabolised via glycolysis to give pyruvate. The latter is then converted to ethanol via the intermediary of acetaldehyde. The regulation of energy transduction via the influence of fermentable sugars on the respiratory pathways is termed **catabolite repression**. Apart from ensuring that ethanol and CO₂ are major products of fermentation, the effects of catabolite repression and the need to balance redox under anaerobic conditions almost certainly have other profound effects on the formation of many metabolites, many of which are important determinants of beer flavour.

The carbon-rich nature of brewing wort and the consequent ease by which yeast generates ATP via substrate level phosphorylation are further reflected by the fact that brewery fermentations are exothermic. In consequence it is necessary to apply cooling throughout primary fermentation. Indeed, a large proportion of the cost of managing commercial-scale fermentations is the need to provide relatively large-capacity refrigeration plants.

Heat output during fermentation is approximately 219 kJ/mol of glucose equivalent fermented. In 100 hL of 10°P wort with a fermentability of 80%, the total heat output would be approximately 0.96 GJ. Of course, this output of heat would be spread throughout the whole of primary fermentation. Cooling capacities of fermenters must be sufficient to cope with the peak output, which occurs during the most active phase of yeast growth. Cooling is applied in fermentation in order to maintain a selected set-point, and thus, the degree of cooling required is dependent on this set-point. In the case of ale fermentations, a range of 18–22°C would be usual. Traditional lager fermentations are conducted under much cooler conditions and a range of 8–15°C is the norm. The duration of fermentation is positively correlated with fermentation temperature (see the following figure). In modern commercial brewing the fermentation stage is commonly the rate-determining step in the whole process. Since the capital and revenue costs associated with large-capacity fermenters are considerable, attempts

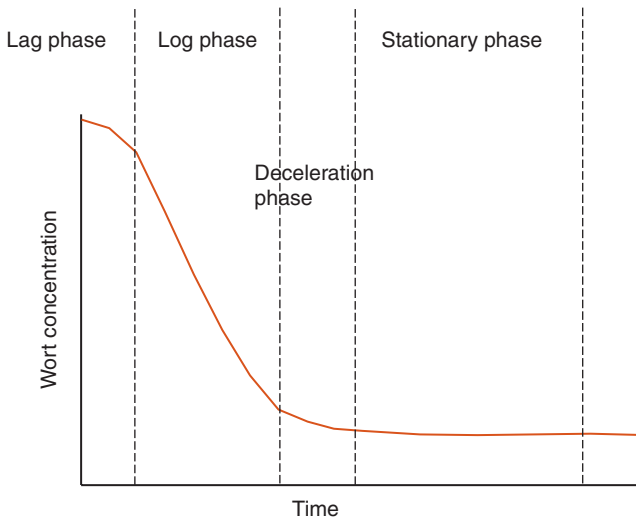
have been made to shorten fermentation cycle times and, therefore, increase the productivity of individual fermenters, by increasing the fermentation temperature. For this reason many mainstream lager brands of the pale Pilsener type now use fermentation temperatures that are close to those associated with ales.



Effect of temperature on the rate of fermentation

Stages in fermentation

The progress of fermentation is usually measured by periodically removing samples of fermenting wort from the fermenting vessel (FV) and determining the concentration of wort [measured either as **present gravity (PG)** or in **degrees Plato (°P)**]. Several phases may be distinguished as shown in the following figure. These may be considered separately, although in actuality they represent a continuum.



Major stages in fermentation

Fermentation is initiated by the addition of yeast (known as **pitching** or **yeasting**) to cooled oxygenated wort (see **pitching** for more details). Usually the addition of oxygen and yeast steps are carried out as the FV is filled with wort – a process usually referred to as **wort collection**. The conditions established during this stage largely regulate subsequent events. Thus, once the vessel is filled, there is little option to exert further control other than to regulate fermentation rate via the application of cooling.

The initial phase is the lag phase, which may persist for a few to several hours after fill, depending on the size of the vessel, the temperature and the method and duration of filling. During the lag phase there is little visible change. It is during this time that the yeast undergoes a transition from stationary (Go) phase to active growth and a large number of yeast genes are up- or down-regulated. The oxygen concentration declines to undetectable levels, and a proportion is used to synthesise sterols and unsaturated fatty acids, as described already. Although the wort appears to be relatively quiescent during the lag phase, the events that occur exert a profound effect on subsequent fermentation performance.

As yeast proliferation commences the stationary phase ends and active primary fermentation commences. During this phase (the log phase) the suspended yeast count rises exponentially, and this is mirrored by a decline in wort concentration and an increase in exothermy. Rates of CO₂ evolution also increase during primary fermentation. Gaseous CO₂ is released into the headspace of the fermenter as soon as the wort becomes saturated. This may be released to the atmosphere, although in the case of larger commercial operations, collection and recovery for use elsewhere in the brewing process are more common.

During primary fermentation the yeast utilises fermentable sugars in an ordered manner. Initially sucrose, fructose and glucose are assimilated followed by maltose (the most abundant fermentable sugar) and then longer-chain sugars. Dextrins are not utilised by brewing yeast strains, and under normal circumstances, these remain in beer and contribute to fullness. Unlike lager strains, ale strains cannot utilise maltotriose. The pattern of sugar utilisation is a consequence of regulation of the yeast genome in response to the presence or absence of particular sugars. It is a manifestation of the fact that when presented with a choice, yeast will always utilise simpler readily assimilable sugars first. Regulation of sugar uptake is complex, and the expression of genes involved in their uptake is influenced by the availability of both exogenous sugars and sources of nitrogen.

During the log phase, yeast growth is balanced and nutrients other than sugars are assimilated simultaneously and used to provide carbon skeletons for new biomass formation and energy generation. Assimilable nitrogenous nutrients comprise ammonia, amino acids, peptides of varying chain lengths and a variety of other compounds such as purines and pyrimidines. Oligosaccharides and proteins are not utilised. These persist into beer where they may exert both positive and negative effects; thus, they are implicated in the formation of hazes and are of importance in head formation. As with sugars the uptake of nitrogen-containing nutrients is complex and regulated. In general, as with sugars, the more easily utilised nutrients are used first. Control is exerted at the gene level in a process termed **nitrogen catabolite repression**. Uptake of amino acids, the most important sources of nitrogen, is effected by a combination of a broad specificity general amino acid permease (GAP) and a number of other permeases, which are specific for one or a small group of individual amino acids. It seems that the GAP is only synthesised under conditions of nitrogen starvation when it functions as a

nitrogen scavenger. The activity of the other permeases is dependent on the nature and spectrum of amino acids present. It seems that those permeases subject to nitrogen repression are responsible for the uptake of amino acids needed for catabolic pathways whereas those not so controlled are responsible for amino acids required for anabolic pathways. The net effect is that the uptake of amino acids is ordered.

Many other nutrients and minerals are also assimilated. Of particular note is zinc. This is an essential cofactor in the function of several yeast enzymes and as such is required for normal growth during fermentation. Some worts may be deficient in zinc, and it is common to add a supplement to fermenter, typically 0.1–0.5 mg/L as Zn^{2+} in the form of hydrated $ZnSO_4$.

During the log phase the pH undergoes a period of rapid decline as a consequence of the efflux of protons by yeast as a result of some transport systems. In addition, several organic acids are formed during this phase, which are important contributors to beer flavour and which may be substrates for other flavour-active yeast metabolites. Typically the pH declines by around 1 unit from an initial value of approximately pH 5.0–5.2 to a final value of approximately pH 4.0.

The majority of fermenters are mixed purely by natural means, principally via the evolution of gaseous CO_2 and via convection currents. In tall FVs fitted with external multiple cooling jackets, mixing may be encouraged by the application of cooling to the upper parts of FVs only. This sets up a temperature differential such that the cooler upper band close to the vessel wall tends to sink and thereby forces the warmer lower layer to rise up the central core. The relatively good mixing helps to maintain (supposedly) homogeneous conditions, and the suspended yeast count remains high throughout this period. It should be noted that recent work investigating large-capacity cylindroconical fermenters has indicated that natural mixing in such vessels is relatively poor and with most, if not all, yeast strains a significant proportion of the population forms a sediment before the log phase of fermentation is completed. By inference, conditions within the fermenter must be heterogeneous. It has been shown that the application of mechanical agitation abolishes this heterogeneity, and fermentation performance and beer quality become more consistent.

The period of rapid changes associated with the log phase gradually slows down and the deceleration phase commences. This phase is triggered usually by the disappearance of an essential nutrient. The identity of this nutrient depends on the composition of the wort. Commonly it may be (free amino) nitrogen, zinc or oxygen. The latter nutrient exerts its influence via the intermediary of unsaturated fatty acids or sterols, as discussed earlier.

The deceleration phase ends when the wort concentration (measured as PG or °P) falls to a minimum value after which no further decrease occurs. This coincides with the assimilation of all the fermentable sugar and the fermentation enters the stationary phase. At this point the wort is described as fully attenuated. Entry into the stationary phase results in the cessation of active CO_2 generation and exothermy, and in consequence, the fermenter contents become relatively quiescent. Under these conditions the yeast cells tend to separate from the wort and either form a sediment or rise to the surface, depending on the type of yeast and geometry of the FV. For those yeast strains capable of so doing, the disappearance of fermentable sugars induces the cells to form aggregates, termed flocs. In the case of bottom-fermenting strains the effect is to increase the net particle size and sedimentation of yeast is promoted.

Top-fermenting strains in appropriate vessels form flocs, which tend to rise to the surface (see **crop**, **yeast flocculation** and *kräusen* for more details).

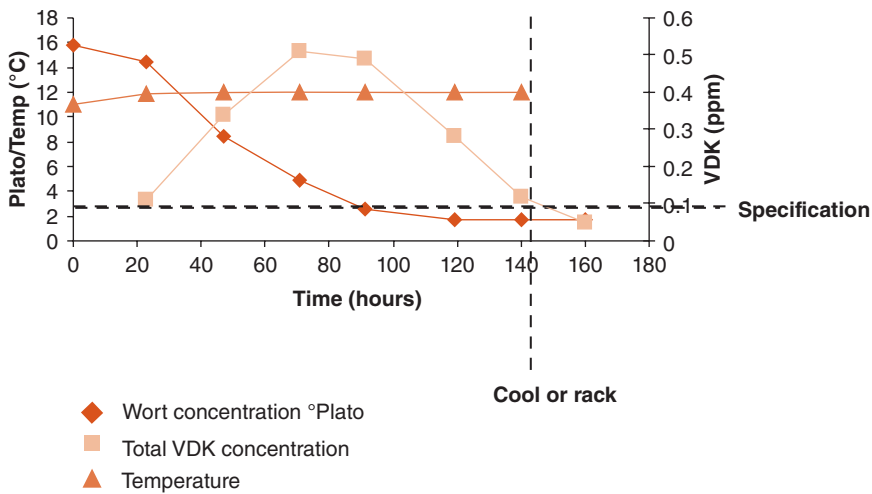
In the stationary phase yeast growth has ceased and yeast separation continues. In this phase the yeast is subject to a period of starvation, and it must rely on the utilisation of internal carbohydrate stores, principally glycogen, for the generation of energy. These glycogen stores are accumulated in mid- to late fermentation and, apart from helping yeast to survive starvation in the late phase in the fermenter, are also required to allow the yeast to withstand the period of storage between cropping and re-pitching. It is important to ensure that as much glycogen as possible is retained at pitch since when oxygen is available, its dissimilation provides carbon and energy for sterol and unsaturated fatty acid synthesis in the lag phase of fermentation.

In ale fermentations and some traditional lager fermentations, the process is effectively complete once the wort is attenuated, and after separation from the bulk of the yeast the beer is moved from the fermenter for finishing. The sedimentation of yeast that remains in suspension after cropping may be accelerated by the use of **fining agents** such as **isinglass**. In addition, the beer may be chilled to abolish convection currents and encourage further the separation of yeast. Occasionally these regimes, which encourage yeast separation, may be applied when some fermentable sugar remains and the wort is not fully attenuated. Typically this applies to traditional practices and is undertaken to ensure that some fermentable sugar remains in the beer to be utilised by residual yeast cells in a secondary fermentation. The latter is allowed to proceed in separate maturation vessels (traditional lagers) or in casks (cask-conditioned ale) or in bottle (bottom-conditioned ale).

As a group, lager fermentations are more complex and several variations are possible. In traditional processes the fermented wort is cooled and transferred to separate lagering tanks in which a separate **secondary fermentation** is conducted (see **secondary fermentation** and **lagering** for more details). The aim of this additional step is for the generation of CO₂, termed **condition**, by utilising the residual yeast of the remaining fermentable sugar (or additional **priming sugar** and/or yeast added during transfer), the maturation of flavour and the removal of potential haze-causing materials.

In more modern lagering processes, secondary fermentation is allowed to occur in the fermenter during the stationary phase. This is performed whilst the green beer is still relatively warm and has the primary aim of flavour adjustment. In particular, during this phase, the concentration of the undesirable compound diacetyl is allowed to decrease to a concentration that is below the flavour threshold in that particular beer. **Diacetyl** is one of a group of compounds termed **vicinal diketones** (VDKs), which have pronounced toffee/butterscotch flavours and aromas and which are considered highly undesirable in pilsener-type lager beers. These compounds arise in beer during primary fermentation as a result of yeast metabolism. In the latter stages of primary fermentation and the stationary phase, VDKs are taken up by yeast and reduced to less flavour-active products. The rate of VDK reduction is dependent on the yeast concentration and on the temperature, hence the need for the warm holding period at the end of primary fermentation. This period is known variously as **warm conditioning**, **warm rest** or **warm stand**, **diacetyl rest** or **diacetyl stand**, and **VDK rest** or **VDK stand**. Commonly fermentation profiles are judged on the basis of the time taken to reach the desired final gravity, termed variously as ‘**time to PG**’, ‘**time to racking gravity**’ or ‘**attenuation time**’.

Typically graphs of wort concentration against time are retained and compared with standard profiles. In addition, the time required for the VDK concentration to fall below a preset minimum value is recorded and described as the ‘time to VDK’ or ‘time to diacetyl specification’. The latter is established via the analysis of samples removed daily, or more frequently, usually from mid-primary fermentation onwards. The profiles of VDK formation and disappearance in relation to changes in wort concentration in a typical high-gravity lager fermentation are shown in the following figure. When the desired VDK concentration is achieved, the fermentation is considered to be complete. In the case of large-capacity modern fermentations, the beer is chilled to 2–4°C via the application of cooling using all available cooling jackets. This is often referred to as **crash cooling**. Reducing the temperature promotes yeast sedimentation, and once the lower set-point is achieved, the yeast crop is removed (see **crop** for more details). The term ‘crash cooling’ infers rapid cooling; in fact, in the case of very large vessels, a rate of approximately 1°C per hour would be usual and, therefore, 12–24 hours might be needed to achieve the lower set-point. Since this is time-consuming, a more modern approach is to remove both the yeast and beer whilst still warm. This practice tends to provide pitching yeast, which retains high viability since the yeast is removed early from the relatively stressful conditions of the cone of large vessels. Beer is removed from the fermenter, termed **racking**. If warm, it is chilled using in-line heat exchangers, a process that is much more efficient than in-tank cooling.



Stages in a typical fermentation showing the peak of total VDK concentration and the time at which the desired concentration of the latter is achieved thereby signalling the point at which the process is considered completed and the green beer can either be cooled *in situ* or moved onto the next stage of processing.

In the case of brewery-conditioned (keg) ales and lagers made by the rapid process, described in the two preceding paragraphs, the conditioning phase is performed at low temperatures, usually –1 to –4°C. Yeast plays no part in this step and efforts are made to reduce cell counts to as low a value as possible, commonly by continuous centrifugation during transfer of beer from the fermenter. This low-temperature phase of storage is termed **cold conditioning**, and its aim is mainly to impart colloidal stability. The cold temperature promotes the formation

of chill hazes and, in general, the colder the beer, the shorter the residence time needed. Very short conditioning times, typically 1–3 days, are achievable. No intentional changes in beer flavour occur in this stage. In traditional lagering, which may be allowed to proceed over several weeks at relatively cool temperatures, the rate of VDK reduction is not particularly important since time is not an issue.

Although not strictly relevant to fermentation the rapid cold-conditioning process is mentioned here since it may be performed in the same vessels as primary and secondary fermentation. In this case, a typical regime would be to cool the beer to an intermediary temperature sufficiently cool to promote yeast sedimentation. Once the sedimented yeast crop has been removed, the beer is chilled to conditioning temperatures and chill haze formation commences at an accelerated rate. These combined tanks, which must be capable of achieving the desired degree of cooling, are variously called dual-purpose vessels (**DPVs**) or **fermentation vessel conditioning tanks (FVCTs)**. Alternatively, they may be called **uni-tanks** and the combined process uni-tanking.

The principal products of fermentation, as stated, are ethanol and CO₂. Both of these compounds contribute to beer flavour in the form of warming effects and mouth tingle, respectively. Many other yeast-derived products contribute to beer flavour. These include organic acids, longer-chain fatty acids, higher alcohols, esters, aldehydes and other carbonyls and various sulphur-containing compounds. The formation of these in appropriate concentrations is determined by the conditions of fermentation. The principal controlling factors are wort composition, yeast strain, fermentation temperature, type of fermenter, initial oxygen concentration and the pitching rate. The importance of the type of fermentation process employed is controversial. It is considered by many that the delicate estery notes and other characters associated with many traditional lagers are intimately related to the slow cool fermentation process employed. It is argued by adherents of these beers that the long secondary fermentation is essential for reasons that have not been fully elucidated. There is some logic to this argument since it is known that when yeast is subject to such prolonged periods of storage, the cells release numerous biochemicals, which are suspected of being implicated, possibly indirectly, in beer flavour and aroma. In addition, the low temperatures employed throughout primary fermentation will tend to lead to the retention of possibly important volatiles. Conversely, proponents of the rapid processes argue that cleaner flavours and aromas can be achieved since yeast is used only when needed. Furthermore, it is claimed that there is no reason why the yeast-catalysed changes associated with slow secondary fermentation should not also occur, albeit at an accelerated rate, during warm conditioning. No doubt the arguments will continue!

Fermentation hall

Alternative name for **fermentation room**.

Fermentation room

Fermentation rooms are also known as fermentation halls, house fermenters and associated equipment. The functions of the rooms are to provide a hygienic environment within which the vessels and any ancillary equipment are enclosed to assist in attemperation and to ensure that CO₂ concentrations remain at safe levels. The sophistication of the room depends on the

nature of the fermenters. The majority of modern fermenters have an enclosed design. It may be appreciated that compared with vessels of more traditional design, which may be open to the atmosphere, the requirements for good hygiene control are less pressing. Similarly, since most modern fermenters have inbuilt attemperation systems, there is no need to pay too much attention to control of the temperature of the room in which they are sited.

Traditional fermentation rooms using open vessels require the highest standards of care since the room must provide an effective barrier to microbial contamination. The essential features of such rooms are the maintenance of a clean atmosphere at a constant temperature and humidity with an extraction system suitable to ensure safe concentrations of CO₂ (<0.5% v/v). In a common arrangement the vessels are sunk into a false floor such that essential services such as valves and pumps are placed beneath a false subfloor. The intermediate false floor provides a space, often referred to as a shell room, which seals off the difficult-to-clean apparatus and the upper surface provides a walkway with access to the upper parts of the vessel. Commonly air is taken from the main fermenting room and introduced to the shell room. Here it is mixed with fresh air and cooled before being reintroduced into the main room. The fermenters are isolated from other parts of the brewery, and access should be restricted to all but essential personnel. All doors and windows must be sealed to prevent entry of airborne contaminants and other pests. Preferably rooms should be operated with a slight positive air pressure to discourage ingress of contamination. Windows should be double glazed to prevent condensation. Floors and ceilings must be provided with smooth coatings and rounded margins to prevent accumulation of dust and other soiling material and for ease of cleaning. In some very early installations, fermentation attemperation was provided by the room itself, no provision being made in individual vessels. This arrangement is highly inefficient, and in most cases, vessels are provided with dedicated attemperation facilities and the atmosphere of the room needs only to be kept cool and dry. Typically the room temperature should be in the region of 15–20°C. A filtered air-conditioning system ensures that the atmosphere remains at a constant temperature and with low humidity. Fittings within the room, especially those on ceilings, should be designed with care. There should be no fittings over the top of open fermenters, which might collect dust or drops of condensation. Floor drains must prevent pooling of water and provided with traps to prevent odours.

The design of modern fermenting rooms is frequently neglected since it is assumed that the enclosed nature of the vessels minimises all risks. In many cases where the climate permits and where the tank farm of cylindroconical vessels is used, there may be no actual fermentation room at all. More commonly, even with cylindroconicals the lower parts of vessels are enclosed in a room. With regard to the finish of the internal surfaces of the room floors, the same standards should be adhered to as those applied to open square vessels. The risk of oxygen depletion and CO₂ accumulation is less where closed vessels are used particularly if the CO₂ is collected. In consequence less care is often taken with regard to air conditioning. A common result is the occurrence of condensation and the growth of moulds on room surfaces. This should be discouraged by the use of coatings made from impervious epoxy resins, which are both smooth and which have an outer coating of fungicidal paint. Washing the walls and floors of the room with an antiseptic spray such as dilute ammonium dipropionate is desirable.

Although the risks of CO₂ accumulation are less suitable monitors of atmospheric CO₂ concentration should be fitted and their output linked to visible and audible alarms.

Fermentation vessel conditioning tank (FVCT)

One of the many terms used to describe vessels that can function as both fermentation and cold conditioning tanks.

Fermenter

The name of the vessel in which fermentation is conducted; for this reason this is also known as a fermenting vessel (FV). Several types are used, the design and operation of which reflect the nature of the beer being made, the properties of the strain of yeast used and the scale of the operation. These are described under individual entries.

Fermentation vessels are either open or closed. Historically the former pre-date the latter; however, the current popularity of craft brewing has led to the manufacture of new vessels often made from modern materials such as stainless steel but based on traditional design.

The requirement of fermenters is that they should be easily cleaned. In traditional vessels this was a manual process. In more modern designs more efficient automatic cleaning-in-place (CIP) systems are fitted. A method is required for adding cooled wort. Typically air, or oxygen, as well as pitching yeast are added during fill (see **wort collection**). Fermentation is exothermic and a means of attemperation is required. In traditional operations this may be achieved by locating fermenters in attemperated rooms. This is an inefficient approach and more commonly vessels are fitted with individual attemperators. In early designs these took the form of internal structures through which coolant, usually water, was circulated. In more modern and large-capacity vessels, coolant is usually supplied to wall-mounted jackets. As it may be necessary to complete fermentation by cooling to less than 4°C, coolants such as ethylene glycol are required. During fermentation it is necessary to record the temperature. This may be performed offline on samples removed from the fermenter using a suitable hygienically designed sample tap. Using such samples the progress of fermentation may be monitored by analysis of wort concentration, expressed in units that relate to specific gravity such as PG or °P. Occasionally, in the case of open vessels, sampling may be via a **dropping can**. At the completion of fermentation the yeast crop and green beer must be removed and the vessel design must take the need for these operations into account. Modern closed vessels are commonly designed to allow collection of CO₂. The exit of CO₂ from the vessel may be restricted to allow generation of top pressure. This helps to prevent ingress of potential beer-spoiling micro-organisms; in addition, pressurisation is used by some as a means of regulating the activity of yeast and thereby, modulating the formation of beer flavour compounds dependent on yeast metabolism.

The use of open vessels for primary fermentation pre-dates the understanding of the importance of good hygiene and the risks of microbial contamination. Open vessels are relatively inexpensive to construct and suit small batch sizes. In the case of the use of top-cropping ale yeast strains, an open design facilitates yeast removal. Perhaps, more importantly, the ability to make a visual examination of yeast heads provides a valuable means for the skilled brewer to make assessments of fermentation progress and rapid identification of non-standard behaviour. A commonly encountered design of open vessel used for the production of ales is the **open square**.

The advantages of open fermenters discussed in the preceding paragraph are outweighed by the problems with achieving good hygiene. The necessity of maintaining a microbial barrier means that the use of closed vessels is favoured by the majority of modern commercial brewers. Of course in the case of traditional bottom-cropping lager fermentations, closed

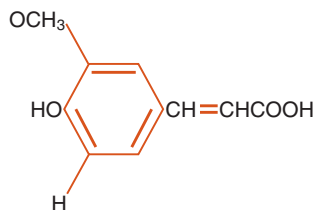
fermenters have a long history, particularly those used for secondary fermentation. These usually take the form of coopered wooden vessels, essentially large casks. With regard to modern closed fermenters the design choices that may be made are rectangular or cylindrical cross section and, in the latter case, upright or horizontal aspect. Examples of all of these alternatives may be found in common use.

Those with a rectangular section used for ale production are essentially open square fermenters, which have been fitted with a top. For obvious reasons these are referred to as **closed squares**. Similar vessels are also used with bottom-cropping lager, often referred to as **box fermenters**. Vessels with a cylindrical cross section are the most commonly encountered design of fermenter. They may be conveniently grouped together in tank farms serviced by a series of shared mains for filling, pitching, cropping, racking and cleaning. Vertically oriented vessels are perhaps most common since these occupy a smaller footprint and are well draining. The bases of such vessels may be dished but much more usually are fitted with a cone to facilitate crop formation and removal. The latter vessels are referred to as cyllindroconicals for obvious reasons. Cylindrical vessels can be very large, typically in the region of 1500-hL capacity, but up to 5000 hL may be encountered. Such vessels are tall and hence yeast at the base is exposed to considerable pressures owing to the hydrostatic heads. It is claimed by some that the high pressures can have deleterious effects on yeast and beer quality. For this reason some brewers prefer to use fermenters that take the form of horizontal cylinders. These avoid the effects of high pressures but at the expense of more difficulties with crop removal and cleaning. Currently there is little agreement on what constitutes the optimum aspect ratio for large-capacity fermenters, and this subject remains controversial.

Fermentation vessels are grouped together in the brewery in fermenting rooms, also known as fermentation halls. The degree of care required in the design of these reflects the nature of the vessels. In the case of open squares, avoidance of microbial contamination is paramount. For this reason access to the fermentation hall is restricted to essential personnel, and commonly the rooms are designed to avoid drips from condensation and to operate under a positive air pressure. In addition, safety aspects with regard to possible oxygen deficiency owing to CO₂ accumulation are of critical importance. Closed vessels present fewer problems. The enclosed nature of operations means that vessels can be sited outside. Depending on the climate there may be no fermentation hall at all or commonly just the base of tall vessels may be enclosed in a building.

Ferulic acid

A simple phenolic compound, one of the series of substituted cinnamic acid derivatives, which are found in worts (see accompanying diagram for structure). Concentrations in unboiled lager wort are reported to be of the order of 1.3 mg/L.



Structure of ferulic acid

Ferulic acid is the most abundant of the cinnamic acid group. It has particular relevance to beer flavour in that a proportion is released into malt worts during mashing from the arabinose residues of pentosans to which it is bound. Certain yeast and bacteria possess a gene, termed POE, standing for phenolic off-flavour, which decarboxylates ferulic acid to form the compound 4-vinyl guaiacol. This compound has a very distinctive aroma and taste of 'cloves' or 'antiseptic'. In many wheat beers this is considered a desirable characteristic; in most malt beers it is considered to be a flavour defect. The pof enzyme is commonly possessed by wild yeasts such as *Saccharomyces diastaticus*, which are also super-attenuators. Tests for the presence of such organisms, which are considered as beer spoilers, rely on growth in a medium that contains ferulic acid. The presence of 4-vinyl guaiacol is detected by a sniff test.

See **polyphenols, tannic acid, wild yeast**.

Ficin

Ficin describes a preparation obtained from the latex of the fig plant (*Ficus glabrata*). It contains proteolytic activity and in brewing it is used as a chill proofing agent by virtue of its ability to degrade high-molecular-weight polypeptide precursors of protein-polyphenol hazes. The **proteases** present in ficin are relatively thermostable, typically retaining significant activity at 60–65°C, and for this reason such preparations have occasionally been added to mashes to ensure that sufficient soluble nitrogen is generated where it is suspected that the concentrations of proteases might be deficient.

Fidelio

A cultivar of the wheat, rye hybrid and triticale.

Fieldbus

A fieldbus is part of the digital communications system used to automate complex industrial processes. It occupies the part of the communications chain that takes the output from field devices, objects such as valve actuators, sensors and switches, and passes this upwards to the programmable logic controller (PLC), which actually controls and supervises the process.

See **programmable logic controller**.

Fieldbus Foundation

Fieldbus Foundation is a non-profit-making consortium of end-users and suppliers of process automation systems that rely on integrated digital communications for data gathering and process control of connected devices. It arose in response to the development during the 1980s of a number of parallel proprietary digital communication systems none of which could be used together. The Fieldbus Foundation was set up with the aim of developing non-proprietary specifications upon which digital communications systems could be based and used to replace non-compatible systems.

For more information see www.fieldbus.org (last accessed 3 January 2013).

Fiery malt

This is the name given to malt immediately after kilning. It is believed that pale malts require a period of storage of 4–6 weeks before use. The use of fiery malts reportedly results in abnor-

mal brewing behaviour symptoms said to be poor run-offs, hazy beers, poor fermentability and non-standard beer flavours.

The reasons for this belief, which seem to be well founded, are not known.

Filipin

Polyene antibiotic obtained from *Streptomyces filipensis*, which owes its anti-fungal action to its ability to bind to sterols and thereby affect membrane function. This ability has been exploited as a rapid method for sterol determination in yeast cells based on spectrophotometric determination of the complex formed when filipin binds to sterols. Filipin can now be obtained attached to a fluorescent dye, which perhaps provides a route to more sensitive assays of free sterols.

Filterability of beer

Most brewers are well acquainted with the filterability of their own brands of beers and the nature of the filters that they use. It follows that they have well-established filtration regimes that provide satisfactory results. In the event of the purchase of new filtration equipment or the introduction of new beer qualities, it may be necessary to make assessments of beer filterability.

With regard to powder filters three approaches can be adopted, either singly or in combination. These are the simple application of empirical observation and prior knowledge, the use of predictive modelling equations and laboratory assessments. In each case the aim is to identify a regime for pre-coating and body feed addition that produces optimum filtration runs.

Empirical observations

This is the most commonly used approach. Optimum powder regimes are usually identified based on collaborations between brewers, filter manufacturers and filter powder suppliers. The approach is largely one of trial and error based on expert knowledge. Some general guidelines can be used, which take into account the nature of the beer and the process used to make it. With an all-malt grist it is likely that concentrations of protein and polyphenol haze materials will be high. In this case the fine grades of pre-coating powder are likely to be necessary. Where colloidal stability is addressed by in-line or in-tank addition of stabilising agents, this will increase the levels of particulates in the unclarified beer and it is preferable to use fine pre-coats and body feeds with high void volumes. Treatments such as the use of enzymes that reduce both beer viscosity and total particulates improve filterability and allow lower body feed rates to be used. Treatments that reduce total particulates, particularly yeast counts, such as fining or pre-centrifugation will also improve filterability and allow the use of fine grades of body feed and lower dose rates. Conversely, where the yeast strain is a non-flocculent-type green beer, counts will be correspondingly high and it is necessary to use a coarse grade of body feed with a high void volume.

Predictive models

Filterability is regulated by the permeability of the filter bed. Permeability is defined by the parameters described in **Darcy's law**. With regard to powder filters it is described as the ability

of a defined volume of cake to allow the passage of fluid of a defined viscosity when the filter is subjected to a defined pressure. In practice, in a powder filter, beer solids that are required to be removed must pass through the spaces between the solid particles of powder. This is termed the void volume, or voidage, of the bed and is the space available for trapping particles. In the case of kieselguhr, which also contains internal pores, the real void volume is greater. However, the mean size of the smallest beer particulates, which require removal, is in the region of $0.5\ \mu\text{m}$, and this is greater than the internal pore size of kieselguhr particles and consequently this portion of the void volume is not available for filtration. To allow for this, filter beds are characterised by a parameter termed the **effective bed voidage**. In the case of perlites, which do not have internal pores, there is less of a discrepancy between the real and effective bed voidage.

The bed voidage is influenced by the size of the particles of filter powder. Since these have irregular shapes it is necessary to characterise these as the mean particle diameter. For filter powders these values are between 9 and $20\ \mu\text{m}$. The filter powder particle size influences the volume in the filter bed that it occupies. This is defined as the specific bed volume, the volume of bed occupied by a given mass of powder. When powders are wetted and subjected to pressure, a degree of compaction occurs, and to account for this, the term apparent wet density or cake density is used. This is the inverse of specific bed volume.

In order for a particle to be trapped within the matrix of filter powder, the mean particle diameter and the effective bed voidage are influential. This is quantified as a parameter termed the mean hydraulic radius (m) of the bed,

$$m = \frac{0.1504 \times d \times \varepsilon}{(1 - \varepsilon)},$$

where d is the mean particle radius and ε is the effective bed voidage.

Low values of mean hydraulic radius will give a brighter product but at the expense of low effective bed voidage and permeability.

These parameters, with others, are used to describe the behaviour of powder filters. The resultant equations can be used to calculate the most appropriate permeability of the filter bed and the optimum body feed rate, which will provide the maximum run length. In practice the behaviour of a powder filter is dynamic and complex, and to make best use of these equations, it is necessary to use an automatic powder dosing system where the addition rate is modulated in response to a computer programme, which is provided with the relevant inputs and the ability to respond accordingly.

The equations that are relevant to the modelling of powder filters may be found in the European Brewery Convention, *Manual of Good Practice, Beer Filtration, Stabilization and Filtration* (1999, Getränke-Fachverlag Hans Carl, Nürnberg, Germany).

Laboratory assessment of beer filterability

Pieces of laboratory equipment are available that attempt to model the behaviour of commercial powder filters. The results obtained are approximate and will not provide a true representation of behaviour at full scale. Nevertheless they are useful in that they are simple rapid tests and the results may be viewed as screening exercises that identify likely powder regimes, which may then be tested at full scale.

Filterability tests are commonly performed using a **bomb filter**. This comprises a stainless steel cylinder that is fitted with a jacket through which coolant can be circulated and an outlet and tap at the base. The base of the cylinder contains a slotted septum in which a coarse filter paper disc is placed. The top of the cylinder comprises a gas-tight lid, which is fitted with an inlet pipe, a valve and a pressure regulator. The inlet is connected to a cylinder of CO₂, which is used to provide the motive force for driving the filtration process. Pre-coats are applied to the filter paper disc by suspending the appropriate powder in water and pouring the mixture into the cylinder. Opening the bottom valve and applying pressure allow the water to escape and leave the pre-coat in place at the bottom of the cylinder. After the establishment of the pre-coats the filtration proper is carried out by adding to the cylinder a known volume of attenuated unclarified beer mixed with a defined quantity of body feed powder.

Once the desired pressure has been established, the bottom valve is opened and the clarified beer is collected in a measuring cylinder. Plots of the logarithm of the volume and the logarithm of time should be linear. The slope of the graph indicates the change in beer filterability with respect to time. The intercept on the y -axis (log volume) is indicative of the ease of filterability.

Filter aid

Filter aid is the generic term used for process aids designed to improve the efficiency of filters. Typical examples are filter powders such as kieselguhr and perlite, which are used as body feed materials with powder filters.

See **filtration**.

Filter cellar

The term given to the area in a brewery where the primary function is to filter beer. The term **filter room** is also used. As the name implies beer filtration is performed at low temperatures in order to prevent **chill haze** material from redissolving and in traditional breweries it was performed in the cool cellars in which beer was matured. In modern operations attenuation is much more important since filtration may be performed at sub-zero temperatures. This is achieved by supplying a suitable coolant directly to the filters and associated plant (see **filtration** for full details).

The typical modern filter cellar is usually complex. Apart from buffer tanks, trim chillers, pumps and CIP facilities, it will also contain the filter or filters, ancillary plant such as filter powder make-up and dosing (where used) and make-up plant for in-filter beer stabilisation and possibly regeneration.

In addition to filtration, other associated tasks, as a matter of convenience, may also be performed in the same location. These are the types of task to which finished beer might be subjected to prior to delivery to packaging. Examples would include de-alcoholisation, dilution of high-gravity beer, adjustments to colour, flavour and carbonation and addition of speciality hop products.

Filter powder

Generic name given to powders such as kieselguhr and perlite, which are used as aids for improving the efficiency of beer powder filters.

See **filtration**.

Filter room

See **filter cellar**.

Filtration

The vast majority of beers are delivered to the consumer with an appearance of brilliant clarity. As would be expected with such a diverse range of beverages there are many exceptions to this, but for most beers, a lack of clarity is perceived as a negative quality attribute. In order to achieve the desired degree of clarity, most beers are subjected to a filtration process prior to packaging. In this regard filtration marks the final stage of the brewing process. After filtration, beer is essentially in its finished form and is referred to as **bright beer**.

The filtration step is required to remove all suspended particulate material. These include yeast cells, precipitated protein and polyphenols and any other solids. The majority of particles in beer are of the order of 5–8 µm in size. The conventional filtration process removes particles down to about 0.5 µm. This is not sufficient to ensure sterility, although this can be achieved by the use of **cold sterile filtration** (see entry for more details). Of course there are several opportunities to remove solids at various stages in the brewing process, for example, as hot break at the whirlpool stage in the brewhouse, as cold break during wort cooling and in the conditioning stages post-fermentation. Since filtration capacity in the brewery may be a rate-limiting step, it is sensible to maximise these earlier opportunities and reduce, as much as possible, the solids loadings of beers presented to the filter.

Satisfactory beer clarity can be achieved with a single filter. More commonly a series of individual filters are used. In the first stage the bulk of the solid materials are removed. This is termed primary filtration. This type of filter, commonly a powder type, may be followed by one in which the beer is subjected to a stabilisation step (see later in this entry); alternatively, or perhaps in addition, **polishing filters** are used. These, which are typically membrane-type surface filters, are designed to remove very small particles and produce beer with a brilliant clarity. They are used in this way since they are very effective at removing small particles but are not tolerant of high solids loadings. Similar membrane filters can be used as a cold sterilisation step. **Trap filters**, which are also usually membrane types, are fitted at the end of the sequence of individual filter elements and are designed as a final security stage in which any extraneous matter that has inadvertently entered the process stream, such as filter powder, is removed.

Ideally the filtration step has no effect on beer other than to remove solids. In practice this may not be the case and depending on the method used, some undesirable changes may occur. These include loss of colour, reductions in bitterness and other flavour changes. Where additions to adjust flavour and colour are made pre-filtration, it may be necessary to adjust addition rates to allow for losses during filtration. This is inherently wasteful, and it may be considered more sensible to make these additions post-filtration. This is often done; however, care must be taken to ensure that beer clarity is not compromised. Since bright beer is usually not sterile and is therefore susceptible to microbial spoilage, it is usual to filter beer immediately before packaging with a minimum of storage time.

Several types of filtration process and equipment are used. The majority of these are closed systems where the beer is forced through a filter and retention of suspended solids is controlled largely by the pore size. This is termed the cut-off of the filter. In such systems the flow rate is controlled by the nature of the beer, the concentration and size of suspended particles

and the applied pressure. Mathematically the filtration process is described by **Darcy's law** (see entry of that name for details). The important variables in this relationship are the pore size of the filter medium (permeability), the depth of the filter, the total solids loadings and viscosity of the beer and the applied pressure. Assuming the provision of a filter medium with a satisfactory pore size, it may be readily appreciated that in order to have long filter runs and provide beer of an acceptable clarity, it is essential to minimise the total solids loadings in the beer and to avoid factors such as high β -glucan content, which will increase beer viscosity and make filtration more difficult.

Several types of closed filter are in common use. Membrane filters, usually made from artificial polymers such as polyethersulphone, polytetrafluoroethylene (PTFE) or nylon, rely purely on pore size for their operation. Filtration is a surface effect only, and for this reason they are not tolerant of high solids loadings and will blind easily. Nevertheless, they have the advantage that they can be made with very accurate control of the pore size. This property, termed absolute filtration, allows them to be used for duties such as **cold sterile filtration** where the pore size is sufficiently small to ensure total removal of yeast and bacteria (typically 0.22–0.45 μm).

Membranes can also be used in **plate and frame filters** of the types used in duties such as recovering beer from cropped yeast slurries.

For the main filtration applied to bulk beer, membrane filters are of limited use since they are blinded very rapidly. This problem is overcome by the use of **filter aids**. These take the form of powders such as **kieselguhr**, which are dosed into beer as it is pumped onto the filter. This type of filter aid is termed **body feed** and the filters are known as **powder filters**. The powder cannot pass through the filter and instead it accumulates on the surface of the filter. This has the effect of preventing blinding of the filter and provides a continuously regenerated filter surface. The suspended solids are trapped in the matrix of powder by a combination of surface filtration and depth filtration (the effect of the tortuous path provided by the filter aid). Electrostatic binding may also play a part. The continual renewal of the filter bed reduces the trans-membrane pressure needed to drive the process. Filtration runs are limited by the capacity of the chambers in the filter to hold the filter aid or by the achievement of the maximum trans-membrane pressure for the particular filter. Preferably these two conditions should be achieved simultaneously.

Several designs of powder filter are used in brewing including **plate and frame filters**, **candle filters** and **horizontal leaf filters**. All share common features in that they have a primary septum that forms the support on which the used filter powder and other solids accumulate. Since this septum has a relatively large pore size, it is first coated with an initial layer (or layers) of filter powder. This is termed the **pre-coat** or pre-coats.

Filter powders are available in different grades each, which have slightly differing filtration properties. Usually the body feed and pre-coat powders are of different grades and are chosen as being most suitable for the particular beer and type of filter being used. The permeability of the bed and hence the pressure that must be applied to drive the process is governed by Darcy's law variables, as described earlier. In order to quantify the filtration properties of different grades of filter powder, units such as the Darcy are used (see **Darcy's law**).

Closed filtration systems such as powder filters suffer from the disadvantage that they will inevitably be blinded by the build up of powder and removed solids. In other words the

pressure needed to drive beer through the filter bed becomes greater than the maximum pressure that the filter is designed to withstand. Alternative systems such as cross-flow systems are becoming increasingly popular for primary beer filtration, especially since these avoid the use of filter powders and the consequent costs of safe handling and disposal. These are membrane-based filters in which the feed is pumped tangentially and continuously across the surface of the membrane. Application of high pressure forces the liquid through the membrane. The continuous movement of the feed across the surface of the membrane reduces the tendency for blinding (see **cross-flow filtration** for more details).

Assessing the filterability of beer can be addressed in several ways. These include simple empirical observation, the use of predictive models and assessments using laboratory-scale apparatus and procedures (see **filterability of beer** for more details).

Filtration can be combined with stabilisation (see **colloidal stability** for details). Filter aids such as **silica gels** or **polyvinylpyrrolidone (PVPP)** can be dosed into beer in-line as it passes from the storage tank onto the filter. Provided that the contact times and temperatures are managed appropriately, the precipitated solids are removed in the filter. Commonly different filters are used in series. One such approach is to pass beer through a primary powder filter, after which PVPP is dosed in-line as the beer passes into a second dedicated filter in which the PVPP and bound polyphenols are removed. This arrangement has the advantage that only those beers such as export types, which require the additional stabilisation, may be passed through the second filter. Those beers that do not require such long shelf lives such as domestic keg types bypass the second PVPP filter. Other possibilities include incorporation of PVPP into pre-coats or impregnation into filter sheets.

Whichever type of filtration system is used, they all share some common requirements. It is essential that the quality of the beer is not compromised, and thus, hygiene and cleanliness are of paramount importance in order to ensure that taints are not imparted to the product. It is vital to avoid oxygen pick-up and in this regard some filter types are better than others. Beer at the filtration stage contains suspended polyphenol and protein complexes in the form of chill haze. In order to prevent this from redissolving and possibly reappearing after packaging, the beer must not be allowed to warm up during filtration. Filtration is an energy-intensive and therefore expensive process. In order to minimise costs, it is preferable to have long runs that minimise down times for emptying and cleaning. Careful planning of the order of filtration of different beer qualities can be helpful in this regard. When emptying and cleaning is required, modern designs usually feature automatic systems that minimise manning levels (see **filter cellar** for more details).

Final gravity

See **attenuation gravity**.

Fine ale tank

A synonym for **bright beer tank**.

Fine/Coarse extract difference

A test used to assess malt modification. Samples are subjected to both fine and coarse grinds and mashed under defined conditions. In poorly modified malts the relatively abundant intact

barley grain cells survive the coarse grind, and during mashing these are inaccessible to the starch-hydrolysing enzymes and extract yields are low. In the case of the fine grind more of the un-degraded cells are broken down and subsequent extract yields are higher. Therefore, the greater the difference between extract yield under both conditions, the poorer the degree of modification. This is termed the **fine/coarse extract difference**.

In the case of fine grind extracts a gap of 0.2 mm is set using a Buhler-Miag disc mill. For coarse grind extracts a gap of 1.0 mm is used.

Extract yields are expressed as l°/kg in the case of the Institute of Brewing (IOB) procedure or as a % of total malt dry weight in the case of the European Brewing Convention (EBC) method.

Fining agent

Any process aid used to encourage the sedimentation of solids and thereby promoting clarification. Fining agents, also known as finings, make use of Stokes' law by binding relatively small and hence, slow to sediment particles, to larger molecules, the fining agent, to form larger and more rapidly sedimenting agglomerates. Binding is via electrostatic interactions, and both positively and negatively charged fining agents are available for the removal of unwanted solids, which carry the appropriate opposite charge. The former are used to remove predominantly positively charged proteins. The latter, a notable example being **isinglass**, are used to remove negatively charged yeast cells. The process may be referred to as fining. Additional descriptors may be used to indicate at which stage in the process the fining agent is used, for example, **kettle finings/copper finings**.

Firkin

The name of a beer container or a measure of capacity of beer equal to 9 imperial gallons or 40.96 L. The word may derive from Middle Dutch *Vierdekijn*, meaning 'four' or 'quarter' referring to the fact that a firkin is equal to a quarter of a barrel. For more details of words related to measures of beer volume, see **barrel**.

First Choice

A New Zealand-bred disease-resistant hop variety released in 1960.

See **Cali**.

First Gold

First Gold is a UK-bred dwarf hop variety. It is derived from Whitbread Golding and a dwarf male. It is a dual-purpose variety (6–10% α -acids, 3–4% β -acids, 33% cohumulone, 0.7–1.3% total oil). It is reasonably resistant to *Verticillium* wilt and powdery mildew but susceptible to downy mildew. In many beers it has been found to confer orange/citrus notes.

First runnings

First runnings, also known as **first worts**, refer to the liquid that is formed during the initial period of separation of sweet wort from the spent grains. It is more concentrated than the subsequent runnings since the latter is diluted with the sparging liquor. In some, now generally archaic systems of brewing, the first worts were collected separately and used to brew a

stronger beer; conversely, the weaker last runnings were used to brew a weaker and by inference poorer quality **small beer**.

See **mash tun**, **parti-gyling**, **small beer**.

First worts

See **first runnings**.

FISH (Fluorescence *in situ* hybridisation)

A genetic analytical technique for the rapid identification of bacteria based on hybridisation with probes specific for ribosomal RNA.

See **yeast differentiation**.

Fitzroy

An Australian malting variety of barley accredited for use in brewing in 2005. It is described as mid- to late maturing, semi-dwarf in character, high yielding and with moderate disease resistance. It is used in domestic Australian brewing.

Flagon

A winter variety of malting barley, which appears on the fully approved for brewing list of the UK-based Institute of Brewing and Distilling.

Flagship

An Australian variety of malting barley accredited for use in 2008 and developed by the University of Adelaide and other partners using European and Canadian parental types. It is described as being early to late maturing and high yielding with good disease resistance. It is primarily aimed at the Asian brewing market.

Flaked cereal grains

Flaked cereal grains are solid adjuncts used as sources of extract in addition to conventional malted barley (see **adjuncts** for more details).

They are prepared from grains of cereals such as barley, wheat, oats, maize and rice. They are produced by cooking the grains at a temperature of 90–100°C after which they are flaked by passage through heated rollers and then dried using a stream of hot air. Flaked cereal grains are good sources of extract that have the benefit of possessing starch grains that are pregelatinised owing to the heating step employed in their manufacture. They are not without problems in that they may contain high concentrations of β -glucans, which can result in very viscous worts and consequent slow run-offs. In this regard barley grains are the most problematic whereas flaked maize grains can generally be used with little problem.

Flash pasteurisation

An in-line heat treatment designed to kill micro-organisms (see **pasteurisation**). The process can be used in any situation where bulk liquids are required to be made microbiologically stable. These might be sugar syrups, recovered beer streams and other process liquids, but the most usual application is to bulk beer prior to packaging into keg.

Flash pasteurisers typically comprise four-stage plate and frame heat exchangers. In the first stage, the regeneration stage, inflowing cold beer is preheated using the hot treated beer as the source of heat. In the second heating stage, the temperature of the beer is raised to the desired operating value (usually 71–78°C) by counter-current contact with hot water. The latter is generated by steam injection into a water supply tank. After passage through the heating stage where the beer receives the bulk of the pasteurisation treatment, it is cooled in the fourth stage, by counter-current contact with cooled glycol. The total treatment time is usually around 15–30 seconds. Units are designed to handle the liquid flow rates required to keep the process supplied with product and are usually of the order of 200–400 hL/h.

In order to guarantee that all beer is treated to specification, very careful consideration of design and operation is needed. Flow rates must be sufficiently high to ensure turbulent flow, that is, Reynolds numbers $> ca. 3000$:

$$\text{Reynolds number} = \frac{d \cdot v \cdot \rho}{\mu},$$

where d is the density of the liquid, v is the velocity of flow, td is the tube diameter and V is the viscosity.

In order to ensure no loss of carbonation the system must be pressurised to prevent gas breakout. Beer is pumped into the pasteuriser against a back pressure of 1 bar and at an operating pressure of the order of 8–10 bars. The pressure in the cooling circuit must be less than that in the beer stream in order to prevent leakage of glycol into the beer stream in the event of seal failure. For these reasons flow rates are fixed and the heat treatment is varied by adjusting the temperature of the heating stage. Balancing of flow rates with other parts of the process are achieved by the provision of buffer tank before and after the pasteuriser. Flow rates and temperatures are monitored continuously and in the event of failure, forward flow is stopped and a recirculation loop is established where the treated beer is passed back into the supply tank. This ensures that no un- or partially treated beer can move forward to the keg filler.

Flavanoids

Flavanoids are polyphenols. They are oligomers of the more simple flavanols and are of importance to beer quality in that they are precursors of hazes.

Examples of relevance to beer colloidal stability include procyanidin B₁, derived from sorghum (a dimer of epicatechin and catechin), and from barley procyanidin B₃ (a dimer of two molecules of catechin) and prodelfinidin B₃ (a dimer of gallic catechin and catechin).

See **colloidal stability** and **polyphenols**.

Flavanols

Flavanols, more properly flavan-3-ols, are a class of monomeric polyphenols that contain the skeleton 2-phenyl-3,4-hydroxy-2H-chromene-3-ol. In beers the most significant flavanols are **catechin**, **epicatechin**, **gallic catechin** and **epigallocatechin**. These compounds, derived mainly from malts, are the precursors of larger polyphenolic polymers of the types, which take part in reactions leading to the formation of beer hazes.

See **polyphenols**.

Flavonoids

Flavonoids are polyphenols that occur in both barley and hops. Chemically they are based on the flavone backbone (2-phenyl-1,4-benzopyrone).

Several subgroups are recognised, which include **anthocyanins**, **flavonols**, **flavanols** and **chalcones**. As a group they are of importance to the brewing process and beer quality in that they are the precursors of beer colloidal hazes, sources of antioxidants and contributors to beer flavour and colour.

See **polyphenols**.

F

Flavonols

Flavonols are polyphenols of the type termed **flavonoids**. Chemically they contain the backbone 3-hydroxyflavone (3-hydroxy-2-phenylchromene-4-one).

Flavonols are found in beer and are mainly derived from hops where they occur as glycosides. Two of the most abundant are **quercetin** and **kaempferol**.

See **polyphenols**.

Flemish brown beer

Most areas of Belgium produce beers that have a dark brown colour; however, the town of Oudenaarde in the municipality of East Flanders is particularly noted for this beer style. The local water supply is similar to that of Munich and suited to the production of this type of beer. The beers are ales made by top fermentation. Many examples are subject to lengthy periods of maturation in bulk and in bottle for periods of up to a year; others are sold in draught form. The latter are comparatively sweet and have relatively modest alcohol contents (3–5% abv) and as with UK mild ales are consumed as is or as a 50:50 mixture with a paler pils-type beer (*half on half*). The bottled types have a drier taste as a consequence of the long period of maturation and may have alcohol contents of up to 9% abv. The secondary fermentation used for the maturation of these traditional brown beers involves both yeast and bacteria and in consequence some sour notes are imparted. These, in conjunction with the elevated concentrations of higher alcohols, give the beers a ‘sweet and sour’ character. These traditional Belgian brown beers are called *Oud bruin* (old brown).

Flemish red beer

Flemish red beer or ale is a beer style that is made from toasted malts, which impart a reddish colour to the beer. The beer is produced via top fermentation and uses a mixed culture of ale yeast strains and lactic acid bacteria. Commonly the beers are subjected to lengthy fermentations, measured in months to a few years in wooden casks. As in the case of **gueuze** beers, blending of young and older batches is carried out to give the desired flavour. The combination of speciality malt and mixed strain fermentation gives beers that have a distinct estery character and an acidic taste and aroma.

See **gueuze** and **lambic beer**.

Flocculins

Yeast cell wall lectin-like proteins involved in interactions that result in **yeast flocculation**.

Flooded font

Beer taps designed for installation in a bar in which the font is fitted with an internal chamber surrounding the beer lines through which a coolant such as chilled water or glycol can be circulated. They are aimed at satisfying the current trend for dispense of beers at very low temperatures.

Flooded mash

A flooded mash is one in which, as the name suggests, the bed of grains in a mash tun becomes overlaid in part or in total with a layer of liquor. It is a reflection of poor practice and indicates that either run-off is impeded owing to the mash becoming set or that the rate of sparging is not being controlled in a proper manner.

See **set mash**.

Floor malting

Floor malting represents one of the oldest technologies for the performance of the malting process. Archaeological studies have recognised floor malting dating back to the third century AD. The process remained in common use until the middle of the twentieth century by which time the majority of floor maltings were superseded by more modern processes. Initially many of the manual processes associated with traditional floor maltings were replaced with mechanical alternatives. Latterly entirely automatic maltings have replaced traditional floor malting, although a few remain in operation.

This type of malting housed storage areas for barley and malt and kilns; however, the name derives from the large enclosed areas, the eponymous floors, given over to beds of grains. In a traditional floor malting the process was initiated by placing the barley grains into a cistern into which water was introduced. After a period of up to 72 hours, the wetted grains were spread onto the floor to form a bed. The beds were moved manually using a variety of shovels and rakes, hence the term malt shovel. Initially the grains were arranged in heaps, termed couches, around 0.5–1 m in depth. The depth was regulated in order to allow an increase in temperature and so promote water uptake and germination. In very cold conditions additional insulation was supplied in the form of sacking or other suitable materials placed over the couch.

When the grains had chitted the couches were broken down and spread manually over the floor to form a bed of grain in which the shoots could develop. The rate of development was controlled by regulating the temperature by changing the depth of the bed. This process was gauged purely by empirical means based on manual judgement of temperature and the appearance of the grains. This required the beds to be turned several times each day for a period of up to 3 weeks. As well as ensuring consistent temperatures throughout the bed, the turning process also prevented excessive matting. When the process was judged completely, the grains were transferred to the kiln for finishing.

Architecturally several floors, each with a relatively low headroom of about 2 m, might be stacked vertically sometimes as many as six being present although one or two being most common. Walls of each room were covered in whitewash, and care was usually taken to ensure that the floors were cleanable, smooth and free from cracks or fissures. Rows of supporting cast iron pillars separated the floors into a series of bays. Windows were provided which

supplied ventilation and thereby crude attemperation of the beds of germinating grains. The design of the windows was often quite sophisticated such that various shutters and arrangements of slides might be used to control the extent of ventilation. Even so the difficulties of controlling temperature in very traditional floor malting restricted their use to the cooler months of the year. In later years innovations included the use of mechanical devices for turning the beds, the introduction of air conditioning and thermometers and automatic means of moving grains between the various stages of processing.

Flouriness

A measure of malt grain quality based on the appearance of the endosperm. It is a synonym for **mealiness**.

Flow cytometry

A technique that allows the automatic enumeration, analysis and separation of populations and sub-populations of microbial cells. It has been applied in brewing to the examination of yeast and other microbial cells relevant to brewing. Cell samples are introduced into a stream of fluid such that individuals are forced through a small orifice in a single file. The stream of cells passes an optical source, usually a laser, and the scattered light is directed towards multiple lenses, usually forward and at right angles to the laser beam. In conjunction with suitable fluorescent dyes and optical detectors sensitive to appropriate wavelengths, the physical and physiological status of individual cells can be investigated. Possible outputs include total count, viability, relative cell size and many other physical and biochemical attributes. The instruments have the added advantage of being capable of sorting and recovering specific fractions based on the response of individual cells to the detection systems.

Flow cytometry is expensive and requires the use of trained personnel and is still mainly the reserve of the research laboratory. Nevertheless, costs are falling, and the development of equipment suitable for in-line use offers a very powerful approach for the investigation of yeast populations such that a reliable method of both measuring viable cell concentrations with simultaneous assessment of yeast vitality is feasible. Similar instruments, together with immunofluorescent dyes, may have utility for the automatic detection of selected beer spoilage micro-organisms.

See **yeast viability**, **yeast vitality**.

Flow meter

Flow meters are designed to measure the velocity of fluid flow. They are used in brewing to measure the flow rates of liquids and gases to monitor and control an aspect of the process that requires knowledge of the quantity or rate of transfer of a fluid.

Several types of flow meter can be used, each of which relies on a different scientific principle for converting the velocity of fluid flow into a proportional electrical signal. Each type of flow meter has its strengths and weaknesses and suitability for a particular set of applications.

Magnetic flow meters, also known as Magflow or Magmeter, rely for their operation on electromagnetic induction as described in Faraday's law (the magnitude of a voltage generated in a closed circuit is directly proportional to the magnitude of a magnetic flux that intersects

the circuit at the right angles). A magnetic field is applied to a tube through which the fluid passes. This creates a potential difference, the magnitude of which is related to the velocity of fluid flow through the tube. This type of meter is probably the most widely used for brewing applications such as measuring the rate of flow of process liquids such as wort or liquid yeast slurries. Magflow meters have the advantage of being totally non-invasive; they are accurate and are tolerant of high solids loadings. They require the fluid to be conducting and for this reason are not suitable for use with deionised water. The electrical properties of the pipework need to be considered in order to avoid the generation of voltages, which can lead to errors in measurement.

Two designs of flow meter rely on the use of ultrasound. Transit time types employ two sensors and ultrasound generators mounted on the pipe wall one upstream of the other. The sensors both send and receive pulses that are directed with and against the direction of fluid flow. The time difference in the transit time is proportional to the rate of fluid flow. This type of flow meter can be used with ultrapure liquids but is not tolerant of the presence of gas bubbles or suspended solids. Wall effects where flow may be disrupted close to the surface of pipes can also cause errors of measurement.

The other design of ultrasonic flow meter relies on the Doppler effect. It uses an ultrasound transmitter strapped to the outside of the pipe and a receiver similarly mounted but downstream of the transmitter. An ultrasonic pulse transmitted into the stream of flowing fluid is reflected by bubbles or particulates present in the fluid. These reflected pulses are detected by the receiver, and these are changed in frequency in proportion to the velocity of the fluid flow. This is also a totally non-intrusive method of measuring fluid flow that works with a high degree of accuracy. However, it requires the presence of some particulates in order to generate the reflected signal and it cannot be used with ultrapure fluids.

Vortex flow meters rely on the principle that when a flat obstructing body is placed in a fluid stream so that the flow is partially restricted, vortices are generated. Associated with these vortices are areas of fluctuating pressure. These pressure variations behave in a predictable manner and can be related to the rate of fluid flow. Vortex flow meters comprise a cell that contains restricting plates through which the fluid flow in the pipework is passed. A pressure sensor is located behind the plate, and output from this is related to flow rate. These devices are used widely in many industries. They can be used for liquids, gases and steam. They require a minimum flow rate for proper function and must be located in a minimum length of straight pipe in order to generate stable vortices.

Differential pressure flow meters rely on Bernoulli's principle, which relates changes in pressure and velocity when a fluid flows through a pipe that contains a restriction, for example, a venturi tube in which the flow meter comprises of a section of tube that smoothly narrows to form a constricted portion which then flares out to the same diameter as the original entry point. Pressure sensors are located within the constricted portion and on the wider inlet. Then the difference in reading between these is used to calculate the velocity of flow. They can be used with gases and low viscosity liquids and are relatively inexpensive. They cannot be used with abrasive liquids, and the restriction causes large changes in pressure.

Turbine flow meters employ a freely rotating vaned turbine, which is aligned with the direction of fluid flow. The fluid causes the turbine to rotate which for each revolution generates a magnetic pulse, which is detected by a processor. Fluid velocity can be inferred from the pulse

count. They can be used for both liquids and gases, and they have a simple design and are relatively low cost. They are most suitable for use with gases and clean low viscosity liquids with no entrained gases or solids. Since they have moving parts and bearings, they incur significant maintenance costs.

Thermal mass flow meters pass the fluid through a heated tube. The fluid picks up heat from the tube and causes a cooling effect, the magnitude of which is related to the fluid velocity. For proper calibration it is necessary to know the density and the specific heat of the fluid. Provided that this is the case, thermal mass meters are very accurate and repeatable. In brewing they are used for gas flow measurements, particularly for the addition of known masses of O₂ or CO₂, for example, for use in carbonation and wort oxygenation systems, respectively.

Coriolis flow meters are another type of mass flow meter that measures flow as units of mass with respect to time. They comprise U- or S-shaped tubes that are fitted with actuators that impart a vibration of the natural frequency of the tube. Fluid is passed through the tube that has the effect of resisting the vibration and causes the tubes to bend slightly. In order to correct for errors due to external sources of vibration, the tubes are arranged in pairs, each of which is induced to vibrate counter to its partner. The extent of the ending effect is related to the velocity of fluid flow through the tubes. The natural frequency of vibration of the tubes is affected by the nature of the tube and its contents. The shift in this parameter caused by the fluid can be used to calculate the density of the fluid. This type of meter is not suitable for use with gases; however, it provides very accurate measurements with liquids. One brewer has made use of it to optimise lauter tun operation used by the automatic measurement of flow rate and density during run-off and sparging.

Fluorescein diacetate

A biological dye (3,6-diacetoxyfluoran, di-*O*-acetylfluorescein) that is used for assessing the viability of microbial cells, including brewing yeast. The dye is taken up by cells where in those that are viable, the presence of esterases converts the colourless dye into the fluorophor, fluorescein. The latter is lipophilic and not able to pass freely through membranes such that it accumulates in viable cells. Thus, non-viable cells may retain some esterase activity but do not fluoresce since the dye is easily lost to the medium.

The rate of efflux of carboxyfluorescein diacetate by yeast cells has been measured using **flow cytometry**, and it has been demonstrated that this provided a measure of the energetic status of the cells, which correlated with specific rates of ethanol formation such that this could form the basis of a vitality test.

See **yeast viability, yeast vitality**.

Fluoride

Water supplies may contain fluoride, either as a natural component or in the case of some municipal supplies as a result of deliberate addition. In the latter case dosage rates are of the order of 0.5–1 mg/L of the fluoride ion added as sodium fluoride or fluorosilicic acid.

Fluoride is an enzyme inhibitor, its principal effects being exerted on glycolysis and in consequence concerns have been raised as to its potential for producing adverse effects in brewing, in particular on yeast and fermentation. At the concentrations encountered in

municipal water supplies, there is no evidence that it has any deleterious effects in brewing. Fluoride is removed by water purification techniques such as **reverse osmosis**.

Flute glass

A tall, thin footed glass with a short stem and popular with lambics and fruit beers.

See **glassware**.

Foam collapse time

Parameter used to assess the foaming ability of beers, which is the inverse of foam stability. Several methods have been devised that measure this parameter (see **Rudin method**, **NIBEM-CLM cling meter** and **Blom method for foam assessment**). The methods share in common the generation of foam and then monitoring the time taken for it to decay. Typically the foam is generated by sparging with CO₂, which must be free from nitrogen and air since both the latter gases influence foam collapse. Tests must be carried out at defined temperatures, and glassware must be scrupulously clean.

Fob

Literally 'foam on beer'. Unlike beer head or beer foam, the term is used in a negative sense to describe the formation of foam by inappropriate handling of beer, which can result in losses or contamination of equipment.

Fobbing

Excessive foaming of beer as a result of inappropriate handling such as over-carbonation of draught beer due to the application of too high gas top pressure or storage at too high a temperature leading to excessive breakout of carbon dioxide. The same term is applied in fermentation to describe the formation of excessive foam as a result of poor process management.

Fob detector

Devices, also known as **cellarbuoys**, that are used to minimise the risk of foam entering the beer **dispense** line when the container is empty. Essentially they are float controls, which in the absence of beer fall and block the beer inlet. On connecting a new container the fob detector is bled hygienically to drain and then filled with beer.

Folin–Ciocalteu method for protein

Name given to a spectrophotometric assay for total protein, also known as the Lowry method, that makes use of the Folin–Ciocalteu phenol reagent (a mixture of phosphotungstic and phosphomolybdic acids).

Font

A branded **counter mount** typically manufactured from stainless steel or ceramic and designed to enclose a single or dual **dispense** tap. Often internal water or glycol cooling is provided to encourage condensation or ice formation on parts of the font surface. Frequently a bespoke design for a brand or brand portfolio is used, and the unit is illuminated for good standout on the bar.

Forcing test

An enrichment technique used in microbiological analyses where sample beers are incubated under conditions that favour microbial growth and allows the early detection of contaminants.

See **rapid microbiological methods**.

Formaldehyde

Formaldehyde has been used in the past as an additive to steep liquor during the malting process. The practice has now been discontinued because of safety concerns, although provided that proper rinsing is carried out, no actual risks have been identified. It is a highly efficient antiseptic when used at concentrations of approximately 0.02%, and it kills a whole range of bacteria and fungi. Hence, it is able to reduce microbial loadings that compete with the grains for oxygen during steeping. Via its ability to kill malt-associated fungi, it reduces the formation of mycotoxins and microbially derived agents that produce gushing in finished beers. Its action as a biocide makes it able to reduce grain **water sensitivity**, and it causes the extraction into steeping water of some anthocyanogens thereby producing malts, which when used in brewing form beers that have an enhanced colloidal stability.

Formazin

See **haze standards**.

Formazin turbidity unit (FTU)

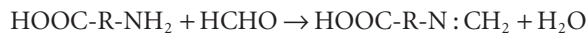
A unit used to standardise haze measurements based on formazin.

See **haze standards**.

Formol nitrogen

The formol nitrogen procedure is used for the determination of **free amino nitrogen (FAN)**. It is an early procedure originally developed by Sørensen working at the Carlsberg Research Institute [Sørensen, S.P.L. (1908) *Biochem. Z.*, 7, 45]. The method has been subject to numerous modifications, in particular the application of automatic titration devices; nevertheless it has now been largely superseded by the **ninhydrin** procedure.

Formol nitrogen determinations rely on the use of formaldehyde, which binds to compounds that have free amino groups. After treatment with formaldehyde, titration of the free carboxyl groups with NaOH allows the quantification of the concentration of compounds with free amino groups (FAN).



For comparison of the formol nitrogen method with other procedures for determining FAN, see **nitrogen** and **free amino nitrogen (FAN)**.

Fosetyl-aluminium

Fosetyl-aluminium (aluminium tris-O-ethylphosphonate) is an organophosphorus systemic fungicide, which amongst other applications has been used in the treatment of downy mildew in hops. It is sold under the trade name Aliette.

Foundation liquor

Foundation liquor (water) is a term used in relation to the operation of a lauter tun. It is hot water added to the lauter tun in the first stage of operation before the addition of the mash. Foundation liquor is allowed to flood the space between the true and false bottom of the vessel and approximately 1–2 cm above the false bottom. This both drives out air from this portion of the lauter tun and provides a cushion upon which the mash may be floated during charging.

Fount

See **font**.

Fourier's Law

Fourier's law describes heat transfer via conduction. It is of relevance to brewing where heat is required to be transferred from one medium to another, for example, the transfer of heat from steam to wort in a kettle.

The physics involved are described according to the following equation:

$$q = \frac{kA\Delta T}{X},$$

where q is the rate of heat transmission, k is the thermal conductivity of the material, A is the cross-sectional area at right angles to the heat flow, ΔT is the temperature difference between the two media and X is the thickness of material separating the two media.

See **wort kettle** for a description of the application of Fourier's law.

4-mL and 8-mL test

A test used for assessing the germinative ability of barley grains.

See **water sensitivity**.

Fourquet

A medieval term, presumably derived from Norman French, applied to a wooden implement shaped like an oar and used to mix grist and liquor in preparation for mashing.

Foxed beer

An archaic term referring to beer that has suffered some type of microbial spoilage. The origin of the word is obscure but might be an allusion to the change in appearance of yeast heads, particularly non-standard colourations, which form on the surface of top fermented beers suffering this type of affliction.

Framboise

Framboise is a type of fruit beer associated with Belgium and traditionally made using a blend of **lambic beer** and macerated raspberries. The fruit is added to ageing tanks such that both the base beer and pulp are allowed to participate in a spontaneous fermentation over a period of several months. The resultant beer and fresh lambic beer are then blended, and after bottling the beer is subjected to a lengthy secondary fermentation.

See **lambic beer**.

Frateur's medium

A microbial medium that differentiates between species of *Gluconobacter* and *Acetobacter*. Incorporation of calcium carbonate leads to the formation of a white chalk deposit around the areas of clearing surrounding the colonies of *Gluconobacter* owing to the formation of CO_2 . Colonies of *Acetobacter* produce clearing as a result of acid formation but no chalk deposit.

Free amino nitrogen (FAN)

Free amino nitrogen, as the name suggests, is descriptive of components of malts, worts or beers that contain free amino groups. These include ammonia, free amino acids, polypeptides and proteins. In practice, the free amino acids and short polypeptides are of most significance. The concentrations of these compounds are important in that they provide the major source of nitrogen-containing nutrients, which support yeast growth during fermentation.

Several methods are available for the measurement of total FAN. Currently the most widely used is that based on the reaction between compounds with free amino groups and **ninhydrin**. Earlier methods, which are still used by some, are **formol-nitrogen** and the **TNBS** (2,4,6-trinitrobenzenesulphonic acid) procedure. Each of these techniques gives slightly different results, and within each procedure, different amino acids give slightly different responses. For this reason it is not possible to make direct comparisons. Further confusion may arise depending on the expression of the results since several variations are possible. For example, in the case of malt samples, or other solid raw materials, the FAN result may be expressed simply as a function of the total dry weight. Alternatively, where the method is used to assess the degree of modification, it is usual to express the result as a percentage of the total soluble nitrogen of an extract prepared under defined conditions. In the case of analyses performed on worts or beers, the results may be expressed as is or corrected to a nominal standard gravity.

See **nitrogen**.

Freeflow dispense

The simplest system of dispense for beers and ciders that does not involve metering technology. The volume of beer delivered to the glass is controlled via manual regulation of a tap by the bar person.

Free oxygen radicals

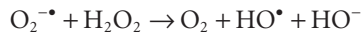
Molecular states of oxygen that have unpaired electrons and thereby are highly reactive, also known as reactive oxygen species (ROS). The formation of these radicals is associated with stress responses in yeast due to exposure to oxygen and to the oxidation reactions that underpin the formation of beer carbonyls linked to beer staling.

Molecular oxygen can react with biochemicals such as ubiquinones, catecholamines and thiols to give the superoxide radical (O_2^-). This highly reactive radical can participate in other reactions that can have potentially fatal effects in the case of yeast cells or produce deleterious staling effects in beers.

Yeast cells have an enzyme, superoxide dismutase (SOD), that converts the superoxide molecule to hydrogen peroxide (H_2O_2). A second enzyme, catalase, in effect nullifies the

potentially damaging effects of superoxide by converting hydrogen peroxide into water and oxygen. Yeast cells possess two SODs, one cytosolic and constitutive; another, which is mitochondrial and inducible and associated with derepressed oxidative growth. Similarly they have a constitutive cytosolic catalase and an inducible peroxisomal isozyme. Whether or not these are able to protect brewing yeast from the potential toxic effects of oxygen radicals under brewing conditions has not been properly investigated. In any event a degree of strain variation is likely.

In acidic media, such as beer, the superoxide radical may form even more reactive oxygen radicals. The superoxide yields the hydroperoxyl radical (HOO^\bullet), which via a spontaneous reaction forms hydrogen peroxide and oxygen. The former can then participate in reactions with superoxide to yield the hydroxyl radical (HO^\bullet) and hydroxyl ion (HO^-) (the Haber–Weiss reaction) and with beer components such as the ferrous ion to form the same products (Fenton reaction).



Haber–Weiss reaction



Fenton reaction

In beers these radicals can take part in reactions with susceptible molecules to form undesirable products, some of which are associated with beer staling.

See **beer flavour stability**.

French barley, malting and beer committee

A French organisation (*Comité Bière Malt Orge*, CMBO) devoted to the accreditation of new malting barley varieties.

French degree of water hardness (°f)

A unit used in France to quantify the hardness of water and equivalent to a mineral content of 10 mg of calcium carbonate per litre of water.

See **water hardness**.

Fret

An archaic UK term applied to hazes that arise in beer as a consequence of microbial growth. The term appears to have been commonly used to describe the haze that develops in cask beers as a result of spoilage by wild yeast infections. The *Shorter Oxford Dictionary* provides a reference from 1664 of fret being applied to liquors that have undergone a secondary fermentation.

Friabilimeter

Friabilimeters are used to assess the friability of malts. This parameter is related to the degree of **modification** of the malt.

The instrument consists of a motor-driven stainless steel drum, the outer surface of which consists of a stainless steel mesh. During operation a rubber-coated roller presses the grain sample against the mesh. Samples of 50 g of grain are tested over a fixed time period of 8 minutes. Fragments of grains that are able to pass through the mesh are collected in a bin. Malt friability (modification) is judged by measuring the relative proportions that are retained within or pass through the mesh. Further information can be obtained by assessing the extent of glassiness of grains that are retained within the drum.

Friability

An indirect measure of malt modification. Malt modification is accompanied by a breakdown of the cell walls of the barley grain endosperm and as a result the extent of modification is related to the ease with which the physical structure of the grains can be degraded by milling. The energy that requires to be expended to grind malts is a measure of friability.

See **friabilimeter**.

Frohberg yeast

A type of lager brewing yeast.

See **Saaz yeast** and **yeast genetics**.

Fuggles

Fuggles is a traditional UK aroma hop named for its discoverer, Richard Fuggle of Brenchley in Kent, containing 3–5.5% α -acids and 0.7–1.1% oil fraction. It derives from a wild seedling cultivated in 1861. It was released as a commercial cultivar in 1875 and by 1949 accounted for nearly 80% of the UK hop crop. It is resistant to downy mildew but susceptible to *Verticillium* wilt. The latter disease devastated the UK crop in the mid-twentieth century. It is now grown mainly in the Midlands area of the UK but only accounts for roughly 8% of the total hop crop. It is cultivated in the United States and in Slovenia where it is known as **Savinja Goldings** or **Styrian Goldings**.

Fuggles is the forebear of many other varieties. It was exported to the United States where it was used as a downy mildew-resistant aroma variety. Breeding programmes aimed at producing new varieties more suited to the United States gave rise to cultivars such as **Cascade**. Triploid US varieties, **Williamette** and **Columbus** are derived from a tetraploid Fuggles. **Williamette** is one of the more important US varieties.

FUN-1

FUN-1 [2-chloro-4-(2,3-dihydro-3-methyl(benzo-1,3-thiazol-2-yl)-methylidene)-1-phenyl quinolinium iodide] is a fluorescent dye that has been used for the determination of yeast viability. It is taken up by cells where it binds to nucleic acids producing a general fluorescence. Viable cells are capable of modifying the structure of the dye with the result that the wavelength of the fluorescence emission is shifted to produce a characteristic red colour.

See **yeast viability**.

Furano Ace

Furano Ace is a Japanese hop variety bred from Brewer's Gold and a Saaz variety and released in 1988. It was developed as part of a programme initiated in the late 1960s to produce new

Japanese varieties that had the aroma properties of Saaz and better agricultural properties compared with the earlier dominant **Shinshu Wase** variety. The analytical profile is 7.0–8.0% total α -acids of which 21% is cohumulone. Total β -acids are 5.0–8.0%. Total oils are 1.5% of which 7.0% is caryophyllene, 12% farnesene, 19.0% is humulene and 50.0% is myrcene.

Fusel alcohol

An alternative name for **higher alcohols, yeast and beer flavour**.

FVCT

Acronym that stands for fermentation vessel conditioning tank.

See **uni-tank**.

Gairdner

An Australian variety of malting barley accredited for use in 1998.

Galaxy

Galaxy is an Australian dual-purpose hop variety. It is a triploid seedless type derived from a female tetraploid and a male with some Perle in its ancestry. Reportedly it provides good bitterness and a citrus, passion fruit aroma.

Analysis is 13.5–14.8% total α -acids of which 35.0% is cohumulone. Total β -acids are 5.8–6.0%. Total oil content is 2.4–2.7% of which 9.0–12.0% is caryophyllene, 4.0–6.0% is farnesene, 0.1–0.2% is humulene and 33.0–42.0% is myrcene.

Galena

Galena is a US-bred high alpha hop variety (11–13% α -acids, 44% cohumulone, 0.9–1.4% total oil) derived from **Brewer's Gold**. It is susceptible to powdery mildew.

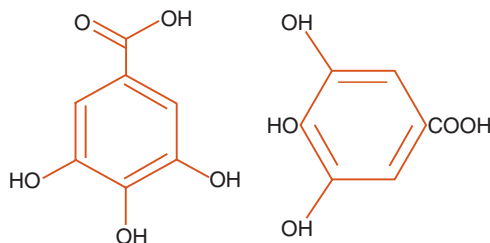
Galland–Henning drum malting

A type of drum malting devised by Nicolas Galland and Julius Henning.

See **drum malting**, **pneumatic malting**.

Gallic acid

A simple phenolic compound; one of the series of substituted benzoic acid derivatives, which are found in worts (see accompanying diagram for structure). It arises from both hops and malt. Concentrations in unboiled lager wort are reported to be of the order of 0.1 mg/L.



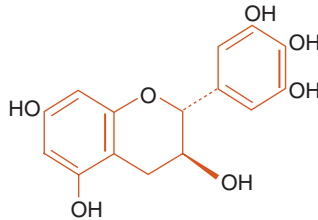
Structure of gallic acid

Glucose esters of gallic acid are found combined in very large polymeric complexes to form tannic acid (gallotannin), the process aid that can be used for removing protein as a stabilisation treatment for beer.

See also **polyphenols**, **tannic acid**.

Gallocatechin

Gallocatechin is a monomeric polyphenol of the flavanol type (see accompanying diagram for structure).



Structure of gallocatechin

It has importance in brewing since it is an important precursor of beer hazes.

See **polyphenols**, **colloidal stability**.

Gallon

The gallon is a measure of capacity that has been and continues to be applied to both liquid and solid goods. The word is derived from the Latin *galleta*, meaning a container of the approximate size of a helmet. The Latin for helmet is *galea*. The measure is relevant to brewing in that it forms the basic non-decimal unit of beer volume used in the United Kingdom and the United States. The gallon is not a standard unit, and the precise volume referenced to a metric unit depends on the nature of the goods and the geographical location. In the United Kingdom the imperial gallon is equal to 4.546L. The UK barrel of beer is made up of 36 imperial gallons. The US gallon used for liquid measure is equal to 3.7854L. For a historical explanation for the disparity between the UK imperial and US liquid gallons, see **barrel**.

To convert UK imperial gallons to US liquid gallons, multiply by 1.20095042.

Galopin

A French term for a small measure of beer, typically 200 mL in volume.

Gambrinus

One of the pantheon of the supposed patron saints of beer or brewing and associated particularly with the Flanders region of Belgium. Various sources of the name are quoted in literature devoted to this subject. Some of these claim that the name is a simple corruption of another word associated with brewing or the consumption of beer, for example, the Latin terms *cambarus* (cellarer) or *ganeae birrinus* (a drinker in a tavern). In other stories it is claimed that the name is a corruption of Gambrivius, ruler of a Germanic tribe, the Gambrivii. Reputedly he was taught the art of brewing by the Egyptian goddess Isis and thereafter introduced the art to Bavaria, an interesting mythology which in terms of the direction of flow of knowledge

may have some basis in fact. Others claim an association of Gambrinus with real historical characters, for example, John the Fearless (1371–1419) or Jan Primus (John I, Duke of Brabant, 1252–1294). The former reputedly introduced hops into the brewing process. The latter, although not directly linked with brewing, at least as a producer, seemingly relieved the brewers of Cologne of, as they saw it, excessive tax burdens levied by the bishops of that city, when he took control of the Rhineland following his victory in the battle of Worringen in 1288.

Gas rouse

To treat liquids or suspensions with a stream of gas, preferably in the form of fine bubbles, in order to mix, re-suspend solid particles, or to change the composition of dissolved gas within the liquid.

See **rouse**.

Gate valve

Gate valves are those in which a plate or disc mounted at right angles to the pipe is lowered into the path of the flow. This is by means of a manually operated screw thread via an automatic actuator. The characteristics of this type of valve are that it has little impact on the pressure due to the fluid flow when open but there is poor correlation between the degree of opening and the rate of flow. Generally a small movement of the valve results in a large increase in flow. In this respect it is not useful where it is necessary to control the degree of throttling. It is not tolerant of high solids loadings. In a brewing situation it is used most commonly for utilities such as water.

Gay-Lussac equation

The Gay-Lussac equation describes the reaction in which one molecule of glucose is converted into two molecules each of carbon dioxide and ethanol.



The reaction, in simplified form, describes the basic reaction that underpins brewery fermentation and by which, as a consequence of the growth and metabolism of yeast cells, a proportion of the sugars present in wort are transformed into ethanol and carbon dioxide.

The equation was formulated in 1810 by the French chemist Joseph Louis Gay-Lussac.

See **fermentation**.

Gay-Lussac, Joseph Louis

Gay-Lussac (1778–1850) was a French scientist, principally a chemist and physicist, noted for two gas laws that bear his name. In addition, and with relevance to brewing, he derived the law, which also bears his name, that describes the chemical basis of fermentation, namely that the dissimilation of a molecule of glucose results in the formation of two molecules each of CO₂ and ethanol.

The work was undertaken in connection with studies on the preservation and spoilage of foodstuffs. He observed that when air was admitted to grape juice, which had been heated and stored in a sealed container, fermentation ensued within a short space of time. Science at

this time did not recognise the vital nature of fermentation, and Gay-Lussac concluded that fermentation occurred in response to exposure to air. In a series of experiments, he demonstrated that in previously heated grape juice, fermentation apparently only took place when air was admitted. He had no notion that microbial contamination was the cause of the fermentation, as of course, was the relation between the lack of spoilage and heating in the initial samples. However, he made the important observation that oxygen was absorbed when fermentation commenced, CO₂ was evolved and sugar was consumed. He failed to appreciate the relationship between the sterilising effect of boiling and the lack of fermentation and perhaps understandably since he was looking for purely chemical explanations, he concluded that heat simply absorbed oxygen and therefore rendered it unavailable.

Geçmen malting system

An early mechanised malting system in which steeped grains were placed in the first of a series of vertically mounted tanks, the floors of which comprised a series of metal plates each mounted on spindles. Rotation of the spindles changed the orientation of the plates such that they presented either a solid barrier or a series of apertures through which the grains could fall from one tank to another and in so doing be turned. A stream of air provided by a fan was used to cool the germinating grains and remove CO₂. At an appropriate time the germinated grains were transferred to another similarly designed tank that functioned as a kiln by replacing the conditioned air supply with one that was heated and dry.

Gelatin

Gelatin is an amorphous protein that is derived from animal collagen. It dissolves in water to form a colloidal solution. Historically it has been used as a kettle fining agent for the removal of polyphenols. It is still used as a fining agent in wine manufacture.

See **kettle finings**.

Gelatinisation

Gelatinisation describes the process that occurs during wort production in which cereal starch grains are converted from their natural state into a form in which they become susceptible to attack by hydrolytic enzymes and as a result release fermentable sugars. The process involves a combination of heat and hydration during which starch grains swell and lose their organised structure. In the case of barley starch grains, this can be monitored by microscopic observation. Intact starch grains possess a birefringent property under polarised light indicative of an ordered structure. This takes the form of the appearance of a characteristic dark 'maltese cross' against a paler background. As gelatinisation occurs the maltese cross disappears, indicative of the disruption of the structural organisation.

During gelatinisation the crystalline regions of the starch grains become hydrated and amylose chains are released, probably due to a loss of weak hydrogen bonding. The combination of loss of structure and release of the starch chains allows access to diastatic enzymes.

Starch grains from various plant sources have slightly differing structures. These differences influence the temperature required to disrupt them. This is termed the gelatinisation temperature. In the case of plant materials such as barley, wheat, rye and oats, the gelatinisation temperature is relatively low (50–70°C). In these cases gelatinisation occurs at temperatures

at which diastatic enzymes retain activity. Therefore, these materials can be used during mashing without premodification. Other starches such as rice, maize, sorghum and millet require comparatively high temperatures for gelatinisation to occur (60–90°C). In the case of these materials it is necessary to pretreat in a cereal cooker to allow gelatinisation to occur prior to adding the heated material to the mash for enzymic hydrolysis.

Gelatinisation temperature

The temperature at which starch gelatinisation occurs.

See **gelatinisation**.

Genetic fingerprinting

General term for techniques based on the analysis of the genome as a means of determining identity. Various techniques are used and are applied to both confirming the identity and purity of brewing strains, and detecting and identifying beer spoilage organisms.

See **yeast differentiation**.

Gent semi-continuous malting system

See **semi-continuous malting**.

Geotrichum candidum

Species of mould, often referred to as machinery mould because of its tendency to grow on the surfaces of plant in factory processing areas, including brewery and packaging facilities. Its presence indicates poor environmental hygiene.

German degree of water hardness (°dH)

A unit used in Germany to quantify the hardness of water equivalent to a mineral content of 10 mg of calcium oxide per litre of water.

See **water hardness**.

German porter

A style of beer produced now rarely in Germany but introduced by some brewers to meet a perceived need for a dark UK-style beer of this type and as a competitor to the more usual German dark lager **Schwarzbier**. The Hoepfner brewery located in Karlsruhe in the Baden region now seems to be the sole producer. This version is made with dark Munich, crystal and black malts, flavoured with Tettnang hops and fermented with a top cropping **Altbier** yeast. Colour is 120 EBC and bitterness is 47 IBU, and the beer is made at a strength of 5.8% abv. An earlier version, now defunct, was made by the Dressler brewery in Bremen using *Brettanomyces* yeast for the primary fermentation.

German Purity Law

See **Reinheitsgebot**.

Germination

Germination describes the processes that occur when a seed shifts from a dormant phase and the growth and development of the embryo begins. With respect to malting it is the first stage

that is initiated by the addition to grains of water, oxygen, controlled heating and any other process additives that might be used.

During germination the grain undergoes **modification**. These are the sum of the changes that occur within grains as they are converted from grains to malt. The first sign of germination that is visible to the naked eye is chitting (see **chit**). This is the white root sheath, or coleorhizae, that appears at the end of the grain and is followed by the appearance of the rootlets (**culms**). At the same time the acrospire begins to develop, in the case of barley grains, beneath the husk. The appearance and length of the acrospire when it eventually protrudes from the husk is used as a visible measure of the progress of malting. Germination of barley grains occurs in the steeping phase of malting and is arrested via the application of heat in the kilning stage (see **barley plant** and **barley grain** for more details).

Germination is initiated by the application of water during **steeping**. Hydration typically occurs over 2–3 days and during this time the grains increase in volume. The embryo hydrates before the endosperm. Initially the embryo uses its own stores of sugars to provide carbon and energy for development. Later these are derived from starch degradation and transport from the endosperm and aleurone layer of the grain.

Germination street

Name given to a long metallic tank designed to be used in **semi-continuous malting** (see entry of the same name).

Germinative capacity

Germinative capacity is a term applied to grains. It is defined as the percentage of grains that will germinate under optimal conditions. It is distinguished from **germinative energy** in that this is a measure of the proportion of grains that will germinate under normal conditions. In this respect germinative capacity is a true measure of grain viability.

In order to measure this parameter it is necessary to provide conditions that overcome dormancy. Several approaches may be used to overcome dormancy. In the direct test recommended by the European Brewing Convention (EBC) and Institute of Brewing and Distilling, samples of the grains under examination are immersed in water containing hydrogen peroxide (0.75% w/v). The hydrogen peroxide both reduces the microbial load and provides a source of oxygen. After 3 days of incubation at a temperature of 18–21°C, the relative numbers of chitted and unchitted grains are counted. In order to ensure that conditions remain favourable for germination, the hydrogen peroxide solution is replaced after the second day of incubation. At the end of the first stage of the test, the unchitted grains are treated to ensure that oxygen and water penetrate into the grain. This is achieved by physically removing the husk and pericarp layers that overlay the embryo. The treated grains are then placed onto wet filter paper and incubated for a further period of 24 hours. After this the additional grains that show signs of germination are scored, and the value is added to those determined in the first part of the test.

This test does not provide reliable results with all varieties of barley, particularly those that exhibit profound dormancy such as *Triumph*. In consequence errors in measurement may arise. To overcome these problems, other treatments may be used with a view to promote germination. These include treatment with sulphuric acid to remove the husk, supplementation

of the hydrogen peroxide solution with gibberellic acid or physically cutting away the husk. These treatments are reportedly unreliable in that some otherwise viable grains may be killed by the treatment. Alternative procedures may be used to treat the grains in such a way that dormancy is overcome prior to assessment of viability using the method described earlier. For example, drying grains to a low moisture content (approximately 5–10%) and holding for up to 4 weeks at 40°C has been found to be efficacious.

Whichever method is used, it is imperative to test a sufficiently large number of grains in order to obtain a statistically reliable result. In the EBC method, duplicate samples of 200 corns free of foreign matter and half corns are taken using a sample divider. The corns are steeped for 48 hours at 19.5°C ($\pm 1.5^\circ\text{C}$) in 200 mL of water containing freshly prepared hydrogen peroxide (0.75% w/v). After this time, the steep water is removed and the hydrogen peroxide solution is replenished. After incubation for a further 24 hours, the steep water is removed, and the grains separated into those which have developed both acrospire and rootlets are counted. If germination is less than 95%, the ungerminated fraction is separated. After peeling back the husk, a dissecting needle is inserted into the end of each grain at the embryo end, and this is used to remove the pericarp and reveal the embryo. These grains are placed in 90-mm-diameter Petri dishes on a bed of filter paper circles moistened with 4 mL of water. After a further period of incubation of 24 hours at the same temperature as the first stage of the test, any corns showing signs of germination are counted and included in the calculation of viability.

Germinative capacity can also be measured via indirect tests. These tests rely on the ability of living embryos to reduce appropriate dyes and produce a visible colour change in half corns. The advantages of this approach are that it is rapid and will produce a positive result with dormant grains. The most commonly used dye is a 1% (w/v) solution of 2,3,5-triphenyltetrazolium chloride. The grains, preferably duplicate samples of 100 grains each, are bisected longitudinally using a suitable cutter. The grains are immersed in the tetrazolium reagent solution, and air is removed by the application of vacuum. Following incubation for 30 minutes at 40°C, the cut grains are examined. Viable grains are those in which the embryo is fully stained. The test has the added advantage that the tetrazolium salts also stain viable aleurone tissue. This provided additional and potentially useful information.

See **germinative energy** and **4-mL and 8-mL test** for additional information.

Germinative energy

Germinative energy is a measure of the ability of grains to germinate under defined conditions. It is defined as the percentage of grains that germinate under the defined conditions of the test. It is distinct from **germinative capacity** in that the latter is the proportion of grains that will germinate under optimal conditions. Thus, the difference in percentage terms between germinative capacity and energy is a measure of dormancy whereas the percentage of grains that germinate in tests designed to measure germinative capacity is a measure of true viability.

Tests of germinative capacity are performed in order to assess the quality of grains, from a brewing perspective the malting quality of grains. In this regard most of the tests that are used are of limited use since the results may bear little relation to actual behaviour in commercial maltings. Thus, malting behaviour is probably best assessed using a micro-malting approach.

Nevertheless, tests of germinative energy are relatively simple to perform and do provide some useful information regarding grain quality.

Three methods are in common usage: the Aubry test, the Schonfield test and the 4-mL and 8-mL method.

In the **Aubry test** samples of grains (500) are allowed to germinate at 20°C. Prior to commencement the grains are placed between two filter paper circles placed on a bed of wetted cotton wool.

In the **Schonfield test** germination is allowed to take place at 20°C in filter funnels in which the grains are retained by blocking the necks with stainless steel gauze. The test uses duplicate samples of 500 grains. Funnels are used since the grains are first steeped in water for 3 hours after which the water is drained off. After an air rest of 20 hours, the grain is again flooded with water and steeped for a further 2 hours after which the water is removed. The grains are then covered in damp filter paper and the funnels are fitted with a cap. After 72 hours the grains are removed and the number that has germinated is counted. Ungerminated grains are returned to the funnels and subjected to a further period of steeping of 30 minutes. After draining and covering the funnel, as before, the grains are scored for germination after a further period of incubation of 48 hours. Test results are recorded as percentage germination after 72 and 120 hours.

In the **4-mL and 8-mL test**, triplicate samples of 100 grains are placed in a Petri dish on two stacked filter paper circles wetted with either 4 mL or 8 mL of water. After incubation at 20°C, the numbers of grains that have chitted are counted after periods of 24, 48 and 72 hours. The result of the 4-mL test is taken as a measure of germinative energy whereas that obtained from the 8-mL test is taken as a measure of **water sensitivity**.

For more details, see **germinative capacity**, **water sensitivity**, and **4-mL and 8-mL test**.

Germinative index

See **germinative energy**.

Germinative percentage

See **germinative energy**.

Gibberellic acid

Gibberellic acid is a hormone that is associated with the control of plant growth. The hormone is ubiquitous in plants. It is widely used in malting to promote breaking of dormancy and so gives rapid and even germination. It is the most common additive used, where permitted, in the steeping phase of malting. The hormone occurs naturally in barley plants and so the exogenous source simply enhances the natural supply and in so doing accelerates the changes associated with the breaking of dormancy, development of the embryo and modification of grains (see **aleurone layer** for more details).

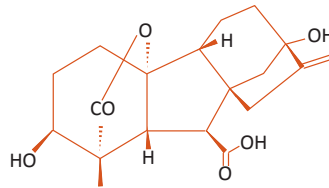
Dosage rates are in the range 0.025–0.25 g of gibberellic acid per kilogram of barley. Care must be taken not to apply too great a quantity since this can result in undesirable changes in malt quality namely greater than usual modification, higher than normal soluble nitrogen levels and an increase in the proportions of simple nitrogenous and carbohydrate components. These changes, as would be predicted, may result in altered patterns of fermentation in worts

prepared from the treated malt grains. The response of different samples of barley can be very variable. In addition, the response is dose dependent. It is particularly useful with barleys that are difficult to induce to break dormancy.

The gibberellic acid is added as an aqueous solution. It may be added directly to the steep water, sprayed into the grains as they are pumped into the steep tank or before the onset of an air rest. All these approaches have advantages and disadvantages. For example, adding to steep liquor late in the process produces an efficient response but is wasteful since not all the gibberellic acid is taken up by the grain and the excess goes to waste. The method of choice depends on the nature of the maltings and other treatments that might be applied. Thus, the gibberellic acid must enter the grain. Usually this is via the micropyle region from where it spreads within the grain and exerts its stimulatory effects. Entry is facilitated if the grains are chitted. For this reason the gibberellic acid may be sprayed with steep liquor, which is also supplemented with a solution of hydrogen peroxide. The latter is known to encourage germination.

Entry of gibberellic acid is also facilitated if the grains are subject to a physical process, for example, by passing the grains through a roller mill. This treatment splits the testa, allowing easier entry of water and any solutes that might be added to the steep water. Care must be taken with such processes since excessive mechanical damage to the husk results in the formation of grains that are very difficult to handle on an industrial scale. Comparatively mild mechanical disruption of grains can be achieved by the process of **abrasion**. This is achieved naturally in the normal course of grain handling via the use of mechanical conveyors, and so on, or by devices designed to control this phenomenon, for example, the use of rotating wire brushes.

Gibberellins are all derived from the ent-gibberellane skeleton (see diagram).



Structure of gibberellic acid

Approximately 135 different gibberellins have been isolated from various plant sources each with a slightly different structure. These are named based on the order of discovery: GA₁, GA₂ and so on. The first to be fully characterised was GA₃, gibberellic acid. Chemically they are all diterpenes and contain 20 carbon atoms. They are synthesised from acetyl-CoA via the mevalonate pathway. Gibberellic acid is produced on industrial scale via fermentation of the fungus *Gibberella fujikuroi*.

Gilbertini Nucleocounter

Proprietary fluorescence microscope and automated cell counting system (http://www.gilbertini.com/area_download/TECH-%20Nucleocounter_ingl.pdf) (last accessed 18 February 2013) that can be used for the determination of total and viable yeast counts. A small

sample is added to a disposable cassette that contains an immobilised preparation of the fluorescent dye propidium iodide. This enters dead cells and binds to DNA. After counting the dead cell fraction, the viable cells are killed by addition of a second proprietary cell lysis reagent, and the total cell count is obtained and by calculation the viability. The claimed operating range is 5×10^4 – 2×10^6 cells/mL.

Gilliland classification of yeast flocculence

A system devised by the Irish brewing scientist R.B. Gilliland in the middle years of the twentieth century for the classification of brewing yeast strains with respect to the degree of flocculation observed during fermentation (see **yeast flocculation**). Four classes were recognised and described as Class I (cells completely dispersed), Class II (formation of small loose clumps in late fermentation), Class III (dense flocs formed late in fermentation) and Class IV (floc formation in early fermentation without separation of daughter and mother cells). Gilliland was a critic of flocculation tests carried out in artificial buffers since he considered that this did not reflect real behaviour in wort. In his flocculation test, working with ale yeasts, he recovered yeast after 3 days of fermentation at 25°C, and after re-suspension and standing for 1 minute, he determined the quantity of yeast remaining in the body of the liquid.

Ginger beer

Traditional ginger beer is not strictly a beer in the true sense but is made by the fermentation of an aqueous suspension and solution of ginger and sugar. Fermentation is performed in a bottle that produces a highly carbonated product with an alcoholic content of up to 11% by volume. Traditionally the inoculum takes the form of a microbial mass termed 'ginger beer plant'. The latter is a gelatinous mass that contains a symbiotic association of several organisms including *Saccharomyces florentinus* and *Lactobacillus hilgardii*.

Giracleur

A giracleur is a device used in malting to ensure that the surface of the bed of grain remains flat and even during filling of a steep tank. In addition, it is used to sweep during discharge of the steep vessel sweeping the grain towards the exit chute. It comprises a series of arms attached to a central motor-driven rotating arm. Each arm is fitted with a number of angled knives. As the steep vessel is filled, the giracleur is rotated and the knives level out the grain bed. As the bed increases in depth, the giracleur is gradually raised so that the knives remain in contact with the bed surface. When the grains are discharged at the end of steeping, the giracleur is employed to push the grains towards the exit chute.

Glacier

Glacier is a US-bred aroma hop released in 2000. It contains 5.5% α -acids and 0.7–1.6% total oil. It has found most favour with craft brewers.

Glassiness

A measure of barley or malt quality based on the appearance of the endosperm. It is a synonym of steeliness or vitreosity.

See **mealiness**.

Glass refresher

A type of modified pressure-sensitive drip tray, typically positioned beneath the tap of a branded font, which directs a spray of cold water onto the inner surfaces of an inverted glass prior to **dispense**. It is used to attemperate warm glassware and to wet the surface to suppress fobbing of highly carbonated beers.

Glass renovation

An extreme glass washing regime used in glass washing machines to remove the residual coating from new glassware and non-rinsing films from difficult-to-clean glassware. Typically it employs chlorinated alkaline detergents, which are supplied in powder or liquid forms. The treatments are used only periodically as regular use damages the visual appearance of glassware as a result of etching corrosion.

Glassware

Glassware used for beer is an increasingly important factor for presentation in the **on-trade** or at home. The shapes and sizes of glassware that are used reflect the diversity of beer styles, the occasions for their consumption and their geographical origin.

The capacities of some common glasses used for beer are shown in the following table:

Glass volume (mL)	Description	Imperial fluid ounces
100		
189	Third of an imperial pint	
250	Quarter of a litre	
284	Half imperial pint	10
300		
330	Third of a litre	
400		
473	American pint	16.7 (16 US fluid ounces) = 0.83 imperial pints
500	Half litre	
568	Imperial pint	20
570	Australian pint	20
600		
1000	Litre	

See also **branded glassware**, **chalice glass**, **flute glass**, **pilsner glass**, **snifter glass**, **Stange**, **Stein**, **tankard**, **tulip glass** and **Weizen glass**.

Glass washing

Before filling with beer, glasses are required to be visually bright, cool and dry, free from odour, free-rinsing and disinfected. This is achieved by manual washing or use of a glass washer. Effective manual washing requires good mechanical cleaning, rinsing with fresh potable water and air-drying on a ventilated surface, rather than use of a cloth or towel. The performance of glass washing machines cannot be assumed and is subject to the quality of regular (daily, weekly and monthly) maintenance. Notably the levels of detergents and rinse aids should be monitored, as should rinse water quality and, importantly, the hygiene of internal surfaces. **Glass renovation** of new glasses and periodically 'in-use' glassware will rejuvenate quality and appearance.

Glattwasser

German brewing term, literally 'smooth water', meaning the last tailings obtained at the end of lautering.

Gliadins

Gliadins are proteins that occur in the grains of wheat. They are **prolamins** that together with albumins, globulins and glutelins form the four major classes of proteins of cereal grains that are distinguished based on their relative solubility and ease of extraction. Gliadins are poorly soluble and require treatment with hot aqueous alcohol for extraction. Gliadins are glycoproteins, and they contain relatively high proportions of proline and glutamine. As with other prolamins, multiple forms occur. These can be distinguished on the basis of relative electrophoretic mobility.

In wheat grains, gliadins, together with **glutenin**, form the **gluten** fraction that has importance in baking and in eliciting the symptoms of **coeliac disease** in those individuals who are so genetically predisposed.

In beers, gliadins contribute to the free amino nitrogen content of worts made with a proportion of wheat, or a wheat derivative, in the grist.

Globe valve

Globe valves are those in which the flow in a pipeline is regulated by a disc that can be moved downwards in a vertical direction and form a seal against a baffle, which cuts across the middle of the body of the valve and which forms an orifice through which fluid flow proceeds when open. The body of the valve is roughly spherical, hence the name. The movement of the disc can be via a manually operated screw thread using a hand wheel or via a spindle, which is operated automatically by an actuator.

The valves can be single seated, double seated or three way. As a group the valves are useful where it is necessary to throttle the flow; thus, they exhibit a defined relationship between the degree of throttling and flow characteristics. They can be used in automatic control systems. The double-seat types have two discs mounted on a common spindle. This gives good balanced flow characteristics but a reduced confidence in the ability to provide a tight seal. In this regard the single-seat types are better able to provide guaranteed leak-proof closure. In addition, three-way globe valves are available, which are designed to mix two flows into a common outlet or the reverse.

In brewing applications, globe valves are used for applications where high standards of hygiene are not essential. A typical application would be for controlling the flow of utilities such as steam.

Globulin

Globulin is the collective term for a class of proteins. Proteins may be classified in several ways (see **protein** for further details). One system is based on relative solubility. Both globulins and albumins are soluble in salt solutions. Globulins are distinguished from albumins by virtue of solubility in pure water.

The globulin fraction of cell extracts contains many proteins that function as enzymes. In this regard the globulin fraction of barley and malt grains contains enzymes that are

responsible for the formation of the soluble components of worts. Similarly the globulin fraction of the proteins of brewing yeast strains contains the enzymes that are responsible for the subsequent metabolism of these compounds during the fermentation stage of brewing. Proteins and polypeptides, which are derived from the globulin fraction of wort, are likely to be implicated in positive beer attributes such as body, mouthfeel and foaming potential. From a negative standpoint they may also contribute to haze formation via interaction with beer polyphenols, although in this regard they are probably less important than barley hordeins.

β -Glucanase

G β -Glucanases comprise the family of enzymes that are responsible for the hydrolysis of **β -glucans**. In germinating barley grains, these enzymes hydrolyse β -glucans in the wall of endosperm cells, thereby exposing starch grains for subsequent breakdown. During the malting process these changes are accompanied by the loss of grain rigidity and the acquisition of a friable character. The enzymes derived from barley and persist into malt are responsible for the degradation of shorter chain-length β -glucans during the mashing phase of brewing. A failure to degrade β -glucans during mashing is associated with undesirable increases in wort viscosity. Where mashing conditions preclude the activity of native barley β -glucanases or the grist is of a type where β -glucanases may be deficient, exogenous enzymes, usually of microbial origin, may be used.

Several enzymes acting in concert are involved in the hydrolysis of β -glucans. In conjunction with β -glucosidases, the relatively large β -glucan macromolecules may be eventually converted to glucose monomers. The initial attack on the β -glucan polymers and associated cell wall structural components appears to be catalysed by a complex of enzymes, which are collectively termed **β -glucan solubilase**. The true nature of this supposed complex of enzymes remains obscure. The action of the solubilase is to release β -glucans and pentosans from cell walls such that they are then accessible to subsequent attack by endo- β -glucanases and pentosanases. Bamforth *et al.* [Bamforth, C.W., Moore, J., McKillop, D., Williamson, G. & Kroon, P.A. (1997) Enzymes from barley which solubilise β -glucan. *Proc. 26th EBC Congress*, Maastricht, Oxford University Press, UK] isolated β -glucan solubilising activity from barley endosperm cell walls. They concluded that feruloyl esterase, a general esterase and possibly a carboxypeptidase derived from barley were probably implicated in releasing β -glucans and pentosans.

Degradation of β -glucan chains is accomplished largely by the activity of endo- β -glucanases. These attack randomly the internal bonds of the β -glucan chains. The enzymes may or may not be specific for the type of bond susceptible to attack. The most important of these in mashing is usually referred to as malt β -glucanase. More accurately it is an endo-(1,3;1,4)- β -glucan 4-glucanohydrolase. Two isozymes occur in barley malt. They have relatively acidic pH optima (*ca.* pH 4.7), and they hydrolyse β -(1-4) bonds that are located adjacent to β -(1-3) linkages. The resultant oligosaccharides are then subject to attack by β -glucosidases. Of the two isozymes of endo-(1,3;1,4)- β -glucan 4-glucanohydrolase, only one, known as EII, is sufficiently thermostable to survive kilning and retain activity in malt. Barley contains minor amounts of endo- β -glucanases that are specific for either β -(1,3) or β -(1,4) bonds. The first of these, endo- β -(1,3)-glucanase, attacks only where there are consecutive β -(1-3) bonds. Since these are comparatively rare in barley malts, the significance of this enzyme in mashing

of malt worts is not certain. Malt mashes also contain **cellulases**, β -glucanases that show activity against β -glucanoses, which contain several consecutive β -(1-4) bonds. It is possible that cellulases are derived from microbial contaminants introduced into mashes inadvertently with malts. The occurrence of exo- β -glucanases in barley has not been confirmed. Such enzymes attack β -glucan chains from the non-reducing ends and give rise to cellobiose and laminaribiose. These are disaccharides, which have not been detected in worts, that consist of two glucan residues linked by β -(1,3) and β -(1,4) bonds, respectively.

Where all-malt mashes are used, there should be sufficient native β -glucanase activity to ensure adequate degradation of β -glucans. Where malts are highly modified or extensively kilned, little or no β -glucanase may persist into the mash. The problem can be exacerbated where adjuncts such as flake or steamed barley, which contain high concentrations of β -glucans, are used. Furthermore, β -glucanases are relatively heat sensitive. Maximum activity is shown at temperatures of around 40°C. At temperatures above 55°C, β -glucanase activity is destroyed after a few minutes. For this reason temperature-programmed mashes ensure that the mash is held at a relatively cool temperature for a sufficient period of time to allow β -glucanases to act. In isothermal mashes this opportunity is diminished; nevertheless even at relatively high temperatures (60–65°C) the use of malts with a high β -glucanase activity is beneficial.

Where mashes contain insufficient native β -glucanase, it may be necessary to supplement the mash with an exogenous source. Several preparations, derived from various microbial sources, are available for use where permitted. The enzymes are either β -glucanases or cellulases. As with many commercial preparations of enzymes several activities may be present. Compared with the native barely enzymes, many of those from microbial sources are relatively thermostable. For example, the β -glucanase from *Bacillus subtilis* has a temperature optimum of approximately 50°C; however, some useful activity is retained at temperatures up to 75°C. It is an endo- β -glucanase specific for mixed β -(1,3;1,4) linkages. Typically commercial preparations also contain proteolytic and amylolytic activity. Preparations made from *Trichoderma reesiei* and *Trichoderma viride* contain cellulases, amylases and pentosanases. They are usually used in temperature-programmed mashes. Preparations of cellulases from the mould *Penicillium emersonii* are heat stable with optimal temperatures of up to 80°C. In addition to cellulases they also contain enzymes capable of hydrolysing pentosans.

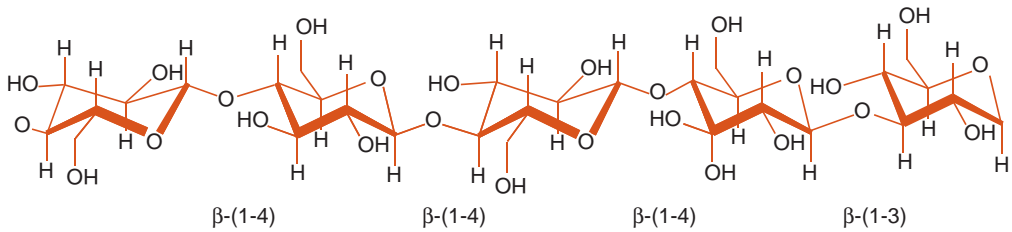
β -Glucans

β -Glucans are complex molecules that consist of linear chains of β -D-glucopyranose units. They are the major constituent of the cell walls of the endosperm cells of barley grains. They also occur in the cell walls of lower eukaryotes including brewing and other yeast species.

During malting the relatively rigid β -glucan molecules are degraded. The loss of endosperm cellular structural integrity that accompanies this degradation results in the grains becoming friable. For this reason **friability** and the presence of residual high-molecular-weight β -glucans in malt grains correlate positively and negatively, respectively, with **modification**.

In undegraded barley endosperm cell walls, the β -glucan molecules consist of linear chains containing up to 250,000 residues. Individual residues are joined by either β -(1-4) or β -(1-3) linkages. The majority of the linkages are β -(1-4) usually occurring in chains of three (cello-triosyl) or four (cellotetraosyl) units. These triplets or quartets of residues are joined by β -(1-3) linked groups. In barley occasional variations occur such as longer chains of β -(1-4) linked

residues and even chains of exclusively β -(1-3) linked residues. Individual chains are not cross-linked.



G

In barley endosperm cell walls, β -glucans account for 70–75% of the total carbohydrate, the remainder being pentosans (20–25%) and holocellulose (2–4%). The β -glucans of barley endosperm cell walls is considered to comprise a water-soluble gum fraction and an insoluble hemicellulose fraction. Degradation of β -glucans is enzyme mediated (see **β -glucanase** for further details). A complex of enzymes is involved, which result in the shortening of the β -glucan polymers to yield shorter and more soluble fragments. Further degradation yields glucose. Additional enzymes may be responsible for the simultaneous degradation of other cell wall components such as proteins and pentosans, which are intercollated with the β -glucans. If significant concentrations of the gum form of β -glucans are allowed to accumulate in worts, the result is an increase in wort viscosity. This can cause prolonged wort run-off times and can reduce overall wort yields. In extreme cases filtration efficiencies are compromised and severe beer hazes may arise. The presence of some β -glucans in beer is beneficial since it results in increased viscosity, and this slows the drainage of beer from foams and thereby enhances foam stability. However, long-chain β -glucans in beer with molecular weights in excess of 200,000 can form precipitates and consequent filtration problems.

Problems with high wort viscosity may be caused by longer-chain β -glucan gums. These may arise via the use of poorly modified malts, high proportions of adjuncts that contain appreciable long-chain β -glucans or mashing conditions that prevent or destroy the activity of the malt **β -glucanase**. In this case it may be necessary to supplement the mash with β -glucanases of microbial origin (see **β -glucanase** for more details).

Several methods are used for the determination of high-molecular-weight β -glucans. Methods may be applied to samples of barley, malts, worts or beers. In the case of barley, β -glucans are first extracted by mild acid hydrolysis. For malt samples, wort is first produced using standard laboratory grinding and mashing procedures. Methods are based on the use of enzymes or using spectrophotometric or fluorimetric analyses. The spectrophotometric procedure makes use of a commercially available kit, which contains a dye. This forms a complex with extracted high-molecular-weight β -glucans with an absorbance maximum of 550 nm. Results are compared against the response of standard solutions of β -glucans. The fluorimetric procedure is similar but relies on the reaction of β -glucans with the fluorochrome calcofluor. The latter forms a complex with β -glucans that have a molecular weight greater than 10,000. In enzymatic procedures, the β -glucans are hydrolysed using β -glucanases of

microbial origin in conjunction with glucosidases to yield glucose. Typically, in samples such as barley where potentially interfering cellulose may be present, combinations of lichenase, which is active against β -glucans but not cellulose, and β -glucosidase are used. In samples that do not contain cellulose, the lichenase may be substituted by cellulase. The concentration of β -glucan in the original sample is inferred from the measured glucose concentration. This enzymatic procedure is laborious and for this reason is not favoured.

The apparent linkage between the β -glucan concentration and wort viscosity has resulted in the suggestion that the latter parameter, which can be measured relatively easily, can be used as an indirect indicator of β -glucan content of worts. This correlation is over-simplistic since many other wort components such as dextrans, pentosans and sugars also contribute to wort viscosity. Their contributions are not additive. Furthermore, the relationship between wort viscosity and β -glucan concentration is not linear; rather it is logarithmic.

β -Glucan solubilase

An enzyme, or group of enzymes, involved in the initial degradation of β -glucans in barley grains. The enzymes involved have not been fully characterised but appear to be not responsible for the degradation of β -glucans per se. Rather they are responsible for the removal of other divesting cell wall materials, thereby rendering β -glucans accessible to attack by β -glucanases.

See **β -glucanase**.

β -Glucan standards

These are preparations of β -glucans of known concentration and guaranteed purity. They are used as standards in methods of determination of β -glucan in samples of barley, malt, worts or beers (see **β -glucans** for further details). They are supplied as freeze-dried powders usually with an added bulking agent. Prior to use they are dissolved in distilled water to give standard solutions of known concentration.

Gluconobacter

See **acetic acid bacteria**.

α -Glucosidase

α -Glucosidase (α -D-glucoside glucohydrolase; EC 3.2.1.20), also known as **maltase**, catalyses the hydrolysis of glucosidic linkages in a variety of substrates, for example, maltose, isomaltose, oligosaccharides, dextrans and starch from the non-reducing ends. The enzyme is very widespread in nature and several isoforms usually coexist. The enzyme is most active against α -(1,4) bonds but also shows activity against other bond configurations including α -(1,6).

The enzyme is found in malting barley. It has a pH optimum of approximately 4.6 and therefore has the potential to contribute to total **diastatic activity** [see **diastatic power (DP)**]. Its ability to cleave α -(1,6) bonds indicates that it may augment the activity of limit dextrinase. In addition, it has been suggested that it may be the first enzymes to attack the surface of starch grains and in so doing allow improved access to α - and β -amylases. It is suggested that this synergistic effect might be possible because of the ability of some forms of α -glucosidases to attack bonds other than α -(1,4) linkages. However, barley α -glucosidases are relatively

non-thermostable (40–45°C), suggesting that they would be active only during the early phases of temperature-programmed mashes.

Attempts have been made to obtain more thermostable preparations of α -glucosidases; either by mutation or by seeking enzymes from alternative sources has been a focus of much attention. Suitable preparations are available commercially. These are used to increase the fermentability of worts where high rates of attenuation and concomitant low fermentable residues and high ethanol yields are required.

β -Glucosidase

β -Glucosidases (β -D-glucoside glucohydrolase; EC 3.2.1.21) are enzymes that hydrolyse the terminal β -linked residues at the non-reducing termini of β -glucan molecules to yield β -D-glucose. **Cellobiase** hydrolyses β -(1-4) linkages whereas **laminaribiase** is active against β -(1-3) bonds. The enzymes form part of the **cellulase** complex, which collectively are responsible for the degradation of β -glucan polymers. The presence of these enzymes in malts is inferred by virtue of the fact that the substrate oligosaccharides do not accumulate during mashing. However, it is possible, indeed likely, that their presence in mashed malt may be due to contamination of malts with enzymes of microbial origin. The enzymes are present in microbial cellulases (β -glucanases), which are used by some brewers, where permitted, to control wort viscosity.

See **β -glucans**, **β -glucanase**.

Glume

Synonym for **husk**.

See **barley grain**.

Glutelins

Glutelins are proteins that occur in cereals. Together with globulins, albumins and prolamins, they belong to the four major classes of cereal grain proteins that are distinguished on the basis of solubility. Glutelins are the least soluble fraction and they require strong alkalis to effect their extraction and solubilisation. In barley grains they may have both storage and structural roles. In cereals such as wheat, glutenin, the equivalent glutelin, and gliadin, the wheat prolamin, constitute gluten. These compounds have importance in baking and are also responsible for eliciting the symptoms in those sensitive individuals who suffer from coeliac disease.

In barley malts the degradation ofutelins and other barley grain proteins contribute to the free amino nitrogen pool of worts and beers.

Gluten

Gluten is a protein component of wheat grains. It comprises two of the principal protein classes of wheat grains, the **prolamins**, **gliadins** and the **glutelin**, **glutenin**. In wheat grains these proteins occupy storage and structural roles. Prolamins andutelins occur in the grains of other cereals, and these are sometimes also referred to as gluten. However, the proteins from these other cereals differ in structure and for this reason true gluten is restricted to wheat (*Triticum* spp.).

Glutens are relatively insoluble, and they form the residue when wheat endosperm is treated with warm water. The principal importance of gluten is as the leavening agent in bread dough. However, in beers that use wheat in the grist, gluten proteins contribute to the nitrogenous content of worts. In addition, some gluten residues, albeit considerably chemically modified, will persist in the resultant beers.

Glutens have medical significance in that they elicit the symptoms that together constitute the condition known as **coeliac disease** in individuals who are genetically predisposed. Coeliac disease is incurable, and afflicted individuals ameliorate the symptoms by adopting a lifelong gluten-free diet. Although wheat glutens are the most effective causative agents, other cereal glutens, for example, barley hordeins and glutelins, may also contribute. For this reason coeliacs are encouraged to avoid beers. The necessity for this absolute abstention is not proven. It is generally held that the symptoms of coeliac disease are only elicited by intact gluten proteins. Since these do not persist into beers, it is possible, if not likely, that the majority of beers, excluding those made with a significant proportion of wheat, would be considered gluten-free. Nevertheless, fragments of prolamin and glutelin proteins, albeit very short peptides, will persist in beer. The possibility that these may elicit undesirable effects in susceptible individuals cannot be ruled out.

See **gluten-free beers**.

Gluten-free beers

Gluten-free beers are those products that are certified to contain glutens at a concentration that is either zero or sufficiently low that they will not elicit a pathological response in individuals susceptible to **coeliac disease**. Whether or not this definition can be applied to all beers made from materials that do not include wheat proteins is a matter of debate. Furthermore, there is no certainty that such beers can be consumed safely by coeliacs.

The coeliac disease response is caused by glutens. Wheat glutens are the most potent but similar materials for other cereal sources such as barley also elicit symptoms in susceptible individuals. However, in beers the causative proteins, cereal prolamins and glutelins, have undergone considerable chain shortening and modification compared with the native proteins. This provides a dilemma in that the comparatively small residual peptides that are found in beers may not be detected by gluten assays. Equally it is unknown whether or not these shorter peptides are effective as promoters of the symptoms of coeliac disease. However, the possibility cannot be ruled out.

There is no universal standard that defines gluten-free beers. In some countries a zero detectable concentration is required. In others a maximum limit is set, for example, 20 ppm in the United Kingdom. Provided that the beer meets the specifications of the country in which it is sold, it may be labelled as being gluten-free. Such beers are made with low gluten barley malts and other sources of extract that are known to be safe for coeliacs, for example, oats, buckwheat and sorghum.

Further work is required to clarify the coeliac status of beers. It is highly likely that those that are certified gluten-free can be safely consumed in moderation. However, there appears to be little information regarding the effects of long term exposure. In this respect those consumers who insist on consuming beer should select those that are certified as being gluten-free and should avoid all others, especially those made with a high proportion of wheat.

Glutenin

Glutenin is a protein found in wheat grains. It is a **glutelin**, one of the four major classes of proteins of cereal grains, distinguished by virtue of their solubility and ease of extraction. Glutelins are the least soluble fraction requiring treatment with strong alkali to effect their extraction and solubilisation. In wheat grains glutelins probably have both structural and storage roles.

When used in brewing wheat glutenins contribute to the free alpha amino pools found in worts and beers.

Wheat glutenin and gliadin constitute gluten, the components of wheat flours that have utility in baking. Individual polypeptide chains within the glutenin fraction form sulphide bridges during the kneading of doughs and in consequence are responsible for firmness.

Wheat glutes elicit the symptoms of **coeliac disease** in those individuals so genetically predisposed.

Glycerol

Compound ($\text{CH}_2\text{OH}\cdot\text{CHOH}\cdot\text{CH}_2\text{OH}$) that arises in beers as a result of yeast metabolism during fermentation. It contributes to beer sweetness and fullness and is usually present at concentrations in the range of 1–2 g/L. Higher concentrations arise from very concentrated worts.

Glycerol is a **compatible solute**, and its formation in beer can be partially explained in terms of a reaction to osmotic stress. Probably of more importance is its participation in **redox-balancing** reactions (see **yeast redox control**).

Glycogen

Glycogen is the major storage carbohydrate of yeast. It accumulates where growth is restricted by depletion of a nutrient other than sugar, which occurs in mid- to late fermentation, and it is mobilised to provide carbon and maintenance energy during periods of starvation, for example, in later fermentation or in the storage phase between cropping and re-pitching. In addition, because of the inability of freshly pitched yeast to efficiently assimilate exogenous sugars, it is used in the initial aerobic phase of fermentation to fuel the synthesis of sterols and unsaturated fatty acids and thereby restore proper membrane function.

In brewing yeast, glycogen accounts for up to 25% of the cell dry weight, which implies that up to 4% of wort sugars are used for its synthesis. Two pools occur in yeast: an acid-soluble structural component, which is found in the cell wall, and soluble intracellular glycogen, which serves as a reserve material and is mobilised in times of need.

Glycogen is a polymer of α -D-glucose arranged in chains of 10–14 residues linked by 1 \rightarrow 4 residues. Individual chains are cross-linked by (1 \rightarrow 6)- α -D glucosidic bonds. The molecular weight is in the region of 10^8 . It is synthesised from glucose 6-phosphate via glucose 1-phosphate to which units of glucose are donated in the form of uridine diphosphate glucose. The latter is formed from uridine triphosphate. Synthesis of the main chains and cross-links are catalysed by glycogen synthase and glycogen branching enzyme, respectively. Glycogen mobilisation is via breakdown to glucose 1-phosphate utilising a glycogen debranching enzyme and glycogen phosphorylase.

The regulation of accumulation and degradation is under complex control and involves reversible phosphorylation of the enzymes involved. The phosphorylases and kinases involved

are activated or inactivated, as appropriate, by other sets of enzymes, which are the products of genes that form part of the complex Ras-cyclic AMP cascade involved in nutrient sensing. In this way glycogen concentration is regulated in response to the nutritional status of the cell.

Within the brewing context it may be appreciated that glycogen levels in yeast are of considerable importance to the well being of yeast during the critical stages between the end of brewing and re-pitching. One of the so-called **yeast vitality** tests is to assess glycogen content. This may be done in a lengthy quantitative procedure via selective extraction and analysis as glucose after suitable treatment, or using a rapid qualitative method based on staining using iodine.

Glycogen staining as a yeast vitality test

Glycogen is the major storage carbohydrate used by yeast to survive periods of starvation encountered in the interval between the end of fermentation, cropping, storage and re-pitching. Good quality pitching yeast should possess good reserves of glycogen. This can be assessed rapidly by staining yeast with Lugol's iodine. Yeasts with a high glycogen content stain a deep red-brown colour whereas those in which this material is depleted appear yellow to pale brown. The test can be used in conjunction with a microscopic examination slide where variations between individual cells can be assessed. Alternatively, it can be applied to a bulk sample of yeast slurry to provide an assessment of average glycogen content. The readings can be quantified via spectrophotometry.

GODA

See *Bryggeriforeningen*.

Golden Promise

A Scottish dwarf spring variety of malting barley widely used for pale UK-style ales and for Scottish whisky. It was the main variety of malting barley cultivated in the period between 1970 and 1990. It was developed in the 1960s using the then new method of gamma irradiation.

Goldings

Goldings is a group of closely related traditional varieties of UK aroma hop. The original variety was selected by a grower of the same name in the Kent village of Malling around 1790. A definitive identification of the Goldings in question has yet to be made.

Several cultivars of Goldings hops are recognised the true origins of which are obscure. Individual members of this group are usually distinguished by a suffix that usually describes the particular area where cultivation was practised. It is thought that these are clones that differ in only a small number of characters. Usually these differences are exhibited as slightly differing times of ripening. Examples include **Amos's Early Bird Goldings**, **Bramling Goldings**, **Canterbury Goldings**, **Cobbs Goldings**, **Eastwell Goldings**, **Mathon Goldings**, **Petham Goldings** and **Rodmersham Goldings**. In each case these are named after the farmer or the district where they were originally grown. It seems that the Canterbury variety might be the original forebear. Currently the different types are distinguished based on the area where they are grown, thus East Kent Goldings, Kent Goldings or simply Goldings (cultivated outside Kent). **Whitbread Goldings** is a wilt-resistant variety, probably not a true Goldings variety. **Styrian Goldings** is misnamed as it is identical to Fuggles.

The hops contain 4–7% α -acids and 0.7–1.1% oil. They are susceptible to viral diseases and have variable resistance to wilts.

Gose

Gose is the name given to a German beer style. It is associated with the area of lower Saxony and takes its name from the river of the same name. The beer is made from a mixture of malted wheat and malted barley; it is flavoured with coriander and hops using top fermentation with a mixed culture of yeast and lactic acid bacteria. The presence of wheat confers very good head forming properties whilst the bacteria impart a sour taste.

The beer is unique in that it has a slight salty character. Originally this was due to the saline nature of the natural spring waters, which are found in the town of Goslar, the place from which the beer originates. When supplies of the water ran out, Gose production moved to the city of Leipzig. For this reason the beer is also commonly referred to as **Leipzig Gose**. As with Berliner Weisse the beer is commonly mixed with sugar syrups containing flavourings such as woodruff. Alternatively it may be fortified by the addition of a measure of schnapps.

The beer had enormous popularity in the Leipzig area although production declined and eventually disappeared with the division of Germany following the Second World War. The reunification of the country has seen something of a resurgence of interest largely by craft brewers.

Graff drum maltings

A drum pneumatic malting system devised in the United States, which was designed to carry out steeping, germination and kilning in a single vessel. The drums were cylinders with diameters of 5.5 m and lengths of nearly 13 m. The capacity was approximately 100 tonnes.

See **drum malting** and **pneumatic malting**.

Grain samplers

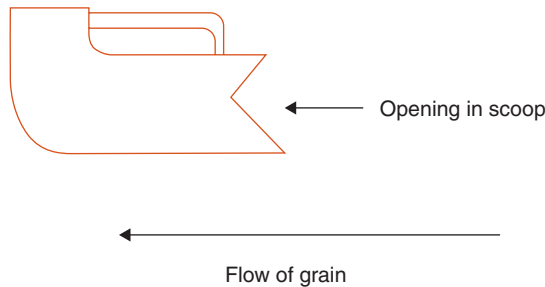
Prior to examination of grains, it is necessary to obtain samples that are representative of the whole. This is inherently difficult since bulk batches of grains are rarely uniform. Unless very small, it is difficult to examine every grain within a batch, and therefore some type of sampling procedure has to be undertaken. The sample may be taken from a bulk source, as in a bin, silo or similar container, or from a smaller primary unit of grain such as a sack. In the case of these static bulk batches of grains, the method must ensure that samples are representative of the whole. This requires that each portion of the whole has an equal chance of being sampled and that the actual number of samples provides a statistically valid representation of the whole. So for example, where a batch of grains consist of more than 100 sacks, it would be necessary to examine samples from a number of sacks equal to roughly the square root of the total. In some cases it may be possible to examine every grain within a sack. Where this is not practical, the samples of grains removed from the selected sacks must be chosen using a procedure that ensures that random choices of individual grains are made. Alternatively, samples may be obtained from bulk grain when it is being moved on conveyor belts, or other transporting devices.

Several different types of grain sampler are in use. These range from simple manually operated samplers to relatively sophisticated automatic devices.

Manual samplers

The simplest devices consist of tubes that are fitted with perforations through which grains may fall. These are called **sample spears**. The perforations and the diameter of the tube are chosen to be suitable for the size of the grain to be sampled. In use the sample spear is plunged into the bulk grain. This is facilitated by the presence of a handle and the pointed anterior portion of the tube. There are several variations on this basic design; for example, long spears that are used for sampling deep beds of static grains may have several pockets distributed at intervals along their length. In the **double-tube sampling spear**, there are two concentrically arranged cylinders, each containing perforations of size suited to the particular grain. The outer tube can be rotated such that when the spear is introduced, the perforations are sealed. When the spear is in place, the tube is opened to allow ingress of grains and the perforations are again closed before the spear is withdrawn. This allows greater confidence that the grains are taken from a representative cross-section of the bed.

The **Ellis cup** and the **Pelican grain samplers** are handheld implements designed to be placed within a stream and remove samples from streams of grain being moved along a conveyor belt.



Cross section of an Ellis cup grain sampler

The Pelican sampler takes the form of a pouch made of cowhide stretched over a metal frame, which is attached to a long handle. The name derives from the shape of the pouch, which is reminiscent of the beak of the pelican. The device is placed within the stream of grain as it exits from a spout or the end of a conveyor, and samples are collected as required.

In some tests it is necessary to count the grains. In order to ensure a random selection, a number of samplers have been designed to capture a randomised fixed number of grains. The **Learner corn counter** consists of a spear-shaped piece of plastic that has 50 shaped slots in it. The spear is plunged into the grain and withdrawn. After ensuring that each slot is filled, the grains are removed for analysis. The **Kickelhayn corn counter** comprises a plate that is fitted over a reservoir. The plate contains 500 slots over which the grains are spread. The surplus is removed leaving each slot filled. A slide arrangement when operated allows the 500 grains to be captured in the reservoir. Suction bed counters use the application of a vacuum to a plate, which also contains a fixed number of slots. The vacuum causes grains to adhere to each slot. The grains can then be recovered by releasing the vacuum.

Automated samplers

Many designs exist that allow the automatic removal of samples from bulk grain stores. Vacuum devices are commonly used for the removal of samples from bulk grain from railway

wagons or lorries. These consist of an arm mounted on a supporting stand, which can be placed over the load of grain at reception. The arm penetrates the grain bed, and a sample is removed via the application of vacuum. The sample is automatically transported to the laboratory of the receiver for logging and analysis. This allows a rapid initial assessment of the load of grain and if necessary turning away without the inconvenience of reloading if it fails to meet the expectations of the customer.

Several samplers are designed to remove samples as grain is transported along conveyor belts.

Diverter samplers are used for the removal of samples of grains being transported on a conveyor belt. They come in several forms but are reliant on the use of suction to capture the grain samples as the main product stream falls from a spout (see diagram).

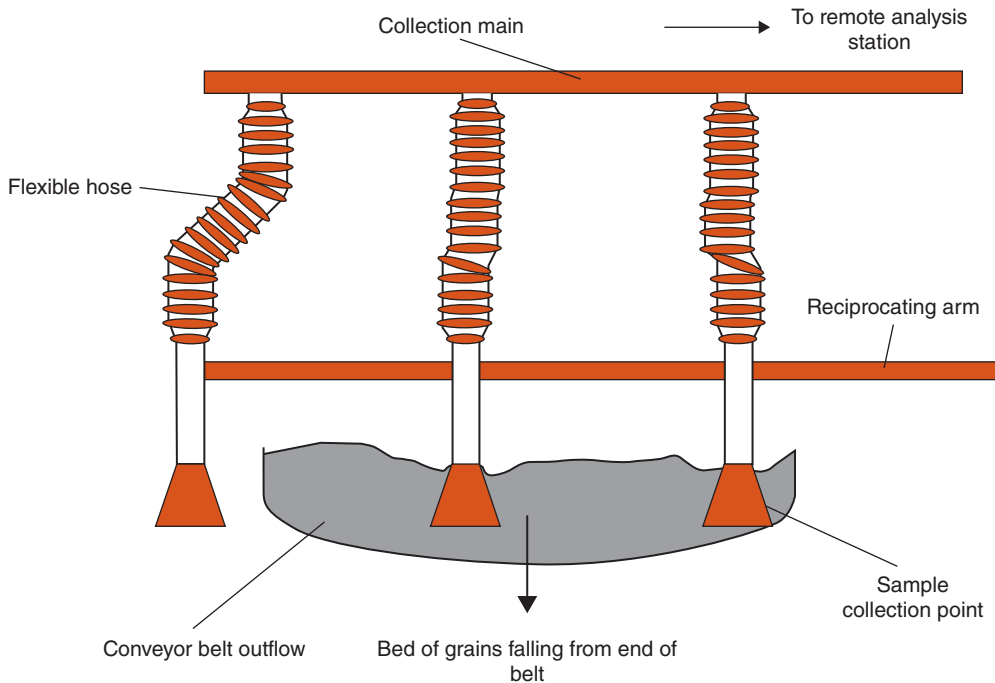


Diagram showing in section the end of a grain conveyor belt fitted with a diverter sampler. The reciprocating arm moves the three collection heads through the stream of grain as it issues from the conveyor belt. This ensures that the whole of the bed of grains is sampled. The grain samples are combined and then conveyed pneumatically to a remote laboratory for analysis. Operation of the sampling procedure is timed to ensure that representative samples are removed from the entire run.

The **Woodside automatic grain sampler** pre-dates the diverter method. It comprises a series of cups that are mounted on chains, which are driven by a motor. Usually three chains each with a sampling cup are mounted in parallel so that the whole cross section of the bed can be sampled. As the grain is transported along a conveyor belt, the cups dip into the bed of grains and remove the samples. As with the grain diverter, the samples are combined and mixed before subsamples are used for analyses.

Sample dividers

Several devices are used that are designed to mix samples of grains automatically such that representative grains can be obtained. The aim is to remove a number of subsamples from the bulk. These are combined and repeatedly divided until a composite sample, small enough for analytical purposes is obtained, that is representative of the whole. The **Boerner grain divider** consists of a hopper, which is mounted above a cone. Within the cone are a number of ducts through which the grains can pass and fall into a collection receiver. In between the ducts are spaces through which a proportion of the grains can also pass. These are collected in a second receiver. Repeated passage of grains through the divider produces a random mix of the grains.

Grain trier

An alternative name for a device that is used to obtain representative samples of grains from a bulk store.

See **grain samplers**.

Grain turners

The name given to the devices that are used in the malting process to turn grains. In the germinating stage, turners have the aim of preventing matting of the developing rootlets and to ensure good temperature control of the germinating grains. In other stages, for example, kilning, the intention is simply to ensure that individual grains are exposed to the same conditions.

Several types of turner are used depending on the sophistication, size and type of malting plant used. In traditional floor maltings, grains were turned manually using malt shovels or forks. In mechanised malting, more sophisticated equipment is employed. In all cases the aim is to mix the grains efficiently in a manner that minimises mechanical damage and which maintain an even bed depth. In deep beds, the grains should be lifted sufficiently to promote passage of air.

Early types of turner that are no longer used were called **paddle** or **Van Caspel turners**. These took the form of a carriage that was made to move through the grain bed. The carriage was fitted with horizontal rotating arms each of which bore a number of paddles or scoops. The latter penetrated the bed as the carriage progressed and lifted and mixed the grains then re-deposited them behind. This type of turner tended to move the grain bed forward with each traverse, and to correct for this it was necessary to carry out the process alternately in opposite directions; nevertheless, in deep beds the turning was inefficient.

In compartment malting, such as the **Saladin box**, the turners take the form of a row of vertically mounted helical screws mounted on a movable platform that traverses the bed of grains. Adjacent screws rotate in opposite directions and the supporting carriage typically traverses the grain bed at a rate of approximately 0.5 m/min. In operation this type of turner fails to provide a uniform bed depth since the screwing motion leads to the formation of 'hills and valleys'. The presence of rods that are mounted on the axle of each screw and that project downwards into the bed helps to minimise the formation of a 'bow wave' of grains. Lifting of the grains is essential to the function of the screws. In order to minimise this effect and keep the grains in the vessel, a metal disc may be attached to the upper part of the screw drive shaft.

Other turning systems are associated with particular designs of malting equipment, especially **semi-continuous malting** plants such as the Lausmann and Seeger Wanderhaufen systems (see **semi-continuous malting**). Grains may be turned by removal from the bottom of a vessel and using a conveying system reintroducing into the top. Alternatively, several tanks may be used with turning achieved during the transfer. Commonly, moving belts that bear buckets can be used to pick up and turn grain beds. Similarly grains may be turned during movement on a series of stacked and moving endless conveyor belts as in the **Plischke malting system**.

Grain washer

G

A device used to clean grains destined for malting and used prior to the initial steeping phase of malting. Its aim is to eliminate dust which if not removed would interfere with steeping. Several types of grain washer may be used. Removal of stones is also commonly incorporated. These grain washers utilise the differences in density of grains and other contaminating particulates. Commonly the unwashed grains are pumped into a moving stream of water where the lighter grains tend to float and the heavier particles of sand and other particles drop out to form sediments.

Gram-negative anaerobic beer spoilage bacteria

Traditionally occurrences of microbial spoilage of beer by bacteria have most often shown to be caused by Gram-positive aerobes or facultative anaerobes, especially strains of *Lactobacillus* and *Pediococcus*. Since the 1990s, reports of spoilage by Gram-negative obligate anaerobes have become more common. This has been ascribed to a general downward trend in in-process and in-pack oxygen levels as a result of better process control and a desire to improve beer freshness. The increased use of cold sterile filtration as a means of assuring microbial integrity increases the level of risk as does the production of low and zero alcohol beers.

Several genera of spoilers have been isolated from breweries and identified. The precision of DNA-based taxonomic analyses has assisted in the latter. This group of organisms is difficult to cultivate in the laboratory, and no doubt this has hampered efforts made to detect them. Indeed it is obviously likely that they have always been common but undetected brewery contaminants. Perhaps the most well known of this group are *Pectinatus* and *Megasphaera*. Both of these are absolute beer spoilers and have predominantly been recovered from un-pasteurised beer, the latter usually from those with a low ethanol content. There are other less commonly encountered but closely related members of this group. *Selenomonas lactificex*, an anaerobic non-motile rod, has been found in pitching yeast as have two species of the genus *Zymophilus*. Undoubtedly others will be discovered as the power of the tools available to microbiologists continues to improve.

Grant

A grant is a now largely archaic term given to a trough or vessel into which multiple outlets discharge wort from a lauter or mash tun. In these older types of mash separation devices, the multiple outlets each ran via an individual pipe, which terminated in a swan neck tube. Each tube was fitted with a tap that allowed control of wort flow across the bed of grains. By dint of experience skilful operators could regulate wort run-off and prevent set beds.

Granulated derivatised cellulose (GDC)

See **Spezyme GDC**.

Gravibeam

The Gravibeam was a system designed to be fitted to large-volume commercial fermenters for the automatic in-line determination of specific gravity [Dutton, J. (1990) FV control with real time SG monitoring. *Brewing and Distilling International*, May 20–21].

See **density meter**.

Gravity bottle

A device used for measuring the density of liquids.

See **pycnometer**.

Gravity meter

See **density meter**.

Green beer

Green beer is beer at the completion of fermentation. The term green is used in the sense of immaturity; in other words, it is beer that is young and inferior to the finished product that is presented to the consumer. The processes that result in the conversion of green beer to finished product are referred to as **beer maturation**. Several processes may be applied in order to convert green beer to matured beer. These are dependent on the type of beer being produced. Several terms are used to describe the maturation process as applied to various types of beer. The changes that occur involve maturation of beer flavour, adjustment or development of an appropriate level of carbonation and, in addition, treatments that result in the removal of the precursors of beer components, which have the potential to produce hazes in packaged beer.

Some terms associated with the maturation of green beer are **conditioning**, **brewery conditioning**, **cask-conditioned beer** or **bottle conditioning**, **warm conditioning**, **cold conditioning**, **ageing**, **lagering**, **stabilisation**, **chill proofing**, **priming**, **secondary fermentation**, **diacetyl/VDK stand** and **warm stand**. The relevant entries should be consulted for more information.

Green beer centrifuge

A continuous centrifuge designed to be located between primary fermentation and conditioning tanks. The aim of the treatment is to remove solids, in particular yeast cells, from green beer before it enters a period of cold conditioning.

See **continuous centrifuge**.

Green Bullet

Green Bullet is a New Zealand-bred high alpha hop variety. It was released in the 1970s. It contains 14% α -acids of which 43% is cohumulone. β -Acids are 7%. Total oils are 1.3%, which comprises farnesene (<0.1%), humulene (18%), caryophyllene (5.8%) and myrcene (56%).

Greenburg

Greenburg is a US-bred hop variety (5.5% α -acids). It has found most favour with craft brewers.

Green malt

Green malt describes grains that have been allowed to germinate but have not been kilned. Green in this usage refers to the lack of maturity. Green malts when mashed produce very high extract levels and high enzyme levels. Consequently subsequent worts are highly fermentable and contain high concentrations of soluble and amino nitrogen. In addition, levels of anthocyanogens are low as is viscosity. These qualities would suggest that green malts would be of great value in brewing. However, this is not the case since the advantages are negated by the undesirable raw grain flavours and aromas that are also characteristic of the immature malt. For these reasons green malts are not used in brewing; nevertheless they are ideal for the preparation of wash in whisky distilling and they are used in the manufacture of some sugar syrups.

G

Green vitriol

Green vitriol, also known as copperas, is an archaic name for ferrous sulphate, usually encountered in the form of the heptahydrate. It was used in the eighteenth and nineteenth centuries in the United Kingdom as an illegal beer adulterant, which was added as a heading agent.

Grimmett

An Australian malting barley variety accredited for use in 1982. Its cultivation has now been largely superseded by more disease-resistant and high-yielding varieties.

Grist

Grist is the mixture of solid raw materials, usually malts and possibly various other solid sources of extract, which have been subject to a controlled milling process to reduce the average particle size, release the components of grains and increase the surface area for subsequent aqueous extraction. The term grist composition is used to describe the nature and proportions of solid materials that make up the charge, which is introduced into the mill or to the milled product.

The type of mill and the manner of its operation influences the average particle size of the grist. These parameters are selected based on the type of plant that is used in the brewhouse to prepare the wort. For example, infusion mashing, using a mash tun, as in the case of traditional UK-style ale production requires a relatively coarse-ground grist made from well-modified malts. Conversely, decoction mashing as used for lager beers with a lauter tun uses a much thinner and more finely ground grist made from less well-modified malts. In both these cases the particle size is important since the fragments of husk are required to form the bed through which the sweet wort is sieved. Hammer mills, which produce a grist with a very fine particle size, are used where mash presses are employed for the wort clarification step. In this case, particle size is not important since the sieving action is performed by the filter itself.

Fine grists are the most rapid to hydrate when water is added, and in consequence the preformed solubles are quickly dissolved and enzymes are rapidly mobilised and are more quickly able to interact with their substrates. Finely divided grists provide the greatest surface area for interaction with soluble enzymes and the products of their activity are most easily able to diffuse into the suspending aqueous medium. Generally, therefore, finer grists give higher extract yields. Similarly, rates of saccharification are more rapid compared with more coarse grists as are yields of total and soluble nitrogen. The more rapid mashing times associ-

ated with fine grists is sometimes considered to give better beer flavour, possibly owing to the reduced extraction of some less desirable components. On the other hand, wort viscosity may also be increased as a consequence of greater extraction of β -glucans.

Grist case

The grist case is the container that receives the grist as it exits the mill. It is used for temporary storage of the grist prior to it being transferred into the mashing plant. In addition to the milled grist, other solid adjuncts that do not require milling may also be added. Grist is hygroscopic and one of the roles of the grist case is to prevent ingress of moisture that might cause 'balling' and therefore inefficient extraction of soluble wort components during mashing-in.

Physically the grist case is made from mild steel and is commonly of conical design. It is located directly below the mill and is sized to either have sufficient capacity for a single or in some cases several brew lengths. The delivery method may also include a metering system such that a controlled proportion of a solid adjunct of the type that does not require milling may be evenly mixed with the grist. The base consists of a chute fitted with a screen from which the grist is transferred into the mashing-in vessel. Occasionally a method of facilitating transport of the grist is provided such that a conveyor belt and vibration devices may also be fitted to ease movement. Whichever method is used care must be taken to avoid excessive damage to fragments of husks and the point of transfer should be airtight to prevent dust formation. Where a single grist case is required to hold a charge sufficient for several brew lengths, it may be mounted on wheels to facilitate movement to the required mashing-in apparatus. Alternatively, the exit chute may be arranged such that appropriate adjustment allows the charge of grist case be delivered to where it is required. Some grist cases are provided with a method of heating, which is sometimes used to preheat the grist.

Grits

Grits are fractions of the grains of cereals such as maize, rice and sorghum. They are prepared from grains in a process that removes the hull and the germ. They are used as sources of extract and in many instances are used as ungelatinised solid adjuncts. The precise composition depends on the degree of processing that has been applied. The most pure forms are essentially pure starchy endosperm. In these cases, termed **refined grits**, the husk material, most of the aleurone, germ and bran components have also been removed.

Grits are prepared in various ways depending on the nature of the starting material. In all cases there is an initial milling step, which may be wet or dry depending on the cereal grain.

In the case of corn grits the maize grains are dry milled to remove the husk, the outer layers of the endosperm and the lipid-rich germ; nevertheless, significant quantities of lipids and proteins remain.

After the initial purification the grits may be subjected to additional processing to provide adjuncts that meet the needs of individual brewers, for example, flaking or micronisation. Further treatments yield more refined products such as pure starch flours.

Grits cooker

A grits cooker is an alternative name for a cereal cooker as used in double mashing regimes.

See **cereal cooker, double mashing**.

Groll Josef

See **pilsener**.

Growler

Beer container usually made from glass or ceramics and a capacity of around 2L. They are designed for consumption of draught beer 'carry-outs' and associated mainly with the United States and Canada. Similar containers, made from plastics, are commonly used in the United Kingdom. The containers are fitted with a closure, typically a screw or hinged cap. Many bear specific branding. They have proliferated with the growth of the craft brewing segment.

Gruit

Gruit refers to the herbs, used singly or in mixtures, that were added to beers for flavour (and perhaps unwittingly as preservatives) before the widespread adoption of hops. The word derives from the old German meaning herbs. Many of the components of gruit have medicinal uses and are widely used in herbal remedies. Some contain components that are psychoactive, and no doubt when added to beers these would augment the effects of ethanol.

Before the use of hops, a wide variety of herbs were used as beer flavourings. They include rosemary, bog myrtle (sweet gale), coriander, caraway, nutmeg, cinnamon, ginger, juniper, milfoil, mugwort and yarrow. The beers made using these components and which are now very rare are referred to as **gruitbeer**.

As with many ingredients used in brewing, in Germany, gruit was also quickly recognised as an opportunity for raising revenue. In this sense the term gruit also became associated with the tax that had to be paid by early German brewers in order to obtain permission to harvest the plants.

Gruitbeer

See **gruit**.

Gueuze

Gueuze is a traditional Belgian bottled beer. It is made from blends of **lambic beers** of varying ages. The latter are beers made from blends of malted barley and wheat and subjected to a lengthy spontaneous fermentation in which several genera of yeasts and bacteria participate. Fermentations for lambic beers are allowed to proceed in wooden casks for periods ranging from several weeks up to a few years at which time they may be consumed. In the case of gueuze, blends of lambic beers are bottled and allowed to re-ferment for a further 1–2 years. This produces further flavour maturation and the development of condition.

In more modern processes a greater degree of control is applied. In this case lambic beers produced by traditional method are blended with a base beer made from a fermentation using a mixture of pure strains of *Brettanomyces*, *Lactobacillus* and *Acetobacter*.

See **lambic beer**.

Gushing

Phenomenon also referred to as 'jumping or wild beer' in which after broaching of small-pack beers there is a sudden and uncontrollable foam generation with consequent loss of product.

When the container is opened the release of pressure is accompanied by the formation of multiple small bubbles throughout the liquid, which expand to generate the excessive foaming.

True gushing, as opposed to problems associated with loss of process control such as inadvertent over-carbonation, has been ascribed to numerous causes. These include the presence of sources of nucleation such as calcium oxalate crystals or heavy metals including iron, nickel, tin and molybdenum. This type of gushing is sometimes called secondary gushing. The most severe cases, primary gushing, appear to be linked to brewing with malts made from barley, which during growth has been heavily infected with moulds, particularly species of *Fusarium* although other genera such as *Penicillium*, *Mucor* and *Rhizopus* have also been implicated. Barleys grown in particularly wet years are most likely to suffer from excessive fungal contamination and produce gushing beers.

The true causative agents remain elusive or are, perhaps, multiple. Hydrophobic polypeptides, hydrophobins, derived from the fungus have been implicated. Purified preparations of these at concentrations as low as 3 µg/mL have been shown to be affective. It is claimed that the hydrophobins form structures that enclose CO₂ molecules. On broaching the container, the decreased pressure causes a sudden fracture of these structures, and this is accompanied by a violent release of CO₂.

Several tests have been developed for testing the ability of specific batches of malt to induce gushing. Many of these are in-house tests but two have gained recognition by the official manuals of beer analysis. The original Carlsberg test required a sample of ground malt to be added to beer sealed in a container, pasteurised and then shaken for 3 days prior to broaching and the degree of gushing assessed by measurement of weight loss. In the later modified Carlsberg procedure, the beer was replaced with a bespoke carbonated water. The Mitteleuropäischen Analysen Kommission (MEBAK) test is similar, requiring protocols for shaking and broaching to be followed but uses carbonated malt extract as the test vehicle.

Gustatores cerevisiae

Name given in medieval England to the officials who were appointed annually to administer the various by-laws, which regulated the quality and strength of beer and the measures by which it was dispensed.

See **ale-conner**.

Gyle

Gyle is an archaic term, although still in used in many UK commercial breweries that describes a single batch of wort. Individual wort batches, or gyles, are commonly given code numbers that provides a convenient means of tracking batches of beer as they progress through the brewery from brewhouse to packaging.

Gypsum

Gypsum is hydrated calcium sulphate (CaSO₄·2H₂O). Its presence in water produces permanent hardness. Its presence at high concentrations in the water derived from the aquifers under Burton on Trent is the prime cause of the suitability of Burton water for brewing UK-style pale ales.

See **water**.

Hach haze meter

A beer haze meter based on the measurement of light scattering at 90° using incident light with a wavelength of 550 nm.

Haemocytometer

A cell-counting chamber, literally blood cell counter, used as an aid when enumerating cell populations, particularly yeast. It comprises a microscope slide that when covered with a slip provides a chamber of known volume. The slide has a grid embossed onto the base that facilitates making manual cell counts. Determination of the number of cells within the grid using a suitably diluted suspension allows by calculation an estimation of the cell concentration of process samples such as pitching yeast slurries. Used in conjunction with bright field vital dyes such as methylene blue, the total and viable cells concentration can be measured and by calculation the viability.

Haffman haze meter

A beer haze meter based on the measurement of light scattering at 90° using incident light with a wavelength of 350–2000 nm.

Halcyon

A traditional UK two-row winter variety of malting barley suitable for producing UK-style pale ales. It is a cross of the similar Maris Otter and Sargent varieties, and like its parental types, it no longer appears on the lists of recommended varieties although the malt is still produced in relatively small amounts to satisfy the current burgeoning craft brewing segment.

Half and half

A term used in the United Kingdom that refers to the habit of consuming draught beers in the form of mixtures of different beer qualities. For example, a pint of beer containing equal volumes of mild and bitter ales. Other expressions such as **mixed** have also been used to describe this practice. See **porter**.

Hallertau Mittelfrüh

Hallertau (for short) is a variety of hop. It is classified as one of the **noble hops**. It is named after the Hallertau or Holledau region of Bavaria in Germany from which it gets its name and an area noted for hop cultivation. Indeed the Hallertau region has a history of hop cultivation dating back to the ninth century AD and was possibly the first site in the world to undertake this industry. This hop cultivar contains relatively low concentrations of α - and β -acids, typically 3–5% of each, and for this reason it is relatively low in bitterness. The content of humulene is relatively high, and the many products devolving from the oxidation of this compound and other hop oil constituents impart a delicate floral aroma and taste to beers made from them. The cultivar was used widely for pale *Helles* type of lager beers.

The original Hallertau hop variety had a marked susceptibility to a wilt disease, and a major outbreak in the 1970s largely wiped out stocks. For this reason in the Hallertau region, it has been largely replaced by another variety with similar properties known as Hersbrucker.

Hamelin

An Australian two-row variety of malting barley bred from Stirling and Hamilton varieties and accredited for use in 2004. It is described as having good malting qualities, but the plant has poor disease resistance. It is considered particularly suitable, when malted, for use in the high adjunct brewing markets of Japan and China.

Hammer mill

Hammer mills are used for the treatment of malt grains and/or other solid adjuncts to produce grist with a desired fineness of grind (see **milling** for a full discussion of the principles involved). They are impact mills that rely for their destructive and comminuting action upon rotating metal hammers or beaters that come into contact with the solid load.

Hammer mills have a long history in brewing being used commonly for the treatment of some relatively intractable solid adjuncts. More recently they have seen widespread adoption for use in conjunction with the new generation of high efficiency mash filters. These require a finely ground grist. Hammer mills are particularly suitable for this duty.

The mill consists of a chamber in which a rotor is mounted with a number of hammers attached, which are pivoted such that they can pivot freely (see diagram). The feed, which has been screened to remove all extraneous solid material, is delivered into the chamber from a hopper via a rotary roller. The hammers impact on the solid grains such that they are broken and the contents released. The action is very vigorous, and a very fine grist is produced. When the particles reach a sufficiently small size, they pass through a screen and out of the chamber. The grist is carried into and out of the chamber pneumatically via an airstream.

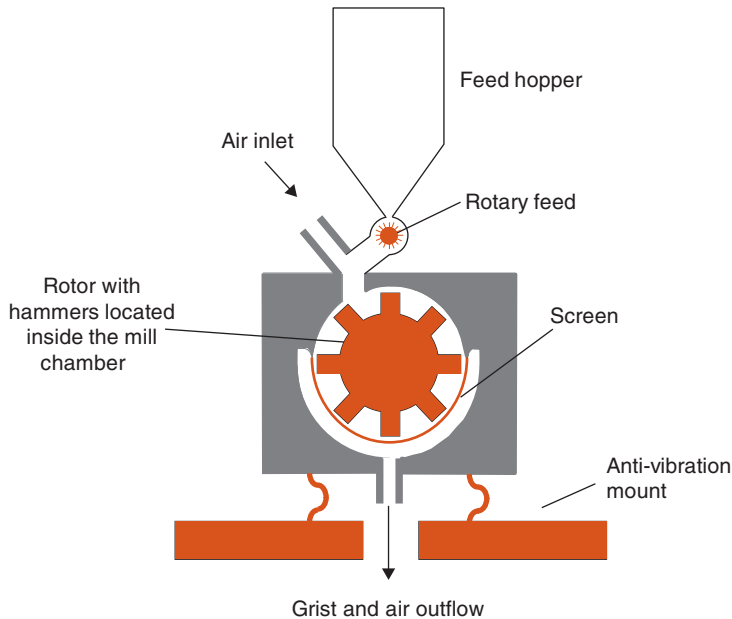


Diagram showing a section through a hammer mill

Hanging fermentation

A fermentation that has arrested before the achievement of the expected attenuation gravity.

Hann

See *Valtický*.

Happoshu

Happoshu describes a Japanese beer class that is made with a low proportion of malt in the grist. Japanese beer excise is levied on the basis of the quantity of malt that is used in its manufacture. Four bands are recognised based on the proportion of the fermentable extract derived from malt. These are less than 25%, 25–50%, 50–67% and greater than 67%. Only those products in the highest category (>67%) are officially classified as true beers. *Happoshu*, which translates as ‘sparkling spirits’, represent an attempt by some Japanese brewers to introduce new products that can claim certain health benefits by being low carbohydrate and simultaneously attract a lower rate of excise duty. The products have attained quite a sizeable market based mainly on the low cost relative to normal beers. This is reminiscent of the phenomenon seen in the United Kingdom initially, and later in other countries, when flavoured alcoholic beverages were introduced.

Predictably the Japanese government has sought to introduce measures to counteract the loss of revenue. In consequence the tax on the second (50–67% malt) band was increased to that of the true beers. In response to this and in order to reap the greatest tax avoidance benefits, the proportion of malt used has been gradually reduced such that the majority of *happoshu* brands now contain less than 25% fermentable extract derived from malt.

The trend towards lower malt content has spawned other beer-related products. These have been termed **third beers**. These are made from materials other than malt and include extracts derived from a diverse range of materials such as pea proteins and soya beans. Many are blended with *happoshu*-type beers. These products are significantly less expensive than conventional beers and for this reason have gained much popularity. In addition, it is said that many modern consumers of alcoholic drinks prefer these 'less-challenging' beverages compared with the more bitter hopped and malt-based beers.

Hard multum

See *Cocculus indicus*.

Hard peg

A non-porous peg or **spile**, made from plastic or wood, that is used to seal the aperture in the **shive** of a **cask** and prevent exit of carbon dioxide. The act of fitting such a device is known as hard pegging.

See **cask beer**.

Hard resins

See **hop resins**.

Harmonie

Harmonie is a relatively new Czech aroma hop variety registered in 2004. It was produced from parental types, which were Czech high alpha (female) and Czech aroma (male). It contains 4–8% total α -acids (19–22% cohumulone) and 4–8% β -acids. Total oils are 1.0–2.0% (6.0–11.0% caryophyllene, <0.2% farnesene, 10.0–20.0% humulene, 30–40% myrcene).

HART

An acronym that stands for Highway Addressable Remote Transducer that is used in communication between devices used in the automation of complex industrial processes such as large commercial breweries. Commonly devices such as the actuators used in devices such as automatic valves have control outputs based on 4- to 20-mA current loops. The HART system was developed in response to the need to equip such devices with a means of communicating with digital supervisory and monitoring systems (e.g., see **Profibus**).

Hartong 45°C index

The Hartong index is a measure of extract used by the Middle European Brewing Technology Analysis Commission (**MEBAK**). It is a simplified version of the full Hartong extract procedure. It is acquired by determining the extract obtained isothermally at 45°C. Commonly the Hartong 45° value is expressed as a percentage of the extract value of the Analytica-EBC extract. In this case it is referred to as the Hartong Index (VZ45). Values are dimensionless. For malts, values less than 30 are considered to be poor and less than 36 insufficient. Values between 36 and 40 are considered satisfactory and greater than 40 to be good.

The full Hartong procedure is based on extract values obtained at isothermal temperatures of 20°C, 45°C, 60°C and 80°C. These temperatures supersede an earlier regime in which 20°C,

45°C, 65°C and 85°C were used. An arbitrary constant is subtracted from the mean of the extract values obtained at the four different temperatures to give the Hartong value. The numerical value of the Hartong index is directly proportional to the degree of modification. Values for typical malts are in the region of 5.

HART protocol

An acronym that stands for Highway Addressable Remote Transducer that is used in communication between devices used in the automation of complex industrial processes such as large commercial breweries. Commonly devices such as the actuators used in devices such as automatic valves have control outputs based on 4- to 20-mA current loops. The HART system was developed in response to the need to equip such devices with a means of communicating with the more modern digital supervisory and monitoring systems (e.g., see **Profibus**). It was developed originally by the US company Rosemount Inc. but later evolved into a freely available protocol.

Haruna Nijo

A Japanese two-row variety of malting barley.

See **space barley**.

Hauptteig

This German term describes the second layer of grains that settles out during the operation of a **lauter tun**. It translates as 'main paste'. It is distinct from the *unterteig* (first paste) and *oberteig* (upper paste). It comprises the bulk of the grains that settle out to form the bed.

See **lauter tun**.

Hayflick limit

An eponymous term that describes the maximum lifespan potential of a cell. This is of relevance to brewing in that contrary to a commonly held misapprehension yeast cells have a finite lifespan. When this limit is reached, the senescent cells are programmed to die. The effect is independent of death brought about by necrotic effects. The latter is defined as the irreparable damage to cellular structures and functions that occur as a result of exposure to stresses. Programmed cell death is termed apoptosis and is viewed as a mechanism by which aged cells, which are likely to have impaired function, are eliminated from the population.

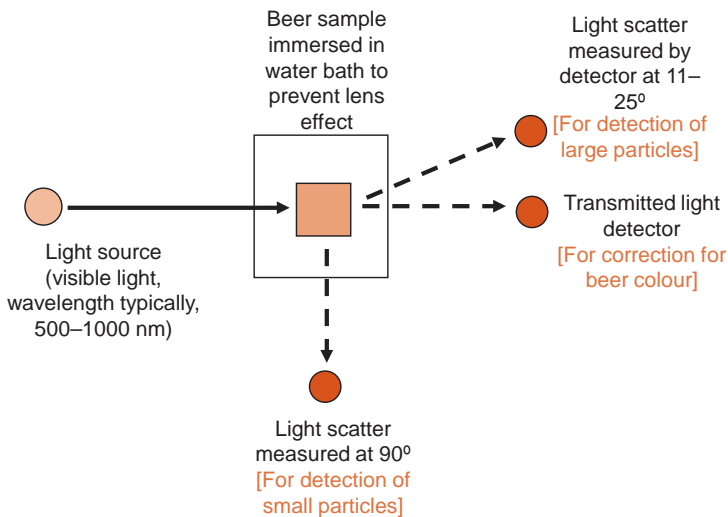
In yeast the potential cellular lifespan is a function of the number of rounds of replication the cell has undergone. Thus, the replicative age of an individual cell can be judged by simply counting the bud scars preset on the cell wall. In brewing yeast strains, the Hayflick limit is strain specific and equates to a value usually within the range of 10–30 replications. It has been shown that cells approaching the end of their replicative lifespans exhibit phenotypic changes. These include an increase in cell size (a factor that increases with each round of budding), a wrinkled cell surface and a granular appearance of the cell contents due to the accumulation of refractile lipid-containing particles. Physiological changes include decreases in cellular tRNA content, protein synthesis and ribosome activity. In addition, there is an increase in generation time. At the termination of replication, the new virgin daughter cell has a reset replicate age, and it can therefore undergo the usual number of replications typical

for that strain. However, it has been shown that in some cases, the offspring of older mothers are also defective and not capable of achieving the usual Hayflick limit. Collectively these changes can be viewed as replicative senescence.

The practical relevance of these effects is that with serial re-pitching, it is possible that the mean average age of the population might increase, and this could be accompanied by a gradual loss of vigour in the pitching yeast. This effect could potentially be made worse by an inappropriate cropping technique where larger (older) cells are selected for, as might be the case where bottom crops are collected and retained. This is one of the reasons why many brewers choose to limit the number of re-pitchings that any yeast can be used for.

Haze meters

Haze meters are used to assess the clarity of beer or other process liquids such as worts. Essentially they are nephelometers that rely on light scattering due to suspended particles to determine concentration. For their operation they rely on shining a beam of light, wavelength 400–1100 nm, through the sample to be analysed. A proportion of the light is scattered due to the presence of suspended particles. The proportion of scattered light is measured using a detector (or array of detectors), which are placed in locations at specific angles to the beam of incident light (see the figure for details).



Schematic showing the features of a generalised haze meter designed for the analysis of off-line samples. See text for more description

The angle of measurement is chosen according to the type of sample and the expected haze value. Most haze meters have one detector, which is located at 90° to the incident beam of light, and a second detector located in the same plane as the incident beam, which measures transmitted light. The ratio between the outputs from each detector is used to measure the magnitude of light scattering and by inference the haze. This type is suitable for those meters that are designed to be used for bright beer, either from a bulk bright beer tank or after packaging. This angle of detection is suitable for beers that might contain very small particles (less than 0.5 μm in diameter) as in the case of **pseudo-** or **invisible hazes**.

Other haze meters might also incorporate a detector that measures forward scatter at an angle of 12–25° to the incident light beam. These detectors are most suited to the measurement of comparatively large haze particles and may be used to assess the clarity of hot wort post-boil. Many haze meters use both forward and 90° scatter and can be used in many locations in the brewery, for example, for bright beer, monitoring of wort clarity and monitoring the operation of centrifuges and filters. A third type of meter, termed a ratio type, measures transmitted, 90° and forward scatter and uses the results to compute a single derived haze value.

Several errors can arise and most instruments incorporate refinements that seek to minimise their effects. A small error is introduced by the colour of the beer. A correction may be applied by the reading obtained from the transmitted light detector. Differences in the refractive indices of the media that the light beam has to traverse are one such potential cause of error. In order to minimise this, the sample cuvette or bottle in the case of packaged beer, is usually located within a bath that is filled with deionised water. This reduces the error since the water has a similar refractive index to beer; however, care must be taken to ensure that the water is clean. The surface of the cuvette or bottle introduces an error due to the so-called lens effect of the light striking the curved surface. In order to minimise this effect, it is usual to record the average of several readings taken after successive manual or automatic rotation of the container.

Haze meters are calibrated using standards that produce defined light scattering. These are based on **formazin** (see entry of same name for more details). Unfortunately haze measurements have not been standardised, and a number of different units are in concurrent use. The European Brewing Convention (EBC) system uses a scale of 1–10 whilst that of the American Association of Brewing Scientists (ASBC) is based on a scale of 1–1000. Results are not directly comparable but 1 EBC unit is roughly equal to 69 ASBC units or 100 ASBC units roughly equal to 1.45 EBC units.

See **beer hazes**.

Haze standards

Several materials have been proposed as being suitable for use as standards for the calibration of apparatus used for assessing beer hazes by nephelometry (see **haze meters**). Standards are necessary so that the results of measurements carried out in different locations can be confidently assured to be reproducible and comparable.

The first haze standard was that of Helm, which was based on a suspension of barium sulphate. Suspensions of fuller's earth have been used by some.

As the basis of the standard procedures and scales used for beer haze measurement and recommended by the ASBC, IOB and EBC, standards are based on formazin.

Formazin is made by reacting hydrazine sulphate and hexamine, which yields polymeric chains of formazin that fold randomly to form particles with diameters within the range of 0.1–10 µm. The particles of formazin are of a similar size to those that occur in beer.

Formazin standards can be prepared by the user or purchased made up and supplied as 'certified standards'. Standards based on polymeric beads are also used by some. These are made of latex or a styrene/divinylbenzene copolymer (mean particle size 0.1–0.8 µm).

ASBC standard

Make the base solution by mixing 25 mL of a solution of 0.966 g hydrazine sulphate diluted to 100 mL with filtered deionised water with 25 mL of a solution of 2.417 g of hexamine in water. A suspension of 15 mL of base solution made up to 100 mL with water is equal to 1000 ASBC haze units.

EBC standard

Dilute 1000 g of hydrazine sulphate in 100 mL of water. Dilute 10,000 g of hexamine in 100 mL of water. Mix equal volumes of these to prepare a base solution. A 1:10 dilution of the base solution is equal to 100 EBC haze units.

Helm standard

Mix a solution of 10 mL 0.5 M barium chloride with 10 mL of a solution of 0.55 M K_2SO_4 diluted to 200 mL with water. A dilution of 2.5 mL of the resulting barium sulphate suspension made up to 330 mL in water has a turbidity of 300 Helm units.

Head retention value

Parameter used to assess the foam stability of the head of dispensed beer. It is the inverse of foam collapse time.

See **beer foam**.

Heat of hydration

See **slaking heat**.

Heat shock proteins

See **yeast stress response**.

Heavy

See **Scottish ales**.

Hectolitre

A unit of capacity, widely used in brewing and equivalent to 100 L.

Hefe

German word for yeast.

Hefetrüb

The term *hefetrüb*, which translates in German as ‘yeast cloudy’, refers to bottle-conditioned beers in which the presence of yeast is made evident in the form of a haze.

Hefeweizen

Hefeweizen, literally the German for ‘yeast wheat’, is one of the many names applied to cloudy, bottle or tank-conditioned top-fermented wheat beers. See **weissbier**.

Helles

Helles is a style of beer which in effect is the German equivalent of the Czech pilsner beers. The word derives from *hell*, German for pale, and this reflects the pale golden colour of the beer. The beer style is comparatively recent in origin, the first product of this type being produced by the Spaten brewery in Bavaria in the late nineteenth century. For this reason the beer may also be occasionally referred to as the original pale Munich lager.

Several variants of the basic beer style are produced with alcoholic contents ranging from approximately 4.5% to more than 5.5%. The flavour is characteristically delicate in which the malts is predominant with low bitterness (*ca.* 20 IBU) and aroma and taste being provided by the use of **noble hops**. Variants are differentiated by various suffixes and prefixes. Thus, *Urhell* means 'original *Helles*', *Spezial Helles*, for specially brewed seasonal variants; *Edel-Hell* means 'noble *Helles*', a reference to the incorporation of noble hops.

H

Hellesbock

Hellesbocks, literally 'pale bock' beers, are pale and generally weaker variants of the bock family of German beers. They are also referred to as *Maibock*.

See *bock*.

Helm apparatus

An eponymous and now archaic device introduced in the 1930s for the assessment of beer hazes based on the measurement of the angle of scattering of a light beam passed through a bottle of beer. Helm introduced the first haze standard based on suspensions of barium sulphate.

See **haze meters**.

Helm method for beer foam assessment

ASBC-recommended method, also known as the Carlsberg method, used for assessing the foaming ability of beer based on the equations derived in the **Ross and Clarke method of beer foam assessment**. A measured volume of the test beer is poured into a cylindrical separating funnel until the foam head reaches a volume of 800 mL, and after precisely 30 seconds, the liquid beer is removed leaving the foam *in situ*. After a further 200 seconds, the liquid formed from the foam collapse is removed and the volume noted (*c*₁). The precise time of collapsed foam removal is noted (*t*). The residual foam is collapsed using a solvent such as isopropyl alcohol, and the volume of this minus the solvent is added to *c*₁ to give the total collapsed foam volume (*c*). The foam collapse time (Sigma value) is calculated from the Ross and Clarke equation:

$$\Sigma = t / (2.303 \log b + c/2).$$

Helm's test

Test used for the rapid assessment of **yeast flocculation**. Various modifications have been made to the original procedure; in this comparatively recent form, yeast is recovered by centrifugation and washed in aqueous ethylenediaminetetraacetic acid (EDTA) to remove metal ions followed by saline solution before re-suspension at a cell count of 1×10^8 cells per millilitre in 250 mM NaCl, pH 4.5. The suspension (24 mL) is placed in a 25-mL measuring cyl-

inder, and CaCl_2 solution is added to give a Ca^{2+} concentration of 4 mM. The suspension is mixed by repeated inversion (18 times) to promote flocculation. At intervals, samples (typically 0.2–1.0 mL) are removed from a fixed depth in the liquid and pipetted into 250 mM NaCl, pH 2.0, to disperse the cells and the optical density measured at 620 nm. A plot of OD_{620} versus time provides a measure of flocculation.

See **haze standards**.

Helm unit

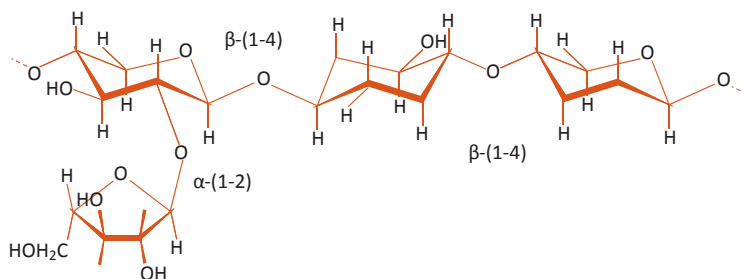
The first standardised haze unit based on the turbidity of suspensions of barium sulphate developed at the Carlsberg Research Institute and named after the inventor E. Helm.

Hemicellulose

Hemicelluloses are non-starch polysaccharide polymers that form part of the structure of plant cell walls. They have a relatively amorphous cross-linked structure and form the matrix of cell walls being interposed within the cellulose component. Unlike the latter, they are not entirely composed of glucose residues; instead other sugars are also present, particularly pentoses such as D-xylose. Collectively they include arabinoxylans and small concentrations of pectins. The former consist predominantly of the pentoses arabinose and xylose. These are classified as pentosans. Hexoses and hexouronic acids are present as minor constituents, and for this reason they are also referred to as heteroxylans.

In barley, hemicelluloses and gums together account for 10% of the plant dry cell weight. Together with fructans, gums and hollocellulose, hemicelluloses constitute the major non-starch polysaccharides present in grists. They may be crudely differentiated based on relative solubility, with hemicelluloses being the least soluble fraction. Hydrolysis of hemicelluloses (soluble in hot alkali) by barley enzymes results in the formation of gums (soluble in water). Further degradation of gums yields oligosaccharides and simple sugars.

The pentosan polysaccharides (arabinoxylans) vary in size and structure. All are based on chains of xylose joined together by β -(1-4) linkages. The xylose residues may be substituted on the C-2 or C-3 positions, or non-substituted. Substitutions occur irregularly along the chains and consist of arabinose units. Some of the arabinose substituting groups also have xylose residues attached to them. In turn some of the xylose molecules are acetylated. Other arabinose molecules are substituted with phenolic acids, especially ferulic acid. Typically chains consist of 1000–5000 residues.



Part of a molecule of arabinoxylan showing part of the β -(1-4) linked D-xylanpranose backbone and an α -(1-2) substituted residue of α -L-arabinofuranose

The enzymology of the breakdown of hemicelluloses and gums in barley grains is complex and not properly characterised. During malting the β -glucan component is preferentially degraded and in consequence the proportion of residual pentosans increases. Residual pentosans that remain undegraded after mashing is completed may contribute to problems associated with very viscous worts. Pentosans can bind water. The complex of pentosan particles when present at sufficient concentration may impede wort run-off.

Several activities are involved in the degradation of pentosans during malting. The initial attack involves the activity of esterases. These remove the substituting acetyl and feruloyl substituents to liberate acetate and ferulic acid. This renders the polysaccharide backbone accessible to subsequent attack by a variety of carbohydrases. Arabinoxylanase strips arabinose substituents from the xylan backbone. Endoxylanases shorten the chain length to form xylan oligosaccharides. The result is the formation of a mixture of xylan oligosaccharides, arabinoxylan oligosaccharides and acetylated and feruloylated arabinoxylan oligosaccharides. Via the action of β -xylanopyrosidase, the shorter xylan oligosaccharides xylobiose and xylotriose may eventually be degraded to xylose monomer.

The ferulic acid that is liberated can under some circumstances be decarboxylated to liberate 4-vinyl guaiacol. This reaction can be carried out by some bacteria and in particular by yeast strains that contain the *pof* gene (**phenolic off-flavour**). This has a strong antiseptic flavour that may be desirable in some beers but in most beer qualities is considered to be a defect. The majority of brewing yeast strains do not possess the *pof* gene and are therefore designated as being *pof*⁻. However, some wild strains of *Saccharomyces cerevisiae*, especially those that have diastatic abilities, are *pof*⁺. Accidental contamination of fermentations with such yeasts results in **super-attenuation** and the formation of the characteristic clove/phenolic taste and aroma.

Henry's law

A law formulated by an English chemist in 1803 that states that the amount of gas dissolved in a liquid at a given temperature is directly proportional to the partial pressure of the gas in equilibrium with the liquid. It is of relevance to brewing in that the concentrations of dissolved gases such as CO₂, nitrogen and oxygen in beers can be influenced by changing the applied pressure. For example, if it is required to carbonate a beer to a desired dissolved concentration this may be achieved by the introduction of gaseous CO₂ into the gas headspace at a defined temperature and pressure.

Herald

A wilt-resistant dwarf hop variety developed at Wye College in the 1990s. It is used as a dual-purpose bittering and aroma variety (11–13% α -acids, 1–1.9% essential oils).

Hersbrucker

The Hersbrucker hills are located in Bavaria in Germany. They give their name to a variety of aroma hop. This cultivar has largely replaced the original Hallertau Mittelfrüh variety on the basis of its much reduced susceptibility to wilt disease.

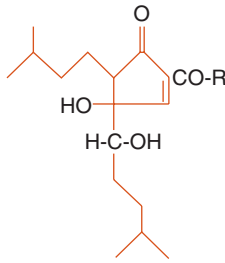
See **Hallertau Mittelfrüh**, noble hops.

Het pint

A traditional Scottish drink associated with Hogmanay celebrations made from whisky, beer, sugar, spices and eggs and served hot.

Hexahydro-iso- α -acids

Hexahydro-iso- α -acids are reduced derivatives of hop iso- α -acids in which six hydrogen atoms have been incorporated into the molecule.



Generalised structure of hexahydro-iso- α -acids

Hexahydro-iso- α -acids are very effective foam stabilisers. They are marginally more bitter than the parental iso- α -acids.

High alpha hops

The term kettle hops may be used to describe hop varieties that have a high content of α -acids and so are suited to impart bitterness to beers. Traditional hop varieties may contain as little as 3% α -acids, measured as the proportion of whole dried cones. Breeding programmes have resulted in the development of varieties that may contain up to 19% α -acids. These are termed high alpha varieties or in extreme cases super alpha hops. High and super alpha varieties generally contain 14–19% α -acids. The elevated levels in these hop varieties are a result of both increased concentration of α -acids in the lupulin glands and an increased total number of lupulin glands per plant. In general in these varieties, the concentrations of the less valuable β -acids are not elevated.

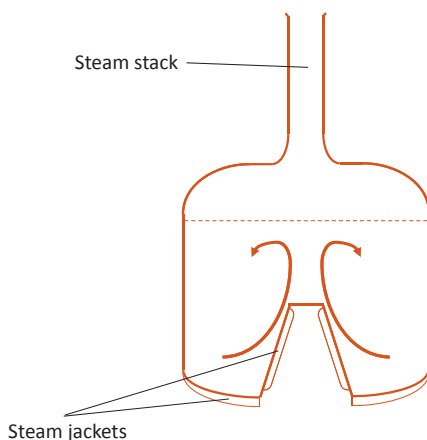
Examples of high alpha varieties are Apollo, Bravo, Columbus/Tomahawk/Zeus (CTS), Millenium, Summit (first dwarf high alpha variety), Super Galena, Chinook and Columbus.

High-conversion syrups

See **high-maltose syrup**.

High-efficiency kettle

So-called high-efficiency kettles are, as the name suggests, designed to improve the process of wort boiling. These kettles are heated by the provision of steam to a series of external jackets. In order to improve the efficiency of heat exchange and in order to promote good mixing, the base of the kettle takes the form of an inverted cone. Steam jackets are provided to the base of the vessel and to the external faces of the cone (see diagram).



Diagrammatic representation of the key features of a high-efficiency kettle showing the circulating convection currents induced by the basal conical intrusion and associated steam jackets. In addition to the features shown, a mechanical agitator may also be incorporated

See wort boiling, wort kettle.

Higher alcohols, yeast and beer flavour

A number of alcohols, also known as **fusel alcohols**, other than ethanol and **glycerol** arise in beer as a result of the activities of yeast during fermentation, and these contribute to beer flavour and aroma. Some of the more abundant are n-propanol (5–50), iso-butanol (5–100), 2-methylbutanol (10–130) and 3-methylbutanol (25–180). Typical concentrations in beers (mg/L) are shown in brackets. Higher alcohols are considered to impart warming and fruity notes.

They are formed during early to mid-fermentation and generally reach peak values when wort free amino nitrogen (FAN) falls to a minimum concentration. In later stages of fermentation, a proportion of higher alcohols are used as substrates for **ester** synthesis.

Higher alcohols can be synthesised by two routes. The precursors are 2-oxo-acids that are decarboxylated to form the corresponding aldehyde and then reduced to the alcohol by an NAD⁺-linked alcohol dehydrogenase. The oxo-acids arise either from an amino acid via transamination or from pyruvate derived from carbohydrate catabolism. The former is termed the **Ehrlich pathway** and the latter the anabolic route. All n-propanol is produced via the anabolic route as there is no corresponding amino acid.

The relative contribution made by each synthetic route is dependent on the availability of the precursor substrates. Where FAN is plentiful, especially in the initial stages of fermentation, oxo-acids are predominantly formed via transamination and the Ehrlich route is operative. In later fermentation, when amino acids derived from wort FAN become exhausted, the anabolic route assumes greater importance.

Predictably wort composition and the factors that influence yeast growth exert control over the final concentrations of higher alcohols arising in beer. High wort FAN levels and conditions that favour yeast growth such as high pitching rates and high levels of wort oxygenation all favour elevated levels of higher alcohols. The use of high fermentation temperature also favours higher levels possibly since a greater proportion of the intracellular pool exits the cell.

Nevertheless, the key parameter appears to be the choice of yeast strain. Group ale strains produce more compared with lager strains, although there is much individual variability.

Metabolic functions for higher alcohol synthesis are usually explained in terms of the terminal reduction of the aldehyde offering the cell a method of fine-tuning of cellular redox. Intriguingly higher alcohols are reported to cause a switch from yeast morphology to a pseudo-hyphal form in some strains. The significance of this remains to be determined.

Higher dextrans

Higher dextrans are polymers of glucose in which individual molecules contain 10 or more glucose units. In worts and beers they form part of the non-fermentable fraction of carbohydrate. Higher dextrans account for 50–60% of the total dextrans in worts. This is equivalent to approximately 1.7–2.2 g per 100 mL of wort.

High-fructose corn syrup

Also known as HFCS, isoglucose or glucose–fructose syrup. It is prepared from cornstarch glucose via treatment with glucose isomerase to produce a mixture primarily of glucose and fructose. The product of the enzymic treatment is blended with glucose in varying proportions to produce a syrup with desired properties. Different grades of the syrup are denoted by the acronym HFCS followed by a number that indicates the relative proportions of fructose and glucose; for example, HFCS-55 contains 55% fructose, 45% glucose. HFCS is used as a priming sugar since it is sweeter than pure glucose syrup, it is liquid and in some markets it is less expensive than sucrose syrup.

High-gravity brewing

A common practice in modern high-capacity breweries, which originated in the 1960s, where highly concentrated worts are produced and fermented and then diluted, immediately prior to packaging, to a desired ‘sales gravity’. The attraction of the technique, which may be viewed as a means of minimising capital expenditure, is that it multiplies the volumes of beer arising from a single batch by the dilution factor and thereby increases overall productivity of a given brewery.

The concentrations of typical high-gravity worts are of the order of 1055–1065 (13.75–16.26°P), and these would be diluted to sales strengths of the order of 1038–1045 (9.5–11.25°P).

There are several requirements for the process to be successful. The brewhouse must be capable of generating the concentrated wort stream, and although lauter tuns can be used, this perhaps favours modern mash presses. There are fewer opportunities for recycling weak worts and wetting losses become more significant. The use of adjuncts, particularly pure sugar syrups, is an attractive method for increasing gravity; however, caution must be exercised lest nitrogen concentrations are diluted to levels that can cause unacceptable perturbations in beer flavour and fermentation performance.

Fermentation conditions must be adjusted in order to ensure that the flavour of the diluted beer is acceptable. Pitching rates and oxygen concentrations must be increased *pro rata*. This requires that the yeast storage and handling plant has sufficient capacity. Nevertheless, some undesirable flavour changes are likely, especially increases in beer esters, which may make

difficulties where flavour needs to be matched to a beer that has been hitherto brewed at sales strength.

Stresses to which yeast is exposed are increased by high-gravity brewing. Although the productivity from individual batches is increased, there is some trade-off in that fermentation cycle times are prolonged compared with sales gravity fermentations. To counteract this it is common to increase fermentation rates by using a higher temperature. This further elevates the levels of stress to which the yeast is exposed. These stresses must be managed carefully such that early warm cropping of yeast is advisable. Even so, the maximum number of times yeast may be re-pitched may have to be reduced to 5–10 cycles. A failure to manage yeast stress can result in low crop viabilities, yeast mutation, high beer pH and poor beer foam.

H

The dilution step requires great care. In order to gain the most benefit, it is best to delay this step until after filtration and thereby maximise filtration runs. In this case it is essential that the dilution liquor is sterile, free from any taints, not contain any component that could cause haze formation and be of a similar ionic composition to that used in brewing.

The limits for high-gravity brewing are dictated by the properties of the yeast with regard to parameters such as ethanol tolerance and ability to attenuate very concentrated worts. With regard to limits for ultra-high-gravity brewing, it is likely that modifications to the composition of an all-malt wort might be necessary. There is considerable evidence that the ionic composition, especially with regard to metal ions such as Mg^{2+} , could require adjustment or supplementation.

High Kräusen

See *kräusen*.

High-maltose syrup

High-maltose syrups are available in a variety of grades. They are usually produced from barley starch using mixtures of amylolytic enzymes. The nature of the enzymes used and the temperature conditions control the eventual mix of sugars in the finished syrups. They are used as liquid adjuncts and are convenient for increasing the fermentability of high-gravity worts. High-maltose syrups are useful since they are non-crystallising at temperatures above 4°C.

The types used in brewing are usually high-conversion syrups in which a typical composition is maltose (30–37%), glucose (35–43%), maltotriose (10%) and other oligosaccharides (15%).

High-osmolarity glycerol (HOG) pathway

A system used by yeast, and other cells, to respond to external applied stresses such as a shift to a medium with a high osmotic concentration. The external change initiates a **MAPK cascade** which amongst other changes stimulates the formation and intracellular accumulation of the compatible solute, **glycerol**.

Hildegard of Bingen

A Benedictine nun, visionary, composer of music, naturalist and herbalist of eleventh- and twelfth-century West Franconia in Germany who is credited with the first written description

of the use of hops in brewing in her book *Physica, sive Subtililitatum diversarum nature creaturarem libri novem*.

Hiochi bacteria

See **ethanol tolerance**.

Hockett

A two-row variety of malting barley that was added to the recommended list of the **American Malting Barley Association Inc. (AMBA)** in 2010. It is particularly suited to drier climates.

Hogshead

A measure of capacity or the name of the container used to hold liquid or solid goods. The precise capacity depends on the country of use and the nature of the goods. In addition, the precise volumes have been subject to revision at various times. In the United Kingdom, a hogshead of beer is equivalent to 54 imperial gallons (245.76 L), prior to 1803 and after 1688 it was equivalent to 51 imperial gallons. In the case of wine measures, a hogshead may be variable but is usually equivalent to 52.5 imperial gallons (approximately 236 L). Since the US gallon derives from the UK wine gallon (see **gallon** for more details), the volume of the US hogshead of beer is also approximately 236 L or 63 US gallons.

The origin of the word is unknown although it has been suggested that it might be a corruption of words used in various European languages, which translate as *oxhead*, for example, the Dutch, *oxhooft* or the Swedish *oxehoved*. The association with containers used for transportation and storing of liquids may have arisen via branding marks used to indicate the type and origin of the contents.

Holocellulose

Holocellulose is the term used to describe the long-chain polysaccharide tissue of plants that remains after soluble materials and lignin have been removed. In a brewing sense, it is the non-starch polysaccharide portion of barley grains that constitutes the undissolved residue when a malt grist is subjected to extraction with hot water and hot alkali. It appears to be derived from the husk and accounts for about 5% of the total dry weight of barley grains. It is thought to persist in wort and is thought to be not subject to modification during mashing.

Hop acids

Hop acids is the collective name given to the combination of α - and β -acids, which together comprise the bulk of the soft fraction of **hop resins**. These are the compounds which after isomerisation form the principal bittering components of hops. The α -acid fraction is of most significance regarding beer bitterness.

Aside from their effects on beer flavour, the hop acids exert antibacterial effects, and thus these compounds have important preservative properties. The effectiveness of individual hop acids is influenced by the number of prenyl groups present. Since the β -acids have three of these, the potency of this group is greater than that of the α -acids.

See **hop resins**.

Hop back

Hop backs are used to separate hop debris from wort during the process of wort production. They are associated with larger traditional breweries, particularly those producing UK-style ales, where whole hop cones are used.

The hop back consists of a closed cylindrical tank fitted with a false slotted base similar in design to a mash tun (see figure). The wort plus hop debris is pumped over the surface of the slotted base where it settles and forms a filter bed. The hop bed is allowed to form and consolidate by an initial recirculation step in which the wort plus entrained solids is drawn off the bottom of the hop back and returned to the in-feed point. When the outflowing wort achieves the desired clarity, the wort is allowed to move forward. Wort recoveries are increased by sparging the hop bed with hot liquor. The operation of hop backs is relatively slow, but they have the advantage that quite a high proportion of the hot break is also retained. Occasionally hop backs may be used to introduce additional flavour hops.

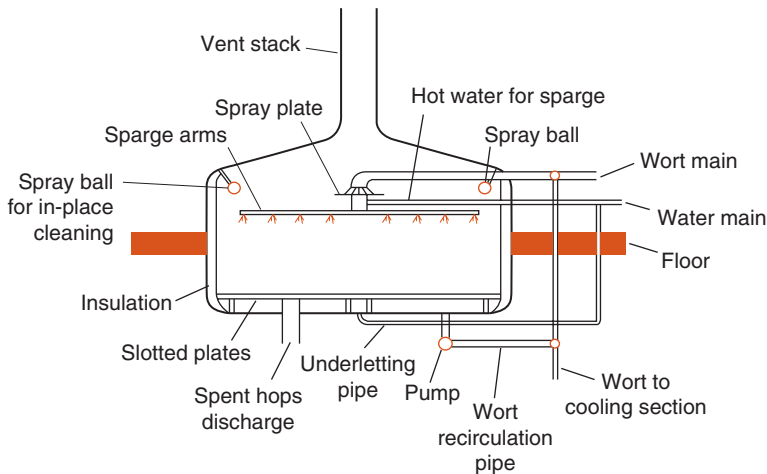


Diagram showing a section of a hop back

Hop bale

Traditionally whole hop cones are packaged into pockets (United Kingdom) or bales (principally in the United States). The US hop bales measure approximately $138 \times 50 \times 76$ cm and weigh 200 lb (91 kg). Filling is accomplished using a baling press. This consists of a wooden chest into which a hessian cloth is draped. The sides of the chest are hinged to facilitate this operation. After closing the sides and ends, the dried hops are added. The hops are compressed using a top-mounted, usually electrically driven, ram. When the bale is completely filled, a top layer of hessian cloth is applied. This is held in place by the ram whilst the wooden sides of the chest are folded flat allowing the top cloth to be secured to the sides by sewing to form the finished bale.

Compared with the UK hop pocket, the baling process is quicker, usually requiring no more than two or three repetitions of filling and pressing (compared with 8–12 for a hop pocket); in addition, the density of hops in the bales is greater and the bales stack more easily.

The amount of compression applied during baling can be varied in order to give products of the same net weight but occupying smaller volumes. Thus, double-compressed bales, half the volume of their normal counterparts have been produced for the purpose of export via ship. Such bales obviously take up less room but do have the disadvantage that the additional compression causes much more damage to the comparatively fragile lupulin glands. This practice has been largely superseded by the advent of hop pellets.

See **hop pocket**, **hop pellets**.

Hop black root rot

A disease of hop plants caused by the fungus *Phytophthora citricola*. The organism persists in soils as an oospore. Under appropriate conditions, especially when soils are waterlogged and the plant is susceptible, cultivar invasion of the rootstock may occur. Visible symptoms of the disease are sudden wilting and the blackening and softening of the crown and bine.

There are no specific chemical treatments although the use of Ridomil as a crown drench is reportedly effective for the prevention of both this disease and downy mildew.

Hop boiler

An alternative name for a kettle (copper).

Hop chlorotic disease virus

A viral disease of European hop crops. The symptoms are the appearance of pale yellow-green spots, chlorotic stripes and tissue necrosis in the regions between leaf veins. Chlorotic leaves become wrinkled and adopt a characteristic bent shape said to resemble the beaks of parrots. Infected plants are much smaller than normal, and inflorescences develop poorly resulting in substantial decline in yields. There are no known vectors, and it is assumed that transmission is via direct plant-to-plant contact or via infected seed.

Hop cone

The term for the mature strobilus of the female hop plant. This structure contains the lupulin glands that produce hop bittering and flavour constituents.

See **hop plants**.

Hop extracts

The active components of hop cones can be extracted to produce liquid extracts, which can be used directly in brewing or as the precursors of other chemically modified hop products with novel brewing properties. When used directly for brewing applications, the extracts have the advantage of being pre-solubilised and do not generate the bulky waste materials associated with whole hop products; they contain high concentrations of the active materials of interest, principally α -acids; typically, the extracts are packaged into cans and therefore can be easily stored and have good flavour stability owing to the exclusion of air.

Products can be made via solvent extraction using hexane or ethanol or now, more usually, carbon dioxide, either supercritical or liquid CO₂, is used. The solvents are removed by evaporation following extraction, and this is most easily accomplished with ethanol-based processes. Nevertheless, solvent-extracted products are less widely used compared with CO₂-derived extracts largely because of the suspicion of the former not being residue-free.

Hop extracts contain mainly soft resins and some other components. Solvent extracts are less selective compared with CO₂-extracted types. Organic extracts contain between 10% and 60% total soft resins, of which the α -acid fraction is more abundant than the β -type. Supercritical and liquid CO₂ extracts contain similar proportions of α - and β -acids but at higher concentrations (up to 95% total soft resins) compared with solvent extracts. Liquid CO₂ extracts give lower yields than supercritical CO₂ extracts. Essential oils are present in all extracts, again more in the CO₂-extracted types. Only a small proportion of the hard resins present in whole hop cones are extracted by any of the methods as is the case with hop polyphenols; however, extracts contain a greater proportion of hop waxes. All of the extracts are essentially free from nitrates and pesticide residues.

For direct brewing applications at relatively modest scales, the extracts are packaged into cans. These are broached using a punch and the cans placed in a basket, which is suspended in the kettle during the boil. For larger batch volumes, the extracts are supplied in bulk containers. After warming to reduce viscosity, the extract is pumped directly into the kettle. Commonly the extracts are prepared with a view to obtain the maximum yield of α -acids. This relatively pure extract is diluted, usually with sugar syrup, to give a product with predetermined α -acid content.

The use of liquid α -acid hop extracts gives better hop utilisation during the kettle boil compared with whole hops. Utilisation rates can be further improved by pre-isomerisation of the α -acids. These isomerised kettle extracts are of several types depending on the method used to prepare them. They may be isomerised in the pure extract resin form to give products termed isomerised kettle extract (**IKE**). As the name implies, these are used in the kettle purely for bitterness. They have the advantage of not containing hop oils whose volatile nature would render them easily lost or perhaps modified to give undesirable products. Isomerisation is carried out via reaction with either potassium or magnesium carbonate; accordingly the products are referred to as **MIKE** or **PIKE** standing for magnesium or potassium isomerised kettle extract, respectively.

The extraction of hop α -acids from hops leaves a residue that contains the β -acids, hop oils, other resinous materials and impurities. This fraction is termed the **base extract**. It is not a waste material; instead, many brewers who practise post-fermentation bittering also add base extract to the kettle. The base extract contains sources of non-isohumulone bitterness; it acts as an anti-foaming agent and is a source of hop aroma materials.

Several other speciality hop products use hop extracts as their starting materials. These materials are more costly than simple hop extracts, a reflection of the increased processing needed to produce them. They are used downstream of fermentation, and because of this, significant improvements in utilisation are achieved. These preparations can be used to impart bitterness, a process known as **post-fermentation bittering** or for other purposes, described as follows. Post-fermentation bittering is particularly prevalent in the case of **high-gravity brewing** where it is beneficial to be able to adjust bitterness levels immediately prior to dilution. The α -acids may be extracted and fractionated prior to chemical isomerisation. The purified α -acids are converted to salts of potassium or magnesium, isomerised by application of heat then sold as aqueous solutions with a known bittering potential for post-fermentation bittering.

Other post-fermentation hop additives confer additional benefits. Extracts rich in hop oils are used as alternatives to **dry hopping** where the potential losses due to volatile stripping

associated with the kettle boil are avoided. Oil-rich extracts are prepared via steam distillation or using CO₂ extraction. Steam distillation of aroma hops is performed using the process of **cohobation** where the oil fraction is retained in a trap and the aqueous phase and water-soluble materials are returned to the boiler. These products can be used as alternatives to dry hopping albeit giving beer whose taste and aroma is generally considered to be inferior. This is probably due to incomplete extraction of all the necessary components and chemical modifications resulting from the high temperatures used.

The highest quality hop oil extracts are prepared using a combination of CO₂ extraction and molecular distillation. The conditions employed are relatively mild, ambient temperature and low pressure. The extracts can be used as simple unfractionated CO₂ extracts or in more pure form. In all cases the essential characteristics of the parental hop are retained. These are known as dry hop essences, supplied as ethanolic solutions and designed to be added to bright beer. The essences can be further fractionated by column chromatography using silica gel to give products with more defined characteristics. These ethanolic solutions of late hop essences (LHEs) have names that indicate the character of the product:

LHE-spicy, mainly mono- and sesquiterpene alcohols

LHE-floral, principally ketones, esters and epoxides

LHE-estery, contains only C6–C10 straight- and branched-chain methyl esters of fatty acids

LHE-citrusy, a mixture of terpene alcohols, ketones and C5–C8 aliphatic acids.

Reduced hop extracts are chemically reduced iso- α - or iso- β -acids, which are made from purified iso-acids using sodium borohydride or Pd catalysts. They are defined based on the number of hydrogen atoms, which have been added to the molecules during their manufacture; thus, they may be dihydro-iso- α -acids (also known as **rho-iso- α -acids**), **tetrahydro-iso- α -acids** and **hexahydro-iso- α -acids** (see individual entries for more details). Apart from conferring bitterness, at the same or greater intensity compared with the iso- α -acid precursors, these products are not susceptible to the development of **light-struck character**. In addition, the dihydro- and tetra-iso- α -acids confer foam stability to beers.

The late addition of largely soluble hop products of known and predetermined properties provides much more precise control of beer flavour, gives better utilisation rates and avoids the development of solids, which must at some stage be removed. However, some of the benefits of kettle hops are lost. These include, amongst others, the absence during fermentation of the protective anti-microbial effects of hop acids, the lack of potentially beneficial hop polyphenols and the ameliorative effects of hop constituents on foaming during wort boiling. In order to avoid these disadvantages, combinations of kettle and post-fermentation hop additions are commonly made. Of course, where beers are required to be light resistant, this may not be possible, and in such cases, appropriate steps must be taken to safeguard against microbial spoilage and to ensure that contamination with iso- α -acids does not occur.

Hopfen

German word for hops.

Hopfenkessel

German for hop kettle.

Hop filter

A small metal mesh trap filter designed to fit in-line between the tap on a beer cask and the hose through which the beer is dispensed. The filter prevents the forward movement of any relatively large particulate materials such as the hop materials, which are added by some brewers to cask beers.

See **dry hopping**.

Hop flea beetle

The hop flea beetle (*Psylliodes attenuata*) is an occasional pest of hop plants. The adult beetle feeds on the leaves, and the larvae cause damage to roots.

Hop *Fusarium* canker

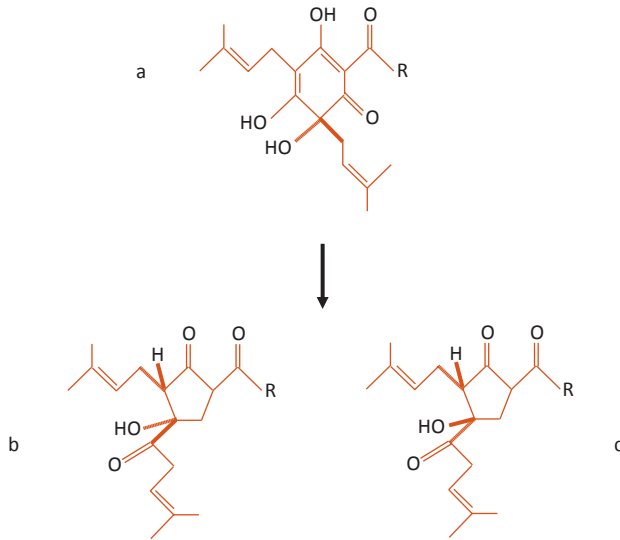
An infection of hops by the mould *Fusarium sambucinum*. Growth of the fungal mycelium in infected plants can occur particularly when conditions are especially wet or the soil has a high water table. The characteristic symptom is that the bine may suddenly wilt, especially when conditions are very hot. The mould invades the rootstock, and cankers on infected roots become evident. Invasion of the cortical region causes inhibition of carbohydrate transport in the infected areas with the result that the base of the bine becomes swollen and may split. Attachment of the bine to the crown is disrupted, and slight mechanical movement may cause complete detachment. Unlike the **Verticillium wilt disease of hops**, the vascular tissue does not become discoloured.

Hop isomerisation

During boiling of wort in the kettle hop, α -acids are isomerised to give iso- α -acids. The latter comprise the major bittering components of beer, and thus, the development of the bitter character is considered to be one of the crucial functions of wort boiling. Reportedly iso- α -acids are nine times more bitter than their α -acids counterparts. The yield of iso- α -acids in beers expressed as a percentage of the total α -acids added to the kettle is a measure of the **hop utilisation**.

Alternatively the hop α -acids may be pretreated to prepare **pre-isomerised hop extracts**. These products have the advantage that they do not require boiling in order to generate bitterness, and thus, they may be added to the process at stages other than the kettle. In the case of pre-isomerised hop extracts, the initial isomerisation step can be conducted under optimal conditions, which are not necessarily the same as those during the kettle boil. For example, isomerisation proceeds more easily at pH values higher than those encountered in wort. Utilisation rates are improved when pre-isomerised extracts are used; thus the α -acid precursors are relatively insoluble, and this factor reduces yields of isomerised product during wort boiling. In addition, the opportunity for adding pre-isomerised hops after the wort boil avoids the inevitable losses that occur via co-precipitation with hot break. Iso- α -acids are approximately 40 \times more soluble compared with the corresponding α -acids.

The chemistry of hops is complex. The principal bittering agents present in boiled wort are the *cis*- and *trans*-isomers of isohumulone, isochumulone and isoadhumulone. They are derived from the corresponding α -acids (see diagram).



Formation of *cis*- (b) and *trans*- (c) iso- α -acids from the precursor hop α -acids (a). R is isobutyl (humulones), *sec*-butyl- (adhumulones) and isopropyl (cohumulones)

The relative proportion of each of the three α -acids depends on the variety of hop. During the boil, iso-cohumulone reaches a maximum concentration after approximately 30 minutes. Isomerisation of adhumulone and humulone takes longer.

Isomerisation is catalysed by divalent ions, especially Ca^{2+} and Mg^{2+} . The proportion of each isomer formed depends on the conditions employed during the isomerisation. In conventional wort boiling, the ratio of *cis*- to *trans*-isomer formed is roughly 70:30. In the presence of magnesium oxide, this is skewed further to become approximately 80:20 in favour of the *cis*-isomer; however, in the presence of aqueous solutions of alkali, the balance shifts to 55:45, *cis*:-*trans*-.

Mixtures of the six iso- α -acids can be analysed by separation of the *cis*- and *trans*-isomers followed by high-performance liquid chromatography (HPLC) of each fraction. The separation step is accomplished by dissolving the mixture in ethyl acetate followed by treatment with dicyclohexamine. This results in the formation of insoluble salts of the *trans*-iso- α -acids leaving the *cis*-isomers in solution.

The balance of each isomer is important since each has different properties. This will influence the nature of commercial preparations of iso- α -acids. Thus, for each pair of isomers, the *cis*-form is significantly more bitter than the *trans*-form. Isohumulones are more bitter than isocohumulones. Iso- α -acids contribute to beer foams. It has been shown that the *trans*-isomers migrate into foams more readily than the *cis*-forms, although there is apparently little difference in the ability of each isomer to stabilise foams. However, isohumulone and iso-adhumulone are less polar than isocohumulone and in consequence the latter is less able to stabilise foams compared with the former.

Hop jack

See **montejus**.

Hop mosaic carlavirus

A viral pest of the hop plant. It causes a systemic infection of affected plants and was first reported in England in 1923. It is probably distributed worldwide, but in many cases, no physical symptoms of infection are evident. Where symptoms do occur, these take the form of chlorotic vein-banding and mosaic. An inability of the bine to attach to supports may be observed. The virus may be transmitted by grafting and by insect vectors such as the damson-hop aphid.

Hop mosaic chlorosis virus

A viral disease of hops that has been described in crops grown in Eastern Europe. Infected plants develop chlorosis and necrosis in the interveinal regions, and the plants become dwarfed and are poor yielding. The virus is spread by direct plant-to-plant contact and via the insect vector, the damson-hop aphid (*Phorodon humuli*).

H

Hop oils

Hops contain a volatile oil fraction that can be isolated by steam extraction and distillation (see **cohobation**), solvent extraction or CO₂ extraction. The oils are located in the lupulin glands and are responsible for the pleasant aromatic nature of the hop plants. The oil fraction accounts for approximately 3% of the whole hop. The total oil concentration is greater in seedless hops.

The composition of the oil fraction is complex and varies with individual cultivars. Those varieties that contain oils, the characteristics of which are considered to be particularly desirable, are termed **aroma hops** and are those that are used for late hopping (mainly lager beers) or dry hopping (mainly ales). In both practices the aim is to preserve as far as possible the volatile oil fraction so that the taste and aroma persists in the finished beer. The oil fraction is the starting material for the various hop extracts designed to replace or augment late and dry hopping (see **hop extracts** for more details).

The composition of hop oils is complex and several hundred individual components have been identified. The precise composition and the concentrations of the individual components, as stated, are specific to individual varieties. The concentrations of individual component changes and new products are formed as a result of various oxidation reactions that can occur during storage of hops. Some of these changes are desirable and are allowed for by the hop handling regimes practised by some brewers.

For the sake of analysis, the hop oils are fractionated by column chromatography on silica gel. Elution with light petroleum gives a fraction that is made up of hydrocarbons. A second fraction, which elutes with diethyl ether, consists of alcohols, acids, esters, carbonyls and small concentrations of sulphur-containing compounds.

The hydrocarbon fraction comprises 50–80% of the total hop oils. It consists of a complex mixture of monoterpenes, especially **myrcene** and sesquiterpenes, especially **humulene** and **β-caryophyllene**. Myrcene is the most potent hop odorant of this group. The hydrocarbon constituents of hop oils are relatively non-polar and therefore easily lost during the wort boil. For this reason these compounds are of more significance for the introduction of aroma and flavour via late or dry hopping or in essences that mimic these practices.

The oxygen-containing fraction of hop oils contains a very diverse group of compounds. As a whole they are less volatile and therefore more likely to survive the wort boil. In total the range of compounds that have been identified include 60 aldehydes and ketones, 70 esters, 50 alcohols, 25 acids, 30 oxygen heterocyclic compounds and 30 sulphur-containing compounds. Many of these compounds have intense odours and aromas and contribute citrus, floral, spicy and estery notes to beers. Many of these compounds are formed during hop storage as a result of oxidation reactions with hop oil hydrocarbons to yield various epoxides. The latter can undergo further reactions to form a complex spectrum of products. In order for these desirable reactions to proceed, some traditional brewers ensured that whole hops were stored for a period in the presence of air.

Many sulphur-containing compounds are components of hop oils but usually at low concentration. The number of compounds increases when hops are exposed to elemental sulphur as used to be the practice as part of pest control regimes. Although only present at low concentrations, many have very low flavour thresholds in beer. Most do not survive hop boiling but can persist in beers when late or dry hopping is practised. Compounds encountered include dimethyl sulphide, dimethyl disulphide and trimethyl trisulphide. These compounds impart onion/rubbery aromas although much of this fraction is lost during wort boiling and in fermentation. The esters *S*-methyl 2-methylbutylthioate and *S*-methyl hexanethiolate are the sulphur-containing compounds that when introduced via dry hopping make the most significant contribution to beer aroma.

It is apparent that the chemistry of hop oils is complex and not yet fully characterised. Different brewing practices, the effects of other raw materials and the availability of numerous hop varieties adds a further level of complexity with regard to the contribution made by hop oils to beer flavour and aroma.

Hop pellets

Hop pellets are preparations of hops made into a pelleted form, which by their nature are more convenient to handle compared with whole hop products. Compared with whole hop products hop pellets are easier to store, they take up less space and they lend themselves to use in systems that provide automatic addition to the kettle. They are packaged in ways in which oxidative deterioration is minimised.

A wide variety of products are supplied in this form. They may be made from partially purified hops or from pre-isomerised extracts. In non-isomerised types the hop cones are dried to 8–10% moisture, cooled to a very low temperature (*ca.* -30°C) and then reduced to a fine powder using a hammer mill. The powder is then pressed in a die to form pellets. During this stage care must be taken to ensure that the powder does not become too warm ($<55^{\circ}\text{C}$) and the pellets should be packaged as quickly as possible in order to avoid oxidation of the hop acids, which will have been released from the ruptured lupulin glands. In some modern processes the pellet-making operation uses liquid nitrogen to ensure adequate cooling and preservation of hop acids.

The pellets are packaged in laminated gas impermeable foil packs either under vacuum or in an inert gas of N_2 or CO_2 . The packs are contained within a secondary cardboard container to minimise the risk of rupture and ingress of oxygen. The hop pellets are usually stored in

cold stores at $<4^{\circ}\text{C}$. The pellets commonly take the form of short cylinders (1–3 cm length \times 0.5–1 cm diameter). Specifications are provided, which describe the concentration of α - and β -acids. This allows the weight of pellets to be used per brew to be calculated. Commonly the pellet names are prefixed with a number as in, for example, ‘type 90’. The number describes the approximate number of pellets obtained from 100 g of starting material.

Type 45 hop pellets, also known as **lupulin-enriched hop pellets**, are of similar size to the type 90 varieties but by definition contain roughly twice the hop acid content. These are made by sieving the hop powder, prior to pelletisation, to remove as far as possible any plant material that does not contribute any useful components.

Attempts have been made to produce hop pellets that have been treated to improve the storage properties. These are termed **stabilised hop pellets**. These products are made by mixing the hop powder with a proportion (2%) of oxides of either magnesium or calcium. During the pelletisation step, the free hop acids are derivatised to form the corresponding metal salts. The salts are much more stable compared with the free acids. The salts have the additional advantage that during storage, isomerisation into the bitter iso-acid form occurs. This improves utilisation rates. The stabilised pellets can be held for approximately 2 weeks at 50°C under which conditions isomerisation proceeds to completion. These products may then be sold as **isomerised hop pellets**.

Hop pillow

Hop pillows are sold as aids to sleeping. They are pillows in which a proportion of the filling comprises dried hops. The active soporific component is thought to be 2-methyl-3-buten-2-ol, an autoxidation product derived from hop β -acids formed when hops age during storage. This compound is not present in fresh hops and therefore these are not suitable for this use.

Hopping rate

In simple terms the hopping rate quoted in a beer recipe is the quantity of hops, or extract thereof, added per unit volume of sweet wort (quoted in g/hl or pounds per barrel). This rate is calculated based on the bitterness of the resultant beer and therefore assumes a known **hop utilisation rate** – in other words the proportion of iso- α -acids that appear in the beer as a proportion of the quantity of α -acids present in the total quantity of hops added.

In practice, the bitterness of the beer usually equates to hop utilisation of less than 40%. For this reason, many brewers use extracts of hops that are pre-isomerised and by definition do not require to be added to the kettle. In these cases the hopping rate refers to the quantity of hop extract added to deliver the desired bitterness level in the finished beer.

See **hop utilisation**.

Hop plants

Hops are perennial plants with a climbing habit. This is reflected in the name since it derives from the Anglo-Saxon *hoppān*, meaning to climb. They require a support for their aerial parts, which in the wild is provided by hedgerows and other plants. In the case of cultivated hops, artificial supports are provided. The aerial parts of the plants die back each year but the rootstocks survive to shoot again the following year. The plants are sensitive to day length and require at least 13 hours of sunlight per day to produce vegetative growth. Shorter day lengths

result in dormancy. In order for flowering to occur, a second light response is exhibited in which the process is inhibited if the day length is too long. This limits the geographical locations where the plants can be cultivated without recourse to artificial illumination.

Hop plants are dioecious; in other words, there are separate male and female plants. The flowers of the male plant are short lived and contain relatively low concentrations of bittering agents, and they die and become detached soon after forming. For this reason they are of no value in brewing. However, male plants do produce copious amounts of pollen, and this can be carried by wind over comparatively long distances resulting in the fertilisation of adjacent female plants with the consequent setting of seed. It can be shown that fertilisation results in increases in yield, and for this reason, in England, male plants were commonly planted in hop gardens. European and American brewers consider that seeded hops are inferior. Whether or not this is justified is questionable. The explanation given is usually either that seedless hops have greater bitterness potential or that the lipids associated with seeds can impart rancidity to beers or even have foam-negative effects. The prejudice has resulted in a legal requirement in Germany to eliminate any male plants from the vicinity of hop gardens. Similar precautions are taken by most American hop producers and the practice has also been adopted by English hop growers who are producing for the export market. European and American hops contain less than 4% seeds by weight, whereas many traditional English hop varieties may contain up to 25% seeds.

Rootstocks are very extensive and contain at intervals thickened sections. These are repositories for starch reserves that are laid down during the autumn and presumably support overwintering. When dormancy is broken in the spring, numerous buds develop in the upper part of the rootstock. These develop into shoots. The climbing stems of the hop plant, or **bine**, elongate by twining in a clockwise direction around any available support. Reportedly a complete revolution of the growing tip takes approximately 2 hours. The growing tendrils attach to the support by means of hooked hair-like structures located on the angles of the stem. Leaves are borne, usually in pairs at each node. The leaves are toothed and have three or five lobes. Flowering is initiated when the day length is sufficiently short and the plant has achieved a minimum number of nodes. The latter effect is variety specific; for example, in the case of Fuggles, it is 30–32. Immature flowers develop in the axils of leaves. This is referred to as the **pin stage**. The flowers of male plants consist of an open panicle. Each flower has five sepals and five anthers each borne on short filaments. Each anther contains a furrow in which a few resin glands are located. The female flower consists of an inflorescence with a condensed central axis, termed a **strig**. In isolation the strig has a zigzag appearance caused by the presence of alternating bract scars. Each node of the axis bears a pair of bracts each of which carries two bracteoles. The base of each bracteole has a fold in which a flower is formed. The flower consists of a perianth, which encloses an ovary. The ovary bears two papillated stigmas. When first formed the female inflorescences comprise closely arranged number of florets. The inflorescence is around 1 cm in diameter and has a compact spiny appearance owing to the presence of the stigmas. They are referred to as **burrs**. During maturation, the central axis, bracts and bracteoles elongate and enlarge to form the strobile or characteristic **hop cone**.

Where pollination has occurred, the flower develops into an achene enclosed on a papery perianth. Seed development causes the strig to elongate and thicken, the nodes may develop pigmentation and the bracteoles bearing seeds become elongated. These changes are easily

visible and for this reason seeded hop cones are easily distinguishable from non-pollinated ones.

Lupulin glands (or resin glands) are sparsely distributed on the undersides of leaves but are most abundant at the bases of the bracteoles. They have the appearance of bright yellow globular or sac-like structures. They are easily detached and may be found sticking to other parts of the cone. These structures contain the hop α - and β -acids that confer bitterness to beers. The sum of these may account for 75% of the total weight of the gland. The quantity of α -acid formed is characteristic of individual varieties, and these may be termed high alpha or low alpha, as appropriate.

Hop plum pox virus

A virus of the family Potyviridae that is usually associated with soft-stoned fruits (*Prunus* spp.) where infections cause severe economic loss. Since the pest of hop plants, the **damson-hop aphid**, overwinters on members of the *Prunus* family of plants, this insect can act as a vector for transmission of this virus into hop plants where disease symptoms and yield reductions may occur.

Hop pocket

Hop pockets are associated with the UK industry and are strong jute sacks used for packaging whole hops. They comprise long tubular sacks approximately 7.5 ft (229 cm) in length and 2 ft (61 cm) in diameter. When filled, each pocket stands approximately 6 ft (183 cm) high and holds 1.5 cwt (approximately 76 kg) of pressed dried hop cones. Originally the hops were pressed into the pockets using the feet of the packers, subsequently mechanical or manually operated **hop presses** were substituted, which were more efficient and caused less damage to the hops.

For filling, the pockets are suspended via a hole in the floor of the drying room. The pocket is held in place and the mouth is kept open using an iron ring over which the sack is folded and secured. The hop press, if used, is suspended over the pocket. Hops are ladled into the press using a large spade known as a **scuppet**. The blade of the scuppet consists of a canvas-covered wooden frame of rectangular section fitted with walls approximately 4 in. (10 cm) high to the side and back. The hop cones fall into the pocket, and when no more can be added, they are compressed by screwing down the press. In order to allow the application of pressure, the pocket is held in a support of webbing, which is attached to the underside of the cooling room floor, passes under the pocket and then up through a slit in the floor where it is then attached to an adjustable roller. Operation of the latter allows the tension of the pocket to be adjusted and maintained thereby allowing application of pressure via the hop press.

The hop pockets are eventually filled via repeated cycles of addition of hops and pressing. When the pocket is full the mouth is removed from the supporting ring and the sack is closed by sewing the ends together with string twine. In the traditional UK industry, this process is termed **coping-up**. Finally the pockets are labelled with the hop variety, weight and date of filling.

Hop press

Hop presses are used in the packaging of traditional whole hop cones into hop pockets. They comprise a cylindrical iron screw-driven compressor, the exit of which is circular in order to

facilitate compression of the hops into the suspended pocket. Alternatively top-mounted, electrically driven rams are used to compress hops into bales.

See **hop pocket**, **hop bale**.

Hop research council

A non-profit-making organisation, located in Oregon, USA, founded in 1979 by a combination of brewers, hop dealers and growers with the aim of promoting hop research (info@hopresearchcouncil.org).

Hop resins

Hop resins, together with hop oils are the constituents of the **lupulin glands** of **hop cones**, which impart flavour, aroma and bitterness to beers. The total resin content of hops is defined as the fraction that is soluble in diethyl ether or cold methanol. The **soft resin** fraction is that which is soluble in hexane and is distinguished from the **hard resin** fraction, which is insoluble in the latter solvent. Soft resins are the least polar fraction and mainly comprise the α - and β -acids and uncharacterised soft resins. Hard resins are more polar and comprise mainly of prenylflavonoids. The major constituent of the latter is xanthohumol. For the purposes of analysis, the hard resins are defined as the difference between the total resins and the fraction (soft resins) removed by solution in hexane.

Differentiation between hard and soft resins is made difficult by the fact that resin fraction of hops deteriorates during storage. As a result of this process, the hard resin fraction increases at the expense of the soft fraction. The deterioration is a consequence of various oxidation reactions that result in undesirable changes on hop flavour and aroma. During storage of hops, the concentrations of both α - and β -acids decrease and in consequence the bittering potential of individual batches of hops also declines with prolonged storage. The acyl side chains of resins become oxidised to form products such as isovaleric, isobutyric and 2-methylbutyric acids. These products impart undesirable stale, cheesy characters to aged hops.

In order to slow the deterioration of whole hops, they are best held at low temperatures in cold stores. In the case of whole hops, this is an expensive process. The development of hop pellets that are less bulky and may be packaged in airtight foil and filled with an inert gas makes storage less troublesome. The rate of deterioration is described by the hop storage index (HSI). This indicates that there is a linear relationship between the percentage of α - and β -acids lost and the formation of hard resins described by the following equation:

$$\%(\alpha + \beta)\text{-acids lost} = 110 \log(\text{HSI}/0.25).$$

Before the deteriorative changes commence, there is a lag phase, the duration of which is variety specific.

Some of the oxidation products of α -acids may contribute to beer bitterness; for example, tricyclodehydroisohumulone derived from the oxidation of humulone accumulates to concentrations of up to 0.3% in stored hops. It has approximately 70% of the bitterness of *trans*-isohumulone and may contribute up to 5% of the bitterness of beer made from such aged hops. Other oxidation products may lack bitterness but may contribute to foam stability.

The principal products of the oxidation of β -acids are hulupones. These are more bitter than α -acids. These may be formed during hop storage but also during the wort boil and may be a significant source of bitterness where hops are boiled with wort more than once, as in for

example, the production of some stouts. A multitude of other products derive from the autoxidation of β -acids, the significance of which in beers has not been reported.

See **α -acids, β -acids, hop isomerisation.**

Hops

In a brewing sense hops are constituents of the raw materials used in the brewing process to impart bitterness particularly but also other flavours to beer. They are obtained from the flower of the female hop plant. Botanically the hop plant is *Humulus lupulus*, a member of the family Cannabinaceae. Apart from *Humulus* the only other member of this family is the hemp plant *Cannabis sativa*. The genus *Humulus* contains only two other species, *Humulus japonicus* and *Humulus yunnanensis*. The first of these is indigenous to China and Japan but is not found elsewhere. It does not produce significant quantities of bittering materials and therefore is of no value to brewing. *Humulus yunnanensis* does not appear to have been subjected to any detailed studies, and information in the literature regarding its habits and biology is very sparse. It is a native of China and as its name suggests is most commonly found in the Yunnan region. *Humulus lupulus* is a native to the Northern Hemisphere. It has been exported to southern regions and is cultivated in Australia, New Zealand and South Africa.

Historical perspective

The historical origins of hop cultivation are not known but probably date to antiquity. The wild form is mentioned in ancient Greek texts as being useful for medicinal and food purposes. The use of hops in brewing probably has its origins in the area of Europe now occupied by Germany. Emanuel Gross in *Hops, their Botanical, Agricultural and Technical Aspect*, translated by Charles Salter, Scott, Greenwood and Co., London, UK, 1900, described the early history of hop cultivation. Mention is made of the donation in AD 768 of a *homularias*, or hop garden, to the monastery of St Denis by King Pépin le Bref, the father of Charlemagne. The author assumes that these hop gardens were for brewing purposes. In later centuries several other references are made to the links between hop cultivation and monastic brewing endeavours.

In another account of the history of the hop (*Hops*, R.A. Neve, Chapman and Hall, London, UK, 1991), evidence is presented which suggests that the use of hops in brewing might be traced back to Finland. Here, a translation of a saga is given, *The Kalevala*, which describes brewing with hops and barley. The saga is reputed to have a vintage of some 3000 years; although since it is part of an entirely oral tradition, there is no definitive proof for this. However, the author also points out that there is written evidence dating to AD 736 which describes a hop garden in the Hallertau region of Germany. This was tended by a person of Wendish extraction, a Slavic race originating for the southern shores of the Baltic Sea. The Slavic name for hops, *hmelj*, may be of Finnish origin and therefore possibly adds weight to the potential link between this country and the early use of hops in brewing. Further documentary records seem to confirm that the region of Europe encompassing Slovenia, Bohemia and Bavaria was the major site for organised hop cultivation, and it was from here that it gradually spread to other parts of Europe and then the other parts of the world.

Hop cultivation spread from central Europe to other areas with strong brewing traditions, for example, to Flanders in the fourteenth century. From here the practice was exported to

other countries such as the United Kingdom. Records suggest that in the case of the United Kingdom, this was in the fifteenth century, although it seems likely that this was simply a resurgence of hop cultivation as opposed to a new introduction. Archaeological evidence has shown that the hop plant is native to the United Kingdom. The introduction of hops into the United Kingdom in the fifteenth century from Flanders was apparently not greeted with total enthusiasm since Kings Henry VII and VIII both produced laws banning its use in brewing. The ban was probably based on a perceived need to protect the commercial interests of purveyors of other beer flavouring agents. Owing to public demand, this situation was temporary.

Widespread hop cultivation for brewing purposes in other parts of the world did not come until the early nineteenth century. The introductions in various countries were largely driven by settlers. Thus, hops were introduced into the United States as early as 1629 but the first commercial cultivation did not begin until 1808 in New York. Immigration to South Africa, New Zealand and Australia during the eighteenth and nineteenth centuries was responsible for the introduction of hops to these countries. In later years (nineteenth and early twentieth centuries), the popularity of beer resulted in the establishment of hop cultivation in Japan, China and India.

Use of hops in brewing

The bittering and flavour components of hops are derived from lupulin glands. These are most abundant on the bracteoles of the flowers of female plants. The bitterness is derived from resins, which are termed α -acids. In order to obtain the bitter form of the α -acid hop resins, they must be chemically modified in an isomerisation reaction. These reactions occur during the wort boil and result in the formation of bitter iso- α -acids. Hop flavour and aroma compounds are derived from essential oils, which are also found in the lupulin glands. The concentrations of hop α -acids and the spectrum of essential oils vary between individual varieties of which many hundreds are cultivated.

Hop α -acids are microbiocides and it is likely that it was for their preservative effects that they were first added to beers. Although this effect is of importance in preventing beer spoilage, hops, or products derived from them, are now used primarily to impart both bitterness and flavour to beer. Depending on the expected contribution to flavour and the form in which they are used, additions may be made at several different points in the brewing process. These may range from the kettle to the maturation tank, or even the cask. The point of addition and the intended effect is reflected in the associated brewing terminology, for example, **kettle hops** for the fraction that is added during the boil primarily to impart bitterness, **late hopping**, where flavour hops are added towards the end of the boil to ensure that volatile essential oils are retained and **dry hopping** where flavour hops are added directly to cask during racking of cask-conditioned UK-style ales.

Hops may be used in brewing in several forms. Traditionally, this was in the form of whole dried hop cones. This form of usage has several disadvantages: the product is bulky, it is difficult to handle, it contains relatively low concentrations of bittering and flavouring agents and it produces copious quantities of waste materials that must be recovered from the brewing stream and disposed of. Several processed hop products are available, which overcome many of these problems. Hops can be dried, milled and transformed into pellets. The hops may be

pre-isomerised before pelletising, in which case these products have no need to be boiled to release their bittering components. This increases the flexibility with which such products may be used. Resins and essential oils can be extracted using solvents or now almost exclusively in supercritical carbon dioxide. The extracts can be used directly as brewing ingredients, or they may be used as the raw material for further processing. Several modified hop products are now available for specific applications. For example, tetrahydro-iso- α -acids are light stable and so do not form sun-struck flavours in clear glass, and they are potent foam-stabilising agents. Essential oils can be extracted by steam distillation and used as a substitute for dry hopping.

Whole hops and the water-soluble extracts of hops contribute polyphenols to beers. It is estimated that approximately 70–80% of total beer polyphenols are contributed by malt and the remainder from hops.

H

Hop separator

Hop separators are devices designed to remove whole hops from boiled wort. Essentially they are refinements of **hop jacks (montejus)**. They are also referred to as **compression hop jacks**.

They comprise a chamber into which the unclarified wort is fed. The rate of in-feed is controlled by level electrodes. The solid hop material is retained on a screen through which the clarified wort passes and is discharged. The retained hop material is transported up into the body of the separator via a screw compression conveyor during which it is squeezed to remove entrained wort. At the end of the separator the squeezed hop material is sparged with water to recover further extract before being discharged via the top of the device. The washings are returned to the main flow of the clarified wort.

The device removes whole hop debris in an efficient manner; however, it is not capable of removing hot break. This requires the use of additional plant such as a **whirlpool**.

Hop split leaf blotch virus

See **Arabis mosaic nepovirus**.

Hop storage index (HSI)

The HSI provides a mathematical relationship describing the deterioration of hops due to autoxidation reactions during storage.

See **hop resins**.

Hop utilisation

Hop utilisation is classically defined as the proportion of iso- α -acids that appear in beer compared with the total quantity of α -acids added with the hops. Thus, the calculation takes into account the proportion of α -acids that are isomerised during the kettle boil and the proportion that are either not solubilised or are lost during the various processes that ultimately result in finished beer. Actual utilisation rates are typically within the range of 10–40%. The shortfall is a consequence of several factors. Of the total α -acids present in the hops, only approximately half are solubilised during a typical wort boil. Further losses occur when hot break is removed from bittered wort. In addition, a further proportion binds to the cell walls of yeast cells and is removed with the yeast crop at the end of fermentation and yet more may be lost during filtration.

In modern commercial brewing, the use of pre-isomerised hops is commonplace. In this case overall hop utilisation rates are usually much higher since apart from the lack of need to extract and isomerise α -acids, the pre-isomerised extracts are usually added much later in the process. Thus, some hop extracts are completely soluble and may be added to filtered bright beer. In this case the utilisation rate is 100%.

Hop varieties

There are numerous different varieties of hops each of which have their own set of characteristics. Currently between 50 and 100 varieties are cultivated commercially for brewing use. Individual cultivars are generally named, and the properties of some of these are described under their individual entries.

Historically, hop varieties with desirable properties were selected based on the plants native to particular locales. Identification of choice varieties from this native population by growers would naturally have led to their selection and so become the dominant cultivars in particular areas. Generally these would be varieties that grow well in that particular region and have desirable brewing properties. This method of selection would explain, for example, the cultivars of German **noble hops**, the names of which reflect the geographical areas where they are derived from and are now produced.

As with any commercial crop, hop growers have long sought to develop improved varieties. Early attempts were centred on classical plant breeding; thus, crosses were made from parental types with desired characteristics with the aim of producing offspring with new properties. Alternatively development of new varieties can be derived from spontaneous mutations (sports). Both of these approaches are time-consuming and somewhat imprecise with the result that many years may elapse before a new variety can be introduced into the market. Greater understanding of plant physiology, its genetic basis and relation to the brewing properties of hops has resulted in the development of more targeted approaches to crop improvement.

Several factors have influenced these developments. Centres for plant breeding maintain germ plasm collections. These aim to provide representative plants of all of the world's collection of hop plants. In this way the breeder ensures genetic diversity and has ready access to any desirable trait. Whilst traditional plant breeding relies on whole plant interactions, modern biotechnological approaches operate at the cellular level. Advances in knowledge of the biochemistry and genetics that underpin plant physiology have allowed the function of many genes of interest to be identified. Provided that the responsible genes for traits are known, the genes can be isolated and transferred into new plants. These approaches are rapid and very precise. The novel genes may be derived from other hop varieties or from entirely separate plant species. The latter allows the production of transgenic plants and has the advantage of introducing totally new characteristics. Of course, whether or not the consumer would object to drinking beer brewed with ingredients that have been made using recombinant DNA technology is a moot point.

Attempts to improve hop plants have followed two broad avenues of research: firstly, production of new cultivars that exhibit superior agricultural performance and, secondly, those that have improved brewing properties.

Examples of the first type include

- (1) improved yields
- (2) development of disease resistance, both to reduce losses or to reduce the need for pesticides

- (3) ability to cultivate desirable varieties in geographical regions to which they are not native
- (4) development of dwarf varieties that are less expensive to cultivate
- (5) development of short-day varieties that can tolerate equatorial conditions without the need for artificial illumination.

Attempts to develop new varieties with superior brewing properties have predictably been driven by the brewers themselves. In most cases they may be described as the development of hop varieties that fulfil specific requirements. Some of these requirements are real, others perhaps less so.

An example of the latter is the development of **triploid hop varieties**. Treatment of plants with the alkaloid colchicine, or similar agents, disrupts chromosome segregation and allows the isolation of tetraploid progeny. Triploid offspring can be obtained from crosses between tetraploid and diploid parents. Female plants are sterile and produce little or no seed even when fertilised. Seedless hop plants are considered desirable, at least by most lager brewers, since it is believed that components of seeds, particularly lipids, result in off-flavours when used on brewing. Whether or not the presence of seeds present a real risk is disputable; nevertheless many of the newer hop varieties are triploids.

Other developments are more real and mirror advances in the knowledge of the relationships between hop properties and beer made from them. Thus, it has long been the case that hop varieties have been described as bittering or aroma types. This reflects the realisation that aroma hops destined for late or dry hopping, either as is or via extracts made from them, are judged on the basis of the essential oil content. The content of α -acids for these types is not relevant. Conversely, where bittering alone is required, a high content of α -acids is important. This has led to the introduction of high alpha varieties and more recently super alpha types. In the latter category the content of total α -acids has more than doubled, to 15–18%, compared with conventional varieties. As knowledge has advanced regarding the relationship between perceived bitterness and hop composition, efforts have been directed towards manipulation of the concentrations of individual hop α -acids. Thus, it is claimed by many brewers that of the three principal α -acids, cohumulone imparts an unpleasant bitterness. For this reason many breeders have sought to produce hop varieties in which the α -acids contain a low proportion of cohumulone.

Hop yellow net virus

A virus that has been reported to infect hop crops in plants cultivated in western and central Europe.

Hordein

Hordeins are barley proteins. They are one of the four classes of barley grain protein, **albumins**, **globulins**, hordeins and **glutelins**. Hordeins are located in the endosperm where they seem to have a storage function. Hordeins account for 20–40% of the total protein content of the mature grain. They are one of a series of storage proteins that are found in cereals that together are termed **prolamins**. In wheat, the equivalent prolamins, gliadin and glutelins constitute **gluten**. Hordeins are distinguished from other cereal proteins on the basis that they are less soluble compared with other protein fractions such as albumins and globulins. Hordeins are solubilised only by hot aqueous ethanol in the presence of a reducing agent such as 2-mercaptoethanol.

Hordein proteins persist into beer, albeit probably in a modified form. They are believed to be involved in both beer foams and in interactions with beer polyphenols, which result in **chill haze** formation. Hordeins are particularly rich in the imino acid proline and in glutamine but poor in charged amino acids such as lysine. The hordein fraction contains approximately four- to sevenfold more proline compared with other barley proteins. Since proline groups are involved in the interactions with polyphenols that result in beer hazes, the involvement of hordeins is explained.

Barley hordeins are a group of proteins. Up to 10 bands can be distinguished on the basis of polyacrylamide gel electrophoresis and up to 40 fractions based on more discriminatory techniques. Smaller groupings are distinguished based on structural grounds. The bulk of these, types B and C hordeins, account for more than 95% of the total.

As with wheat **gliadins** there is a possibility that degraded hordeins that persist in beer might elicit adverse reactions in those people susceptible to **coeliac** and related diseases. It is claimed that quite small fragments of such molecules consisting of fewer than 20 amino acid residues can elicit a toxic response in susceptible individuals. Fragments of this size are relatively soluble and will persist through the brewing process. Whether or not the concentrations found in the majority of beers are sufficiently high to cause these adverse reactions is not clear. It seems likely that for most individuals, moderate consumption of mainstream beers, made wholly or substantially from malted barley, would be unlikely to cause noticeable symptoms. However, the risks cannot be entirely discounted.

Hordenine

Hordenine (N,N-dimethyl-4-hydroxyphenylethylamine; di-N-methyl tyramine) is an alkaloid. It has antibacterial properties and is the major alkaloid found in the rootlets of germinating barley grains, and it is liberated into wort during mashing where it forms part of the fraction of simple phenolic compounds.

Hordeum

Hordeum is the botanical name of the genus of which barley is a member. Cultivated barley is classified as *Hordeum vulgare*. Both two- and six-rowed types are placed within this grouping although the former is also referred to as *Hordeum distichon*. A third cultivated species, *Hordeum irregulare*, which is similar to two-rowed varieties, is also recognised. Many species of *Hordeum* occur in the wild. The cultivated forms are probably derived from one of these, *H. vulgare* var. *spontaneum*.

See **barley**, **barley plant**.

Horizon

Horizon is a US-bred hop variety released in 1998. It is a dual-purpose type with 10–16% α -acids but low cohumulone (17–22% total α -acids) and 1.9% total oil. It includes **Brewer's Gold** in its lineage and shares a parent with Nugget.

Horizontal leaf filter

This is a type of powder filter that comprises a cylindrical stainless steel body in which cylindrical horizontally mounted filter elements are contained. The latter take the form of mesh

discs, which are attached to a central shaft that contains the inlet and outlet mains. After removing any air by filling the filter with chilled de-aerated water, pre-coat powders are first pumped into the filter, usually via the top, where they form on the upper surfaces of each filter element. In some designs both inlet and outlet are located at the bottom. When stable pre-coats are established, unclarified beer plus body feed powder is pumped into the body of the filter. The beer is filtered as it passes through the pre-coats and filter discs and the clarified product collects in the hollow central shaft and from there is conveyed to the basally located outlet.

When the void between the plates is completely filled with powder, or the trans-filter pressure has reached the minimum permissible value, the run is terminated and any residual beer is allowed to drain out. Some designs are fitted with basal pre-coated plates, which are not used in the primary filtration but facilitate removal of these last runnings. The filter is discharged by rotating the discs such that the powder is thrown off where it falls to the base and is removed via mechanically driven ploughs.

Horizontal leaf filters have the advantage that the cake is very stable and this provides good draining properties. This usually allows changes of beer quality without intermediate water flushes. Compared with plate and frame and candle filters, horizontal leaf types have the highest productivities. Typically productivities of 5–10/hlm²/h¹ are achievable.

See **powder filter**.

HortResearch

HortResearch is a New Zealand-based company devoted to the development of fruit crops. It is wholly owned by the New Zealand Government from which it derives 60% of its funding. The remainder flows from commercial exploitation of its new cultivars. It was founded in 1992 as one of nine new 'Crown Research Institutes'.

It is associated particularly with the development of new hop cultivars. HortResearch was largely responsible for the development of seedless **triploid hop cultivars**.

Hot break

Hot break, also termed **trub**, is the solid material that forms as a precipitate during wort boiling. It is distinct from **cold break**, which is the material that, although similar in composition, is formed when wort is cooled. In a well-conducted boil, hot break takes the form of large flocs that separate easily from wort, typically in a whirlpool or hop back. An important feature of wort boiling and kettle design is the necessity to avoid high shear forces, which can lead to disruption of the large flocs of hot break with the result that very fine particles are generated which are not removed using conventional hot wort clarification techniques and consequently wort clarity is poor.

Various agents, termed **kettle (copper) finings**, may be added to assist with the formation and separation of hot break. As the name suggests these materials are added to the kettle; however, in the case of an agent such as carrageenan, this is a convenience since this material is insoluble at temperatures below 60°C. It exerts its fining effect during wort cooling and increases the formation of cold break.

The composition of hot break is shown in the following table:

Average particle diameter (mm)	30–80
Bittering substances (%)	10–20
Protein (%)	40–70
Polyphenol (%)	5–10
Carbohydrate (%)	4–8
Lipid (%)	1–2

As may be seen the major component of hot break is protein. The protein component of hot break is formed by coagulation. Precipitation via reaction of protein with polyphenols is relatively unimportant since the complexes are not stable at temperatures above 100°C. The formation and stability of such complexes is indirectly related to temperature; thus, protein/polyphenol interactions are much more important in the formation of cold break. Protein coagulation is dependent on pH since it occurs more readily at their isoelectric point. The pH of wort decreases during boiling, and the amount of protein that coagulates is less at pH values below pH 5.0. An important aspect of wort composition is to ensure that the decline in pH during boiling is not excessive.

The optimum degree of wort clarity, as determined by the proportions of trub and cold break that persist in wort at the start of fermentation, is somewhat controversial. For the standpoint of consistent wort composition and avoidance of contamination of bottom-cropped yeast with trub, it is advantageous to produce bright wort. However, trub may be of some importance to fermentation either as a source of nucleation sites for formation of CO₂ bubbles or as a source of yeast nutrition. With regard to the latter, the mineral and lipid components of trub may be significant. It is known that a proportion of Zn²⁺ ions may be eliminated from wort in the trub fraction. Since this metal ion is essential for the activity of several yeast enzymes, a shortage can result in poor yeast growth and sluggish fermentation performance. Consequently, a supplement of zinc, usually in the form of the hexahydrate sulphate, is commonly made to wort during fermenter collection. In addition, the lipid fraction of trub may include some sterol and unsaturated fatty acids, both essential nutrients for yeast growth and metabolism during fermentation under anaerobic conditions. Synthesis of these essential nutrients by yeast takes place during the aerobic phase of fermentation, and this is the principal reason for oxygenating wort during fermenter fill. In effect the quantity of oxygen added controls the quantity of sterol and unsaturated fatty acids formed, and in turn, this regulates the extent of subsequent yeast growth. The presence of uncontrolled concentrations of sterol and unsaturated fatty acids in trub may result in uncontrolled yeast growth. In this sense, at least, the ability to produce essentially trub-free wort is preferable.

Hot water extract (HWE)

The HWE is a commonly used measure of malt quality. Specifically it estimates the amount of extract that is obtained when a sample of milled malt is subjected to laboratory-scale mashing in distilled water. It is one of several similar methods used in various parts of the world. All share the common feature that the conditions of the milling, mashing and

separation stages of the test are performed under stringently controlled conditions. This allows comparisons to be made between individual samples of malts.

The HWE procedure is particularly associated with UK ale brewers and is described in the Institute of Brewing and Distilling (formerly Institute of Brewing (IOB)). Other tests are described in the methods manuals of the American Society of Brewing Chemists (ASBC) and the European Brewing Congress (EBC). The parameters that are controlled during the performance of the test are the weight of malt, the type of grind, the relative weight and volume of malt and water, the temperature and duration of the mash and the type of agitation applied during mashing. After the mashing period is completed, the wort is separated from the spent grains by filtration. The specific gravity of the wort, at a predetermined temperature, is measured. The yield of extract is calculated with respect to the original weight of malt used in the test. In the IOB test, the standard grind uses a Buhler-Miag disc mill, 0.7 mm. The specific gravity of the extract measured (expressed per litre) at 20°C using an isothermal infusion extraction of 1 kg of malt.

H

The HWE procedure and other similar tests provide useful information regarding malt quality; however, they are of small value for predicting malt performance at production scale. Apart from the fact that the test assesses only one or a few facets of malt quality, the conditions used in the laboratory are very different from those used in commercial brewing. For example, the HWE test uses high liquor to grist ratios and no effort is made to recover wort entrained in the bed of spent grains. In order to make the test more predictive, individual brewers may modify the test to make it more representative of their own particular brewing operation.

The HWE test was designed to mimic an infusion mashing procedure using a comparatively coarsely ground grist, as might be used by a traditional ale brewer.

Hot wort filtration

Hot wort can be clarified using powder filters or cross-flow filtration. In the former case the same types of filter (vertical, horizontal leaf or candle) can be used for beer filtration. Of course, grades of powder, pre-coats and body feed rates have to be optimised for this duty. In the case of cross-flow filtration, ceramic elements are needed, which are designed to cope with the relatively high solids loadings. In all cases a preliminary screening procedure is required to reduce as far as possible the solid loadings and therefore ensure long filtration runs.

These approaches are expensive both in terms of revenue costs and the initial capital investment. Even with pretreatments the filters tend to become fouled easily, and problems with microbial spoilage may also be encountered. For these reasons they are used rarely and are used only by those brewers who have concluded that fermentation performance and beer quality are improved to the extent that the investment can be justified.

Hot wort sedimentation tank

These are tanks that are used for the clarification of hot wort via simple sedimentation of suspended hot break gravity under the influence of gravity. In this regard they may be regarded as being developed from the earlier **coolships**. In this regard they are more hygienic and have a much smaller footprint.

Several designs may be encountered. Typically they comprise cylindrical enclosed vessels with a conical bottom. Cooling of the hot wort may be promoted by the provision of wall-mounted jackets through which cold water is required. In this case the heat extracted into the cooling water may be recovered. The vessels are filled from the base in a manner that minimises oxygen pickup. After a stand time, typically around 1 hour, during which sedimentation of hot break proceeds, the clarified wort is removed from the surface via a hinged take-off point. The latter is fitted with a float which ensures that only the surface layers of liquid are removed. This arrangement allows clarified wort to be removed before sedimentation is totally completed. The rate of wort take-off may be regulated by reference to a measure of turbidity. The bottom layer, which is rich in hot break, is collected separately and treated to recover entrained extract.

Hsu's *Lactobacillus* and *Pediococcus* medium (HLP)

Commercially available medium designed for the detection of *Lactobacillus* and *Pediococcus*. A nutrient medium, solidified with agar, which contains cycloheximide to inhibit the growth of yeast and sodium thioglycollate, an oxygen scavenger. The medium is made up in water and boiled, but not autoclaved, to prepare a solution. It is dispensed into sterile tubes and allowed to set. The sample is inoculated by stabbing the gel. After incubation at 28–35°C, for 2–4 days, a positive result is seen as growth in the depth of the medium. The presence of the oxygen scavenger removes the need for an anaerobic incubator or jar, and hence this represents a cost-effective approach for microbrewers where the costs of more conventional microbiological testing facilities may be prohibitive.

Hukster

A term used in medieval England for a woman who retailed beer that she had not brewed herself but rather had purchased from another brewer. Typically the latter was also a woman.

See **ale wife**.

Hull

Synonym for **husk**.

See **barley grain**.

Hüll

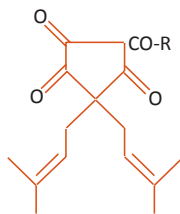
Location of a hop research institute founded in the Hallertau region of Bavaria as a result of cooperation between the German Society of Hop Research and the free state of Bavaria. Apart from a desire to develop new commercial cultivars with good aroma characteristics, it was founded largely to conduct research into diseases such as *Verticillium* wilt and downy mildew, which at that time were causing devastation to crops. An early success was the introduction of **Hüller Bitterer**. This was quickly superseded by the more popular dual-purpose variety **Perle**. This institute has been responsible for breeding approximately 75% of German commercial hop varieties.

Hüller bitterer

Variety of hops bred at the Hüll hop research institute in Bavaria, Germany. It was the first variety that was developed to be fully resistant to *Verticillium* wilt.

Hulupones

Hulupones are the major oxidation products of the β -acids of hops. They comprise hulupone, cohulupone and adhulupone (see the structure in the diagram).



Structure of hulupones, where R = $\text{CH}_2\text{CH}(\text{CH}_3)_2$, hulupone; $\text{CH}(\text{CH}_3)_2$, cohulupone; $\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$, adhulupone

H

Hulupones are bitter in nature, in fact, roughly twice the bitterness of iso- α -acids. The β -acids autoxidise during storage and hence, the concentration of hulupones increases with hop age. Oxidation is accelerated during the wort boil, and these compounds may be found in some beers and make a contribution to bitterness. Their significance in terms of beer flavour is most important where the brewing conditions favour autoxidation of β -acids, in particular where hops are subjected to prolonged boiling as in the case of some stouts.

Humularia

An archaic term dating from the ninth or tenth century for a hop garden. The terms **humuleta** and **humileta** were also used. The hop gardens were frequently associated with monasteries.

See **hops** for a discussion of the origin of hop cultivation for use in brewing.

Humulene

Humulene is a sesquiterpene which together with β -caryophyllene form the two most abundant representatives of this class of hydrocarbons found in hop oils.



Structure of humulene

The ratio of these two compounds is constant for any particular hop variety. Humulene reacts with oxygen during storage of hops to form a number of epoxides. These can interconvert and hydrolyse to give more than 30 products. These compounds are major contributors to hop aroma although the role of many individual components has yet to be resolved. The highly prized noble hops are particularly rich in sesquiterpenes, which apparently confirms their importance.

Humuleta

Archaic name for a hop garden. The variant 'humileta' is also found.

α -Humulone

α -Humulone is one of the principal hop-derived α -acids, which are the precursors of bittering components of beer.

See **hop isomerisation**.

Humulus japonicus

Humulus japonicus (the Japanese hop) is native to Japan and China. Although a member of the same genus as *Humulus lupulus*, the brewing hop *H. japonicus* produces cones with few or no lupulin glands and consequently is of no value in brewing. It is grown as a decorative plant, although it is highly invasive and considered by many to be an undesirable weed.

Humulus lupulus

The botanical name for the hop plant.

See **hop plants**.

Humulus yunnanensis

Humulus yunnanensis is a native plant of China and with *H. japonicus* and *H. lupulus* comprise the three species of the genus *Humulus*. It resembles *H. japonicus* more than *H. lupulus* and like the former produces little or no lupulin glands and consequently is of no value to brewing.

Husk

Synonyms for **hull**, **glume** and chaff. The protective outer layer of cereal grains made up of two leaf-like bracts termed the palea and the lemma.

See **barley grain**.

Huzzar

A term used in malting which describes grains in which the acrospire has grown to a length greater than the overall length of the whole grain. These are generally undesirable since the grains may be rich in enzymes but low in extract.

See **acrospire**.

HybriScan®

Proprietary system (<http://www.sigmaaldrich.com>) (last accessed 20 December 2012) designed for the rapid identification of beer spoilage bacteria or yeast based on an RNA sandwich hybridisation technique. A sample of cells is recovered by centrifugation from the test medium, either directly or after a pre-incubation enrichment step, and lysed to release the nucleic acids. The sample containing the target RNA sequences is mixed with two probes, which are both complementary to the target sequence of RNA but not to each other. When mixed the two probes and the target sequence form a complex by hybridisation. One probe, the capture probe, binds to a solid support plate. The second probe, the detection probe, has an antibody-labelled enzyme system. After removal of excess unbound material, activation of the latter system elicits a chromogenic response that is detected spectrophotometrically. Specific probes are available for yeast and spoilage bacteria such as lactic acid bacteria, *Megasphaera* and *Pectinatus*. Positive identification is claimed within 2 hours for unenriched samples or after 24 hours with pre-culturing.

Hydrocyclone

Hydrocyclones are used in brewing for the separation of hop residues and hot break from boiled wort. Commonly they are used where the wort has a high loading of hops, typically in the form of pellets (as opposed to whole hops where a **hop jack** would be used). Usually the hydrocyclone would be used as a preliminary screening step before final clarification using a continuous centrifuge. The procedure can be used for the whole wort stream or as a method for the recovery of extract from hot break collected from an earlier separation step such as a wort sedimentation tank. As an alternative to the hydrocyclone, a rotary brush strainer may be used.

Hydrocyclones are continuous devices that comprise a chamber through which the liquid to be clarified is passed. The entry point is mounted tangentially to the chamber; as the feed is introduced, a circular rotation is induced. Owing to the centrifugal forces formed within the chamber, the denser particulate and less dense liquid fractions are separated. The solid material passes downwards through the chamber and out of the exit (reject) point. The lower parts of the chamber are conical in shape, the precise dimensions of which regulate the separation capability of the device. The liquid fraction, which is less dense, moves upwards and is collected from an upper discharge (accept) point.

H

Hydrogels

Hydrogels are types of silica gel process aid that are used to improve beer colloidal stability via the removal of potentially haze-containing proteins.

See **silica gel**.

Hydrogen peroxide

Hydrogen peroxide (H_2O_2) has been used as an additive at a concentration of 0.1–1.0% to steep water in malting. It helps with breaking dormancy by virtue of its ability to function as an antiseptic agent, which reduces the levels of microbial loadings. In addition, since it releases oxygen after decomposition, it assists with providing aerobic conditions that are necessary for germination. It is now rarely used owing to its relatively high cost.

The addition of hydrogen peroxide to steep water is used as the basis of a test for assessing grain viability. In this test, also known as the **Thunaeus test**, grains are immersed in a solution of 0.75% (w/v) hydrogen peroxide and incubated for 3 days at 20°C. This treatment breaks dormancy in most grains, and the visible evidence of chitting can be used to determine grain viability. Grains that have not germinated after 3 days are rinsed to remove residual hydrogen peroxide and then have the husk, pericarp and testa removed to expose the embryo. The grains are placed on a bed of wet filter paper, and after a further period of incubation, the number of additional chitted grains is counted and added to the value obtained in the initial assessment. The additive value as a proportion of the whole is used to calculate the viability (**germinative capacity**) of the sample of grains.

See **germinative capacity**.

Hydrogen peroxide test

See **Thunaeus test**.

Hydrometer

A hydrometer is a device used for measuring specific gravity of a liquid. Hydrometers are used widely in brewing as they provide a rapid and simple method of assessing the specific gravity of worts. Typically hydrometers are used to monitor the progress of fermentation and to provide a rough indication of the gravity of worts.

Hydrometers consist of slender glass tubes that are attached to a bulbous weighted base. The thin tube is calibrated with a suitable scale. The hydrometer is allowed to float freely in a sample of the liquid to be tested. The depth at which it settles is related to the specific gravity of the liquid. Thus, the level at which the hydrometer settles is a function of its buoyancy, and in turn this is related to the density of the liquid. The greater the density of the liquid, the higher the hydrometer will settle. The precise point at which the bottom of the meniscus of the liquid intercepts the scale is taken as the measure of the specific gravity.

The precise degree of weighting in the bulb is chosen based on the range of gravities that is required to be measured. In the case of brewing, hydrometers are calibrated in **degrees saccharin**. Hence, in brewing (and for the determination of the specific gravities of sugar syrups), the hydrometers are referred to as saccharometers. A group of approximately six saccharometers would be used in a typical brewery, covering the range from high-gravity worts (1060–1120; 15–30°P) to fully fermented worts (1001–1010; 0.25–2.5°P). The majority of manufacturers provide colour codes to ease rapid selection of the appropriate model.

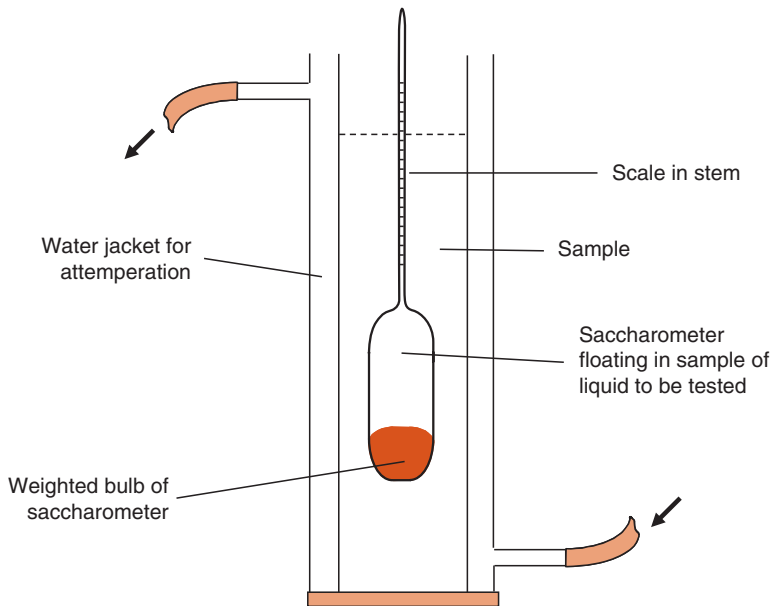


Diagram showing a saccharometer suspended in a sample within its associated sample jar

Measurements are conveniently taken using a dedicated sample jar. These are constructed of either copper or stainless steel, typically with a total capacity of approximately 500 mL. The jar is fitted with a jacket through which water can be circulated to maintain a constant temperature. After filling the vessel with sample, the temperature is allowed to equilibrate. The

saccharometer is placed into the liquid sample. When it reaches a stable position, the reading is noted together with the temperature. Gravities are usually expressed at 20°C. These values are obtained from look-up tables that provide specific gravities at a range of temperatures. When fermentation samples are used, the rates of CO₂ production can be considerable and the evolving gas can produce errors due to excessive foaming. It is important to ensure that no gas bubbles have adhered to the base of the saccharometer. This can be accomplished by imparting spin onto the saccharometer as it is lowered into the sample.

Hydrometers have a long history. An early version used was described by Robert Boyle in 1675. The first device aimed at liquid measurements was designed by Clarke and described in the *Philosophical Transactions* (March, April, 1730, 413, 278). The Richardson version of 1784 appears to be the first designed for use in brewing. In early versions the weights in the bulb took the form of lead shot or liquid mercury.

H

Hydrometers have been used for the purposes of determining liability for excise for spirits and for worts. The latter system of measurement has been used in countries such as the United Kingdom which in the past used a wort-based excise system. Several designs have been selected by different legislatures as being the standard hydrometer for use for this purpose. In the United Kingdom, the **Sike's hydrometer** fulfilled this requirement. This instrument was chosen by the UK excise authorities in 1816 based on the results of a competition to find a device that was more precise than the earlier Clarke version. It consisted of a brass or silver ball fitted to a calibrated stem. A series of weights could be attached to the ball, thereby extending the operating range of the instrument. The Sike's hydrometer remained the legal standard up until 1907. A similar device was adopted by the United States.

Hydrometers remain in common usage in brewing as a convenient means of rapidly checking liquid density, particularly for monitoring the progress of fermentation. However, more precise and automatic instrumentation tends to be used where accuracy is important, for example, the use of densitometers which have automatic temperature compensation and which rely on principles such as the degree of damping caused by a liquid on the oscillation of a vibrating U-tube.

See **densitometer**.

ρ -Hydroxybenzoic acid

A simple phenolic compound, one of the series of substituted benzoic acid derivatives, which are found in worts. Concentrations in an unboiled lager wort are reported to be of the order of 0.6 mg/L.

See **polyphenols**.

Hygiene and cleaning

The brewery is a site for the production of foodstuffs and therefore the legal regulations which govern such establishments must be adhered to. Packaged product issuing from the end of the brewing process must be free from any source of taints of chemical or microbiological origin, whether they represent an actual health threat to the consumer, or simply lead to unpalatable products. It follows that all potential routes must be eliminated which might lead to the inadvertent introduction of any foreign materials or, via the actions of microorganisms, result in their formation. Clearly, an essential part of this philosophy is that all

brewery plants must be scrupulously clean. This applies particularly to the internal parts of the plant that come in direct contact with the product and its constituent components. Since most modern commercial brewing processes are now essentially closed systems, it might be supposed that cleaning and hygiene may be restricted to these areas. This is not the case. Proper care of the external environment is also of key importance and microbiological sampling plans should include the general environment. Very high microbial counts, even with non-beer spoilage organisms, should be recognised as signs of increased risk. There have been many instances where severe microbial spoilage issues have been shown to have arisen from dirty areas of the interiors of brewery buildings. These have included infections of packaged beer with obligate anaerobes such as *Megasphaera* and *Pectinatus*, which might be supposed to not be able to survive in such locations; however, it is known that within **biofilms**, this is not the case.

There are two aspects to brewery cleaning and hygiene. Firstly, the plant must be properly designed. The best cleaning protocols are doomed to failure if the plant was not built with the thoughts of hygiene uppermost in the mind of the designer. Large breweries are complex with numerous interconnected runs of pipework, associated valve blocks, tanks and specialised pieces of equipment that often have complex hard-to-clean components. Individual pieces of equipment provided by third-party manufacturers are provided with efficient means of cleaning and sanitation (see **CIP**). This is of little value if the connecting pipework is the source of subsequent infection. The possibility of areas in horizontal pipe runs that are never completely filled because of insufficient flow rates, air pockets and poorly maintained and leaking joints must all be guarded against. Similar arguments can be made with items such as flexible hoses, again common causes of problems if not properly cleaned.

Cleaning fulfils several roles. It must remove soiling that might be a source of taints, it must disinfect where necessary and it must remove accumulations that might reduce the effectiveness of operations, for example, clogging of heat exchangers with scale or other solids. This infers that the risks of failure are not equal across the process. In the brewhouse up to wort cooling, there is little chance of microbial spoilage, and therefore the task is to keep the process plant free from the material used in wort production. High temperatures are used, which increases the risk of scale formation, and the process streams may have very high solid contents; after wort cooling, the same tasks are required and with the additional risk of microbial spoilage. In most cases, after wort cooling it is necessary to clean and disinfect. This is true within the brewery and in the premises where draught beers are consumed.

The type of brewery has an impact on cleaning operations. In small craft breweries and some larger traditional plants, much of the plant may be open to the atmosphere. It follows that the design of rooms becomes even more important; for example, see **fermentation room**. In these situations much of the cleaning and disinfection are manual processes. In larger breweries whilst it may be necessary to make some manual connections in some, in newer installations all cleaning and disinfection processes are fully automatic. The efficiency of many cleaning and related chemical agents is influenced by the temperature, and this must be controlled as needed. The action of the chemical agent may need the application of mechanical energy in order to make it effective. Cleaning agents must not be corrosive to the material to which they are applied, and since many are hazardous, appropriate safety measures must be taken.

There are a number of terms that describe the process states related to cleaning and hygiene and the agents used for achieving them. A surface that is chemically clean is one which wets completely with water to give a continuous film and does not impart any taint to any product coming into contact with it. This is achieved using cleaning agents such as **detergents**. In addition to chemical cleanliness, a surface may also be microbiologically clean, which implies the absence of microbial contamination. This will be in addition to chemical cleaning, although both processes may be accomplished at the same time. This combination is termed sanitation and is performed using **sanitisers**. Where the aim is to just sterilise the process is termed disinfection. This can involve physical treatments or chemical disinfectants.

Hyperfiltration

See **reverse osmosis**.

H

Hypochlorite

Chlorine-containing disinfectant used as a terminal sterilant and in soak tanks. Commercial preparations are supplied as alkaline solutions in which form it is relatively stable. For use, it is mixed with acid where at pH values below pH 5.0 it forms hypochlorous ions, very powerful biocides with a broad spectrum of activity. It is used at a concentration within the range of 50–300 mg/L. It has several disadvantages. The concentrate is hazardous and the active form is relatively unstable liberating chlorine. Most significantly it is corrosive, and there are concerns regarding its ability to react with organic compounds to form trihalomethanes. For these reasons its use is declining in favour of the more benign **chlorine dioxide** or ozone.

Ice beer

Style of beer which during manufacture undergoes a process of controlled freezing in a way that crystals of pure water are formed, which can be removed as ice leaving a beer with increased alcohol content. Traditional German *eisbock* beers are made in this way. The Labatt Brewing Company of Canada devised a large-scale commercial process in which green beer was centrifuged and the temperature reduced to -4°C . In the process the ice crystals were removed leaving a liquid with increased ethanol content. The initial driver for the process was a method to reduce costs of distribution of keg beers such that the concentrate could be diluted during dispense. However, it was noted that the beer had a much smoother taste, and it was found that this was a consequence of polyphenols and proteins being removed with the ice. The popularity of the new beer initiated a new beer style, ice beers which at its height captured a significant market segment of the North American beer market.

iJuba process

The iJuba process is a method used for the industrial production of a maize and sorghum beer in South Africa. It is associated with the Zulu people. It differs from other sorghum beers in being less viscous, a result of greater starch degradation than is usual for this type of beer. This is achieved by the introduction of a step that precedes the usual souring lactic acid fermentation during which the action of amylases from sorghum malt or bacterial amylases causes extensive starch degradation.

See also **Native African beers**.

IKE

An acronym for **isomerised kettle extract**.

See **hop extracts**.

Imhoff cone

Apparatus used to assess the clarity of wort. It comprises a transparent conical container made from clear plastic or glass with a capacity of just over 1 L. The walls of the container are usually graduated to allow an estimation of the relative proportions of liquid and solid sediment.

Several Imhoff cones may be placed in a wooden rack designed to hold them securely and the whole assembly placed in front of the source of diffused light to facilitate visual examination of the wort sample. A sample of hot boiled wort, usually 1 L, is decanted into the cone and allowed to stand for 5 minutes. After this time the clarity of the wort and the compactness and amount of sediment are assessed. Having multiple Imhoff cones allows sequential samples to be removed during the course of the wort boil and the efficiency of protein coagulation to be assessed.

Imidacloprid

Imidacloprid (N-[1-[(6-chloro-3-pyridyl)methyl]-4,5-dihydroimidazol-2-yl]nitramide) is an insecticide, which is an analogue of nicotine. It is one of the insecticides that may be used to treat or prevent insect infestations of crops such as hops.

Immobilised yeast

Immobilised yeast cells are defined as cells that are attached to inert surfaces or otherwise confined within a space such that they retain their catalytic activity but are not freely suspended. They can be used for processes such as primary and secondary fermentation or the production of low or zero alcohol beers in plant designed for continuous use. The development of immobilised yeast technology has been responsible for the renaissance of interest in continuous brewing processes, which has occurred from the 1980s to the present time. Commercial-scale processes based on this technology are currently in use for continuous secondary fermentation and for the production of low and zero alcohol beers by restricted fermentation. They are not used at present for primary fermentation of normal strength beers although this may be temporary.

The use of immobilised cells in brewing overcomes many of the disadvantages of continuous systems based on freely suspended cells (see **continuous fermentation** for more details). Thus, any yeast strain may be used, as opposed to the heavily flocculent types that are required for some continuous systems. It is possible to achieve very high yeast concentrations and in turn this allows the use of relatively small reactors operated at high flow rates and provides very rapid and efficient rates of the biochemical conversions associated with primary and secondary fermentation. Certainly productivities are much greater than those that can be achieved with conventional continuous fermenters. The high biomass loadings provide conditions in which other chance contaminants have difficulty in competing, and separation of product from yeast is relatively easy. Once loaded with biomass, start-up times are rapid and the ability to use several parallel modules allows flexibility. In common with conventional continuous systems, yeast handling becomes much simplified since there is less need for propagation, and cropping and storing of pitching yeast are not needed.

In common with all continuous brewing systems, there are some disadvantages. It is necessary to provide a continuous supply of wort, and this must be relatively free from suspended solids in order to prevent clogging of the bed. Evolution of CO₂ can cause disruption of some reactor beds, and at very high biomass loadings, solute transfer can be impeded. As with continuous systems the sequential nature of fermentation requires the use of multiple vessels, and even so the lack of take-up of this approach for primary fermentation is largely a result of the difficulty of matching beer flavour. As with any relatively new technology, capital costs

may be high, and because of an existing conventional plant, this type of plant is only likely to be taken up at green field sites. The low rates of CO₂ evolution make this technology very suitable for continuous warm maturation (removal of vicinal diketone (VDK)) and low/zero alcohol beer production.

Immobilised cells are defined as those that are physically confined within a particular space with the retention of catalytic activity such that they can be used repeatedly and continuously. The process liquid makes transient contact with the yeast cells, and in consequence biotransformations are allowed to occur. Growth, in the sense of cellular proliferation, is not precluded but it is not necessary.

Several methods may be used to immobilise the yeast cells. Whichever method is used the support requires to be non-toxic, capable of retaining the cells but freely accessible to nutrients and products. Mechanical strength of the support is important in some applications, and outgrowth and loss of cells should be minimal.

Simple flocculation may be used in which cells are retained in the reactor by the force of gravity against an upward flowing stream of process fluid. This is not true immobilisation since the cells are still freely suspended and at high flow rates may wash out.

Cells may be entrapped in a porous matrix that allows passage of liquid but retains the cells. Commonly gels such as calcium alginate, κ-carrageenan, polyacrylamide, agarose, pectin, gelatine and chitin are used for this application. This is a popular method of immobilising yeast cells since the carriers are inexpensive and capable of supporting high biomass loadings. Typically the gels are made in the form of disposable beads in which the yeast cells are entrapped. Beads with a diameter of 0.5–3.0 mm offer the best compromise between ease of diffusion of solid solutes and gases and biomass loadings. However, the beads have low mechanical strength and are easily damaged. They are also compressible, which can restrict fluid flow in some systems. Loss of yeast via outgrowth may be considerable. Greater rigidity can be obtained by increasing the degree of cross-linking in the beads, albeit at higher cost and more restricted diffusion rates.

Cells can be entrapped in porous materials via a process of colonisation. In this case the material consists of a solid structure in which relatively small surface pores lead into larger internal cavities. Yeast cells gain access to the cavities by the pores and there grow and form entrapped aggregates via a combination of cell-to-cell binding and surface attraction. Materials that fit into this category include sponges, glass beads, ceramics and silicon carbide rods. The advantages of this type of support are that they have high mechanical strength and are resistant to compression. Since the cells are protected inside the cavities, losses of cells via outgrowth are small and reactors with high rates of liquid flow can be used. The enclosed nature of the environment in which the cells are located places some restrictions on diffusion and indeed some studies have concluded that cells at the centre of such beads probably take little or no part in biotransformations owing to restrictions of access to nutrients and dispersion of metabolic by-products. In similar fashion the beads are more difficult to regenerate because of the need of cleaning agents to gain access to the internal porous structures.

Yeast cells have negatively charged surfaces and will bind to inert surfaces with a net positive charge via electrostatic forces. In addition, hydrophobic interactions may also be important as well as cell-to-cell attachments. Several inert materials with high mechanical strengths can be used. These include various ceramics, wood chips, resins, cellulose, cotton fibres and

kieselguhr. Positive ligands may be bonded to the surface of the support material to promote electrostatic binding of yeast cells. The major advantage of this method is the ease of access of immobilised yeast cells to the process liquid. This is at the expense of relatively high rates of cell loss. The latter can be reduced by attaching cells via covalent bonding, such can be achieved with glutaraldehyde cross-linked gels; however, these methods are also associated with cytotoxic effects. The most commonly used support of this type for brewing applications is diethylaminoethyl (DEAE) cellulose. This is a cellulose material that has been given a net positive charge via derivatisation with an ionisable tertiary amino group (diethylaminoethyl), which bears a positive charge at neutral pH values. This material is capable of binding quite high biomass loadings, approximately 500×10^6 cells per gram of carrier. It is supplied in bead form, and these are relatively robust and can be regenerated by treatment with hot dilute solutions of NaOH.

I Yeast can be immobilised by the use of semipermeable membranes that retain cells but allow passage of gases and dissolved solutes. Cells may be bound to the inner surface of the membrane or be freely suspended in the cavity that is enclosed by the membrane. Although simple in design, such reactors suffer from poor transfer efficiency since the membranes tend to hinder diffusion.

With regard to brewing applications, beads made from DEAE cellulose or glass have proven most popular based on their ability to withstand the rigours of the production environment and provide acceptable performance. The majority of commercial bioreactors are based on these materials. Promising pilot-scale trials have been performed using reactors that contain ceramic supports in the form of cylinders, which contain channels containing a matrix of silicon carbide in which the yeast cells are entrapped. The claimed advantages of this approach are high rates of mass transfer, ease of removal of CO₂, reduced rates of clogging and ease of cleaning.

Several reactor types can be used. Most commonly these are of the packed- or stirred-bed type. Fixed-bed types take the form of vertical columns in which the support material is retained by a supporting disc. The direction of flow is upwards to prevent compression and clogging. Even so these reactors are liable to channelling where the liquid feed tends to find the easiest route through the bed but with inefficient contact with the support medium. Similarly, gas breakout can disrupt the bed, and with soft supports, rates of diffusion are poor as are rates of dispersion of heat. On the other hand, the reactor is simple, and it is possible to establish plug flow in which, in theory the individual stages of primary fermentation could be mimicked.

Fluidised-bed types are similar, but a continuous pumped loop system allows the bed to be lifted off the supporting structure and thereby prevent clogging. The feed is into the loop via the base of the column. In this type of reactor the rate of inflow of liquid is at a velocity that exceeds the weight of the packed material. In this situation the bed becomes 'fluidised' and mass transfer rates are commensurately higher. A similar end point can be achieved using a vessel fitted with a means of mechanical agitation. These vessels are termed continuous stirred tank reactors (CSTRs). Care must be taken to ensure that the impeller does not damage the support material. Where the support material is relatively fragile, for example, in the case of gel-type beads, gas lift reactors have been proposed. These comprise a cylindrical reactor that is fitted with a centrally mounted hollow 'draught tube'. A stream of air or CO₂ is fed into the base of the draught tube, and this causes an upward flow of liquid. When this reaches the

top of the vessel, it is forced back to the base via the gap between the outside of the draught tube and the internal vessel wall. The infeed is via the base and the product is continuously removed via a top-mounted outlet.

In commercial systems used in brewing for low or zero alcohol beers, fluidised- or fixed-bed reactors containing DEAE cellulose beads are commonly used. A low-fermentability wort is used, and this is filtered and subject to a prolonged boil to reduce unwanted volatile aldehydes and carbonyls to low concentrations. In operation, care is exercised to maintain strict anaerobiosis, and the temperature is held at approximately 2–4°C. Under these conditions the yeast reduces the undesirable carbonyls responsible for ‘worty’ characters, principally 2-methyl propanal, 2-methyl butanal and 3-methyl butanal. Glucose and fructose levels increase during the process, and this is at the expense of sucrose hydrolysis. Ethanol levels remain at very low concentrations and some limited synthesis of higher alcohols and esters occurs.

Commercial continuous maturation systems using immobilised yeast reactors have been in use since the early 1990s, principally in Finland. In these systems, green beer from primary fermentation is passed through a continuous centrifuge to reduce yeast loadings. The beer is heated at 90°C for 7 minutes to convert the pool of α -acetolactate to free diacetyl. After cooling to 15°C, the beer is passed through a bioreactor containing yeast cells attached to DEAE cellulose or a glass support. Contact time is 2 hours and during this phase free diacetyl is converted to acetoin and 2,3-butanediol. Beer issuing from the reactor is cooled to –1 to –2°C and passed on for colloidal stabilisation, filtration and packaging.

Impedimetry

System of measurement based on changes in the electrical properties of liquids. It is used for the detection of microorganisms. Microbial growth and metabolism, together with the accompanying assimilation of nutrients and generation of products, many of which are charged, change the electrical composition of the medium. Three related parameters may be used as the basis of measurements: the resistance to passage of an electric current (impedance), the ability to transmit a current (conductance) or the ability to retain an electrical charge (capacitance). The growth medium must be suitable to support microbial growth and have suitable electrical properties, and the growth conditions such as temperature must be carefully controlled.

Changes in the electrical properties of the medium require growth, and bespoke apparatus based on these principles has been developed to replace traditional forcing tests, for example, the now defunct **Malthus Detection System** apparatus and the still available **Bactometer**[®] (<http://www.biomerieux.ch>) (last accessed 23 December 2012). In brewing applications they can be used to detect spoilage bacteria in samples of beers and with suitable media with suppressing additives the presence of bacteria in pitching yeast. Results can be obtained in several hours as opposed to days; however, the sensitivity is relatively low (*ca.* 10⁶ cells/mL).

See **rapid microbiological methods**.

Index of protein modification

This is defined as the ratio of permanently soluble nitrogen and the total nitrogen of malt using wort produced using the standard procedure as described by the Institute of Brewing and Distilling. The measure, also termed the **coefficient of modification**, is descriptive of malt modification. Lloyd Hind [Hind, L. (1948) *Brewing Science and Practice*, Vol. 1, pp. 247–249,

Chapman & Hall, London, UK] describes a scale of acceptability for various malts. Values for this parameter were given for two-rowed and six-rowed malts, respectively, as >41, 34, very fully or over-modified; 36–40, 30–33, well modified; 32–35, 26–29, moderately modified; and <31, 25, low or under-modified. The measure is now largely defunct.

Indian rice beer

Generic name for an alcoholic beer-like beverage made from rice. It is the most commonly consumed alcoholic beverage in Asia. Several names are used to describe the beverage depending on the precise geographical location. These include tapé ketan (Indonesia) and pachwai and ruhi (India).

The process of manufacture is reminiscent of that used for sake. Preparation involves an initial preparation of a starter in which boiled rice is inoculated with a mixture of fungi and yeasts derived from rice and other plant sources. The starter is used to inoculate boiled rice grains suspended in water contained within an earthenware jar. After approximately 24 hours the fermentation liquor is collected for consumption.

India Pale Ale

India pale ale, often referred to simply by its initials IPA, is a style of **pale ale** that originated in the United Kingdom during the eighteenth century. The beer is highly bittered and produced using top fermentation with pale malts and with water that is hard and of a composition which resembles that found naturally in Burton on Trent.

The name refers to the fact that historically, the beer was exported from the United Kingdom to India during the period of the Raj. The beer was transported by ships of the East India Company supposedly because its highly hopped nature made it particularly resistant to the rigours of the long sea journey. Whether this beer style was especially durable compared with other contemporary beer styles does not appear to have been the subject of direct experimental testing. Furthermore, the precise chronology of how the trade arose and the importance of the various participants are subject to dispute; however, it is certainly true that the beer style is most associated with Burton on Trent. In this centre of brewing excellence, the hard nature of the local water with its high content of gypsum is particularly suited to the production of this style of beer. Supposedly the Burton Brewers entered the Indian export market in response to the fact that the then existing Baltic market was rendered inaccessible by the Napoleonic wars. The beer was exported via the London docks, and its subsequent popularity in both the domestic and export markets provided the impetus for several major London brewers to relocate to Burton on Trent. The rise in popularity of the relatively pale and well-hopped pale ales of which true IPA can be viewed as a premium example, was responsible for the decline in the sale and consumption of darker porters and stouts such that '**bitter**' became the predominant beer associated with the United Kingdom.

Initial heat

Initial heat is a largely archaic term used for infusion mashing in traditional ale production in the United Kingdom. It is the temperature of the mash measured in the mash tun shortly after the completion of mashing-in.

See **mashing**.

In-line keg racker

See **keg filling**.

Institut Francais des Boissons de la Brasserie et de la Malterie (IFBM)

The IFBM or French Institute of Brewing and Malting (<http://www.ifbm.fr>) (last accessed 23 December 2012) was founded in 1893 and was formerly known as the Brewing School of Nancy, the city where it is based. It offers teaching courses in brewing, malting and other disciplines relevant to the industry. It possessed extensive pilot-scale brewing and malting facilities. In 1994 it formed a daughter company, Qualtech, which provides analytical services. It works in conjunction with the **French Barley, Malting and Beer Committee** (CBMO) to perform the testing on which the latter bases its decisions regarding accreditation for use in brewing of new malting barley varieties.

Intensive temperature-programmed mashing

Intensive temperature-programmed mashing is a German technique that is designed to produce highly fermentable worts. It is used to produce a beer that has a low carbohydrate content but where the use of exogenous enzymes, which can be used for the hydrolysis of dextrins, is prohibited.

The process is essentially that used in conventional temperature-programmed mashing but with a large number of individual stands in which the upward shifts in temperature are relatively small. A typical programme may be 30 minutes at 50°C, 45 minutes at 62°C, 45 minutes at 65°C, 30 minutes at 68°C, 30 minutes at 70°C, 15 minutes at 72°C followed by finishing and wort collection at 74°C.

This intensive programme provides the maximum opportunity for saccharification and hence provides wort that is highly fermentable. Even so some residual dextrin may still be present in the clarified wort, and in order to reduce this in concentration without recourse to enzymes, powdered diastatic malt is added to the fermentation.

Internal cask washer

The name given to the device used for washing the interior of a cask prior to it being filled. In small brewing operations this remains a largely manual process. Where larger throughputs are needed, an automatic system is used. The operation first requires the removal of beer residues, old labels, shives and keystones and external cleaning. This is followed by cleaning of the interior together with treatment with steam to reduce microbial contamination. The processes used do not sterilise but reduce microbial loadings sufficiently to ensure appropriate performance during cask conditioning and dispense.

Automatic internal washers usually take the form of moving beams and associated cask handling devices, which pick up dirty containers, transport them through cleaning stations and place them in an appropriate orientation as they pass through sequential steps that remove debris, wash and drain the casks and finally deposit them at the collection point for filling. Cleaning requires the use of hot water, which must be at a temperature of at least 80°C, and sprays capable of delivering a force of 80 bar. The water may be supplemented with acid or alkali, and partial recovery systems can be used in the interests of economy. As part of the

cleaning process, hot detergent may be used on external surfaces, and after cleaning and rinsing, the interior of the casks is subjected to a final treatment with steam.

Internal wort heating systems

Internal wort boiling systems are those where the heating apparatus is located inside the kettle. Typically they consist of bundles of vertically arranged pipes enclosed within a chamber, which is supplied with steam.

See **wort kettle**.

International Barley Genome Sequencing Consortium (IBSC)

An organisation formed in 2006 (<http://barleygenome.org>) (last accessed 23 December 2012) and charged with characterising the whole genome of the barley plant (*Hordeum vulgare* L). The consortium was founded by representatives of research groups from Australia, Finland, Germany, Japan, the United Kingdom and the United States.

Release of the non-repetitive portion of the genome is expected to be completed by 2011.

International Bitterness Unit (IBU)

See **bitterness**.

International brewing awards

Name given to a periodic competition, currently held in Burton on Trent, UK, in which brewers may enter commercially produced beers, in various categories, to be judged via blind tasting by a panel of industry experts (<http://www.brewingawards.org>) (last accessed 23 December 2012). The competition is styled by the organisers as being 'the Oscars of the brewing industry' and those which are given awards may advertise the fact that they have been judged, by fellow brewers, to produce outstanding commercial products of recognised beer styles.

The earliest incarnation of the competition, a UK event only, dates to 1886 and was held in the Agricultural Hall at Islington in London, UK. Interestingly, for aficionados of real ales of the two classes, one was for beers made with at least 15% gelatinised rice malt or torrefied barley malt, the second was for beers brewed with at least 10% gelatinised rice malt. The 1886 competition attracted more than 100 entries. The 1930 competition featured 800 beers with separate categories for mineral waters and ciders. By the 1960s entries from Europe and Commonwealth countries were accepted and the venue moved to Burton on Trent, although in 2005 it was held in Munich at the Drinktec exhibition. After a short break the newly styled 'International Brewing Awards' was instituted and the 2011 competition, held in Burton on Trent, attracted some 800 entries distributed amongst 32 classes.

International Centre for Alcohol Studies (ICAS)

ICAS (<http://www.icap.org>) (last accessed 23 December 2012) is a non-profit-making organisation funded by several leading producers of alcoholic beverages. The founding members were Asahi Breweries, Bacardi-Martini, Beam Global Spirits and Wine, Brown-Forman Corporation, Diageo plc, Heineken N.V., InBev, Molson Coors, Pernod Ricard, SABMiller plc, Scottish and Newcastle. It was founded in 1995 by Marcus Grant.

The stated aims of the organisation are to promote the understanding of the role of alcohol in society and to prevent alcohol abuse via a programme of sponsored research and communication.

International centre for brewing and distilling

Centre for teaching and research in brewing and distilling located at Heriot-Watt University on Edinburgh, UK (<http://www.sls.hw.ac.uk/research/international-centre-for-brewing-distilling.htm>) (last accessed 23 December 2012).

International hop growers convention

As association founded in 1998 with a secretariat based in Celje, Slovenia, and with the aim of promoting the interests of the international community of hop growers. Activities include the collation of data regarding hop crops (acreage, varieties, prices, etc.), the promotion of scientific research relevant to hop production and the maintenance of a database detailing technical developments in hop production. The membership is international.

Further details may be found at <http://www.hmelj-giz.si/ihg/> (last accessed 17 February 2013).

Inversion point

The inversion point describes the temperature of beer at which its density is maximal. For most beers this temperature is in the region of 3°C. It has great significance in terms of the management of high-capacity fermenting and cold conditioning tanks. The inversion temperature in °C (T_{MD}) can be calculated using the following formula:

$$T_{MD} = 4 - (0.65 RE - 0.24A),$$

where RE is real extract (°P) and A is the concentration of ethanol (w/w).

Water is most dense at 4°C. At temperatures below this value, it will tend to sink, and conversely, at values greater than this, it will tend to rise. As indicated in the relationship given earlier, the presence of alcohol and extract depresses this value, hence the range of 2–3°C. This value is close to that used during the cooling phase at the end of primary fermentation where yeast is allowed to settle at the base of closed fermenters such as **cylindroconical fermenters**. At the inversion temperature the movement of beer due to natural convection currents ceases. It follows that it is possible to have beers with the same density but different temperatures and that in large vessels stratification is possible. In order to avoid this in the case of large cylindroconical vessels, it is common practice to incorporate small mechanically driven stirrers to avoid the occurrence of stratification.

Invertase

Invertase (EC 3.2.1.26; β -D-fructofuranoside fructohydrolase, sucrase) is an enzyme that catalyses the conversion (or inversion) of sucrose into fructose and glucose. The enzyme may be used to produce invert sugar from sucrose, although chemical acid hydrolysis is more usual.

Invertase is found in brewing yeast strains. The production of invertase is dependent on SUC genes. A constitutive cytoplasmic form of invertase is produced whose function is unknown. A glucose repressible form occurs in the yeast cell wall or periplasm. This enzyme

is responsible for sucrose hydrolysis during fermentation. The activity of this enzyme is responsible for the transient increase in glucose concentration that may be observed to occur in the early stages of some brewing fermentations.

Invertase test

A relatively crude test carried out to ascertain if beer has been pasteurised. It relies on the presence in beers of the enzyme invertase, which is derived from yeast cells. In pasteurised beers the heat treatment is sufficient to denature the enzyme and consequently it cannot be detected. A sample of the beer is supplemented with sucrose and incubated at room temperature for 30 minutes. After which the formation of glucose can be detected by immersing a test strip in the beer, which contains glucose oxidase and a dye that reacts with glucose to give a green-coloured product. The test is of qualitative value only.

Invert sugar

Invert sugar is a mixture of glucose and fructose. It is prepared from the hydrolysis of sucrose. The process is termed inversion, hence the name. The cleavage of sucrose to fructose and glucose is catalysed by the enzyme invertase (EC 3.2.1.26; β -D-fructofuranoside fructohydrolase, sucrase). This enzyme may be used to manufacture invert sugar, although this route is not typical because of cost considerations; instead, acid hydrolysis using sulphuric or hydrochloric acids is more common. After hydrolysis the product is neutralised, decolourised and purified with charcoal and then concentrated to give a syrup. In this form it solidifies when cooled and for use as a liquid must be stored in tanks, which are heated to approximately 50°C. If it is pumped via mains, the pipework must also be heated to prevent solidification and blockage. Alternatively invert sugar may be supplied in blocks as a solid material and pre-dissolved in water prior to use.

For brewing applications invert sugar may be used as an adjunct; alternatively it may be used as a priming sugar. Liquid syrups may be slightly coloured (30–100 EBC units) depending on the degree of purity. The coloured materials are melanoidins formed during inversion via reactions between sugars and nitrogenous impurities. The coloured impurities and related flavours can be the reason for choosing the use of this sugar material.

See **priming**.

Invisible haze

The somewhat paradoxical term applied to beer hazes in which the average particle size is less than approximately 0.5 μm and therefore not visible to the naked eye. Although not directly visible, these very small particles cause some light scattering with the result that the beer lacks brilliant scattering and takes on a dull appearance. The name was coined to explain the observation that where such particles are present, nephelometric analyses of beer hazes based on light scattering at 90° can give significant readings. The synonymous term **pseudo-haze** is also used, and perhaps this is a more acceptable description of this phenomenon.

See **beer hazes**, **nephelometry**, **haze meters**.

Iodine test

The iodine test is used to gauge the progression of starch breakdown and release of fermentable sugars during the mashing phase of wort production. Solutions of iodine react with helices

that are formed by the long chains of glucose units that occur in the amylose and amylopectin molecules in starches. In the case of amylose molecules, the complex with iodine is a deep blue-black colour, whereas with amylopectins the complex is red-violet in colour.

The test is performed by taking a sample of mash and adding a few drops of iodine solution and noting any colour change. Visualisation is improved by the use of a white glazed ceramic tile. The colour and intensity of the reaction with iodine is diagnostic of the progression of starch breakdown and saccharification. Deep blue black indicates the presence of high concentrations of amylose. Deep red/brown indicates high concentrations of limit dextrans and large amylose fragments. A red/pink colouration indicates that starch breakdown has progressed to the point at which some larger dextrans remain. Conversion is completed when the natural yellowish colour of the iodine is unchanged.

The iodine test provides a quantitative guide only. Lipid inclusions that naturally occur in starches prevent reaction with iodine and may lead to underestimates of starch conversion. This can be overcome by pretreatment with a solvent such as butanol.

Iodophores

Name given to iodine-containing biocides. Iodine is a powerful biocide, and it is used as a disinfectant in terminal sterilants in rinse waters and in soak tanks and as a spray for surface disinfection. Iodine concentrates are activated by mixing with a surfactant. The resultant working solution is effective at an iodine concentration of *ca.* 10 mg/L. At higher concentrations it is corrosive and can impart taints where residues come into contact with the product. For these reasons alternatives such as chlorine dioxide and ozone are gaining popularity.

Ion exchange

From a brewing standpoint, ion exchange describes the processes used in the purification of water in which undesirable ions are removed by attachment to resinous materials as the water passes through beds of a support material, the structure that contains charged groups to which the ions become bound. In the attachment process the undesirable ions are exchanged for substitutes that are acceptable for the purposes for which the treated water is to be used.

Three types of ion-exchange processing are commonly used for the treatment of brewing water. These are removal of bicarbonate ions to reduce water alkalinity, water softening by removal of substituting sodium ions for those of magnesium and calcium or full demineralisation of water. In addition ion-exchange treatments are also occasionally used to remove nitrate ions from water.

The resins are either naturally occurring, for example, zeolites, or now more usually, artificial polymers, either polyacrylamides or polystyrenes, specially designed for the task. The resins are supplied in the form of beads that have the desired properties of porosity, mechanical strength and large surface area for binding the target ions. Two types of resins are used, which are designed to remove positive or negative ions, hence cationic and anionic exchange resins, respectively. Cationic types contain sulphonic acid residues that bind cations in exchange for hydrogen ions. Anionic types contain quaternary ammonium groups in which hydroxyl ions are released in exchange for negatively charged ions.

The appropriate resin is chosen for the required task. In the case of complete demineralisation, both cationic and anionic resins are used in combination, either in discrete or in

combined beds. The water requires some pretreatment prior to ion-exchange purification. All traces of iron and manganese must first be removed as these can give rise to slimes that can block the resin beds. Chlorine must also be removed as this can cause deterioration of the beads.

For de-alkalisation treatments, a weakly acidic cationic resin is used in which calcium and magnesium ions are exchanged with hydrogen ions and thereby release CO₂, which is released in a subsequent gas scrubbing step. Water softening is achieved by passage through a strongly acidic cationic exchanger in which calcium and magnesium ions are exchanged for sodium ions. For complete demineralisation, a combination of strong and weak acid cationic exchangers is used followed by the removal of anions using weak basic anion exchangers.

After use the resins required are to be regenerated using treatments that remove the bound ions and any other occluded material and rebind the exchange ions. The precise regeneration treatment depends on the type of resin. Weak acid cationic resins are regenerated by treatment with mineral acids. Sodium forms of strong acidic cationic exchange resins are regenerated by treatment with NaCl. Anion exchangers are regenerated by treatment with NaOH.

See **water** and **reverse osmosis**.

IPA

IPA is an acronym that stands for **India pale ale**.

Irish Brewers Association

Trade association of the brewers of the Republic of Ireland. It was founded in 1904, and its members account for more than 85% of the country's total beer production. Further information can be obtained at <http://www.irishbrewersassociation.ie> (last accessed 23 December 2012).

Irish coffin box

The name given to a beer dispense unit that consists of a bar-mounted box, often made from hardwood, with brand plaques on the consumer facing side and an integrated drip tray. Three to six dispense taps are fed into each unit.

See **T-bar beer dispense unit**.

Irish Moss

Irish moss is the common name for the marine red alga *Chondrus crispus*. It is also known as carrageen. It contains the polysaccharide κ-carrageenan, which is used as a kettle fining agent.

See **kettle finings**, **κ-carrageenan**.

Isinglass

A fining agent, derived from fish swim bladders that is used to promote the sedimentation of yeast cells. It is derived originally from the sturgeon but now more usually tropical estuarine species. These have large swim bladders, a necessity for life in waters subject to large variations in density. The swim bladders are largely made up of very pure collagen molecules. The raw dried bladders are allowed to react with a dilute acid solution, usually tartaric, malic or sulphuric. The process is known as cutting and results in a viscous solution, which contains collagen. Various subsequent purification steps may be performed to yield solutions, pastes

or powders in which purity relates to cost. The active collagen molecules take the form of very large triple helices. These bear positive charges that interact with the negatively charged cell surface of yeast cells. The exact mode of binding is not fully understood but may involve the formation of bridges between NH_3^+ groups on the collagen molecules and negatively charged carbohydrate groups on the yeast cell surface. The result is the formation of large aggregates of collagen and attached much smaller yeast cells. In this way sedimentation of yeast cells is promoted. Isinglass finings are relatively unstable and with time degrade to give gelatine, which has no fining action. Aside from their ability to sediment yeast cells they also remove some phospholipids and fatty acids. Since these are foam negative the result is an improvement in beer head performance.

Isinglass may be used to clarify cask beers, usually by direct addition to the cask; alternatively, they may be used in conditioning tanks or even fermenter. They are most associated with the United Kingdom but are also commonly used in countries such as Africa and Australia.

Iso- α -acids

Iso- α -acids are the principal hop-derived bittering components of beers.

See **hop isomerisation**.

Iso- α -adhumulone

Iso- α -adhumulone is one of the principal hop-derived bittering components of beer.

See **hop isomerisation**.

Iso- α -cohumulone

Iso- α -cohumulone is one of the principal hop-derived bittering components of beer.

See **hop isomerisation**.

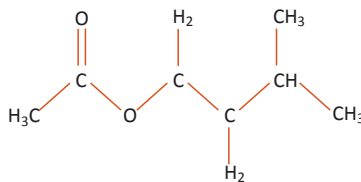
Iso- α -humulone

Iso- α -humulone is one of the principal hop-derived bittering components of beer.

See **hop isomerisation**.

Isoamyl acetate

Ester produced by yeast during fermentation with the structure as shown in the figure. It has a flavour and aroma of pear drops and is probably the most important yeast-derived ester. It has a flavour threshold in beer of approximately 1 mg/L and occurs in beer at concentrations within the range of ca. 0.3–4.0 mg/L.



Structure of isoamyl acetate

See **esters, yeast and beer flavour**.

Isoglucose syrup

See **high-fructose corn syrup**.

Isomerised hop pellets

See **hop pellets**.

Isomerised kettle extract

Hop preparations that contain pre-isomerised alpha acids, often abbreviated to IKE. Since they do not require extensive heat treatment they can be added later in the boil and therefore improve utilisation rates.

Japanese hop

See *Humulus japonicus*.

Joala

A native African beer made from sorghum and native to Lesotho.

See **Native African beers**.

Jonsson drum malting system

An early design of drum malting in which attemperation of the germinating grain was accomplished in part by circulating cold water through the shell of the cylinder and several internal elements. This reduced the need for the forced flow of air characteristic of drum malting systems (by some 70%) and which if poorly controlled can result in drying of the grain bed. The drums were made to rotate at a rate of 1 revolution in 45 minutes using an oscillating system in which after each 1.25 revolution, the direction was reversed.

See **drum malting** and **pneumatic malting**.

Josef Groll

See **pilsener**.

Jumping beer

Synonym for **gushing** beers.

Jump-mashing

Jump-mashing is a German mashing technique where it is known as *Springmaisverfahren*. It is used for speciality beers in which the wort is designed to have a low fermentability.

The mash is collected at 35–40°C and stirred continuously after which boiling liquor is added during a period of 15 minutes such that the temperature is increased to *ca.* 72°C. This regime allows the mashing enzymes to remain active for just a short period of time such that starch gelatinisation and liquefaction occurs but saccharification is limited because the

saccharifying enzymes are rapidly denatured and inactivated. The resultant wort has a high dextrin content but a low fermentability (attenuation limit of approximately 40%).

Jungbukett

German word meaning 'young aroma' and applied to the aroma of fresh wort, in particular, the undesirable volatile components that are removed during wort boiling and subsequent processing.

Juniper

The berries and twigs of the juniper plant, *Juniperus communis*, have been used for beer flavouring. They are used for flavouring the traditional ale of Finland termed *sahiti*.

See **gruit**.

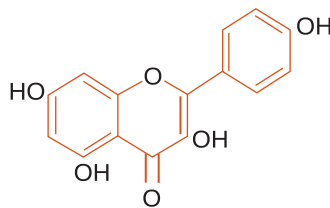
K

K

Kaempferol

A flavonol polyphenol found in beer and derived from hops where it usually occurs as a glycoside (see accompanying diagram for the structure).

See **polyphenols**.



Structure of kaempferol

Kaffir beer

A pejorative term for beer of native African origin.

See **native African beers**.

Kafirin

Kafirins, also known as sorghumins, are prolamin proteins that occur in the grains of the cereal sorghum. They are the equivalent of hordeins in barley.

Karyotyping

Method of yeast strain identification using genetic analysis based on the relative mobility of whole chromosomes using pulsed field electrophoresis.

See **yeast differentiation**.

Kashiri

Name given to manioc beer by native tribes of French Guiana and Brazil.

See **manioc beer**.

Kauri pine

Species of pine tree native to New Zealand the wood of which was a popular choice for the construction of traditional UK square fermenters. The wood was most suitable for unlined vessels owing to its durability, very close grain and freedom from knots.

Keeve

See **kieve**.

Keg

A container developed in the United Kingdom during the 1960s and used for draught pasteurised, chilled and filtered beers. The containers have the advantage of being able to allow for dispense of beer over a period of time, significantly longer for that of casks, weeks versus days. Kegs may be of various capacities ranging from 10 up to 163 L. The 11 imperial gallon, 50-L size, is most commonly used. Kegs were originally made from an aluminium alloy, called H₃O, which contained 0.7% manganese and 0.9% magnesium and lined with an epoxy resin. Although some still exist, aluminium kegs have been largely replaced by those made from type 304 ferritic stainless steel (containing 18.5% chromium and 9% nickel). Although stainless steel kegs are heavier than aluminium ones, they are more robust and provide a more inert surface. Thus, aluminium kegs are liable to elution of Al³⁺ ions and they cannot be cleaned with alkali-based detergents because hydrogen gas is generated. In addition, because of the relatively low melting point, theft and subsequent smelting is a perennial problem.

Kegs are designed to withstand hydraulic pressure, but with reference to the pressure regulations they are not classified as pressure vessels. They comprise cylinders to which are welded top and bottom protective chimes (chimbs). The top chime has hand holds to facilitate manual handling. Unlike casks kegs have a single aperture located in the centre of the top dome which is used for cleaning, filling and dispense. The aperture contains a threaded bush, termed a Barnes neck, or bush. The thread takes a valved fitting called a spear or keg extractor. The spear consists of a hollow tube that extends down to the bottom of the keg. The latter has a central well or dimple into which the base of the spear extends and so ensures a minimum of ullage. The junction between the spear and the top of the keg comprises a synthetic gas-tight gasket. The top of the spear contains two concentrically arranged spring-loaded valves. The outer valve allows the entrance of an inert gas, either CO₂ or a CO₂/N₂ mixture, and as a result of pressurisation beer exits the keg via the inner valve.

Keg spears are not designed to be removed other than for repair by appropriately qualified engineers. In the filling operation, which is automated, a leakage check is first made to ensure a good seal. In transit the head of the spear is protected by a plastic cap which bears branding information. Dispense of beer is accomplished by attaching a bayonet-type head to the top of the spear. Several designs are in use many of which are not interchangeable; however, all share in common that when the dispense head is securely fitted the valves are automatically opened to allow entry of the dispense gas and exit of beer.

Prior to filling beer is made microbiologically stable via passage through an in-line flash pasteuriser. Empty kegs are first checked for fitness to fill by carrying out a pressure test and checking the security of the attachment of the Barnes bush. Old labels are removed from the exterior of kegs by washing with hot detergent. The interiors of kegs are cleaned and sterilised

prior to filling using a machine called a **keg racker**. In the washing phase the kegs are usually inverted and hot water and detergent are forced in via the spear. Prior to filling the kegs are sterilised with steam and air is removed via counter-pressuring with CO₂ or a mixture of CO₂/N₂. Beer enters the keg via the spear and the counter gas exits via the valve used to admit gas during dispense. The volume of beer added is regulated either by weight or more usually via a volumetric controller. After filling the kegs are labelled and the Barnes bush is fitted with a plastic cap.

See **keg racker**.

Keg cooler

A refrigerated box built to contain one or a small number of beer kegs. This is designed for use in low-throughput accounts or underbar where a **cellar** or a cold room is unavailable.

Keg drop test

A test used to check the robustness of beer kegs. The test simulates the effects on integrity of dropping a full keg from a height of 1.5 m onto a concrete surface at an angle of 45°. Kegs should be able to withstand this without damage to the chimbs and rolling rings.

Keg filling

Keg filling involves packaging chilled, filtered and microbiologically stabilised beers into clean and sterile kegs with a specified liquid volume at a desired level of carbonation and pressure. Both ales and lagers may be filled into kegs. Operations may be largely manual or fully automated. Small units are capable of filling 20–30 kegs per hour; larger automatic rackers can handle up to 2000, or more, kegs per hour. Before packaging the beer is prepared to ensure it meets all specifications. Typically carbonation levels are of the order of 1.5–2.5 vol (3.0–5.0 g/L). Occasionally for **smooth flow beers** lower carbonation levels are used together with a proportion of dissolved N₂. Before packaging the bulk beer is usually rendered microbiologically stable by flash pasteurisation. More rarely it may be cold sterile-filtered. Since kegs are returnable containers they must be cleaned and sterilised before refilling. Before this can happen the integrity of the kegs must be tested. The condition of the keg and its component parts is checked as is its ability to withstand pressure. The exterior surfaces of those which are deemed satisfactory are cleaned and old labels are removed by treatment with hot detergent.

The filling plant is termed a **keg racker** and is provided with facilities for keg internal washing, sterilisation and filling. Empty kegs are delivered on pallets to a de-palletiser. All operations take place with the spear *in situ*; the keg is usually inverted during the cleaning cycles for ease of draining and may be inverted or upright for filling. The sequence of events in a typical commercial operation is deullaging, pressure test, washing in hot water (70°C), cleaning, rinsing with hot water, steam sterilisation, purging with CO₂, pressurisation with CO₂, filling with beer against back-pressure to minimise gas breakout, neck wash, passing onto the capper and labeller. Washes are pulsed to increase efficiency, and between steps the kegs are purged with sterile air. Fill levels may be controlled via weight or volumetric dispense. The former is considered better and may be required in some countries. Kegs are filled against a counter-pressure of CO₂, usually around 3 bar pressure. During the operation the beer enters

through the gas port in the keg and the displaced gas passes out via the spear. Flow rates for beer are initially fast and then reduced at the end to prevent excess fobbing and to provide better control. When filling is complete the weight is checked and those failing to meet specification are rejected. All operations after the keg sterilisation must be sterile. Culinary steam is used for sterilisation, although in some small manual filling operation sanitisers such as **peracetic acid** or **chlorine dioxide** may be used. Where stainless steel kegs are used the cleaning agent is hot caustic soda. If aluminium kegs are used, or a mixture of stainless and aluminium, the cleaning agent is usually phosphoric acid (2% v/v).

Two types of keg racker are used. **In-line keg rackers** are arranged in a linear sequence of stations at which each of the necessary operations occurs. Empty kegs are fed into the racker from a conveyor located at right angles to the start of each lane. Kegs move along the lane and after all operations are completed they are discharged to a common discharge conveyor. Total capacity is governed by the number of lanes. **Rotary keg rackers**, as the name suggests, are circular and have multiple stations where all services are provided from a complex centrally located distribution system. Several kegs are handled at the same time and the entry and discharge points are located at a tangent to the racker. A typical arrangement would be 24 prewashing stations, 32 washing stations and 20 racking heads. This would allow filling rates of around $1000 \times 50\text{L}$ kegs/h. Rotary rackers are simpler and faster than in-line types but are not suitable where there are frequent changes of keg size. In-line rackers can cope with different keg sizes more easily. In-line systems are more flexible since the individual lanes can be used independently, and in the event of breakdown it may be possible to isolate a single lane and to maintain production with others. Similar arguments can be made with regard to maintenance. Rotary rackers must usually be stopped in the event of breakdown.

After completion of filling the kegs are labelled with brand and lot codes. Since the beers are mainly destined for trade outlets the former may be relatively inconspicuous, although some breweries do use their own populations of branded kegs. The top of the keg is fitted with a cap by either heat-shrinking or crimping. In both cases the object is to protect the neck and to provide proof against tampering.

See **keg**.

Keg racker

Name given to a plant used to clean, sterilise and fill kegs with beer.

See **keg filling**.

Kent Goldings

See **Goldings**.

Kettle finings

Kettle finings are process aids that are added to hot wort with the aim of promoting the formation and sedimentation of hot and cold break and thereby assisting in the generation of clear cooled wort. The name refers to the fact that they are added to the kettle, although as discussed later, they may not necessarily exert until later in the process.

Several agents have been used as kettle finings. Early reports describe the use of fish glue, agar and calves foot. More recently sodium bentonite, kiesegeluhr, nylon, tannic acid and silica

gel have been used by some brewers. In modern practice the most commonly used kettle fining is κ -carrageenan, also known as Irish moss, or a related name referring to the various algae or preparations thereof from which it is obtained.

All kettle finings serve to remove proteins from wort, which might cause haze problems in finished beers. For their action they depend upon adsorption or electrostatic attraction. Following the initial binding with protein, subsequent removal is dependent on the manipulation of the variables described by Stokes's law, in other words, filtration or sedimentation either under the influence of normal gravity or enhanced via centrifugation.

Some kettle finings promote directly the formation of large flocs of hot break and thereby improve the efficiency of hot wort clarification in a whirlpool or other trub separation device. In the case of κ -carrageenan the material is added to copper solely to take advantage of the hot temperature since it is insoluble at temperatures below 60°C. However, the binding to and separation of wort proteins does not take place until the wort has cooled and the cold break has formed.

See **κ -carrageenan**.

Kettle hops

Kettle hops are self-evidently those hops (or hop extracts) that are added to the kettle during the wort boil. The term is used in recipes to describe the quantity and types of hops required for individual beer qualities. It distinguishes kettle hops from other bittering or flavour hops that might be added further down-stream in the process. At its simplest the recipe may call for a single addition of a single hop variety, but several more complex hop additions are possible. Blends of hops might be used, for example, both bittering and aroma varieties. In this case the bittering hops would need to be added early in the wort boil in order to ensure adequate **hop isomerisation**. The aroma types would be added towards the ends of the boil (**late hopping**) in order to preserve the volatile hop oils. Increasingly, in modern brewing practice, **pre-isomerised hop extracts** may be used. These may be incorporated into the wort during the kettle boil, either singly or in conjunction with non-isomerised hops. Of course, pre-isomerised hops do not need to be boiled and it is now commonplace to add totally soluble and fully utilisable hop extracts post-fermentation. These may be for the purposes of bittering and/or adjustments to flavour and aroma. The latter would include whole hops or pellets added to cask beers (**dry hopping**) or pre-isomerised extracts such as the reduced **iso- α -acids** such as **tetra** or **rho**, which are added before packaging for adjustment of bitterness, beer foam stabilisation and avoidance of **light-struck character**.

Kettle-whirlpool

Kettle-whirlpools are vessels designed to combine wort boiling (kettle) and hot wort clarification (whirlpool). Typically they employ external wort boilers linked via a pumped loop system in which the wort take-off point is at the base of the kettle. The wort is heated as it passes upwards through an array of steam-heated circular stainless steel tubes in the external heat exchanger after which it is returned to the kettle. The entry point is tangential to the kettle such that a rotational motion is induced in the wort in the kettle. This causes the trub to separate and settle at the base of the kettle. The base of the latter is commonly inclined towards a trub take-off point.

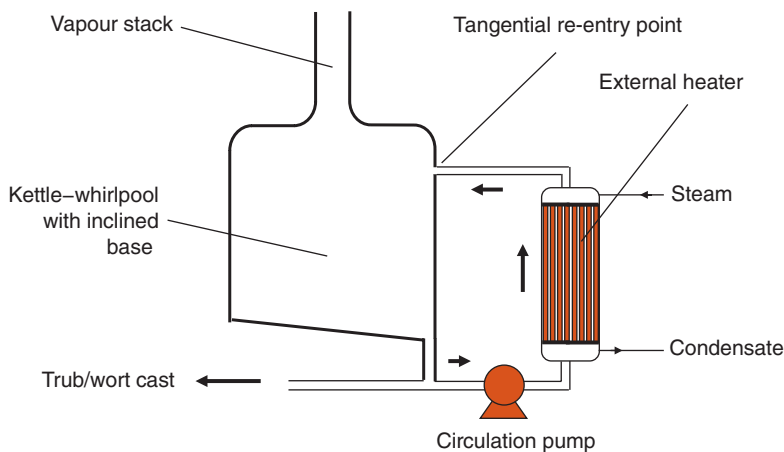


Diagram showing the principal features of a kettle-whirlpool

K

See **wort kettle**.

Keystone

A wooden bung which seals the lower aperture in a beer **cask** and through which the tap is placed on broaching.

See **cask**.

Keyworth's Midseason

Keyworth's Midseason and Keyworth's Early were two varieties of hop which were bred from crosses with **Fuggles** and a wild American female variety. They were developed as wilt-resistant substitutes for Fuggles in which they were successful; however, the aroma properties were inferior to Fuggles, and for this reason their cultivation was discontinued in favour of types with more desirable characteristics.

Kickelhayn corn counter

This is a device which is used to obtain a fixed number (500) of representative grains from a bulk store.

See **grain samplers**.

Kieselguhr

Kieselguhr, also known as **diatomaceous earth** or **diatomite**, is a mined material which comprises the fossilised remains of the skeletons of microscopic phytoplankton. After processing it is used in brewing as a filter aid in **powder filters**.

Kieselguhr derives from marine or freshwater deposits of phytoplankton. Deposits were originally discovered and exploited commercially in Germany in the nineteenth century. Subsequently other deposits have been discovered in other European countries such as France and the Czech Republic. Extensive deposits are also found in the United States.

In its raw form it is a soft off-white powder which contains between 80% and 90% amorphous silica. It forms powders which are very light, abrasive and highly porous. In addition to silica it contains small amounts of alumina and iron. The silica takes the form of complex shapes containing pores which form part of the structure of the original cell wall of the organism. These convoluted shapes provide the basis of its excellent filtration properties.

The raw material contains particles with average sizes of about 5–250 µm in diameter. For use as a filter aid it is processed by heating with or without additives. The heat treatment removes organic impurities and is used to control the particle size. So-called calcined kieselguhr, which is pink/off-white in colour, is prepared by heating the raw kieselguhr in a kiln which fuses the material to give particles with an average diameter of 5–20 µm and retaining the fine structure of the siliceous skeletons which are essential for filtration properties. Calcined kieselguhr is suitable for use as a body feed and fine pre-coat. In an alternative process termed activation or flux-calcining, a proportion of sodium chloride or calcium carbonate is incorporated. This material is white in colour and is more free-flowing owing to a larger particle size (greater than 20 µm). Flux-calcined kieselguhr is used as a first pre-coat.

Kieselguhr is a hazardous material. It generates dust, the exposure to which is known to produce debilitating or potentially fatal silicosis in humans. For this reason all operatives who might come into contact with the dry material should wear appropriate protective clothing and breweries must be provided with facilities to prevent the generation of airborne dusts. In smaller breweries powders are supplied in the form of 20-kg paper sacks. Prior to use the powder is required to be slurried in water. If this is a manual operation masks must be worn at all times and facilities for dust extraction must be used. In larger breweries automated and totally enclosed systems of powder handling, slurring and transport are used. In this case the powder is usually supplied in bulk in 500-kg 'big bags'.

The hazardous nature of kieselguhr is a result of the presence of a material termed **cristobalite**, which has known carcinogenic properties and which is formed during the calcining processes. It is a crystalline form of SiO₂ that is formed from amorphous silica when kieselguhr is subjected to heat. The proportion formed is directly proportional to the temperature employed in the kilning stage. Between 1000 and 1200°C up to 60% of the treated material may be in the form of cristobalite. This reduces to zero at temperatures below 900°C.

The grade of kieselguhr destined for use as a beer filter aid should have a low content of metals ions, particularly iron. The latter can be leached from the powder during filtration and pass into beer where its ability to participate in reactions leading to the formation of reactive oxygen species will have a negative impact on beer flavour and colloidal stability.

Although attempts have been made to find uses for spent kieselguhr, for example, as a soil conditioner, the majority is disposed of via landfill. This attracts disposal costs and has a negative environmental impact. Regeneration of spent kieselguhr is possible using treatments with alkalis, acids and enzymes. These treatments have to date been only partially successful. Typically the regenerated material is of a lower grade than that originally treated. The levies made for filter powder disposal, coupled with the health aspects of handling kieselguhr, have increased the likelihood that its use might, at least in some countries, be prohibited. In any case it is, of course, a natural product and supplies will eventually dwindle. These factors have resulted in a search for less hazardous filter aids or the use of membrane-based beer filtration systems such as cross-flow filtration. It seems likely that these will become of increasing

importance; nevertheless, at the present time, kieselguhr and powder filters remain the most popular choice for the majority of brewers.

Kieve

Kieve is the name used in Ireland for a mash tun. In the United Kingdom similar terms, **keev** and **kyse**, are also used.

Kilderkin

A word used principally in the United Kingdom which is the name for a container of beer that holds 18 imperial gallons (81.92 L). It probably derives from the Middle English *kylderkin* and refers to a container which had a capacity of a quarter of a tun. For more details of the names of beer containers and volumes, see **barrel**.

Killer yeast

Yeast strains, mainly *Saccharomyces* types that produce exogenous toxins that are lethal to other competing yeast strains including brewing strains.

See **wild yeast**.

K

Kilning

Kilning is the final stage in the malting process in which the germinated grains are subjected to heating under controlled conditions. The heating step kills the embryo and arrests germination. The aims of malting are to convert green malt into a stable finished product. For any particular type of malt a defined set of specifications must be achieved when kilning is complete. These include flavour, aroma, colour, friability, extract yield and enzyme complement. Many of these characteristics are controlled by the conditions imposed on the malt during kilning. When kilning is completed the rootlets should be dried and brittle and easily removed.

In traditional malting processes the grains were simply spread out into a thin layer and allowed to dry in sunlight or in a bespoke building such as a ventilated loft. As such the degree of control that could be achieved was poor, and in consequence the resultant malt quality was variable. In modern processes the degree of control of the conditions applied during kilning, particularly the regulation of temperature and humidity, is much more precise. This has allowed improvements to be made in consistency and in consequence the use of much larger batch sizes, deeper beds. Production times are more consistent and operating costs are reduced.

Kilning is considered to consist of two distinct stages, although in practice the transition from one to the other is not clearly demarcated. In the first, the drying stage, temperatures are kept comparatively low (*ca.* 30°C) and the removal of moisture is promoted by a passage of air through the grain bed. When the malt is judged to be sufficiently dry the temperature is increased and the final **curing** phase takes place. The temperatures and relative humidity during the curing phase have profound effects on the colour, aroma and flavour of the final malt. In general, all of these characteristics increase in intensity with an increase in temperature. A typical modern procedure would be to ensure that the grains are heated to approximately 30°C during the initial drying phase whilst applying a free flow of air through the bed. As the bed of grain dries the temperature is gradually increased to, say, approximately 70°C

and the airflow is decreased. As the grains become progressively drier the air may be recirculated through the bed. The proportion of air that is recirculated is gradually increased. In the curing stage temperatures of approximately 100°C might be used for ale malts. In the case of paler lager malts lower curing temperatures of 80–85°C might be used.

In some traditional kilning processes there is an intermediate step between drying and curing that is termed **withering**. The aim of this stage is to ensure that the grains are sufficiently dry prior to curing to prevent **stewing** from occurring. This can occur when grains are allowed to overheat when they still have comparatively high moisture contents. In this event the endosperm liquefies and becomes crystalline after cooling. For most malt types this is undesirable, although it is essential for some speciality varieties such as caramel malts. Traditional withering takes the form of spreading the grains into a thin bed over a withering floor. This has a slatted bottom to allow free passage of air. The efficiency of drying is promoted by frequent manual turning of the grains.

The biochemical changes that accompany kilning are complex. These must be controlled by the conditions employed in kilning in order to ensure that the particular malt acquires its final desired characteristics. In the early stages some enzyme development and activity continues and in consequence further modification occurs. As the drying proceeds and the temperatures are increased some enzyme denaturation occurs. The characteristics associated with raw grains become less pronounced and the precursors of dimethyl sulphide (DMS) decrease in concentration. Amino acids and reducing sugars undergo Maillard reactions in consequence the malt colour and aroma increase in intensity. In the early phase of kilning the processes associated with germination continue to occur. Thus, acrospire length increases and respiration continues to proceed. Owing to the continued activity of malt enzymes β -glucan declines and levels of soluble nitrogen and cold water extract increase. In the curing phase, enzyme activity declines, as do total soluble nitrogen (TSN) and free amino nitrogen (FAN), the latter via denaturation and melanoidin formation. The wort attenuation limit, wort pH and diastatic power of malts all decline with the extent of curing. Conversely, wort filtration time and wort clarity increase.

It may be appreciated that the conditions that are employed during kilning exert profound effects on malt quality and must be selected carefully in order to obtain malts of the desired properties.

Kimberley process

The Kimberley process is a method used for the industrial-scale production of native African opaque beers. It was designed specifically for use with sorghum malts with low diastatic powers. As opposed to the more usual linear method of an initial lactic acid fermentation followed by an alcoholic fermentation a parallel procedure is used. This comprises a lactic acid fermentation made with milled sorghum malt and a concurrent mashing phase made from an extract of milled maize grits and sorghum malt possibly supplemented with bacterial amylases. The main mashing process is arrested by adding the low pH sour fermentation, and after removing the grains the alcoholic fermentation is initiated by the addition of active dried brewing yeast. As with most of these types of beers the product is removed from the fermenter, packaged and sold with no further treatment.

See **native African beers**.

Kitamidori

Kitamidori is a Japanese high α -acid hop cultivar developed by the Kirin Brewery Hop Research Centre. It does not appear to be grown commercially. It contains 9–12% α -acids of which 22% are cohumulone. The β -acid content is 5–6%. Total oils are 1.4% of which 8–10% are caryophyllene, 6–7% farnesene, 31% humulene and 34% myrcene.

Kjeldahl

The Kjeldahl procedure is used for the determination of the concentration of total organic nitrogen compounds. It is widely used in the food and allied industries but was originally developed for application in the brewing industry by Johan Kjeldahl in the 1880s whilst employed at the Carlsberg Laboratory in Copenhagen.

In brewing the method can be used for determining total organic nitrogen in malts, worts and adjuncts.

The method relies on digestion of a known weight of sample by treatment with a solution of boiling concentrated sulphuric acid. This converts the organic nitrogen to ammonium sulphate. Catalysts are added to the mixture to increase the efficiency of the reaction. In earlier incarnations of the procedure mercuric salt catalysts were used. For reasons of safety these have been replaced by copper. In a subsequent distillation step the digest is boiled in the presence of an excess of NaOH. This results in the release of free ammonia. During the distillation the ammonia is collected in an acid receiving solution after which a titration is performed. In the case of brewing applications the ammonia is captured using boric acid. The titration result is used via back-calculation to determine the concentration of nitrogen in the original sample.

Several versions of the classical Kjeldahl apparatus are available. The classical 'macro-Kjeldahl' is suitable for sample sizes of 250–500 g (up to 10 mg/L total nitrogen [TN]). In order to accommodate rapid throughputs banks of flasks and associated distilling apparatus and heating mantles allow simultaneous determinations to be performed. Miniaturised versions, micro-Kjeldahls, allow nitrogen determinations in smaller samples. Nevertheless, the method requires the use of hazardous reagents and conditions. For this reason it has been largely superseded by the **Dumas procedure**.

KL-2B medium

Microbiological growth medium developed in the laboratories of the Kirin brewery in Japan for the cultivation of lactic acid bacteria beer spoilers, superseded by the later **KOT medium**. It contains extracts of peptone, yeast and malt, metal salts, phosphate buffer, citric acid, Tween 80, sodium azide and cycloheximide.

Klebsiella

Gram-negative bacteria, members of the Enterobacteriaceae, which are potential beer spoilers. They are slender, straight non-motile rods which usually have capsules. They are facultative anaerobes, tolerant of hop acids, capable of fermenting sugars but not able to utilise ethanol. They are not tolerant of ethanol and consequently are able to grow in early fermentation but do not persist into green beer. The major products of metabolism are acetoin and 2,3-butanediol. Some species are **phenolic off-flavour (POF)** and produce the characteristic medicinally flavoured 4-vinylo guaiacol from malt-derived ferulic acid, others form DMS.

Kluyver effect

A phenomenon observed in some yeast, notably species of *Kluveromyces* in which growth on certain sugars (galactose, raffinose, maltose) requires respiratory conditions. Growth is precluded under anaerobic conditions or where the respiratory pathways are blocked by the presence of inhibitors. *Saccharomyces cerevisiae* is Kluyver effect-negative. In common with negative strains, those showing a positive response apparently contain the same genes required for the dissimilation of these sugars; however, it is suggested that, although they also possess the permeases required for their uptake, they have insufficient capacity to take up the sugars at the higher rates required to fuel the increased rates of glycolysis associated with fermentative growth.

Knives

Knives are components of lauter tuns. They are attached to a rotating beam and are used to raise and loosen the bed of grains during the lautering process. Several designs may be found depending upon the preferences of the individual equipment manufacturer.

See **lauter tun**.

Kolbach index

The Kolbach index, also known as the **soluble protein ratio**, is a parameter used to assess the quality of malt. It is defined in the following formula:

$$\text{Kolbach index} = \frac{\text{Total soluble protein}}{\text{Total malt protein}} \times 100.$$

It is one of a raft of tests that are used to assess the nature and disposition of the nitrogen content of malts. Several tests are used to determine malt nitrogen. For example, **total soluble nitrogen (TSN)** and **free amino nitrogen (FAN)**. Methods which describe the total nitrogen content are primary measures of malt type and quality.

Methods which measure the ratio of total and soluble nitrogen [**soluble nitrogen ratio (SNR)**, total soluble nitrogen (TSN)/total nitrogen (TN)], or the ratio of total and soluble protein as in the case of the Kolbach index, are illustrative of the degree of modification of the malt.

The total soluble nitrogen content of worts is important in that it confers body to beers and contributes proteins for head formation. In addition, the free amino acid fraction provides essential nutrients for yeast growth during fermentation.

Typical specifications for traditional lager malts are soluble nitrogen ratios of 33–37%. Values above or below this range are indicative of over- and under-modification, respectively. Where malts are produced by **simple infusion mashing** an SNR of 36–42% would be considered acceptable.

Koningshoeven

One of the Trappist monasteries, the only one located in the Netherlands, producing Trappist beers.

See **Trappist beers**.

Koppaklear™

Koppaklear™ is a preparation of refined carrageenan which is supplied by Murphy & Son, UK. It is supplied as a powder or in tablet form and is designed to be used as a kettle fining agent.

See **kettle finings**, **κ-carrageenan**.

Kořal

See **Valtický**.

Korefe

Korefe is a native beer produced in the Begemder region of Ethiopia. Barley is de-husked and after steeping overnight it is toasted, milled and mixed with water and the dried leaves of the Gesho plant (*Rhamnus prinoides*). This mixture is stored in clay jars where a spontaneous fermentation occurs. The brewing process is completed by removing some of this material, diluting it with water and leaving for a further day before consuming.

KOT medium

Microbiological growth medium (Kirin Okhochi Taguchi) designed at the Kirin brewery in Japan for the cultivation and detection of lactic acid bacteria, in particular *Pediococcus*. The medium was developed based on observations that some fastidious strains of *Pediococcus* would not grow on other commonly used lactic acid bacteria media. It contains extracts of malt, meat and yeast, metal salts, glucose and maltose (principal carbon sources), L-cysteine (reducing agent), cytidine, thymidine, L-malate (stimulatory to *Pediococcus*), cycloheximide (inhibitor of yeast) and sodium azide (inhibitor of Gram-negative bacteria). Beer is also added to promote the growth of potential beer spoilers but inhibit those that are not.

Kräusen

Kräusen is the German term used to describe the rocky, cauliflower appearance of the yeast head which forms during the active period of primary fermentation. It translates literally as 'wrinkled' or 'curled'.

The term is modified to describe the stage which primary fermentation has reached. Initially (up to about day 2 in a traditional lager fermentation) the yeast head is relatively thin and this stage is referred to as **low kräusen**. By day 3 the full characteristic cauliflower head has formed and this stage is called **high kräusen**. This stage persists for about a further 3–4 days after which the head begins to subside, termed falling kräusen.

Kräusen may also be used as a verb or adverb. In this case it refers to the practice by which a proportion of actively fermenting wort (at the high *kräusen* stage) is removed and added to green beer which has been transferred to the secondary conditioning phase. This provides some fermentable extract and, more importantly, actively fermenting yeast cells which catalyse the first warm secondary fermentation stage in traditional lager production.

Kriek

Kriek is a type of fruit beer associated with Belgium and traditionally made using a blend of **lambic beer** and macerated sour cherries. The fruit pulp is added to ageing tanks such that

both the base beer and the cherry pulp are allowed to participate in a spontaneous fermentation over a period of several months. The resultant beer and fresh lambic beer are then blended, and after bottling, the beer is subjected to a lengthy secondary fermentation. Alcohol contents are of the order of 5–6% abv. Other variants not based on lambic also exist. For example, the Liefmans Brewery located at Oudenaarde in Belgium uses the local Belgian brown beer in place of the more usual lambic. The beer is subject to a very lengthy multistage fermentation and ageing process. More modern versions of kriek beers use less traditional and more rapid production processes in which fruit syrups are used.

See **lambic beer**.

Krug

An earthenware or stoneware beer drinking vessel used in Germany and in the shape of a mug with a handle. Different capacities are in use, the version which holds 1 L of beer being termed a *mass krug*. Vessels of the same shape but made from glass are termed *seidels*.

Krystallweissen

Krystallweissen is the name used in Germany for filtered wheat beer.

See **weizenbier**.

Kubessa process

The Kubessa process is a mashing technique in which the husk fraction of the grist is separated from the flour and grits and the fractions are mashed separately. The flour and grist fractions are subjected to a conventional process of increasing temperatures and stands until it reaches the boiling point. Simultaneously the husk fraction is mashed using an isothermal 50°C regime. When the normal mash reaches the boiling point the husk mash is mixed with the result that the overall temperature is reduced to approximately 70°C. The temperature of the mixed mash is then increased to 78°C to inactivate enzymes after which the sweet wort is separated from the spent grains and collected.

The claimed advantages of the Kubessa mashing technique are that some of the harsh and undesirable flavour components which are introduced into worts by high-temperature treatments of husk materials are avoided.

Kuchasu

A native opaque beer made from maize by the Chewa tribes of Malawi and associated with religious ceremonies. In Zambia a similar product called kachasu is made. In this case the beer is distilled to make a potent spirituous beverage containing between 30% and 70% ethanol by volume. The beverage is also called lituka. In addition to maize other sources of extract may be used including sugar and flavourings such as banana peel. The variability reflects the fact that production of this beverage is an illicit undertaking. Nevertheless, its production appears to be commonplace in other southern African countries including South Africa and Zimbabwe. The name appears to reflect the links with Africa's colonial past via Portugal and the slave trade in Mozambique. Thus, the name appears to be derived from the Brazilian distilled spirit, cachaca.

Kurrunu

Name given to a beer associated with ancient Babylonia.

Kützing, Friedrich Traugott

German scientist (1806–1893) much associated with the study of algae but with the Frenchman Charles Cagniard-Latour and fellow German Theodor Schwann is credited with the discovery of the vital nature of yeast and its role in fermentation.

Kvas

One of several names used for a scientific journal associated with brewing in the now Czech Republic. The journal was first published in 1873 and was accompanied, until 1938, by a German language version entitled *Der Böhmischer Bierbrauer* (*The Bohemian Brewer*). In the Second World War the name was changed to *Gambrinus*, but following the re-establishment of Czechoslovakia the name *Kvas* was resurrected. Since 1992 the journal has been published by the Czech Research Institute of Brewing and Malting under the name *Kvasny Průmysl*. The current journal (<http://www.kvasnyprumysl.cz>) (last accessed 10 February 2013) is published in both Czech and English.

K

Kvasny Průmysl

See *Kvas*.

Kvass

Kvass is a mildly alcoholic beer (typically less than 2% v/v) made from black (rye) bread. It is a common drink in Russia and many Central European Slavic countries. The name translates as *bread drink*, which gives a clue to the method of manufacture. In common with many early beer-like beverages, the starting material is bread. This is mixed with water and fermented by the addition of a yeast starter. The finished product is commonly flavoured with herbs and fruits.

Its history can be traced back through many centuries and, as with other early beers, it was the drink of choice by low-status individuals. No doubt it was a useful dietary supplement and provided a degree of protection against common pathogens found in contaminated water supplies.

In the modern day it is produced commercially and is often sold by street vendors. Some modern commercial versions are purely compounded non-alcoholic products in which there is no fermentation step. It is also commonly produced domestically for home consumption.

Kwak

Kwak is a type of strong amber Belgian beer now made by the Bosteels Brewery, named after Pauwell Kwak, a brewer and keeper of the De Hoorn Inn in Dendermonde, Belgium. According to the story the inn was on the route for mail coaches the drivers of which were not allowed to vacate their vehicles during the stops. In order to enjoy the fruits of the inn Kwak invented a new type of glass which took the form of an extended hour glass similar to the English **yard of ale**. The glass was fitted within a wooden frame which could be attached to the coaches for

the convenience of the drivers. In modern bars the brand image of the product is retained by the continued use of the unique glass and wooden frame.

Kyse

Name given in Medieval England and associated with the western counties for a large tub-shaped vessel used for brewing. The word may be a variant of and carry the same meaning as keeve.

Labatt ABM continuous fermentation system

A continuous fermentation system introduced into the Canadian Labatt brewery in the 1960s and there used briefly for commercial lager production. It comprised a cascade of four vessels which provided facilities for continuous yeast propagation, fermentation and yeast separation. The system relied on a supply of sterile wort which was produced by a conventional batch process and held in chilled storage vessels ready for use. The first tank of the fermentation system into which wort was pumped was used as a propagator. Yeast growth was encouraged by the continuous provision of oxygen, and the presence of a mechanical agitator ensured good rates of oxygen transfer. The wort and freshly propagated yeast was pumped into the second and third vessels. Here anaerobic conditions were maintained and the fermentation proper was allowed to proceed.

The wort supply rate was set such that residence time in the fermentation vessels was approximately 40 hours. After this time the green beer was pumped into the fourth vessel in which yeast was separated. The partially clarified green beer was then transferred to chilled conditioning vessels for finishing. Part of the recovered yeast was recycled into the fermenting vessels, and in this way very high yeast concentrations were achieved, which, it was claimed, resulted in shortened process times and a reduction in overall rates of yeast growth.

Labeorphilist

A collector of beer bottles, or beer bottle labels.

Lacing

Synonym for **cling**, a phenomenon where a portion of the foam head of a beer attaches itself to the inner wall of the glass as the liquid level falls as the beer is consumed.

See **lacing index** and **NIBEM-CLM cling meter**.

Lacing index

Name given to the result of a test designed to quantify the amount of beer foam which adheres to the inner wall of the glass as the beer is consumed, generally considered to be a desirable trait related to the foaming properties of beer (see **beer foam**).

Beer is degassed and then decanted into a glass container which has a sinter and a drain located at the base. Foam is generated by passing a stream of CO₂ through the sinter. The liquid is allowed to drain from the container in gradual steps to simulate consumption. When all the liquid has been removed the residual foam (lacing) is washed out using water and its absorbance (230 nm) is measured using a UV spectrophotometer. The value is directly related to the quantity of foam lacing.

See also NIBEM-CLM.

Lactate lead acetate medium (LL-agar)

Medium designed for the cultivation and identification of strains of *Pectinatus* spp. Lactate is the sole carbon source. Lead acetate reacts with the H₂S produced by the target organisms and stains the colonies black, allowing differentiation from non-staining H₂S-negative organisms. 2-Phenyl ethanol is added to inhibit aerobic Gram-negative bacteria.

Lactic acid bacteria

A relatively diverse group of bacteria which includes the important beer spoilers, *Lactobacillus* and *Pediococcus*. They are Gram-positive rods or cocci tolerant to acid and ethanol, strictly fermentative but often tolerant of microaerophilic conditions, and many are resistant to hop acids. They are spoilers of worts and beers and may be homofermentative (lactate producing) or heterofermentative (mixed acid production). Other products of spoilage by some members of this group include diacetyl and phenolic compounds. Turbidity and ropiness may be the visible signs of growth and metabolism.

Lactobacillus

Members of the lactic acid bacteria and potent beer spoilers. The most common beer spoiling representatives of this genus are *Lactobacillus brevis*, *Lactobacillus casei*, *Lactobacillus curvatus*, *Lactobacillus plantarum* and *Lactobacillus delbrückii*. They comprise slender Gram-positive non-motile rods which are tolerant of oxygen and low pH and many species are resistant to hops. They are fermentative bacteria which are able to compete with brewing yeast, but the risk of spoilage is most common in green and packaged beer. The consequences of spoilage are sour aromas and tastes as a result of acid production, accompanied by 'silky' turbidity and often the appearance of 'ropiness' due to the ability of some strains to produce extracellular polysaccharides. In addition, diacetyl may be produced, giving an unpleasant butterscotch taste and aroma.

The potential for spoilage by these bacteria is related to their resistance to hop acids, notably *trans*-isohumulone. A continuum of strains with varying degrees of resistance has been recognised with only those at the higher end being considered potent beer spoilers. A pH dependency has been demonstrated such that as this increases the antiseptic effect of the hop acids is commensurately reduced. *Lactobacillus* bacteria are difficult to cultivate in the laboratory. The use of nutrient media (**MRS medium**) supplemented with *trans*-isohumulone (20 µM) has proven useful as a selective medium for beer spoiling *Lactobacillus*.

Strains of *Lactobacillus* may be homofermentative (mainly producing lactic acid from pyruvate generated by glycolysis) or heterofermentative (producing a mixture of products including lactate, acetate, glycerol and ethanol, via the phosphoketolase pathway). Diacetyl production

is via a different route to that associated with brewing yeast (see **diacetyl cycle**) and may arise either via enzymic oxidation of α -acetolactate to give diacetyl or synthesis from acetyl-CoA and acetaldehyde (see **diacetyl:2,3 pentanedione ratio**). Some strains are able to decarboxylate wort phenolic acids that yield unpleasant medicinal aromas and tastes [see **phenolic off-flavour (POF)**].

Lager

The term lager has come to refer to a particular beer style which is distinguished from ales in that worts are commonly produced by decoction mashing and by bottom fermentation. The latter terminology refers to the use of a lager yeast strain which, amongst other characteristics, is one that settles to the bottom of the vessel during and after the completion of fermentation. In addition, in the final production phase, traditional lager beers are subjected to a long period of storage phase at cool temperatures during which flavour maturation and clarification occurs. It is this storage phase that gives the beer style its name, the word being derived from the German word *lager*, meaning a store.

Many different types of beers are produced using this basic process and all can be referred to as lagers. There is an enormous variety of these and they encompass all the colours from very pale to very dark and an equally large range of flavours. Each type is referred to using a particular beer style name. Examples include bock, *dunkel*, Helles, Marzen and pilsener. Details of these may be found in their individual entries.

The darker products predate the paler varieties, a consequence of the fact that poor control of the malting process resulted in most malts being comparatively dark in colour. Subsequent development of pale pilsener malts and the popularity of beers made using them has resulted in this type of beer becoming the most widely brewed and consumed beer throughout the world. In consequence the term lager is often used (erroneously) to refer to this beer style.

Since the pale pilsener type of beer has achieved such dominance in the world brewing market the process by which it is made has been subjected to intensive research and development and, in consequence, much revision. Typically this has taken the form of shortening the lengthy process associated with the traditional product. Thus, in order to shorten the production process and in so doing increase the productivity of individual vessels, fermentation temperatures have been gradually increased from the 6–10°C typical of the traditional process to 10–20°C, fermentation temperatures more associated with ales. In addition to the fermentation of very concentrated worts followed by dilution prior to packaging, a process known as **high-gravity brewing** is also widely used. In conjunction with the introduction of very large fermentation vessels, usually of cylindroconical design and with capacities of 1000–5000 hL, individual batch sizes have become very large. These have been required to underpin the production of the huge international beer brands the majority of which are pilsener-type lager beers.

In the 1960s **continuous fermentation** processes were developed and adopted by some brewers for the production of pilsener-type beers. These are now rare, although there has been something of a renaissance of interest in recent years, particularly with the development of practical immobilised yeast reactors.

The most dramatic change in the traditional lager process has occurred in the storage phase. Traditionally the lagering phase might take several weeks to complete. Conversely, the modern process is conducted at a very low temperature (−1 to −3°C) and can be completed in one to a few days.

See **lagering/cold conditioning**.

Lagering

Lagering is the period of cold storage, associated principally with the production of traditional lager beers, during which **secondary fermentation** occurs. It takes its name from the German word *lager*, meaning to store.

See **secondary fermentation**.

Lagering tank

A brewery vessel in which the process of lagering is performed.

See **lagering, secondary fermentation**.

Lager malt

Lager malt is the UK equivalent of **pilsener malt**. It is prepared using a similar regime to that used for pilsener lager malt (see this entry for more details); however, the final kilning temperature is usually slightly higher than that used for the latter such that the colour of the malt is marginally higher (3 EBC units compared with <2.5 EBC units for pilsener malt).

Lager yeast

Name given to those strains of brewing yeast that are associated with the production of lager beers and which typically form a bottom crop when they separate from green beer at the completion of primary fermentation. Taxonomically lager yeasts are classified as members of the species *Saccharomyces pastorianus*. In earlier classifications the names *Saccharomyces uvarum* and *Saccharomyces carlsbergensis* have also been used, and these are still in common parlance.

See **yeast**.

Lamb-ales

A UK medieval feast featuring consumption of ale and held at the time of sheep shearing.

See **ale**.

Lambda-cyhalothrin

Lambda-cyhalothrin is a mixture of isomers of the synthetic pyrethroid cyhalothrin (3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethyl-cyano(3-phenoxyphenyl)methylcyclopropanecarboxylate). It is a fluorinated pyrethrin analogue insecticide of the type which may be used for the treatment or prevention of insect infestations of crops such as hops.

Lamberto

A cultivar of the wheat and rye hybrid, triticale.

Lambic beer

Lambic beers are produced in the Pajottenland region situated to the southwest of Brussels in Belgium. The name may derive from the Lambeek municipality of Belgium. The beers are made from a mixture of predominantly malted barley and a smaller proportion of wheat. Worts are produced such that they have a high dextrin content. The unique aspect of lambic beers is that they are made via **spontaneous fermentation** in a lengthy process involving the growth of several successive populations of both yeast and bacteria. Commonly hops which have been used already for brewing are incorporated into the wort or aged hops are used. These are added for their antimicrobial properties, rather than bitterness, and so limit the variety of microorganisms that are capable of participating in the initial phase of the fermentation.

In traditional breweries the hot wort is run into large shallow open coolships where it is allowed to reach room temperature. The rooms in which the coolships are located are designed to provide the maximum opportunity for airborne contamination to occur. Thus, ventilation is good and great care is taken not to disturb the natural flora of the buildings. The cooled and contaminated wort is transferred to large casks where the bulk of the fermentation is allowed to proceed over a period of several months. Initially enteric bacteria and species of the yeast genus *Kloekera* proliferate. Growth is accompanied by a rapid decrease in pH owing to the formation of acetic acid. After a few weeks species of *Saccharomyces* yeasts become predominant and ethanol and some esters accumulate. During the following months bacterial growth becomes dominant, principally species of *Lactobacillus* and *Pediococcus*, and this is accompanied by the formation of lactic acid. In the final phase, 5–8 months into the fermentation, a population of the yeast *Brettanomyces* develops.

The combined effects of these microbial populations produce a beer with a distinct sour taste. It is sold and consumed in many different forms. It is served direct from the cask after the first fermentation has been allowed to proceed from several weeks up to 1 year. This 'young' form of lambic beer is referred to as **lambic doux** and has a characteristic cloudy appearance and a very sour taste. After at least 2 years in a cask the beer may be dispensed from the cask and sold as **lambic vieux**. The prolonged fermentation modifies the sour taste of lambic doux such that the beer acquires a dry and wine-like character. In addition, the older beer is much less cloudy.

Lambic beers of various ages are blended to give a product with a desired balance of flavours. These beers are packaged into bottle and are allowed to undergo a further fermentation of 12–24 months. This leads to further flavour modifications and carbonation. These blended and aged bottled beers are sold as **gueuze**. In more modern processes a greater degree of control is applied. In this case lambic beers produced by the traditional method are blended with a base beer made from a fermentation using a mixture of pure strains of *Brettanomyces*, *Lactobacillus* and *Acetobacter*.

Historically, lambic beer was blended with a second conventional un-aged beer and the mixture sweetened with sugar or caramel. The blending beer was called *Meerts bier*. This translates as 'March beer' and is a reference to the common practice in many countries in the Middle Ages of brewing stronger beers in the spring, immediately before the summer, when brewing was either impracticable because of the effect of the warm temperatures on fermentation or was subject to various legal prohibitions. The resultant relatively low-alcohol blend of

Meerts bier and lambic was called **faro** and was the everyday drink of the common people. In addition to faro another relatively weak lambic-type beer that used to be produced was termed **Mars**. In this case the beer was made from the weaker second wort runnings. In this regard it can be viewed in the same way as 'small beer', the UK equivalent.

Commonly lambic beers are modified by the addition of various fruits. Several fruits can be used including peach, blackcurrant, banana, apple, plum, pineapple, lemon, apricot, cherry and raspberry. The latter two are the most common, have the longest pedigree and are sold under the names **kriek** and **framboise**, respectively. In traditional processes the fruits are macerated and added to ageing tanks in the brewery prior to bottling. This imbues the beers with the fruit flavour but provides opportunities for further modifications to flavour by allowing sugars and other fruit components to participate in the secondary in-bottle fermentation. Some more modern versions are made by simple blending using fruit syrups or essences and are considered inferior by many beer aficionados.

Lambic doux

Lambic doux is the youngest form of lambic beer, the Belgian beer produced by spontaneous fermentation of malted barley and wheat wort. It is sold direct from a cask when the fermentation has been allowed to progress for a period of several weeks up to 1 year, which in lambic terms is considered to be a relatively short time. The beer has a characteristic cloudy appearance and a very sour taste.

See **lambic beer**.

Lambic vieux

Lambic vieux is a Belgian beer produced by the spontaneous fermentation of wort made from a mixture of malted barley and wheat. The suffix *vieux*, or old, is in reference to the fact that the fermentation must be allowed to proceed in a cask for at least 2 years before the beer can be given this name. It is distinguished from lambic doux in which the beer is consumed at a time ranging from a few weeks up to a year of fermentation. The young lambic doux product is cloudy and very sour owing to the combined activities of yeast and lactic acid bacteria. In the older product the beer is clearer, and the action of later-occurring microbial populations, especially *Brettanomyces* yeast strains, confers drier and more wine-like qualities.

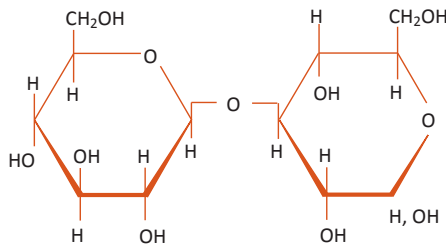
See **lambic beers**.

Laminaribiase

Laminaribiase is a **β -glucosidase** that hydrolyzes the disaccharide laminaribiose (β -D-glucopyranosyl-(1,3)-D-glucopyranose) to form β -D-glucose. The enzyme may occur, although definitive proof does not apparently exist, in barley embryo and aleurone tissue. If present, it does not appear to survive the malting process. As with other β -glucosidases activity present in mashes, which is presumed since the disaccharide does not accumulate, may derive from microbial contamination of malts.

Laminaribose

Laminaribose (β -D-glucopyranosyl(1-3)-D-glucopyranose) is a disaccharide consisting of two residues of D-glucose linked by β -(1-3) bonds.



The enzyme **laminaribiase** is a **β -glucosidase** that hydrolyzes laminaribiose to form β -D-glucose. The enzyme is present in the embryo and aleurone layer of barley grains; however, it does not seem to survive the malting process.

Laminarin

Laminarin is a polysaccharide of glucose in which the individual residues are linked by β -(1-3) and β -(1-6) bonds. It is used as a storage reserve material in brown algae. A similar laminarin glucan with all glucose residues joined by β -(1-3) bonds occurs, albeit at low concentrations, in barley endosperm cells.

See **β -glucans**.

L

Laminarinase

Trivial name for the enzyme endo- $(\beta$ -(1-3) glucanase. The enzyme catalyzes the hydrolysis of β -glucans in which the chains are joined by repeated sequences of β -(1-3) bonds as in the β -glucan polymer known as **laminarin**. Such polymers occur in barley endosperm, albeit at much lower concentrations, compared to the more abundant mixed β -(1-4) and β -(1-3) linked glucans. The relative scarcity of substrates and the low concentrations of laminarinase in barley malts suggest that the contribution of this enzyme to β -glucan degradation during mashing is of minor significance.

See **β -glucans** and **β -glucanase**.

L'Association des Brasseurs du Canada

See **Brewers Association of Canada**.

L'Association des Buveurs d'Orge (ABO)

ABO is the Swiss arm of the European Beer Consumers Union. It was founded in 1991 and is a consumer group campaigning for traditional beers and against its perceived globalisation of the world brewing industry.

Contact details are at <http://www.abo-ch.org> (last accessed 11 February 2013).

Late hopping

Late hopping refers to the practice of adding aroma hops to the kettle towards the end of the wort boil. These hops are added for flavour, as opposed to bitterness. The flavours are derived from essential oils and it is important to prevent as much as possible the loss of these delicate volatile components, hence the late addition. Since there is no isomerisation step these hop products do not need to be present for any length of time.

The control of flavours and aromas derived from late hopping is inherently difficult since the levels of essential oils vary with individual batches of hops. For this reason alternative and more controllable regimes have been developed. These involve the use of essentially sesquiterpeneless oils in which the insoluble hydrocarbon fraction has been removed. These products are fractionated to give products with defined spicy or floral characters which are sold as 1% solutions in ethanol. These may be added directly to bright beer and in effect mimic the process of late hopping but with the difference that utilisation is 100% and therefore entirely predictable.

Lausmann system

A **semi-continuous malting** system.

Läuterbottich

German for lauter tun.

Lauter tun

A lauter tun is used for separating sweet wort from spent grains at the end of the mashing phase of wort production in the brewhouse. They are associated primarily with decoction mashing as used for lager production by mainland European brewers. Like mash tuns the grains are allowed to settle and form a bed through which the wort is filtered and clarified. The name derives from the German word *läuter*, meaning to purify, clarify or refine. Unlike the mash tun the lauter tun is used solely for mash separation, the conversion step being performed in a separate mash mixing vessel (see **decoction mashing** for more details).

Lauter tuns are generally circular tanks made from stainless steel and insulated to assist with attemperation. Modern versions are enclosed and are fitted with a chimney for steam exhaustion. They are similar in design to **mash tuns** but generally have a greater diameter. This is because more finely ground grists are used in lauter tuns such that in order to ensure rapid run-offs the grain bed is required to be comparatively shallow; hence, in order to maintain high capacity the diameter must be commensurately large. Typical bed depths are 30–50 cm using loadings of 340–150 kg/m².

The precise design of lauter tuns is dependent upon the preferences of individual manufacturers, although there are several common features, described as follows. The lauter tun contains a false bottom made from stainless steel and which contains perforations, either circular holes or slots, through which the sweet wort percolates. A side-entry point is provided and is designed to allow filling of the lauter tun in a non-turbulent manner. In order to prevent air ingress the vessel may be filled under a blanket of CO₂. Multiple entry points may be provided so as to allow a more rapid filling. Beneath the false is a void, typically about 20 mm, below which lies the true bottom. The true base is fitted with channels through which the wort is collected. Several proprietary designs are used all of which seek to minimise the under-deck volume and, hence, minimise the volume of water needed to flood the grain bed during sparging and to avoid over-dilution. Several tubes with conical shoulders are located at the true base of the vessel through which the wort is collected. The conical arrangement provides an even flow of wort. In modern vessels the run-off points are combined and the wort is collected into a receiving vessel or is transferred directly into the copper. This process and plant is designed and performed to avoid exposure of wort to air.

At the top of the lauter tun is a beam which can be rotated and which supports a number of rakes. The latter take the form of knives of various proprietary designs which when lowered and rotated lift the mash. The knives are carefully arranged to ensure that the whole of the grain bed is treated. This assists with wort run-off and maximises extract yield. As the grain bed is raked sparging liquor is applied via overhead sprays. These may be attached to the rake arms or placed at fixed locations on the dome of the vessel.

In operation the lauter tun is first heated and the under-deck void filled with warm mashing liquor at a predetermined temperature. After this the mash is pumped into the vessel after which it may be raked to ensure even distribution on the false floor. The bed is then allowed to settle such that a layer of relatively clear wort is formed above the grains. Run-off then commences and the first turbid worts are recirculated back into the top of the lauter tun, again taking precautions to avoid ingress of air. When the wort is judged sufficiently clear the flow is directed towards the copper or intermediate storage vessel. When the grain bed becomes visible sparging commences. The rate of wort run-off, wort clarity and trans-bed pressure differential are monitored, and when conditions dictate raking is performed. Depending on the response depth of the rakes can be varied to either increase or decrease the degree of raking.

Wort collection is discontinued when the concentration falls to a predetermined minimum value. After this time the bed is allowed to drain and the grains are discharged. This is achieved using the rotating knives, sometimes operating in the reverse direction to that used in raking. The spent grains are directed towards multiple discharge ports designed to make emptying as rapid as possible and thereby to reduce the overall cycle time. Modern lauter tuns are fitted with efficient and automatic cleaning in place (CIP) systems. Depending on the nature of the grist and the loading rate, up to 15 cycles per 24-hour period are achievable.

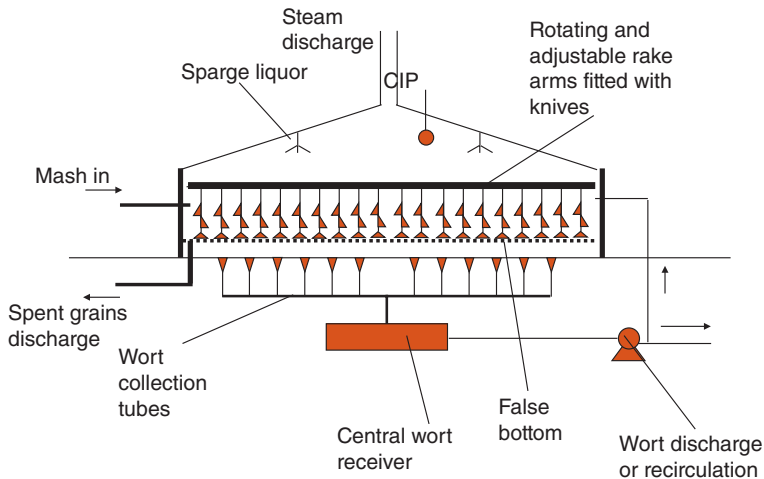


Diagram showing the essential features of a lauter tun

Lavender

The lavender plant, *Lavandula angustifolia*, produces perfumed flowers which, together with leaves that have a bitter flavour when boiled, have been used to add flavour to beers.

See **gruit**.

Lawrence of Rome

Another of the plethora of saints regarded as patrons of brewing for reasons that are not clear. Lawrence was martyred as a Christian in Rome in the third century by the somewhat unusual method of being roasted on a gridiron over a pit of coals. Perhaps more understandably he is also associated with maltsters. His reportedly pithy comment during the treatment that he should be turned over before eating as one side was done resulted in him also being regarded as patron saint of both chefs and comedians. Presumably in modern practice the patron saint of brewpubs which feature food and stand-up comedian acts would seem to provide a satisfying manifestation of all of his attributes.

Lead conductance value

The lead conductance value (LCV) is a parameter used in the determination of the concentration of hop α -acids. The procedure relies on the fact that hop α -acids react with lead acetate to give salts which take the form of yellow precipitates. Since these lead salts of α -acids are soluble in the presence of an excess of lead acetate an additional procedure is needed to make the procedure quantifiable. This is accomplished using a conductimetric procedure.

The α -acids are dissolved in methanol with an addition of pyridine to which aliquots of a standardised solution of lead acetate dissolved in methanol is added. After each addition the conductivity (or resistance) of the solution is measured. It may be observed that the conductivity remains constant until an excess of lead acetate is present. This produces an inflexion point in the curve after which the conductivity increases in a linear fashion. Extrapolation of the two linear components of the curve allows the true end point of the titration to be determined and this value, the lead conductance value, LCV, is related to the concentration of α -acids present in the solution.

The LCV does not distinguish between individual α -acids, but in fresh hops it provides a reasonably accurate measure of the bittering potential. This can be used as the basis of commercial decisions where the value of batches of hops requires to be assessed. In older hops oxidation reactions result in the formation of derivatives of α -acids, which will also react with lead acetate. In this case alternative procedures must be used usually which incorporate a separation step.

Learner corn counter

This is a device that is used to obtain a fixed number (50) of representative grains from a bulk store.

See **grain samplers**.

Lectins

Proteins that bear groups that bind to sugars. They are found in all cells, including viruses, and the binding is highly specific for the target sugar. This allows lectins to function as signalling receptor molecules. In brewing they are of significance since they take part in the binding reactions involved in floc formation.

See **yeast flocculation**.

Lees multi-differential agar

General-purpose microbiological growth medium for the detection and cultivation of commonly encountered brewery-related bacteria. It contains tomato juice, peptonised milk,

sorbitol, phosphate, glucose, calcium carbonate, calcium pantothenate, magnesium sulphate, manganese sulphate, ferrous sulphate, sodium chloride citric acid, Tween 80 and bromocresol green.

Leet-ale

See **ale**.

Legacy

A six-rowed variety of malting barley which appears on the recommended list of the United States and Canada. It was developed by Busch Agricultural Resources Incorporated in Colorado.

Leipzig gose

See **Gose**.

Lemma

The lemma, or palea inferior, forms the part of the husk that encloses the rounded dorsal portion of cereal grains.

See **barley grain**.

L

LG Auto haze meter

A beer haze meter based on the measurement of light scattering at 90° using incident light with a wavelength of 565 nm.

Lg-automatic beer foam tester

Danish device [<http://www.lg-automatic.com> (last accessed 11 February 2013)] designed for the automatic assessment of beer foaming ability via measuring the foam collapse time. Beer is placed into the cylinder of the machine through a nozzle that generates a foam. The decay of this is monitored electronically using two optical infrared (IR) reflection detectors located on the outside of the glass cylinder.

Liberty

Liberty is a US-bred aroma hop variety released in 1991. It is a triploid cultivar bred from a tetraploid Hallertauer Mittelfrüh female and a male resistant to downy mildew. It contains 3–5% α -acids, 24–30% of total α -acids is cohumulone and 0.6–1.2% total oils of which 20–40% is myrcene, 35–40% humulene and 9–12% carophyllene.

Licensed premise

In the United Kingdom an establishment, either permanent or temporary, that has been licensed by the relevant authorities to serve alcoholic drinks. It is a legal requirement that the licensee is a named individual and the name must be publicly displayed.

Liebig, Justus von Friedrich (1800–1882)

German chemist (1803–1873) who, with colleague Friedrich Wöhler (1800–1882), published a satirical response to the independent assertions of **Charles Cagniard-Latour** in Paris, **Theodor Schwann** in Berlin and **Friedrich Traugott Kützing** in Nordhausen, Germany, that

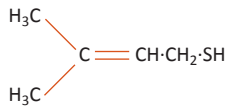
alcoholic fermentation was a vital process catalyzed by the actions of yeast. The lampoon took the form of a claim that with the use of a powerful microscope the yeast 'infusoria' could be observed to *gobble sugar, and discharge ethyl alcohol from the intestine and carbon dioxide from the urinary organs*. These opinions were expressed to bolster the views of Liebig and Wöhler that organic compounds could be synthesised *in vitro* without the need for a 'vitalistic' intervention, in part based on the fact that the latter had managed to synthesise urea in his laboratory. Nevertheless, Liebig demonstrated that yeast could be concentrated and made into a packaged foodstuff, and in this sense he is also credited as a pioneer in the development of the yeast-based food **Marmite**™)

Light ale

Light ale is a name used for the beer style which originated in the United Kingdom and which is more commonly referred to as **pale ale**. In this sense the word 'light' is indicative of the pale colour as opposed to the more recent connotation applied to some mainly pilsener lager-type beers of lacking body and by implication carbohydrates or calories.

Light-struck character

Light-struck character, also termed **sunstruck** or '**skunky**' flavor, is an off-flavour that develops in some beers when they are exposed to light. The effect is caused by the appearance in beer of 2-methyl-2-butenyl mercaptan (thiol).



3-Methyl-2-butenyl mercaptan (thiol)

This compound is derived from the photolysis of isomerised hop α -acids, principally iso-humulone. It has a very low flavour and aroma threshold in beer of the order of 0.05–0.1 ppb (ng/L).

In order to prevent the formation of this compound beer must be packaged into a brown glass. The increasingly common trend for the use of clear or green glass bottles has required other strategies, namely, the development of hop bittering substances that are not susceptible to photolysis. This is accomplished by reducing hop iso- α -acids to produce novel hop extracts in which the light-sensitive acyloin group has been removed. Three types of reduced iso- α -acid may be produced, dihydro-, tetrahydro- and hexahydro-iso- α -acids, which vary by the number of hydrogen atoms which have been incorporated during the reduction (see individual entries for more details). Apart from the lack of light sensitivity some of these processed hop acids have foam-promoting properties.

Light transeflectance meter

This describes a piece of equipment and technique developed at the Brewing Research Institute in the United Kingdom and used to assess the extent and homogeneity of mealiness/steeliness in barley and malted barley grains. The device relies on the fact that the extent of mealiness

or steeliness in malt grains influences the ability of the surface of malt or barley grains to reflect light.

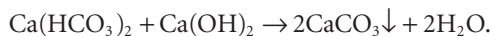
Barley or malt grains are placed with the ventral surfaces facing downwards into a carousel. Each grain in turn passes through a beam of laser light with a wavelength of 680 nm. Sensors detect both reflected and transmitted light and from these values the relative mealiness can be computed. Since a large number of individual grains are assessed the extent of homogeneity can also be gauged using this approach.

Limbus

Limbus is a Polish aroma hop variety. Analysis is 5.3% total α -acids of which 35.5% is cohumulone. Total oil content is 1.7% of which 12.0% is caryophyllene, 26.9% is humulene and 40.8% is myrcene.

Lime water

Lime water is a solution of saturated calcium hydroxide. Its relevance to brewing is that it is used in the treatment of water. This may be as a method of removing temporary hardness from brewing liquor via its ability to react with dissolved calcium bicarbonate and to produce a precipitate of calcium carbonate:



In addition, in malting it may be added to the first steep water in order to produce alkaline conditions and thereby to reduce microbial loadings.

Limit dextrinase

Limit dextrinase is an enzyme also known as **debranching enzyme**, **pullulanase**, **R-enzyme** or, more properly, α -dextrin 6-glucanohydrolase (EC 3.2.1.41). The enzyme hydrolyzes α -(1,6) glucosidic bonds which are found in substrates such as pullulan, amylopectin and amylose. It works in concert with malt enzymes such as **α -amylase** and **β -amylase** to break down starch during the mashing phase of wort production (see **starch** for further details). As such it is a member of the group of starch degrading and saccharogenic enzymes which are grouped together as **diastase**. The name derives from the fact that the activity of amylases is restricted to the hydrolysis of α -(1,4) glucosidic bonds. In consequence during mashing starch degradation by amylases proceeds to a point where all the α -(1,4) glucosidic bonds within a few residues of an α -(1,6) glucosidic branch point. These partial degradation products are termed limit dextrans. Further hydrolysis is dependent upon the activity of limit dextrinase. Following hydrolysis of α -(1,6) glucosidic bonds further degradation via amylases can proceed.

Two types of limit dextrinase have been recognised. These are distinguished on the basis of substrate specificity. The first group includes pullulanase. These are endohydrolases which hydrolyze α -(1,6) glucosidic bonds in pullulan (a polysaccharide that consists of maltotriosyl residues linked by α -(1,6) glucosidic bonds). The second group includes isoamylases, which are capable of hydrolyzing α -(1,6) glucosidic bonds in glycogen and amylopectin but not pullulan. This differentiation is confusing and appears to be based on the size of the substrate molecule that the enzyme shows activity against. Thus, the pullulan type shows a preference

for hydrolyzing α -(1,6) glucosidic bonds in oligosaccharides as opposed to larger polysaccharides. This type of enzyme is that which is properly referred to as limit dextrinase, although it has also been termed R-enzyme. It is the sole type that is found in barley.

Limit dextrinase is produced in the **aleurone layer** of barley from where it is released into the endosperm. During development of the barley grain the activity decreases until at maturity very little active enzyme can be detected. This is due to the presence of inhibitors which bind to the active site of the enzyme and render it inactive. The inhibitors are polypeptides which are synthesised during the development of barley grains. Presumably their role is to restrict limit dextrinase activity during starch formation. The inhibitors disappear during germination and therefore limit dextrinases are activated during malting. However, the degree of activation and the consequent persistence into mashing seems to be dependent on the particular cultivar and environmental conditions during cultivation of the barley plant.

The role of limit dextrinases in mashing remains the subject of debate. Where worts with high fermentability are required it is common to add a supplement of a preparation of a microbial pullulanase. The survival of the native barley enzyme into mashing seems to be highly dependent upon the conditions imposed during kilning. However, it seems likely that some activity persists into mashing, especially during the initial phases of temperature-controlled processes. In a recent publication [Wang, X.-D., Yang, J. & Zhang, G.-P. (2006) Genotypic and environmental variation in barley limit dextrinase activity and its relation to malt quality, *J. Zhejiang Univ. Sci. Bull.*, 7, 386–392], the limit dextrinase activity of eight barley cultivars was investigated. It was concluded that enzyme activity correlated negatively with malt viscosity and positively with **Kolbach index** and malt extract. However, no significant correlation was observed with malt protein content or diastatic power.

Lincoln equations

The Lincoln equations [Lincoln, R.H. (1987) *MBAA Tech. Quart.*, 24, 129] are a series of mathematical equations that provide relationships between some parameters which form the basis of common brewing calculations regarding commonly used units of extract. The equations avoid the use of tables and can be used in simple programmes.

The equations are

$$\text{Extract (E, in pounds per US barrel) from degree Plato (P)} = 2.58(P^{-1} - 0.00382)^{-1}$$

$$\text{The same relationship in kg/hL} = 0.9974(P^{-1} - 0.00382)^{-1}$$

Degree Plato from extract (E, pounds per US barrel)

$$^{\circ}\text{P} = (E)[2.58 + 0.00382(E)]^{-1}$$

Relationship between specific gravity (SG) and degree Plato ($^{\circ}\text{P}$)

$$\text{SG} = \text{P}[258.6 - (0.8796\text{P})]^{-1} + 1.0$$

or

$$^{\circ}\text{P} = 463 - (205\text{SG})(\text{SG} - 1).$$

Linde, Carl von

A German scientist and engineer (1842–1934) responsible for the introduction of the first reliable large-capacity refrigeration plant into breweries.

Line

Name given to the tubing used to transport beer from container to tap. Typically, a number of lines are bundled together in an insulated **python**.

See **medium-density polyethylene (MDP)**, **multilayer barrier dispense tubing**, **nylon** and polyvinyl chloride (PVC).

Lin's wild yeast medium

Nutrient medium which is made selective for *Saccharomyces* **wild yeast** strains by the addition of crystal violet. Reportedly it is less effective than **MYGP copper medium**.

Lintner degree

Lintner degrees are units used to quantify the **diastatic power (DP)** of malt. In the original test an extract of malt produced under standardised conditions was mixed with a substrate of soluble starch and allowed to react under defined conditions. The diastatic power of the malt extract was assessed by determining the volume of the resultant sugar solution that was required to reduce a known quantity of Fehling's solution. Using this protocol 100° Lintner correspond to the diastatic power of a malt of which 0.1 mL of a 5% w/v extract reduced 5 mL of Fehling's solution.

The relation between Lintner degrees and other commonly used measures of diastatic power (**Windisch–Kolbach units** and **maltose equivalent**) are given as follows:

$$\text{Lintner degree} = \frac{^{\circ}\text{W-K} + 16}{3.5}$$

$$\text{Maltose equivalent} = ^{\circ}\text{L} \times 4.$$

Lipid transfer protein 1 (LTP1)

LTP1 is a heat-stable protease resistant albumin protein found in barley and in other cereals. The *in vitro* role of these proteins remains obscure. The native protein has a hydrophobic core and this allows it to bind lipid molecules. It has been suggested that it may be implicated in resistance to stresses, binding and detoxification of heavy metals and possibly to resistance to pathogens.

The stability of the protein allows it to survive the brewing process relatively unchanged, a property shared by very few other cereal proteins (see **protein Z** for further details). In beer, lipid transfer protein contributes to beer foam stability and foaming potential. The native barley enzyme does not possess these properties, and it has been suggested that structural changes to the molecule are made at various stages in the brewing process and these result in the acquisition of these beneficial properties. The modifications are thought to be glycation via **Maillard reactions** during malting and acylation and conformational changes during mashing and the wort boil. Together with protein Z, lipid transfer protein is a major beer allergen.

Liquid adjunct

Liquid adjuncts, as the name suggests, are sources of fermentable extract, other than malt, which are supplied in the form of liquid sugar syrups. They do not require any form of pre-processing other than sterilisation and by convention are added to the copper (kettle) during boiling. For this reason they are also commonly referred to as **copper adjuncts**.

See **adjuncts**.

Liquid malt

Sometimes used as a synonym for malt extract but also a product used in German brewing made by mashing unkilned green barley followed by concentration and removal of undesirable flavour components. Although the material is used as an adjunct, its use for the production of beers subject to the restrictions of the *Reinheitsgebot* is permitted. As such it can be used as an additional source of enzymes.

See **adjuncts**.

Liquor

Liquor is the term used in brewing to describe water, in particular, that used for preparing the initial mash. Usually the word is preceded by an adjective describing the use to which the particular grade of water might be used; for example, brewing liquor describes water which, either naturally or by design, has an ionic composition suitable for the particular style of beer being made. Other descriptors are hot, cold, dilution (cutting) or de-aerated, and so on.

The origin of the term does not appear to have been recorded. The Shorter Oxford English Dictionary gives a UK reference dating from 1691 describing the use of the term for water used in brewing. Presumably the origin refers to the fact that the water used for mashing would have been chosen as being particularly suitable for brewing the local beer and, as such, was distinct from other sources.

Liquor heat

Liquor heat is the temperature of the hot liquor in the tank which feeds the mashing machine. It is distinguished from the temperature of the liquor at the point of entry into the mashing machine, which is referred to as the striking heat.

See **mashing**.

Lite (light) beers

Lite beers are those that are marketed specifically as having a low calorie content. Usually this is achieved by making highly fermentable worts such that when fully attenuated the residual gravity is very low. It should be noted that such beers may qualify as low carbohydrate but cannot be low calorie unless steps are taken also to reduce the ethanol concentration.

See **diet beer**.

Load cell

A load cell is a device that is used to convert force into an electrical signal the magnitude of which is proportional to the force applied. In brewing applications load cells are used to weigh the contents of vessels such as storage tanks for pitching yeast slurries and sugar syrups. The

devices are tared such that the weight of the empty vessel is automatically deducted from the weight reading. Output may take the form of a simple readout on a gauge mounted on the vessel, giving the weight of the vessel contents in kilograms. More usually the signal is transmitted to a remote PC for data logging and control purposes. For example, the reading from a load cell might be used in a control system designed to transfer a defined quantity of the contents of the vessel to some other stage of processing.

Many different designs of transducer are available which are suited to particular applications and weight ranges. The majority used in industrial applications rely on strain gauges in which the sensor takes the form of a foil in which the electrical signal is generated in response to shear, compression or tension. Typically sets of four strain gauges are used, arranged in two pairs which are compressed or placed under tension. A change in the applied force results in a proportional change in the electrical resistance. Temperature compensation circuitry is also provided.

Load cells are useful but suffer some drawbacks in that they may be subject to errors as a result of vibrations. Compensatory damping mechanisms are usually employed to reduce this effect. As alternatives to load cells in some control situations flow cells may be used.

Lodging

Lodging is a term used in relation to the growth of barley and other cereal plants. It refers to the situation in which the plant loses its upright habit and therefore causes problems during harvesting. The problem can arise through a buckling or kinking of the stem or a failure of the root system to support properly the aerial parts of the plant. These two conditions may be referred to as stem or root lodging, respectively. It can be a significant problem resulting in yield losses of up to 40%.

Lodging can arise from several causes. Predictably, some of these are due to external influences such as adverse climate and soil conditions which may result in stressed plants that are more susceptible to lodging. In addition, varietal differences are also of significance. Thus, the height and robustness of the stem and the diameter of the culms are influential. Two-rowed varieties are more susceptible than six-rowed types. This may be a consequence of the on average shorter culm length and larger culm diameter of the latter. Many modern varieties have been bred to have shorter and more robust stems compared with some older types in order to reduce the propensity to lodging.

Lodicule

See **barley grain**.

London beer flood

The London beer flood describes an accident that occurred in the city of that name in October, 1814 when at the Meux and Company Brewery a beer storage vessel with a capacity of 3750 UK barrels ruptured. The escaping liquid caused the failure of a number of other adjacent vessels and the ensuing flood, which amounted to some 9000 UK barrels of ale, and engulfed nearby houses and a public house. Eight people drowned in the incident with a ninth victim reportedly succumbing to alcoholic poisoning the following day. The precise circumstances of the latter death are not recorded!

Loom

An alternative name for a **python** used in draught beer dispense.

Lovibond tintometer

An early device used for the determination of the colour of beers and worts (and by inference malts used in their making via a standard wort production procedure) developed for colour measurements in many fields in the middle of the nineteenth century by Joseph Lovibond. It contains a method of viewing the sample and simultaneously comparing the colour with a series of glass discs. The one most closely resembling the colour of the sample forms the basis of the measurement [quoted as degrees Lovibond (L)].

Discs suitable for beer colour were introduced in 1893 and later adapted by the European Brewing convention (EBC) with new discs suitable for dark and paler beers in 1950. Ranges from 2 to 27 EBC colour units were recognised.

See **beer colour**.

Low-alcohol beers

See **reduced-alcohol beer**.

Low Kräusen

See *kräusen*.

Lowliner

Name given to a beer dispense system that consists of a horizontal closed cylinder mounted on a wooden plinth with brand badges (usually illuminated) and between two and six taps on either side. It is also known as a **bar hugger**.

Lubelski

See **Lublin**.

Lublin

Lublin is a generic name given to hop varieties grown in the Polish region of Lublin. The specific variety is also known as **Lubelski** and is probably descended from a Saaz variety of the Czech Republic. It is used as an aroma hop in Polish European-style pilsener lagers to which it imparts grassy and woody aromas. The hops contain 3–5% α -acids of which 25–30% is cohumulone. Total oils are 0.5–1.2% (22–35% myrcene, 30–40% humulene, 6–11% carophyllene, 10–14% farnesene).

Lucan

A Czech aroma hop variety which is a clone of Saaz.

See **Zatecky Chmel**.

Lucilite

Lucilite™ is a generic trade name for a group of silica gels manufactured by the company INEOS Silicas.

See **silica gel**.

Lugol's iodine

A solution of iodine (1% w/v) and potassium iodide (2%) in distilled water used as a rapid stain for **glycogen** and **starch**.

Luke the apostle

One of the plethora of names quoted as being patron saints of brewing. Luke is described as being a physician of Syrian descent and living in the Greek city of Antioch. The reason for his association with brewing does not appear to be recorded. Some commentators claim that the reason may be linked to his being a member of the medical profession and the fact that, in ancient times, beer could be considered as a microbiologically safe form of water. This explanation does not seem satisfactory.

Luminometer

Device that measures light intensity and used in methods for the rapid detection of microorganisms or hygiene testing based on ATP bioluminescence.

See **ATP bioluminescence**.

Lupulin-enriched hop pellets

See **hop pellets**.

Lupulin gland

Sac-like structures that occur principally in the hop cones of female hop plants. They contain the resins that are responsible for the bitter and other hop-related flavours in beers.

See **hop plants**.

Lupulone

Lupulone is one of the principal components of the β -acid fraction of the soft fractions of hop resins.

See **β -acids**, **hop resins**.

Lysine agar medium

Nutrient agar medium, available commercially, comprising glucose, vitamins, salts and L-lysine as the sole source of nitrogen. The medium is used for the detection of non-*Saccharomyces* wild yeasts since *Saccharomyces* types cannot grow. The selective effect is not absolute and some growth due to carry-over of nutrients may occur. In this respect **MYGP** copper medium provides more definitive results.

MacConkey's medium

Commercially available medium used for the detection of Gram-negative bacteria, especially coliforms. It contains bactopectone, proteose peptone, lactose, sodium chloride, bile salts, neutral red and crystal violet. Both crystal violet and bile salts inhibit Gram-positive bacteria. The neutral red is taken up by the growing bacterial colonies that are capable of growing on lactose and are stained red to aid visualisation.

Maffei malting system

A mechanical **floor malting** system that originated in Germany in the early part of the twentieth century. As opposed to the conventional floor malting it included flat-bottomed steeping tanks the discharge points of which were spouts the direction of which could be manipulated to facilitate spreading the grains. In addition, there was a mechanical system for emptying the kilns. The floors took the form of a series of parallel brick-lined semicircular tunnels equipped with a mechanical ventilation system.

MAGB

See **Maltsters' Association of Great Britain**.

Magflow meter

See **flow meter**.

Magnum

Magnum is a high alpha hop variety bred at the German Hop Research Institute in Hüll, Bavaria. It derives from the US bittering variety Galena and a German male hop. It contains 10–12% α -acids of which 25–30% is cohumulone and 2–3% total oils (35–45% myrcene, 8–12% carophyllene, trace of farnesene, 25–30% humulene).

Maibock

Maibocks (also called *Hellesbock*) are pale and generally weaker variants of the bock family of German beers.

See **bock**.

Maillard reaction

The Maillard reaction (named after Louis-Camille Maillard) describes reactions that occur between the nucleophilic amino groups of amino acids and the reactive carbonyl groups of reducing sugars. The reactions require heat and occur most readily under alkaline conditions. They are associated with browning reactions and the formation of flavoured compounds, particularly toffee/caramel-type flavours and aromas. The coloured compounds that arise from these reactions are termed **melanoidins**. Maillard reactions form the basis of many of the transformations that underpin colour and flavour changes associated with the kilning stage of malting and the boiling stage of wort production. The combination of the reactions that occur during malting and wort boiling is responsible for the colour of beer. The caramels which may be used where permitted by some brewers used for colouring and flavouring are produced by Maillard reactions when sugar syrups are boiled with ammonia.

Maillard reactions occur in three phases:

- (1) The condensation of a simple sugar with an amino acid and the loss of a molecule of water form an N-glycoside.
- (2) The resultant immonium ion is unstable and this undergoes an isomerisation reaction to yield a ketosamine (1-amino-1-deoxy-2-ketoses). This reaction is termed an **Amadori rearrangement**. Many Amadori compounds have been identified in malts. The majority of these derived from reactions with fructose and various amino acids.
- (3) The ketosamines undergo a variety of subsequent dehydration, degradation or polymerisation reactions to give a multitude of products depending upon the nature of the precursor and the type of reaction.

Dehydration reactions yield reductones or dehydroreductones, which are caramels. These have antioxidant properties and are important determinants of beer flavour stability. Some of the degradation products, those derived from 1,2-enolisation of Amadori products, have a negative impact on beer flavour since their concentration can be correlated with the perception of staleness, for example, the formation of 5-hydroxymethylfurfural. The 2,3-enolisation of Amadori products give rise to compounds such as maltol and isomaltal. These compounds have pleasant, sweet caramel flavours. Other degradation products include smaller molecules such as diacetyl, acetol and pyruvaldehyde. These undergo reactions with amino acids via Strecker degradations to yield aldehydes and ketones. Strecker aldehydes have potent aromas and tastes which are generally unpleasant at high concentration. Since they are relatively volatile their concentrations are much reduced during wort boiling. In addition, they may be reduced to the corresponding alcohols by yeast during fermentation. The amino ketones undergo condensation and oxidation reactions to form pyrazines. These compounds form the basis of the burnt, toffee, coffee character associated with kilned or roasted grains.

Maischbottich

German for mash tun.

Maischkessel

German for mash kettle.

Maischpfanne

German for mash copper.

Maitland grist hydrator

The Maitland mash hydrator is a **mashing machine** that is used for mixing grist with mashing liquor. It is associated with the comparatively thin mashes used in **decoction mashing** or **temperature-programmed infusion mashing** regime.

It is an in-line device in which the grist is delivered at a controlled rate, via a slider valve at the base of the grist case, into a vertically mounted chamber. The latter contains a centrally mounted perforated tube through which hot liquor is delivered in the form of a spray. The liquor plus suspended grist passes into the mashing vessel via a side entry such that the mash slides down the side of the vessel and oxygen pickup is minimised. The mashing rate (proportions of liquor and grist) is regulated via control of the rates of addition of grist and liquor.

Makgeolli

See **takju**.

Malt

Name given to the finished product after the process of malting. Usually the term is followed by the name of the grain that was used as the source cereal, for example, barley malt or sorghum malt. The term is also used in reverse as in malting barley or malting sorghum.

See **malting**.

Malt abrader

Malt abraders are mechanical devices designed to partially disrupt the integrity of barley grains prior to steeping. Their use is based on the observation that such treatments accelerate the malting process. Several reasons for this effect have been proposed, for example, promoting the ease of ingress of oxygen and water from the outside to the internal tissues of the grain. The process is often used in conjunction with treatment with gibberellic acid. Abrasion must be used with care to avoid excessive damage to grains. It appears to be particularly successful when applied to poor quality barley grains; nevertheless, abrasion is now rarely used.

Maltase

A synonym for **α -glucosidase**.

Malt bushel

A non-decimal measure used for quantifying batches of malt. The precise weights vary in different countries. All are given as fresh weights:

United Kingdom, South Africa = 42 lb, 19.1 kg

Australia and New Zealand = 40 lb, 18.1 kg

United States, Canada = 34 lb, 15.4 kg.

Malted barley

Barley grains that have been subject to malting.

See **malting**.

Maltese cross

Intact starch grains of barley grains and other plants when viewed under a microscope with polarised light exhibit birefringence. This takes the form of a characteristic dark ‘maltese cross’ against a paler background. This is indicative that the starch grains have an organised structure (see **starch** for more details). When the starch grains undergo gelatinisation during the mashing phase of wort production the disruption of this organised structure can be observed by the loss of the maltese cross appearance.

Malt extract

Malt extracts are produced via the hydrolysis of cereals which, after clarification, are concentrated via a vacuum evaporative process to 75–85% solids. Depending on the source of grist the hydrolysis may be achieved using endogenous enzymes alone or supplemented with various exogenous enzymes. The composition of malt extracts is complex and depends upon the nature of the grist and the conditions used during the mashing phase. Thus, they contain a mixture of various sugars, nitrogenous materials and assorted minerals and yeast coenzymes and various growth factors. They may be made in a way that conserves the activities of hydrolytic enzymes or, conversely, they may be devoid of enzymic activity and highly coloured. Where enzyme activity is conserved the preparations are often referred to as **diastatic malt extract** (or non-diastatic, where there is no residual enzyme activity). They are highly viscous and usually require storage at warm temperatures in order to render them amenable to transport via pumps.

In commercial brewing they may be used as a highly concentrated source of extract used to supplement conventional worts, although this application is now comparatively rare. More commonly they are used by craft or home brewers where the extracts may or may not be hopped.

See **adjuncts**.

Malthus detection system

See **impedimetry**.

Malting

Malting describes the process in which the seeds or grains of various plants are allowed to germinate under controlled conditions. Raw materials are usually cereal grains, barley being the most common; however, maize, various millets, oats, rye, sorghum, rice or triticale may also be used. In addition, notably in Asia, various pulses are malted for use as foodstuffs. In the context of brewing the product, **malt**, which is usually made from barley grains, provides the source of fermentable sugars and a wide variety of nutrients which are utilised by yeast for growth during the fermentation stage of brewing.

The name malt is possibly of Anglo-Saxon derivation from *metan*, meaning to melt or dissolve. This is probably a reference to the softening of the grains that accompanies germination of the grains. Alternatively, the term may derive from the Anglo-Saxon *malled*, which means broken into fragments, alluding to the preliminary stage of brewing in which the malt is milled to form the coarse flour known as the **grist**. The derivation of the term gives some clue to the antiquity of the process. It seems likely that malting, together with baking and

brewing, represents the earliest manifestation of organised biotechnological processes (see **Ninkasi**).

The malting process is usually described in terms of the major component stages – steeping, germination and kilning. This may give a somewhat false view of what is a complex process, and from a practical standpoint many other steps are actually required to be performed. These relate to preliminary considerations such as ensuring that appropriate varieties of grain are cultivated by the farmer and that these are delivered to the maltster in a condition that is fit for purpose. Once at the malting the grains must be sampled and assessed then stored under appropriate conditions. Before use the grains must be treated to remove any entrained waste materials as well as broken and substandard grains. During the malting process waste materials are generated and these must be separated, treated and disposed of. At completion, finished malts must be sampled, subjected to appropriate analyses, stored and then packaged prior to despatch. Nevertheless, despite these added complications, the essence of the process is encapsulated within the few steps described below.

Germination is initiated by immersion in water, known as **steeping**. The hydrated grains are then recovered and allowed to germinate under controlled conditions of temperature and humidity with mechanical agitation to prevent matting together of the developing rootlets. During this phase enzymes required for the degradation of starches, proteins and other biological macromolecules are synthesised. As a consequence the starch-containing endosperm is partially degraded and other smaller soluble metabolites accumulate. The gross manifestations of these changes are the appearance of rootlets and the **acrospire** (leaf sheath or coleoptile) and a loss of the physical integrity of the grains such that they become friable in nature (see **friability**). These changes are collectively termed **modification**. When the process is judged to be sufficiently advanced further activity is stopped by the application of heat in the process, termed **kilning**. This converts the immature or **green malt** into its finished form. After **dressing**, in which the rootlets are broken off and removed, the malt can be stored prior to use. Thus, the malt consists of the partially germinated grain, which contains starch and other reserve materials, such as proteins, together with a package of enzymes required for the degradation of these materials. The process of degradation, which begins during germination and is arrested by kilning, is allowed to progress to completion during the **mashing** phase of brewing.

From a brewing perspective the severity of the kilning process influences the nature and subsequent use of the malt. Where the heat treatment is comparatively slight pale malts are produced. In these the survival of sugar and protein degrading enzymes is considerable, and such malts make a large contribution to the degradation reactions that occur during mashing. Where kilning is more prolonged and at a higher temperature the malts become progressively darker and depending on the nature of the process acquire additional flavours and characters. In consequence enzyme survival is reduced, in some cases to zero. These dark malts are used to impart specific flavours and colours to the beers made from them.

Malting barley – recommended varieties

These are varieties of barley which have been assessed and given approval for use in malting, either for application in brewing and/or distilling. The process is overseen by a number of independent bodies which are responsible for evaluation and approval within various

countries or economic federations. The process is necessary since it allows growers to select varieties with agronomic properties appropriate for the geographical areas in which they operate and, in addition, which possess desirable malting and brewing properties.

In the United Kingdom the process is overseen by the Institute of Brewing and Distilling (IBD). The latter, in 2002, passed the administrative duties of approval to the Maltsters' Association of Great Britain (MAGB). This body takes information regarding crop evaluation from Crop Evaluation Limited, a division of the HGCA, which is the cereals and oilseeds division of the Agriculture and Horticultural Development Board, based at Kenilworth, UK [<http://www.ahdb.com> (last accessed 12 February 2013)]. Malting trials are overseen by the Malting Barley Committee (MBC) of the IBD. Actual evaluation of the malting properties of individual varieties is carried out by both English and Scottish micro-malting working parties.

The process of evaluation and potential recommendation takes place as follows:

National List 1 (NL1). Potential varieties enter the system and are assessed for agronomic and micro-malting properties.

National List 2 (NL2). Promising varieties from NL1 are subjected to a further round of assessment by a combination of plant breeders, agronomists and the English and Scottish working parties of the MBC. Those that are deemed to have commercial potential are placed on the 'recommended list' for further evaluation.

Provisional approval. After a further series of malting and brewing trials at micro and pilot scales successful varieties are awarded 'provisional approval' status. In addition, promising varieties which have passed through the evaluation and approval systems of other countries and which have a suitable body of supporting data may pass directly to this stage.

Full approval. Subject to further assessment of malting and brewing properties at commercial scale, successful varieties are awarded recommended status and are placed on the full approval list. Provisionally approved varieties that do not achieve full approval within 2 years are removed.

The approved malting barley list for brewing (2010) is as follows:

Winter varieties. Full approval; Pearl, Flagon, Cassata

Spring varieties. Full approval; Optic, Cocktail, NFC Tipple, Westminster, Quench

Spring varieties. Provisional approval; Concerto.

The Wintmalt variety was removed from the Provisional Approval list.

A list of US recommended varieties of malting barley may be found in **American Malting Barley Association Inc. (AMBA)**.

Maltings

The place in which **malt** is made.

See **malting**.

Malt modification

Modification refers to the sum of the processes that occur within the starchy endosperm tissue of cereal grains during malting. It is descriptive of the state of malt grains in which germination has commenced and has been allowed to proceed to a point when it is terminated by kilning. Its relevance to brewing is that it is predictive of the performance of the malt during the brewing process and the yield of extract that is obtained. Both the extent and evenness of

modification are important measures of malt quality. Its importance as a determinant of malt quality may be judged by the large number of tests that are used to assess it.

From a physiological standpoint modification is initiated by the provision of water. The germination of cereal grains, usually barley grains, is accompanied by an increase in the concentration of many enzymes. Many of these are of importance during the mashing phase of brewing. In addition, they are responsible for changes in the physical and chemical structure of the starchy endosperm of the grain. Initially, various hydrolases are produced in the scutellum. Later, in response to the stimulatory activity of various gibberellin plant hormones, liberated by the embryo, other enzymes are produced in the aleurone layer. This package of enzymes is transported to the endosperm layer where they catalyze modification.

Modification commences beneath the face of the scutellum and from there proceeds through the endosperm. Progress is more rapid when enzymes from the aleurone layer appear. The products of enzyme activity are principally sugars and amino acids and smaller concentrations of various salts and metal ions. These accumulate within the endosperm where they provide nutrients for the development of the embryo.

During modification, β -glucans and pentosans in the walls of cells of the endosperm are degraded. Some proteolysis occurs and starch granules, especially the small type, are broken down. These changes result in a change in the physical appearance of the grain. The endosperm is transformed from a relatively tough structure into a softer, more friable form.

The modification process is terminated by kilning at some chosen point when the process is judged to have proceeded to a satisfactory extent.

Modification is commonly accelerated by the addition of exogenous gibberellic acid. This usually has some undesirable side effects in that it may also stimulate excessive accumulation of soluble nitrogen compounds. This effect may be checked by the use of agents that are inhibitory to proteases such as sodium or potassium **bromate**.

Malt modification can be measured by a simple examination of the properties of whole grains or an examination of the microscopic structure of sections of grains with or without the aid of specific visualisation agents. Other tests rely on assessments of the biochemical changes that accompany modification.

At its simplest malt modification is assessed by crushing grains between thumb and forefinger. Well-modified grains are easily crushed and have no hard ends. Poorly modified grains remain hard and difficult to crush. It is considered (not reliably) that fully modified malt corns float in water, whereas unmodified barley grains sink. Partially modified grains exhibit intermediate behaviour. A more sophisticated and commonly used test involves a piece of equipment known as a **friabilimeter** in which a sample of malt is abraded and the fragments separated from whole grains using a sieve. The relative proportions of fragments that are retained or pass through the sieve provide a measure of friability.

The extent of modification may also be gauged by the proportion of cell walls remaining in the endosperm layer of the grains. This can be assessed by direct microscopic analysis, but more usually it is accomplished by grinding the grains to expose the endosperm layer followed by visualising cell walls using stains such as the fluorochrome **calcofluor**. This binds with β -glucans which are present in unmodified regions of the endosperm. In **sanded slab tests**, representative malt grains are set in a slab of resin. The surface of the slab is sanded to reveal

the internal structure of the grains and to allow visualisation of remaining cell walls. For example, see the **calcofluor Carlsberg sanded slab test**.

The presence of un-degraded cell wall material in poorly modified malts causes problems in milling. They may give low extract yields since levels of hydrolytic enzymes may also be low. In addition, a high proportion of the starch grains may not be accessible to the hydrolytic enzymes. High concentrations of pentosans and β -glucans cause high viscosity, which in turn results in poor wort run-off.

Other measures of modification are based on an assessment of the amount of extract that is obtained from ground samples of the malt under examination. The **cold water extract** test assesses the amount of extract that is formed when coarse ground malt is stirred for 3 hours at 20°C in the presence of an inhibitor of ammonia that inhibits the activity of hydrolytic enzymes. Thus, it measures the pool of soluble metabolites that accumulate within the endosperm during germination and prior to mashing. It is also known as **preformed soluble nitrogen**. Their concentration, at any given time during modification, is governed by the difference between the rate of formation during endosperm breakdown and the rate of utilisation by the developing embryo.

The degree of malt modification may also be assessed by measuring the amount of extract that is obtained when samples are subjected to both fine and coarse grinds and mashed under defined conditions. In poorly modified malts the relatively abundant intact cells survive the coarse grind, and during mashing these are inaccessible to the starch hydrolyzing enzymes and extract yields are low. In the case of the fine grind more of the un-degraded cells are broken down and subsequent extract yields are higher. Therefore, the greater the difference between extract yield under both conditions, the poorer the degree of modification. This is termed the **fine/coarse extract difference**.

Malt modification is accompanied by a degradation of protein which is located in the matrix surrounding starch granules. The extent of protein degradation is reflected in the concentration of soluble nitrogen that arises in worts after mashing. Tests which are designed to measure this are that recommended by the Institute of Brewing (IOB), the **soluble nitrogen ratio** (SNR) and, in the case of the European Brewing Convention (EBC), the **Kolbach index**. In both cases wort is produced using a standard mashing regime and the total and soluble nitrogen concentrations are measured.

Maltose equivalent

The maltose equivalent is a measure of the **diastatic power (DP)** of malt. It is used in the United States and is based on the **Windisch-Kolbach units** method. Numerically it is equivalent to the diastatic power measured in **Lintner degree** multiplied by 4.

Malt quarter

A pre-decimal measure used in the United Kingdom and South Africa for quantifying batches of malt. It is equal to a fresh weight of 3 hundredweights (152.4 kg).

Malt Research Association

See **American Malting Barley Association Inc. (AMBA)**.

Malt steeping plant

Malt steeps are the devices used for the steeping process in which barley grains are subjected to a controlled process of wetting and aeration in order to induce germination. The basic requirements of the steep are filling, wetting, aeration, draining, provision of air in the rest period after draining, CO₂ extraction, emptying and cleaning (see **steeping** for more details). Important factors are hygienic design, consistent treatment of grains and good temperature control. More recently the amount of water consumed in steeping has become an important design consideration.

Several designs have been used over the years often employing complex internal fittings designed to promote efficient aeration and circulation. Modern types are usually circular tanks made from stainless steel with either flat or conical bottoms. Commonly the conical types are fitted with devices such as air lift tubes and spreaders or distributors which facilitate good mixing of grains, water and air. Provision is made for filling the steeps possibly incorporating a means of separating grains from contaminating dust and stones. Associated hoppers may be used to store the initial charge of barley and for collecting the germinating grains. During operation the beds of grains can be drained by allowing the steep water to escape. During this process a means of allowing air to be sucked in to the top of the tank and through the grains is provided. Additional fittings may be added in the form of perforated bases or top-mounted tubes to facilitate removal of CO₂. In each case it is important to ensure that the incoming air is attemperated to avoid undue seasonal temperature variations and that drainage of the bed of grains is even so as to ensure an even flow of incoming air.

Modern batch sizes can be up to 300–500 tonnes for flat-bottomed steeps, whereas those for conical types are usually around 50 tonnes. Flat-bottomed steeps can be larger than conical types since although relatively shallow beds may be used, the high capacities are achieved simply by increasing the diameter. In this type a perforated false bottom supports the bed of grains. The centrally located shaft is driven by a motor. The shaft bears a number of blades, termed **giracleurs**, which serve to level the bed after filling and to strip the bed in the discharge phase. The space below the false bottom is provided with a means for addition of air and removal of water and CO₂.

See **steeping**.

Maltsters' Association of Great Britain (MAGB)

A trade organisation founded in 1827 and charged with servicing the interests of the UK malting industry [<http://www.ukmalt.com> (last accessed 12 February 2013)]. Originally the MAGB was formed in order to represent the interests of the malting industry from the standpoint of government legislation regarding taxation. In the early years the association played a large part in ensuring the repeal of a great deal of restrictive legislation.

Membership is drawn from sales, brewing and distilling maltsters. The activities include primarily looking after the interests of its member companies. Activities include assuring the supply of malting raw materials, safeguarding malt quality and wholesomeness, interpretation of relevant legislation, improvement of the competitiveness of the UK malting industry via the identification and promotion of appropriate innovations, and overseeing training and qualifications in malting.

Malzbier

Malzbier is a sweet and dark zero-alcohol beer, originating in Germany, sold as a health drink for children, invalids and pregnant women.

See **reduced-alcohol beer**.

Mammut

A preparation of pitch which was applied to fermenting vessels made from steel and used to provide an inert surface.

Manioc beer

An alcoholic beverage native to South America popular since pre-Columbian times and made from the roots of the manioc plant (*Manihot esculenta*). The traditional product is made by women, and as with many of these native beers, the roots are macerated and chewed before spitting out. This practice introduces salivary amylases which are responsible for breaking down the plant starch and for providing fermentable sugars. The beverage is drunk after a short fermentation and is not filtered. It provides both alcoholic stimulation and a source of food. Several names are used to describe this type of beer, depending on the region of origin. These include yarake, kashiri, masato and chichi. The latter term is used specifically to describe a similar product made from maize but can also be used as a generic term for any native fermented beverage including manioc beer.

M

Maris otter

A two-row variety of winter malting barley produced from a cross between the varieties Proctor and Pioneer and placed on the recommended list of brewing malts in 1966. It has now been removed from the list but is still used and highly favoured by many brewers of traditional UK-style cask conditioned ales.

Marmite™

Yeast-based food-spread made from surplus brewing yeast and manufactured originally in Burton on Trent by the Marmite Food Extract Company, founded in 1902, now part of Unilever. The initial invention is German since the renowned chemist Justus von Liebig was the first to develop a process for concentrating and packaging yeast. It owes much of its original popularity to the discovery in the years immediately preceding the First World War of the role of vitamins in human diet and the realisation that this product is an excellent source of B vitamins. The rise in popularity resulted in the opening of a second production facility in Vauxhall in London. The name is considered to derive from the French word *marmite*, a type of casserole similar in appearance to both the jar and the depiction on the label and presumably reflective of the cooking process used to make a cell-free extract. Similar yeast-based products are produced in Australia (Vegemite and Promite) and New Zealand (New Zealand Marmite). UK enthusiasts and purists decry these products since, unlike the original, they contain caramel and sugar. Other yeast-based products are made in Switzerland (Cenovis) and in the United States (Vegex).

Mars

Mars beers are low-alcohol versions of Belgian **lambic beer** and are made with the weaker second wort runnings. They are no longer made commercially.

See **lambic beer**.

Marynka

Marynka is a high alpha hop variety (11% α -acids of which 25% is cohumulone, 2.3% total oils). It is cultivated in the Lublin region of Poland. Reportedly it imparts strong 'licorice' characters to beers.

Märzen

Märzenbier, literally March beer, is a style of beer originally most associated with Bavaria in Germany, although similar products are now brewed in other parts of the world. The beer is usually gold or dark coloured, although pale variants also exist. The beers are produced using **Vienna malt**. The latter is dark, imparts a marked malty flavor, but with no caramel notes.

The name derives from the fact that a piece of sixteenth century Bavarian legislation forbade brewing during the summer months. This was in part responsible for the practice of lagering (storing) beers in caves during the summer. In order to keep the temperature as cool as possible the natural chill of the caves was enhanced by the use of ice. Natural supplies of ice became unavailable in the spring and, hence, the month of March marked the end of the brewing season.

Märzen beers are usually quite strong (6–8% abv) and well hopped. This provided some protection against microbial spoilage during the long months of maturation. Many *Märzen* beers are now continuously available; however, originally they were seasonal products most associated with the *Oktoberfest*. Some brewers retain the seasonal practice.

Masato

Name given by certain indigenous tribes of Brazil to manioc beer.

See **manioc beer**.

Mash filter

A mash filter is an alternative name for a mash press.

See **mash press**.

Mashing

Mashing is the stage in wort production in which the grist is mixed with brewing liquor and the resulting mash is held for a predetermined period of time at a controlled temperature (or range of temperatures). More precisely, a mixture of ground malts, possibly other solid adjuncts, salts and enzymes, is carefully mixed with a measured volume of brewing liquor with a salt composition that has been adjusted to be appropriate for the quality of beer to be made. The mixture is held at a chosen temperature, or range of temperatures, for a controlled period (or periods) of time after which the resultant sweet wort is separated from the residue of solid material, the spent grains. During the mashing process soluble materials are extracted from the grains (**for example, preformed soluble nitrogen**); in addition, as a result of the activity of enzymes usually derived from the grains or occasionally added to the mash,

insoluble components of grains and other grist components are degraded and solubilised. Together, the preformed soluble materials plus the solubilised components comprise **sweet wort**. The composition of sweet wort is very complex. Several thousands of compounds may be found. All the major classes of biochemicals are represented. They include sugars, principally maltose but ranging from simple mono-, di- and trisaccharides through to longer-chain dextrans. In addition, many other polysaccharides such as pentosans and their breakdown products, derived from husk and cell wall materials, are also found. Proteins, simple and more complex polypeptides and amino acids make up the bulk of the nitrogenous components, although free bases derived from nucleic acids and their breakdown products also occur as do various amines. Lipids are represented by phospholipids, glycolipids, mono-, di and triacylglycerols, free fatty acids and steryl esters. Various phenolic compounds arise from malt husk material and other solid adjunct material. A large number of simple aliphatic acids at relatively low concentration, such as pyruvic, lactic, citric, oxalic, malic, succinic, fumaric and alpha-ketoglutaric acids, are found. These are common products of intermediary metabolism and are presumably derived from malt grains. Similarly, various coenzymes and vitamins are also extracted from the grains. In addition to these organic constituents various inorganic ions derive from the mashing liquor.

Many of these sweet wort components are simply extracted from the ground malt and other grist ingredients, whereas others are formed as a result of modifications by the enzymes present in the mash, which retain activity under the conditions imposed during mashing.

The biochemistry of mashing is predictably very complex. The combined activities of many enzymes are involved. The reactions are principally hydrolyses and oxidations, but others also occur. The substrates are mainly starches, proteins, polypeptides, nucleic acids and lipids. Each of the enzymes has its own specific requirements for pH and temperature. In addition, activity can be modulated by the presence of coenzymes, cofactors such as inorganic ions, substrate concentration and the presence of activators and inhibitors. Mashing is a linear time-dependent process such that as the many enzyme-catalyzed reactions proceed, individual enzymes may be sequentially inactivated either due to heat denaturation, via the increase in concentration of inhibitors or via selective proteolysis. Conversely other enzymes may be activated. Regulating the relative activity of these enzymes is managed by control of the grist composition but especially via control of the temperature. The degree of control that can be exerted is somewhat slight in that such a large number of enzymes are involved, each of which have different pH and temperature optima; it follows that some degree of compromise is inevitable.

The physical state of the grist is also important. The size of the fragments of grains in the grist influences the ability of many of the enzymes to gain access to their various substrates. For example, if intact grain cells persist into the mash the presence of intact cell walls can impede the entry of enzymes.

It has been estimated that mashing under conditions which retain enzyme activity results in between 50% and 70% more material being solubilised as compared with the simple preformed soluble materials. Thus, mashing results in the degradation of large macromolecules such as starches and proteins such that simple sugars and amino acids and short polypeptides are formed, as well as a vast number of other potential yeast nutrients. The nutrients are utilised by yeast during the fermentation stage of brewing to form more yeast biomass, ethanol, CO₂ and other yeast-derived metabolites. The residual non-fermentable materials such as

dextrins persist into beer, where they contribute to beer body and mouth feel. Similarly a fraction of the non-degraded proteins confer head-forming properties to beer. Other wort components which include some proteins and phenolic compounds form the precursors of haze-forming materials which will usually require removal during hot wort clarification, conditioning or the filtration stages of brewing.

The conditions of mashing and the composition and physical state of the grist must be suitable for the type of beer being made and the brewery equipment used in its making. Several terms are used to distinguish different types of mashing regime. These include **simple infusion mashing**, **temperature-programmed infusion mashing**, **decoction mashing** and **double mashing**. These are described in more detail under their respective headings. In general, traditional UK-style ales are produced by simple infusion mashing using a **mash tun**. In this case the initial temperature is controlled by selecting the appropriate temperature of the hot liquor. Subsequent temperature changes can be brought about by the addition of more hot liquor via the base of the mash tun, known as **underletting**. Traditional European lagers are made using decoction mashing. In this process the mash is prepared in a mash conversion vessel. At intervals a proportion of the mash is pumped into the copper where heat is applied. The portion of heated mash is returned to the mash conversion vessel and this results in an overall increase in the temperature of the whole volume of mash. This 'decoction' process may be repeated a number of times to give a series of stands of gradually increasing temperature. This stepped approach allows flexibility in providing optimum conditions for the activities of different classes of enzymes which underpin mashing. In decoction mashing the terminal separation process of sweet wort from grains is performed in a **lauter tun**.

In many modern lager mashing regimes, particularly in the United States, solid adjuncts such as rice are commonly used. These materials require a higher temperature in order to achieve starch gelatinisation. This is performed using a separate **cereal cooker**. The separately treated adjunct mash is then returned to the main mash. The temperature change brought about by adding the contents of the cereal cooker is used as part of the decoction process. The use of separate cereal and main mash mixing vessels results in this process being called **double mashing**.

Temperature-programmed infusion mashing is used for both lager and ale production. The process is essentially performed within a single vessel. Temperature-programmed stands are managed via the use of heated vessels. This obviates the need for decoction mashing.

In the case of decoction mashing, double mashing and temperature-programmed infusion mashing the final wort separation step may be carried out in a lauter tun. Alternatively, a **mash press** (also called a **mash filter**) may also be used.

Mashing-in

Mashing-in is the process in which the grist is mixed with mashing liquor (water with the appropriate mineral composition for the style of beer being brewed). It is also referred to as **doughing-in**, particularly in the United States. The process marks the start of the mashing stage of brewing. The requirements are that the grist is mixed evenly such that the suspension is homogeneous and in particular there is no balling since this would reduce the efficiency of mash conversion. In addition, it is essential that when mashing-in is completed, the mash is at a desired and controlled temperature.

Various pieces of apparatus have been designed to ensure that the requirements of mashing-in are satisfied. Collectively these are referred to as mash mixers. Each is designed to fulfil the needs of different mashing regimes. Examples include the Steel's mash mixer, Maitland mash hydrator and the vortex mash mixer. These are described in more detail under their respective entries.

Mashing machines

Mash machines are pieces of brewery apparatus that are designed to mix the **grist** with hot liquor at the commencement of the mashing stage of wort production. They are required to ensure that the grist is suspended evenly within the mashing liquor such that there is no stratification of particles of different sizes within the mash and, most importantly, there is no clumping or 'balling' of the wetted material. In addition, the apparatus must deliver the mash at an appropriate temperature.

Mechanical mashing machines have mechanised a process that used to be achieved by manual stirring of the mash during grist addition. Several different mashing machines are in use and these are described in detail under their respective entries.

See **Steel's mash mixer**, **Maitland grist hydrator**, **vortex mash mixer**.

Mash (pre-)hydrator

This is the generic name given to an apparatus that is designed to mix grist and hot liquor in preparation for mashing.

See **mashing machines**.

Mash press

A mash press is a device used at the end of the **mashing** phase of wort production for the separation of sweet wort from spent grains. Mash presses are alternatives to **lauter tuns**. Several designs are in common usage, but essentially they comprise plate and frame filters in which arrays of cloths or filter sheets, arranged on frames, provide surfaces which retain the spent grains but allow the passage of sweet wort. The filter plate elements and intervening chambers are held together and are made watertight by means of hydraulic or screw presses. The plates are arranged such that channels are formed which allow filling with mash and recovery of the filtered sweet wort. Wort entrained in the spent grains is recovered by washing the grain beds with water in a process analogous to the sparging step in lautering.

Mash presses have a long history, the first commercial examples being introduced in the late nineteenth century. In early types the presses are constructed from iron. They consist of plates over which cotton filter cloths are placed. Each iron plate contains grooves through which the wort is collected. Interleaved between each pair of plates are hollow frames which, when the press is closed, form chambers in which the mash is pumped, and after filtration is completed the spent grains are retained. After mash separation and sparging is completed the filter is opened and the spent grains are allowed to fall from the frames, usually with some manual intervention to assist detachment, and are collected in bins located below the press.

In operation the cleaned filters are closed and heated by treatment with steam of hot water. This pre-heating step allows confirmation that there are no leaks. The filter is then filled with

mash whilst allowing gas to vent to the atmosphere. When full the initial cloudy worts are recirculated until the desired clarity is achieved. Early mash filters were provided with individual taps for each frame through which the filtered wort was collected via a series of swan necks which emptied into a common wort receiver. On completion of recovery of the first worts, sparge liquor is added from the top of the plates such that the downward passage of water pushes the entrained wort out of the filter. In early mash filters the sparging step was applied in a two-stage process to alternate frames. This ensured that the whole of each grain bed was subjected to washing. After each use the cotton cloths were stripped off the filter and cleaned.

Several modifications have been introduced since the early manifestations of filter presses with the intention of improving the efficiency and operating costs of mash separation. Cotton cloths have been replaced with more durable and more easily cleaned alternatives such as polypropylene with or without additional liners.

Several novel designs of chambers have been devised by individual manufacturers. Commonly the plates are made from reinforced polypropylene, which reduces heat loss. An example of this modern design is the Meura 2001 Carbo+ mash filter. The filter elements comprise polypropylene plates which are covered on both sides with cloths. The capacity of the filter is regulated by the size and number of individual plates. Modern designs provide some flexibility in terms of the amount of mash that can be loaded. In some designs the frames are covered by elastic membranes into which air can be injected. This causes the membranes to expand such that the grain beds are compressed against the filter cloths. This squeezing step ensures high yields and, by inference, very dry spent grains. This type of filter is termed a **membrane compression filter**. All operations are fully automatic. Before use the filter is filled from the bottom with CO₂ in order to exclude oxygen and to prevent staling reactions. Prevention of oxygen ingress is also favoured by bottom filling of the mash. The compression step is applied once the filter is filled, and this allows a claimed 80% recovery of soluble sugars such that subsequent sparging rates can be reduced to less than 2.5 hL/100 kg grist. After sparging and the final compression step the spent grains are very dry compared to earlier designs (>30% dry matter).

Modern mash filters such as the Meura 2001 are designed to use thick mashes made from finely milled grists, usually hammer type or wet hydromills. Yields are very high (equal or greater than laboratory yield tests) and very high-gravity first worts (up to 30°P) are obtainable. Cycle times are such that up to 14 mash separations per day are possible.

In most modern large-scale commercial breweries the choice between mash separation systems is lauter tun or mash press. Both are capable of producing relatively clear high-gravity worts. Both can be automated and in modern designs oxygen ingress can be minimised. Generally slightly fewer cycles per 24 hours are achievable with a lauter tun, although the differences are small. Lauter tuns have a larger footprint but are generally less costly than mash filters. Extract yields from the latter are greater, worts are more concentrated and spent grains are drier. On the other hand lauter tuns are inherently more flexible in terms of loadings.

Mash rate

The mash rate describes the relative proportions of grist and liquor used in mashing. In infusion mashes as used for ales typical mash rates are 1.6–3.2 hL liquor per 100 kg grist. For

decoction or temperature-programmed infusion mashes lower mash rates are used (typically 3–5 hL liquor per 100 kg grist).

See **mashing**.

Mash tun

Mash tuns are associated with traditional UK-style ale production. They are vessels which serve the dual functions of mash conversion and separation of sweet wort from spent grains. Mash tuns have a long history and early examples were fabricated from wood, iron or copper. Modern examples are made exclusively from stainless steel because of the good hygienic properties and rates of heat transfer associated with this material.

Modern mash tuns are of circular design. The diameter and depth are variable depending on the batch size of grains that is required to be processed. The vessels are covered with a domed top and have flat bottoms. The sides and base are insulated to prevent heat loss and to assist the process of attemperation of the mash. The interior of the base of the vessel has a raised false bottom which is made up of a series of slotted plates pierced by perforations usually around 1 mm in width. Several different designs of false bottom may be encountered, depending on the preferences of the manufacturer. In all cases attention is paid to liquid flow and ease of cleaning. In older designs the latter was a manual operation. It is now automated as is cleaning of the whole mash tun via sophisticated cleaning in place (CIP) systems.

The void between the false and true bottom accounts for about 10–15% of the total capacity of the vessel. The false bottom incorporates a valve (or multiple valves) which, when open, allows automatic discharge of the spent grains when wort separation has been completed.

In operation the wetted mash is added to the mash tun, which has been preheated to a predetermined temperature, via the top, usually using a **Steel's mash mixer**. Before the mash is added the false bottom is usually filled with hot liquor both to exclude air and to ensure that when the mash is added the tendency to compact is reduced. The presence of air in the mash causes most of the grist to float. The quantity of mash used is variable and, indeed, this is one of the advantages of mash tuns as compared to lauter tuns or mash filters. Typically the mash would be 1.5–3 m in depth. Traditional mash tuns were fitted with movable rakes which ensured that the grist formed an even bed. These are not necessary in more modern mash tuns.

Once filled with mash to the desired depth the process of mash conversion is allowed to proceed. Although these vessels are associated with simple infusion mashing, various methods are used (and have been for many years) to increase the temperature of the mash. These include direct steam injection into the mash or into the false base or circulation of wort via an external heat exchanger. More commonly attemperation of the mash is accomplished via **underletting**. In this procedure hot liquor is introduced into the base of the vessel underneath the false bottom such that the mash is gently mixed and diluted and the temperature of the whole is adjusted accordingly.

At the completion of the mash conversion phase the wort is run-off via a pipe located in the true base of the vessel. Since the first worts are very turbid these '**first runnings**' are recirculated into the top of the mash tun. When the desired wort clarity is observed (termed running bright) **wort run-off** commences. The separated wort may be held temporarily in an **underback** at approximately 80°C to prevent microbial attack; alternatively it may be immediately transferred into the kettle.

When the first worts have been collected the surface of the grain bed is sprayed with hot liquor in the process termed sparging. In order to ensure that the grain bed is evenly sprayed with liquor the mash tun is fitted with a series of **sparge arms**. These are located close to the top of the vessel and consist of a series of sprays that are made to rotate either mechanically or via the angled point of entry of the liquor. Care is taken with the design of these sprays in order to ensure that the treatment is evenly applied. The hot liquor percolates through the grain bed at a rate that is controlled by the pressure difference induced by the difference between that caused by the hydrostatic head of liquid and that caused by the application of suction at the base of the vessel. This must be controlled to avoid compaction of the bed and restricted run-off or, at worst, a **set mash**. Various devices or practices are used to prevent this eventuality. The rates of sparging and run-off can be balanced by means of controlled pumping. Alternatively, the mash tun may be fitted with a weir which takes the form of an adjustable inverted u-tube (a valentine) that controls the height of the liquid head. In traditional mash tuns multiple wort run-off points were provided in the true base of the vessel. Each of these was connected via taps and tubes with a swan-necked configuration to a common trough into which the sweet wort was run before transfer to an underback or a kettle. Each wort outlet tube drained a specific part of the grain bed. Skilled mash tun operators regulated flow through each outlet in order to maintain even drainage through the whole of the grain bed. More efficient methods of wort discharge have obviated the need for this task.

Sparging is allowed to proceed until the concentration of the wort (specific gravity) has fallen to a predetermined value. At this point sparging is discontinued and the bed is allowed to drain. The drainings may be discarded, or where economics dictates it necessary, they may be incorporated into the next mash and in this way the entrained extract is recovered. The temperature and ionic composition are important and must be controlled to ensure that there is no loss of wort quality. After this the spent grains are discharged and the vessel cleaned.

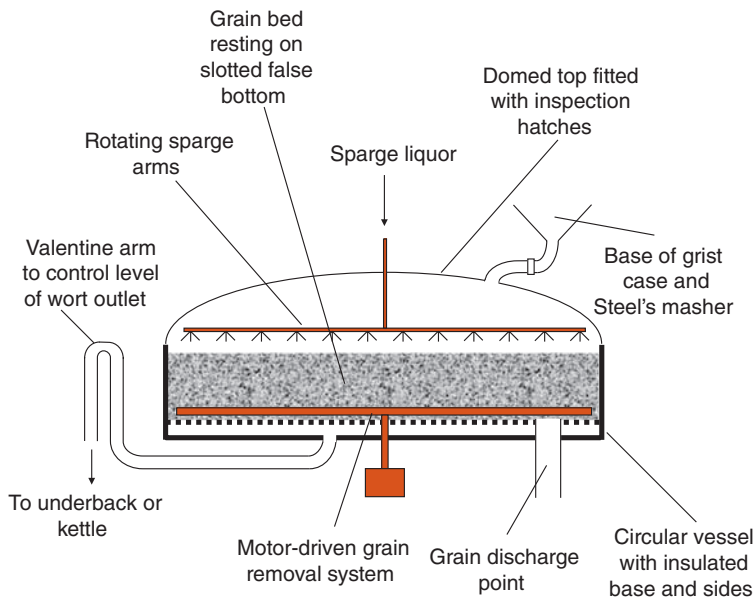


Diagram showing the essential features of a modern mash tun

Mash tuns use thick mashes and comparatively deep beds and in consequence are capable of producing very bright worts. The deep bed necessitates the use of coarse ground grists and turn-round times are long. Control of temperature is difficult and, in consequence, extract recoveries are modest, typically 85–95%, compared to laboratory mashes.

See **simple infusion mashing**.

Mash tun adjunct

Type of adjunct, usually solid, that requires processing in order to render the extract available for conversion into fermentable sugar.

See **adjuncts**.

Mass krug

See **krug**.

Mathon goldings

A variety of one of the group of Goldings, traditional UK-style aroma hops selected in 1901 in the village of the same name in Worcestershire.

See **Goldings**.

Matters soluble

See **cold water extract**.

Maturex[®]

A preparation of the enzyme α -acetolactate decarboxylase which is available commercially [Novozyme; <http://brewing@novozyme.com> (last accessed 12 February 2013)] and which reduces the formation of diacetyl during fermentation by conversion of the precursor, α -acetolactate, directly into acetoin.

See **α -acetolactate decarboxylase, diacetyl cycle**.

Mbweje

A beer native to Tanzania made from malted millet and an adjunct made from an extract of bananas.

See **native African beers**.

Mealie beer

See **Umqombothi**.

Mealiness

This term is used to describe the appearance of the endosperm of sectioned barley and malt grains. A distinction is made between mealiness (floury) and steeliness (flinty, glassy, vitreous). Intermediates between these two extremes are recognised. In the case of barley grains mealiness correlates positively with the ability of the grain to absorb water during malting. The degree of mealiness of malt grains correlates with the extent of modification. Fully modified grains have a white soft floury appearance. This is due to the presence of many thousands of minute cracks which surround the numerous starch grains present in mature good quality

malt grains. Mealy grains score highly in the **friability** test. Immature and poorly modified malt grains, on the other hand, have a hard steely or glassy appearance. As the terms suggest very mealy grains are softer than steely types and are more easily disrupted. A positive correlation also occurs between steeliness and protein content.

Malt grains may be classified on the basis of their suitability for brewing on the basis of the relative degrees of mealiness and steeliness. A semi-arbitrary scale is used in which a representative number of grains are examined and scored as being mealy (kernels where the endosperm is not more than 25% steely), half steely (more than 25% of the endosperm, usually at the ends, is steely) and steely (more than 75% of the endosperm is steely). Base malts destined for infusion mashing should have grains that are at least 95% mealy and less than 1% wholly steely. See also **vitreosity**.

Attempts have been made to automate the measure of grain mealiness based on the relative reflectance of the surface. The UK Brewing Research Institute developed an approach using a light transfectance meter in which grains are illuminated by a beam of laser light and the relative transmitted and reflected light detected. From this a measure of mealiness/steeliness of individual grains can be computed. Assessment of a number of grains allows the degree of homogeneity to be assessed.

Mean brewery tables

See **original gravity (OG)**.

Mean hydraulic radius

This is a parameter that is used to characterise the filtration properties of powder filters such as kieselguhr which have internal porosity. It is defined mathematically, but in effect it describes the size of the mean radius of the voids in a bed of filter powder through which particles can pass. In this sense it relates to the clarity of the filtered product since it quantifies the maximum size of particle that in theory could pass through a filter bed.

Mean hydraulic radius (m) has the unit of micrometre and is defined by the following equation:

$$m = \frac{0.1054 \times d \times \epsilon}{(1 - \epsilon)},$$

where m is the mean hydraulic radius (μm); d is the mean particle diameter (μm); and ϵ is the effective bed voidage.

The lower the value of this parameter the brighter the filtered product; however, the permeability of the bed is also low as is the effective bed voidage, implying that more filter powder would be required.

MEAS

An Irish-based organisation that promotes social responsibility in alcohol production and consumption [<http://www.meas.ie> (last accessed 12 February 2013)]. The name is both an acronym (Mature Enjoyment of Alcohol in Society) and a pun, in the sense that *meas* is Gaelic for 'respect'. The organisation is funded by a cooperative of all the major Irish brewing companies.

MEBAK

MEBAK is an association whose role is to standardise and publish analytical methods used in brewing and malting. In German it stands for *Mitteleuropäischen Analysen Kommission*. It translates as the Middle European Brewing Technology Analysis Commission. MEBAK, together with the EBC, the IOB [now the Institute and Guild of Brewing (IGB)], and the American Society of Brewing Chemists (ASBC), is responsible for collating, validating and publishing methods used in brewing and malting analyses. In most cases there is a lack of standardisation with the result that each association has developed its own set of methods and, in some cases, its own set of units.

MEBAK gushing test

See **gushing**.

Mechanical vapour compression

Mechanical vapour compression systems are used in brewing operations for energy recovery and conservation primarily in wort boiling. Such systems use an electrically driven compressor to pressurise the vapour exiting from the kettle. At an over-pressure of 0.7 bar the temperature of the vapour may be increased to approximately 112°C. This is fed back onto the heat exchanger of the kettle where it supplements the main steam feed.

See **wort kettle**.

Medium-density polyethylene (MDP)

Polyethylene is a polymer consisting of long chains of the monomer ethylene (IUPAC name ethene) and is classified into several different categories based on its density and branching. MDP is used in pipes and fittings, sacks, shrink film and carrier bags and is widely used in **dispense** tubing for beer, soft drink and water or glycol recirculation lines. MDP lines are considered to be superior in terms of hygiene (line cleaning) and flavour taints than those constructed from **ethylene vinyl acetate (EVA)** or polyvinyl chloride (PVC). In turn, nylon lines are smoother than MDP and microorganisms are less able to attach and establish biofilms. The advent of **multilayer barrier dispense tubing** (constructed from MDP with a nylon inner surface) provides benefits in terms of cost and functionality.

Meerts Bier

Meerts bier, literally March beer, is a beer associated with Belgium. It makes reference to the fact that in many countries during the Middle Ages brewing was a seasonal occupation. Thus, all-year-round brewing was not possible because of the difficulty of controlling beer quality during the warmer months of the year. In addition, at various periods in various countries, legislation prohibited brewing during certain months of the year, particularly in the summer. For this reason, special beers, which had relatively high alcohol contents and high hopping rates, were produced in the spring at the end of the brewing season. The intention was that such beers would be consumed throughout the summer. A relatively long shelf life was favoured by the high concentrations of alcohol and hops.

Meerts was blended with **lambic beer** and sweetened with brown sugar, caramel or molasses to produce **faro**.

See **lambic beer** and *Märzen*.

Megasphaera

Gram-negative obligately anaerobic non-motile cocci borne in pairs or short chains. The organism *Megasphaera cerevisiae* is considered to be a beer spoiler and occupies a similar ecological niche to *Pectinatus*. It has been recovered from the brewery environment particularly in small-pack packaging halls, associated with CO₂ gas lines and in pitching yeast. Presumably all of these locations could indicate routes to beer infection. As with other obligate anaerobic beer spoilers, occurrences of spoilage by *Megasphaera* have been linked to reductions in in-process and in-pack oxygen levels and with the current increase in popularity of cold sterile filtration. The organism is not tolerant of ethanol (>3–4% v/v) or low pH and ferments sugars such as fructose, which would suggest that spoilage would be most likely to occur in pitched worts after exhaustion of oxygen, although low- and zero-alcohol beers would also be at risk. The products of metabolism are short-chain fatty acids such as butyric and caproic, together with acetic, valeric and isovaleric acids. In addition, hydrogen sulphide and other sulphur-containing metabolites are formed and spoiled beer has a putrid aroma and taste.

Melanoidins

Melanoidins are coloured, high-molecular-weight compounds formed from reactions between amino acids and sugars under conditions of high temperature and low water activity. They are the products of **Maillard reactions** and contribute to the browning reactions which occur during the kilning or roasting steps associated with malt production and in wort boiling.

See **Maillard reaction**.

Membrane compression filter

A membrane compression filter describes the modern type of mash press in which there is provision to squeeze the grain bed after separation of the first grains and sparging in order to maximise yields and provide dry spent grains.

See **mash press**.

Merissa

A native beer associated with Sudan in Africa. It is an opaque beer made via spontaneous natural fermentation of extracts of malted and raw sorghum and millet by lactic acid bacteria and yeast. The beer is traditionally made by women and a variety of methods can be used involving individual stages for souring (acid production) and alcoholic fermentation. Some descriptions of its manufacture include a stage in which a proportion of the grain is chewed before spitting out and adding to the ferment. This practice is common to the production of many indigenous alcoholic beverages and presumably is a learned procedure that makes use of salivary amylase to promote starch degradation. Merissa is acidic (approximately pH 4.0) and, although it is commonly sieved through cloth before consumption, it is viscous and opaque. It is designed to be consumed whilst the fermentation is still in progress and therefore the ethanol content is variable. Since Sudan is a Muslim country consumption of alcohol is proscribed, and in strict observance Merissa should be consumed whilst very young, in which case it can be regarded as a non-alcoholic foodstuff. If allowed to ferment alcohol contents of up to 5% may be achieved. In this regard the time of day of consumption was taken as a measure of the soundness of adherence to religious practice: early morning, low alcohol and

safe; late evening, higher alcohol content and an infringement of the religious code. Presumably midday consumption might be considered mildly sinful.

Merlin wort boiling system

The Merlin system is a high-efficiency combined wort kettle and whirlpool designed by the Steineker Company of Germany.

See **wort kettle**.

Metalaxyl

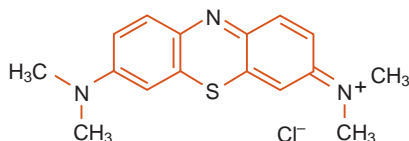
Metalaxyl (N-(methoxyacetate)-N-(2,6-xylyl)-DL-alaninate) is a fungicide which has been used for the treatment of downy mildew in hops. It is sold under the trade name Ridomil®.

Metered dispense

A term used to describe the controlled dispense of a half or a pint of beer into an oversized glass by the use of an approved flow meter which accurately delivers the required volume of beer. Metered dispense was widely used in the United Kingdom but is now found most commonly in the more complex, innovative push button systems such as **fast dispense**.

Methylene blue

A biological stain, [7-(dimethylamino)phenothiazin-3-ylidene]-dimethylazanium chloride, also known as methylthioninium chloride, and with a structure shown in the following diagram. Aqueous solutions containing citric acid are used to determine yeast viability.



Structure of methylene blue

See **yeast viability**.

Methylene blue, safranin-O stain

Modification of the **methylene blue** yeast viability stain in which the sample is counterstained with safranin-O in a technique which allows an assessment of yeast vitality. Four staining reactions are recognised; dark blue [viable cells, pale blue (slightly deteriorated), pink (grossly deteriorated), red (non-viable)].

See **yeast viability**, **yeast vitality**.

Methylene violet 3-RAX

A dye, N,N-diethylphenosafranin, which can be used for determining the viability of yeast. It is claimed that, compared with the industry standard method which uses methylene blue,

it is less prone to oxidative demethylation and in consequence staining reactions are more uniform.

See **yeast viability**.

Meura 2001

The Meura 2001 is a proprietary name (Meura S.A., Péruwelz, Belgium) for a design of a compression type of mash filter. It typifies the advances that have been made in mash filtration in which rapid turn-round times, good oxygen control, high yields and very dry spent grains are achieved.

See **mash press**.

MgANS

Shorthand name, more properly, the magnesium salt of 8-anilino-1-naphtha sulphonic acid, given to a fluorescent dye that is used as the basis of a yeast viability test. Viable cells exclude the dye, whereas in non-viable cells with impaired membrane function it is taken up where it binds to cytoplasmic proteins and produces green fluorescence.

See **yeast viability**.

Microbiological media

A variety of media have been developed specifically for the detection and identification of yeast and bacteria of interest in brewing. Details may be found for each in their respective entries. Originally media were made using wort or beer from the brewery, solidified by the addition of agar to give wort or beer agar media, respectively. More commonly commercially available media are now used in order to ensure consistency and, by inference, more reliable results. However, a proportion of beer may still be incorporated in order to provide a degree of selection when the aim is to detect spoilage organisms. General-purpose media are used for the routine cultivation of brewing yeast strains. Wallerstein Laboratories Nutrient medium (**WLN medium**) is probably the most often used for this purpose or **MYGP medium**, which does not contain a pH indicator.

For many microbiological analyses it is necessary to use media which are either selective for particular groups of organisms or contain ingredients which prevent the growth of non-target bacteria or yeasts. An obvious example would be the need to detect small numbers of wild yeast or bacteria in the presence of large numbers of culture yeast. Further selectivity is provided by choice of appropriate incubation conditions, including temperature but especially the presence or absence of oxygen.

The subsequent table provides some of the more commonly used selective media together with their intended target groups of microorganisms. The list is by no means exhaustive. It may be appreciated that in the case of lactic acid bacteria there is an almost bewildering array of potential cultivation media. This reflects the importance of this group as beer spoilers. It is also a testament to the fact that there is not a single medium that is suitable for all members of this relatively diverse group. In practice most brewery laboratories have a preferred medium which, based on experience, suits the particular spectrum of microorganism routinely found in their environs. Commercially available media are preferred, and understandably the medium of choice may be the one that was developed within the geographical location or

country where the brewery is situated. The next table shows components added to media to provide selectivity and their intended functions.

Examples of selective media for common brewery spoilage microorganisms

Medium	Target organisms
WYGP + copper	Wild yeast
Wallerstein laboratory differential (WLD)	Wild yeast, Gram-negative bacteria, <i>Obesumbacterium proteus</i>
Schwartz differential medium	Wild yeast
Lin's wild yeast medium	<i>Saccharomyces</i> wild yeast
Crystal violet agar	
Lysine agar	Non- <i>Saccharomyces</i> wild yeast
MacConkey's agar	Gram-negative bacteria
Raka Ray	Lactic acid bacteria
Universal beer agar (UBA)	Lactic acid bacteria
MRS	Lactic acid bacteria
Kirin Okhochi Taguchi (KOT)	Lactic acid bacteria
Nachweismedium für bierschädliche bacterium (NBB)	Lactic acid bacteria
VLB-S7	Lactic acid bacteria
Hsu's <i>Lactobacillus/Pediococcus</i> (HLP) medium	<i>Lactobacillus</i> , <i>Pediococcus</i>
Lactate lead acetate agar (LL agar)	<i>Pectinatus</i> spp.
SMMP	<i>Pectinatus</i> and <i>Megasphaera</i>
Dadd's and Martin's medium	<i>Zymomonas</i>

M

Components which confer selectivity to microbial media

Component	Selective action
Hopped beer	Inhibits non-beer spoilers
Ethanol	Inhibits non-beer spoilers
Isohumulone	Inhibits many non-beer spoilers
Copper	Inhibits brewing but not wild yeasts
Cycloheximide	Inhibit yeast growth but not bacteria
Crystal violet	Inhibits Gram-positive bacteria and is selective for <i>Saccharomyces</i> wild yeast.
Lysine	Inhibits <i>Saccharomyces</i> yeast but not non- <i>Saccharomyces</i> wild yeast
2-Phenyl ethanol	Inhibits Gram-negative bacteria (and some lactic acid bacteria)
Sodium acetate	Stimulates growth of many lactic acid bacteria
L-Malate	Stimulates growth of many lactic acid bacteria
Sodium nitrite	Tolerated by many lactic acid bacteria but inhibits other beer spoilers
Vancomycin	Inhibits Gram-positive bacteria
Sodium azide	Inhibits Gram-negative bacteria
Sodium thioglycollate	Provides reducing conditions for cultivation of obligate anaerobes
L-Cysteine	Provides reducing conditions for cultivation of obligate anaerobes

Microbrewery

Usually a synonym for craft-brewery (**craft brewing**).

Microcalorimetry

A technique by which the activities of microorganisms can be detected as a result of the exothermy of their metabolism and useful as a means of detecting contaminants in process samples or to assess the vigour of pitching yeast (see **rapid microbiological methods, yeast vitality**). Heat formation is converted to an electrical signal by the use of a thermocouple. The technique allows detection of relatively low concentrations of viable cells, of the order of $1 \times 10^3/\text{mL}$ and has been used in some industries but has yet to see take-up in brewing.

Micro-colony

Name given to a microscopic microbial colony growing on solid medium but which has not yet developed to the extent that it is visible to the naked eye. Monitoring the formation of micro-colonies is used in a relatively rapid method for the assessment of yeast viability.

See **yeast viability**.

Micronised grains

Micronisation in general refers to a process by which materials are subjected to some sort of abrading treatment such that the particles are reduced in size. In brewing cereal grains of wheat, barley or maize used as adjuncts may be so treated. The process is accomplished by passing a thin layer of grains placed on a conveyor belt underneath a series of heated ceramic tiles. The tiles emit infrared radiation and this causes the grains to swell, lose moisture and fracture. After this the heated grains are subjected to a milling process to reduce the particle size.

During the heat treatment the starch grains gelatinise and therefore, when these materials are incorporated into mashes as adjuncts, they are immediately susceptible to the activities of malt amylases and need no prior heat treatment.

See **gelatinisation, adjuncts**.

Micropyle

An opening which, in the case of barley grains, provides the means by which moisture enters during the initiation of germination.

See **barley grain**.

Midwest Barley Improvement Association (MBIA)

See **American Malting Barley Association Inc. (AMBA)**.

MIKE

An acronym that stands for magnesium isomerised kettle extract.

See **hop extracts**.

Mild ale

Mild ale is a beer style associated with the United Kingdom. Originally the name was used for any ale that had not been aged. In the modern sense mild beers are produced by top fermentation and are typically made with dark malts (dark mild), although paler variants also exist (light mild). Generally they are sold in draught form and are of a lower strength than

the corresponding draught 'bitter'. Early examples of mild beers could have comparatively high alcohol contents (>6% abv) and some mainly craft-brewed examples have continued this tradition. However, as a result of the effects in the United Kingdom of revisions in the duty laws at the time of the First World War and thereafter, the strengths of traditional mild ales were reduced and 3–4% abv became typical. Bottled versions of dark milds are usually described as being **brown ales**. Tastes are malty and often quite sweet.

As a style the traditional modern mild ales were less expensive than paler and stronger bitter draught ales and for this reason they were perceived as the beer of the working classes. They were highly popular and throughout the first half of the twentieth century in the United Kingdom accounted for approximately 40% of the draught beer trade. They were mainly consumed in areas with large concentrations of manual labour. The decline in the United Kingdom of the mass manual labour market has mirrored the decline in the popularity of mild ales, although some pockets have retained a loyal following particularly South Wales and the Midlands.

As with many draught beers the practice of mixing different styles in the same glass has been commonplace. In the North of England a pint of beer made up of equal volumes of mild and bitter was called '**mixed**'.

Mild ale malt

Mild ale malt is that produced for brewing traditional UK-style top fermented mild ales. They are similar to **pale ale malts** although usually slightly less well modified. They have slightly greater colour compared with pale ale malts (6–8 EBC units) as a consequence of the use of a slightly higher kilning temperature. The higher kilning temperature imparts a greater malty character compared with pale ale malts. Apart from colour the properties of mild ale malts are similar to those of pale ale malts. Hot water extract values are 295–300 L^o/kg; diastatic power is marginally higher (55–58°IOB); and soluble nitrogen is 1.6–1.7%.

Millennium

Millennium is a high alpha hop variety bred in the United States. It is a seedless triploid variety bred from a tetraploid Nugget parent. It is high yielding, has good storage properties and is reasonably disease resistant. It contains 15.5% α -acids of which 30% is cohumulone. Total oil content is 2%. It constitutes one of the major high alpha crops grown in Washington State and Oregon.

Millet

Name given to a range of small-seeded annual grasses, members of the Poaceae (Gramineae). The plants grow wild but are thought to be one of the earliest cultivated crops. The grains are used as foodstuffs in many countries and also for the production of native beers (see **millet beer**). The grains can be malted, and in recent years interest has been shown in using them for the production of gluten-free beers.

Milletts have very short growing seasons and they can be grown successfully in a wide range of climates. In developed countries cultivation is mainly for bird or animal feedstocks. In countries such as Africa or India they are important constituents of human diets.

Several individual species are known and most are members of the tribe Paniceae. These include *Panicum milanaceum* (proso millet), *Pennisetum americanum* (pearl millet), *Setaria italica* (foxtail millet). The tribe Chlorideae contains a single representative, *Eleusine coracana* (finger millet).

Millet beer

A beer-like beverage made in several African countries using the malted grains of the cereal **millet** (see appropriate entry for more details).

The grains are soaked in water and exposed to the sun to promote germination. At an appropriate point the grains are separated from the water and spread in a thin layer and are allowed to dry in the sun, a process analogous to the kilning stage of malting. The treated grains are reduced to a pulp by treatment in a mortar and pestle, mixed with water and boiled for 24 hours. The extract is allowed to ferment, either spontaneously or, in more modern versions, after inoculation with yeast, and is then consumed with no further treatments after a further 24 hours.

See **native African beers**.

Milling

Milling is the process in which malt grains and other solid adjuncts, if used, are subjected to a treatment in which the materials are broken and reduced in size to smaller particles such that the best yield of extract may be most easily obtained using the chosen mashing system. The product that derives from milling is termed the **grist**.

As the foregoing definition suggests the milling operation must be tailored to suit the mashing and sweet wort clarification system used. In all cases no intact grains should survive the process. In most cases the husk material is used to form a bed through which the wort is filtered, and so it is essential that this proceeds with ease, hence the need to match the milling and clarification processes. The finest grists are used with mash presses, the most coarse with mash tuns. Lauter tuns require an intermediate grade of grist.

In order to achieve a grist with the desired fineness and composition different types of mill may be used. In addition, the operation of individual mills may be adjusted to suit the type of feed material used. Thus, the finely ground grists required for mash filters are typically produced using hammer mills, whereas roller mills of various designs are used with lauter or mash tuns. In all cases the grist must be of a uniform nature, be free from any form of contaminating materials and must not contain any whole or largely intact grains. The particle abrading and degrading action of mills derives from either impact (as in the **hammer mill**) or abrasion between rotating discs (**disc mills**) or via crushing (**roller mills**).

The majority of mills are designed to grind dry grains. This process is termed dry milling. Roller mills are designed so that the grains are crushed along their longitudinal axes. This releases the contents of the grains with a minimum of damage to the husks. The rollers may be smooth but more usually have fluted surfaces. The rolls are arranged in pairs and the width of the gap between them is adjustable to allow treatment of different types of grain or adjunct. Simple mills may have just a single pair of rolls, whereas more complex types have additional pairs and other associated machinery. The rolls rotate at velocities of up to 500 rpm and all or just some may be driven. Where all are driven each roll may rotate at different velocities. The

grains are broken by a combination of crushing, shear (where there is a differential in rotational speed of adjacent rollers) and cutting (where the surfaces of rollers are fluted). The capacity of individual mills is controlled by the width of the rollers. In simple two-roller types the milling action is achieved in a single pass. In more complex types the fine particles deriving from the first pair of rollers are collected without further treatment. The larger particles are separated via appropriately sized sieves and these are fed into subsequent sets of rollers for further milling. Two roll mills tend to be restricted to very small breweries. Four roll types are commonly associated with UK-style ale breweries using well-modified malts. Six roll types provide very flexible control of the milling operation and for this reason are commonly found in larger breweries, which are likely to have to deal with a wide range of materials.

Impact mills comprise disc and hammer mills. Rather than rely on crushing, cutting and shear forces these mills disrupt and degrade grains by bringing the latter into violent contact with hard surfaces. Hammer mills comprise a chamber into which the grains are introduced at a controlled rate via a rotary valve. Inside the milling chamber is a rotor that revolves at a rapid rate, typically 1000–2000 rpm. Attached to the rotor are the hammers which take the form of pieces of metal mounted so that they may swing freely. The hammers impact against the grains and in so doing they are broken up. This disruptive action may be further enhanced by the incorporation of metal projections located on the inside of the chamber. The chambers are ventilated by a stream of air. This carries the grist particles which have been comminuted to a sufficient extent to be able to pass through a wire mesh sieve. Those particles that are retained are subjected to further abrasion until they can pass through the screen and out of the mill chamber with the stream of air. Disc mills, also termed pin mills, are generally used in pilot or very small-scale breweries. They comprise two closely mounted metal discs with a gap in the centre into which the grains are introduced. The interior faces of the discs usually have short projections, which increases the abrading action. Several arrangements of the discs are used, those in which both may be rotated, often in reverse direction, or there may be a single rotating disc and one that is static. Usually disc mills are operated dry. The grains are milled as they pass from the centre of the discs to the periphery from which they are carried away by a stream of air.

In some cases the grains may be moistened before milling with the intention of making the husk more flexible but keeping the interior dry and therefore brittle. The aim of this is to control the milling process such that the endosperm material is sufficiently degraded in size whilst retaining quite large husk particles. This arrangement favours efficient mash separation but adequately high yields. This is termed wet milling and several types of process and associated plants may be used. They differ in the degree of control of the wetting process. In older and by inference less well-controlled processes, the malt and other solid adjuncts, if used, are placed in a steep tank located above the mill. After the treatment, which may last for up to 30 minutes, the water is allowed to drain away after which the moistened grains, with a moisture content of up to 30%, are delivered to the mill. The mills are of two- or four-roll types and are arranged such that the wet and softened grains are gently squeezed. This allows the contents to be separated for the relatively intact husks. This process is termed **steep conditioning**. It is not a particularly efficient process since the wetting of the grains may be uneven; however, it does provide open well-draining filter beds in the mash separation stage and, thus, rapid cycle times. The wetting stage may be made more uniform by circulating the steep water.

A more controlled process is that termed **conditioned dry milling**. In this case malt and other cereal grains are subjected to a controlled wetting process, termed conditioning, immediately before milling. The intention is to increase the pliability of the husk but to ensure that the interior remains dry and brittle. Thus the arrangement allows the milling process to abrade and degrade the interior structures of the grain so as to ensure adequate yield in the subsequent mashing process; however, it leaves the separated husks relatively intact and hence provides a good bed through which the sweet wort may be filtered in the mash separation step.

The controlled wetting process is performed using either steam or warm water. Exposure times are short, usually 1–2 minutes, which results in an increase in the moisture content of the husks by no more than 1.5–2%. The wetting treatment is carried out as the grain is delivered to the mill. The transporting step is accomplished using a mechanical conveyor, termed a conditioning screw, which is located within a heated casing.

Compared with conventional dry milling the conditioned material requires a finer setting on roller mills. On the basis of sieve tests the conditioned husk fraction is increased by approximately 30%. Understandably the spent grain fraction increases in volume, but this is set against claimed improvements in yield, faster saccharification and increased attenuation.

An alternative to conditioned dry milling, but one which has the same *raison d'être*, is termed **spray steep roller milling**. In this case grain conditioning, milling and mashing-in are all combined in a unit operation. Dry malts are fed from a storage hopper into a chamber. As the malt transits through this chamber it is subjected to a spray of water heated to 50–80°C. The precise temperature is inversely related to the time of exposure. This varies between 1 and 1.5 minutes. After the controlled wetting process the grain is delivered to a two- or four-roll mill the operation of which and the feed rate are regulated via sensors which detect the resistance of the grains to milling. The whole apparatus may be filled with an inert gas to prevent oxygen ingress. After the milling stage the grist is suspended in mashing liquor and the mixture is immediately transferred to the mash vessel.

More recently the requirement for the production of very fine ground grist to feed mash filters has resulted in the use of wet impact disc mills. In this case milling and mashing-in are combined in a single operation. The discs are suspended in de-aerated water to minimise undesirable oxidation reactions. The grains are fed into the gap between the discs, the latter being variable in order to control the fineness of the grind. The grist exits the mill already suspended in mashing liquor.

In dry milling operations the grist is usually stored temporarily before being mashed-in. The containers used for this are termed **grist cases**. Grist cases are made of mild steel. They are sized according to the needs of the particular brewery. They are made to contain dust but since the grist is hygroscopic to exclude moisture. Grist cases are designed to be filled directly from the mill. The delivery method may also include a metering system such that a controlled proportion of a solid adjunct of the type that does not require milling may be evenly mixed with the grist. The grist case has an exit which feeds the mashing-in system.

Several standardised methods are used to assess the efficacy of the milling process. In the case of dry milling sieving methods are used. These comprise a series of horizontal sieves each with a different width of mesh mounted one above the other. A sample of the grist is loaded onto the top sieve and the whole assembly agitated using a mechanical shaker. This allows the

grist to be fractionated based on particle size. The grist is assessed by determining the relative proportion by weight of each fraction. The methods manuals of each of the major brewing codes (ASBC, EBC and MEBAK) each use their own set of standardised sieves. By convention each fraction is named after the material which supposedly constitutes its greatest part (see the following table).

ASBC system			EBC system		
Sieve number	Mesh width (mm)	Fraction	Sieve number	Mesh width (mm)	Fraction
10	2.000	Husk	1	1.270	Husk
14	1.410	Husk	2	1.010	Coarse grits
18	1.000	Husk	3	0.547	Fine grits I
30	0.590	Coarse grits	4	0.253	Fine grits II
60	0.250	Fine grits	5	0.152	Flour
100	0.149	Flour	Through	–	Fine flour
Through	–	Fine flour			

The naming of these fractions, as indicated in the table, is a convenience since there is much cross-contamination; however, it does provide a convenient method of assessing the fineness of the grind.

In the case of wet milling it is not possible to assess milling directly via particle size analysis. In this case the efficacy of milling must be assessed indirectly via the examination of the mashing process. In this case parameters such as extract yield, run-off time, wort clarity and the appearance and proportion of spent grains would be taken into consideration.

Millipore Milliflex™

A proprietary system [<http://www.millipore.com> (last accessed 12 February 2013)] designed for the rapid enumeration of microbial samples in filterable samples, such as beers. The system makes use of **ATP bioluminescence** plus image analysis applied to membrane filtered samples to allow the rapid detection of viable cells. The limits of detection are claimed to be one yeast or approximately 100 bacterial cells.

Mini-fermenters

Small fermentation systems designed for running multiple small-scale fermentations. The vessels comprise glass hypovials with operating volumes of 50 or 100 mL, each of which is supplied with a small magnetic follower. The bottles are sterilised empty by autoclaving and in this stage the opening is closed with a foil wrapped foam bung. A measured volume of sterile wort, or another desired growth medium, is transferred aseptically into each bottle and fermentation is initiated by pitching. Initial oxygen concentration is controlled by sparging the bulk wort with a desired gas mixture prior to transfer to the vials. The foam bungs are replaced by rubber septa secured using the typical crimped metal seals. A sterile needle fitted with a Bunsen valve is passed through the septum to allow evolved CO₂ to be vented. The mini-fermenters are located on multi-place magnetic stirrers if mechanical agitation is required. Attenuation is achieved by placing the vessels in a temperature-controlled incuba-

tor or similar. Fermentation progress is assessed by periodic weighing of the entire hypovial. Samples may be removed during fermentation using a sterile needle and syringe, but more commonly analyses are performed at the end of the fermentation. The strength of this system is that it allows many individual fermentations to be performed simultaneously in which the effects of one or more variables are assessed. Thus, this provides a very powerful tool for preliminary screening exercises.

Minipin

See **polypin**.

Mitogen-activated protein kinase (MAPK) cascade systems

Signal transduction pathway, of which at least five occur in yeast cells, by which the presence in the medium of relatively simple molecules triggers complex responses in which multiple genes are up- or down-regulated and so provide a coordinated system of gene regulation which underpins global metabolic shifts. Such systems are used by yeast to respond to signals which result in responses such as growth, response to sexual pheromones and responses to various stresses. The systems are mediated by a number of kinases in which phosphorylation and de-phosphorylation events modify proteins which in turn up- or down-regulate target genes.

See **yeast stress response**.

Mixed

See **mild ale**.

Mixed gas dispense

The term used to describe the use of defined mixtures of carbon dioxide and nitrogen in beer **dispense**. Mixed gas is used to propel beer over long pipe runs and where there is a significant vertical rise and without using electric or gas **dispense pumps**. Under such conditions carbon dioxide cannot be used alone to push beer as an increase in partial pressure above the balance pressure results in over-carbonation and **fobbing**. A mixture of nitrogen and carbon dioxide enables the applied gas pressure to be higher, but because nitrogen is <1% as soluble in beer as carbon dioxide, the desired **dispense** speeds are achieved without any fobbing issues. Carbon dioxide and nitrogen are blended (e.g., at 50:50 at 32 psi/221 kPa or 60:40 at 38 psi/262 kPa) using gas blending systems of the individual cylinder gases or where the nitrogen is generated from an air separator.

For the dispense of stouts and **cream flow beers** are carbonated (1–1.3 vol) and nitrogenated (15–40 mg/L) during packaging. They are dispensed under mixed gas (30% carbon dioxide: 70% nitrogen) at 32 psi/221 kPa. In this application the use of mixed gas provides motive force and maintains the desired gas mixture in the beer. In terms of presentation, the involvement of nitrogen and an **orifice plate** in the tap nozzle delivers products with a thick creamy head and a softened palate.

Mix-proof double-seat valve

This is a valve type in which two different process flows pass each other at right angles within a common valve body. Two individual valve seats ensure that there is no intermixing between

the two process flows. There is a gap between the two valve seats and this is provided with an opening that vents to atmosphere. In the event of failure of either of the valve seats fluid may be observed leaking from the vent and this provides rapid identification of failure.

This type of valve is most commonly used as part of complex routing systems such as the control of fluid flows within large tank farms. They ensure that there is no accidental mixing of incompatible fluids such as beer and cleaning agents. This type of valve has excellent shut-off properties but is not suitable for regulating the rate of flow.

Modification

Modification describes the sum of the changes that occur within grains during the malting process. The term encompasses both physical and chemical changes and for this reason is relatively imprecise.

Modification is initiated in grains by the provision of water, oxygen and heat. These trigger germination in grains which are in an appropriate state to germinate. The changes associated with germination largely occur within the endosperm. These are the appearance of the enzymes which are responsible for degrading the cell walls of the endosperm, proteolytic enzymes that result in the formation of smaller soluble nitrogen-containing metabolites and amylases. Modification is arrested by the application of heat during the kilning phase of malting. This kills the developing embryo and retains the mixture of enzymes and products of partial degradation of the grain that are needed for further enzymolysis during the mashing phase of brewing. The extent of degradation of the endosperm that occurs during malting is described as the **degree of modification**. Preparation of malts and worts suitable for different beer types and associated brewery apparatus require an appropriate degree of modification. This is regulated by the choice of grain and the conditions employed during malting.

Modification is measured by many of the tests that are applied to malts to assess their quality. These tests are described elsewhere. They are of two types. The first assesses the extent of modification based on the physical changes in grains that accompany germination, for example, assessment of **mealiness** and **friability** as might be measured in procedures such as **sanded slab tests**. The second group of tests is typically based on measurement of the concentrations of various groups of metabolites that arise in worts prepared under defined conditions at laboratory scale using the samples of the malts under examination. These include such tests as **soluble nitrogen ratio**, **Kolbach index**, **Hartong 45°C index** and **cold water extract**.

Monitek haze meter

A beer haze meter based on the measurement of forward light scattering at 13° using incident white light.

Montejus

A montejus, also known as a **hop jack** is a piece of brewery brewhouse apparatus. It is used to separate hop debris from hot wort. It is associated with traditional brewing processes where whole hop cones are used. The relatively high hop solids associated with this type of process require special equipment to carry out the separation.

It comprises a cylindrical tank fitted with a conical bottom (see the following diagram). Hot wort is pumped into the vessel where a mesh screen filters out hop debris allowing the clarified

wort to pass through for recovery via a discharge main. The separation process is assisted by a mechanical agitator. In order to improve the recovery of wort a sparging system is provided through which hot liquor may be sprayed over the surface of the retained hops.

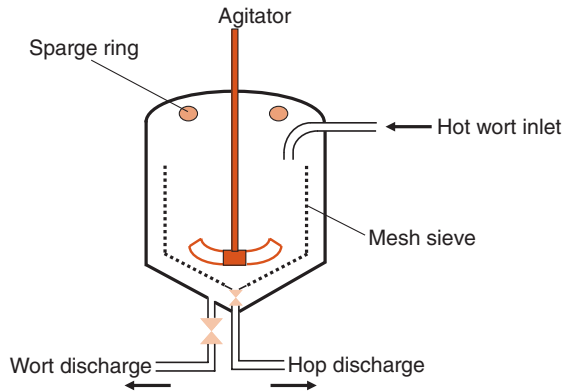


Diagram showing the essential features of a montejus

Morex

A six-row variety of malting barley bred in Minnesota and released in 1978. The variety was the most widely cultivated in terms of acreage in Idaho in the early 1990s. It is used as an international standard for genome sequencing of barley.

Moromi

The name given in Japanese to the mixture of water, steamed polished rice, *Aspergillus oryzae* and *Saccharomyces cerevisiae* (var. *saké*), which comprises the main mash in the initial stages of saké brewing.

See **saké**.

Motueka

Motueka is a dual-purpose hop variety (7–8% α -acids, marked citrus aroma) bred and cultivated in New Zealand. It can be supplied as an organic variety accredited under the New Zealand **Bio-Gro hops** system.

Mould

A synonym for the powdery mildew disease of hops.

See **powdery mildew**.

Mount Hood

Mount Hood is a US variety of aroma hop released in 1983. It is a triploid type derived from a tetraploid German Hallertau variety and a US male. It shares its ancestry with the Ultra, Liberty and Crystal varieties. It contains 5–8% α -acids of which 23% is cohumulone. The total oil content is 1.1% (8–15% carophyllene, 23–35% humulene and 30–40% myrcene).

MRS medium

Nutrient medium containing metal salts, phosphate, glucose, peptone, 'lab-lemco' (proprietary meat extract) and Tween 80 (surfactant and source of fatty acids), named after its inventors, deMan, Rogosa and Sharpe and designed for the isolation of *Lactobacillus*. It contains sodium acetate and ammonium citrate, which inhibit the growth of many competing bacteria.

Mugwort

The plant mugwort (*Artemisia vulgaris*) was used in the Middle Ages before the widespread adoption of hops as a flavouring for beer (see **gruit** for more details).

Mugwort is a close relative of *Artemisia absinthum* or wormwood and a source of the psychoactive chemical thujone {(1S,4R)-1-isopropyl-4-methylbicyclo[3.1.0]hexan-3-one}, the chemical found in the liqueur absinthe.

The name mugwort supposedly refers to its use in beers since in the Middle Ages these were drunk from mugs; however, this is disputed and it is also claimed that the name derives from the old Norse word for marsh.

Multiferm fermentation system

See **EBC tall tubes**.

Multilayer barrier dispense tubing

This is a type of tubing used for beer dispense. It is constructed from **medium-density polyethylene (MDP)** with a **nylon** inner surface. This provides a functional but cost-effective solution with low gas permeability, enhanced flexibility and the hygienic benefits of nylon.

Multum

Word used in nineteenth century United Kingdom describing a preparation used as a substitute for hops or malts which provides colouring, bittering and possibly narcotic properties. Usage was illegal and for this reason precise compositions were not disclosed. The active ingredients were usually of plant origin and were frequently toxic.

See **hard multum**.

Munich malt

Munich malts are coloured types which have a rich malty, caramel flavour. They are used in the production of the dark highly flavoursome lagers associated primarily with Munich; also similar beers are brewed elsewhere. Munich-type malts are produced from high-nitrogen barley varieties in a complex multistage process that promotes the formation of high levels of amino nitrogen and reducing sugars followed by limited stewing to induce some caramelisation and finally a heating step for the formation of coloured melanoidins.

In traditional maltings a twin-deck kiln was used in which in the first stage the well-germinated grains were allowed to dry slowly at a cool temperature of around 38°C. This allowed the formation of reducing sugars and free amino nitrogen and some stewing to generate the caramel components. After this, when the grain had reached a satisfactory level of dryness, it was transferred to the lower deck. And the temperature gradually increased in steps up to a top heat of 90–120°C for colour development. In the modern process single stage kilns

are used where the temperature and degree of moisture are controlled by recirculation of the air stream, as necessary.

Light Munich malt has a colour of 13–15 EBC units. The dark variety has a colour in the range of 20–25 EBC units. The maximum kilning temperatures for each type are 100 and 118°C, respectively. The darker variety is most associated with *dunkel* beers.

MYGP copper medium

See MYGP medium.

MYGP medium

General-purpose nutrient medium for yeast containing malt extract, yeast extract, glucose and bactopectone. It is also known as a 'yeast and mould' (YM) medium. For the detection of wild yeasts agar plates of this medium are supplemented with copper sulphate, added as a sterile solution to the molten medium to give a Cu^{2+} concentration of 200 mg/L. In this case it is known as MYGP copper medium. Copper inhibits the growth of brewing yeast but allows the growth of many **wild yeasts**, both *Saccharomyces* and non-*Saccharomyces* types. The copper concentration may be manipulated to other values than that quoted here since there is much variability between the tolerance of both wild and culture yeast strains.

Myrcene

Myrcene is a monoterpene which forms one of the components of the hydrocarbon fraction of hop oils. It is considered to be the most potent odourant of this fraction of hop oils.



Structure of myrcene

Myrcene is the last of the hydrocarbon fraction of hop oils to appear as the hop ripens and therefore its concentration can be used as an indicator of hop maturity.

Myrica gale

Bushy plant which prefers wet habitats such as peat or moor lands. It is also known as the bog myrtle or sweet gale. Individual plants form either male or female catkins. The former have a scaly appearance slightly reminiscent of hop cones. The plant produces resins. In several European countries extracts of the plant, alone or in combination with other plant extracts, have been used as alternative to hops to flavour and preserve beers. Use of the plant has been largely superseded by hops, but speciality beers, particularly in Scandinavia, are still produced.

Naked barley

Naked barley varieties are those in which the husk (palea and lemma) is not firmly attached to the pericarp. During threshing the husk is easily detached, hence the name. True naked barley varieties are two rowed and are classified as *Hordeum vulgare*, subspecies *distichon*, var. *nudum*. In some varieties of barley the husk is relatively poorly attached and these may be termed half-naked. However, these are still classified as husked varieties.

Historically naked barleys were cultivated in Europe, mainly in Norway and Belgium. They are more widely grown in Ethiopia, Japan and Nepal, where they are commonly used as a foodstuff. Naked varieties are also cultivated in Canada as animal fodder.

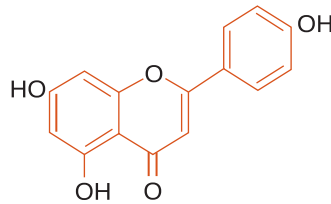
The husk has a protective function and in its absence the naked corns are easily damaged. Naked barleys are not usually malted and they are not generally used in brewing since the lack of husk would lead to poor bed formation and therefore impede wort separation in the operation of lauter tuns. Some speciality flavour or colour malts may be made from naked barleys where the relatively small proportion used in grists does not produce separation problems.

Malts made from naked barley grains at laboratory scale are reported to have a high protein content and high Kolbach index. Worts produced from such malts produced high extract contents but were difficult to filter, had high viscosity and attenuated poorly [Blazewicz, J., Liszewski, M. & Zembold, A. (2007) Technological properties of worts obtained from malts of naked barley grains, *Acta Sci., Pol., Technol.*, **6**, 37–48].

Naringenin

Naringenin is a polyphenol flavanone which is found in hops and is an intermediate in the formation of flavonols (see diagram for structure).

See **polyphenols**.



The structure of naringenin

Nathan brewery

Breweries built to a design of the Swiss inventor Leopold Nathan. The brewery design was developed during the early parts of the twentieth century. It employs a novel method for wort clarification and cooling coupled with the use of cylindroconical vessels for combined fermentation and cold conditioning. This was the first recorded use of vessels with this design. Using this design cycle times for Pilsener lager-type beers were reduced from 3 to 4 months to approximately 12 days.

See **Nathan vessel**.

Nathan vessel

Dual-purpose fermenting and conditioning vessels named after a Swiss brewer, Leopold Nathan. The vessels were the first incarnation of the now familiar cylindroconical design and were patented by Nathan in 1908 and 1927. All modern fermenting and conditioning vessels with this configuration are based on this early design.

The original Nathan system required the use of combined cylindroconical fermenting and cold conditioning vessels. In addition, a novel method of cooling and clarifying wort was introduced. This whole was termed the Nathan system and was held in 'Nathan Breweries'. The whole system comprised a hop back through which hot wort was passed as quickly as possible before delivery to a rectangular tank lined with cork insulation. It was considered essential to remove as much hop material as possible before delivery to the holding tank but to ensure that at receipt the wort temperature had not fallen below 100°C. This was to prevent condensation of undesirable volatiles, particularly 'onion' characters, which could not be removed later in the process. In order that this was the case Nathan advised that runs should be as short as possible and that all pipework should be insulated so as to retain heat. From the top of the holding tank the hot wort was pumped to an open refrigerator. In order to minimise the risk of contamination the rooms enclosing the refrigerators were held at a positive pressure and with sterile filters fitted to air inlet points. An air exhaust system carried away steam and volatiles. The cooled wort at a temperature of 3–4°C was returned to the bottom of the hot wort receiving tank. This displaced the hot wort above it such that it passed into a cylindrical upper portion fitted with a series of parallel inclined plates. During the cooling process the resultant break material (trub) settled on the surface of the plates where it was retained after the wort was pumped to the fermenting vessels.

Nathan's original fermentation and conditioning vessels had capacities of 100 hL. The first types were lined with enamel, but later designs were constructed from rolled sheets of polished aluminium welded together to form the walls. This reflected the advances that had been made at that time in handling aluminium. It was considered particularly suitable for this duty since

unlike copper, aluminium metal ions are not toxic to brewing yeast. Unfortunately the corrosion problems which can be very problematic with the use of aluminium were not recognised.

The vessels were fitted with a cone which had an internal angle of 55°. Cooling jackets were located around the straight sides of the cylinder and the cone. Clarified wort was transferred from the cooling vessel to the fermenter and was pitched en route with yeast slurry taken from a cooled storage tank. The initial temperature at the completion of collection was low, around 3–4°C. The low temperature was considered to be essential since the high degree of mixing obtained via natural convection currents in the vessels led to very vigorous fermentation. Cooling via the wall jackets restricted yeast growth and metabolism to acceptable levels. Nathan claimed that the vigour of the fermentation and extent of yeast growth was equal to that performed in the then more conventionally shaped rectangular vessels using cloudy worts. He considered that although trub provides growth-stimulating yeast nutrients, this advantage was outweighed by its negative impact on beer flavour and its tendency to contaminate yeast bottom crops. The efficient natural mixing was augmented, as required, by sparging with CO₂ through a porous stone located near the base. This gassing action was also efficient at removing more undesirable volatile materials, the so-called *jungbukett*, which was removed by collection in a gasometer and purification battery. CO₂ was collected using this system and retained for use elsewhere in the brewing process.

When the fermentation had reached a desired degree of attenuation the vessel was allowed to pressurise up to 0.5 bar, a condition that promoted yeast sedimentation. After the latter was removed from the cone the beer was further gas-washed for a further 24–36 hours until the exiting CO₂ gas stream was considered to be odourless. After this time the beer was cooled to 0–1°C, which took 12 hours, and then was held for a further 12 hours for cold stabilisation. The finished beer was then ready for subsequent finishing.

In the early parts of the twentieth century several breweries were installed using the Nathan system. The majority of these were in countries other than the United Kingdom and include Australia (Tasmania, Adelaide and Melbourne), Central America (Managua, Nicaragua), Italy (Genoa), Africa (Zaire) and India. Take-up in the United Kingdom was poor since the majority of ale brewers considered that their processes required mixed cultures of yeast strains and were not suited to the use of pure yeast strains that formed an essential part of the Nathan process. Nevertheless, a Nathan brewery was installed in the early years of the twentieth century in Moss Side in Manchester and the process was used with apparent success.

National Institute of Agricultural Botany (NIAB)

NIAB [<http://www.niab.com> (last accessed 11 February 2013)] is based in Cambridge, UK, and is a centre for research into agronomy, plant science and crop evaluation. It was founded in 1919 and charged with the development of new varieties of crops of agronomic importance, the development of new strains and providing advice regarding husbandry.

The institute is responsible for evaluating new crop varieties including malting barleys.

Native African beers

The term native African beer describes a loose grouping of diverse beverages that are made from plant sources native to this continent. These include sorghum, millet, maize, manioc

(cassava) and banana as the primary source of starch. Wheat and barley may also be used. Many of the beers are opaque and the collective term *opaque beer* is often used as a descriptor. This is inexact since some examples are clear. Similarly the term *sorghum beer* is not appropriate since many examples use other sources of extract, as alluded to already.

Opaque beers are viscous, have an ethanol content of 2–4% abv and contain high concentrations of higher alcohols. They are acid (pH 3.2–3.9) and have suspended solid contents in the range of 2–4% (w/w). Much of the solid material consists of undegraded starch granules.

Individual beers have many names. Some of these are pejorative, such as Kaffir or Bantu beers, and are presumably reflective of early colonial mores. Others are names native to the tribe, region or country from which the beer derives. Examples include *otika*, *pito*, *oyokpo*, *burukutu* (Nigeria), *utshwala*, *bjala* (South Africa), *joala* (Lesotho), *pombe* (East Africa), *bouza* (Egypt, Sudan), *merissa* (Sudan), *ajou*, *busaa*, *mbweje* (Kenya, Uganda, Tanzania), *urwaga* (Rwanda), *tchouk* (Benine) and *chibuku* (Southern Africa).

As in the case of early domestic brewing in Europe most native African beers were produced largely by women and they were often associated with ceremonial occasions. At the beginning of the twentieth century, particularly in Southern Africa, the demands made by large populations of urban workers resulted in the development of commercial operations, and as a result of these developments current annual production volumes amount to several million hectolitres.

The majority of these beers are made by a two-stage fermentation process in which there is an initial souring phase catalyzed by species of *Lactobacillus*. This is followed by a more traditional fermentation in which the growth of yeast results in the formation of ethanol and CO₂. Many of the beers are designed to be consumed before the fermentation is complete and the shelf life is commonly no more than 2 or 3 days. Ethanol concentrations are usually quite low (1–2% abv), although some examples contain up to 8% abv. In some cases demand for the beers in urban locations has resulted in the development of industrial processes in which the product is packaged in a form in which it can be more easily distributed, for example, in various waxed plastic packages. In these cases the beer may be sold as a live product with a short shelf life. Alternatively some native beers are bottled and pasteurised or use chemical preservatives such as sodium benzoate.

As a group the beers are commonly opaque and viscous and often have a sour taste as a result of the action of lactic acid bacteria. Although many are sieved in the finishing stages to remove solid materials, levels of suspended solids remain high. Many of the beers contain partially gelatinised but un-degraded starch granules and these are the major source of viscosity. Although the beers are consumed for their alcoholic content in the case of many of these native beers, this is of secondary importance and the beers are valuable sources of nutrition and may be viewed as ‘mildly alcoholic porridges’. Indeed, similar non-alcoholic versions also coexist with the beers.

Several industrial-scale methods are used for the production of African native beers. Examples are the **Reef process**, **ijuba**, **Kimberley process** and **Chibuku process**. Apart from scale these processes share the common characteristics of introducing greater control and predictability to the initial souring and subsequent alcoholic fermentation phases. This is achieved largely by the use of pure cultures of lactic acid bacteria and active dried brewing yeast. In some the initial souring fermentation phase is replaced with the direct addition of lactic acid.

A key aspect of the brewing processes is to provide sufficient nutrients to support the growth of lactic acid bacteria (where used) and yeast. Coupled with this is the requirement to control starch degradation so as to provide fermentable sugars and to ensure that a proportion persists into the finished beer to provide the necessary 'body'. The proportion of residual starch varies with different beers depending on the preferences of individual countries or regions. Most industrially brewed beers use sorghum or maize grits and sorghum malt. Since sorghum malts have low and variable diastatic powers and are low in proteases various enzyme preparations may be used.

Naturtrüb

Naturtrüb is German for 'naturally cloudy', a term that is applied to beers which are unfiltered and are therefore not bright. The term *hefetrüb* may also be used, which translates as 'yeast cloudy', referring to bottle-conditioned beers in which the presence of yeast is made evident in the form of a haze.

NBB medium

Microbiological growth medium (*Nachweismedium für Bierschadliche*) designed for the growth and detection of brewery spoilage bacteria, especially lactic acid bacteria. It contains glucose as the principal carbon source, L-cysteine hydrochloride, yeast extract, beef extract, casein digest, disodium phosphate, L-malate, potassium acetate, sorbitan monooleate and chlorophenol red. The latter is a pH indicator that causes colonies to assume a red colour. Beer may be included in the medium to increase the selection for beer spoilers.

N

NCGR-Corvallis – *Humulus Germplasm*

See **USDA hop cultivar collection**.

NCYC

National Collection of Yeast Cultures.

See **yeast culture collections**.

Near beer

Near beer is a term used to describe low- or zero-alcohol beers.

See **reduced-alcohol beer**.

Necrotic crinkle mosaic disease

See **prunus necrotic ringspot virus**.

Nelson Sauvin

Nelson Sauvin is a triploid hop variety bred in New Zealand and released in 2000. It is described as dual purpose [12–13% α -acids, of which 24% is cohumulone; 1.1% total oils which includes myrcene (22%), humulene (36%), carophyllene (11%) and farnesene (0.4%)].

The predominant aroma of the hop is described as being reminiscent of ‘crushed gooseberries’, which is a characteristic of the sauvignon blanc grape variety, hence, the name. It is mainly favoured by craft brewers.

Neoplanta

Neoplanta is a hop cultivar which originated in the late 1960s in the former Yugoslavia. It was one of a group of cultivars (with **Vojvodina** and **Dunav**) which were bred with the intention of replacing the poor yielding traditional landrace aroma variety **Backa**. It derives from a cross with Northern Brewer and a male derived from a cross with Savinja (Styrian) Goldings and a wild male.

Analysis is 7.0–12.0% total α -acids of which 36% is cohumulone. Total β -acids are 3.0–5.0%. Total oils are *ca.* 1.3%.

Nephelometry

Nephelometry, literally the measurement of clouds, describes the technique used for the estimation of the concentration of suspended particles by measuring the proportion of scattered light as it passes through a sample. The phenomenon, also referred to as turbidometry, is distinct from light absorption in which the proportion of light absorbed as it passes through a sample is measured.

The technique is used in brewing principally for the enumeration of particles which contribute to beer hazes. In addition, a similar approach, the spectrophotometric method, described below, can be used to quantify the concentrations of organisms such as yeast cells in process fluids.

Conventional spectrophotometers can be used for turbidometric analyses using transmittance, or the derived phenomenon optical density. In this case the sample is placed in a cuvette and a light beam, typically with a wavelength of 500–600 nm, is allowed to pass through it. The detector is located in a direct line with the incident light beam and the proportion that is absorbed is measured. The result is compared to a standard curve made up using samples of the same organism of known concentration (dry weight, gram per litre or cell count, cells per millilitre). The result, at best, provides an approximation of cell concentrations and does not correct for viability.

In true nephelometers light scattering is detected using an arrangement in which the detector is located at a point that is not directly incident to the source of light. Typically the detector is mounted at 90° to the incident light beam or at an angle between 12 and 25°.

See **haze meters**, **beer hazes**.

Nettle head disease

Nettle head disease describes the symptoms which occur on hop plants that are infected with the **Arabis mosaic nepovirus**. Infected plants develop smaller than usual leaves which are pale yellow-green in colour. In the early stages the leaves are narrower than usual and develop toothed margins which are reminiscent of the leaves of the nettle plant, hence the name. As the condition develops the leaves become wrinkled and deformed and the veins become very pronounced. The cones are poorly developed and in the case of severe infections losses in yield may be as high as 50–75%.

Newdale

A Canadian two-rowed variety of malting barley accredited in 2001 and still appearing on the approved list in 2011/2012.

NewFlo

Term applied to the phenotype of many brewing yeast strains which characterises the conditions under which flocculation occurs, that is, only in late fermentation when fermentable sugars have been exhausted.

See **yeast flocculation**.

Newport

Newport is a hop variety derived from Hallertau Magnum. It contains **Brewer's Gold** and Hallertau Mittelfrüh in its ancestry. It is a high alpha variety (15% α -acids) and was bred largely as a disease-resistant high alpha substitute for **Galena**.

NFC tippie

A spring variety of malting barley which appears on the fully approved for brewing list of the UK-based Institute of Brewing and Distilling.

NIBEM-CLM Cling meter

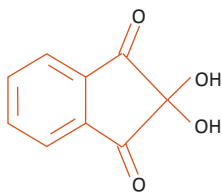
Proprietary device [<http://www.haffmans.nl/resources/images/607.pdf> (last accessed 11 February 2013)] designed for the automatic assessment of the lacing ability of beer (cf. **lacing index**). Beer foam is generated in a standard glass and after draining the residual foam adhering to the inner walls is detected by lowering a scanning head into the rotating glass. A 300-mm band, 10 mm below the top, is scanned, and using reflectance the proportions that are clear or covered in foam are measured.

Nibem meter

A device used to quantify the foaming ability of beer. It relies on conductivity measurements for determining the time it takes for the foam to collapse. This is accomplished by generating foam in a glass. Five electrodes are mounted on a top assembly. Four of the electrodes are short and arranged in a ring around the fifth, which is longer and centrally mounted. The electrode assembly is mounted on an arm such that it can be raised or lowered by a servo motor. The electrodes are placed in contact with the surface of the foam and the resultant electrical circuit switches off the servo motor. As the foam collapses the circuit is broken, the motor is activated and the electrodes are lowered until they again come into contact with the foam. The time it takes for the foam to collapse over pre-set distances is determined. Different intervals are chosen for beers of varying carbonation. Modern versions of the meter provide automatic compensation for differences in atmospheric pressure, humidity and foam temperature as well as automatic logging of results and comparison with specified values.

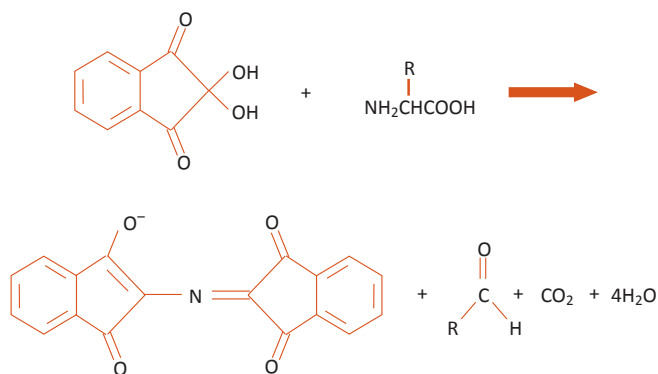
Ninhydrin

Ninhydrin (1,2,3-indanetrione monohydrate) is used for the quantification of compounds with free amino groups in malts, worts and beers, typically free amino acids, polypeptides and proteins [see **free amino nitrogen (FAN)** for more details].



Structure of ninhydrin

Ninhydrin reacts with compounds with free amino groups. In the case of amino acids the product is an aldehyde, free ammonia, and the carboxyl group is released as CO_2 . The partially reduced form of ninhydrin (hydrindantin) reacts with the ammonia to form a coloured compound. With most amino acids this product is coloured a deep purple. It is usually referred to as Ruhemann's purple. The coloured product can be quantified using a spectrophotometric procedure. Not all reactive compounds produce the purple-coloured product; for example, the imino acid proline forms a product with a yellowish colour.



Reaction of ninhydrin with an amino acid

Ninkasi

Ninkasi is the name of a Sumerian female deity reportedly associated with beer, or beer-like beverages. Evidence for Ninkasi and the link with brewing is based on the translation of writing on Sumerian clay tablets. These apparently date brewing and malting as organised activities to as early as 5000 BC. One particular tablet, the *Hymn to Ninkasi*, a translation of which is reproduced as follows, is considered to contain one of the earliest known brewing recipes. Modern brewers have attempted to reproduce the recipe, for example, The Anchor Brewing Company in San Francisco, USA. The beer is made with malt, honey and spices but not hops. The resultant beverage is considered palatable but sweet.

The Hymn to Ninkasi

Translation by Miguel Civil

Borne of the flowing water (. . .)
Tenderly cared for by the Ninhursag,

Borne of the flowing water (. . .)
Tenderly cared for by the Ninhursag,

Having founded your town by the sacred lake,
She finished its great walls for you,
Ninkasi, having founded your town by the sacred lake,
She finished its great walls for you

Your father is Enki, Lord Nidimmud,
Your mother is Ninti, the queen of the sacred lake,
Ninkasi, Your father is Enki, Lord Nidimmud,
Your mother is Ninti, the queen of the sacred lake.

You are the one who handles the dough,
[and] with a big shovel,
Mixing in a pit, the bappir with sweet aromatics,
Ninkasi, You are the one who handles
the dough, [and] with a big shovel,
Mixing in a pit, the bappir with [date]-honey.

You are the one who bakes the bappir
in the big oven,
Puts in order the piles of hulled grains,
Ninkasi, you are the one who bakes
the bappir in the big oven,
Puts in order the piles of hulled grains,

You are the one who waters the malt
set on the ground,
The noble dogs keep away even the potentates,
Ninkasi, you are the one who waters the malt
set on the ground,
The noble dogs keep away even the potentates.

You are the one who soaks the malt in a jar
The waves rise, the waves fall.
Ninkasi, you are the one who soaks
the malt in a jar
The waves rise, the waves fall.

You are the one who spreads the cooked
mash on large reed mats,
Coolness overcomes.
Ninkasi, you are the one who spreads

the cooked mash on large reed mats,
Coolness overcomes.

You are the one who holds with both hands
the great sweet wort,
Brewing [it] with honey and wine
(You the sweet wort to the vessel)
Ninkasi, (. . .)
(You the sweet wort to the vessel)

The filtering vat, which makes
a pleasant sound,
You place appropriately on [top of]
a large collector vat.

Ninkasi, the filtering vat,
which makes a pleasant sound,
You place appropriately on [top of]
a large collector vat.

When you pour out the filtered beer
of the collector vat,
It is [like] the onrush of
Tigris and Euphrates.
Ninkasi, you are the one who pours out the
filtered beer of the collector vat,
It is [like] the onrush of
Tigris and Euphrates.

N

Nip

A nip is the name applied to a type of beer bottle with a capacity of one-third (19 mL) or a half (28.5 mL) of an imperial pint. Typically this type of bottle is used for stronger beers and this is implicit in the name.

Nisin

A bacteriocin, produced by fermentation by the bacterium *Lactococcus lactis*, which consists of a short polycyclic peptide and which is used in the food industry as a preservative. It has been suggested that it could be used as a method of disinfecting pitching yeast (see **acid washing**) since it is effective against many potential beer spoilers, including *Lactobacillus* spp. Unlike acid washing it would confer some residual activity; however, owing to the reluctance of many brewers to use additives its use has not seen any take-up.

Nitrogen

Nitrogen is relevant to brewing from two standpoints. Firstly, the use of dissolved gaseous nitrogen in packaged beers. Secondly, and qualitatively much more importantly, the effects of

nitrogen-containing compounds on brewing raw materials, the brewing process, yeast metabolism and beer quality. It is difficult to overestimate the profound effects of these compounds on brewing, yeast and beer. Predictably this has resulted in a plethora of methods which may be used for the measurement of nitrogen-containing compounds in raw materials and in beer.

Gaseous nitrogen

Nitrogen gas is colourless, odourless, chemically inert and relatively insoluble in beer. It is used, principally in keg and canned UK-style ales, to produce beers with the low carbonation characteristic of these beers but with a profuse tight creamy head. These effects are possible because of the property of nitrogen gas to produce much smaller bubbles compared with CO₂. In keg products treated in this way, so-called **cream flow beer** or **smooth flow beer** kegs are filled under an atmosphere of nitrogen and CO₂. Similarly beers may also be served using **mixed gas dispense**. In small-pack canned beers nitrogen is introduced within a 'widget' during packaging. This device contains nitrogen under pressure. When the can is opened the gas escapes via a small hole in the widget and in so doing on dispense produces the characteristic tight creamy head but still with the low carbonation of draught products.

Organic nitrogen

Several classes of nitrogen-containing compounds occur in all living cells. The most important of these are **proteins** and nucleic acids. Typically protein accounts for more than 50% of the total cell dry weight. In addition, there are pools of smaller polypeptides and free amino acids. Smaller concentrations of other nitrogen-containing compounds such as amines, nucleosides and free nucleotides and their degradation products also occur.

In barley plants the total nitrogen content by dry weight reaches a maximum of 6–7% during early growth but declines by approximately 10-fold as the plant matures. During malting there is a slight decline in the total nitrogen content of the grains. Significant decreases occur in the concentrations of **hordeins** and **glutelins** but increases in albumins and globulins. In a typical brewing malt the total nitrogen content is of the order of 1.6–1.8% dry weight. Of this some 0.2–0.3% is nucleic acids (70% DNA and 30% RNA). The other minor nitrogen-containing compounds account for 8–9% of the total. Much of the remainder is protein. The usual conversion factor that is quoted to convert nitrogen to protein is to multiply the former by 6.25. It should be appreciated that this is at best only a rough approximation. The protein content of barley and malts has a direct bearing on the utility of the former in brewing and the conditions employed during wort production using the latter. Thus, very high protein levels in barley grains will reduce the extract potential of malts, and consequently, very high protein varieties tend to be restricted to fodder use. However, relatively high protein levels will also produce concomitantly high enzyme levels and diastatic power in malts, and so high protein levels are an advantage where high adjunct levels are used in the grist. US six-rowed malting barleys, where high adjunct usage is common, typically contain 12–13.5% protein. Two-rowed malting barley cultivars generally have protein levels (11–13%). In UK ale breweries where more highly modified malts are used, 8–10% protein would be considered acceptable.

The total nitrogenous components of worts account for approximately 4–5% of the total dry weight. Much of this (85–90%) is made up of free amino acids, peptides and proteins. In

concentration terms worts typically contain 700–800 mg/L total nitrogen of which approximately 20% is protein, 22% polypeptides, 58% smaller peptides and free amino acids. The latter are usually expressed in terms of the **free amino nitrogen (FAN)**. Recommendations for the latter are 150–250 mg/L for a wort of 10.5°Plato. Where high levels of adjuncts are used which do not contain appreciable nitrogen, for example, sugar syrups, there is a risk that yeast growth and the production of flavour compounds dependent upon yeast growth will be compromised. These adjuncts are referred to as **nitrogen diluents**.

Up to 50% of amino acids in wort arise unchanged from malts; the remainder is formed from proteins and polypeptides during mashing via the action of a complex mixture of proteases. In all-malt wort the spectrum of amino acids is relatively constant. Generally an increase in mashing temperature results in a reduction in amino acid concentration.

Nucleic acid concentrations in worts account for 5.7–6.4% of the total nitrogen. The ratios of adenosine+guanosine to free adenine+guanine to are approximately 3:1. Total nucleic acids in worts are of the order of 280–330 mg/L. Smaller concentrations of ammonia (25–30 mg/L) and various amines, methylamine, dimethylamine, amylamine, tyramine, hordenine and choline, also occur. Some of these, **biogenic amines**, may be involved in certain hygiene issues.

During fermentation the spectrum and concentration of nitrogen-containing compounds changes owing to assimilation by yeast and excretion of yeast metabolites. The nitrogen content of beer is therefore a combination of these compounds, those that persist unchanged from raw materials and those that are modified by the physical conditions used in brewing. The total nitrogen content of the majority of beers is within the range 300–1000 mg/L, although very strong beers may contain more. The amino nitrogen fraction consists of proteins, polypeptides, small peptides and free amino acids. Typical total FAN values are 200–300 mg/L. Very few native proteins appear to survive into beer and most of the non-free amino acids appear to be in the form of polypeptides. Fractionation of nitrogenous beer components on the basis of size has concluded that approximately half have a molecular size greater than 5000. Polypeptide molecular weights range from 2000 to 100,000 with the majority being less than 15,000. The majority of free amino acids in wort are utilised by yeast during fermentation. The imino acid proline can be metabolised by yeast only under aerobic conditions and, therefore, in most beers this is the most abundant source of FAN. Typically it accounts for 5–10% of the total nitrogen in beer.

Degradation products of nucleic acids include various nucleotides, nucleosides and free bases. Guanosine, uridine, adenosine, cytidine, cytosine and thymidine are the most abundant (10–70 µg/mL). Some of these are considered to have subtle effects on beer flavour. Possibly they are implicated in ‘drinkability’ or ‘moreishness’, although this has yet to be definitively confirmed. Various volatile amines as well as ammonia are found in beers, usually at sub-flavour threshold concentrations. These include a wide range of primary, secondary and tertiary amines. Ammonia is the most abundant (5–35 mg/L). The concentrations of the other amines range from 0.02 to 0.1 mg/L.

Measurement of nitrogen

The measurement of nitrogen concentration in beer and brewing raw materials is complicated since a wide range of methods, extraction procedures and expression of results are used.

Total organic nitrogen in raw cereals, malts, other raw materials, worts and beers may be measured via digestion of the material with concentrated sulphuric acid in the presence of a copper catalyst to convert nitrogenous components into ammonium sulphate. Free ammonia is released by distillation and quantified by titration with HCl. This is the basis of the **Kjeldahl** method. More usually the Kjeldahl method has been replaced with the **Dumas procedure**. Here the sample is subjected to intense heat in the presence of oxygen such that organic nitrogen compounds are converted to oxides of nitrogen. Using a catalytic procedure, the nitrogen oxides are reduced and the released nitrogen determined using a thermal conductivity meter. Since this method is also sensitive to elemental nitrogen in some samples it tends to overestimate the result compared to the Kjeldahl procedure.

In the case of malts it is usual to determine nitrogen, or some fraction of it, in terms of extracts. This allows an assessment of the brewing quality of the malt. In this case the malt is mashed under standardised conditions to produce wort. The total nitrogen content of the wort is then measured using a procedure such as the Dumas combustion method. The result, the **total soluble nitrogen (TSN)**, is expressed in terms of the dry weight of malt used to make the original wort. Most proteins contain approximately 16% nitrogen. It follows that multiplication of the total nitrogen result by 6.25 will give a figure that approximates to the total protein concentration. This is referred to as **crude soluble protein**. The ratio of total to soluble nitrogen concentration in malts allows an assessment of modification. Several methods are used, each with different terminologies. The **soluble nitrogen ratio** is the ratio of the percentage total soluble nitrogen to the percentage total nitrogen of malt (dry weight) using the Institute of Brewing mashing procedure. In the European Brewing Convention (EBC) procedure the same ratio but using the mashing procedure recommended by this organisation is termed the **Kolbach index**.

In earlier accounts of brewing methods other methods of nitrogen determination have been described. These are no longer used but are included for the sake of completeness. **Permanently soluble nitrogen (PSN)** is that which remains in solution after wort is boiled. The fraction that is lost via precipitation is termed **coagulable nitrogen**. The procedure was favoured by German brewers in the early years of the twentieth century. It was considered that it differentiated between small- and high-molecular-weight fractions. A similar procedure, the **index of protein modification**, was employed in the United Kingdom. This is defined as the ratio of the PSN of a wort prepared under defined conditions from a known quantity of malt compared with the total nitrogen concentration of the malt. The results were classified in ranges such that for two- and six-rowed malts, respectively, >41, 34 was considered over-modified; 36–40, 30–33, good; 32–36, 26–29, average; and <31, 25, poorly modified. **Preformed soluble nitrogen** is the concentration of soluble nitrogen obtained when an extract is made using fine ground malt at 0°C or in the presence of inhibitors of enzymes such as mercuric salts. Alternatively, extracts can be made by very brief mashing at higher temperatures. In all of these cases the aim is to inhibit the activity of malt proteases, which would otherwise cause solubilisation of nitrogen.

Amino acids and peptides are collectively determined as **free amino nitrogen (FAN)**. Several methods exist for determining this important parameter and the results may be expressed in several forms, so care must be taken when comparing results from different sources. It is now usual to measure free amino groups using a colorimetric procedure after

reaction with **ninhydrin**. Before this method saw wide adoption an early method was that used in the **formol nitrogen** procedure. Here the sample is first treated with formaldehyde. This reacts with free amino groups and allows determination of the remaining carboxyl moieties of the molecules via titration. Alternatively, another colorimetric procedure relies on the reaction of 2,4,6-trinitrobenzenesulphonic acid (**TNBS**) with free amino groups. The ninhydrin, TNBS and formol nitrogen procedures all give a slightly different response with different amino group-containing molecules, and so the results with each procedure are not comparable. Both ninhydrin and TNBS give a low colour response to proline, although the former is stronger. On the whole TNBS gives a more consistent response with the whole range of commonly encountered amino acids compared with ninhydrin. TNBS gives a stronger response to peptides compared with ninhydrin. The ninhydrin method underestimates FAN by approximately two-thirds compared with the formol procedure.

Results of FAN determinations may be expressed in several ways. In the case of malts it may be as a simple percentage of dry weight, or as a percentage of the total soluble nitrogen using an extract prepared under defined conditions. In worts or beers the result is either expressed as is or corrected to a defined gravity.

Nitrogen catabolite repression

Name given to the phenomenon whereby yeast cells are able to assimilate individual nitrogen-containing nutrients from a complex mixture in an ordered and controlled fashion. Brewing yeast strains are able to utilise a wide variety of nitrogenous compounds, but in pure form some are better at supporting growth than others. When presented with a mixture, as is the case with wort, the preferred sources of nitrogen are assimilated first. Sources of nitrogen that support good growth such as ammonium, glutamine and asparagine decrease the levels of enzymes required for the uptake and metabolism of less-preferred sources. The effect requires the use of signal transduction pathways that influence gene transcription and post-transcriptional modifications.

In brewing fermentations the phenomenon is of importance since it results in an ordered uptake of amino acids. This influences the appearance of important yeast-derived beer flavour compounds, most notably, **diacetyl**.

Nitrogen diluents

Adjuncts which have a low or zero nitrogen content which when added to grists at too high concentrations risk producing worts with a concomitant low nitrogen content. The results of this are that there are insufficient nitrogen-containing nutrients for yeast growth. In consequence yeast growth may be compromised. At best this results in unexpected perturbations in beer flavour. At worst yeast crops may be low and of poor quality, and fermentations may be slow and fail to achieve the desired attenuation gravity. The risks of this are particularly high in the case of high-gravity brewing where the high wort concentration is achieved by the use of relatively pure sugar syrups at the expense of malt.

Nitro-keg beer

See **smooth flow beers**.

Noble hops

Noble hops are specific cultivars which are low in bitterness but are noted for their aroma character. The term is reserved for four European cultivars, **Hallertau Mittelfrüh**, **Tettnang**, **Spalt** and **Saaz hop**. The hop varieties are named after the regions in which they arose, thus, Hallertau from the name of the same region in Bavaria, Tettnang a town in southern Baden-Württemberg, Spalt from the Spalter region south of Nuremberg and Saaz a town of the Labem region in the Czech Republic. There is evidence which points to the Hallertau region as being the site from which the cultivation of hops as an organised undertaking originated, perhaps as early as the ninth century.

It is thought that the cultivars arose in these particular regions by chance selection followed by asexual reproduction such that plants with one particular genotype came to dominate the regions with which they are associated. The Hallertau variety is susceptible to a wilt disease. A particularly bad outbreak in the 1970s and 1980s caused this variety to be largely replaced by Hersbrucker cultivar. Although not actually grouped with the noble hops, some English varieties of aroma hops such as Fuggles and Goldings have similar characteristics.

From a chemical standpoint the noble hops contain low concentrations of the bitter α - and β -acids. Typical values are 3–5% for each. The noble hops contain relatively high concentrations of humulene. Oxidation of this and other hop oil components is responsible for the delicate floral aromas and tastes that these hop varieties impart to beers.

These varieties of noble hops are used in the production of the classic pale European lager beers such as pilsener and helles.

N

Non-biological haze

A haze that arises in beer by any means other than by direct microbial spoilage.

See **beer hazes**.

Non-fermentable extract

The proportion of extract present in wort that is not able to be utilised by yeast during the course of fermentation.

Nonic glass

A glass commonly used in licensed outlets in the United Kingdom. Pint and half-pint versions are available. The glass is straight-sided but with a bulge close to the rim. This improves grip and reduces the tendency for chipping of the rim, hence the name which is a contraction of *no nicking*.

Nooter tun

A Nooter tun is an alternative name for a Strainmaster.

See **Strainmaster**.

Norden high-pressure mash filter

The Norden high-pressure filter is a device designed to carry out the separation of sweet wort from spent grains at the completion of the mashing phase of wort production. The filter comprises an array of polypropylene filter pockets separated by vertically grooved plates. The

whole is held together in a frame which after the pockets are filled with mash is used to exert pressure on the pockets. This forces the sweet wort through the walls of the pockets from whence it is collected.

The claimed advantages of this arrangement are that the first worts are very bright such that recirculation is not required. Spent grains are exceptionally dry (40–50% solids).

Norkies

A name dating back to the nineteenth century referring to the itinerant labourers who each year, following the barley harvest, moved to brewing towns such as Burton on Trent to carry out the malting process. At that time the malting process was highly labour intensive, hence the need for additional temporary help. This itinerant workforce moved to the Midlands of the United Kingdom from counties such as Norfolk, hence the name. Large numbers also came from neighbouring Suffolk and in consequence these were sometimes referred to as *Suffolk Jims*.

Norske Ølvenners Landsforbund (NORØL)

NORØ is the name of a Norwegian consumers association founded in 1993 and which seeks to champion for what are perceived as traditional beers and campaign against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Northdown

Northdown is a UK dual-purpose hop variety. It was bred originally at Wye College from a cross between Northern Brewer and a male that was selected based on resistance to downy mildew. It was released for commercial use in the 1970s.

It contains 7–9% α -acids of which 30–32% is cohumulone. Total hop oils are 1.2–2.2%, which contains caryophyllene (15%), farnesene (1.2%), humulene (43%) and myrcene (26%). It is sensitive to verticillium wilt and powdery mildew but is reasonably resistant to downy mildew.

Northern Brewer

Northern Brewer is a hop variety which, together with **Nugget** and **Brewer's Gold**, was one of the cultivars bred at Wye College in the United Kingdom in the mid-twentieth century. It was bred from a male seedling of Brewer's Gold and Canterbury Golding. It produced lower yields compared with Nugget and Brewer's Gold but more consistent and higher contents of α -acids (6.5–10%). It is moderately tolerant to downy mildew and is grown in the United States, Germany, England and Belgium, mainly for bitterness. It was a parental type for many of the newer higher α -acid varieties.

Nottingham, University of, Centre for Bioenergy and Brewing Science

Centre for teaching and research in brewing and bioenergy located at the Sutton Bonington Campus of the University of Nottingham, UK. Brewing science was established at the university in 2005 by the arrival of Professor Katherine Smart [<http://www.nottingham.ac.uk/brewingscience> (last accessed 3.04.2013)].

Nucleate boiling

Nucleate boiling describes a condition in which bubbles which form at the interface between liquid and solid surfaces separate from the solid surface and pass back into the liquid phase. It is of relevance in brewing with respect to the heat transfer in wort boiling systems (see **wort kettle** for more details).

Many wort kettles are fitted with internal or external heaters. These take the form of bundles of vertically arranged cylindrical tubes through which the wort is passed. The tube bundles are placed within a heating chamber which is supplied with heat in the form of steam. With regard to the efficiency of heat transfer the temperature of the steam, the pressure within the tubes, the nature of the tube material and the velocity of flow are all influential.

As the wort enters the base of the tubes it begins to boil and bubbles form at nucleating sites which take the form of minute cavities in the metal of the wall. The bubbles grow and eventually detach from the wall and are carried into the body of the liquid. Since the temperature of the bulk liquid is lower than that of the wall the bubbles collapse.

This condition is termed nucleate boiling and favours efficient heat transfer. In the case of wort boiling in a kettle constructed from stainless steel the steam must be at a pressure of no more than 3 bar and wort flow must be turbulent. At higher steam pressures the relatively large temperature differential does not permit separation of bubbles from the wall. The resultant gas film impedes heat transfer. The tendency of bubbles to separate from the wall is influenced by the material of construction. Compared to stainless steel, bubbles are more easily detached from copper surfaces, and because of this difference with the latter metal it is possible to use steam pressures up to 5 bar.

N

Nucleating glassware

Glassware designed to initiate bubble formation in beers and to generate abundant foamy heads.

See **nucleation, beer foam**.

Nucleation

Nucleation, in respect to brewing, describes the phenomenon by which dissolved gases such as carbon dioxide break out and form visible bubbles. The phenomenon is important in beer dispense where it is involved in head formation and possibly also with regard to the behaviour of fermenting worts.

Gas breakout occurs at so-called nucleation sites which in the case of glass include microscopic cracks and fissures, dust particles and dirty hydrophobic 'non-rinsing' areas. The small bubbles that are formed then act as nucleating sites and grow in size before detachment and ascent to the foam at the top of the glass. A consistent train of bubbles is considered appealing, particularly as it enhances the presentation of the beer by replenishing the head.

Nucleating glassware exploits the phenomenon by incorporating etched areas at specific sites at the base of the glass. These act as artificial nucleation sites. The principle is to enhance and support foam appearance and not to act as a substitute for poor quality beer and/or dispense. The density of nucleation sites are specific to the brand and dispense specifications. Accordingly nucleating glasses are typically brand specific as a universal unbranded nucleating glass is hard to envisage. The technology of applied nucleation has moved on from diamond

etching and sandblasting to the application of baked-on glass paste to laser etched pits at the base of the glass. Designs range from concentric rings to brand logos.

With regard to fermentation, solids present in wort are known to act as nucleation sites which promote the formation of bubbles of carbon dioxide. The clarity of wort is an important determinant of the extent of gas breakout. It has been argued that very bright worts, with a low solids loading, may produce slow fermentations because the dissolved carbon dioxide concentration remains high and exerts toxic effects on yeast.

NucleoCounter™

Proprietary instrument [<http://www.chemometec.com> (last accessed 11 February 2013)] designed to make automatic yeast cell counts based on staining with the fluorescent dye propidium iodide and suitable for routine use with a minimum need for skilled operatives. The device comprises an integrated fluorescence microscope together with the electronics necessary to make automatic cell counts and display these on a dedicated readout or alternatively output the data to an external computer or printer. An untreated sample plus necessary reagents are placed into a disposable cassette. The latter is preloaded with immobilised propidium iodide. The dye reacts with the DNA of dead cells which after suitable excitation emits a red fluorescence that is quantified by an integrated camera. Pretreatment of duplicate samples with an enzymic lysing buffer gives total cell counts and by difference the viability can be computed. The claimed operating range is 5×10^3 – 2×10^6 cells per millilitre. Results are obtained within 30 seconds.

Nugget

Nugget is a hop variety that originates from Oregon. It was bred from Brewer's Gold with contributions from Canterbury Golding and Early Green, among others. It is a high α -acid variety (12–14%). It is fairly resistant to downy mildew and has good storage properties.

Nutrient pads

Aid for routine microbiological testing produced by Sartorius AG [<http://www.sartorius.co.uk> (last accessed 11 February 2013)]. They comprise circular pads which when supplied contain a sterile dehydrated nutrient medium. A pad is placed in a sterile Petri dish and rehydrated by the addition of sterile deionised water. The sample to be tested, usually in the form of a membrane filter recovered from a concentrating technique, is overlaid onto the pad and after incubation under appropriate conditions examined for growth. Pads containing media of interest in brewing include wort agar (general purpose), lysine agar (wild yeast) and VLB S7 (lactic acid bacteria).

Nylon

Nylon is an insoluble polyamide material, various grades of which have been used as adsorbents of polyphenols from worts or beers as a means of improving beer colloidal stability. The grade of nylon most associated with this approach is termed nylon 66 (sometimes written as nylon 6,6). This is a polymer which is a diamine containing six carbon atoms. The repeating unit is $[\text{C-NH}-(\text{CH}_2)_6\text{-NH-CO}(\text{CH}_2)_4\text{-CO-}]$.

The material can be used to adsorb polyphenols from beer using addition rates of 150–300 g/hL. Nylon has also been used as a **kettle fining** material. The use of nylon for this purpose has not attracted much interest largely because of cost. It can be regenerated by treatment with caustic soda solution, although the separation process is difficult. For this reason other materials tend to be used in its place, in particular **polyvinylpyrrolidone (PVPP)**.

In beer dispense, nylon provides a premium solution for **dispense tubing** (directly or as a liner – see **multilayer barrier dispense tubing**) since its smooth surface discourages the formation of biofilms.

Nylon 66

See **nylon**.

NZ Cascade

A New Zealand-bred hop variety which can be supplied in an organic form accredited under the New Zealand **Bio-Gro hops** system. It is a medium α -acid high aroma variety which derives from Fuggles parentage and has a marked citrus aroma.

NZ Hallertau aroma

NZ Hallertau aroma is a variety of hop with moderate α -acids (8.5%) but good aroma (1.25% essential oil). It was bred in New Zealand and carries the **Bio-Gro** organic accreditation mark.



Oast house

An oast house is the name given in the United Kingdom to a building designed to store and dry hop cones. Similar buildings may also be found in other countries with a history of the cultivation of hops such as Germany, Belgium and the Czech Republic.

The building is designed to store, dry and package whole hop cones. The use of such buildings has now been largely supplanted by modern hop processing factories and for this reason many have been demolished or converted for other uses.

The earliest purpose-built oast houses were cylindrical buildings fitted with one or a number of characteristic conical roofs the tops of each of which terminate in a rotating cowl. Movement of the latter is driven by a vane in response to the prevailing wind. In later designs and for ease of construction the circular construction was replaced with a more conventional square section.

In operation green hops were collected in sacks and stored in a barn area usually located on an upper floor. From here the hop cones were removed and spread over the floor of a kiln to a depth of approximately 300 mm. The kiln floor took the form of a lattice work of timber battens attached to joists the whole being covered by a horsehair cloth. Beneath the kiln floor a furnace was located and this provided the heat source for drying the hops. The efficiency of the drying process was increased by ensuring that air was drawn through the bed of hops. A good airflow was maintained by locating a flue in the cowl through which the humid air was discharged to the atmosphere. This process was assisted by ensuring that the rotation of the cowls was such that the backs were always pointing in the direction of the prevailing wind. After the moisture content of the hops was reduced from more than 80% to less than 6% the bed was discharged and allowed to cool before packaging into hessian sacks termed pockets (see **hop pocket** for more details).

Predictably new technological developments resulted in innovations in oast house design. Thus, early wood-fired furnaces were replaced with those that used charcoal, later coal and then gas. In order to improve the efficiency of the drying process diesel or electrically driven fans were introduced, and since this obviated the need for the rotating cowl the roofs were modified to include a number of louvres.

Oasties

Collective noun used in the traditional hop-growing and processing industry in the United Kingdom for the skilled workers who operated oast houses.

See **oast house**.

Obergärig

Obergärig is the term used in German to describe beers that are made by top fermentation, in other words analogous to ales.

Oberteig

This German term describes the upper and therefore last layer of solid material that settles out during the operation of a **lauter tun**. It translates as 'upper paste'. It comprises a very thin layer of fine particles and provides the most impenetrable barrier to the passage of liquid wort. It is distinct from the *unterteig* (first paste) and **hauptteig** (main paste). Disruption of this layer by the raking action of the lauter tun knives is essential for efficient wort filtration.

See **lauter tun**.

Obesumbacterium proteus

Enteric catalase-positive bacterium seen as short rods which are facultative anaerobes and moderately ethanol tolerant. They are typically found as contaminants of brewery pitching yeast since they may proliferate in wort during early fermentation. Growth is associated with the formation of dimethyl sulphide (DMS), diacetyl and various other products which impart a characteristic 'parsnip' odour to beer. In serious infections fermentation may be severely inhibited, resulting in low ethanol yields and high residual gravity. The organism does not survive the brewing process, but of particular note is the ability of these to participate in reactions leading to the formation of potentially carcinogenic **apparent total N-nitroso compounds (ATNCs)**. Since the occurrence of these compounds in beers is strictly controlled pitching yeast may be subjected to a disinfection process, termed **acid washing**.

The taxonomic status of these organisms has been questioned. Two biogroups are recognised. It is proposed that members of biogroup 1 be assigned to the genus *Hafnia* and those in biogroup 2 to *Shimwellia pseudoproteus*.

October beer

Name given to seasonal beers of the United Kingdom that were brewed in October. October was considered a propitious time to brew beer since the following relatively cold winter months were considered to provide the best conditions for beer maturation.

Oechsle scale

The Oechsle scale is used as a measure of the specific gravity of solutions. It is associated with the German wine industry. It is used to express the sugar content of wines in musts.

A degree Oechsle (°Oe) is defined as $1000 \times (\text{specific gravity} - 1)$ measured at 20°C.

Off-trade

Term used in the United Kingdom to describe beer that is not sold in licensed premises such as bars, pubs and restaurants and therefore is that fraction which is sold in retail outlets such

as supermarkets and other shops. By implication it is mainly beer packaged into cans or bottles.

OG gain

See **original gravity (OG)**.

Okolehao

Name given to a beer-type beverage native to Hawaii. It is made principally from an aqueous extract of the baked root of the Ti plant (*Cordyline terminalis*). Other sources of flavourings and fermentable extracts may also be added including sugar cane, pineapple, taro (*Colocasia esculenta*) and rice. Although consumed as a beer in latter years, and as a result of western influences, an additional distillation step may be included to yield a spirit.

Oktawia

Oktawia is a high alpha bittering hop variety of Polish origin. Analysis is 10.6% total α -acids of which 33.5% is cohumulone. Total oil content is 1.6% of which 7.6% is caryophyllene, 33.6% is humulene and 39.7% is myrcene.

Old goldings

A synonym for the **Canterbury Goldings** variety of aroma hops.

See **Goldings**.

Olulitto

Olulitto is the name of a consumer organisation founded in Finland in 1992 and which champions for what are perceived as traditional beers and campaigns against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Contact details are at <http://www.olut.org> (last accessed 11 February 2013).

O'Malley continuous brewing system

A system for continuous wort production, fermentation and beer maturation devised in Canada during the 1960s at a time of great interest in continuous brewing processes. It was not implemented at commercial scale.

It comprised a system for continuous wort production of very novel design which incorporated a combined mashing and lauter tun and a cylindrical multistage horizontal kettle. The fermenter comprised four individually attemperated and linked tanks and was designed for plug flow with a minimum of back-mixing in order to mimic the individual stages of a conventional batch fermentation (see **plug-flow fermenter** for more details). Thus, it was envisaged that the lag phase of fermentation occurred in the first vessel, active primary fermentation in the second and third and cooling and partial clarification in the last vessel. The second, third and fourth vessels were provided with means of collecting separated yeast either from the top or bottom depending upon the proclivities of the yeast strain.

After 3–4 days residence on the fermentation system, green beer was transferred to a continuous maturation plant. This comprised a series of linked tanks similar to those used for fermentation. Passage through these tanks was accompanied by a gradual decrease in temperature. The tanks were fitted with angled bases which assisted with the collection of cold

break. Maintenance of the temperature gradient was promoted by ensuring that liquid flow was as non-turbulent as possible.

Omethoate

Omethoate (2-dimethoxyphosphorylthio-N-methyl-acetamide) is an organophosphorus pesticide that has been used as an acaricide for the treatment of **red spider mite** infestations of hop plants. Use is now not common because of the perceived risks associated with pesticide residues and problems with resistance in the target mites.

One thousand corn (kernel) dry weight (TCW)

The weight of 1000 barley corns on a dry weight basis. It is used to obtain an average measure of the weight of individual samples of barley corns. By inference it provides a predictive test of the quantity of extract that might be obtained. Values are within the range 30–45 g. Generally two-rowed barley varieties give higher values compared to six-rowed types.

The calculation is performed using a sample of 500 g of **dockage-free** barley. This is separated several times using a mechanical divider to obtain two equal portions of each weighing 40 g. After removing any foreign material and broken kernels the net weight is calculated. The number of whole kernels in the cleaned weighed sample is calculated using a mechanical counter. This value is used to calculate the 1000 kernel weight.

On-trade

The descriptor applied to commercial, **licensed premises** where alcoholic beverages are retailed and consumed within the premises. Examples include public houses ('pubs'), bars, restaurants, hotels, airports and sporting arena. Although draught beer dispense predominates, bottle products can feature exclusively in smaller or less beer-focussed accounts. The market share of the on-trade worldwide is significantly smaller than that of the off-trade. The major on-trade markets are broadly in the order of 30 mL/p.a. (United Kingdom), 20 mL/p.a. (Germany and the United States), 10 mL/p.a. (Spain, Czech Republic and Japan) and 5–10 mL/p.a. (Brazil and China).

Opal

Opal is a German aroma hop. It is described as being disease resistant, with average bitterness, average storage stability and good aroma. Analysis is 5.0–8.0% total α -acids of which 13.0–17.0% is cohumulone. Total β -acids are 3.5–5.5%. Total oil content is 0.8–1.3% of which 8.0–15.0% is caryophyllene, <0.1% is farnesene, 30.0–50.0% is humulene and 20.0–45.0% is myrcene.

Opaque beer

See **native African beers**.

Open fermenting vessels

Open fermenters are those that are generally the least sophisticated and are associated with traditional brewing processes. As the name suggests they are simple containers which are open to the atmosphere. They are most associated with the use of top-fermenting yeast strains where

the easy access obviously facilitates removal of the yeast crop. They are also used by some in traditional lager primary fermentations where the initial heads which form and which are rich in trub may be removed and discarded.

Open fermenters may be circular or rectangular in profile. The former are the most primitive and typically consist of open coopered wooden casks, also known as rounds. They are usually small, 10–30 hL in capacity, have a shallow and wide aspect and a bottom-mounted tap for beer racking. No internal attemperation is usually provided; instead dissipation of heat is reliant on the ambient temperature of the room in which they are located. This is facilitated by the large surface area and, in addition, they are usually mounted on short legs to allow a flow of air around and beneath the vessel.

Open fermenters with a rectangular geometry are the most common. They are relatively easy to construct and are conveniently grouped together in **fermentation halls**. They may be constructed from slabs of slate or, perhaps most commonly, wood. In order to prevent pickup of taints and to make cleaning easier, liners of various materials, such as resins, glass, waxes, enamel, pitch or varnish or metals such as aluminium, copper or stainless steel, are usual. The nature of the liner can have a profound effect on beer flavour. For example, copper is very efficient at removing undesirable H₂S from beers via formation of the insoluble copper sulphide. A change from a copper to a stainless steel liner has resulted in unexpected increases in rotten egg flavours and aromas in beers. Caution is also required with the use of this metal since its ions are toxic to many brewing yeast strains. The smoothness of the finish influences CO₂ bubble formation and retention and yeast separation. Generally smoother surfaces are associated with rapid yeast separation and lower attenuation extent of worts. Since some surface materials carry electrostatic charges repulsion or binding of charged beer particulates may also be significant. More modern versions may be made entirely from metals such as stainless steel. Comparatively soft metals such as aluminium require an outer carcass of wood or concrete to provide mechanical strength. Since aluminium is prone to corrosion care must be taken to provide electrical insulation. In the case of microbrewers inert rigid plastic may be used to fabricate open fermenting vessels.

In general open square fermenters are more sophisticated compared with their circular counterparts. They are most associated with the production of UK-style top-fermented ales. Typical capacities are 30–150 hL. Usually internal attemperators are provided which take the form of copper coils through which cold water is circulated. Care must be taken to avoid the use of different metals for vessel liners and attemperators without suitable insulation such that electrical cells may be formed with the consequent risk of corrosion, for example, copper attemperators in aluminium vessels. Where metal-lined vessels are used yeast heads and associated trub form very adherent scums which are difficult to clean. The effects of these may be ameliorated by coating the top of the vessels with pastes made from kaolin or calcium bisulphite.

Provisions are made for the removal of the yeast crop. These may take the form of a top-mounted **skimming board** fitted with a handle such that it may be drawn over the surface of the vessel and push the yeast crop into a drain provided for collecting the same. Alternatively a **parachute** may be used to crop the yeast. This takes the form of a tube which passes down through the depth of the vessel and whose exit is connected to a drain through which the yeast head is collected. The top of the tube is flared, hence the name, to provide a wide open

aperture for collection of yeast. The parachute is usually connected to a rack and pinion device allowing its height to be adjusted such that in operation it can be lowered so that yeast can be directed towards the opening. Yeast collection can be accelerated by the application of suction.

Operation of such vessels, particularly cleaning, requires a high degree of manual input. Since this requires entry into the vessels great care must be exercised to avoid the risks of CO₂ accumulation and consequent oxygen depletion. Attempts have been made to introduce cleaning in place (CIP) systems to these types of vessel. During the clean a temporary hood is fitted to the vessels.

See also **dropping system**.

Open square

Shorthand term given to an open fermenting vessel with a rectangular or square geometry.

See **open fermenting vessels**.

Open vertical cooler

Open vertical coolers are (now largely defunct) systems designed for cooling hot wort. They comprise a vertically mounted array of water-cooled metal tubes over the surface of which hot wort is allowed to trickle downwards in the form of a thin film.

See **wort cooling**.

Optic

A spring variety of malting barley which appears on the fully approved for brewing list of the UK-based Institute of Brewing and Distilling.

Organic acids, yeast and beer flavour

Both organic acids and short-chain fatty acids accumulate in beer during fermentation. This contributes to the observed decline in pH which occurs when wort is transformed into beer. In addition, they confer acid, sour and salty tastes.

More than 100 organic and fatty acids have been identified in beers. Concentrations of organic acids in beers can be relatively high, for example, acetic (10–50 mg/L), pyruvic (up to 200 mg/L), malic (50–100 mg/L), 2-oxo-glutaric (up to 20 mg/L) and citric (up to 250 mg/L, succinic (50–150 mg/L).

It may be noted from the previous list that many are intermediates of the citric acid cycle. This is explained in that under the anaerobic and repressing conditions in fermentation the citric acid cycle becomes branched as a result of the repression of the gene(s) coding for 2-oxoglutarate dehydrogenase. Others may derive from the catabolism of amino acids. The presence of pyruvate is surprising given the pivotal role it occupies in the central metabolic pathways leading to a multitude of other metabolites essential for yeast growth. Presumably it is testament to the unbalanced nature of wort composition.

Orifice plate

The name given to a device that is used to enhance the appearance of draught beers. An orifice plate consists of a circular metal or plastic plate with a number of carefully sized holes arranged

equally spaced in a circle effect located within the **dispense** tap nozzle for mixed gas products. When the tap is opened the beer is forced through the holes in the orifice into a glass. The action of being forced through the holes accompanied with a substantial pressure drop causes gas bubbles to come out of solution and to generate foam. The number of holes varies but is often four or five with a diameter of 0.6 or 0.9 mm. The orifice plate approach is attributed to Arthur Guinness Son and Company. They are also known as a **creamer** or **restrictor plate**.

Original extract

Original extract is a synonym of **original gravity (OG)**. It refers to the concentration, expressed in degrees Plato, of wort before fermentation has commenced. It is the terminology used in the methods of analysis recommended by the European Brewing Convention (EBC) and the American Society of Brewing Chemists (ASBC). As with the UK procedure [see **original gravity (OG)** for further details] original extract of a beer, or partially fermented wort, is determined by measuring the specific gravity of the filtered beer, the specific gravity of a distillate of beer (from which the alcohol content can be determined from look-up tables).

The original extract (p) is calculated using the following equation:

$$p = 100 \left(\frac{2.0665A + E_R}{100 + 1.0665A} \right),$$

where

p is the original extract (% w/w) equals degree Plato (°P);

A is the alcohol content of the beer (% w/w, determined from the specific gravity of the distillate);

E is the apparent extract (% w/w, determined from the specific gravity of the filtered beer);

E_R is the real extract (% w/w, determined from the specific gravity of the residue made up to the original volume).

Original gravity (OG)

OG is the specific gravity of wort measured at 20°C before fermentation has commenced. The term is used since when samples are analyzed it is usually after pitching has occurred and hence fermentation has commenced. In such circumstances it is not possible to obtain an accurate figure for the starting gravity since a proportion of the sugar will have already have been assimilated by the yeast and converted into ethanol. Where excise payments were levied on the sugar concentration of worts, as used to be the situation in the United Kingdom, it was necessary to have some method of calculating the actual value of the starting gravity.

Providing the ethanol content and the specific gravity of a sample of fermented wort are measured it should be possible to calculate the original specific gravity of the wort prior to the commencement of fermentation. In practice, this calculation would be in error since a proportion of the sugar is not converted into ethanol; instead, it is utilised by yeast to generate the additional biomass associated with growth. During the years 1909–1910 Thorpe and Brown examined ale fermentations at a number of UK breweries and determined the proportions of sugars that were used to support yeast growth. These data were used to construct what became known as the **mean brewery tables** [Thorpe, E. & Brown, H.T. (1914) Reports on the determination of the original gravity of beers by the distillation process, *J. Inst. Brew.*, **20**,

569–713]. In later years a similar exercise was performed with lager fermentations in continental Europe [HM Customs and Excise, 1997, Notice 226. Beer Duty (including Update 1, December 2000)].

In the procedure a sample of beer or wort of known volume and temperature is subject to a distillation process. The distillate and residue are collected and each is diluted to the same volume as the original sample. The difference in specific gravity between the two samples is termed the **spirit indication of distillate**. Using this figure the proportion of the original specific gravity of the wort used for yeast growth is read off from the mean brewery tables. Addition of this figure to the specific gravity of the residue gives the OG of the initial wort.

The traditional method of determining OG via distillation is still widely used; however, it is relatively time-consuming. More modern rapid approaches have now been developed. These use derived procedures for determining specific gravity and ethanol concentration. For example, specific gravity at a defined temperature can be inferred by determining the degree of damping induced in an oscillating tube containing the test solution. Alternative procedures for ethanol determination include gas–liquid chromatography, near infrared spectroscopy, catalytic combustion and via measurement of the refractive index. It should be noted that not all of these procedures have the backing of the legal authorities and therefore some cannot be used for assessing excise liability; however, since many are very rapid they are commonly used for quality control.

In practice, the calculations do not hold true for many modern large-capacity fermentations. By the application of rigorous control it is possible to conduct fermentations in which a smaller proportion of yeast is utilised for yeast growth than the current mean brewery tables would suggest. In this case the measured OG will be higher than the actual measured initial specific gravity. This phenomenon has been termed **OG gain**.

O

Orval

One of the Trappist monasteries of Belgium producing Trappist beers.

See **Trappist beers**.

Ostertag bucket-and-chain turner

A device used to turn and move beds of germinating grains as part of automated malting processes.

See **semi-continuous malting**.

Osvald's clone

Czech aroma hop varieties which are clones of Saaz.

See **Zatecky Chmel**.

Otika

Name given to a native African beer of Nigerian origin made from sorghum or maize.

See **native African beers**.

Oud bruin

Traditional Flemish brown beer.

See **Flemish brown beer**.

Outeniqua

Outeniqua is a South African hop variety which was bred from the Super Styrian variety **Atlas** and a wild Slovenian male type. It is a high α -acid type used for bittering. It takes its name from the Outeniqua Mountains in the Western Cape region of South Africa.

The analysis is 12.0–13.5% total α -acids of which 29.0% is cohumulone. Total β -acids are 4.1–5.1%. Total oil is 1.6% of which 9.5% is caryophyllene, <0.1% is farnesene, 28.0–33.0% is humulene and 38.0–43.0% is myrcene.

Overgrown corns

A term used in malting which describes grains in which the acrospire has grown to a length greater than the overall length of the whole grain. These are generally undesirable since the grains may be rich in enzymes but low in extract.

See **acrospire**.

Oversized glasses

See **pint glass** and **metered dispense**.

OWK

Acronym that stands for 'one-way keg' and a generic term describing beer containers which, unlike conventional kegs, are designed to be filled and used once only.

See **Ecokeg**.

Oxine®

A sanitiser of which the active ingredient is **chlorine dioxide**. It is supplied as an inert concentrate and before use requires activation by the addition of food-grade acids (phosphoric or citric) to achieve a pH of 2.5–3.0. Recommended rates for surface and other sanitation duties are 20–100 mg/L.

Oyokpo

Name given to a native African beer of Nigerian origin made from millet.

See **native African beers**.

Ozonisation

Ozone is a very powerful oxidising agent and is used by some as a sterilising agent in pretreatments of water used for brewing purposes. Ozone is generated by subjecting air or oxygen to an electrical discharge, typically via corona discharge. Dosage rates are dependent upon the loadings present in the water and are of the order of 0.5–3.0 mg/L. Recommended contact times are at least 15 minutes. Residual activity is negligible. Ozone is a potent sterilising agent and is also capable of reacting with organic materials, which may result in the disappearance of some taints. On the other hand, it is toxic and very corrosive, so care is required to safeguard the health of both personnel and plant.

Pablo mash separation system

This is a system used in mashing in which the sweet wort is separated from spent grains using two double-stage decanting centrifuges. It has not been exploited commercially.

Pachwai

A beer-like beverage made in made by certain hill tribes of India using rice and various grains as the source of extract. A starter material is prepared which is called bakhar, the equivalent to the koji, associated with Japanese sake. It comprises a mixture of rice flour and ginger and other dried and ground plant derivatives to which is added *Rhizopus* sp., *Mucor* sp. and a yeast. The starter is mixed with water and an inoculum derived from a previous batch of beer and small cakes are formed. These are wrapped in leaves and then left to ferment for 3 days. After drying in the sun the bakhar is powdered and mixed with water and steamed rice and placed in earthenware jars where the main alcoholic fermentation takes place. The beer is consumed without further treatment after 1–2 days' fermentation.

Pacific Gem

Pacific Gem is a high alpha hop cultivar bred in New Zealand. It can be supplied as an organic variety accredited by the New Zealand **Bio-Gro hops** system. It contains 14–16% total α -acids of which 41% is cohumulone; β -acids are 8–8.5%. Total oils are 1.5% of which 6% is caryophyllene, <0.1% is farnesene, 17–18% is humulene and 54% is myrcene.

Pacific Hallertauer

Pacific Hallertauer is a New Zealand triploid dual-purpose hop variety released in 1994. It has a very similar aroma profile to its parent, Hallertauer mittelfrüh. It contains 6.2% α -acids of which 27% is cohumulone. β -acids are also 6.2%. Total oils are 1.1%, which comprises farnesene (0%), humulene (35%), caryophyllene (12%) and myrcene (34%).

Pacific Jade

Pacific Jade is a seedless triploid hop variety developed in New Zealand and released in 2004. It was bred from **First Choice** and a Saaz male. It is a high alpha variety with low cohumulone.

It is claimed to have a peppery citrus aroma and for this reason it can be used as a dual-purpose hop. It contains 12.0–14.0% total α -acids of which 24.0% is cohumulone. Total β -acids are 7.0–8.0%. Total oils are modest at 0.8% of which 10.2% is caryophyllene, 0.3% is farnesene, 32.9% is humulene and 33.3% is myrcene.

Pack filter

See **pulp filter**.

Paddle turner

See **grain turners**.

Pad filter

A synonym for **sheet filters**.

Palea

The palea, also known as the palea superior, forms the part of the husk that encloses the ventral portion of cereal grains. For more details, see **barley grain**.

Pale ale

Pale ale is a generic term describing a beer style the most notable incarnations of which originated in the United Kingdom, although similar beers have long traditions in other parts of the world. In the United Kingdom the term pale ale is often used for this style of beer which is bottled, as opposed to ‘bitter’, a similar type of beer but that which is sold in draught form. The UK variant is now widely copied, particularly by the new wave of craft brewers. Several synonyms may be used and these include **bitter**, **amber ale**, **India pale ale (IPA)**, **Burton pale ale** and **light ale**. Similar beer styles originating from other countries include *bière de garde* from France, *altbier* (Germany) and **American pale ale**. Although used as synonyms, each of these terms carries its own particular nuances of meaning. These are described in more detail under the individual entries.

As the name suggests pale ales are made using relatively pale malts using top-fermenting ale yeast strains. The pale malts impart a copper colour (*ca.* 4–50 Lovibond units) and are usually highly hopped (20–80 IBU). Alcohol contents are moderate usually within the range 3–6.5% abv and original gravities of 8–20°P. The flavour of these beers tends to have a slight malty note but is dominated by hop bitterness.

The beer appearance owes its origin to the development of malting processes which produced pale malts, in particular the use of coke-fired kilns which were developed during the eighteenth century. The liberal use of hops owes its origin to the fact that these beer styles were often required to be stored for long periods, either because brewing was seasonal or because they were exported and had to survive lengthy sea voyages. In addition, the source of brewing water was an important determinant for this type of beer. For best results the water should be very hard as that found *par excellence* in the aquifers of Burton on Trent. See **Burtonisation**.

Pale ale malt

Pale ale malts are those that are most associated with the production of traditional top-fermented cask-conditioned ales. They are produced from low-nitrogen (<1.5%) two-rowed

barleys, such as Maris Otter, Halycon and Pipkin. The malts should be evenly and well modified and kilned at temperatures of 95–105°C to a moisture content of around 1%. Moisture levels at delivery should be 3–4%. The malts produce high extracts (typically around 300 L/kg) total soluble nitrogen of 0.58% and have low colour (4.7–5.0 EBC units). Diastatic power is moderate at around 40–45° IOB.

Beers made using pale ale malts have more malt character compared with those made from the paler lager malts. There should be no immature raw grain notes. It is considered that the best pale ale malts are produced in traditional floor maltings.

Palisade

Palisade is a hop variety bred and introduced by the US company Yakima Chief Inc. It derives from a Tettninger parental type. It is primarily an aroma variety with moderate bittering potential. It contains 5.5–10% α -acids of which 24–29% is cohumulone. Total oil content is 1.4–16%, which comprises caryophyllene (16–18%), farnesene (0%), humulene (19–22%) and myrcene (9–10%).

Panaché

Panaché is the name given in France to shandy, a mixture of beer and lemonade.

Papain

Papain is a **proteolytic enzyme** obtained from the latex of the fruit of the papaya plant (*Carica papaya*). The most common application of papain is as a meat tenderizer. In brewing, preparations of papain are used for chill-proofing, by virtue of the ability of the enzyme to degrade the high-molecular-weight polypeptide precursors of protein-polypeptide beer hazes.

The active enzyme is a cysteine protease, although in commercial preparations mixtures of endo- and exopeptidases are present, which confer broad substrate specificity. It exhibits broad temperature and pH optima. Activity is destroyed by the high temperatures (>70°C) and by oxidising agents such as iodoacetic acid.

It is relatively inexpensive, hence its attractiveness for use as a stabilising agent; however, its broad substrate specificity means that it is also capable of degrading beneficial beer foam-enhancing proteins. For this reason its choice as a stabilising agent tends to rank below other more specific agents.

Parachute

The name given to a device fitted to open fermenters and used for the collection of yeast heads.

See **open fermenting vessels**.

Paraflow

See **plate and frame heat exchanger**.

Partial and full recovery CIP sets

Cleaning in place (CIP) systems where a proportion or all of the used cleaning fluid is recovered after a clean and restored to full strength by the addition of fresh reagent.

See **CIP**.

Parti-gyling

Parti-gyling is an archaic brewing practice in which after the removal of the first and therefore concentrated wort runnings the spent grains were recovered (without sparging), re-mashed and used to produce a second and weaker wort. Both strong and weak worts were fermented separately with the result that the maximum quantity of extract was obtained from each batch of grains and two distinct beer qualities, one strong and one weak, were generated.

Pasteur effect

Eponymous term named after **Louis Pasteur** defined as a decrease in the rate of glycolysis which occurs when conditions are changed from anaerobic to aerobic or the converse, increased rates of glycolysis under anaerobic conditions. Since energy generation via oxidative phosphorylation is so much more efficient than the substrate-level phosphorylation characteristic of fermentative metabolism, it is logical that where respiratory metabolism is permitted lower glycolytic rates will be adequate to generate the same quantity of energy sufficient to maintain growth.

In actuality the real picture is more complex and varies with the organism in question. Strains of *Saccharomyces cerevisiae*, including brewing types, have a very limited respiratory capacity and, therefore, exhibit only a weak Pasteur effect. Conversely, other yeasts exhibit a much stronger and more typical response. For example, exponential anaerobic cultures of the facultative anaerobes *S. cerevisiae* (strongly fermentative) and *Candida tropicalis* (strongly respiratory) have similar glycolytic rates, based on the quantity of glucose consumed per unit of time per unit of dried biomass. After undergoing a transition to aerobic conditions the glycolytic rate of the latter yeast decreases by around 90%, whereas in the case of the former there is little or no change.

In order to demonstrate a significant Pasteur effect in *S. cerevisiae* strains it is necessary for growth to be either glucose or nitrogen limited. Under these conditions the overriding effects of glucose repression, which ensure that metabolism is essentially fermentative even under aerobic conditions, are not effective.

See **Crabtree effect**.

Pasteurisation

Name given to the process where foodstuffs, including beer, are heat treated in order to reduce the concentrations of living microorganisms, thereby ensuring that spoilage does not occur within the intended shelf life of the product. It does not imply that the product is rendered sterile. Two types of pasteurisation processes are used in the brewing industry. **Tunnel pasteurisation** is a heat treatment applied to packaged products, usually bottled or canned beers. **Flash pasteurisation** is an in-line heat treatment applied to bulk liquid, in brewing typically for beers destined to be packaged into kegs. It may be appreciated that the tunnel treatment carries the greatest level of security since, providing the containers have been properly secured, there should be no chance of subsequent infection. Conversely, flash pasteurisation relies on all processes downstream of the heat treatment being sterile.

Pasteurisation is an energy-intensive and therefore costly process. In addition, heating of beer, especially if oxygen control is poor, is harmful in terms of beer flavour. For these reasons

it is necessary to establish a minimum heat treatment which ensures microbial stability but causes the least amount of flavour deterioration and uses the smallest amount of energy.

Pasteurisation treatments are quantified in terms of duration and temperature. By convention these are quoted in terms of pasteurisation units (PU). One pasteurisation unit is equal to a heat treatment of 1 minute at 60°C (140°F). The nature of the liquid, the microbial loading and the type of cell influence the degree of heating that must be applied to provide the desired degree of microbial stability. For example, if it is necessary to destroy bacterial endospores, which are very heat resistant, it follows that a much more severe heating regime must be used compared to that needed to kill simple vegetative cells. The original studies in which the parameters for pasteurisation of beer were identified relied on the experimental determination of thermal death curves at a range of temperatures for a range of brewery spoilage organisms, both yeast and bacteria, suspended in beer supplemented with wort. It was revealed that for the organism tested there was a logarithmic relationship such that at values above 50°C, an incremental increase of 7.2°C resulted in a 10-fold increase in the death rate. The 50°C start point is an arbitrary figure below which it is considered that there is no effect. The thermal resistance of an organism is quantified as the **Z value**. This is defined as the interval in temperature required for a decimal decrease in death time, or put another way, the increase in temperature required to increase the killing rate by a factor of 10.

The lethal rate may be expressed as

$$\text{Lethal rate (LR) at } T^{\circ}\text{C} = 10 \times e^{\frac{(T-60)}{Z}} \text{ PU/min.}$$

The numerical value of Z is 7°C per decade and the line intercepts the 60°C point at 5.6 minutes, which indicates that, for this organism, 5.6 PUs would be needed to achieve the required degree of thermal inactivation, termed industrial sterility.

The relationship between the heat treatment, expressed in terms of duration and temperature and number of pasteurisation units, is given as

$$\text{PU} = t \times 10 \times e^{\frac{(T_c - 60)}{Z_c}}$$

where t is the time in minutes and T_c is the temperature in Celsius, $Z_c = 7^{\circ}\text{C}$.

In practice, it is not practicable to heat beer instantaneously to the target killing temperature and similarly, the beer cannot be instantly cooled to remove the heating effect. The process time is allowed for by calculating total PUs based on the measurement of the total area below a graph of time versus temperature using a defined temperature as the base point. Furthermore, since the early defining work it has been demonstrated that the Z values for many common beer spoilers are significantly higher than 7. Values of 15 have been determined for some organisms. The difficulties with Z values prompted the development of another index of thermal inactivation, the **D value**. This *decimal reduction* (D) value is defined as the time needed at a given temperature to inactivate 90% of the initial population. Plots of D values against temperature for ranges of beer spoilers show much variation both in terms of D value at a given temperature and the slope of D value versus temperature. Thus, as in the case of the Z value, this measure confirms that there is much variation in the thermal resistance of different organisms. There is further complication in that the nature of the suspending medium

is important. For example, the presence of ethanol increases the susceptibility of all organisms to thermal inactivation. For this reason low- and zero-alcohol beers require more stringent pasteurisation regimes compared to normal strength beer. For these reasons pasteurisation regimes used for beers are typically 15–25 PUs. This is probably at least double the treatment needed to reduce microbial loadings to the desired values. The additional treatment is viewed as providing a prudent safety margin.

The threshold value at which PU values are computed is a matter of choice. Commonly the total PUs are calculated based on a threshold value of 55°C. With some high-risk products it may be considered prudent to use higher absolute temperatures to guarantee sufficient killing rates. In these cases it is common to use a threshold value of 60°C and the total PU loading is referred to as the lethal PU number.

Pasteurisation, especially where the beer has relatively high dissolved oxygen concentrations, leads to some deterioration in flavour. From this standpoint it is better to use a short exposure time and higher temperature since the organisms are inactivated, but there is insufficient time for extensive chemical degradation. The degree of predicted flavour deterioration can be assessed by the use of the parameter termed the **thermal degradation unit** (TDU). This uses a threshold of 20°C below which it is assumed that there is no effect. The following relationship is used:

$$\text{TDU} = t \times 2 \exp \frac{T - 20}{10},$$

where t is time and T is the temperature at which the calculation is made. The value derived from this equation is divided by 10 to give the decimal TDU (dTDU).

Pasteuriser performance is assured by a system of rigorous checks of all pertinent process parameters typically linked to a fail-safe holding system should conditions fall outside expected values. In addition, the brewery microbiological sampling plan will include testing of representative packaged beers. These must be treated with some caution since the lethal effect of heating is not instant and, if sampling is too soon, recovery can occur when otherwise dying but not dead organisms are transferred to growth media.

See **flash pasteurisation** and **tunnel pasteurisation**.

Pasteurisation unit

A scale for the quantification of heat treatments used to impart microbial stability to products. One pasteurisation unit (PU) is defined as treatment at 60°C (140°F) for 1 minute.

The relationship between pasteurisation units and time and temperature is given as follows:

$$\text{PU} = t \times 1.393^{(T-60)},$$

where t is the time in minutes and T the temperature in Celsius.

See **pasteurisation**.

Pasteur, louis

Louis Pasteur (1822–1895) was a French chemist and early pioneer of microbiology. Among many notable contributions to mainstream science he provided the definitive evidence of the

animate nature of fermentation and the role of yeast. In his *Etudes sur la bière* published in 1876 he reported investigations which demonstrated the role of bacteria in beer spoilage. He is credited with showing the value to brewers of the use of scientific apparatus such as the microscope. He designed brewing equipment such as hygienic fermentation vessels and associated wort aeration plant and the heat treatment applied to beers and other sensitive food-stuffs to make them resistant to spoilage, pasteurisation, bears his name.

Patent black malt

This is a name used for the darkest grade of roasted black malt. It may also be referred to simply as **patent malt**. In order to obtain the very dark colour it is subjected to the most intense roasting treatment of all the coloured malts. For this reason it has a very marked roast, burnt character and as such should be used sparingly (1–2%) for colour.

See **chocolate malt** and **roasted barley**.

Patent malts

Patent malts are those malts that are prepared using a heating step carried out in a roasting drum. This process post-dates the earlier process of roasting over open fires. When the drum-based process was introduced into the United Kingdom in 1817 it was the subject of a patent, hence the appellation.

The names of certain speciality roasted malts may be prefaced by the word patent to indicate that they are prepared using a roasting drum.

PDX wort boiling system

This is a novel wort boiling system that uses technology originally developed for marine propulsion; compared with conventional external thermosyphon pumped systems (see **wort kettle** for more details) savings in steam usage of more than 50% are claimed. In its present form it has usually been designed as an add-on fitted to existing kettles which have an external heating loop that can be used for the introduction of the novel heating system. It comprises a heating unit in which high-pressure steam is introduced into an annular chamber that is wrapped around the PDX unit. The latter injects the steam into the wort line in such a way that it is accelerated to supersonic velocity of 1000 m/s. This low-density, low-pressure shock wave provides conditions in the PDX unit pipework in which the rates of chemical reactions are accelerated and excellent mixing occurs. This is achieved in a unit that contains no moving parts. The precise details of the PDX units have not been revealed by the supplying company, Pursuit Dynamics plc.

The PDX device is used to raise the temperature of the wort up to the boil. This requires a steam supply at 5 bar. Subsequently the device is used for volatile stripping, which uses steam at 1.5–2.5 bar. For the purposes of retrofitting to existing kettle parallel units may be fitted the total number of which is suited to the capacity of the kettle. In most cases it is necessary only to circulate part of the wort flow through the PDX units. The continuous circulation of wort necessitates purchase of an appropriately sized pump. Since the steam is injected directly into the wort it is essential to use appropriate filters to ensure adequate cleanliness. The injected steam condenses into the wort and, as a result, a dilution of approximately 4% occurs. This requires the evaporation loss of the kettle to be controlled in order to take this into account.

The effect can be somewhat offset by preheating the wort before delivery to the kettle and PDX units.

The PDX approach would obviously lend itself to other operations where heat is required, such as cereal cookers and mash conversion. At the time of writing this entry none of these applications have been reported.

Peaked cans

A fault in which cans filled with beer after tunnel pasteurisation are deformed as a result of the build-up of high internal pressures, which cause the top to bulge outwards. The problem occurs as a result of the combination of elevated temperature during pasteurisation causing breakout of dissolved gases. The problem can be exacerbated if the cans are subjected to excessive vibration during transit through the pasteuriser, and the current use of very thin-walled cans can also be problematic.

Pearl

A winter variety of malting barley with full Institute of Brewing and Distilling (IBD) approval for brewing use.

Pearl barley

Pearl (or pearled) barley is a product in which raw barley grains have been subjected to a milling process that removes the hull and bran. Pearl barley can be used as a brewing adjunct since compared with the source raw grains it yields more extract per unit weight and contains less lipid and polyphenols. These benefits are to some extent negated by the fact that on a weight basis it contains more β -glucan than naked barley grains and this will impart a penalty in terms of wort viscosity and run-off.

Peated malt

Peated malts are produced by carrying out part of all of the kilning phase over open peat fires. This process imparts the malt with colour and particularly with phenolic flavours. This type of malt is most associated with the production of some peaty Scottish whiskeys; however, a small proportion has been incorporated into the grists used for some ales.

Pectinatus

Obligate anaerobic motile rods occurring singly or in pairs or short chains. Two species are recognised, *Pectinatus cerevisiiphilus* and *Pectinatus frisingensis*. They have been implicated in incidences of spoilage of small-pack beers but only since the 1990s, a phenomenon that has been ascribed to improvements in the control of dissolved oxygen concentrations both in-process and in-pack. Spoilage is characterised by turbidity and a strong aroma of rotten eggs as a result of the formation of hydrogen sulphide. The organisms have been detected in breweries in several production areas, and it is assumed that they survive in biofilms, indicating the importance of environmental hygiene. The route into beer is not clear, but coexistence with pitching yeast is possible.

Pedicel

Pedicel is a botanical term referring to the small stalk that bears an individual floret within an inflorescence.

Pediococcus

A member of the lactic acid bacteria and potent beer spoilers. They are Gram-positive non-motile cocci which occur in pairs, tetrads or very occasionally in groups of eight cells. The latter behaviour resulted in them being erroneously classified as sarcinae and the undesirable results of beer infections by being referred to as **sarcina sickness**. The most commonly encountered species in brewery environments is *Pediococcus damnosus*; a second species, *Pediococcus inopinatus*, has also been isolated. The former is most often found in late fermentation or green beers, whereas the latter has been found in association with pitching yeast. The consequences of spoilage are the production of copious amounts of diacetyl and lactic acid via the homofermentative pathway. Visible manifestations of growth can include slimes and ropes.

Pelican grain sampler

This is a device that is used to obtain representative samples whilst grains are transported along a conveyor belt.

See **grain samplers**.

PEN

Polyethylene naphthalate.

See **PET**.

Penny ale

See **small beer**.

Peptides

See **polypeptides, protein**.

Peracetic acid

Powerful disinfectant with the chemical structure $\text{CH}_3\text{-CO}\cdot\text{OOH}$, commonly used as a sanitiser for surfaces and brewery plants or as a terminal sterilant. It is made by oxidation of acetic acid with hydrogen peroxide, and preparations contain both the product and precursors as a means of stabilisation. Dosage rates are of the order 75–300 mg/L. It is effective but hazardous and odorous, and for these reasons the use of chlorine dioxide for the same duties is becoming more common.

Pericarp

The pericarp is a botanical term describing the plant tissue surrounding the seed and which has developed from the wall of the ovary of the flower in which the fruit originated. Depending on the type of fruit it can take many forms, both dry and fleshy and is usually many-layered. In the case of cereals used in brewing, such as barley, it lies beneath the husk where it forms a protective layer surrounding the grain.

Periplasmic space

A term used in cytology which, in those cells that possess a wall, is used to denote the space which lies between the exterior of the plasma membrane and the interior of the cell wall. In yeast cells it is the site for several enzymes including invertase.

See **yeast**.

Perle

Perle is a German hop variety which was bred at the Hüll Research Institute in Bavaria from the UK variety **Northern Brewer**. It is a dual-purpose hop with good resistance to German verticillium wilt and downy mildew. It was released in 1978 as an alternative to **Hüller bitterer** based on its superior resistance to viruses as well as good bittering properties and good aroma. It contains 5–7.5% α -acids of which 28–32% is cohumulone. Total oils are 0.9–1.3% of which 8–10% is caryophyllene, traces (<1%) of farnesene, 30–38% humulene and 17–25% myrcene.

Perlite

Perlite is a natural ore. Chemically it is an amorphous aluminosilicate volcanic glass. In brewing it is used as a filter powder.

The filter powder is made by heating the natural ore up to 900°C. This results in softening and a loss of trapped water molecules such that the material expands by several times its original volume to give a much less dense solid foam. For use as a filter powder the expanded material is milled and graded to give a product with the desired particle size and filtration properties.

Compared to **kieselguhr** its filtration capabilities are generally inferior. It is not possible to produce very fine particle sizes, it is not as resistant to pressure and it is not capable of absorbing as much solids loadings as kieselguhr. Nevertheless, it has good free-flowing properties. For these reasons it tends to be used as a first pre-coat material or as a body feed where relatively large particles require to be removed, for example, in a yeast recovery press.

See also **kieselguhr, filtration, powder filter**.

Perlon

Perlon, originally termed Perlulon, is a polyamide similar in structure to **nylon**. It was developed in Germany in the late 1930s. It has been used to remove potential haze-forming polyphenols from beers and/or worts. Its use has been largely superseded by other stabilising agents such as **polyvinylpyrrolidone (PVPP)**.

Permanent hardness

See **water hardness**.

Permanent haze

Permanent haze is defined as a beer haze which is formed when beer is cooled to 0°C but which, unlike chill haze, does not redissolve when the beer is allowed to warm up to 20°C or greater.

See **colloidal stability, chill haze**.

Permanently soluble nitrogen (PSN)

PSN is defined as the nitrogen that remains in solution after wort produced under defined conditions is boiled. The proportion that is lost via precipitation after boiling is termed **coagulable nitrogen**. This measure was favoured by German brewers prior to the Second World War but seemingly now has fallen out of favour. It is considered that boiling tends to precipitate that proportion of soluble nitrogen that has a relatively high molecular weight. In this

sense, the remainder, the lower-molecular-weight fraction, should correlate with malt modification.

Permeability

Permeability is a parameter used to characterise the properties of a filter. It is described as the ability of liquid of a defined viscosity to pass through a filter bed of defined depth and area when the bed is subjected to a defined differential pressure.

See **Darcy's law**.

PET

Plastic material, polyethylene terephthalate, widely used for the manufacture of bottles for soft drinks and other foodstuffs. A small but growing volume of beer is packaged into PET containers of varying capacities. These may be 0.5, 1 or 2L. In addition, larger sized containers are used for 'home draught' products of various designs. In many markets beers packaged in PET have a less than premium image; however, this is changing and undoubtedly their share of the market will increase. PET is a linear thermoplastic polymer made from terephthalic acid and ethylene glycol. Containers are made via stretch blow moulding. The process can be carried out on-site as an adjunct to the packaging process which, compared to glass, avoids having to store stocks of empty containers and the associated transport costs.

PET has both advantages and disadvantages. It is less costly than glass and much lighter, therefore less expensive to transport. It is shatterproof, which is advantageous both in the brewery and the trade. It is the packaging material of choice at outdoor occasions where glass may be hazardous. The plastic is fully recyclable. Its major drawbacks are lack of rigidity and the fact that untreated PET is gas permeable, and as a result, packaged beers lose carbonation and suffer oxidation as a result of oxygen ingress. PET bottles cannot be crowned as the necks are too fragile to bear the forces needed to apply them. Threaded screw-on caps are the usual means of closure and these also provide another route for air ingress. This problem can be ameliorated by the use of liners. When filling PET containers cannot be pre-evacuated as they will not withstand the vacuum and they must be handled in similar fashion to cans. Furthermore, most types of bottle will not survive tunnel pasteurisation and they must be filled aseptically. Much development work has been carried out to improve their barrier properties. Newer PET bottles are usually multilayered, in some cases up to seven. Another option is to make the plastic oxygen-impermeable, applying thin surface films of ethylene vinyl alcohol or polyvinylidene chloride to single-layered bottles. In multilayered bottles internal oxygen barrier layers may take the form of carbon or silicon dioxide. An additional oxygen-scavenging layer may be fitted on the liquid side. All of these improvements come at a cost. An alternative to PET is polyethylene naphthalate (PEN). It has higher mechanical strength than PET and is approximately five times less permeable to oxygen. When used alone it is, at present, prohibitively expensive, although it can be blended with PET to reduce lower-cost alloys with improvement in performance but at a reduced cost.

Petham Goldings

A variety of one of the group of Goldings, traditional UK-style aroma hops.

See **Goldings**.

Petite mutants

Yeast strains which lack some or all mitochondrial DNA (termed rho⁰ or rho⁻) and are respiratory deficient. When grown on solid media the resultant colonies are relatively small, hence the term petite. They may be differentiated from wild type 'grande' strains by virtue of the fact that they cannot grow on non-fermentative substrates such as glycerol or ethanol. Since growth on fermentative substrates such as sugars is still possible replica plating on suitable solid minimal media allows detection of petites. However, the conventional method of detection used in the examination of brewing yeast is the **tetrazolium overlay test** (see entry for details).

Petite mutants can grow under the conditions of brewery fermentation; however, their presence in large concentrations is associated with atypical performance and undesirable changes in beer flavour and aroma as a result of the loss of mitochondrial functions other than those associated with respiration. Thus, fermentations are slow, particularly with regard to diacetyl metabolism; sugar uptake may be slower than normal and the spectrum of beer flavour volatiles may be significantly altered.

The formation of petite mutations can be encouraged by treatments with mutagens such as ethidium bromide. Petites can arise spontaneously particularly when yeast is subjected to external stresses such as may be encountered in large-capacity high-gravity fermentations at relatively high temperatures and with prolonged serial re-pitching. For this reason many brewers monitor petite formation in cropped yeast and discard when the frequency exceeds a predetermined value.

See **yeast genetics**.

Pevakh

A mildly alcoholic beer produced from rye, emmer, wheat and honey produced by the ancient Etruscans (Italy).

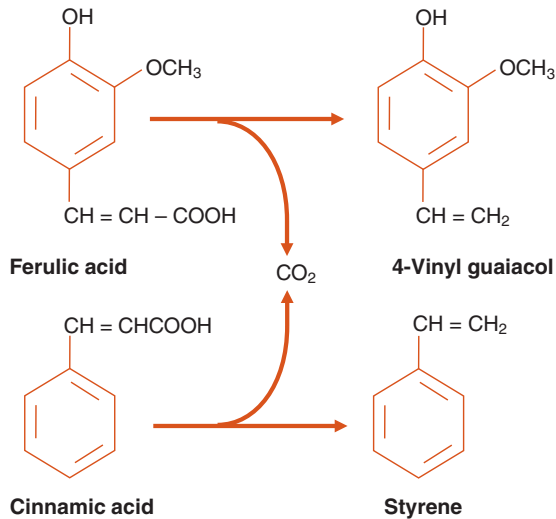
Pfungstadt planisifter

The Pfungstadt planisifter is a piece of apparatus designed to assess the fineness of grist following milling. It comprises a set of five sieves with meshes of differing but known sizes. The mesh sizes of each Pfungstadt sieve, in millimeters, are 1, 1.270; 2, 1.101; 3, 0.547; 4, 0.253; and 5, 0.152. The sieves are stacked one above the other and mounted on a spring-loaded base that is attached to the drive shaft of an electric motor. In use a sample of grist, 100 g if coarsely ground, 50 g if finely ground, is loaded into the top where the coarsest sieve is located. The motor is activated and set to rotate at 300 times per minute. Before loading with grist the three lower smaller-graded sieves each have three rubber balls with a diameter of 15–20 mm placed within them to assist with the passage of the smaller particles. After 5 minutes' treatment the individual sieves are removed and the various sub-fractions of the grist recovered and weighed.

Phenolic off-flavour (POF)

A flavour defect in most beers in which phenolic, medicinal and clove-like characters develop due to infection with a wild yeast carrying the *POF* gene which codes for an enzyme, phenolic acid decarboxylase. The enzyme is active against malt-derived wort phenolic acids such as **ferulic acid** and cinnamic acid, which after decarboxylation yield 4-vinyl guaiacol and styrene,

respectively, the compounds responsible for the off-flavours (see the following diagram for structures). These wild yeasts are **diastatic yeasts** and usually also produce amyloglucosidases which degrade wort dextrins and result in super-attenuation. The primary yeasts used in fermentation of many wheat beers are POF^+ , and in this case the products of decarboxylation are considered desirable. The *POF* gene is also carried by some species of *Klebsiella*, which are seen as occasional contaminants of pitched worts. Surveys have shown that the possession of the *POF* gene by yeasts is widespread and, in this respect, brewing strains are perhaps the exception to the rule. The gene is carried by the majority of wine strains and most wild yeast strains including many representatives of the genera *Brettanomyces*, *Candida*, *Cryptococcus*, *Hansenula*, *Pichia* and *Rhodotorula*.

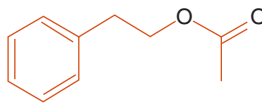


Decarboxylation reactions of wort phenolic acids by POF^+ microorganisms

See **wild yeast**.

Phenyl ethyl acetate

Ester produced by yeast during fermentation with the structure as shown in the following figure. It has a flavour and aroma described as rose or floral. It has a flavour threshold in beer of approximately 3.5 mg/L and occurs in beer at concentrations within the range of ca. 0.1–0.8 mg/L.



Structure of phenyl ethyl acetate

See **esters, yeast and beer flavour**.

Phlobaphene

Phlobaphenes are a class of brick-coloured compounds which are formed via the oxidation and polymerisation of phenolic compounds. They may be formed during the brewing process and in beer after packaging and therefore contribute to beer colour. The oxidation reaction which occurs during their formation may have significance in terms of beer flavour stability. Phlobaphenes are soluble in alcohol but not in water. They occur naturally in plant tissues as pigments in tree bark, pericarp and the testa of some seeds. They contribute to the red colour of wheat, maize and sorghum. They can be formed by heating condensed polyphenols under acidic conditions.

Phosphorylase

Phosphorylase (α -1,4-glucan: orthophosphate glucosyltransferase: EC 2.4.1.1) catalyzes the cleavage of terminal α -(1,4) bonds at the non-reducing ends of amylopectin and amylose chains, the constituent glucose containing polymers in starch granules. The glucose unit is not released but is attached to a phosphate molecule to yield glucose 1-phosphate. The enzyme is present in barley grains and should be active under the conditions of mashing. Given that a plentiful supply of inorganic phosphate is also present the enzyme has the potential of making a contribution to starch breakdown in conjunction with the other malt diastatic enzymes, α -amylase and β -amylase, limit dextrinase and α -glucosidase. However, no detailed work has apparently been performed and reported to confirm or deny this putative role.

Phytic acid

A compound whose precise structure is subject to debate but which contains *myo*-inositol and a number, probably six, of phosphate groups and which is abundant in the **aleurone bodies** of cereal grains including barley (up to 0.9% of total malt dry weight). It is a powerful chelating agent and for this reason its presence in food is considered deleterious since it may reduce the bioavailability of metal ions. Conversely, its ability to bind iron may confer antioxidant properties. In mashing the presence of phytase, derived from malts, progressively removes phosphate groups leaving free *myo*-inositol. By this action the concentration of phytic acid in most beers is low. Degradation of phytic acid during mashing provides the majority of the phosphate available for reaction of calcium ions.

Piece

The term used in the United Kingdom for a batch of grain that is being subjected to the processes which result in its conversion from raw grain to finished malt.

Pigment strand

A structure found in cereal grains such as barley. It comprises a cylindrical column of cells that lies in the crease region along the longitudinal ventral surface and which forms a seal with the edges of the testa. The sheaf cells are anchored to the pigment strand.

See **barley grain**.

PIKE

An acronym standing for potassium isomerised kettle extract.

See **hop extracts**.

Pils

See **pilsener**.

Pilsener

Pilsner is a style of beer that is now the dominant type consumed throughout the world. The beer owes its name to the town of Plzen in what was Bohemia and is now part of the Czech Republic. The terms pils and pilsner are synonyms.

The original Czech language product was called *Plzenky Prasadroj*, meaning the 'original source of pilsener'; however, the German brand name was Pilsener Urquell (from *ur*, meaning original, and *quell*, meaning source).

The beer is brewed by bottom fermentation using pale malts and very soft water. The dominant flavour of the original Czech product is a delicate fruity aroma and taste derived from the use of **Saaz hops**. Many other variants of the original pilseners are produced throughout the world and many of these are the enormous 'superbrands' produced by the major world brewers. Apart from the pale colour and use of bottom fermentation many of these in terms of raw ingredients and methods of production bear little resemblance to their forebears.

Although the original pilseners have obvious Czech associations their origins have an international dimension. Thus, as with other areas of noted brewing excellence early beers tended to be dark and produced by top fermentation. In order to counter a perceived lack of quality a new brewery was built in Plzen according to the Bavarian style and a brewer from the same location, one **Josef Groll**, was employed to manage it. Using bottom fermentation and pale malts, the latter produced using novel kilning techniques which Groll had observed whilst examining developments in the UK brewing industry, the original pale pilsener-type beer was produced. By happy accident the native malts were naturally pale in colour and this, together with the very soft local water, provided ideal conditions for this style of beer.

Pilsener malt

Pilsener (also known in the United Kingdom as **lager malt**) is a product in which colour-producing Maillard reactions are kept to a minimum by the use of low kilning temperatures. The products were originally associated with the Czech Republic but are now extensively used elsewhere, particularly Germany and Belgium. Pilsener malts are prepared from two-rowed barley varieties with total nitrogen contents of 1.6–1.8%. The grains are steeped to achieve a moisture content of about 43% and then are allowed to germinate at the low temperature of less than 17°C. When fully modified it is dried to less than 8% moisture and then kilned at a low temperature of up to 85°C. The combination of low temperature and moisture ensures that colour formation is minimal (usually 2.5 EBC). The malt has a sweet but strong malty taste. Enzyme levels are high (diastatic power of around 63°L) and, as such, it can be used as a base malt with no further additions to the grist. The resultant beers have the very pale appearance characteristic of pilsener-type lagers.

Pilsener glass

A straight-sided glass which narrows toward a short stem and base. Typically used for 250–330 mL of pilsener.

See **glassware**.

Pilsner

See **pilsener**.

Pin

A measure of beer volume equal to 4.5 imperial gallons, 36 pints or 20.48 L.

Pin mill

Pin mills are disc mills which rely on a combination of frictional shear and direct impact forces to break up the feed materials. Pin mills are used in brewing for the treatment of small samples of malts and other solid adjuncts in the preparation of extracts under standardised laboratory conditions (see **Bühler–Miag disc mill** for more details).

The mills take the form of two discs which are placed together on a common spindle and separated by a small adjustable gap. The discs are made to rotate using an electric motor, a single disc either with the other being stationary or with both discs rotating usually in opposite directions. The inner faces of each disc are fitted with hardened steel projections. These are the pins which give this type of mill its name. The pins are arranged in concentric rings over the faces of each disc such that the pins from one project into the gaps left in the other. The material to be milled is fed into the centre of the gap between each disc where it is subjected to shear and other mechanical forces which result in comminution. The frictional forces imparted by the rotating discs force the milled material outwards from whence they exit the mill.

Pin stage

A stage in the growth of the hop plant occurring during late spring and which is characterised by the emergence of young flowering shoots in the leaf axils.

PINT

Pint is the name of a consumer group, the Vereniging Promotie Informatie Traditioneel Bier. It was founded in the Netherlands in 1980 with the aim of championing what are perceived as traditional beers and campaigning against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Contact details are at <http://www.pint.nl> (last accessed 11 February 2013).

Pint glass

A type of glass used widely in the UK **on-trade**. Two styles are found. The dimpled mug or jug in thick glass with a wide mouth popular with cask ale. The ‘nonic’ or conical pint glass is taller, straight sided, tapering toward the base with, in some styles, a bulge toward the top to improve grip. Glass volume is certified by marking ‘PINT’ together with a crown stamp or, with newer glasses, Customs and Excise marking. Glasses may be brim full to a pint (nominal

volume 585 mL) delivering at least 95% liquid (after foam collapse) or lined to a pint. Less common are oversized 22 (or 24) fluid ounce glasses (a pint is 20 fluid ounces) which are calibrated by marking 'PINT TO LINE'. **Oversized glasses** are used with the comparatively rare **metered dispense**.

Pioneer (barley)

A two-rowed variety of winter barley. Pioneer was the first variety to be placed on the UK **National Institute of Agricultural Botany (NIAB)** recommended list, in 1945, for use in brewing based on high yields and disease resistance. It was used for brewing for more than 20 years before it was replaced by other varieties with superior properties. Together with Proctor it was a parent of **Maris Otter**.

Pioneer (hop)

Pioneer is a UK dual-purpose hop variety. It is sister to the high alpha dwarf variety, Herald. It contains 7–11% α -acids of which 37% is cohumulone. Total oil content is 0.8–1.8%.

Pipkin

A traditional two-rowed winter variety of malting barley much favoured for producing pale UK-style ales.

Pitch

Pitch is the verb used to describe the inoculation of wort with yeast. Thus, the addition of yeast to wort is described as **pitching** and **pitched wort** is wort to which yeast has been added. The concentration of yeast cells suspended in wort is described as the **pitching rate**. Yeast which has been recovered from a previous fermentation and stored ready to inoculate fresh wort is described as **pitching yeast**. In the United States the terms **brink yeast** and, hence, **brink rate** are synonymous with pitching yeast and pitching rate.

The origin of the term **brink**, as used in this context, is, perhaps, relatively easy to understand in that it refers to the brink, in other words, the start of the fermentation. Thus, understandably, the **brink rate** is the yeast count present in wort at the start of fermentation and **brink yeast** is that which is recovered from a previous fermentation and used to initiate the next. The origin of 'pitching' in the brewing context is less immediately apparent. Possibly, it simply refers to the action of throwing some yeast into a fermenter; however, this presupposes an understanding that yeast is the causative agent in brewing fermentation. This association was not made until the early part of the nineteenth century, although before this time brewers had appreciated that fermentations were more vigorous and consistent when a portion of the beer from a previous fermentation was retained and added to the next. In some Scandinavian countries this practice has facilitated the use of small circular structures made of slats of wood. These were referred to as **pitching wreaths**. These were cast into the fermenter after the wort had been added. During the fermentation yeast cells became lodged in the wreath, a process encouraged by the large surface area and multitude of crevices made by the wooden slats. This yeast was introduced into the next batch of wort when the wreath was recovered and transferred.

Pitched wort

Wort that has been inoculated with yeast.

Pitching

The process of inoculating wort with yeast.

Pitching rate

Pitching rate describes the concentration of yeast added to wort at the start of fermentation. Properly, the pitching rate is the viable yeast count per unit volume of wort and it may be expressed in this manner. Alternatively, the relationship between yeast count and yeast wet weight may be inferred and the pitching rate measured by using the unit of wet weight of yeast suspended per unit of wort. This method is used since it is easier to calculate and measure the quantity of yeast slurry required to be added to a given volume of wort which will give a defined viable cell count.

Pitching rates should be corrected for the gravity of the wort and for the viability of the yeast, although the latter is less important where viabilities are routinely greater than 95%.

Typical pitching rates would be 10 million viable yeast cells per millilitre of wort at a gravity of 1040 (10° Plato). This equates to approximately 1 lb per UK barrel of pressed wet yeast (around 450 g/brl, 275 g/hL).

See **pitching, yeast slurry analysis**.

Pitching wreath

In archaic Scandinavian brewing practice a wooden device coated in yeast and used to inoculate wort.

See **pitch**.

Pitching yeast

Yeast used to inoculate a batch of wort and to initiate a new fermentation.

See **pitch**.

Pitching yeast dilution

The practice of diluting concentrated slurries of cropped yeast, suspended in beer, with cooled, sterile, de-aerated liquor as a means of reducing ethanol concentration and therefore reducing potential stresses on stored pitching yeast. In addition, in the case of highly flocculent strains, dilution reduces the viscosity of the slurry and makes it more amenable to handling and pumping.

See **crop**.

Pito

Name given to a native African beer of Nigerian origin made from sorghum or maize.

See **native African beers**.

Pivo

Word used throughout the Slavic world for beer.

Plate and frame filter

Plate and frame filters are those which comprise a framework that contains a number of chambers separated by filter elements through which an un-clarified liquid such as rough beer is passed. Each chamber is fitted into a common frame and the whole is clamped together. A series of gaskets ensures that the whole arrangement is sealed. Entry and exit pipes link each chamber together. The advantage of the multiple chambers is that it provides a convenient method of increasing the total surface area, and consequently the capacity, of the filter. When the filter is sealed pressure is applied, which provides a motive force such that fluid passes through the filter sheets.

This type of filter may be used for several operations in the brewing process. In the brew-house they are used for wort clarification where they take the form of the **mash press** or mash filter (see individual entry for more details). At the fermentation stage plate and frame-type filters are commonly used for the recovery of beer from cropped yeast. In this case the filter elements are usually made from sheets of polypropylene. Pressures up to 15–20 bar are needed to ensure good beer recovery. In order to prevent premature blockage it may be necessary to add filter powder to the yeast slurry.

Plate and frame filters are commonly used for primary filtration of green beer. In this application they are types of powder filter and may be used as alternatives to candle or horizontal leaf filters (see **powder filter**). The plates and frames are arranged in alternate fashion. Each frame is of rigid metal construction and contains a hollow chamber into which the un-clarified beer is pumped. The plates comprise chambers which are perforated to allow entry of beer. Each plate and frame is separated by a filter sheet. When the filter is closed compression is applied to the filter sheets and a watertight seal is formed. Top- and bottom-mounted pipes are linked to each plate and frame. These are separated by gaskets such that when the filter is closed these form common exit and entry mains, respectively.

Filter sheets may be made from a variety of materials. Commonly they are made from mixtures of resins and cellulose designed to have good strength when wet.

In use the filters are first pre-coated with a desired grade of filter powder by pumping in a slurry made up in de-aerated water. After this is in place the rough beer plus body feed filter powder is pumped into the filter. Some users substitute the pre-coat with an additional liner, colloquially called a 'nappy', mounted over the main filter sheets.

During filtration the chambers fill up with powder and the pressure required to drive the process gradually increases. The process is terminated when either of these parameters limits further filtration. At this point any entrained beer is flushed out with de-aerated water. The volume of the latter should be small, providing that the filtration run has ceased because the chambers are completely filled with powder. This situation is preferable to termination of runs as a consequence of reaching the maximum operating pressure.

At the end of each run the filter is opened by releasing the pressure. This allows the individual frames to separate and the powder cake falls out into bins located beneath the filter. Opening and closing the filters is a manual operation in older equipment or it may be automated using hydraulic rams in modern types.

See **powder filter**.

Plate and frame heat exchanger

A plate and frame heat exchanger, also known as a **paraflow**, is one which comprises a series of thin plates the gaps between which form narrow channels through which process fluid or heat exchange fluid is allowed to pass. Plates are sandwiched together in a frame held together by screw clamps. The gaps between plates are made watertight by the provision of gaskets. The channels and gaskets direct the fluid flow such that each passes through the gaps between adjacent plates in countercurrent flow. The alternation of process fluid and heat exchange fluid, the large surface area and the tortuous route provides excellent heat exchange. The efficiency of the device is governed by the number and size of plates, the gap width, the temperature of the heat exchange fluid and the relative flow rates of the latter and the process fluid. The enclosed design favours good hygiene; however, the plates may be difficult to clean, especially where the process fluid contains appreciable solids. Automatic CIP systems are used, but even so, occasional stripping and separation of the plates are sensible to allow for checks of cleanliness and examination of the integrity of the gaskets. It is important to note that the plates are held together purely by the force applied by the clamps. Any deformation of the plates or gasket failure can in principle allow intermixing of the process and heat exchange fluids such that, for instance, beer might become contaminated with a refrigerant. In order to prevent this happening it is usual to ensure that the pressure on the product side is higher than that on the heat exchange fluid side.

The type of heat exchange fluid depends upon the duty of the heat exchanger. It may be hot water, where the process requires an increase in temperature, or it may be a coolant. In the latter case this may be water, brine or a refrigerant such as ethylene glycol.

Plate and frame heat exchangers are commonly used for cooling duties, for example, hot wort cooling, and chilling of green beer and bright beer. Smaller types may be used as **trim chillers**, for example, in between maturation tank and bright beer tank, where the use of a green beer centrifuge might have resulted in a slight increase in temperature. In this case the trim chiller provides correction of temperature before the green beer is filtered.

See **wort cooling**.

Plate counts

See **yeast viability**.

Platometer

The Platometer is a device used for the automatic in-tank measurement of specific gravity and designed for use in a fermenter [Moller, N.C. (1975), Continuous measurement of wort/beer extract in fermenter, *Master Brewers Assoc. Americas Tech. Quarterly*, **12**, 41–45].

See **density meter**.

PLC

PLC, an acronym that stands for programmable logic controller, is essentially a programmable computer that is used for the automation of complex processes such as are found in a large commercial brewery. It is designed to withstand the rigours of industrial environments and is fitted with an interface which has multiple inputs and outputs that are linked to the actual

devices such as pumps, valves and switches it controls and monitors. The operations that the PLC supervises are programmed and stored in its memory. Programming is via an interface which in complex set-ups takes the form of a computer, either one or part of a network. The computer also provides feedback from PLC operations which may be linked to a global data gathering and supervisory system. Multiple PLCs can communicate with each other and also with the field devices under their jurisdiction using a system such as **Profibus**.

Plischke malting system

An early semi-automated malting system which comprised a series of endless driven conveyor belts mounted in a vertical stack. Each belt, driven by hand cranking or via electrical motors, moved in opposite directions to the ones immediately above or below and were offset such that the grain could fall from one to the next and so could be turned. Grains on the lowest belt could either be discharged to the kiln or, if the process was judged incomplete, returned to the top belt via a bucket elevator for further treatment.

See also **pneumatic malting**.

Plug-flow fermenter

A plug-flow fermenter is a type of continuous fermenter that attempts to take into account the sequential utilisation of nutrients in complex media.

Conventional continuous systems such as chemostats employ a stirred growth vessel which is fed with a continuous supply of fresh nutrients. The volume of the culture is maintained at a constant value by a weir arrangement which allows an equal volume of the culture to be displaced (see **chemostat** for more details). This arrangement has a major disadvantage from the perspective of fermentations such as those used in brewing in that the continuous addition of fresh medium (wort) does not allow for the ordered utilisation of nutrients. Thus, in a brewing fermentation the presence of nutrients such as glucose inhibits the assimilation of other wort sugars such as maltose. In a conventional chemostat-type continuous fermenter this phenomenon causes incomplete sugar utilisation and in consequence deleterious effects on beer composition. In a plug-flow fermenter this effect is taken into account by an arrangement in which the growth vessel takes the form of a long tube into which fresh medium and inoculum is introduced continuously. Providing back-mixing is minimised, termed plug flow; hence the name, the flow of liquid through the fermenter can be considered as a continuum of batch fermentations. With careful management the out-flowing culture should have a similar composition to that which is obtained at the end of a conventional batch fermentation.

True plug-flow fermenters are theoretical entities only since it is not possible to eliminate entirely the effects of back-mixing; however, a consideration of their mode of operation explains why the majority of continuous fermentation systems which have been developed for commercial brewing have employed a series of linked reaction vessels. The individual components of these systems can be viewed as portions of a plug-flow fermenter.

See **continuous fermentation**.

Plzenky Prasadroj

Plzenky Prasadroj is the name in the Czech language for the beer Pilsner Urquell. It translates as the 'original source of Pilsener'.

See **pilsener**.

Pneumatic malting

A generic name given to an automated malting system in which streams of air, with varying temperature and humidity, are forced through the grains and thereby used to control the various stages of the process. Pneumatic malting share in common means for filling and discharging grains in an efficient and gentle manner and when in operation provide a supply of air of desired humidity to prevent drying of the grains, to ensure adequate oxygen, to remove CO₂ and to maintain a desired temperature by removal of the heat of germination.

The systems were introduced in the mid- to late nineteenth century with the intention of replacing much of the labour-intensive manual work associated with floor malting and of providing a more controlled process which could be operated at any time of the year. Historically, several individual systems were devised which shared in common, first, a manual method, and later, a mechanical means of turning the grains plus a system of fan-driven airflow. Of these the most influential was that devised by a French brewer, Nicholas Galland. His first system, built in 1873 at Maxeville in France, used rectangular boxes fitted with slotted bottoms through which air, with a controlled humidity and temperature, was forced. The grain beds required to be turned manually, a task which could not be achieved efficiently. Nevertheless, several maltings based on the Galland prototype were introduced throughout Europe and the United States.

Mechanical methods for turning the grain beds were introduced by Galland's co-worker Charles Saladin. The eponymous box system (see **Saladin box**) was fitted with a row of vertically mounted helical screws, each turning in opposite directions, which were mounted on a moving platform which traversed the grain bed and, in so doing, turned the grains. In response to this Galland developed the drum system. In this the grains were moved by placing them in a slowly rotating drum into which streams of air were introduced via a central duct. Improvements to the original concept were made by the engineer Julius Henning. The patented Galland–Henning drum system found commercial application in many parts of the world. **Drum maltings** of this design comprised long horizontally mounted cylinders made from steel, or occasionally aluminium. The drums were mounted on rollers and were made to rotate via a system of gears attached to electrically driven motors. Loading and unloading was via a series of doors located on the central periphery of the drum. The former was accomplished using a top-mounted spout and subsequent grain removal by bottom discharge onto a mechanical conveyor belt. Conditioned air was introduced into the drums via ports located in the exterior walls of the drum and removed through a central duct. In later developments various arrangements for entry and exit of air were used, typically in conjunction with systems which reduced the tendency of air to bypass the grain bed and pass into the headspace of the drum. Systems for wetting the grains were also fitted as were internal partitions which prevented the grains slipping as the mass was rotated.

Modern malting are based on the original box or drum designs albeit of much larger capacities and with many modifications designed to improve the control of the process and with much more automation.

Podalsak

Czech aroma hop variety which is a clone of Saaz.

See **Zatecky Chmel**.

Pod beer cooler

See **remote beer cooler**.

POF test

Test for the detection of wild yeast which carry the **phenolic off-flavour (POF)** gene. The yeast is inoculated into a nutrient medium supplemented with **ferulic acid**. *POF*⁺ yeast decarboxylate the latter to give *4-vinyl guaiacol*. This has a characteristic clove-like aroma and, hence, its presence can be readily detected in a sniff test. It should be noted that since potentially carcinogenic compounds may be generated in this test its routine use is now discouraged.

Pokal

A type of German beer glass often with a stem. Modern versions are comparatively small, typically with capacities of 200 or 300 mL and are commonly found in Northern Germany. Antique versions may have much larger capacities and are usually very ornate.

Polishing filter

A polishing filter is one used as part of a sequence of beer filters, usually located after a primary powder filter, and designed for the removal of very small particles. The effect is to produce beer which has a brilliant clarity, hence the name. Typically these are membrane filters which have very small pore sizes and by inference are not tolerant of high solids loadings.

See **filtration**.

Polnischer Lublin

An aroma variety of hop from the Lublin region of Poland thought to be a relative of Saaz. It is a mild hop containing 3–5.5% α -acids.

See **Lublin**.

Polymerase chain reaction (PCR)

Process used as the basis of many protocols aimed at the definitive identification of yeast and bacteria of interest in brewing.

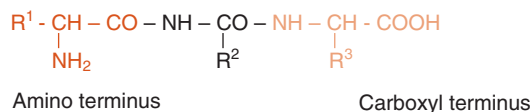
See **yeast differentiation**.

Polymyxin B

An antibiotic, particularly effective against Gram-negative bacteria, which, before the realisation of the risks of the profligate use of such compounds, was suggested as a suitable agent for disinfecting pitching yeast.

Polypeptides

Polypeptides are linear polymers of amino acids linked by covalent bonds between the amino and carboxyl groups bound to the α -carbon atom of the amino acid residue. Together with free amino acids, polypeptides and proteins are the most abundant source of nitrogen in worts and beers.



Generalised structure of a tripeptide molecule

Polypeptides are the constituent parts of protein molecules (see **amino acids**, **protein** for more details).

The ability of amino acids to bond together and form polymers means that there is a continuum of possible molecules from dipeptides (two amino acid residues) up to very large molecules consisting of several hundred thousand amino acid residues. It is usual to categorise these in terms of peptides (up to 10 residues), polypeptides (11–100 residues) and proteins (>100 residues). This classification is arbitrary. Others have delineated proteins from polypeptides in terms of function. In other words a protein would be defined as a macromolecule made up of one or more polypeptide chains in which the *in vivo* structure is intact and functionality, for example, in terms of enzyme function, is retained.

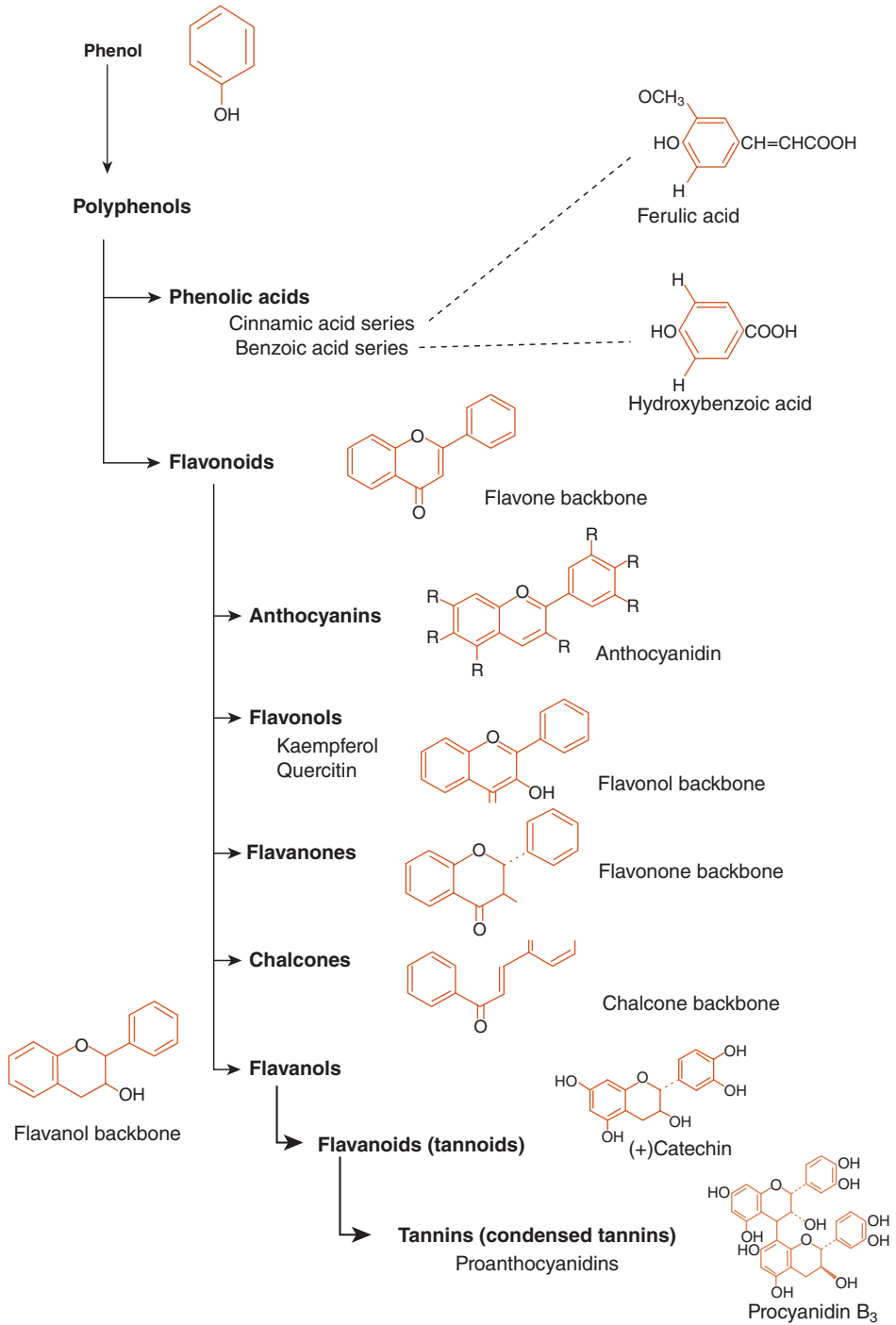
With regard to this more stringent definition of proteins it would seem likely that very few would persist unchanged throughout the brewing process. In this sense the bulk of nitrogenous material in worts and beers is either free amino acids or polypeptides.

Polyphenols

Phenolic compounds are aromatic organic compounds in which one or more of the carbon atoms in the carbon ring are attached to hydroxyl groups. In other words, they are derivatives of monohydroxylated benzene. Polyphenols are molecules which contain two or more phenolic groups linked together. Polyphenols arise in beer from malt and hops. Their significance is multi-fold. They contribute to beer flavour by imparting astringency and mouthfeel. Oxidised polyphenols contribute to beer colour. Via their ability to bind to proteins they are responsible for the formation of beer hazes (see **colloidal stability**). In a positive sense they have antioxidant properties and, therefore, they contribute to beer flavour stability. Aside from their positive influence on beer flavour stability their antioxidant properties reportedly provide health benefits to moderate consumers of beer. Indeed, although the linkage between polyphenol consumption and benefit to health has become linked in the collective public consciousness largely with red wines, the evidence suggests that beer is equally efficacious in this regard.

The chemistry of beer phenolic compounds is complex; a large number of individual compounds are involved and the terminology is confusing. The terms tannins and derivatives such as tannols and tannoids are used synonymously with polyphenols. This is based on the fact that several of these compounds have found use as tanning agents in the production of leather via their ability to bind to and precipitate proteins present in animal hides. Although not all polyphenols have tanning properties, the terms tannins is often applied *carte blanche* to all polyphenols present in plant extracts. Some authors restrict the use of the term tannin to those polyphenols capable of precipitating proteins.

The major groups of polyphenols of importance in brewing are summarised in the following figure.



P

The major groups of polyphenols of importance in brewing

Boiled wort contains both simple and polymerised phenolic compounds. The first of the simple types are monophenolic acids of two groups, substituted benzoic acids and substituted cinnamic acids. The former group includes **gallic acid**, **protocatechuic acid**, **p-Hydroxybenzoic acid**, **vanillic acid** and **syringic acid**. The cinnamic acid group includes **caffeic acid**, **p-coumaric acid**, **ferulic acid** and **sinapic acid**. These monophenolic compounds occur freely or as esters or glycosides. In addition, the monophenolic amines and amino acids tyramine, N-methyltyramine, tryptamine and tyrosine occur in beers at concentrations of around 3–20 mg/L. **Hordenine** is the major alkaloid found in the roots of sprouting barley.

Flavonols, which are derivatives of 3-hydroxyflavones and have a backbone consisting of 3-hydroxy-2-phenylchromen-4-one, are derived largely from hops. They consist of **quercetin** and **kaempferol** and their glycosides of which 14 have been identified.

Flavan-3-ols are monomeric polyphenols and include (+)-**catechin**, (-)-**epicatechin**, (+)-**gallocatechin** and **epigallocatechin**. These materials are colourless, but when cleaved with acid they can oxidise and polymerise giving rise to anthocyanidin pigments. For this reason collectively, they are referred to as **proanthocyanidins**. To add further confusion the same group of compounds is usually referred to in the brewing literature by the now outmoded term **anthocyanogens**. Flavanols undergo oxidation and polymerisation reactions to form dimers, trimers, tetramers and pentamers. In total more than 50 individual compounds have been identified. Collectively these are known as **tannoids**. Examples are procyanidin B₃ and prodelphinidin B₃. Further oxidation and polymerisation steps lead to the formation of much larger molecules termed **tannins**.

In a typical all-malt beer the total content of polyphenols is of the order of 150–350 mg/L. Of this approximately 66% is derived from malt and the remainder from hops. Aroma hops are considered to be a richer source of polyphenols compared with bittering types. With regard to malts winter varieties of barleys contain more polyphenols than spring types. The total content of polyphenols which arise in beer is influenced by the nature of the raw materials, in particular how the malt was kilned, and the conditions employed in the brewing process. Well-modified malts yield more phenolic materials during mashing probably as a consequence of less protein remaining in the grist and available to bind phenolic constituents. The quantity of polyphenols extracted during mashing is positively influenced by temperature and elevated pH. Polyphenols are subject to oxidation reactions and degradation during mashing and therefore the presence of oxygen is important. Enzymes such as polyphenol oxidase, peroxidase and perhaps catalase are important. Treatments with chemicals such as hydrogen peroxide and formaldehyde are effective at removing polyphenols either via oxidation or by binding to proteins and precipitation, respectively. Polyphenols, via their reactions with proteins, are lost at various stages in the brewing process as hot break, cold break and chill and permanent hazes. Further polyphenolic material may be removed via the action of stabilising agents such as PVPP.

The relationship between the various classes of polyphenols which arise in beer and the formation of hazes is of crucial importance to beer colloidal stability. The relatively small tannoid polyphenols can be detected in beer and are able to interact with beer proteins but are not able to form visible hazes directly, presumably because the complexes are too small to be visible to the naked eye. It has been suggested that in beer these small polyphenols exist in free form and complexed to proteins in a reversible equilibrium. During storage of beer the

flavanoid fraction gradually undergoes oxidation and polymerisation to form larger tannoid molecules and eventually tannins. These latter two groups are implicated in the formation of visible hazes via interactions with sensitive proteins. This process occurs naturally with time in all beers. Its extent is, of course, governed by the concentrations of precursor molecules which survive into packaged beer and in turn this is a function of the rigour of stabilisation treatments applied during the brewing process. In packaged beer physical parameters such as oxygen content, temperature and degree of agitation all promote haze formation.

See individual entries for details of molecular structures.

Polypin

In the United Kingdom a polypin is used to describe a plastic container contained within a cardboard outer enclosure which is used to supply draught beer, especially cask ales, for home consumption. Typically polypins hold 32 or 36 imperial pints or, in metric versions, 20L of beer. Smaller versions holding 17 imperial pints are also available and these are termed minipins. They may also be referred to as beer in a box. The word is actually a registered trademark of Biovision GmbH and describes the polyethylene plastic liner.

Polyvinylpolypyrrolidone (PVPP)

See **PVPP**.

Pombe

Name given to a beer made from millet and native to East Africa. The name is the Swahili for beer. The fission yeast *Schizosaccharomyces pombe* was isolated from pombe by Lindner in 1893.

See also **native African beers**.

P

Ponto

See **dropping system**.

Pony keg

In the United States, pony keg is the name given to a beer keg containing a quarter of a US barrel, 7.75 US gallons (29.33 L).

Porter

Porter is a style of beer which originated in the United Kingdom but examples of which are now produced by breweries throughout the world.

The origins of the term are obscure, but it appears that the name came into use in London in the early eighteenth century. According to one source [King, F.A (1947) *Beer Has a History*, pp. 91–92, Hutchinson's Scientific and Technical Publications, London, UK], at this time in the United Kingdom, beers were classified into three categories: ale, beer and **twopenny** (or tuppenny). Commonly the three beer categories were dispensed into glasses as mixtures of combinations of two of each type or all three, hence the expression **half and half** referring to a glass filled with equal volumes of beer and ale. A mixture of all three beers was reportedly referred to as **three-threads**. According to King, in 1722, an East London brewer named

Harwood had the idea of producing a single beer which was the equivalent of a mixture of ale, beer and twopenny. This early example of new product development had the unique selling point of producing a significant reduction in dispense time, no doubt a great boon to the busy publican. The new beer was sold under the name **entire** or **entire butt**, an obvious allusion to its roots. Reportedly the first recipient of the new beer style was the Blue Last, a public house located in Great Eastern Street in Shoreditch in London. Many of the customers who frequented this establishment were porters by trade and supposedly they appreciated both the product and the rapid dispense. The association of the beer with this category of customer resulted in the product acquiring the name porter. Then veracity of this story regarding the origin of porter is not known and, indeed, several brewing science historians claim that it is nothing more than a myth. It remains to be seen if more definitive evidence will be unearthed.

A characteristic of porters was that they were subject to a lengthy aging process which was carried out in the brewery. The popularity of these beers, termed London porters, was such that they were responsible during the nineteenth century for the establishment and growth of some of the most well-known London brewing companies, for example, Whitbread, Trueman and Thrales. These breweries were noted for the large numbers of high-capacity tanks required for the storage of porter.

Porters are dark-coloured beers described as being rich and acidic in nature and were well hopped. They were originally made using brown, snapped or blown malts (see **porter malt**). The beers were produced using top-fermenting ale yeasts. In common with many beer styles with a long provenance, the characteristics of porters have been shaped by the availability of raw materials, new process developments and external pressures such as taxation. The early exclusive use of brown malts was based purely on the fact that it was less expensive than pale malts. However, when scientific advances allowed such measurements to be made, it was observed that the brown malts yielded much less extract compared with pale malts. As a reaction to this and to increases in taxation porters came to be made from pale malts and a variety of colouring agents intended to mimic the older styles. When subsequent laws prohibited the use of these colourants the porter brewers resorted to the use of pale malts and a small proportion of very dark roasted malt (see **patent malt**).

The popularity of porter in the United Kingdom in the nineteenth century resulted in the introduction of a number of varieties of varying strength. Many of these included the name **stout** and this is the origin of this appellation, presumably alluding to the 'body' of the beer. Examples, of varying alcoholic strength, include single stout porter (OG 1066, 16.5°P), double stout porter (OG 1072, 18°P), triple stout porter (OG 1078, 19.5°P) and imperial stout porter (OG 1095, 24.75°P). Predictably the porter part of the names was eventually dispensed with and the beers came to be known simply as stouts.

In the United Kingdom the porter style of beer declined in popularity with the advent of paler bitter ales as typified by those produced in Burton on Trent. However, many UK brewers continued (as they still do) to produce a dark porter type of beer although in much smaller volumes compared to the high days of the London porter trade. Modern variants are mostly much weaker than their forebears (typically OG 1040–1050, 10–12.5°P). In recent years there has been something of a renaissance in the form of the craft brewing market where many examples may be found.

The stout beer style has come to be most associated with Ireland. It was first brewed in Dublin in the late eighteenth century. The modern draught beers, such as Guinness, are of the dry type, contain 4.2% abv and are made from pale and patent malts.

Porter or stout types of beer are now brewed in many countries of the world. Many of these owe their origins to the popularity of porters that were exported by the UK brewers in the nineteenth century. At this time many of the latter had flourishing export markets in the Baltic countries. This triggered the establishment of many locally produced copycat beers in countries with a Baltic coastline. These became known as **Baltic porters**. Originally these were made using a similar top-fermentation process to that practised in the United Kingdom; latterly, many of these brewers have adopted bottom fermentation. A similar phenomenon occurred on the eastern seaboard of the United States and indigenous porter production was initiated in response to UK exports. The majority of these brewers also used bottom fermentation.

Porter malt

This is an archaic malt type no longer produced but originally used for making beers of the same name. Synonyms are **blown malt** or **snapped malt**. Porter malt was made by kilning the grains over an open wooden fire. As with the German *Rauschmalz* used for smoked beers, beechwood was particularly favoured. The starting material was well-dried germinated green malt. The process was two-stage. An initial heating step (100–120°C) was conducted at moderate heat with the aim of further drying the grains. After cooling the grains were turned and in the second stage the heat was reapplied (160–170°C). Attenuation was crude, being achieved by the periodic application of water. In this second phase the grains became swollen and eventually burst with an audible pop, hence the alternative names.

The final product was very dark and predictably had an intense smoked flavour. It is likely that survival of enzymes was poor and in consequence the fermentability of worts from these malts would have been poor and variable. These malts have now been superseded by other roasted types.

Portman group

The Portman Group [<http://www.portman-group.org.uk> (last accessed 3rd. April, 2013)] is a non-profit-making organisation established in 1989 by leading members of the UK brewing industry. Its name derives from the location of the inaugural meetings held at offices of the Guinness Brewing Company in Portman Square in London. Its membership is responsible for more than 60% of the total UK alcoholic beverage production. Its original aim was to prevent alcohol misuse and to promote sensible alcohol consumption. In 1989 it became embroiled in the controversy regarding the manufacture, naming and marketing of flavoured alcoholic beverages, the so-called alcopops. In response to this it formulated a code of practice to cover these issues. In 2004 it launched a website, <http://www.drinkaware.co.uk> (last accessed 3rd. April, 2013), which is now the principal UK site for education on moderate alcohol consumption. The site is alluded to in marketing material produced by many of the member companies. The Portman Group is a recipient of complaints regarding merchandising of alcoholic beverages. It adjudicates on these, issues judgements and has the power to take sanctions against companies who refuse to conform with its findings.

Posset

A drink associated with medieval England served hot and made from a mixture of milk, spices and beer or wine.

Post-fermentation bittering

Post-fermentation bittering is the practice where hop extracts containing relatively pure preparations of isomerised α -acids are added to beer at a stage after fermentation. A typical application would be adjustment of bitterness levels of high-gravity beers immediately prior to dilution. Other hop preparations, either added to the kettle or post-fermentation, would also be used to impart aroma and taste and for ensuring the brewing process proceeds normally.

See **hop extracts**.

Pot boy

A worker employed in UK public houses in the Victorian era charged with filling large jugs with draught ales from casks held in cellars and carrying the beer to the bar for dispense. Pot boys were made redundant by the introduction of the **beer engine**.

Pounds gravity

See **Brewers' pound**.

Powder filter

Powder filters are those in which a filter aid is used as a means of extending the useful run time. In the case of the majority of such filters in current use the filter aid is kieselguhr (diatomaceous earth).

Powder filters use depth filtration as their principle of operation (see **filtration** for more details) in which the septum of the filter is first coated with a relatively coarse layer of powder, termed pre-coating, after which the rough beer is pumped in and mixed with a proportion of a finer grade of filter powder. The latter is termed body feed and ensures that the filter surface is continuously regenerated throughout the run.

Three designs are in common use. These are **plate and frame filter**, **candle filter** and **horizontal leaf filter**. The plate and frame powder filter was the earliest and was introduced into the United States in the 1930s. After the Second World War these filters were rapidly adopted in other countries, particularly in the United Kingdom and in Japan. Plate and frame filters have the inherent problems of being difficult to automate and therefore requiring a high degree of manual input and being prone to oxygen ingress. Nevertheless they are capable of producing beer with excellent clarity. Superior designs which are largely enclosed and therefore provide better hygiene and ease of control of oxygen exclusion and attemperation as well as facilities for automation were introduced in later years. The leaf filter was first introduced by the Schenk Company (now Pall Food and Beverage) and the candle filter by the German Enzinger Company (now part of KHS AG). For more details see the entries for individual filter types.

Powdery mildew

Powdery mildew is a serious fungal infection of hops caused by *Sphaerotheca macularis*. Several synonyms describe this infection. These include 'mould', 'white mould' and 'red mould'. The differences in names refer to the appearance of infected plants at different phases in the

life cycle of the causative fungus. In Germany it is called *Echter Mehltau*, meaning true mould, which is distinguished from *Falscher Mehltau* (=false mildew), which refers to downy mildew.

The disease has been a cause of serious commercial losses in the United Kingdom, Belgium and some other parts of Europe. Occurrences in Germany were comparatively rare until susceptible cultivars such as Northern Brewer were imported. The disease became prevalent in the hop farms of the east coast of the United States and the damage was such that it provided the spur to set up the hop industry in the West Coast where the fungus was thought not to occur. The disease was identified in the Yakima Valley in 1997 and powdery mildew has since become the most serious disease of hops in the Pacific Northwest of the United States. As with downy mildew, strict quarantine laws have prevented occurrences of the disease in Australia, New Zealand and South Africa.

Infections take the form in early stages in the form of spots on leaves. On the underside these take the form of raised blisters in which a white mycelium appears. Infected cones are either totally undeveloped or take on asymmetric distorted forms. The latter case, where infection occurs at the burr stage, is the most serious and can result in losses in yield of up to 80%. In addition the cones of heavily infected plants develop a musty aroma. In the early stages the mycelium is white (hence the name) and contain numerous chains of conidia. From July onwards dark-coloured spore-containing structures called cleistocarps develop. These are formed as a result of fusion between different mating types. Infected cones have a dark red-brown colour owing to the presence of the cleistocarps, hence the alternative name for the disease.

The cleistocarps are resistant structures in which ascospores are able to overwinter. These are released the following spring and are able to infect other hop plants. Infected leaves containing the white conidia are able to infect other parts of the same and other plants via passage of the spores.

Treatment is via removal of the diseased plant material, the use of various fungicides and the development of resistant cultivars.

P

Pre-coat

Pre-coats are layers of filter powder, usually **kieselguhr** or **perlite**, which are pumped into powder filters before addition of rough beer. The operation of adding these layers of filter powder is described as pre-coating. The role of pre-coats is to provide a bridging layer over the filter elements and which therefore prevent particles bleeding through with the first runnings of beer. Commonly multiple layers of pre-coating powder may be used. The first layer is a relatively coarse grade (coarse pre-coat) and subsequent layer(s) comprise finer grades of powder (fine pre-coats). Thus, the first layer bridges the pores in the surface of the filter elements and the second layer provides the first filter layer through which the beer is to be filtered and the initial bed on which body feed powder accumulates. During the pre-coating phase the filter is run in a recirculation mode which allows the pre-coat layer to form and ensures that any powder that passes through the filter is returned.

Preformed soluble nitrogen

Preformed soluble nitrogen is a measure of soluble nitrogen present in malts prior to mashing. It is one of a raft of procedures [see **index of protein modification**, **coefficient of modifica-**

tion, permanently soluble nitrogen (PSN), coagulable nitrogen] that relate to modification, which have now largely fallen out of favour. This measure is the concentration of soluble nitrogen that is obtained when a sample of malt is mashed under conditions in which malt enzymes would not be active, for example, extraction at 0 or 75°C or extraction in the presence of an inhibitor of enzyme activity such as mercuric chloride.

Preformed solubles (preformed sugars)

See cold water extract.

Pre-gelatinised adjuncts

Pre-gelatinised adjuncts are grains or extracts thereof which when manufactured have been subjected to a heat process such that their starch granules are gelatinised. Such adjuncts can be incorporated into mashes without the need for pre-cooking since the starch grains are already in a form in which they are susceptible to attack by malt (or other) hydrolytic enzymes.

Examples of pre-gelatinised adjuncts are flaked or micronised grains of barley, wheat or maize.

Pre-harvest sprouting damage (PHSD)

A condition associated with crops of brewing significance such as barley, wheat, rice and sorghum in which the grains begin to germinate prior to harvest. This premature germination phenomenon occurs, in susceptible cultivars, as a result of high humidity, which can occur when there are periods of prolonged rainfall when the grains have matured but have not been harvested. Visible manifestations are grain swelling within the ear and the emergence of shoot and root. Where this has occurred the harvested grains can be of poor quality and produce malts which are low yielding.

Susceptibility to PHSD and the regulation of dormancy are related. The latter is a genetic property. It is generally desirable in malting varieties of cereals that dormancy levels are low so as to allow malting soon after harvest. A side effect of this is that such cultivars have an increased susceptibility to PHSD should the appropriate climatic conditions (warm and wet conditions) in the interval between maturation and harvest occur.

Pre-germination is triggered in susceptible plants and embryo development is initiated. If the wet conditions do not persist a subsequent dry period can arrest these processes. Such grains bear no outwardly visible signs, although they have a much reduced storage potential. Under persistent wet conditions the germination process continues and pre-harvest sprouting occurs. When harvested the embryos of such grains may be non-viable and therefore may be useless for malting purposes. It is predicted that PHSD may become an increasing problem with respect to climate change.

Several tests have been designed to detect pre-harvest sprouting. Many of these are based on the detection of α -amylase the presence of which is a marker of germination. Rapid tests include the use of fluorescent dyes applied to sectioned grains. A commonly used and simple procedure is the **falling-number test**. The method assesses the viscosity of a suspension of milled grains by placing it into a suitable test tube and measuring the rate at which a plunger is able to pass through it. Since α -amylase decreases viscosity by virtue of starch degradation a more rapid falling number is indicative of PHSD.

Pre-isomerised hop extracts

Hop extracts that contain pretreated isomerised hop α -acids.

See **hop extracts**.

Pre-masher

A pre-masher is an alternative name for a mash hydrator.

See **mash (pre-)hydrator**.

Premature yeast flocculation (PYF)

A phenomenon in which during fermentation yeast flocculates too soon and often to a greater degree than is usual for the particular strain. The result is that worts may fail to attenuate to the usual degree, VDK stand times may be prolonged, green beer yeast counts are lower than usual and yeast crops have a greater consistency (are more concentrated) than usual. High residual sugars in green beers arising from PYF fermentations contain less than expected ethanol concentration and they may be more susceptible to microbial spoilage. The severity of the symptoms can be very variable, ranging from all of the above through to comparatively mild effects such as a small increase in the proportion of cells in yeast crops and slightly lower than usual green beer cell counts. This range of symptoms is suggestive of more than one cause, as discussed later. However, it is clear that any of these effects is undesirable and can carry a substantial financial burden if not identified quickly and dealt with. These effects are all the more serious in that yeast cropped from a PYF fermentation retains the altered phenotype such that similar effects to those described already may also be observed in subsequent fermentations.

PYF is related to malt or the barley from which it was made. Thus, a particular batch of malt can be described as PYF positive. The microbial flora associated with grains has been implicated since the phenomenon can be reduced in severity by washing the surface or by husk removal.

It has been shown that extracts may be purified from PYF malts which have the ability to cause premature flocculation when added to otherwise normal worts. These have been shown to be acidic polysaccharides which are capable of binding to yeast cell walls such that they can contribute to the adhesive forces associated with normal **yeast flocculation**. This effect has been termed the polysaccharide bridging theory. It is assumed that the PYF factors are derived from husk material and formed as a result of the activity on husk of fungal enzymes. Depending on the nature and activity of these enzymes, fractions of various sizes are generated all of which may show PYF activity providing specific groups are present which are capable of interacting with yeast cell walls in developing flocs.

In addition to the polysaccharides other compounds have been implicated in PYF. There is a body of evidence that suggests that when barley is subjected to fungal attack it produces defensive metabolites, small basic peptides, and these have been linked to PYF. These are termed defensins, thionins and non-specific lipid transfer proteins. It has been shown that these can persist into worts and beers where their antimicrobial properties may be exerted against yeast cells and where, for example, they could partially inhibit sugar uptake and therefore produce the effect of high residual extract. The antimicrobial compounds and bridging polysaccharides may operate independently or possibly in concert since in both cases they represent classes of individual compounds; perhaps this serves to explain why it is difficult to provide a single unifying definition and cause of PYF.

The degree of PYF using a PYF-positive malt is influenced by the conditions employed in the brewhouse presumably via those factors which might affect how much PYF factor persists into wort. Yeast strains also differ in susceptibility. In general ale strains tend to be less affected compared to lager types. More flocculent strains appear to be particularly susceptible.

Malts may be assessed for PYF using laboratory scale fermentations where the degree of flocculation is detected using a measure of suspended cell count with respect to time or a related parameter such as light scattering. In addition, the residual gravity may also be monitored.

Premiant

Premiant is a relatively new hop variety bred in the Czech Republic and derived from the Saaz noble hop aimed at bittering or for dual-purpose use. It was registered in 1996. It contains moderately high bitterness levels (7–9% α -acids of which 19–26% is cohumulone and 3–6% is β -acids. Total oils are 1.0–2.0% (7–11% caryophyllene, 0.5–3.0% farnesene, 25–35% humulene, 35–50% myrcene).

Present gravity

A unit of wort concentration equal to the specific gravity measured at 20°C multiplied by 1000 and minus 1000 and expressed in degrees. It is commonly used by UK brewers for the expression of wort concentration during and after fermentation. In order to convert (approximately) present gravity to degree Plato the value should be divided by 4. Thus, wort with a present gravity of 60 is approximately equal to 15°Plato.

Pride of Kent

Pride of Kent is a UK hop variety derived from a cross with **Brewer's Gold**. It is a high alpha variety (8–11% total α -acids of which 27–40% is cohumulone). Total oil content is 1.6–2.5% (3–5% caryophyllene, 0.1%, farnesene, 5–15% humulene, 60–85% myrcene).

It is no longer used commercially but is best known as a parent of the dominant Australian bittering variety **Pride of Ringwood**.

Pride of Ringwood

Pride of Ringwood is a high alpha Australian hop variety. It was released in 1965, at the time one of the highest alpha varieties available and now accounts for the majority of the Australian hop crop. It contains 9–11% total α -acids of which 33% is cohumulone. Total oil content is 2% (5–10% caryophyllene, <0.1%, farnesene, 3–8% humulene, 25–50% myrcene). The hop was bred from a wild Tasmanian variety and the UK cultivar Pride of Kent. It is used as a bittering variety for many Australian lagers.

Primary fermentation

Primary fermentation is the initial and most active phase in which all, or the bulk, of fermentable sugar is utilised by yeast and converted into ethanol, CO₂, more yeast, heat and a multitude of other products of yeast metabolism which are associated with the conversion of wort into green beer.

See **fermentation**.

Primary filtration

The term used to describe the stage in the filtration of beer where the majority of the suspended solids are used. Commonly this will be a powder filter.

See **filtration**.

Priming

Priming refers to the practice of adding sugar to finished beer. This may be simply to adjust sweetness. In the case of beers subjected to a secondary fermentation following transfer to the final package, as is the case for bottle or cask-conditioned beers, the sugar provides a carbon source which is used by the yeast to produce CO₂ (condition) and a small amount of ethanol and associated yeast-derived flavour compounds. No doubt the addition of the sugar as a preliminary to the formation of condition explains the origin of the term.

The sugars used for this purpose are referred to as priming sugars. For sweetening purposes relatively pure preparations of sucrose, maltose, fructose or glucose are usually used. For priming purposes for secondary fermentation similar sugars may be used but would possibly be less pure. In the latter case any non-fermentable impurities will persist in the finished beer. Typically these are provided as solutions with a concentration of 35–40°P and are added at concentrations of 0.3–2.0 L/hL.

Priming sugar

See **priming**.

Proanthocyanidin

Name given to a class of flavan-3-ol polyphenols. In brewing parlance they are often referred to as anthocyanogens.

See **polyphenols**, **colloidal stability**.

Proanthocyanidin-free malt

Varieties of barleys which on malting yield grains that have a substantially reduced content of proanthocyanidins (anthocyanins) which should in theory produce beers with a reduced potential to form colloidal hazes (see **colloidal stability**, **beer hazes**). This would reduce the cost associated with the use of stabilising regimes.

The proanthocyanidin polyphenols, which are potent precursors of beer colloidal hazes, are found in the testa of barley grains. In the 1970s work at the Carlsberg Research Institute sought, via classical plant breeding techniques, to produce malting barley cultivars which contained defective genes in the pathways leading to the formation of proanthocyanidins.

Several such cultivars have been produced and brewing trials have indicated that the predicted benefits have been obtained providing polyphenol-free hop extracts are also used. In the United Kingdom the variety *Clarity* has shown some promise, although little interest from commercial suppliers has resulted. The reasons for the lack of take-up are a result of the unfortunate observation that the majority of the cultivars are relatively low-yielding.

Process water

Name given to water that is actually used as a constituent of beer. In the majority of cases the water requires pretreatments before it is suitable for use (see **water** for more details). Synonyms are production water, brewing water (or liquor).

Water which may be used in the brewing process and therefore form part of the final product may arise from several sources. The bulk derives from that which is used to prepare the initial mash. Further water may be added in the form of **sparge water** where a lauter tun is used for wort production. In some breweries cropped yeast is slurried in or diluted with water. Where **high-gravity brewing** is practised the concentrated beer which arises after fermentation and conditioning must be diluted to the desired sales strength (see **dilution water**).

For each of these applications the water must meet desired specifications. These are likely to be quite different.

See individual entries, as above, and **water** for more details.

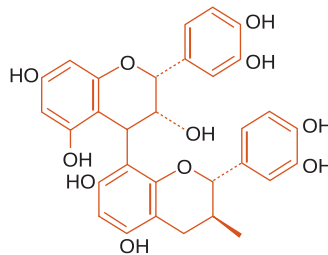
Proctor

Proctor is a variety of barley which was introduced to UK agronomy in 1953 based on its high yields and excellent malting properties. The variety was produced by George Douglas Hutton Bell, an early Director of the Plant Breeding Institute in Cambridge, UK. Proctor, together with Pioneer, was a parent of the more well-known malting barley **Maris Otter**.

Procyanidin B₁

Procyanidin B₁ is a polyphenol of the flavanoid type. It is a dimer of epicatechin and catechin (see structure in the accompanying figure) that is found in cereals such as sorghum. It is of relevance to beer quality in that it is a precursor of beer haze.

See **polyphenols, colloidal stability, beer hazes**.

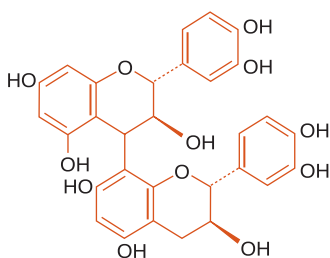


Structure of procyanidin B₁

Procyanidin B₃

Procyanidin B₃ is a polyphenol of the flavanoid type. It is a dimer consisting of two molecules of catechin (see structure in the accompanying figure) that is found in cereals such as barley. It is of relevance to beer quality in that it is a precursor of beer haze.

See **polyphenols, colloidal stability, beer hazes**.

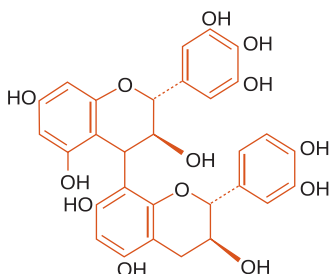


Structure of procyanidin B₃

Prodelphinidin B₃

Prodelphinidin B₃ is a polyphenol of the flavanoid type. It is a dimer consisting of molecules of catechin and gallocatechin (see structure in the accompanying figure) that is found in cereals such as barley. It is of relevance to beer quality in that it is a precursor of beer haze.

See **polyphenols, colloidal stability, beer haze**.



Structure of prodelphinidin B₃

P

Production sterility

Somewhat nonsensical term which describes the condition in which plant or process liquids are rendered microbiologically stable such that spoilage will not occur within the limits set. By implication it does not imply absolute sterility.

Production water

Production water, also known as process water or brewing water (or liquor), is that which is used directly for the production of beer. The precise composition varies with the beer type and may occur naturally or by design.

See **water**.

Product release tank

A synonym for **bright beer tank**.

Profibus

Profibus is a system used in the automation of complex processes. The name is an acronym for Process Field Bus and it was developed in Germany in the late 1980s by a conglomeration of several companies who wished to promote a universal method for the automation of indus-

trial processes. The system is now used widely throughout the world and it has been adopted by several major brewers.

The Profibus approach provides a standard method of communication which links all the individual elements such as actuators and sensors used in an automated process control system. Links to individual devices are made via wireless or fibre optic cables in a common network which provides a high-speed bidirectional capability. The use of a networked system saves costs since it is not necessary to provide communication and control with every individual element.

Detailed information is available at <http://www.profibus.com> (last accessed 11 February 2013).

PROFi membrane system

A diatomaceous-free filtration system for beer. It comprises an integrated high-speed centrifuge and high-efficiency cross-flow filtration system. The system is the result of collaboration between GEA Westfalia Separator GmbH (Oelde, Germany) and PALL Food and Beverage Company (Port Washington, USA). The system is automated for high-speed continuous operation and claims to minimise water and utility consumption. Waste generation is minimised by the use of a single-pass cross-flow filtration system.

Programmable logic controller

See PLC.

Progress

Progress is a UK high alpha hop variety bred in the 1960s as a disease-tolerant substitute for Fuggles. It contains 5–7% total α -acids.

Progressive beer duty

Reduced rates of beer taxation for brewers producing low annual volumes. The development of the **craft brewing** sector has resulted in calls in several countries for differential rates of taxation with a view to making trading conditions easier for brewers with relatively modest volume outputs. In Europe the proposal was initiated by Germany and later endorsed by the EU albeit as a voluntary measure in member countries. Similar arrangements are in place in the United States and in Japan.

Organisations with interests in brewing have suggested that an upper volume limit is set above which all beer is taxed at a standard rate. Production below this threshold value should be taxed progressively using a linear scale. In practice, governments have adopted banded systems where the same rate is charged irrespective of where individual breweries sit with the band.

In the United Kingdom the following discounts apply:

Less than 5000 hL p.a.	50% reduction
5000–30,000 hL pa	33% reduction
30,000–60,000 hL p.a.	4% reduction
>60,000 hL p.a.	Standard rate of excise

Prolamins

Prolamins are proteins that occur on the grains of cereals. Prolamin is the collective term for the protein fraction of cereal grains that can be extracted and solubilised by treatment with hot solutions of aqueous ethanol. Solubilisation is further enhanced by the addition of reducing agents such as 2-mercaptoethanol. Prolamins are the major class of storage protein in cereal grains and, as such, during malting and mashing they form the major source of FAN in worts.

Prolamins from some cereals are named individually:

Cereal	Prolamin
Barley	Hordein
Wheat	Gliadin
Maize	Zein
Oats	Avenin
Rye	Secalin
Sorghum	Kafirin Sorghumin

Prolamins tend to be high in proline and glutamine but low in lysine. In beer the barley prolamins, hordeins, are implicated in foam formation and by virtue of their high proline content in interactions with polyphenols to form temporary and permanent hazes.

The prolamins of some cereals, notable wheat gliadins, are implicated in eliciting the symptoms of coeliac disease in those who are genetically predisposed to this condition. See **coeliac disease**.

Prominant

A variety of proanthocyanidin-free barley.

Promitochondria

Name given to the undifferentiated mitochondria that occur in brewing yeast growing under repressed conditions.

See **yeast cytology**.

Propagation

See **yeast propagation**.

Propargite

Propargite (2-(4-tert-butylphenoxy)cyclohexylprop-2-yne-1-sulphonate) is a pesticide which is used as a treatment for mite infestations. It is one of the treatments that can be used for red spider mite infections of hop plants.

Propidium iodide

A fluorescent biological dye that is used as an indicator of yeast viability by the selective staining of dead cells. It is excluded from viable cells but enters those that lack an integral mem-

brane where it binds to DNA and RNA. Excitation with radiation with a wavelength of around 490 nm produces a red fluorescence.

See **yeast viability**.

Propylene glycol

Propylene glycol (1,2-propane diol, propane-1,2-diol; HO-CH₂-CHOH-CH₃) is a colourless, slightly sweet-tasting, slightly viscous liquid used extensively as a solvent or emulsifier in foodstuffs and pharmaceutical preparations. In brewing it is widely used as a secondary coolant. It is miscible with water and in mixtures with the latter acts as an anti-freeze. The freezing point depends upon the proportion of propylene glycol in the mixture (−3°C, 10% v/v; −7°C, 20% v/v; −12°C, 30% v/v; −20°C, 40% v/v). For brewing purposes concentrations in the range 30–60% v/v propylene glycol are used.

It is effectively non-toxic compared to ethylene glycol and for this reason its use as a coolant is preferable where there is a chance of accidental contamination of foodstuffs. Nevertheless, the material should be treated as toxic and precautions should be taken to ensure that leakage into product cannot occur, for example, by ensuring that pressures on the product side of coolers are higher than those on the coolant side.

It is less efficient as a coolant compared to ethanol [industrial methylated spirit (IMS)] because heat transfer in the case of the latter is improved because of the lower viscosity.

Propylene glycol is not entirely stable and in time will degrade to give acidic products, notably lactic acid. These materials can cause corrosion of metals which if unchecked can lead to catastrophic failures. For this reason it is usual to include corrosion inhibitors. It should be noted that superficially inexpensive sources of coolants may owe their low cost by omitting to add these ingredients.

Propylene glycol alginate

Compound used as a beer foam stabiliser. It is a permitted additive sold under trade names such as *Stabilfoam*. It is dissolved in hot water with vigorous agitation then after cooling dosed into bright beer, immediately before filtration. The large molecule bears carbonyl groups and these form electrostatic interactions with amino groups in the polypeptides in the bubble walls of the foam. These interactions stabilise the foam. Care must be exercised since overdosing may result in precipitation of foam polypeptides, leading to haze formation.

Protafloc™

Protafloc is a commercial preparation of partially refined carrageenan supplied in tablet form and used as a kettle fining agent.

See **kettle finings**, **κ-carrageenan**.

Proteases

Proteases (also termed proteinases) are hydrolase enzymes that catalyse the hydrolysis of peptide bonds of the **polypeptide** chains which together form **proteins**. They occur in all living cells where they are responsible for catalysing those reactions involved in protein catabolism and turnover. Since some of the protein substrates may also be **enzymes**, the action

of proteases may have regulatory significance. Extracellular proteases may be excreted by some cells as a mechanism for generating smaller assimilable nitrogenous nutrients.

Proteases perform several roles in brewing, some desirable and others less so. Their primary importance is in the mashing stage of brewing where they break down proteins to produce the soluble amino nitrogen fraction of worts. In an all-malt wort proteases, together with their protein substrates, are provided by malt grains. In order to obtain desired concentrations of amino acids in wort the malt must contain sufficient active enzymes and an appropriate concentration of protein. Mashing conditions, particularly duration and temperature, must be regulated in order to ensure that protease activity is controlled such that the desired concentration of **free amino nitrogen (FAN)** is generated. The concerted action of many proteolytic enzymes is involved in mashing. Briggs *et al.* [Briggs, D.E., Boulton, C.A., Brookes, P.A. & Stevens, R. (2004) *Brewing Science and Practice*, pp. 142–146, Woodhead Publishing, Cambridge, UK] describe the detection in malt of 42 soluble endopeptidases, 4–5 aminopeptidases and 4 carboxypeptidases. The majority have acidic pH optima and are thiol dependent. In mashing the combination of carboxypeptidases and endoproteases is considered to be responsible for the formation of the bulk of wort soluble nitrogen components with the latter being rate determining.

Proteases derived from various plant sources may be used as process aids, typically for the prevention of beer hazes (see **bromelain**, **ficin** and **papain**). Where brewing conditions result in the contact of beer and yeast which has a compromised physiology, yeast protease may be released via autolysis. These enzymes may utilise beer proteins with a consequent reduction of beer foaming ability. This problem is exacerbated where small-pack beers are cold sterile-filtered as opposed to pasteurised. In this situation active yeast proteases may persist into packaged beer free to exert deleterious effects over a long time period.

Proteases are a diverse group of enzymes. They are classified mechanistically based on manner in which the reaction proceeds. Alternatively they are classified based on the way in which protein substrate molecules are degraded. The former system recognises six groups of protease (aspartic, cysteine, glutamic, metalloproteases, serine and threonine). The latter system, based on the site of cleavage, divides proteases into **endopeptidases** (those which attack polypeptides at various locations along amino acid chains) and **exo-peptidases** (those which attack at the chain ends of polypeptides). The latter are described as **aminopeptidases**, which attack the chains from the amino terminus, and **carboxypeptidases**, which exert their effects from the carboxyl terminus of polypeptide chains.

Protein

Proteins are biological macromolecules which are ubiquitous in living organisms. Proteins and nucleotides form the predominant nitrogen-containing molecules in all cells. Typically proteins account for 50%, or more, of the total cellular dry weight. The ubiquity of proteins in living organisms coupled with their ability to occupy both structural and functional roles, the latter as enzymes, the biological catalysts that underpin metabolism, means that they have far-reaching effects on brewing raw materials, the brewing process and beer quality.

Malts and other brewing raw materials are the sources of proteins and their constituent parts that arise in worts. Using malts and the barleys that they are derived from with an

appropriate protein content is an essential precursor to brewing. The preformed enzymes in malts, together with other sources of enzymes from other raw materials and, where permitted, those added directly as process aids, are responsible for the reactions which during mashing result in the formation of fermentable sugars and the multitude of other biochemicals that arise in worts and beers.

The catabolism of proteins from malts and other raw materials that occurs during mashing produces a range of simpler nitrogen-containing molecules including amino acids, polypeptides and short peptides. These are used to support growth of yeast during fermentation. An essential part of the brewing process is to ensure that worts have an appropriate concentration of protein, protein-degradation products and enzymes. These are governed by the malts and other raw goods used in the grist and the conditions employed during wort production.

Proteins and polypeptides that persist in beer after fermentation is completed have both positive and negative attributes. Desirable properties include contribution to beer body and mouthfeel. In addition, they are important in the formation of beer foam. During boiling, **Maillard reactions** between sugars and amino compounds, including amino acids, produce coloured and flavour-active products which contribute to beer properties. Undesirable properties are related to the ability of beer proteins to react with polyphenols and form a **temporary haze** and a **permanent haze**.

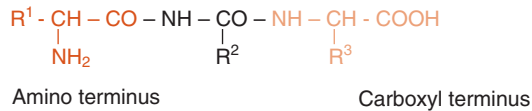
The importance to beer and brewing of proteins and their constituent parts is reflected by the fact that a multitude of measures are available for their quantification in brewing raw materials and beers.

The chemistry of proteins is complex and here it is possible to provide only an overview. For more detailed information mainstream biochemistry texts should be consulted.

Proteins are polymers of **amino acids** with molecular sizes ranging from approximately 10,000 to 10,000,000. All contain carbon, nitrogen, hydrogen and oxygen. Most proteins contain sulphur. In some proteins additional elements may be present such as phosphorus, and metals such as iron, zinc and copper. In living organisms they have structural, storage and functional roles. Functional proteins, or **enzymes**, are a class of proteins that are capable of acting as biological catalysts and in so doing speed up rates of chemical reactions, many hundredfold, over that which would occur in their absence.

Some 20 different amino commonly occur in proteins. A few more are found more rarely. Proteins are the direct product of the transcription of the genetic code. Each triplet within the DNA genome codes for a specific amino acid. Reading of the genetic code results in individual amino acids being assembled into proteins. These proteins, termed the proteome, via their action as enzymes are responsible for catalyzing the multitude of reactions which collectively underpin metabolism. The particular sequence of amino acids found in proteins has a profound effect on their structure and function.

The structures of protein molecules are complex. They are described in levels of hierarchical complexity termed primary, secondary, tertiary and quaternary structures. The primary structure describes the arrangement and order of amino acids that together form polypeptide chains. Individual amino acids possess both terminal amino and carboxyl groups both of which are attached to the α -carbon of the molecule. Covalent peptide bonds between these amino and carboxyl groups link individual amino acids to form peptides.



Generalised structure of a tripeptide made up of three amino acid residues joined by peptide bonds

Individual polypeptide chains may be arranged together in ordered single-dimensional structures, for example, helical coils or pleated sheets. In the case of helices, the α -type is the most common in which there are 3.6 amino acid residues per turn of the helix. The helix is stabilised by hydrogen bonds between amino and carbonyl groups that are adjacent to each other within the spiral helix. This next level of organisation is the secondary structure. The tertiary structure refers to the ability of polypeptide chains to bend and fold and so form complex three-dimensional shapes. Finally, some proteins have a quaternary structure in which individual polypeptide chains are arranged into associations. In this case the individual component polypeptides are usually referred to as subunits and such proteins are termed polymeric. The secondary, tertiary and quaternary structures involve a number of different types of bonding other than covalent types. These include disulphide bonds, hydrogen bonds, van der Waals forces, hydrostatic salt bridges and hydrophobic interactions. Typically, covalent bonds are not involved in quaternary interactions. The combination of secondary, tertiary and quaternary structures are often referred to as the conformation of the protein. The typical form of this is termed the native structure. Proteins that take the form of sheets are termed fibrous. Typically they have structural roles. Those which adopt a more tightly folded spherical form are termed **globulins**. Many proteins can bind to other biochemicals such as sugars (glycoproteins) and lipids (lipoproteins).

P

In the case of enzymes the higher organisation of the protein molecule introduces a functional element. Particular parts of enzymes, termed active sites, provide an environment in which the reactant, termed the substrate, can bind. In the bound form the activation energy of the reaction catalyzed by the enzyme is reduced and, hence, an increase in reaction rate compared to that which would be the case in the absence of enzyme is favoured. Molecules such as cofactors which either promote or inhibit enzyme activity exert their effects by changing the structure of the active site. This is termed a conformational change. Protein structure is affected by the physical environment. Changes in parameters such as temperature and pH may result in structural changes in protein molecules. These may be permanent changes and are termed **denaturation**. For many proteins denaturation results in loss of solubility and precipitates are formed. In the case of enzymes denaturation is associated with an irreversible loss of activity. These effects explain why conditions in steps such as mashing have to be controlled to ensure that conditions such as temperature and pH are appropriate to ensure that the activity of desirable enzymes is conserved. In addition, it explains how during wort boiling unwanted protein is removed with **trub** via the process of coagulation.

See

Albumin

Amino acids

Chill haze

Enzyme
Formol nitrogen
Free amino nitrogen (FAN)
Globulins
Gluten
Glutelins
Hordein
Kolbach index
Lectins
Maillard reaction
Nitrogen
Permanent haze
Permanently soluble nitrogen (PSN)
Prolamins
Proteases
Sensitive proteins
Soluble nitrogen ratio
Total soluble nitrogen (TSN).

Proteinase

See **proteases**.

Protein stand

The protein stand refers to a stage in temperature-programmed mashing in which the conditions, principally a relatively cool temperature, are controlled such that the activities of proteases are favoured. It has been shown that based on the concentration of PSN in wort maximum levels arise using a mashing temperature of approximately 55–60°C. The effect is not simple since the temperature optimum decreases with the duration of the stand.

See **decoction mashing, mashing**.

Protein Z

Protein Z is a protein with a high lysine content that is widely distributed in plant and animal tissues. In cereals such as barley it is a major albumin protein typically occurring at concentrations of 1–3 mg/g of the dry weight of grains. It is highly resistant to denaturation and proteolysis. These properties mean that it is one of the few proteins to survive the brewing process more or less intact, and consequently it comprises 10–25% of the total non-dialysable protein content of beer. In concentration terms protein Z occurs in beers at concentrations of the order of 20–200 mg/L. Thus, protein Z is an important contributor to beer foam and to a lesser extent as a precursor of hazes.

Protein Z is a **serpin** (serine protease inhibitor) and presumably this describes its function *in vivo*. In other words it is implicated in the control of protein synthesis, accumulation and degradation in barley and other cereal grains. In barley grains protein Z is linked via disulphide bonds to the starch degrading enzyme β -amylase. The major antigen in beer (**antigen I**) appears to derive from protein Z. Thus, both have the same molecular weight, have similar

amino acid composition and cross react with the same antibody. However, antigen I contains approximately 2.5% carbohydrate, which is not found in protein Z. In addition, antigen I contains some 16% fewer lysine residues than protein Z.

Protein Z consists of two distinct isoforms, termed Z4 and Z7, although others may also exist. The numeral refers to the chromosome on which the gene coding for the isoform resides. The major component is Z4, accounting for some 80% of the total. It has been shown that levels of the Z4 fraction present in malts correlate positively with the head retention but not with the foam-generating properties of beers made from them.

The immunological properties of protein Z is of medical significance in a small number of humans. In the relatively small population sensitivity to beer serpins is the cause of an allergic reaction.

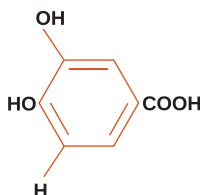
Proteolytic enzyme

See **proteases**.

Protocatechuic acid

A simple phenolic compound, one of the series of substituted benzoic acid derivatives, which is found in worts (see the accompanying diagram for structure). Concentrations in an unboiled lager wort are reported to be of the order of 0.5 mg/L.

See **polyphenols**, **tannic acid**.



Structure of protocatechuic acid

Prunus necrotic ringspot virus

A virus which infects many species of the genus *Prunus* but which can also produce diseases in hops, presumably being transmitted via insect vectors such as the **damson-hop aphid**. In some cases the symptoms of infected plants are the appearance of yellow-green rings and spots on leaves. In other cases the death of plant tissues occurs and in severe cases losses in hop yield of up to 30% may occur. Leaves showing these effects become small, downward twisted and distorted in shape. The tissue surrounding veins become brown and necrotic and the surrounding areas continue to grow and assume a wrinkled appearance. These more serious effects are described collectively as necrotic crinkle mosaic disease.

Pseudo-haze

A synonym for **invisible haze**.

Ptyalin

A trivial name given to an α -amylase which occurs in human saliva. It has relevance to brewing in that the production of many native beers includes a stage in which sources of extract that contain starches are first chewed before spitting out the macerated product into the fermentation vessel. Presumably in times past the producers of the beverage, often the female members of the society, had learnt by experience that this process resulted in a more alcoholic end product.

See **native African beers**.

Pullulanase

Pullulanase (pullulan 6-glucanohydrolase; EC 3.2.1.41) is an enzyme which is capable of hydrolyzing α -(1,6) glucosidic bonds in molecules which contain at least two α -(1,4) bonds. The substrate after which the enzyme is named, pullulan, is a polysaccharide which consists of maltotriosyl residues linked by α -(1,6) glucosidic bonds. The enzymes also show activity against α -(1,6) glucosidic branch points in amylopectin and amylose components of starches (see **limit dextrinase** and **starch** for further details). Preparations of pullulanases derived from various microorganisms are available commercially. Where permitted these may be used during the mashing phase of wort production or in fermentation to increase wort fermentability. This results in an increase in the yield of ethanol with a concomitant decrease in residual dextrin content of beer. This approach may be used to increase beer yields and is of particular value in the formation of low carbohydrate 'lite' products. It must be used prudently for the production of more normal beers since the reduced dextrin content results in a consequent lowering of fullness and mouthfeel.

Pulp filter

Pulp filters, also called disc filters, were originally designed by the German Lorenz Adelbert Enzinger and were introduced for the primary filtration of beer in the early 1900s. They were used widely in the brewing industry but largely based on safety concerns over the choice of filtration medium have now been largely replaced by powder filters.

Pulp filters use a mixture of cellulose and asbestos pressed and made into thick discs as the filtration medium. The discs were mounted into circular frames which supported the filter cake and provided channels for entry of the rough beer and removal of bright product. The frames could be located vertically or horizontally. Multiple filter discs were held together and made watertight by a screw compression arrangement. As with plate and frame-type filters, the capacity of the filter is governed by the surface area and the number of discs used. Commonly two filters were used in a serial arrangement, the first for a preliminary rough filtration and the second for polishing. After completion of a run the polishing filter would be reused as the first rough filtration stage in the subsequent run.

In vertical types, which were commonly used in the United States where they were called pack filters, the discs are located within a cylinder. The beer is pumped upwards through a gap between the cylinder wall and the individual filter discs. From here it passes through the discs and the clarified beer is collected via a central channel.

The cake, or pulp, was made up of a mixture of cellulose mixed with about 1% of asbestos fibres. The latter was prized for its ability to act as a strong adsorbent.

Pulp cakes were formed by preparing an appropriate mixture of cellulose and asbestos and packing this onto the supporting sheets. The latter was formed by compressing the filter. After use the discs are washed, after which they could be reused. This might be a manual operation but in larger breweries was achieved with automatic washers. These were large tanks fitted with a means of agitation and a sieve which allowed dirty cleaning fluid to be discharged whilst retaining the fibres. After washing in cold water the pulp was sterilised with hot water, possibly a rinse with sodium hypochlorite to bleach the pulp and finally another rinse with cold water.

Understandably health concerns regarding asbestos handling were a paramount cause of the falling from favour of this type of filter.

Pulque

A native beer produced in Mexico and made from the fermentation of the sap of the agave plant, in particular the maguey or century plant (*Agave americana*). The drink is opaque and white and for this reason is also called octli (white). The drink has a long history and was originally used in sacred rites. This restricted use gave way to more general consumption, and the beverage was produced in Mexico on a commercial basis and sold in outlets called *pulqueria*. Latterly Western influence made standard beers popular and pulque production declined; however, it remains popular in rural areas.

PU monitor

See **Redpost**.

Pump clip

A badge which attaches to the handle used to dispense draught cask ales. The clip faces the customer and provides information regarding the brewer, brand name and usually additional information such as alcoholic strength and possibly a description of the brand.

Puncheon

A measure of beer equivalent to 72 imperial gallons (327.68 L), also in a historical sense the name of the coopered wooden staved and metal hooped container designed to hold this volume of liquid. The name probably derives from the same Latin root as punch, as in a tool used to impress designs by hammering. In this case, the impressed marks described the contents of the cask. For example, the fifteenth century Middle French *poinçon*, describing a mark which certifies the contents of goods.

Purl

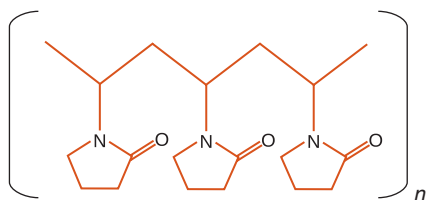
A beverage of eighteenth century England comprising ale flavoured with aromatic herbs, in particular wormwood, taken as a tonic. In later years it came to mean a heated mixture of beer, gin, sugar and spices.

PVPP

PVPP is a beer stabilising agent which is used to remove potentially haze-forming polyphenols from beer. It is the most widely used beer stabilising agent and is often used in conjunction with silica gel for the removal of both polyphenol and proteins. PVPP is a synthetic polymer

which is insoluble in water and ethanol and which provides a very large surface area for binding to polyphenols.

The structure of the repeating unit is similar to that of proline, the amino acid which is considered to be an important constituent of the proteins of worts and beers which are known to be involved in the formation of colloidal hazes (see the accompanying diagram and **colloidal stability** for more details). This similarity is presumed to be the underlying reason as to why this molecule is a very effective beer stabilisation agent.



Structure of PVPP

PVPP is supplied in a number of different grades and these reflect the different ways in which it can be used. It can be added to maturation tank or dosed in-line in beer as it is transferred to filtration. In these instances the PVPP is discarded after use, either as part of the sediment in maturation tanks or with the waste powder when the filter is discharged. In both of these cases a relatively fine grade of powder is used, which provides a large surface area for adsorption of protein. Addition rates are of the order of 10–30 g/hL of beer and a contact time of approximately 10 minutes is used. Alternatively, beer can be treated with PVPP in a dedicated filter, usually a candle or horizontal leaf type. The filter is used as for a powder type in which the PVPP is used as both pre-coat and body-feed. For this application a coarser grade of powder is used. PVPP filters are used in addition to conventional powder filters and are placed before the latter. This provides flexibility such that only those beers which require prolonged shelf lives and in consequence extensive stabilisation, as might be the case with a small-pack export type, need to be given the PVPP treatment. Aside from flexibility the major advantage of PVPP filters is that the polymer can be regenerated by treatment with caustic soda, hot water and dilute acid.

PVP-silica

PVP-silica is a beer stabilisation agent which comprises a composite of silica gel and polyvinylpyrrolidone and is capable of removing haze-forming polyphenols from beers.

See **PVPP, colloidal stability**.

Pycnometer

A pycnometer is a device used for measuring the density of liquids. It is also known as a **density bottle** or a **gravity bottle**. It takes the form of a glass bottle fitted with a close-fitting ground glass stopper. In use the bottle is weighed empty, when filled with distilled water and when filled with the test liquid. By subtraction the weight of water and that of the test liquid can be calculated and the ratio of these gives the specific density at the temperature at which

the measurements were made. In order to ensure that the bottle is brimful before weighing the stopper is fitted with a capillary tube such that excess liquid can be carefully removed with absorbent tissue prior to weighing.

The precision of the measurement is limited by the accuracy of the balance. Typically those capable of weighing to four or five places of decimals are used. When performed correctly the method has reference status. In practice a considerable degree of skill is required to ensure accuracy, which few now seem to possess. No doubt this explains why easier to use, but much more expensive devices, such as density meters, have superseded the humble gravity bottle.

Pyrodextrins

See **torrefied grains**.

Pyrolysis mass spectrometry

Method for the rapid identification of microbial species based on spectrometric analysis of the volatile products of thermal degradation of biomass from a pure culture.

See **yeast differentiation**.

Python

A system used in multi-brand beer **dispense** and designed to minimise pickup of heat between the cellar/cold room and the tap. The python consists of a bundle of tubes through which the beer is passed, together with additional tubes which carry a coolant, the whole bundle being surrounded by a suitable layer of insulation. Depending on the draught beer configuration, python runs can range from 1 m to *ca.* 25 m or significantly longer. Beer lines are cellophane wrapped in a bundle, jacketed with insulation and covered with polyvinyl chloride (PVC) tape. The insulation is typically a closed cell, elastomeric nitrile, flexible foam of thickness of 13 or 19 mm. Under conditions of high ambient temperatures and humidity, the insulation thickness can be up to 32 mm. Depending on the brand specification for **dispense** temperature the product enters the python directly (e.g., standard ales) or with lagers, is cooled by 'dipping' via a product coil immersed in cold water or **glycol** in a **remote beer cooler** in the cellar. On transfer to the tap, the **dispense** lines in the python are cooled by circulating cold water or glycol to/from the **remote beer cooler** via wide bore tubing (e.g., 11.5 mm id/15 mm od). The number of dispense lines in a python, clustered around the cooling lines, varies but typically can be 4, 8, 10, 14, 16 or, occasionally, more.

Q

QATS

Shorthand term for the group of disinfectants, **quaternary ammonium compounds**.

Quartering iron

Quartering irons are used for sorting and obtaining representative samples of grains. They consist of two metal bars, each 900 mm in length and 30 mm in height. The two bars are joined in the middle at right angles. Grains are piled into a conical-shaped pile and using the quartering irons divided into four equal parts. Alternate piles are combined and the quartering exercise repeated until a sample that is representative of the whole is obtained. The procedure is sometimes referred to as coning and quartering.

Quassia

A substance used (illegally) in the United Kingdom in the eighteenth and nineteenth centuries as a beer adulterant and substitute for hops. The name describes preparations made from the heartwood of the Brazilian shrub *Quassia amara*. The latter contains a triterpene lactone, known as quassin, which is extremely bitter.

Quaternary ammonium compounds

Cationic **surfactants** with wetting activity and biocidal properties used in soak baths and as surface cleaners. They are salts of quaternary ammonium cations with the general formula NR_4^+ , where the anion is a halide, sulphate or acetate. Biocidal activity, which acts via disruption of biological membranes, is conferred by the presence of a long alkyl or aryl group (C_8H_{17} – $C_{18}H_{37}$). Their surfactant activity makes them prone to foaming and so they are not of use in CIP systems. They show poor activity against Gram-negative bacteria and they can be a cause of ‘fishy’ taints. For these reasons their use is declining.

Quebec beer drinkers’ cardiomyopathy

See **Arsenic-beer drinkers’ disease**.



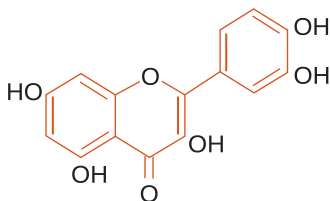
Quench

Quench is a spring variety of malting barley. It was awarded the **National Institute of Agricultural Botany (NIAB)** Cereals Cup in 2009 based on its combination of excellent field characteristics and malting properties.

Quercetin

A flavonol polyphenol found in beer and derived from hops where it usually occurs as a glycoside (see accompanying diagram for the structure).

See **polyphenols**.



Structure of quercetin

Quinoa

Quinoa (*Chenopodium quinoa*, *Chenopodium nuttalliae*) is a plant that derives from South America where it has long been cultivated for its edible seeds. It is classified as a pseudo-cereal. The grains are gluten free and the surface layers contain appreciable concentrations of bitter-tasting saponins.

The grains can be malted. The starch grains are small and have a low gelatinisation temperature. Some experimentation in the use of malted quinoa grains as brewing adjuncts has been made. The saponins have antibacterial properties and can serve as alternatives to hops. Beers made entirely from malted quinoa grains would have the benefit of being gluten free.

R

RABIT yeast vitality test

Rapid automated bacterial impedance technique (RABIT) is used in several tests aimed at the rapid detection of microorganisms, usually bacteria, based on measuring changes in conductance due to accumulation of CO₂ in a KOH/agar bridge. Samples are placed in glass tubes the base of which comprises the electrode detection system. Multiple samples can be used and the results are recorded using a dedicated computer. Unlike the typical microbial detection methods here the system is provided with a yeast inoculum, and it has been claimed when used this way that the technique can be used to assess yeast physiological condition.

Race cask ventilator

A device that is designed to replace both soft and hard spiles in the stillaging of cask beers. It comprises a double plastic housing containing a system of valves that prevents ingress of air except when beer is being dispensed. It is fitted after secondary fermentation is completed. The valving allows egress of some carbon dioxide from the cask but retains enough to ensure a slight overpressure. The exclusion of air extends the shelf life of cask beers by several days. The device can be used in both conventional horizontal and **vertical stillages**.

Rachilla

Name given to a basal bristle found at the base of the stalk where the grain is attached to the stem.

See **barley grain**.

Racking

Term used to describe the process of moving a batch of beer from one tank to another. Typically it describes moving the product from one stage to the next, for example, from the primary fermenter to a conditioning tank.

Racking gravity

Term used to describe the measured value for wort density, expressed as **specific gravity**, **present gravity** or **degree Plato** at which the primary fermentation is considered to be

completed and by inference the point at which the green beer can be transferred (racked) to the next stage of processing. In the case of a fully attenuated wort this corresponds to the point at which all the fermentable sugar has been assimilated by the brewing yeast. Alternatively, where some fermentable residue is required it equates to the wort density at which the fermentation is arrested by, for example, the application of chilling, to encourage separation of yeast from green beer.

Racking tank

A term principally associated with UK ale brewing. It describes a vessel that beer issuing from primary fermentation is transferred into prior to it being dispensed into a cask. Use of the racking tank allows an opportunity for some solids removal and to make adjustments to fermentability and yeast concentration.

Radiometer haze meter

A beer haze meter based on the measurement of light scattering at 90° using incident light with a wavelength of 514 nm.

Radlermass

Radlermass is the German equivalent of **shandy**. It is made from a mixture of lemonade and usually a pilsener-type pale lager beer. Commonly it is sold in cans or bottles pre-mixed. The name derives from the German for cyclist and litre and fulfils the perceived need of such individuals for a refreshing but low-alcohol drink. The name *Radlermass* is associated with Bavaria where it was apparently developed in an act of serendipity when a large rally of cyclists required their thirsts quenched with beer. In order to avoid a stock-out situation an enterprising Bavarian diluted the beer with some difficult to sell lemonade and a new beer style was invented.

A similar beverage is sold in Northern Germany and called *Alsterwasser*, named in homage to the waters of the river which flows through Hamburg.

R

Ragi

Name given to a starter culture made from rice and which contains mixtures of moulds, yeast and bacteria and used in the production of alcoholic glutinous rice-based beverages in Indonesia. The culture is sold in the form of small cakes. Similar products are used in other Asian countries, for example, *look-pang* (Thailand) and *chiu-yueh* (China).

See **tapé ketan**.

Rainier uni-tank

A dual-purpose fermentation and conditioning vessel designed by the Rainier Brewing Company of Seattle, USA. The vessels were introduced during the 1960s in response to a perceived need for low-cost high-capacity vessels for use in a fermentation and conditioning process that provided relatively short cycle times.

The vessels were cylindrical, with an aspect ratio of 1:1 and constructed from an arrangement of welded stainless steel plates. The total capacity was 5500 hL. The base of the vessel took the form of a shallow cone where the included angle was 12.5°. Attenuation was

achieved using liquid ammonia as the coolant via a wall-mounted jacket located towards the top of the straight sides of the vessel. A layer of polyurethane foam some 15 cm in thickness provided insulation and this was located beneath an outer weatherproof aluminium skin.

Filling of the vessel required 10 batches of wort leaving a freeboard of 13% of the total capacity. Primary fermentation was conducted at 13°C for a period of 3–4 days. After a further 2–3 days' warm diacetyl rest the yeast crop was removed from the shallow cone and the green beer was cooled to -1.7°C. This required 6 days and during this time mixing and cooling was assisted by injecting a vertical flow of CO₂ via a bottom-located ring placed at the base of the vessel. After the cold-conditioning phase the green beer was transferred for further processing and the tanks cleaned via an automatic cleaning in place (CIP) system.

Raka Ray medium

Microbiological medium selective for the cultivation of lactic acid bacteria and recommended by the European Brewing Convention (EBC) and American Society of Brewing Chemists (ASBC) methods manuals. It contains maltose, tryptone, fructose, glucose, yeast extract, potassium aspartate, potassium glutamate, betaine hydrochloride, diammonium hydrogen citrate, magnesium sulphate, potassium phosphate, liver extract, N-acetylglucosamine, cycloheximide, phenylethanol and sorbitan monooleate. The complex composition reflects the fastidious requirements of these organisms. The mixture of sugars serves to support those organisms that cannot utilise maltose. 2-Phenylethanol and cycloheximide inhibit the growth of Gram-negative bacteria and yeast, respectively. Other additions are made by some, for example, vancomycin (inhibitor of non-beer spoilage Gram-positive bacteria) and isohumulone (increases selectivity for beer-spoiling lactic acid bacteria). The medium is solidified by the addition of agar and plates are incubated under anaerobic conditions.

Rakes

Rakes are components of lauter tuns. They comprise a series of knives which are attached to a rotating beam and are used to raise and loosen the grain bed during lautering.

See **lauter tun**.

Rapid

See **Valtický**.

Rapid microbiological methods

Classical microbiological methods are too slow to provide real-time data in support of modern brewing operations where there is a desire to minimise stockholding and release products to trade as quickly as possible both in the interests of economy and product freshness. In this situation it is necessary and sensible to ensure that robust quality assurance systems underpin all operations. Nevertheless, the risks of spoilage are such that there remains a very real role for the generation of routine QC data via classical microbiological analyses since they confirm the fitness for purpose of brewery processes. However, the results can only be of historical value. Where products are rendered microbiologically stable via a pasteurisation process the risks are acceptable. In the interests of product freshness many brewers are opting for cold sterile fill of small-pack beers. Since this removes the security blanket of pasteurisation there

is a commensurate increase in the level risk. These developments, with others, such as reductions in hop usage, production of low- and zero-alcohol beers, more regulatory requirements and the obvious need for early detection of problems so that costly re-working can be avoided, have all provided the impetus for the development of rapid methods of microbial analysis. Coupled with these developments is the need to manage costs, in particular, those relating to the size of the workforce.

In many breweries there has been a reduction in staff numbers skilled in classical microbiological techniques and the laboratory infrastructure necessary for their support. The result has been the almost universal use of commercial media and test kits which provide excellent and necessary reproducibility and do not require the same levels of skill. The logical development is the provision of an apparatus which performs microbiological analyses automatically, logs the results and inputs these directly into brewery quality management systems. Of course, this approach still requires the collection of samples and some degree of manual processing. More timely results and faster response times can be obtained if the testing equipment is located online. Such equipment is costly and tends to be the preserve of industries such as pharmaceuticals where product value is much higher than beer and the risks of failure are perhaps more severe. However, costs continue to fall and the severe financial consequences of a product recall from a very large high-speed packaging line mean that automatic online sampling and testing equipment is now beginning to appear.

Two approaches are possible. The first offers two possibilities. In both it is necessary to have growth or metabolic activity. The result of these activities can be detected, either directly via analysis of the microbial biomass or indirectly via detection of the consequences of microbial metabolism. Secondly, individual cells can be recovered and subjected to direct analysis in order to determine precise identity.

Problems with rapid microbiological techniques, apart from the generally relatively long generation times, are that contaminants may be present in very low numbers and in some cases in the presence of very large numbers of culture yeast. The use of differential media which prevent the growth of some groups of microorganisms but allow the growth of others is described in **microbiological media**. With regard to very small numbers it is necessary either to employ a preliminary enrichment step or to use a direct method which is highly sensitive.

Enrichment procedures can take the form of a pre-culture step the duration of which inversely correlates with the concept of rapid. By way of example a sensitive test which might produce a tentative result in a few hours could require 24 hours to give a result if a pre-growth enrichment is used. This approach may take the form of a **forcing test** where packaged beer is incubated at a warm temperature to promote rapid growth. This may be undertaken to allow testing of samples of a batch of sensitive products whilst the bulk is held in the warehouse. A negative result allows release to trade. Alternatively, samples of beers, or other process liquids, may be mixed with a suitable nutrient medium and incubated. On solid media the presence of micro-colonies may be generated within 12–24 hours and used as a source of biomass for subsequent analysis. Using filterable media such as bright beer it is possible to enrich by simple filtration. A sample of beer is passed through a membrane filter, typically with a pore size of 0.45 μm , and any cells retained on the surface can be analysed. The volume of beer filtered increases the detection limit. Organisms can be visualised *in situ* on the membrane usually

stained with fluorescent vital stains [see **yeast viability**, **direct epifluorescence filter technique (DEFT)**]. This approach can also be used as a preliminary to an enrichment procedure. Many suppliers of microbiological media and associated items provide bespoke solid media which are designed for use with membranes loaded with potential contaminants (see **nutrient pads**).

Indirect methods for detecting microbial activity include indirect detection of growth using **turbidometry**, microcalorimetry, impedimetry and **ATP bioluminescence**.

The majority of modern and sensitive detection methods are based on genetic analyses. The techniques based on the **polymerase chain reaction (PCR)** allow very small quantities of genetic material, perhaps from a single cell, to be amplified in a matter of a few hours to provide sufficient material for identification at the strain level. Since these operations can be carried out automatically the reluctance of many brewers to become involved in the complexities of genetic analyses is overcome, albeit at a considerable cost. Already results can be obtained within a few hours of sampling; as the precision of the techniques improves and take-up becomes more widespread it seems inevitable that these will be the primary tools used for microbial assurance in large-scale commercial brewing operations.

Rauchbier

Rauchbier, literally smoked beer, is a speciality beer produced in Germany using malted barley in which the kilning stage is carried out using an open fire. The drying process, which typically uses beechwood chips, imparts a smoky character to the malt. Some of this character is carried over into the finished beer.

Rauchbier is produced in Bamberg, a German town located in Bavaria. The town boasts several breweries. One of the most well-known smoked beers is Aecht Schlenkerna Rauchbier produced by the Brauerei Heller. Three varieties, *Urbock* (a dark bottled or draught beer with 6.5% abv and a bitterness of 40 EBU), *Märzen* (a dark draught beer produced by top fermentation, with 5.1% abv and a bitterness of 30 EBU) and a wheat beer (unfiltered bottle-fermented dark beer with 5.2% abv and a bitterness of 20 EBU), are produced.

Rauschmalz

Rauschmalz is German for 'smoked malt'. It is the malt associated with the German town of Bamberg, renowned for the production of *Rauschbier*, or smoked beer. The malt is kilned over an open fire of beech chips, which gives the malt a characteristic smoky flavour.

See *Rauchbier*.

Reactive oxygen species (ROS)

See **free oxygen radicals**.

Real ale

The term real ale has its origins in the United Kingdom. It came to prominence in the early 1970s with the formation of the Campaign for Real Ale (**CAMRA**), a campaigning organisation that seeks to promote the traditional beers associated with the United Kingdom.

Real ales are those which are produced using a traditional process, in other words, via infusion mashing and a relatively warm fermentation using a top-fermenting yeast strain. When

the primary fermentation is completed the green beer is transferred to a racking tank where some adjustments to colour and flavour may be made and finings might be added to promote clarification. At this stage the beer is transferred to the container from which it will eventually be dispensed. Typically this will be a cask, occasionally a bottle or, more rarely, a cellar tank located in the public house or other retail premise. The beer is not pasteurised or filtered.

In the container from whence the beer is dispensed the presence of residual yeast cells and fermentable sugars allows a secondary fermentation to occur. This is primarily for the formation of carbon dioxide, although some additional ethanol is formed. In addition, there is some modification to flavour, notably an increase in dryness owing to the disappearance of sugar. The secondary fermentation performed in large containers is referred to as cask conditioning (**cask-conditioned beer**). A similar process may be allowed to occur in a bottle, termed **bottle conditioning**. The beer is real in the sense that it contains live yeast cells; however, there is also a secondary pejorative meaning in that 'real' differentiates these products from those beers which are brewery conditioned, filtered and pasteurised before release to the retail trade. The latter are considered by some as inferior and by this definition 'unreal'.

See **cask-conditioned beer**.

Real attenuation limit gravity

See **apparent attenuation limit gravity**.

Record

Record is a Belgian hop variety. It is a medium alpha type containing 5.5–8.5 total α -acids of which 30% is cohumulone. Total oils are *ca.* 1.8%.

Red Mould

A synonym for powdery mildew disease of hops.

See **powdery mildew**.

Redpost

Proprietary device from the company of the same name [<http://www.redpost.com> (last accessed 11 February 2013)] designed to monitor the performance of a tunnel pasteuriser. It comprises a battery-powered solid-state monitor which quantifies, in **pasteurisation units** (PU), the heat treatment to which the product has been subjected. The electronics are mounted in a waterproof container, the case of which provides a stand on which a sample container, a bottle or a can, can be secured. A probe is fitted into the container via a gas tight seal. The measurements are usually made in the so-called cold spot in the container, usually a few centimetres above the centre of the base. The Redpost is allowed to pass through the pasteuriser together with filled containers. After recovery, data can be downloaded and include pasteurisation units (measured with reference to a PU cut-off temperature, typically 5°C below the actual process temperature), temperature of the spray jets, pressure inside the container and the temperature of the container at exit from the tunnel. Usually, the Redpost is used continuously throughout packaging runs, the position being moved each time, for example, top deck, right, centre and left, repeat with the bottom deck. In this way a more accurate picture is provided of the performance of a pasteuriser.

See **pasteurisation, tunnel pasteurisation**.

Red spider mite

The red spider mite (*Tetranychus urticae* Koch) is a pest which can affect several cultivated plants including hops. The mites take sap from the cells of infected plants. Mild infestations cause little damage, but in severe cases significant reductions in yield may occur.

The adult female, which is bright red, overwinters in the soil and in the spring colonises plants where it produces eggs which hatch to produce numerous small mites which are greenish in colour and have two black markings on the abdomen. These are known as **two-spotted mites**.

Treatments can be via the use of insecticides, although the mites are resistant to many organophosphorus types. Natural pyrethroids such as Bifenthrin and Propargite are effective. Other more novel control measures include the use of sprays containing hop β -acids, which are repellent to the mites, and natural predatory mites such as *Phytoseiulus persimilis*.

Reduced-alcohol beer

Brewers from any countries have a tradition of making beers with low alcohol content. Typically these were intended for consumption at times when a fully alcoholic standard beer was deemed inappropriate, for example, whilst engaged in heavy manual labouring. Sometimes the impetus for producing low- or zero-alcohol beers was driven by economic reasons, for example, shortages of raw materials as occurred during the two World Wars. More recently a number of brands have been launched which have reduced or zero alcohol content. These are aimed at the health conscious and also for those not wishing to fall foul of drink drive legislation. Reduced-alcohol beers may also be produced in such a way that they fit into specific, and usually lower, excise bands.

Many traditional low-alcohol beers were, and continue, to be made in a way that pays only a small regard to the actual alcohol concentration that is achieved. In more recent incarnations of reduced-alcohol beers aimed at mass markets a more stringent approach is necessary in order to comply with legislation. To this end, most countries, or trade associations, have devised legal definitions of beers which must be satisfied in order for the products to be sold and labelled as being low or zero alcohol. For example, a common requirement would be that a zero-alcohol beer should contain no more than 0.5% abv, whereas a low-alcohol beer should contain no more than 1.5% abv. Beers with higher (but lower than usual) concentrations of alcohol may be produced and these may attract a low rate of excise duty; however, although the actual value will be mentioned, they cannot be labelled as being 'low alcohol'. In Germany, there are three categories of low- or zero-alcohol beers. Zero-alcohol beers must contain no more than 0.5% abv. **Einfachbier** (plain beer) must be made from a wort containing 2–5.5% extract (0.5% and 1.5% abv). **Schankbier** (tap or draft beer) must be made from a wort containing 7–8% extract (1.5–2.6% abv).

Traditional low-alcohol beers are made using worts containing a low concentration of fermentable sugar. An example would be the UK '**small beers**', those that were made using the last and therefore weaker wort runnings. Many similar beers have and continue to be made in various countries of the world. For example, in Germany, **Dünnbier**, literally 'thin' or 'diluted' beer containing around 2.5% abv and made from a diluted wort, was aimed at industrial workers for consumption whilst at work. Similarly, **Erntebier**, or harvest beer, was a product of similar strength made to slake the thirst of farm labourers.

Low-alcohol beers can be made by using dilute wort, although this approach tends to result in a product which inevitably tastes thin. The efforts of new product development departments of several major brewers have long been focussed on the development of beers which have reduced alcohol content but have the same fullness of taste of fully alcoholic beers. This goal has yet to be achieved. The challenge of making a palatable zero-alcohol beer that bears more than a passing resemblance to the full-strength product is even more difficult.

These products are made using two general approaches: either by restricted fermentation such that the alcohol is not produced or by de-alcoholisation of a normal fermented beer.

In the former case worts are produced which are designed specifically for this type of beer. Usually they have lower than normal fermentability. These worts are then exposed to yeast under conditions which restrict the ability of the cells to form alcohol yet still allow those reactions to occur which reduce many carbonyls and other wort components and thereby remove 'worty' components. The restriction of fermentation can be achieved by the use of very low temperature. For example, in the patented **cold contact process**, the wort is cooled to -0.5°C mixed with yeast and allowed to ferment for approximately 48 hours. Under these conditions the alcohol concentration remains low, but wort carbonyls are reduced. More recently, several types of reactor have been developed which have a support medium to which yeast cells are immobilised. Wort is allowed to pass through the reactor and the very high yeast concentration allows carbonyl reduction, but the very short contact time restricts ethanol formation. In yet other approaches novel yeast strains have been employed which, unlike standard brewing strains, are unable to ferment the normal range of fermentable sugars found in worts.

De-alcoholisation of normally fermented and full-strength beers can be achieved in a number of ways. Here the problems are that it is very difficult to remove just ethanol. Inevitably a proportion of other volatile beer components are also removed. The result is that the treated beer tastes thin and insipid. A partial remedy can be achieved by separating the volatile fraction from the ethanol and adding this back. Alternatively base beers that are more strongly flavoured than normal full-strength products can be prepared such that the proportion that is lost with the ethanol returns the treated beer back to a more balanced state. Another approach is to produce artificial essences that can be simply added back to the base beer to compensate for the lost material.

The techniques used for the de-alcoholisation process include vacuum distillation, vacuum evaporation, dialysis and reverse osmosis (RO). All of these techniques are capable of removing alcohol leaving a product that fulfils the legal definitions of zero-alcohol beer. All have advantages and disadvantages and the criteria for choosing which are largely based on economics grounds. All are expensive in terms of process plant and revenue costs.

The results of endeavours to make alcohol-free beers have been mixed. Beers produced by restricted fermentation tend to retain some worty character which many discerning beer drinkers find objectionable. As a group, the beers made by de-alcoholisation tend to have unbalanced characters. These difficulties have tended to restrict the zero-alcohol beer brands to approximations of pale pilsener-type lagers. Since these are typically consumed at low temperature and in any case have relatively bland flavours they are perhaps more forgiving than the more complex tasting darker beers. For this reason examples of zero-alcohol ales and stouts are relatively non-existent. An exception to this is, perhaps German, *Malzbier*. This

product is made in a similar manner to the cold contact process described earlier. It is made from dark malted barleys with very little hops. Before the yeast is pitched the temperature of the wort is reduced to less than 0°C. The low temperature restricts the activity of the yeast and the alcohol concentration remains less than 0.5% abv. This allows the beer to be described as alcohol free. Before packaging the beer is carbonated. It is very sweet and nutritious and for this reason is considered suitable for children and invalids. *Weizenmalzbier* is a similar product made from a mixture of malted barley and wheat.

Reduced hop iso- α -acids

Reduced hop extracts are chemically reduced iso- α - or iso- β -acids which are made from purified iso-acids using sodium borohydride or Pd catalysts. They are defined based on the number of hydrogen atoms which have been added to the molecules during their manufacture; thus, they may be dihydro-iso- α -acids (also known as **rho-iso- α -acids**), **tetrahydro-iso- α -acids** and **hexahydro-iso- α -acids** (see individual entries for more details). Apart from conferring bitterness, at the same or greater intensity compared to the iso- α -acid precursors, these products are not susceptible to the development of **light-struck character**. In addition, the dihydro- and tetra-iso- α -acids confer foam stability to beers.

Reefer

Refrigerated rail trucks, particularly associated with the United States, for the distribution of beers.

Reef process

The name given to an industrial process commonly used for the production of sorghum or native African beer.

Several variants of the process are used, but in general milled sorghum malt is slurried in water at a temperature of approximately 48°C and inoculated with thermophilic lactic acid bacteria. After 18 hours the pH falls to around pH 3.2 and some limited proteolysis and starch degradation occurs. The soured extract is diluted with water and maize grits and/or sorghum adjunct is added. This mixture is boiled for 2 hours and after cooling to 80°C the mixture may be supplemented with another addition of milled sorghum malt. The latter reduces the viscosity via further starch degradation. The mixture is cooled to 60°C and further sorghum malt is added to initiate a mashing phase. In this phase free amino nitrogen (FAN) levels increase as a result of proteolysis, but starch gelatinisation does not occur and sugar production is limited as a result of the inhibition of amylases by the low pH. The wort is separated from the spent grains by screening or centrifugation then transferred to fermenter where it is pitched with a culture of pure dried brewing yeast. Fermentation times are relatively short at 8–48 hours and the temperatures are high (28°C). The beer is removed from the fermenter and dispensed into vented containers from which it is consumed.

See **native African beers**.

Reeked hops

Reeked hops, also termed stewed hops, is UK terminology for hops which have been dried incorrectly such that part of the bed of cones became wet and cool owing to the formation of

condensation. In consequence the hops become discoloured. The problem occurs when the inlet temperature to the hop drier is too high and the airflow rate too low. It can be avoided by commencing drying at a relatively low temperature and not allowing it to increase until enough moisture has been removed and the risk of condensation is therefore diminished.

Refined grits

See **grits**.

Refined starches

Refined starches may be used as adjuncts. They are purified from a variety of plant sources including wheat, barley, corn, cassava or potato. They represent the purest form of mash tun adjunct. They may be sold as flours or used to make syrups. The precise purification method depends upon the nature of the plant source. Where they have low gelatinisation temperatures they may be incorporated directly into mashes; otherwise, they require pre-cooking. The purer forms cause no problems with run-off and do not contribute significant flavour; however, they are generally low in nitrogen. Flours, especially wheat, may be used as adjuncts. Wheat flour is essentially pure endosperm. It is produced by a process of milling and sieving, which separates the endosperm material from other contaminating materials. Most often for brewing the flour is further purified to produce a product that is low in nitrogen. For brewing, flours are combined with a binding material which increases the average particle size and reduces dust formation. The product has the same advantage and disadvantages of raw wheat, that is, good head formation but high wort viscosity.

See **adjuncts**.

Regional brewer

A medium-sized brewery which produces beers typically for a local market and usually of styles traditional for the geographical area it serves. By implication they are usually independent of the larger brewing companies. They may undertake contract brewing for major brewers, particularly where the latter have closed their own facilities for making some traditional beer styles.

Reinheitsgebot

The *Bayerische Reinheitsgebot*, also known (incorrectly) as the **German Purity Law**, describes the ingredients that can be used to make beer. It is the world's oldest extant consumer protection law being introduced in Bavaria in 1516.

Early German legislation, the Augsburg regulations, had sought to control the then widespread use of various adulterants in Bavarian beers. These were codified in 1516 by the co-rulers of Bavaria, Dukes Wilhelm IV and Ludwig X, as the first incarnation of the *Reinheitsgebot*. This both set the prices for beer and limited the sole acceptable ingredients for its manufacture as barley, hops and water. This legal protection was both intended to protect beer quality and to ensure that more valuable grains such as wheat and rye were reserved for baking. Yeast was not included as an ingredient since its participation in the brewing process was, at that time, not recognised. In subsequent years the Bavarian law was modified to include yeast and malted wheat.

A law which also applied to other regions of Germany, with some exceptions, was introduced in 1871 as part of the foundation of the German empire of Bismarck. This applied the same strictures to bottom-fermented lager beers, but the use of sources of extract other than malt was allowed in certain parts of the empire that had a history of such practices for the production of specific beer styles. Later, in 1906, the law was applied to the whole of Germany although again only to lager beers. This was not an entirely welcome development and had the effect that several traditional non-Bavarian beer styles, which included flavouring ingredients such as spices and fruits, became illegal and as a result disappeared.

More recent updating of the beer laws (Beer Taxation Law, *Biersteuergesetz*, 1952; Provisional German Beer Law, *Vorläufiges Deutsches Biergesetz*, 1993) have addressed some anomalies and relaxed, somewhat, the rigour of the act. The following words are now included: 'In the preparation of bottom-fermented only barley malt, hops, yeast and water may be used. The preparation of top-fermented beers is subject to the same regulation, except in so far as the use of other malted cereals and of pure cane, beet, or invert sugar are also permitted. In these beers, sugars derived from starch, as well as colouring agents derived from pure sugars, may be used as well.'

In historical times the beer purity law was enforced in a few other countries that at various times came under the sway of Germany, for example, the then Czechoslovakia and Greece. Some of these traditions have been retained in these countries but without any current legal requirement to do so. In modern day Germany the spirit of the original 1516 law continues to be followed in Bavaria. The more relaxed law is adhered to in other parts of the country.

Extracts from the current German beer purity law

- (1) Only barley malt, hops, yeast and water may be used for the brewing of bottom-fermented beer, with the exceptions contained in the regulations in paragraphs 4 to 6.
- (2) The brewing of top-fermenting beer underlies the same regulations; however, other malts may be used and the use of technically pure cane, beet or invert sugars as well as dextrose and colouring agents derived from these sugars is allowed.
- (3) Malt shall be taken to mean: any grain that has been caused to germinate.
- (4) The use of colouring beers, if brewed from malt, hops, yeast and water, in the preparation of beer is allowed but is subject to special supervisory measures.
- (5) Hop powder, hops in other milled forms and hop extracts may be used in brewing, so long as these products comply with the following requirements:
 - (1) Hop powder and other milled hop forms, as well as hop extracts must be produced exclusively from hops.
 - (2) Hop extracts must:
 - (1) contribute the same flavouring and bittering substances to the wort as would have been contributed had hops been simmered with the wort.
 - (2) fulfil the requirements of the German Pure Food Laws.
 - (3) only be added to the wort before or during the simmering phase.
- (6) Only materials which act mechanically or by absorption and are thereafter removable, leaving no, or only such residue in the beer which is of no health, taste or odour concern may be used to clarify beer.

- (7) Upon request, in individual cases, such as the preparation special beers and beers intended for export or scientific experiments, exceptions to the requirements of paragraphs 1 and 2 can be made.
- (8) The requirements of paragraphs 1 and 2 are not applicable to brewing for personal consumption (home brewing).
- (9) After establishing the original extract content in the fermenting room, water may not be added to beer without permission of the customs office. The customs office can permit the brewer to add water to beer after the original extract content has been established in the fermenting room, provided the appropriate precautionary measures have been observed. Beer wholesalers or publicans are, under no circumstances, allowed to add water to beer.
- (10) Brewers, beer wholesalers or publicans are not allowed to mix beers of different original extract contents nor to add sugar to beer after the beer tax has been calculated. The Finance Minister can allow exceptions by decree.

Relative gravity

Relative gravity is a synonym for specific gravity. The specific gravity of a solution (also termed relative density) is equal to the ratio of the density of a liquid at a specified temperature compared to the density of water at 4°C (the temperature at which its density is maximal). It has no units.

Relict crops

These are descriptive of crops which were of historical importance but have now been replaced by more high-yielding varieties. Some of them may still be cultivated, but they tend to be restricted to particular geographical areas and are commonly marginalised in locations where the climate and soil conditions may be unsuitable for more mainstream crops. Examples with relevance to brewing include emmer, einkorn and spelt.

Re-mashing liquor

An alternative but rarely used synonym of **sparge water**.

Remote beer cooler

A device used to cool draught beers prior to dispense. The units are typically located in the cellar used where the attemperation in a beer cellar is insufficient to ensure that the beers are dispensed at the appropriate temperature. This is increasingly common as a result of the trend towards serving beers at very low temperatures (see **dispense temperature**).

Remote beer coolers typically comprise a stirred bath that contains chilled water. A number of metal coils are submerged in the water and these are attached to the beer delivery lines in between the beer container and the dispense tap. The water is chilled via an ice bank which is formed in the cooler unit as the result of the activity of a compressor. The ice bank approach is chosen since in many countries it allows use of off-peak and therefore less expensive electricity.

Some remote coolers designed to cope with the demand for ever colder and more rapid beer dispense rely on a supply of glycol in order to achieve the required low temperatures. In

these cases the coolant is circulated through the **python** as the beer is dispensed. If required additional cooling units, termed **pod beer cooler** or **shelf coolers**, or **under-bar coolers** may be used to augment the remote cooler. These are located close to the point of dispense.

R-enzyme

R-enzyme is an early form of terminology used in the classification of enzymes which are capable of hydrolyzing α -(1,6) glucosidic bonds. These include the **limit dextrinases**, which are implicated in starch degradation during the mashing phase of wort production.

See **starch** and **limit dextrinase**.

Required degree of attenuation

A term that describes the proportion of fermentable extract present within a wort which is required to be utilised by yeast during the course of fermentation. It may or may not equate to the total fermentable extract present in the wort at the start of fermentation depending upon the requirements of the individual beer.

The terminal wort concentration achieved at the end of fermentation is termed the **final gravity**. Since it is usually measured in the presence of ethanol the final gravity is less than would be measured in the absence of ethanol. For this reason it is referred to as the **apparent final gravity**.

Research Institute of Brewing and Malting (RIBM)

Based in Brno in the Czech Republic, the RIBM [<http://www.beerresearch.cz> (last accessed 11 February 2013)] was founded in 1887 and charged with undertaking research into brewing and malting. Diversification has resulted in a research programme that encompasses the whole beverage and food industry, especially those companies making products that require the use of plants. The institute offers an analytical service, deals with relevant legislative matters, and organises and acts as an expert referee in beer contests. In addition, it is responsible for undertaking assessment trials for new varieties of malting barleys.

Residual alkalinity

A phenomenon that is related to the mineral composition of brewing liquor in which the pH of a mash is reduced as a consequence of interactions between cereal components such as phytic acid, inorganic phosphate, proteins and polypeptides and ions of calcium and magnesium in which hydrogen ions are liberated.

See **water alkalinity**.

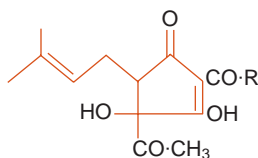
Resin A

Resin A was the name originally given to iso- α -humulone the principal hop-derived bittering compound found in beers.

See **hop isomerisation**.

Resin B

Name originally applied to 4-acetylhumulinic acid, a hop-derived intermediate of the hydrolysis of humulone.



Structure of 4-acetylhumulinic acid

Resin gland

A synonym for lupulin gland, the sac-like structures found in the cones of hop plants and which contain the resins that confer bitterness and other hop-related flavours to beers.

See **hop plants**.

Responsible Brewers' Initiative

An association formed in 2003 by the Czech Brewers and Maltsters Association by member companies, Budějovický Budvar n.p., Královský pivovar Krušovice a.s., Plzeňský Prazdroj a.s., Pivovary Staropramen a.s. and Starobrno a.s. The aim of the association is to provide information on brewing via a multilingual website [<http://www.napivosrozumem.cz> (last accessed 11 February 2013)] and to promote responsible marketing, advertising and consumption of beer.

Restrictor plate

See **orifice plate**.

Retrogradation

Retrogradation describes the phenomenon whereby after **gelatinisation** soluble starches can crystallise out to form insoluble precipitates. The process is of importance where preparations of starches are processed to form gels. In brewing retrogradation is undesirable since in this form starches are relatively resistant to enzymatic degradation. Consequently, if it is allowed to occur during wort preparation steps, extract yields will be reduced. Retrogradation may be prevented by ensuring that starches are subjected to treatment with diastatic enzymes as soon as possible after gelatinisation has occurred.

It follows that the area of greatest risk is where adjuncts with relatively high gelatinisation temperatures such as sorghum and rice have to be pretreated in a cereal cooker before being added to the mash. The high temperatures used in cereal cookers are sufficient to inactivate native diastatic enzymes and it is essential to transfer as soon as possible pre-gelatinised raw materials into mashing vessels.

Retrogradation can also occur in mashing-in vessels where the raw materials used have a low level of endogenous diastatic enzymes. In this situation and where permitted it may be prudent to supplement the mash with preparations of commercial amylases.

The ability of starches to undergo retrogradation is related to the length and abundance of the linear chains of the constituent amylopectin and amylose chains of starches. Where long unbranched chains are plentiful retrogradation is favoured. The presence of starch inclusions such as lipids tends to inhibit retrogradation.

Reverse osmosis

Reverse osmosis (RO), also known as hyperfiltration, is a membrane filtration technique in which molecules are separated on the basis of size. In the context of brewing it is used for the purification of water. The process depends upon the principles of osmosis such that where two solutions are separated by a semipermeable membrane the smaller solvent molecules will tend to migrate through the pores in the membrane, via diffusion, until a state of equilibrium is established. Larger solute molecules cannot pass through the pores. The magnitude of the difference in the concentrations of solute molecules on either side of the membrane provides the driving force for the solute exchange and this is termed the osmotic pressure. In the case of RO pressure is applied, which drives the flow of solvent molecules. The fluid passing through the membrane is termed the permeate, whilst the portion that contains the solutes is called the retentate. As the process proceeds the retentate becomes increasingly concentrated.

RO is part of a continuum of membrane separation processes which are classified according to the pore size of the membrane, as indicated in the table.

Process	Cut-off
Reverse osmosis	100 molecular weight
Ultrafiltration	10,000 molecular weight
Microfiltration	0.2–2.0 μm

In the majority of cases the process is operated as crossflow, in which during filtration the retentate is continuously recirculated through a loop such that the fluid flow passes tangentially across the surface of the membrane and, hence, reduces the likelihood of fouling.

RO is commonly used for the production of totally demineralised brewing liquor. The treated water is essentially free of all organic contaminants and is sterile. Some pretreatment is required since the membranes are susceptible to damage by contaminants such as chlorine and are not tolerant of high solids loadings; hence, preliminary steps such as sand and carbon filtration are required. Membranes are made of cellulose acetate or polyamide and are provided in spiral wound, hollow fibre or tubular configurations. Membranes are fitted into modules and these can be provided in multiples in order to size the plant for the required production capacity. The major operating cost is for the relatively high-capacity pumps required to generate the typical operating pressures of around 10 bar.

See **water**.

Rhanella aquatilis

Small, usually motile bacilli formerly classified as *Enterobacter agglomerans*. They are an important group of Gram-negative beer spoilers. They are tolerant of hop acids but relatively intolerant of ethanol such that they can survive low-gravity fermentations to co-crop with yeast but do not persist where more concentrated worts are used. As with *Obesumbacterium proteus* they are contaminants of pitching yeast and may be eliminated by disinfection with acid (see **acid washing**). Their presence in pitching yeast results in accelerated early fermentation but high residual gravity. Undesirable products of their metabolism include very high

levels of diacetyl and dimethyl sulphide. Other products are acetaldehyde and methyl acetate resulting in beers which have an objectionable fruity and sulphury taste.

Rho

Term used as a shorthand abbreviated form of rho-iso- α -acids, preparations of hop bittering agents which are not susceptible to the development of light-struck flavour.

See **rho-isohumulones**.

Rhodamine 123

A cationic fluorescent dye which can be used for assessment of yeast viability. The dye is taken up by and retained by viable cells. It has been demonstrated that it associates with mitochondria and that it is not retained in anaerobic repressed yeast cells which by definition have impaired mitochondrial activity. For this reason it is not suitable for viability determinations of pitching yeast, unless an assessment of mitochondrial activity is required.

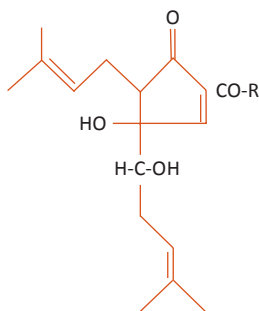
See **yeast viability**.

Rho-iso- α -acids

See **rho-isohumulones**.

Rho-isohumulones

Rho-isohumulones (rho-iso- α -acids) are derivatives of iso- α -acids in which two hydrogen atoms are incorporated following reduction with sodium borohydride. Unlike the parent iso- α -acids the conversion of the acyloin group into a diol renders the molecules insensitive to light, and thus, when these materials are used as bittering agents in beers they do not produce the undesirable light-struck 'skunky' flavours and aromas.



Generalised structure of rho-iso- α -acids

Each of the three principal iso- α -acids, isohumulone, iso-adhumulone and iso-cohumulone, may give rise to two epimeric dihydro-iso- α -acids; thus, bearing in mind that the starting materials may be the *cis*- or *trans*-isomers, 12 possible products may be formed. In practice, the reaction conditions are such that fewer products are actually formed. Apparently there are no differences between the bitterness of each; however, as a group they are slightly less bitter than the parental iso- α -acids.

Rho strains

A term applied to yeast strains which is descriptive of the status of the mitochondrial genome.

See **yeast genetics**, **petite mutants**.

RiboPrinter®

Equipment manufactured by the DuPont Company [<http://www2.dupont.com> (last accessed 11 February 2013)] designed for the rapid identification of microorganisms, especially contaminants of process streams. It is based on the analysis of ribosomal RNA. Genetic analyses are automatic and the results compared to a database to provide positive identification. Libraries for all major groups of beer spoilage bacteria are available. Detection times are of the order of 8 hours. Equipment costs are relatively high and a third party service is offered by the independent company Accugenix [<http://www.accugenix.com> (last accessed 11 February 2013)].

Rice malting system

A mechanised malting system devised in the United States in the early years of the twentieth century. Following conventional steeping the grains were allowed to germinate as beds layered onto perforated metal shelves. A fan provided a forced stream of conditioned air. At intervals the beds were turned automatically by dropping into a garner and reforming on the same shelf.

See **drum malting**, **pneumatic malting**.

Ridomil

Ridomil is the trade name for a fungicide which is used in the control of diseases such as downy mildew in hops.

See **metalaxyl**.

Roasted barley

Unmalted barley grains may be roasted and used for the production of certain beers, notably stouts, where they impart the characteristic pleasant astringent burnt taste and aroma. When used in brewing the resultant beers have very dark colours, often greater than 80 EBC units. The heating treatment destroys all enzymatic activity.

The roasting process is carried out in a drum using a temperature profile in which the grain is raised up to *ca.* 230°C over a period of 2.5 hours. At the end of the period of heating the process is terminated by spraying the roasted grains with cold water. During the treatment the grains swell and take on a dark red to black appearance. In taste they are astringent, dry and burnt.

Roasted malts

Roasted malts are speciality products in which the final kilning process is performed at a relatively high temperature. This produces characteristic changes in flavour, aroma and colour. As a consequence of the conditions employed in kilning the majority of enzyme activity is destroyed. As such these malts are used in conjunction with more conventional malts, the

latter providing the enzymes that are required during the mashing phase of wort production and the former being used to introduce flavour and colour.

Roasted malts are described in terms of their colour. The depth of colour correlates with the intensity of the roasted treatment applied during their manufacture; thus, varieties of roasted malts are termed amber, brown, chocolate and black.

The chemistry that underpins the changes that occur during barley roasting is complex. Briggs in *Malts and Malting* [Briggs, D.E. (1998) *Malts and Malting*, pp. 221–222, Blackie Academic and Professional, Thompson Science, London, UK] summarises the changes as primarily interactions between amino acids and reducing sugars to form Schiff's bases. Via a series of Amadori rearrangements these are converted into aldosamines, ketosamines and diketosamines (via further interactions with reducing sugars). The diketosamines are unstable and produce various degradation products including reductones and hydroxymethylfurfural. Reductones interact with amino compounds which condense to form coloured components, melanoidins. Higher kilning temperatures lead to melanoidins with higher molecular weights and these are more highly coloured. In other reactions the amino acids and reductones are further degraded via Strecker reactions to form a variety of aminocarbonyl compounds and aldehydes. In other reactions the reductones give rise to a heterogeneous group of acids, alcohols, aldehydes, esters and various heterocyclic compounds. Many of these compounds contribute flavour and aroma notes to malts. In addition, bitterness is imparted by the formation of β -diketopiperazines; coloured phlobaphenes are formed from polyphenols; and sugars are caramelised. Starch grains become pigmented and more resistant to enzymic attack owing to the formation of new linkages between sugar residues.

Traditionally the roasting process was carried out by heating relatively thin layers of malt over open wooden fires. In modern processes a roasting oven is used. The ovens consist of rotating drums fitted with internal vanes to ensure good mixing and even roasting. Exclusion or provision of water is regulated to either prevent or promote stewing, respectively, depending on the type of malt being produced. Similarly, depending on the nature of the final product, the starting material may be green, kilned or un-germinated grain. In modern well-controlled roasting processes the heat treatment is terminated by the application of cooling. This prevents overtreatment, which can result in an over-processed product.

R

Roasting drum

Roasting drums are pieces of plants used to heat grains under controlled conditions. The products made in roasting drums include amber, brown, chocolate and black malts. Modern roasting drums have capacities of up to 5 tonnes. Grains are fed into the cylinder from a hopper. In use the drum rotates at 20–25 rpm and internal baffles ensure that the grains are continuously turned over. Heat may be applied directly into the drum in order to produce a dry roast product. Alternatively the heat may be applied to the exterior surface of the drum, thereby allowing moisture to be retained as in the manufacture of stewed grains such as crystal malts. The drums have sampling ports which allow the operator to examine progress and stop the application of heat when necessary. In this regard management of the process requires a skilled operator; however, the introduction of devices leading to better monitoring and control has reduced the need for such intervention. The fumes that emanate from the roasting drums are highly unpleasant and their release into the atmosphere is prohibited by law. Consequently,

plants such as catalytic converters and afterburners are used, which treat the exhaust gases and eliminate the organic components. In order to control the end of process precisely, in the preparation of some products, the heated grain may be sprayed with water. In addition, coolers are provided in which the discharged grain is mixed by mechanical agitation whilst cold air is passed through it.

Rochefort

One of the Trappist monasteries of Belgium that produce Trappist beers.

See **Trappist beers**.

Rocky yeast head

The term rocky yeast head describes the appearance of the surface of fermenting wort which occurs during the period of very active yeast growth. In traditional relatively cool bottom fermentations, where it is possible to view the surface of wort, rocky or cauliflower heads appear after about 3 days. The head consists of a mixture of yeast, some entrained non-yeast solids and foam owing to the presence of CO₂ bubbles. This combination takes on a characteristic rocky form which is very reminiscent of the surface of a cauliflower. For this reason it is also known as a cauliflower head. In German the term *kräusen* is used, which is literally descriptive of the curled and wrinkled surface features of the fermenting wort.

See *kräusen*.

Rodmersham Goldings

A variety of one of the group of Goldings, traditional UK-style aroma hops.

See **Goldings**.

Roggenbier

Roggenbier is a beer associated with Bavaria made from a grist containing at least 50% malted rye. Rye beers are dark in colour and have a strong grainy flavour. They were popular in Germany in the medieval period but virtually disappeared when the *Reinheitsgebot* decreed that rye had to be reserved for the purposes of baking. In recent years there has been a slight resurgence in the use of malted rye for brewing purposes.

Roller mills

Roller mills are used in the first stage of wort production to subject cereal grains and other solid adjuncts to a process of comminution such that a grist with a desired average particle size and composition is produced. Several types of roller mill are used. The grains may be dry (dry milling) or pre-wetted (wet milling).

Roller mills are provided with one or more pairs of rollers through which the grains pass. In so doing the grains are disrupted, depending on the design, by one or a combination of crushing, shear and cutting. The rolls are spring loaded and can be adjusted to vary the gap between each pair in order to suit the nature of the feed material. The gap controls the fineness of the grind. In some roller mills only one of each pair is driven, the other following roller being made to rotate by the frictional force exerted by the grains. In others both rollers in each pair may be driven usually at different speeds. This differential exerts shear forces on the

grains, which aids disruption. The surfaces of the rollers may be smooth or commonly they may be provided with grooved flutes of several designs. These indentations allow the grains to be cut. The grains are fed into the mill aligned in such a way that they are split along the longitudinal axis, the intention being to release the contents but to cause minimum damage to the husk.

The capacity of each mill is regulated by the width and diameter of the rollers. The gaps between the rollers are checked by measuring the diameter of soft wire rods made from a non-toxic metal such as copper or lead-free solder after passage through the mill. It is important to do this whilst the mill is under load. For proper operation it is essential that the rollers are properly aligned and not worn.

Roller mills may possess just two or may have multiple rolls. The former is the simplest and allows only a single pass. These types can be used only with well-modified malts and, even so, are suitable only for very small commercial or pilot-scale breweries. The advantages of the more advanced types are that the multiple pairs of rolls allow separation of fractions during the milling operation. Thus, after treatment by the first pair of rollers the fine particles of grist are collected after passage through a screen placed between this and the remaining pairs of rollers. The larger particles are retained and allowed to pass through the subsequent sets of rollers. Different sets of rollers may be set with different gap sizes, thereby allowing more control of the milling process.

Four-roll types in which the two pairs are mounted vertically above each other are commonly used in smaller UK-style traditional ale breweries. In these cases well-modified malts with uniform grain sizes are used; typically, gap widths of 1.3–1.9 mm for the first and top pair of rolls and 0.3–1.0 mm for the bottom and second set of rollers. In traditional designs the grains are split by the first pair of rollers. The grains fall into an intermediate chamber which is fitted with rotating beaters which effect a preliminary separation of husk material from flour and grits. After this the material falls into the second set of rollers for a second treatment after which it is fed into the grist case. In more sophisticated types the intermediate chamber incorporates screens which ensure that only the coarse grits are subjected to the second milling treatment, thus minimising damage to the split husks.

In eight-roll mills the grains are first screened and separated into large and small fractions. Each fraction may then be milled using the four-roller arrangement described already. The preliminary screening allows each set of four rollers to be set up for optimal performance with small and large grains.

Mills with odd numbers of rollers do exist but are now not commonly used. As with the four-roll types these rely on multiple passes through pairs of rollers with intermediate screening and separation of fractions of the grist. The design introduces some cost savings by sharing the grinding duties of individual rollers. Thus, in a five-roll type the first pass may use rollers one and two, and the second pass rollers two and three, and the final pass rollers four and five. In this way the expense of a roller is avoided.

The most commonly used roller mill in large modern breweries is the six-roll type. Essentially these are similar to the four-roll type, described already but with an additional pair of rolls, which provide greater efficiency and flexibility. Thus, after passage through the first set of rollers the coarse fraction is retained and passed onto the second set. The husk and flour

devolving from the second set is separated using a second set of screens whilst the remaining grits pass onto the third set of rollers (see the following figure).

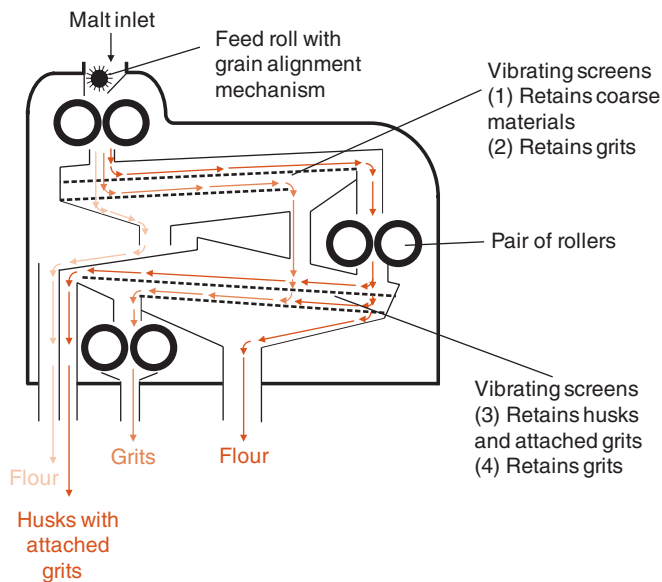


Diagram showing a section through a typical six-roll-type mill indicating the flow, separation and crushing of the various fractions

The mills described may be used with dry grains or those that have been treated to a conditioning phase (see **conditioned dry milling** for more details). Roller mills used for steeped grains generally use much larger rolls which are designed to gently squeeze and release the contents of the grains.

See **milling**.

Root beer

Root beer is a beverage most associated with the United States. Although usually now non-alcoholic, original versions were subject to a limited bottle fermentation which resulted in the formation of approximately 0.5% abv. In traditional versions a wide variety of flavourings were used; principally, extracts of the roots of the sassafras plant (*Sassafras albidum*) together with extracts made from the Sarsparilla plant (*Smilax regelii*, *Smilax glyciphylla*) and the root beer plant (*Piper auritum*). In modern versions artificial flavourings are now used since safrole, the active flavour component of sassafras oil, has been determined to be carcinogenic.

Ross and Clarke method of beer foam assessment

An early method, dating from the 1940s, developed to assess beer foaming ability and one that forms the basis of modern procedures such as the **Rudin method**. It assesses the foam collapse time and introduced the concept of the Sigma foam collapse time.

A known volume of beer is poured into a vessel and after a given period of time, the beer is removed, leaving the foam. The latter is collapsed by the addition of a known volume of amyl alcohol. The volume of liquid minus that of the amyl alcohol can be related to the foam collapse time:

$$\Sigma = t/[2.303 \log b + c/2],$$

where Σ is the foam collapse time, t is the time in seconds during which the sample was allowed to stand after dispense, b is the volume of beer formed after time t , and c is the volume of beer formed from the residual foam.

One of the current ASBC methods (**Helm method for beer foam assessment**) uses the Sigma collapse time principle.

Rosy rustic moth

The caterpillar stage of the rosy rustic moth (*Hydroecia micacae*) feeds on hop plants. The damage can be serious, causing the bines to collapse where boring occurs at the junction between the bine and the rootstock. In addition, the damage caused by feeding can provide a route for infection by fungi such as the *Fusarium* canker. In hop gardens in the Czech Republic it has been noted that damage by this pest can be made more serious where adjacent waterlogged areas provide suitable habitats for plants such as the quackgrass (*Elytrigia repens*), which acts as a breeding ground and food source for emerging larvae which can then go on to damage the hop plants. The damaging effects of the pest have been recorded in hop gardens in Germany, Slovenia, Russia and England. Attacks are more common following heavy rainfall and flooding. Control is best exerted in the form of prevention by eliminating surrounding waterlogged areas which can act as reservoirs of infection.

Rotary brush strainer

Rotary brush strainers are used for the removal of hop residues from boiled wort. Typically they are used as a pretreatment prior to other methods of hot wort clarification such as a whirlpool. In this case the type of hop preparation used is usually a deciding factor. They may also be used as the first stage in a process of extract recovery from hot break. In this case the rotary brush strainer is used as a preliminary screening step which reduces the solids loadings onto equipment such as **decanter centrifuges** or **hydrocyclones**.

The rotary brush strainer is a continuous device which comprises a chamber fitted with an inner wall which contains perforations. The wort is pumped through the chamber where the liquid portion passes through the perforations and from there to the outlet. The solid detritus is retained on the screen from where it is removed continuously by a mechanically driven screw worm arrangement.

Rotary keg racker

See **keg filling**.

Rough beer

A name sometimes used to describe beer which has not yet been clarified by filtration and subjected to any other adjustments which might be required to render it into a form in which it can be packaged.

In many breweries beer is stored in this rough state since in this form, particularly if some viable yeast cells are present, it is relatively resistant to microbiological attack and, thus, filtration is usually carried out immediately before packaging and establishment of microbiological stability.

Round

Name given to open fermenting vessels which have a circular geometry.

See **open fermenting vessels**.

Rouse

The term rouse is used in brewing to describe the action of mixing a liquid or a suspension; thus, any implement which is employed to perform the stirring action is described as a **rouser**. This might be a simple manual stirring tool or it might be a mechanical device driven by electricity or some other motive force such as a pump.

In addition to the description of simple mixing the word rouse also carries the connotation of 'bringing back to life' or 'reinvigorating'. In this sense the word might be used, for example, where it is felt that a fermentation might be failing to reach attenuation, in other words, is 'stuck', as a result of the yeast having separated out from the wort such that most is no longer available to participate. In this case the stirring action is intended to re-suspend the yeast such that it is again brought into intimate contact with the wort. In so doing the yeast or the fermentation is 'roused' into further action. Since it is believed, often mistakenly, that addition of oxygen to a stuck fermentation might remedy the situation the phrase 'rouse with some air or oxygen' is also commonly used. In this case the added gas might be used both for its effect on the biochemistry of the yeast cells and also as a physical mixing agent via the effects of the bubbles passing through the liquid. In a similar vein, where the dissolved oxygen content of a beer is considered to be too high, a remedy would be to '**gas rouse**' with CO₂ in order to drive out some of the dissolved oxygen.

Rouser

A term used to describe an implement or system for mixing liquids or suspensions.

See **rouse**.

Rubin

Rubin is a relatively new Czech bittering hop registered in 2007. It derives from the **Saaz hop** variety. It contains 10.0–14.0% total α -acids (25–33% cohumulone) and 4.0–6.0% β -acids. Total oils are 1.0–2.0% (7.0–10.0% caryophyllene, <0.5% farnesene, 13.0–20.0% humulene, 35.0–45.0% myrcene).

Rudin method

Method and apparatus for assessing beer foam based on the time taken for foam to collapse under controlled conditions and commonly used in Europe. Beer which has been degassed is placed into a jacketed attemperated glass tube (2.6-cm diameter \times 35 cm high) up to a line which marks 100 mm. A stream of CO₂ is passed through the beer via a glass sintered disc resulting in the formation of foam which is allowed to reach a height of 325 mm. When the

gas supply is discontinued the foam collapses and the time taken for the boundary between beer and foam to move between 50 and 75 mm is recorded as the half-life of the foam (Rudin head retention value).

Ruhi

See **Indian rice beer**.

Rummager

A rummager is the name given to a device whose function is to stir the contents of a copper (kettle) during wort boiling. It takes the form of a mechanical stirrer which is fitted with a number of short lengths of chain, usually made from copper, which sweep the base of the vessel and prevent the deposition of solid particles.

See **wort kettle**.

Rummer

A drinking glass with a bowl shape mounted on a short stem. Antique versions are commonly large and often highly ornamented. They were originally intended for beer drinking but are now more associated with wine consumption. Rummagers were often used for communal toasts and this is reflected in the etymology of the name in that it appears to be a corruption of the German *römer*, meaning a large glass via *roem* in Middle Dutch *to praise*.

Running bright

Running bright is the term associated with the process of separating sweet wort from the spent grains using a lauter or mash tun. It describes the stage in wort run-off where, following initial recirculation of the first turbid worts back through the bed of grains, the issuing stream of sweet wort has achieved the desired degree of clarity.

See **mash tun, lauter tun**.

Run-off

Run-off, also known as wort run-off, describes the process where sweet wort is separated from the spent grains. Typically this will be the stream of wort issuing from a **mash tun**, a **lauter tun** or a **mash filter**.

Different run-off regimes are used depending on the type of mashing plant used. In general the time required with a mash filter is much shorter compared with that of a mash or lauter tun. This can be significant in that the activity of some mash enzymes may be retained during this phase.

Generally the first worts are of a higher quality compared with that obtained at the end of run-off. During run-off, sparging of the grains results in dilution, usually increased temperature and an increase in pH as buffering materials are washed out of the grain bed with the first runnings. In consequence undesirable components such as astringent polyphenols may be leached from the spent grains with the last worts.

Saaz hop

Saaz is the name given to a hop cultivar that originated in the town of the same name in what was Bohemia and now the Czech Republic. Saaz is a German name, which in Czech is Žatec. Saaz hop is one of the four **noble hop** varieties prized for their low bitterness and delicate flavour and aroma. It is widely used in brewing but is most associated with the classic pale Czech pilsener-type beers.

Saaz hops contain relatively low contents of α - and β -acids, 2.5–5% and 5–8%, respectively. The oil fraction contains 6% caryophyllene, 15% farnesene, 19% humulene, 42% myrcene and 0.5% selinene.

Saaz yeast

A type of lager brewing yeast originally isolated from a Czech brewery in Zatec (Saaz) by the German brewing microbiologist P. Lindner in the late nineteenth century. The same scientist isolated another strain in a German brewery in Froberg. Strains derived from these two yeasts are used commercially by many lager brewers throughout the world and are now described as 'Saaz' or 'Froberg' types. Originally both groups were subdivided into two subgroups, which were bottom and top fermenting, respectively. The Froberg types are described as being much more strongly attenuating compared with the Saaz. Recent detailed genetic analysis suggests that the two groups may be representative of two separate hybridisation events between a *Saccharomyces cerevisiae* ale strain and two closely related *Saccharomyces bayanus* strains.

See **yeast genetics**.

Saccharification rest

The saccharification rest describes the phase in mashing in which the conditions, principally the temperature, are regulated such that starch degradation and the resultant formation of simpler fermentable sugars are favoured.

In decoction or temperature-programmed mashing techniques saccharification is favoured in the later hotter stages. Thus, α -amylases, β -amylases and β -glucanases show their maximal activities at 70, 60 and 40°C, respectively.

The conversion of starch to simpler sugars accounts for the greatest part of the extract formed during mashing. Before breakdown can proceed freely the starch must be gelatinised, and this requires a comparatively high temperature. For barley malt this temperature is in the region of 50–70°C. In the case of other cereals such as sorghum, rice, maize and millet, it is higher (60–90°C). In the case of this second group the grist requires separate treatment in a **cereal cooker** to gelatinise the starches before returning to the main mash for saccharification. Nevertheless, even at lower temperatures, starch degradation does proceed, albeit at a reduced rate. Thus, in the case of simple infusion mashing, the temperature chosen represents a compromise that is optimal for neither proteolysis nor saccharification; nevertheless, with well-modified malts sufficient proteolysis and extract formation occur to ensure that the wort meets specification. In the case of mashing regimes that utilise ramped attemperation, such as decoction and temperature-programmed infusion, the mashing conditions are regulated to favour the activity of selected groups of enzymes. In the case of saccharification this is in the latter hotter phases.

Saccharification time

Saccharification time is a term used in the assessment of malt and mashing. In the European Brewing Convention (EBC) test it describes the time, measured in minutes, taken for a mash held at a temperature of 70°C to stop giving a positive result with the iodine test. In other words it describes the time taken, for that particular malt, for starch breakdown to occur.

Saccharimeter

A saccharimeter is a device used for measuring the concentration and purity of sugars. It is distinct from and should not be confused with a saccharometer, the hydrometer used to measure specific gravity.

Saccharimeters rely on indirect means of quantifying sugar concentration. The two most common methods are a measure of refractive index or polarimetric approaches that rely on the optical activities of sugars such as sucrose.

Saccharometer

Saccharometers are hydrometers that are used for measuring the specific gravity of worts, fermenting worts and sugar solutions. For this purpose they are calibrated in **degrees saccharin**.

See **hydrometer**.

Saccharomyces

Name given to the genus of yeasts that includes all of those species used in biotechnological processes, such as baking, and the manufacture of alcoholic beverages such as beer. The name comes from the Latin roots for 'sugar' and 'fungus'.

See **yeast**.

Saccharomyces carlsbergensis

A now defunct term for the genus and species into which strains of brewing yeasts classified as lager types were placed. Using current taxonomic principles the correct nomenclature for these strains is *Saccharomyces pastorianus*.

See **yeast**.

Saccharomyces cerevisiae

Species of yeast and member of the *Saccharomyces sensu stricto* group. Within the latter it forms a cluster with *Saccharomyces paradoxus*. Members of *S. cerevisiae* are considered to be domesticated yeast strains, which include those used for brewing, baking and enology. The brewing strains are those that are considered to be ale yeasts. They are distinct from lager brewing strains, which are currently classified as *Saccharomyces pastorianus* (syn. *S. carlsbergensis*). Strains of *S. cerevisiae* can be distinguished from *S. paradoxus* using genetic analyses and by virtue of strains of the latter being able to assimilate D-mannitol.

Saccharomyces diastaticus

Species of spoilage yeast now reclassified as *S. cerevisiae*.

See **wild yeast**.

Saccharomyces eubyanus

A putative wild ancestor of the non-*Saccharomyces* ancestral parental strain that took part in the hybridisation event that led to the formation of lager brewing strains.

See **yeast genetics**.

Saccharomyces pastorianus

The genus and species into which strains of brewing yeasts classified as lager types are placed.

See **yeast**.

Saccharomyces sensuo stricto

The name given to a taxonomic grouping in which brewing yeasts and other closely related strains that are used in biotechnological processes are currently classified.

See **yeast**.

Saccharomyces uvarum

A now defunct term for the genus and species into which strains of brewing yeasts classified as lager types were placed. Using current taxonomic principles the correct nomenclature for these strains is *S. pastorianus*.

See **yeast**.

Saddle

A system for cooling individual casks of beer. The saddle comprises a series of stainless steel tubular elements through which a coolant such as ice-cold water can be circulated. The saddles are shaped to fit casks of various capacities. An insulating jacket may be fitted over the saddle.

Safir

See **Valtický**.

Sahti

Sahti is a traditional beer of Finland. It is brewed from a mixture of cereals but usually including malted rye. As with many traditional beers, bread such as black (rye) bread may be included. The beer is top fermented using ale-type yeasts. These impart a strong banana flavour owing to the high concentrations of esterified higher alcohols. The beers are also flavoured by the addition of juniper berries. Commercial versions are produced. Typically these are sold unfiltered with relatively high alcohol contents (*ca.* 8% abv).

Saint Abdon

A Persian martyred in Rome in the reign of Emperor Diocletian together with a companion now known as St Sennen. He is considered to be the patron saint of coopers. The reasons for this seem obscure although his remains are claimed to reside in Soissons, the town in France associated with Arnold of Soissons, another patron saint of brewing.

Saint Amand

A French born cleric of the sixth or seventh century associated with the evangelisation of Ghent and the foundation of several monasteries in Flanders. He is considered to be a patron saint of brewing, in particular those people associated with serving beer, presumably a reference to the monastic practices of providing food and drink to travellers.

Saint Barbara

Another of the many personages claimed as a patron saint of brewers. Saint Barbara is probably mythical but is usually claimed to have been born in Turkey in the fourth century and a daughter of royal and pagan ancestry. Following conversion to Christianity she was martyred at the hands of her less-than-impressed father. As a result the latter was reportedly killed by divine lightning bolts. For this reason she is claimed as the patron saint of artillery men and all things explosive. The reasons for her associations with brewing are obscure, although on her feast day of 4 December in the Provence region of France, it is customary by some to germinate wheat grains in saucers for subsequent decorative purposes throughout Advent, perhaps a somewhat tenuous link to malting and brewing.

Saint Boniface

Saint Boniface, also known as the Apostle of Germany and Winfrid or Wynfrith, is known as a patron saint of brewers and bar staff, particularly in Germany. Although reportedly born in Devon in the United Kingdom in the seventh century, he spent much of his life evangelising in Holland and in Germany. In the latter country he was responsible for founding several monasteries, presumably, the basis for his association with the production and distribution of beer.

Saint Brigid

Irish patron saint of brewers also known by various names including Bridget of Ireland, Brigid of Kildare and Mary of the Gael. Reputedly she was born in Ulster in the fifth century and

was Abbess of Kildare. The reasons for her association with brewing are obscure, although many stories describe her ability to provide sources of pure water for the local populace. Several sites of wells in Ireland are dedicated to her. Many miraculous cures are ascribed to her, particularly in relation to lepers. In one account she reputedly converted unwholesome water into good ale for the delectation of said lepers.

Saint Florian

A fourth-century Roman clandestine Christian who was martyred as a result of anti-Christian purges of the Roman emperors Diocletian and Maximian. He is a patron saint of Poland and Upper Austria. Although primarily named as the patron saint of firefighters, he is also associated with coopers and brewers.

Saint Martin of Tours

A fourth-century ex-Roman soldier born in Pannonia, now in modern Hungary, and who later evangelised in France, became Bishop of Tours and founded a monastery at nearby Marmoutier. He is considered to be a patron saint for innkeepers largely based on the story in which he tore a piece off his army cloak to provide clothing for a freezing beggar.

Martinmas, the saint's feast day, is celebrated on 11 November throughout much of Europe and is often marked by special celebrations and feasting followed by a period of fasting. The saint also has associations with the spread of viticulture, being cited as the introducer of vine pruning and being responsible for the introduction of the Chenin Blanc grape variety. Paradoxically St. Martin is also the patron saint of recovering alcoholics.

Saint Medard of Noyon

A sixth-century French bishop and saint, one of the many claimed to be the patron saints of brewers. No explanation for the linkage is obvious other than the legend by which he was apparently sheltered when caught in a storm by the wings of hovering eagles. The latter miracle was responsible for his being also described as patron saint to those requiring protection from bad weather, especially field workers, perhaps providing a tenuous link between brewers and the farmers responsible for producing the raw materials.

Saint Nicholas of Myra

St Nicholas of Myra was Bishop of Myra, now in modern Turkey, in the third century. He is also known as St Nicholas of Bari, Nicholas the Wonderworker and the basis of Santa Claus, and amongst many other accomplishments is regarded as one of the many patron saints of brewers (and coopers). As with many patron saints associated with brewing, the reasons are obscure. Apart from his association with Christmas and the custom of the giving of gifts, there seems little in his recorded life linked to brewing. In some accounts of his deeds he is credited with saving the lives of three clerics who were staying in an inn, although in other versions, the story replaces clerics with children and the inn with the premises of a butcher. He is credited with performing a miracle in which in a time of famine in Byzantium, a shipload of wheat was made to multiply thereby perhaps providing supplies for beer making. Of course, the association of St Nicholas with Christmas, a time of feasting and merriment and

by inference a time when the consumption of strong beers might be expected, would provide another route for the association of this saint with brewing.

Saint Urban of Langres

A saint and bishop of the French town of Langres from AD 374 until his death in AD 390. According to myth he escaped persecution by being hidden by workers in a vineyard and as a result is considered as a patron saint of viticulturalists and coopers of all kinds. The association with the latter is not made clear; perhaps the wine workers hid the bishop in a barrel.

Saint Wenceslas of Bohemia

The patron saint of Czech brewers, historically Wenceslas I, Duke of Bohemia (AD 907–935) and sanctified after his death as a result of reported miracles. He is the basis of ‘Good King Wenceslas’, the subject of the popular Christmas carol. His association with Czech brewing in part perhaps relates to real historical events in that he was apparently responsible for several laws that sought to protect the exclusivity of the Bohemian hop-growing industry. A second historical character, Wenceslas (1271–1305) who ruled over Bohemia, Poland and Slovakia was responsible for the establishment of the town of New Plzen (1295), what is now modern Plzen and in granting the families of 260 citizens the right to brew and sell beer.

Saison

Saison is the name given to a **seasonal beer**, which originated in the Wallonia region of Belgium. The name reflects this heritage since it translates from French as ‘season’. The original beers of this style were brewed usually in farmhouses in the autumn and stored throughout the winter and consumed in the following summer. In particular the beers were provided to farm workers for refreshment during the harvest. The original Saison beers were produced by top fermentation using ale yeast strains and then subjected to a secondary fermentation in bottle. As befitted their intended use as a refreshing drink for manual workers ethanol contents were usually modest at 3–4% abv. Modern versions are now produced by commercial brewers both in Belgium and by craft brewers in other parts of the world. These are usually stronger (5–8% abv) compared with their traditional counterparts.

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Saké

Saké is an alcoholic beverage associated with Japan and made from rice. Although in appearance it is reminiscent of wine it may be considered to be a beer in that as in the brewing process there is an initial stage analogous to malting in which the starch present in rice grains is converted into fermentable sugars.

Saké production has a long history, and it is similar to many rice-based alcoholic beverages that are native to Asia. As with the brewing of more conventional beers industrial processes have been developed from traditional methods. Although still primarily associated with Japan the demand for the product has resulted in saké breweries opening in several locations including North and South America, Australia and China.

The starting material is large grain rice. This is milled to remove the bran and most of the grain protein and lipids. The polished rice is then washed and finally steeped in water. The grains are then steamed to gelatinise the starch grains and denature any remaining protein.

The next stage is equivalent to the malting phase of conventional brewing. A proportion of the steamed rice is inoculated with a culture of *Aspergillus oryzae*. The mould is added in the form of a mixture of mycelium, which is rich in spores and rice grains. The whole is termed *tane-koji*. The mould grows on the rice grains to produce a mixture of grains, enmeshed in mycelium, the mixture being called *rice-koji*. The latter is mixed with steamed rice and water to prepare an initial mash that is called *moto*, or more properly *shubo*. This mixture is inoculated with a culture of the ethanol-tolerant yeast, *S. cerevisiae* (var. *Saké*). In this initial phase the growth of the natural bacterial flora leads to the formation of lactic acid and consequent reduction in pH. The latter effect inhibits the growth of many other undesirable bacteria. In modern processes the natural acidification is replaced by the direct addition of lactic acid. Over succeeding days further steamed rice, *koji* and water are added. This allows the yeast count to increase and ensures that sufficient cells are present to catalyse the main ethanolic fermentation. In this way saké production differs from conventional brewing in that saccharification and ethanol formation occur in parallel. When all the rice has been added for a single batch, the complete mash is termed the *moromi*.

The fermentation is allowed to proceed over a period of up to 6 weeks at a temperature of not more than 10°C. As in the case of brewing in the Western style, longer fermentation times are associated with a traditional process (and by implication better quality) as compared with a modern, more rapid, higher-temperature fermentation. In this period starch degradation and ethanol formation continue in parallel until the final ethanol concentration reaches 17–20% by volume.

When fermentation is judged complete the product is clarified by pressing. At this stage additional pure ethanol may be added to extract additional flavour-positive components. Where practised this has the effect of increasing the ethanol concentration by a further 1–2% by volume. In some cases additional flavour adjustments may also be made at this stage. Usually after a final polishing step the now brilliant product is pasteurised, adjusted to a desired ethanol content (*ca.* 15% abv) and bottled. After a period of storage for flavour maturation, it is consumed. It may be served chilled or warm depending on individual preference.

Saké is graded on the basis of the extent of the initial rice polishing step; in addition, there are several variants used in the finishing steps. It may or may not be pasteurised, the extent of filtration is variable providing a range of products that can be cloudy to clear, the dilution step may be omitted, some types are made to be consumed immediately after the fermentation is completed and some types may be matured for several years either in bottle or in cask.

Saladin Box

The name given to a piece of process equipment used in malting and devised in the late nineteenth century by the French engineer Charles Saladin. Saladin boxes were introduced in an attempt to mechanise the malting process and replace the manual input required for turning the beds in floor maltings. They comprise open rectangular tanks, initially made of concrete but in more modern incarnations, stainless steel. The tanks may be up to 50 m in length. Steeped grain is transferred mechanically into the vessel and formed into a bed of 0.5–1.5 m depth. During germination the grain is turned using a row of rotating helical screws. These are mounted laterally on a horizontal beam that automatically traverses the Saladin box and

in so doing turns the grain bed. The deck of the tank is perforated. A stream of attemperated and humidified air is forced through the perforations and into the bed of grains. Adjustment of the humidity and temperature of the air stream allows control of the malting process.

Sales gravity

Beer strength, in terms of alcohol content, at which it is presented to the consumer. The term is commonly used within the context of **high-gravity brewing** where, for reasons of economy of plant usage, a concentrated beer stream is generated and diluted immediately prior to packaging.

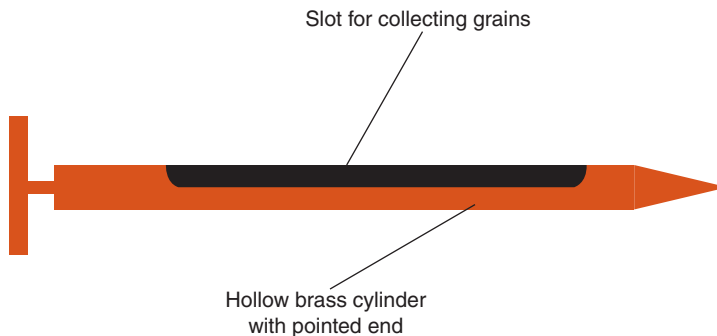
Salmon, E.S.

Ernest S. Salmon (1871–1959) was a noted agricultural scientist who whilst employed at Wye College in the United Kingdom in the years leading up to the Second World War embarked on a programme of hop breeding. By training, Salmon was a plant pathologist, and it is likely that work on the disease powdery mildew led him to specialise in the study of hops. Amongst his many achievements was a hop breeding programme that pioneered the use of combinations of European aroma and US varieties. The latter naturally has high alpha acids contents but generally was considered, in Europe, at least, to have inferior ‘American’ aromas. Salmon reasoned that the aroma and high alpha acid traits were apparently independent, and therefore, it should be feasible to produce hybrids with high resin contents but desirable aromas. As a result of the programme the **Brewer’s Gold** and **Bullion** varieties were released in 1934 and 1938, respectively. Later, in 1944, **Northern Brewer**, derived from Golding and a US male, was released. This latter variety was considered to be the first to achieve Salmon’s initial stated aims. These three varieties have been the progenitors of the vast majority of the current high alpha varieties grown throughout the world.

Sample spear

Sample spears are devices designed for removing and obtaining samples of grains from a bulk source. Several different designs and sizes are used depending on the size of the grain. Those for smaller grains tend to be of approximately 12 mm in diameter whilst those for larger grains have a diameter in the region of 25 mm. They comprise of cylinders, which are pointed in order to facilitate passage through the bulk of the grain. A handle is usually fitted to ease this operation. The cylinders have an aperture along part of the length of the cylinder to allow entry of the grains. Cylinder length is typically 40–45 cm.

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Sample spears are useful for removing grain samples from sacks of grain; however, the samples are not representative of the whole. For example, where some grains are infested within a bulk of largely clean grains, this simple type of sampling device may not detect this defect. In order to obtain more representative samples, more sophisticated devices are needed.

See **double-tube sampling spear, Ellis cup grain sampler, conical divider, diverter automatic grain sampler, pelican grain sampler.**

Sanded slab tests

Sanded slab tests are designed to assess the degree and homogeneity of modification of malt grains. Representative malt grains are placed on a slab and immersed in a liquid resin. The grains become anchored in place when the resin has set. The surface of the resin and embedded malt grain are sanded away to reveal the interior of the grains. The extent and homogeneity of modification of the grains is then assessed after treatment with chemical agents, which react with the exposed endosperm tissue and by virtue of the colour changes that occur reveal details of the cellular structure.

Several such tests have been designed. The most common is the **calcofluor Carlsberg sanded slab test**. In this test, which is described in *Analytica-EBC*, Method 4.14, *Modification and homogeneity of malt: calcofluor method*, the sanded grains are treated with calcofluor. This reagent reacts with β -glucans in the walls of endosperm cells. Examination of the stained grains using a suitable source of illumination reveals the fluorescence due to the β -glucan-calcofluor complex. A high level of fluorescence indicates poor modification. Uneven fluorescence reveals a lack of homogeneity.

Sanitisers

Chemical agents used for both cleaning and disinfection.

See **disinfectants.**

Santiam

Santiam is a US-bred aroma/dual-purpose hop variety that derives from a German Tettninger and Hallertau Mittelfrüh female crossed with a selected US tetraploid male. It is susceptible to powdery mildew but resistant to downy mildew. It contains 5.5–7.0% total α -acids (20.0–22.0% cohumulone) and 7.0–8.5% β -acids. Total oils are 1.3–1.7% (5.0–8.0% caryophyllene, 13.0–16.0% farnesene, 20.0–25.0% humulene, 30.0–45.0% myrcene).

Saphir

Saphir is a relatively new (post-2000) German aroma hop variety bred at the Hop Research Institute at Hüll. It has very good disease resistance and therefore is viewed as a substitute for the more disease-prone Hallertauer Mittelfrüh. It contains 3.0–5.0% total α -acids (11.0–15.0% cohumulone) and *ca.* 6.5% β -acids. Total oils are 1.5% (*ca.* 10% caryophyllene, 0% farnesene, *ca.* 20% humulene, *ca.* 40% myrcene).

Sarcina sickness

Historic name given to the symptoms of beer spoilage via infections with the lactic acid bacterium, *Pediococcus*, notably, the formation of turbidity, sometimes slimes and ropes, together

with sour odours and tastes and a strong butterscotch aroma owing to the formation of high concentrations of **diacetyl**.

SASPL

This test, an acronym for saturated ammonium sulphate precipitation limit test, is designed to assess the tendency of beers to form colloidal hazes. It is comparatively rapid and therefore provides a quick indication of the likely colloidal shelf life of a beer or the efficacy of stabilisation regimes.

It relies on the fact that ammonium sulphate is able to react with proteins and form visible precipitates. Since proteins and polypeptides react with polyphenols to form colloidal hazes (see **colloidal stability**), it follows that methods that assess the protein content of beers are likely to provide an indication of propensity for haze formation. In the test a saturated solution of ammonium sulphate is dosed into a sample of the beer. The amount that must be added before a visible precipitate is formed correlates positively with the protein content and by inference the shelf life. The method has the drawback that it has a low degree of discrimination. Methods that are aimed at detecting those proteins (**sensitive proteins**) that are known to be involved in haze formation are probably of more use.

Saturated ammonium sulphate precipitation limit test

See SASPL.

Satus

Satus is a US high alpha hop with relatively good disease resistance and reportedly similar in character to **Galena**. It contains 12.5–14.0% total α -acids (32.0–35.0% cohumulone) and 8.5–9.0% β -acids. Total oils are 1.5–2.8% (7.0–10.0% caryophyllene, 0% farnesene, 15.0–20.0% humulene, 40.0–45.0% myrcene).

Savinja Goldings

See Styrian Goldings.

Savinski Goldings

See Styrian Goldings.

SCADA

SCADA is an acronym standing for supervisory control and data acquisition. SCADA systems are centralised systems that monitor and control complex automatic processes of the types used in large-scale commercial breweries.

The systems are built up of several individual layers. They comprise field devices that operate the various individual parts of processes via the operation of switches, actuators on automatic valves, sensors and so on. The operation of the field devices is controlled by programmable logic controllers (PLCs). Outputs from the latter are linked via a digital communication system that outputs process data to a central supervisory system. The latter includes a human-machine interface (HMI), which, as the name suggests, allows the operator to gain access to the various data streams that the SCADA system generates. Commonly the HMI takes the

form of a graphical interface in which the process is depicted as a software-generated mimic of the various pieces of plant involved in the process. The status of steps in the process is indicated on the mimic. An important feature is the ability of the system to recognise out-of-control situations and raise alarms to trigger remedial actions. Collection of data with time allows trend analyses to be performed, the results of which can be used to prompt maintenance programmes.

SCADA systems operates in a hierarchical fashion such that the PLCs control a set of pre-defined conditions whereas the supervisory system, via the HMI, allows the operator to monitor process conditions and if necessary change the value of a set-point.

Scandinavian School of Brewing

The Scandinavian School of Brewing is located at Copenhagen in Denmark. It was founded in 1925 in a joint venture by the national brewing associations of Norway, Sweden and Denmark. In 1993 the Finnish Brewers' Association became a joint co-owner. The school is privately owned by the co-owners, receives no state subsidies and is not linked to any other technical institute or university. It has an advisory body that is made up of senior members of the brewing industry. Its aim is to provide an educational facility for the training of brewers. The training culminates in a Diploma of Master Brewer, although other general and bespoke courses are offered. Students are mainly Nordic although other nationalities are accepted.

Schalk continuous fermentation system

The Schalk semi-continuous brewing fermentation system was an early attempt to develop methods for continuous brewing and was patented in 1906. It comprised a series of six linked vessels. Aerated wort was added to the first vessel together with yeast sufficient to give a pitching rate approximately double that which would be used for a conventional batch fermentation. After 24–48 hours when primary fermentation had commenced, half the volume of tank one was transferred to the second vessel and both were topped up with fresh wort. After a further 24–48 hours the process of decanting and topping up was repeated with the second and third vessels. This process was repeated until all six vessels were filled with pitched wort. After the first vessel had reached attenuation, which occurred when the contents of vessel six were still undergoing vigorous primary fermentation, the green beer was removed and a further round of fermentations was initiated in tank one by adding fresh wort and half the contents of vessel six.

The system had the potential for high productivity and simplified yeast handling; however, the risks of contamination were severe. It was not exploited at commercial scale.

See **continuous fermentation**.

Schankbier

Schankbier describes one of the German categories into which beers are placed for the purposes of levying taxation. In this case the beer must be made from wort, which contains no more than 7–8% extract, equivalent to 1.5–2.6% abv alcohol.

Schneible continuous fermentation system

A two-tank semi-continuous beer fermentation system, patented by J. Schneible in the United States in 1902, which used a cascade-type approach to both shorten cycle times and reduce

yeast handling. Pitched wort was transferred into the first vessel where a vigorous fermentation was encouraged by continuous aeration and agitation. The fermenting wort was transferred to the second vessel where the fermentation was allowed to proceed to completion. After removal of the green beer leaving the bulk of the yeast behind, fresh wort was added to the same vessel and the process was repeated.

See **continuous fermentation**.

Schonfield test

The Schonfield test is one of several methods that are used to measure the germinative energy of grains.

See **germinative energy**.

Schooner

Schooner is an Australian malting barley variety accredited for use in 1983. Although being susceptible to many plant diseases, it was the dominant malting variety cultivated in central and southern low to mid-rainfall areas of New South Wales but has now largely given way to other superior varieties.

Schooner glass

In modern brewing, the name given to a measure of beer, or the glass it is served in, equivalent to three quarters of an imperial pint (425 mL). The schooner measure was introduced in some states in Australia as a means of providing smaller than usual volumes of draught beers both as a cost-saving strategy and as a means of preventing binge drinking. A similar measure is planned for introduction into UK bars.

Schwann, Theodor

A German scientist (1810–1882), a pioneering cytologist and, with the Frenchman, Charles Cagniard-Latour and fellow German, Friedrich Trautgott Kützing, is credited with the discovery of the vital nature of yeast and its role in fermentation.

Schwartz differential medium

Commercially available microbiological growth medium for differentiating wild from brewing yeast. Yeast nutrients are provided as meat extract, yeast extract and malt extract. Carbon sources are glucose and dextrin. The dye, basic fuchsin and sodium sulphite are added to inhibit the growth of Gram-positive bacteria. Wild yeasts form pink colonies whereas brewing strains appear as a background of thin growth. The medium is heat labile and must be sterilised by boiling but now autoclaving.

Schwarzbier

The name *Schwarzbier* derives from the German for 'black beer'. Thus, these beers, at least in appearance, are the visual equivalents of stouts. However, in nature they are actually simply darker versions of the *dunkel* variety of dark lager beers. The beers are produced by bottom fermentation using lager yeast strains and are fully attenuated. Hopping levels are moderate as are alcoholic strengths, values of 4.5–5.0% abv being typical. In consequence the beers are dry, moderately bitter and derive most of their character from the dark malts used in their manufacture. Thus, maltiness, sweet but not cloying and good body are dominant characters.

Scotch

A name given to a wedge used to secure casks of beer on a **stillage** and prevent rolling.

Scotch ale

Scotch ale is the name of a beer style associated with Scotland.

See **Scottish ales**.

Scottish ales

Scottish ale is a generic name for certain beers that originate from Scotland in the United Kingdom. The beers are ales produced by top fermentation. A number of different styles are recognised, and these are based largely on alcoholic strength. These are light, **heavy** and export. These have original gravities of approximately 1032 (8°P), 1037.5 (9.4°P) and 1045 (11.2°P), respectively. A fourth and stronger beer known as **Scotch ale** (OG 1080, 20°P) is also recognised. This may also be referred to as ‘**Wee Heavy**’ probably a reference to one-third of an imperial pint bottle (or ‘nips’) in which these stronger beers were sold. An alternative system of nomenclature is the **Shilling system** based on the price of each category of beer. Thus, barrels (36 imperials gallons) of each type of beer were invoiced as 60 shilling (60/–, light ale), 70 shilling (70/–, heavy), export (80/–, export) and 90 shilling (90/–, Scotch ale, Wee Heavy). These terms, which date from the nineteenth century, are still used often as part of specific brand names. Several variants may be found, particularly in the case of the stronger categories; thus, examples from 80 shilling (80/–) up to 160 shilling (160/–) may be found.

As a group the flavours of Scotch ales tend to be dominated by malty notes. They are quite well attenuated and are comparatively lightly hopped. The latter no doubt is a consequence of the fact that hops are not cultivated in Scotland.

Scuppet

The name given in the United Kingdom to a large spade traditionally used to load hop cones into pockets.

See **hop pocket**.

Scutellum

Literally ‘little shield’; the name given to a component of the embryonic tissue in grains such as barley. In the latter it forms a layer that separates the embryo from the endosperm.

See **barley grain**.

Sdružení přátel piva

Sdružení přátel piva is a consumer group based in the Czech Republic and with the aim of championing for what are perceived as traditional beers and campaigning against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Contact details are at <http://www.pratelepora.cz> (last accessed 18 February 2013).

Seasonal beers

Historically brewing tended not to be performed as an all-year occupation. In most cases this was due to the fact that it was difficult to control fermentation temperature during the warmer months of the year. In consequence attempts to brew in warm periods of the year resulted in

very rapid and uncontrolled fermentations. This would result in severe perturbations in flavour and in addition, microbial contamination and subsequent spoilage would have been commonplace. For this reason before the advent of industrial brewing, beers were often produced at certain times of the year. Owing to the plentiful supply of barley for malting and hops together with the relatively cooler weather conditions, beers were commonly produced during the autumnal months. Such beers were then often stored throughout winter and consumed from the following spring and throughout the summer.

Many countries with a long tradition of brewing have such beers whose names reflect this heritage. Examples include *Bière de Garde* associated with the Pas de Calais region of France, **October beers** from rural areas of the United Kingdom and *Saison* from Belgium.

The beers share no particular set of characteristics other than having a heritage of being brewed at particular times of the year. Thus, the beers may range from light to dark and with a variety of flavours. The majority tend to be ales and are produced by top fermentation. Commonly hopping rates were high presumably as a perhaps unwitting aid to preservation during the storage phase. The original beers were often produced as refreshing drinks for rural labourers and for this reason tended to be of relatively low alcohol content, typically around 3% abv. Alternatively, stronger versions might be diluted with other weaker beers. Several modern incarnations of these beer styles are now produced by commercial brewers. Many of these are much stronger than their more rural forebears.

Seawater

Desalinated seawater can be used for brewing, although in most circumstances the high costs of purification are prohibitive. It is, or has been, used where fresh water is not available or is in short supply. For example, the Amstel Brewery in Curaçao in the Caribbean uses treated seawater for brewing purposes. Towards the end of the Second World War, two UK naval vessels, HMS *Menetheus* and *Agamemnon*, were refitted as amenity ships, for the benefit of troops serving in the Far East. The amenities included breweries that used distilled seawater for brewing purposes. In the event only one of these, the *Menetheus*, was actually used for brewing although after hostilities had ceased. More recently a German cruise liner, the *AIDAblu*, has been fitted with a 5-hL microbrewery, which also uses the on-board ship desalination plant for brewing purposes.

In Japan, untreated seawater has been used as an ingredient in sakè brewing. In this case the so-called deep sea water is used. It is claimed that such water, which as the name suggests is abstracted from great depths, is of a constant cool temperature, free from bacteria and pollutants and with a high (and reportedly desirable) mineral content. The latter, it is claimed, leads to increased ethanol yields in sakè fermentations. The supposed health benefits associated with this source of water has captured the imagination of certain health-conscious consumers and in response the Asahi brewing company uses it as an ingredient in its *happoshu*, near beer called *Hannama*.

Secalins

Secalins are storage proteins found in the grains of rye. They are **prolamins**, one of the four major groups of proteins found in the grains of cereals, classified on the basis of their solubility and ease of extraction. Presumably secalins together with the corresponding rye glutelins will

make a major contribution to the protein contents of beers made with malted rye such as the German **Roggenbier**.

Secondary dormancy

Secondary dormancy is the phenomenon by which dormancy in grains can be prolonged to a greater than normal extent that would be typical for any particular plant variety. The effect is commonly caused by the plant being subjected to a period of rainfall immediately prior to harvest.

See **germination**.

Secondary fermentation

The term secondary fermentation is used in a rather loose sense to describe the phase that occurs after primary fermentation is finished but in which other changes occur that require the presence of viable yeast cells. The processes that may be associated with secondary fermentation, depending on the type of beer and the method of fermentation, are flavour maturation and formation of carbonation, the latter being termed conditioning. In addition, since secondary fermentation may also involve a period of storage at relatively cool temperatures, there may be some clarification due to the sedimentation of suspended solids. This does not require the presence of yeast but is merely an associated phenomenon that occurs, at the same time the clarification step does not form part of the secondary fermentation.

In the case of many beers, both lagers and ales, produced by modern rapid processes secondary fermentation occurs immediately after primary fermentation in the same vessel in which primary fermentation has been conducted. An example of this type of process would be the warm **diacetyl stand** associated with the production of many modern lager beers. In the case of these beers the distinctions between primary and secondary fermentation are arbitrary since the whole process represents a continuum. Lager beers produced by traditional methods and many ales have distinct secondary fermentations, which are usually carried out after primary fermentation is completed and the beer has been transferred to the next stage of processing.

Lagering

In the case of traditional lagers when the primary fermentation is judged complete, the beer is cooled and moved to dedicated maturation (lagering or ageing) tanks where the secondary fermentation occurs. Several options are possible, and these may take from a few days to several weeks or even months. Typically the primary fermentation is arrested by the application of cooling when some fermentable sugar remains (1–2°P) together with suspended yeast ($1\text{--}4 \times 10^6$ cells per millilitre). Lagering tanks are usually located in chilled cellars and the beer within them is cooled to 1–2°C. In the initial phase the yeast begins to utilise the residual sugar and forms CO₂ and a variety of other metabolites. Some of the latter, such as H₂S, are considered undesirable and are removed from the beer by allowing the tanks to vent to atmosphere. When the time is judged appropriate, usually after 1–2 days the tanks are sealed and allowed to pressurise to approximately 0.5 bar to allow carbonation to develop. Commonly the temperature is gradually decreased in order to allow the formation of chill haze. The lower the temperature that is achieved, the better the colloidal stability of the subsequent beer.

Occasionally the warmer initial and colder final storage phases may be carried out in separate lagering vessels. In the latter cold phases the role of yeast (and by implication whether or not it forms part of the secondary fermentation) is questionable. Undoubtedly the phenomena of **yeast shock excretion** and cellular lysis will result in the release of a multitude of yeast metabolites into beer. These may or may not contribute both positive and negative attributes to the finished beer. Whether these changes are different to those that occur in the warm conditioning stage associated with rapid modern techniques remains an area for speculation.

Several variations on this basic procedure are practised. Generally, these relate to the difficulties of controlling beer composition at the end of primary fermentation, particularly yeast count and fermentable residue. Some brewers use two yeast strains one of which is relatively non-flocculent. The strains may be either mixed in primary fermentation or run as two separate primary fermentations that are blended before transfer to lagering tanks. The underlying principle is that by blending it is easier to achieve the desired yeast count and fermentable residue. Alternatively, in the practice of *kräusening* (see *kräusen*), a proportion of actively fermenting wort (removed at the high *kräusen* stage) is added to the beer in lagering tanks in order to provide both yeast and extract to fuel secondary fermentation. Usually the volume added is approximately 10% of the total beer which is to be secondarily fermented.

Secondary ale fermentations

In traditional ale production, secondary fermentations are carried out either in large pack (**cask-conditioned beer**) or in small pack (**bottle conditioning**). At its simplest, beer is removed from primary fermentation after cooling, cropping the yeast and when the residual fermentable extract and yeast count are judged appropriate. At this stage the beer may be simply transferred into a cask or bottle wherein secondary fermentation occurs. The latter is mainly to generate CO₂ but some flavour changes that result from the release of yeast metabolites also occur, especially in the case of bottle-conditioned beers where the shelf life is relatively long. Although this process is simple it is difficult to control, and for this reason an intermediary tank, termed a **racking tank**, is used as a temporary store between fermenter and final pack.

Beer is held in a racking tank for 1–2 days during which time some yeast and other solid material settle out. The residual suspended yeast count should be approximately 1×10^6 cells per millilitre. Whilst the beer is held in racking tanks, adjustments can be made to colour and flavour. Additional fermentable extract is commonly added in the form of a syrup of sucrose or glucose. This process is termed priming. Priming rates are of the order of 0.35–1.75 L/hL of a 37°P syrup. This is sufficient to generate approximately 2 g per litre CO₂ in the beer in cask after secondary fermentation is completed. Even with the use of racking tanks, precise control of yeast count and extract is difficult. Some brewers choose to avoid this problem by filtering beer prior to transfer to racking tank and then adding back yeast cells to achieve a desired suspended viable yeast concentration. As well as allowing good control of yeast count prior to packaging, this approach also provides an opportunity to select a different strain for secondary fermentation to that used in primary fermentation. This process is termed cask beer re-seeding.

See **cask beer**, **bottle-conditioned beer**.

Seedless hops

Seedless hops are those cultivars that have been genetically modified so that they are sterile and do not produce seeds. This development has arisen as a consequence of the belief that the presence of seeds in hops used for brewing can result in the development of undesirable flavours. The basis of this prejudice is that oxidation of lipids present within the seeds may be the source of rancid flavours. The evidence for this relationship between seeds and the generation of off-flavours is not well proven and is despite the fact that the overall yields of seeded hops are greater than their unseeded counterparts. Nevertheless, most hop-growing areas take great pains to ensure that setting of seed does not occur. Indeed, most hop specifications include a maximum value for seed content, usually less than 2–3%. In Germany there are regulations that require that when wild hops are discovered in hop-growing areas, they must be destroyed. The exception is the United Kingdom where the realisation of the positive correlation between setting seed and yield resulted in most hop gardens being planted with male plants. This practice has been exported to the United States in areas where traditional UK aroma varieties were cultivated.

In studies performed in the United Kingdom during the 1960s, it was confirmed that the yields of unseeded hops were reduced by approximately 30% compared with their seeded counterparts; however, this was somewhat offset by the observation that there was an increase in the content of α -acids of the former. In this regard there is little advantage to be gained by growing high alpha varieties in seeded form. This observation did not apply to traditional aroma varieties such as **Goldings** or **Fuggles** where, in any case, the α -acid content is not particularly relevant. In the case of these cultivars, seeded cultivation remains the norm.

Seedless varieties of hops are usually triploid produced from crosses between tetraploid and diploid parents. Both aroma and high alpha varieties have been produced using this technique. This development has been particularly successful in New Zealand. The majority of triploid varieties are later maturing compared with standard types. In countries such as the United States or New Zealand this is not a disadvantage, unlike the United Kingdom where the lateness has made most of these types uneconomic.

See **hop varieties**.

Seeger grain turner

See **semi-continuous malting**.

Seidel

See **krug**.

Select

Select (also known as Spalt Select) is a German hop variety bred at the Hüll Hop Research Institute during the 1980s. It is an aroma variety with properties similar to Hallertauer and Spalt noble types but with much better disease resistance. It contains 3.5–5.5% total α -acids (20.0–25.0% cohumulone) and 3.0–4.5% β -acids. Total oils are 0.8–1.2% (6.0–8.0% caryophyllene, 10.0–15.0% farnesene, 15.0–20.0% humulene, 40.0–50.0% myrcene).

Selective medium for *Megasphaera* and *Pectinatus* (SMMP)

Microbiological broth designed for the cultivation and detection of the important anaerobic beer spoilage organisms *Megasphaera* and *Pectinatus*. The basal medium contains yeast extract, bactopectone, sodium lactate as the principal carbon source, sodium and potassium phosphates, sodium bicarbonate and sodium chloride. The addition of sodium thioglycollate and L-cysteine hydrochloride provides strong reducing conditions, which favour the growth of these extreme anaerobes. The basal medium is sterilised by autoclaving and when cooled supplemented with an ethanolic solution of sodium fusidate, cycloheximide and crystal violet. Sodium fusidate is an antibiotic that disrupts protein synthesis mainly in Gram-positive bacteria. The sterile broth in a sterile bottle is mixed with the suspect beer sample to brim-full thereby excluding air from the headspace. Positive growth can be detected within 2 weeks after incubation at 28–30°C. Ethanol and isohumulone in the beer suppress the growth of lactic acid bacteria, crystal violet and sodium fusidate inhibit Gram-positive bacteria, and cycloheximide prevents the growth of yeast.

Self-clarifying disc stack centrifuge

See **continuous centrifuge**.

Semi-continuous malting

These are malting plants in which the germinating grains are turned automatically by removal from the base of a vessel and return to the top or by moving between individual multi-compartments.

An example of the former approach is the **Engerth malting system** in which grains were germinated in rectangular tanks. Turning was achieved by dropping the grains from the base into a container from which an elevator conveyed them upwards for discharge onto a belt and back into the top of the same tank. In an early system patented in the United States in 1889 by J.F. Gent, a series of germination compartments were arranged vertically in a tower. The floors of each tank were perforated to allow forced ventilation from beneath. The floor of each compartment could be opened allowing the grains to move downwards, with mixing during each transfer, as germination proceeded.

The **Lausmann system** also used multiple tanks arranged laterally with transfers between each as germination proceeds. Each compartment has a perforated deck on which the grains sit and through which air is blown. Individual decks can be raised or lowered at controlled rates using a system of hydraulically driven pistons. Grains are transferred between compartments using a system of scrapers that are attached to an endless mechanically driven belt, which is suspended on a gantry which is suspended over and which can be moved along the row of tanks. Grains are transferred from a conical-bottomed steep to the first tank where they are evenly distributed on the deck. At this point the floor of the first tank is at its lowest point whilst that of the second is at its highest elevation. Germination is allowed to proceed by forcing moist air through the perforated floor and into the grain bed. After an appropriate period of time the floor of the first tank is raised and that of the second lowered. The scraper system is activated and thereby moves the bed from one tank to the next in a process that takes around 30 minutes and provides gentle but efficient turning. As germination proceeds the grains are gradually moved down the row of tanks and ultimately to a kiln.

The **Wanderhaufen** system adopts a similar approach to the Lausmann plant with the difference that the grains at different stages of germination are not separated into individual tanks but form a continuous bed. The steeped grain is transferred into one end of a long metal box fitted with a perforated floor through which attemperated air is forced. The box is termed a **germination street**. Multiple streets may be used, and these are usually arranged in pairs. At intervals the grain is turned and at the same time moved along the box. Germination is allowed to proceed as the grains move along the box until it is completed when it reaches the end and from which it can be removed or transferred directly into an adjacent kiln. As the bed moves down the street the increased degree of germination causes the bed to thicken and greater heat production. The temperatures and rates of flow of air are adjusted accordingly in individual parts of the bed. The grain turner usually takes the form of an endless belt to which is attached a number of buckets with alternating plastic brushes, termed an **Ostertag bucket-and-chain turner**. The belt is triangular in section and can be lowered into the bed of grains. In operation it picks up the grain in front of it and deposits it behind as it moves through the bed. The plastic brushes pick up any missed grains. Mixing is both very efficient and gentle. In another and more modern design (the **Seeger grain turner**), the turner takes the form of a row of helical screws. These are inclined and when lowered into the bed the grains are raised from the front and discharged at a distance behind. The discharge is onto a short endless moving belt which allows a long or short throw depending on the direction of rotation. The turners are mounted on a supporting arm, which allows them to be moved to turn the grains of parallel streets. Hoists allow them to be raised to allow them to be moved to the appropriate starting point without disturbing the bed.

Sensitive proteins

Sensitive proteins, or polypeptides, are those that are capable of forming colloidal hazes in beers by interactions with polyphenols. Mechanistic studies of haze formation suggest that haze formation occurs via binding between hydroxyl groups on polyphenols and proline groups in proteins; therefore, sensitive proteins or polypeptides in beers or worts are those that are rich in proline residues.

The concentration of sensitive protein in a sample of beer can be determined by measuring the amount of haze formed following the injection of a solution of tannic acid.

Sensory analysis

Techniques used to investigate the organoleptic properties of beer that rely on tasting by trained assessors under controlled conditions.

Beers contain many hundreds of constituent chemical compounds, often at low concentrations and many which are known to contribute to beer flavour and aroma. Many arise at concentrations close to their flavour threshold values. The contribution made to overall palate by individual components is complex since many interactions occur.

The power of the analytical techniques that can be applied to beer continues to grow. Methods are available that allow positive identification of most beer volatiles and techniques such as gas chromatography/olfactometry provide a means of resolving complex mixtures and assessments to be made of the taste and aroma of individual components. Devices such as the so-called **electronic nose** generate chemical fingerprints of the volatile constituents of

individual beers which in theory allow excellent discrimination between brands or individual batches of the same brand.

Despite these developments, routine chemical analyses of flavour-active beer components are usually very limited. Typically a volatile spectrum of any particular brand is likely to comprise specifications for no more than a handful of key components such as the most abundant esters and higher alcohols. For the most part assessments of beer flavour and aroma remain dependent on human tasters.

Bodies such as the EBC and American Association of Brewing Scientists (ASBC) have provided frameworks indicating how beer sensory analyses should be carried out. Most major breweries have sensory panels comprising brewery personnel who have been trained to taste beer in a consistent and objective manner. Results can be used to underpin routine production via confirmation that individual batches of beer fall within the normal range. They can be used for troubleshooting, to check the effects on organoleptic properties of new processes and raw materials and as part of new product development.

In order to perform these tasks the panellists need to be able to distinguish between batches of beer, where differences are perceived they need to be able to describe these and they are required to be able to quantify the differences. All of these tasks must be performed in a consistent and repeatable manner.

Selection and training is of paramount importance. Assessors must be trained to use a common lexicon to describe various attributes. Analytical method manuals of the EBC and ASBC have agreed 122 separate terms to describe beer flavour characteristics each of which has its own unique name. Those that are related are grouped together and where possible reference standards are described. More than 30 individual compounds have been identified and agreed for use as flavour training reference standards and this list is expanding.

Panellists are trained to be able to detect and discriminate between individual characters. Assessment of standards or spiked beers at given decreasing concentrations above flavour thresholds of chosen compounds allows identification of those tasters capable of producing repeatable results. The ability to identify consistently the odd-one-out in **triangular (three-glass taste) tests** confirms the abilities of the taster. Panels must have sufficient numbers of members to eliminate bias and make the results statistically valid and the performance of individuals must be monitored regularly to identify where additional training is needed.

Design of the sensory suite is important. The room must be quiet, held at a pleasant ambient temperature and separate to the production environment to ensure that it is odour-free. Lighting may be subdued if the appearance of the beer is not to be examined. Identical, clean and odour-free glasses must be used to serve beers, and they may be made from blackened glass to avoid subjective judgements made on appearance. Results may be recorded using paper, but more commonly a networked computer is provided into which results are input for subsequent analysis. Software packages are available to assist with statistical analyses. Tasters are seated in individual booths to minimise distractions and each is usually fitted with a hatch through which the samples are delivered. The process is managed by a dedicated sensory manager who is responsible for training, running tests, ensuring they are performed properly and analysing and reporting of results.

A number of testing procedures can be adopted. Descriptive analyses are performed by trained panels, typically, with at least 15 participants. Beers are assessed according to an agreed

list of attributes, and each of these is given a numerical score using an agreed scale. The results allow profiles of individual brands to be assembled and compared. The intensities of particular characters can be recorded graphically to facilitate comparisons to be made. For example, **spider web plots** use a wheel-type graphical representation of beer sensory characters. Individual attributes are shown as spokes radiating from the centre. Scores for each are marked on the spokes, the distance from the centre indicating the intensity. The points are joined together to give a two-dimensional shape, which characterises the particular beer. Results can be overlaid to indicate degrees of similarity or difference.

Other tests can be performed by trained panellists; they can be used as part of training programmes or used to assess beers by involving a wider number of participants. The triangular test is as described already. Directional difference tests require tasters to compare two beers and indicate the way in which the two differ with respect to a particular character. Paired comparison tests provide sets of two samples each bearing a random code number. Tasters assess the pairs in a given order and are either forced to indicate perceived differences, even if they cannot discriminate between them, or they can conclude that no difference was perceived. Statistical analyses of the results confirm or deny real sensory differences. Controls use identical pairs of beers. The same methods can be used in wider consumer testing where the testers are asked to declare a preference. These external consumer tests are expensive but useful where it is necessary to ensure that changes in the brewery have no adverse effects on the perceptions to the beers of the wider public.

Sequestering agents

Chemical agents that act as chelators of metal ions. By removing metal ions from solution they prevent reactions in which they might otherwise participate. In brewing they are commonly used as additives in cleaning in place (CIP) detergents. They sequester metal ions that might otherwise participate in reactions that lead to the formation of undesirable insoluble scales or precipitates. They are of two types. Stoichiometric sequestrants chelate metal ions and prevent the formation of insoluble metal salts. Threshold sequestrants influence the structure of potentially scale-forming metal salts by forming non-adherent complexes.

Examples of sequestering agents used in brewing

Sequestering agent	Function
Stoichiometric types	
Ethylenediaminetetraacetic acid (EDTA)	Form stable soluble complexes with scale-promoting metal ions
Nitrilotriacetic acid	
Gluconic acid derivatives	Chelators of metal ions whose effectiveness is promoted at high temperatures in alkaline conditions. For this reason they are used in conjunction with caustic soda in brewhouse cleaning and for bottle washers.
Sodium salts of polyphosphates	Constituents of powdered detergents
Threshold types	
Amino, tris-(methylenephosphonic acid)	Used in conjunction with caustic soda-based cleaning agents to maintain metal ions in a solution.
1-Hydroxyethane diphosphonic acid	

Serebrianka

Serebrianka is a Russian variety of hop, possibly related to **Saaz hop**. It has good aroma characteristics but no commercial importance because of poor vigour, yield and storage properties; however, it is part of the female lineage of the Cascade variety.

Serial fermentation

Serial fermentation describes the practice by which yeast cropped from one fermentation is used to re-inoculate a subsequent fermentation. This requires yeast to be cropped, stored temporarily and then inoculated (pitched) into a new batch of wort. Usually yeast crops from individual fermentations are isolated and not mixed with crops from other fermentations. These are referred to as **yeast lines**. In usual modern practice, a new yeast line, derived from a laboratory culture, is introduced periodically into the brewery, a process termed **yeast propagation**. The new yeast culture is pitched, cropped and re-pitched through a number of serial fermentations. With each cycle the 'generational age' of the yeast line increases. Most modern breweries put a limit on the number of times this procedure can be repeated before which a new yeast line is introduced. In order to manage this process it is necessary to keep precise records of the origin and fate of each yeast line. The number of serial fermentations any particular yeast line has been used for is termed the generational age or **yeast generation number**. Typically these are labelled as G_n , where n is the number of serial re-pitches. As with many aspects of practice the labelling systems of individual breweries may have their own peculiarities. Thus, some brewers refer to the initial pitch from the propagator as G_0 ; others may use G_0 as the crop from the first fermentation.

In the case of top-cropped fermentations, which by their nature trend to produce very clean yeast crops with low levels of contamination with trub and other non-yeast solids, the process may be repeated many times. Indeed, many traditional brewers successfully practice serial fermentation, for many thousands of generations over several years with no apparent adverse effects. Conversely, where bottom cropping is practised, as is the case for the vast majority of modern brewers using large-capacity vessels, the number of permissible generations is limited, usually between 5 and 20 times. Factors that increase the levels of stress to which yeast is subjected to such as very large batch sizes, elevated fermentation temperature and use of very concentrated worts have resulted in a general trend towards the lower levels of this range. There are several other reasons for reducing the number of times that yeast can be re-pitched. Bottom-cropped yeast is always contaminated with some trub and other non-yeast solids. The proportion of this undesirable material, which can produce errors in pitching rate control and be a source of inconsistency in beer analysis, increases with yeast generation number. Individual yeast cells are subject to a natural ageing process and undergo programmed senescence and death. Predictably, the fermentation performance of senescent cells is poorer than younger and more vital cells. The cropping procedure used can select for the older and less desirable fraction, and thus, this effect can be exacerbated with prolonged serial fermentation. Brewing yeast strains are not entirely stable genetically and periodically mutants can arise. These may have undesirable properties compared with the wild type. The likelihood of the formation and selection of mutants increases with each subsequent serial fermentation.

See **fermentation, crop**.

Serpins

Serpin is a contracted form of **serine protein inhibitor**. They are a superclass of proteins widely distributed in plant and animal cells. Occurrence in prokaryotes and eukaryotes such as yeast cells has not been confirmed. Over 1000 serpins have been isolated and described. As the name suggests they are usually inhibitors of serine proteases, although others inhibit cysteine proteases whereas some have no detectable inhibitory activity. They appear to have multiple roles *in vivo*. In animals they have regulatory functions and appear to be involved metabolic cascades. These may result in gross changes such as the control of clot formation in blood. In plants no definite functions have been definitively proven although they may serve to restrict the activity of proteases where activity would be inappropriate, for example, in cereal grains laying down storage proteins.

Serpins that exhibit inhibitory activity towards proteases do so via a unique so-called, *suicide substrate* mechanism. The serpin binds to the target protease in a way that involves a conformational change in the serpin molecular structure. The enzyme–serpin complex inhibits further proteolytic activity. The enzyme–serpin complex is unstable and eventually dissociation occurs. This liberates active enzyme but inactivates the serpin, hence the name of the effect.

Serpins have indirect relevance to brewing in that they occupy key roles in developing cereal grains. However, in a more direct sense, the major barley serpin is **protein Z**. This is one of the few proteins to survive the brewing process and to persist relatively unchanged in beer where it appears to be the major contributor to beer foam stability.

See **protein Z**.

Set mash

A set mash (also known as a **dead mash**) is one in which the mash separation process, usually in a mash tun, has been operated in an inappropriate manner such that the grains have been allowed to form a mass that is so compacted that the flow of liquid wort is impeded. Usually the problem is caused by the application of too much top pressure (the difference between that due to the liquid head in the vessel and that exerted under the false bottom to draw off the separated wort). This can occur when the rate of run-off is excessive. The problem may also arise from the use of poor quality malts, malt that has been ground too finely, one in which there is a high proportion of solid adjunct or one in which the presence of high concentrations of β -glucan causes high viscosity.

The likelihood of set mashes occurring can be prevented by the proper use of the mash tun and by the use of a mash with an appropriate make-up. In historical times in order to ensure that the mash was free-flowing, additional components such as oat husks were added to the mash to give it a more open structure. This process cannot be recommended since the additions can confer undesirable flavours. In modern operations, where permitted, the addition of various enzymes such as pentosanases, cellulases and β -glucanases can be used to control wort viscosity.

Where a set mash is encountered the remedy is to lift the mash off the plates by the application of liquor from beneath the false bottom of the vessel. This process is termed **underletting**.

Seventy shilling (70/-)

Also 70 Shilling, a name commonly applied to Scottish ales of medium alcoholic strength. These beers are also known as Scottish heavy ales.

See **Shilling system** and **Scottish ales**.

Shake-out

See **TPO**.

ShakesBeer

The ShakesBeer is a proprietary mash mixer and mashing tank produced by the Steineker company. It comprises a pre-masher in which the grist and mashing liquor are mixed and attemperated before addition to a mash mixing vessel. The latter is fitted with a novel mechanical agitator, the blades of which incorporate water jets, which are claimed to improve heat transfer. In addition, the mash vessel is fitted with devices which take the form of tubular structures, which contain motors that generate sonic vibrations. The makers claim that application of vibrations of defined frequencies at specific points in the mashing regime results in increased yields and shorter process times.

Shamit

Shamit is a native beer made by the Gurage ethnic group of Ethiopia. It is made from a ground mixture of bekel (germinated barley), Tef (a native grain similar to millet) and kita (a bread made from whole grain flour). The grist is mixed with water and allowed to undergo a natural fermentation for 3–4 days. The solids are removed by sieving when milled, toasted, dehusked barley is added. After a further day of fermentation the beer is flavoured with cardamom, black cumin and bishop's weed (*Ammi majus*) before consumption.

Shandy

Drink made from roughly equal quantities of beer and lemonade.

Sheaf cells

A column of cells found in barley grains that is fused to the testa in the central ventral furrow and projects into the endosperm.

See **barley grain**.

Sheet filters

Sheet filters are those that rely on an array of membranes through which the medium to be clarified is passed. They may be configured as a series of vertical rectangular sheets located in a frame as in the plate and frame configuration. Alternatively they may take the form of a stack of vertically arranged circular discs enclosed within a stainless steel envelope.

The sheets may be made from a variety of materials including cellulose or various artificial polymeric materials. The cellulose sheets are usually strengthened by cross-linking with resins. The resin provides greater wet strength and also increases the zeta potential. The latter improves the ability of the filter to remove particles via electrostatic attraction (see **zeta potential** for more details). Cellulose sheets can also be impregnated with filter aids such as

kieselguhr or perlite, which improves retention. Other impregnating materials include activated carbon and polyvinylpyrrolidone (PVPP), the latter for stabilisation in filter.

Sheet filters can be used in brewing for a variety of purposes. They are used for primary filtration where batch sizes are small or as stabilisation filters located after primary filtration. They may be used for the recovery of beer from waste yeast slurries, and they are employed for cold sterilisation.

Shekar

A Hebrew word describing any strong intoxicating drink. It is also used in the bible in a specific sense with regard to a distilled beverage made from the fermentation of an extract of corn and honey or dates.

Shelf cooler

See **remote beer cooler**.

Shell room

Name given to the space in traditional fermenting rooms between the false subfloor and the real floor of the room. The space is used to house and isolate pipework and other associated equipment, which is needed to service the fermentation vessels and to control the atmosphere of the room.

See **fermentation room**.

Shilling system

The shilling system is a historic system of nomenclature that originally arose in Scotland in the nineteenth century and was applied to Scottish ales. The names refer to the invoice cost, in shillings (1 shilling equals 5 pence in pre-decimal UK currency) per imperial barrel of beer. In this sense the numerical value correlates with the original gravity of the beer: thus, light ale (60 shilling), heavy ale (70 shilling), export ale (80 shilling) and 90 shilling, or greater, for Scotch ale (Wee Heavy). The old symbol for shilling (/–) was usually used, and this terminology has often been retained as part of the brand names for beers of this type.

See **Scottish ales**.

Shinsu Wase

Shinsu Wase is a hop variety bred from a Saaz parent in Japan. It was developed in response to the perceived need to produce native hop varieties and so reduce the dependence on imports. It was released in the early part of the twentieth century and became the dominant variety in Japan until the late 1960s when the breeding and release of other varieties with superior agricultural properties led to its demise.

Shive

A wooden or plastic bung used to seal a **cask** after filling.

See **cask**.

Short grown malts

See **chit malts**.

Sicera

A Hebrew word that describes any alcoholic beverage, including beer, other than wine.

Sigma head value

See **Helm method for beer foam assessment**.

Sigrist haze meter

A beer haze meter based on the measurement of light scattering at 90° using incident light with a wavelength of 546 and 600 nm.

SIHRB (Slovene Institute of Hop Research and Brewing)

The SIHRB (*Inštitut za mheljarstvo in pivovarstvo Slovenija*) is a centre for research primarily into hops located in the hop-growing region of Slovenia. It has been responsible for the breeding and release of 11 hop varieties, 4 of which account for the majority of the modern Slovenian hop crop.

Sikaru

A type of beer described on tablets produced by ancient Sumerians in Mesopotamia (*ca.* 5000 BC). The beer was made from spelt, barley or a mixture of the two. The product was flavoured with spices, especially cinnamon. Fermentation was spontaneous and for this reason this type of beer is claimed to be the antecedent of modern Belgian lambic beers.

Sike's hydrometer

A hydrometer used for the determination of the specific gravity of liquids. The Sike's hydrometer was the standard device used for assessing the liability for excise payments of spirits and worts in the United Kingdom up until 1907.

See **hydrometer**.

Silica gel

Silica gels of various types are process aids used to improve the colloidal stability of beers via the removal of potentially haze-forming proteins.

Silica gels are manufactured by reacting sodium silicate with an excess of mineral acid at a temperature between 45 and 55°C. The reaction product takes the form of very fine particles, which together form a matrix in which water molecules are immobilised. The resultant product is a **hydrogel**, which contains between 30% and 70% moisture, the remainder being SiO₂. In the final stage of production the hydrogel is washed to remove residual sodium sulphate. The washing process, which is carried out at controlled pH and temperature, such that the gel becomes cross-linked to produce a gel that contains pores of defined size. This material is milled to produce particles with a desired average diameter. In addition, the product can be subjected to a further drying process, which removes moisture to give a gel with a water content of less than 20%. These drier products are termed **xerogels**.

Silica gels remove proteins (or protein polyphenols complexes) via a combination of hydrogen bonding of the carbonyl groups of proteins to the surface of the gel particles and via absorption into the pores of the gel.

Stabilisation of beer with silica gel is particularly useful since they tend to selectively bind proteins with molecular weights of approximately 40,000 and with a relatively hydrophilic nature. These tend to be the proteins that are responsible for haze formation. Larger hydrophilic proteins, which are implicated in foam formation, tend not to be removed by silica gel.

Silica gel may be used as a kettle fining or during beer maturation either added directly to ageing tanks or incorporated into pre-coats in filtration. The grade of silica gel used depends on the application. Hydrogels generate less dust. Xerogels are a more recent development. They have high capacities for binding proteins and are very quick acting. This makes them particularly suitable for use as partial replacements of kieselguhr or other filter powders in the pre-coats of filters.

Silicone anti-foam

See **anti-foam**.

Silver

Silver has bacteriostatic and bactericidal properties. These properties can be made use of in a number of applications in brewing, in particular, for the sterilisation of water. This can be as a primary treatment of water destined for use as brewing liquor or for treatment of water used as a coolant, for example, in cooling towers where precautions are required to be taken against threats such as *Legionella*. More recently, the development of nanotechnology has resulted in the development of technologies in which surfaces can be imbued with antiseptic properties by providing them with a coating of silver nanoparticles. It is suggested that this approach could be used in sensitive and otherwise difficult to clean areas such as those parts of high speed filling machines, which come into direct contact with beer.

Silver ions exert their antimicrobial activity via their ability to bind to thiol groups in biomolecules of the target organisms. This causes inactivation of several key enzymes and in addition, disruption of DNA replication as a result of dimerisation of pyrimidines. The antimicrobial activity extends to both prokaryotes and eukaryotes.

For the treatment of water, an electrolytic process is used where the ions are generated by a cell that uses a silver anode and a cathode of carbon or stainless steel. Silver concentrations of 0.5–1.0 mg/L are used for disinfection.

Simcoe

Simcoe is a US high alpha dual-purpose hop variety released in 2000 and bred at Yakima Chief Ranches. It contains 12.0–14.0% α -acids, of which 15–20% is cohumulone, and 4–5% β -acids. Total oils are 2.0–2.5% (5.0–8.0% caryophyllene, 0% farnesene, 10.0–15.0% humulene, 60.0–65.0% myrcene).

Simon impact abrader

A device used to abrade barley grains (see **malt abrader** for more details). It comprises a conical-shaped housing into which a flow of grains is supplied from the top. The housing encloses a rotor, which consists of two discs separated by a number of steel pins. Rotation of the discs throws the flow of grains against the pins and thence onto a silicon carbide abrading ring located on the inner surface of the top of the chamber. The abraded grains pass

downwards into an inverted cone, which spreads and separates the flow. A stream of air is fed into the base of the conical housing, and this carries away dust and other small particulates via a laterally located exhaust pipe.

The machines are designed to handle flow rates of the order of around 10 tonnes per hour, and during this process some 0.5–1.0% of the total weight of grain is lost. In some installations two machines are used in series, although care must be taken to avoid too much damage to the outer husk layers.

Simple infusion mashing

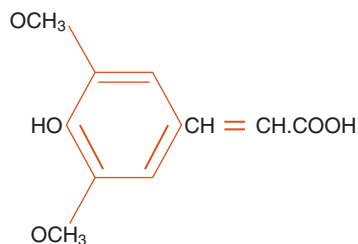
This is the mashing regime associated with the production of traditional UK-style ales. The process of mashing and sweet wort separation is carried out in a **mash tun**. Thick mashes are used made from coarsely ground well-modified malts. In a typical regime the grist is mixed with hot liquor (2.15–2.42 hL per 100 kg grist) to achieve a mash with a predetermined initial temperature (the **initial heat**, typically 63–67°C). The mash is allowed to stand until it gives a negative reaction using the iodine test. Typically this takes about 30 minutes. After this time the temperature might be increased by **underletting** (addition of hot liquor via the base of the mash tun). After underletting the usual temperature range of the mash would be 67–69°C. After a further stand of 2–3 hours, wort collection, re-circulation and **sparging** using water at 75–77°C commence. In a typical process up to 1.3 hL hot liquor per 100 kg grist would be added via underletting and a further 3.8–4.3 hL per 100 kg grist via sparging.

Compared with many mashing regimes the simple infusion process is lengthy to perform, up to 6 hours being commonplace but often much longer. Some time savings can be achieved by replacing the mash tun with a lauter tun since the latter allows the use of thinner mashes in which run-off is more rapid but care must be taken not to compromise extract yield and overall wort quality.

Infusion mashes may use grists, which include various adjuncts. The lack of flexibility with temperature means that these must contain starches that are pre-gelatinised or that have low gelatinisation temperatures. Commonly used adjuncts are raw barley, wheat flour, torried barley or wheat, flaked maize or wheat grits.

Sinapic acid

A simple phenolic compound, one of the series of substituted cinnamic acid derivatives, which are found in worts (see accompanying diagram for structure).



Structure of sinapic acid

Concentrations in unboiled lager wort are reported to be of the order of 0.4 mg/L.

See also **polyphenols**, **tannic acid**.

Single-use CIP set

Cleaning system where the cleaning agents are used once and then disposed of.
See **CIP**.

Siran™

Trade name given to porous borosilicate glass beads produced by the Schott Glaswerke Company. The beads are used as a support medium in immobilised yeast reactors.
See **immobilised yeast**.

Sirem

Czech aroma hop variety, which is a clone of Saaz.
See **Zatecky Chmel**.

Sixty shilling (60/-)

Also 60 Shilling, a name commonly applied to Scottish ales of the lowest alcoholic strength. These beers are also known as Scottish light ales.
See **Shilling system** and **Scottish ales**.

Sizer abrader

The Sizer abrader is a device used to abrade grains in order to accelerate the malting process (see **malt abrader** for more details). It comprises a chamber made from two horizontally orientated tapered cylinders mounted end to end at the wide ends. The chamber encloses rotating paddles to which are attached a number of projections. Grains are fed into the chambers via two top-mounted inlets where they hit the paddles and are forced into each other and against silicon carbide plates located on the inner surfaces of the chambers. The abraded grains fall into a central outlet shaft where they are cleaned of debris via passage through a vertical stream of air. The treatment results in a loss of approximately 0.3–0.5% of the total weight of the unabraded grains. The device is very efficient and care must be exercised to avoid too much damage or even total dehusking of the grains.

Skimming

The name given to the process of removing the yeast head from an open fermenter; an allusion to the action of removing the surface layer of yeast, which is formed during fermentation whilst creating a minimum of disturbance to the beer lying beneath.
See **open fermenter**.

Skimming back

See **dropping system**.

Skimming board

A device used to facilitate the removal of yeast heads from open fermenters.
See **open fermenting vessels**.

'Skunky' flavour

See **light-struck character**.

Slack malt

Slack malt is that which has been stored under inappropriate conditions such that it has a higher than normal moisture content. This is undesirable as deterioration of the grains is favoured in moist conditions. Malts are hygroscopic and in consequence easily absorb moisture. The storage conditions must reflect this risk and prevent occurrences such as sudden temperature changes that might induce condensation. Good quality malt should have a moisture content of no more than 4%.

Sladek

Sladek is a Czech hop variety bred in the Saaz (Žatec) region, registered in 1994. It contains moderate α -acids (5–7%, 25–30% cohumulone) but like many hop varieties from this region has relatively high levels of β -acids (6–9%). The latter are claimed to impart the ‘fine bitterness’ associated with Saaz hops. It contains 1.5–2.0% total oils (7–11% caryophyllene, <0.1% farnesene, 20–30% humulene, 40–50% myrcene).

Slaking heat

Slaking heat is the temperature increase that occurs when malt is mixed with water. It is also termed the heat of hydration. The amount of heat generated is inversely proportional to the moisture content of the malt.

It is of importance where it is necessary to predict the temperature of the mash in older infusion mash systems where it is essential to control precisely the initial temperature at mashing-in (see **mashing** for more details).

The initial heat of a mash (I) is described by the following equation:

$$I = \frac{[St + RT]}{S + R} + \frac{0.5H}{S + R},$$

where S is the specific heat of the mash, t is the temperature of the malt, R is the weight of water, T is the temperature of the water and H is the slaking heat of the malt.

Typical values for H range between *ca.* 5.5 g-cal/°C for a malt with a moisture content of 8% and *ca.* 17.0 g-cal/°C for a malt with a moisture content of zero.

It should be noted that the relationships given in the equation are approximate since the heat loss due to the mashing equipment is not taken into consideration. This will vary depending on the nature of the latter but it explains why the value of H is halved. Others prefer to estimate the heat loss and take this into account and in this case the value for H is not halved.

Slide culture

See **yeast viability**.

Slide valve

Slide valves are those in which a seal is made by a movable partition mounted at right angles to the pipe. The valve is closed by lowering the partition such that flow through the pipe is restricted. A rubber gasket provides a seal. In essence slide valves are similar in design to gate valves; however, in brewing applications they are used most commonly for regulating the flow

of dry goods such as malt or grist. Regulation of flow of dry goods by partial opening of the slide is reasonably effective.

Sloop

An Australian malting barley variety accredited for use in 1998. It was favoured over Schooner on the basis of improved yield and grain plumpness. It has been superseded by varieties such as Buloke and Flagship.

Sloop SA

An Australian malting barley variety which is similar to Sloop being early maturing but reportedly being especially suitable for cultivation in low rainfall areas. It has now been largely superseded by the Buloke and Flagship varieties.

Sloop Vic

An Australian malting barley variety released for use in 2002. It matures later than the Sloop and Sloop SA varieties and is reportedly most suitable for regions of relatively high rainfall.

Small beer

Small beer is the term used to describe beers that are of a lower alcoholic strength than usual. The term generally carries the inference of inferiority, for example, the practice of making small beer using the last runnings and therefore weaker worts. No doubt this explains the passage of the term into general usage as descriptive of anything that is relatively unimportant. In medieval England these weaker beers were sold at a lesser price than their full-strength counterparts. For this reason the small beer was also known as **penny ale**. Such beers might have the association of low status but they were also consumed by children or when the consumption of strong beer was not considered appropriate. Historically, in the United States, small beer was a low alcohol product intended for everyday consumption.

See **reduced alcohol beers**.

Smaragd

Smaragd (in English, *Emerald*) is a German aroma hop. It is described as being resistant to *Verticillium* wilt and downy mildew but sensitive to powdery mildew. It has average bitterness, average storage stability and good aroma. Analysis is 4.0–6.0% total α -acids of which 13.0–18.0% is cohumulone. Total β -acids are 3.5–5.5%. Total oil content is 0.4–0.8% of which 9.0–14.0% is caryophyllene, <0.1% is farnesene, 30.0–50.0% is humulene and 20.0–40.0% is myrcene.

SMaSH brewing

SMaSH is an acronym standing for single malt single hop. The process alludes to a practice recommended by some (mainly the United States) home brewers and microbrewers to produce a beer made with just a single variety of malt and hop. The suggestion is that this allows the brewer to identify with certainty the contributions to beer flavour made by these ingredients. This is logical provided that the effects on flavour of the yeast are also taken into account by ensuring the use of the same strain and one which has a relatively small flavour impact.

Smoked beer

Smoked beers are those in which the grist contains a proportion of smoked barley malt. The most well-known of these is the German *Rauchbier*, although similar products are brewed in Austria, Italy, Japan and Sweden. The style of beer has been adopted by some modern practitioners, particularly microbrewers, and hence, examples may be found in various parts of the world. Historically it is likely that many beers would have had some smoky character since malts were commonly kilned over open fires. With the advent of industrial malting and the use of closed kilns this practice has become rare and therefore smoked beers are largely reduced to regional peculiarities.

Smoked malt

In the majority of processes used for kilning malt an indirect source of heat is used since this prevents the introduction of flavours and aromas from external sources. Contrary to this smoked malts are those in which the drying process is carried out in the presence of a source of smoke. This imparts the finished malt with a characteristic smoky flavour and aroma. This is used for the manufacture of some speciality beers, for example, German *Rauchbier*. Usually the malts are dried by exposing them to the smoke from fires which are fuelled with beechwood chips.

Smoothcone

A New Zealand-bred disease-resistant hop variety released in 1961.

See **Cali**.

Smooth flow beers

Beers, usually ales, that may be canned or draught keg types, packaged with a headspace gas that contains both CO₂ and nitrogen. Nitrogen is less soluble than CO₂ in beer and its presence has the effect of producing a very stable creamy head, a consequence of the much smaller bubble size compared with normal beer foams. In addition, the level of CO₂ is reduced, which ameliorates the mouth tingle sensation associated with highly carbonated beers. The beers are packaged and dispensed, in the case of draught, with CO₂ content, typically *ca.* 1.2 volumes (2.4 g/L). This is significantly lower than the more usual 2.5–3.0 volumes (5.0–6.0 g/L) associated with most canned and keg beers. Nitrogen levels are of the order of 32–38 mg/L. Smooth flow beers can be packaged into cans, with or without a **widgit**; alternatively they may be packaged into kegs where they may be also known as **cream flow** or **nitro-keg beers**. Nitrogen is added to the beer before packaging and, for draught ales, is used in dispense (see **mixed gas dispense**).

For keg beers there are several approaches to obtaining the necessary gas composition. In all cases care must be taken to exclude oxygen. The requisite gas mixture can be introduced into bright beer tank via top pressuring and sparging via a sinter. It is easier to add the gas mixture in-line via thermal mass flow meters immediately before the pasteuriser, the turbulent flow nature of which assists with efficient gas solution and the back-pressure used prevents gas breakout. In-line dissolved nitrogen meters are used to ensure specifications are achieved. In the case of canned beers it is usual to adjust the carbonation in bright beer tank and then

add nitrogen immediately before sealing in the form of a carefully metered drop of liquid nitrogen.

Snapped malt

This is a synonym for **porter malt**.

Snifter glass

A stemmed and footed glass, bulbous at the bottom and narrow at the top. As with spirits such as brandy for which this type of glass is also associated, they are designed for stronger beers, such as barley wines, where aroma is an important part of the drinking experience.

Soak tanks

Receptacles filled with liquid disinfectants used as temporary storage for brewery fittings such as pipe connectors, valves and hoses. The fittings are used in applications where they come into contact with beer or other sensitive fluids and are required to be readily sanitised for immediate use. A variety of disinfectants/sanitiser can be used.

See **disinfection**.

Sodium hydroxide

Chemical (NaOH), also known as caustic soda, widely used in brewing as an alkaline detergent and cleaning agent.

See **detergents**.

Soft peg

A type of **spile**, often made from porous cane, inserted through a **shive**. Unlike hard pegs these are porous and allow carbon dioxide to escape during **conditioning**. The use of such spiles is called soft pegging.

See **cask**.

Soft resins

See **hop resins**.

Solid adjuncts

Solid adjuncts are sources of fermentable extract that are derived from a variety of cereals such as barley, rice, wheat, sorghum and maize. They may be supplied in many different forms that differ in the extent of pre-processing to which they have been subjected prior to supply to the brewery.

Examples include unmalted (raw) barley or wheat, grits of maize or rice, flaked maize, barley and wheat, torrefied or micronised wheat or various cereal flours. The physical nature of the adjunct and the gelatinisation temperature of the starch grains influence the degree of processing and plant required in order to make use of any particular solid adjunct. Predictably the nature of the adjunct and the proportion used in wort production has far-reaching effects on the brewing process and the resultant beer.

See **adjuncts**.

Soluble nitrogen ratio

The soluble nitrogen ratio is defined as the ratio of soluble to total nitrogen concentration. It is applied to extracts made from known quantities of malts ground and mashed under defined conditions. Analyses are performed using standard analyses, and the results are expressed with reference to the dry weight of malt used. This measure is that employed by the UK Institute of Distilling and Brewing. It is analogous to that employed by the EBC. In this case the extract is performed according to the conditions defined by the EBC and the result is referred to as the **Kolbach index**.

Both soluble nitrogen ratio and Kolbach index are used to gauge the degree of malt modification. The greater the magnitude of the result, the greater the extent of modification.

Soluble protein ratio

Synonym for **Kolbach index**.

Sooty mould

Hop plants and cones can become discoloured as a result of the growth of moulds such as *Cladosporium* spp. or *Fumago* spp. The moulds do not cause particular damage, and growth usually occurs on deposits of honeydew as a result of aphid infestation. However the unsightly nature of the mould growth will reduce the commercial value of hop cones. Control of aphids will reduce the risk of this defect.

Sorghum

Sorghum (*Sorghum vulgare*) is a member of the cereal family of plants, which grows in tropical regions. It was domesticated in pre-historical times and is now the fifth most important world cereal crop after wheat, maize, rice and barley. It is associated particularly with Africa where it is the second most important cereal grain after maize. The grains can be malted and are used widely in Africa for the production of beer.

Malting of sorghum grains began as a domestic enterprise used for the production of the so-called Native African opaque beers (see **native African beers**), but as demand grew it became an industrial process generating a product suitable for the production of clear sorghum beers similar to conventional lager beers.

The malting process is similar to that used for barley. Some sorghum varieties, often termed birdproof types, contain very high concentrations of tannins to the extent that the latter can inactivate malt enzymes during mashing. To obviate this problem grains can be steeped in formaldehyde or sodium hypochlorite for a period before rinsing and replacing with fresh steep water. In the malting process sugars and diastatic enzymes are formed. A key factor is that soluble nitrogen must be generated in sufficient concentration to support the growth of yeast and souring lactic acid bacteria in subsequent fermentation. Extract yields are of secondary importance since much of the latter is supplied in the form of adjuncts. Diastatic powers of sorghum malts are low compared with those of barley malts.

Sorghum beer

A beer in which all or a proportion of the extract is derived from raw or malted grains of the cereal sorghum (*Sorghum vulgare*).

See **Native African beers**.

Sorghumins

Sorghumins, also known as kafirins, are a class of prolamin proteins found in the grains of the sorghum plant. They are the equivalent of hordeins in barley.

Soubya

An Egyptian beer made from rice.

Southern Brewer

Southern Brewer is a high alpha bittering hop variety bred in South Africa. It has **Fuggles** parentage and in order to be usable was bred as a short-day variety.

The analysis is 9.0–15.0% total α -acids of which 38.0–41.0% is cohumulone. Total β -acids are 3.6–4.5%. Total oil is 1.5% of which 9.2% is caryophyllene, 13.3% is farnesene, 19.0% is humulene and 41.0% is myrcene.

Southern Cross

Southern Cross is a New Zealand triploid high alpha hop, dual-purpose variety that is derived from a cross with the **Smoothcone** cultivar. It was released in 1994. It contains 11–14% total α -acids of which 25–28% is cohumulone; β -acids are 5–6%. Total oils are 1.2% of which 6–7% is caryophyllene, 7% is farnesene, 20% is humulene and 32% is myrcene.

Southern Hallertau

Southern Hallertau is an Australian hop bred in 1986 from the German Hallertau Mittelfrüh aroma variety. Analysis is 4.9–6.3% total α -acids of which 22.0–26.0% is cohumulone. Total β -acids are 1.3–1.7%. Total oil content is 0.6–0.7% of which 10.0–14.0% is caryophyllene, 0% is farnesene, 25.0–47.0% is humulene and 2.0–12.0% is myrcene.

Southern Promise

Southern Promise is a South African hop variety that derives from a cross between Southern Brewer, another South African variety, and a wild Slovenian male. It is a high alpha acid bittering type but with a pleasant aromatic quality, which makes it suitable for dual-purpose use.

The analysis is 9.5–11.5% total α -acids of which 20.0–22.0% is cohumulone. Total β -acids are 3.6–5.4%. Total oil is 0.7% of which 9.0% is caryophyllene, <0.1% is farnesene, 25.5% is humulene and 22.0% is myrcene.

Southern Saaz

Southern Saaz is an Australian aroma hop produced in 1997. It is a seedless triploid variety bred from a Czech Saaz parental type. It shares with the parental type a high content of farnesene. Analysis is 4.6–7.0% total α -acids of which 23.7–28.0% is cohumulone. Total β -acids are 3.0–4.6%. Total oil content is 0.5–1.1% of which 6.0–9.0% is caryophyllene, 23.0–25.0% is farnesene, 19.0–26.0% is humulene and 17.0–23.0% is myrcene.

Southern Star

Southern Star is a hop variety bred in South Africa from another local variety, **Outeniqua**, and a South African male. It is a high alpha bittering variety.

The analysis is 12.0–14.0% total α -acids of which 31.0% is cohumulone. Total β -acids are 4.8–5.2%. Total oil is 1.6% of which 14.6% is caryophyllene, 12.0% is farnesene, 21.9% is humulene and 38.9% is myrcene.

Space barley

Brand name given to a beer produced by the Japanese brewer Sapporo made from malt grains, which were the fourth-generation progeny of seeds that had spent 5 months in space during 2006 on the International Space Station. The variety was Haruna Nijo and the crop was produced in 2009. The hop component of the beer was also derived from seeds that had been exposed to space.

Spalt

Spalt is a variety of hops that takes its name from the Spalter region south of Nuremberg in Germany. It is one of the four varieties of **noble hops** noted for low bitterness and delicate aroma and flavour.

It contains relatively low concentrations of α - and β -acids (4–5% w/w of each). Total hop oil concentration is 0.5–1.1 mL/100 g and contains myrcene (10–20%), humulene (20–30%), caryophyllene (12–17%) and farnesene (12–17%).

Spalt select

See **Select**.

Spanish juice

Name given in eighteenth- and nineteenth-century United Kingdom to an aqueous extract of liquorice made from the root of the plant *Glycyrrhiza glabra* and used as an adulterant in dark beers, particularly, stouts and porters.

Sparge arms

Sparge arms are devices fitted to mash tuns or lauter tuns that facilitate spraying the bed of grains with hot liquor to release entrained wort.

See **mash tun**, **lauter tun**.

Sparge heat

Sparge heat is the term used to describe the temperature of the liquor that is used to sparge the grain bed during the mashing phase of brewing.

See **mashing**.

Sparge temperature

See **sparging**.

Sparge water

Sparge water, also known as sparge liquor, is water that is used in the operation of a lauter or mash tuns where the bed of grains are sprayed in order to remove entrained wort and possibly to control the temperature of the mash.

The composition of sparge water is similar to that used for mashing; in particular, the pH, hardness and calcium levels are important. Alkaline sparge liquor must be avoided in order to prevent over-extraction of malt polyphenols, which would have negative effects on beer colloidal stability and flavour.

See **water**.

Sparging

The term sparging, according to the *Oxford Shorter Dictionary*, is a Scottish or Northern England dialect word which describes the action of sprinkling with water. It is associated with brewing where it is used in relation to mashing or occasionally to various gassing processes.

In mashing, sparging describes the process using a mash or lauter tun by which liquor is sprayed onto the surface of the mash bed. In the case of mash tuns this is accomplished using a set of sprays (sparge arms), made to rotate either mechanically or using the angle at which the water is directed into the vessel, which are arranged such that the whole surface of the bed of grains is exposed to the liquor treatment in an even manner and at a controlled rate and temperature. In the case of lauter tuns the presence of rakes or knives that disrupt the grain bed lessens the need for rotating sparge arms, and therefore these may be fixed or rotating depending on the preferences of individual fabricators.

Sparging is used to ensure that the maximum quantity of wort is extracted from the spent grains. In addition, the addition of liquor at a defined temperature is used to control the temperature of the mash. For this reason the temperature of the applied liquor and hence the temperature of the mash may be referred to as the **sparge temperature** or **heat**.

Sparging is also used where it is necessary to treat liquids with gas in order to cause a change in the dissolved concentrations of the same. In this sense the word sparging is used to suggest that the gas is added in the form of a spray of fine bubbles such that rapid solution is favoured. Examples would be where oxygen or air might be added to wort in a fermenter in order to provide stimulus to the yeast in the event of a stuck or sluggish fermentation, and treating liquor or beer with a stream of CO₂ to reduce dissolved oxygen concentration or to adjust carbonation. In both of these examples it would be usual to use a sinter or candle in order to reduce the bubble size of the stream of added gas.

Sparkler

A device used in draught beer dispense, which consists of an adjustable and removable tap nozzle, typically made from stainless steel or (coloured) plastic, containing small holes that causes beer to produce foam at the point of **dispense**. Tightening, loosening or removing is used to control the size of the foam head of ales (**keg** and **cask**).

Spartan

See **Valtický**.

Spear

A component of a beer keg through which the container is both filled and beer is dispensed.

See **keg**.

Speciality malts

Speciality (or special) malts are those products that are used mainly to impart flavour, colour or both to beers. As such they do not require possession of the enzymes that are needed to catalyse the reactions of saccharification and proteolysis associated with the mashing phase of brewing. Indeed many, if not most, special malts are made in such a way that enzyme activity is destroyed. For example, many speciality malts are manufactured using heating in order to generate the coloured and flavoured compounds that contribute some of the characteristic features of individual beer styles.

Speciality malts are used in conjunction with **base** or **white malts**. The latter provide extract and the bulk of the enzymes needed in the mashing phase of wort production.

Specific bed volume

The specific bed volume is a parameter used to quantify the properties of filter aids used in beer filtration. It is defined as volume of filter bed produced per unit mass of dry filter aid. Values for kieselguhrs vary approximately between 2.5 and 3.0 m³/kg for fine and medium grades, respectively. Values for perlites are higher and of the order of 4.0 to 5.0 m³/kg for fine and coarse grades, respectively. A related value is the apparent wet density, also termed the cake density. This is the reciprocal of the specific bed volume.

These parameters provide a rough measure of the quantity of powder needed for a filtration run; however, they do not necessarily give a good indication of the efficiency of various filter aids, although, in general, the lower the value for specific bed volume, the finer the grade of powder.

Specific gravity

The specific gravity of a solution (also termed **relative gravity**) is equal to the ratio of the density of a liquid at a specified temperature compared with the density of water at 4°C (the temperature at which its density is maximal). It has no units.

In the United Kingdom the specific gravity of worts or beers is usually quoted times 1000. Thus, a wort with a specific gravity of 1.060 would be generally be referred to as having a gravity of 1060.00, or simply 1060.

S

Spectrophotometry

See **turbidometry**.

Spelt

Spelt (*Triticum spelta*) is an early form of hulled wheat similar to emmer and einkhorn. It is used commercially in some Bavarian beers (where it is referred to as *dinkel*) and has been included as an occasional ingredient by some craft brewers.

The spelt plant is hexaploid and arose via hybridisation between tetraploid hulled wheats, such as emmer and either diploid wild grasses or other domesticated wheats.

In archaeological terms cultivation of spelt is associated more with Europe than with the Near and Middle East. The latter geographical areas are more usually associated with the early domestication of wild cereals for use in baking, brewing and other foodstuffs. It was a principal cereal crop up to the Middle Ages in many European countries. Since that time its popularity

declined with the concomitant rise of higher yielding and more tractable wheat species. In recent years its popularity with consumers of organic foods has increased, a trend that owes much to the fact that it prospers in poor soils without excessive use of fertilisers.

Spent grains

Spent grains (also known as draff) constitute the solid residue that remains after wort has been separated from the mash. In the vast majority of breweries they are a waste material. The composition varies with the type of grist used; however, the spent grains contain the remnants of the husks and other plant materials minus the soluble components that have been extracted and removed with the liquid wort. Predictably, therefore, the spent grains contain a high proportion of polysaccharide cell wall material with some lipids and proteins. In addition, a proportion of entrained wort remains. The actual concentration of residual extract and the water content depends on the method of mash separation employed. Thus, mash presses give the driest product (50–55% moisture compared with 75–85% from a lauter tun).

In the majority of breweries spent grains are sold for a small profit to be used as animal feed, particularly for ruminants. In many cases it is sold as is. In some cases it may put through a dewatering process using a screw or roller press. Apart from generating a drier and more easy-to-handle product, this process recovers some of the entrained extract that can be returned to the brewing stream and thereby improve overall yields. However, this approach must be subject to careful control since spent grains are readily colonised by a variety of spoilage microorganisms. The results of spoilage generates unpleasant aromas, and it is important to ensure that the grains are stored in an appropriate location away from other process streams and in plant which is properly cleaned. In order to prevent microbial attack, spent grains destined for animal feed are commonly treated with preservatives such as propionic acid. More rarely the grains may be dried with hot air. Other brewery waste streams, including excess yeast, trub, spent hops and even filter powders may also be added to spent grains.

The relatively small economic value of spent grains has provided the impetus for attempts to develop new processes by which their value can be increased. Several potential opportunities have been proposed. These include use as soil improvers, mushroom composts, poultry feed, fish feed and building materials. The majority of these have proven both difficult and generally uneconomic because of the need and cost of removing water. The most promising opportunities would seem to be treatments where the grains are used for the generation of biogas in various types of digester. Alternatively it has been proposed that with the aid of appropriate enzyme treatments, it may be possible to hydrolyse the cell wall and other structural polysaccharides and produce additional extracts.

Spezial Helles

Variant of the German *Helles* style of light-coloured Bavarian beer. The prefix indicates that these beers are seasonal types brewed for special occasions.

See *Helles*.

Spezyme GDC®

Name given to preparations of beads of diethylaminoethyl (DEAE) cellulose used as a support medium in immobilised yeast reactors. The beads supplied by Cultor of Finland are described

as granulated derivatised cellulose (GDC) and are claimed to be robust and provide a relatively sheltered environment for bound yeast cells thereby reducing risks of accidental sloughing off due to shear forces. The beads comprise DEAE cellulose attached to a polystyrene support with added titanium dioxide to increase the density of the beads.

See **immobilised yeast**.

Spheroconical dual-purpose vessel

Vessels that comprise of a spherical body to which is attached at the base a cone for collection of yeast were installed in the 1970s in the El Aguila Brewery in Madrid, Spain. They owe their novel design to the perceived requirement to develop a vessel with a large capacity suitable for both fermentation and cold conditioning and which minimised the cost of construction materials. These vessels meet this need in that the spherical configuration offers the optimum geometry for enclosing the maximum volume within a container, which has the minimum surface area. In addition, spheres are very resistant to deformation caused by internal pressures, and attenuation via wall-mounted cooling jackets should be efficient as should be mixing via the strong convection currents generated via thermal gradients and CO₂ evolution. Wetting losses should be small since spherical tanks have excellent draining properties and CIP systems ought to be highly efficient.

The Spanish vessels were constructed from stainless steel. Since they were constructed at a location where the climate was hot, the stainless steel body was insulated with foam and an outer weatherproof shell made from epoxy resin. The operating capacity was 5000 hL. Cooling was provided by a supply of propyleneglycol (25% aqueous solution) circulated through four jackets located on the spherical portion of the vessel and one surrounding the cone. The total cooling area was 150 m². The diameter of the sphere was 10 m. The cone, located at the base of the vessel, was 1.95 m in height.

The worts were of 11.4°P and were fermented at an initial temperature of 12°C using a dissolved oxygen tension of 3–5 mg/L and a pitching rate of 30×10^6 viable cells per millilitre. The yeast strain was highly flocculent. Primary fermentation lasted for 4 days during which the temperature was allowed to rise to 14°C. After this time cooling was applied and over 20 hours the temperature was reduced to 8°C. After removal of the yeast crop, which collected in the cone during the cooling phase, the temperature of the green beer was reduced to 0°C and it was held for a maturation phase of 21 days. In this phase the carbonation was adjusted an operation it was claimed that was made easier by being able to pressurise the tank. Compared with beer made using tanks with a more conventional geometry, it was noted that it was necessary to reduce the hopping rates by 12% in order to achieve comparable hopping rates. This was ascribed to reduced loss rates owing to a diminution in foaming. This author has made similar observations using cylindroconical fermenters fitted with mechanical agitators. It is tempting to suppose that improved mixing might be implicated in the reduced bittering losses.

Despite the apparent advantages offered by spheroconical fermenting and conditioning vessels, their use has not seen adoption by the other brewers. Almost certainly this is a consequence of the perceived difficulty of constructing spherical vessels compared with those with a cylindrical geometry.

Spherosome

Name given to structures found in the endosperm of barley cells and which function as lipid storage bodies.

See **barley grain**.

Spider web plot

A tool used to provide a graphical representation of the sensory characters of a beer.

See **sensory analysis**.

Spile

Name given to a peg, usually made from wood or plastic, which is hammered into the shive of a cask. The spile is used to restrict or allow the passage of gases into (air) and out (carbon dioxide) of the cask. Spiles that are porous and allow gas exchange are called soft spiles or pegs whereas those which are not permeable are called hard spiles or pegs.

See **cask, cask-conditioned beer**.

Spirit indication of distillate

See **original gravity (OG)**.

Split treatment

Split treatment is the term given to a process that can be used in the softening of brewing water, which contains high levels of magnesium bicarbonate. The water to be treated is split into two portions. One of these, equivalent to roughly a third of the whole, is dosed with high levels of calcium hydroxide (lime). This causes the precipitation of calcium carbonate and magnesium hydroxide.



The treated water is then mixed with the remaining untreated portion and as a result the calcium bicarbonate is precipitated as the insoluble carbonate, and iron and manganese ions are precipitated as hydroxides. The treated water is alkaline and must be acidified before use.

Spontaneous fermentation

A spontaneous fermentation is one in which inoculation of the growth medium with an organism, or group of organisms, responsible for the fermentation, occurs via chance contamination.

Undoubtedly all archetypal fermentations occurred in this fashion; thus, yeast strains capable of catalysing ethanolic fermentation occupy ecological niches where sugary solutions may be found. Spoilage of foodstuffs such as fruits would have resulted in the production of ethanol. The ability of yeast to scavenge oxygen would prevent utilisation of ethanol by other organisms and therefore it would accumulate. The low pH, anaerobic conditions and presence of ethanol would prevent the growth of many other contaminating organisms and a beverage, the result of spontaneous contamination would have resulted. In nature several species of

animals are known to be attracted to spoilt fruits and to consume them, presumably an acknowledgement of the mind-altering effects of ethanol. No doubt, very early in the history of mankind, the benefits of alcohol consumption were also recognised.

Before the role of yeast in ethanolic fermentation was recognised, all fermentations were to some extent spontaneous. The environment of the brewery with its plentiful supply of suitable nutrients would have resulted in the acquisition of an equally plentiful yeast flora as well as a range of other microorganisms capable of growth on beer or its raw materials. Even when attempts were made to control the inoculum, it would have been true that many of these chance contaminants would have also contributed to the fermentation. The modern industrial brewing process has developed from this unwitting beginning. The development of modern microbiology was required to unravel the role of these various organisms. This explains why many modern commercial brewers still use mixtures of brewing yeast strains.

Spontaneous fermentation, albeit in a semi-controlled fashion, is practised in the production of Belgian **lambic beers**. In this case the wort is allowed to cool in open vessels and is allowed to be contaminated by chance ingress from the microbial community which is found in the room.

See **lambic beer**.

Spray balls

Components of CIP systems that are designed to distribute cleaning fluids over the internal surfaces of items being cleaned. Typically they are located in the central upper parts of tanks, and the actual location must be chosen carefully to ensure that all surfaces are within reach. Low-pressure types are fixed units and are simple hollow stainless steel balls pierced by a number of holes that provide the necessary jets of fluid. High-pressure types are made to rotate by the force of the incoming fluid and provide a pattern of spray whose field of reach covers the whole of the internal surface of the vessel being cleaned. These types may be highly sophisticated with multiple spray heads able to rotate in several planes (horizontal and vertical) ensuring very efficient coverage.

Spray steep roller milling

Spray steep roller milling is a technique in which malt grains are moistened before milling. The intention is to subject the grains to a controlled wetting process that renders the husk more pliable whilst keeping the interior structures of the grain dry and hence brittle and amenable to dry milling. This treatment ensures that the husks survive milling in a largely intact form and therefore provide an open well-draining filter bed during the mash separation stage of wort production; however, the endosperm material is still subjected to an adequate milling treatment so as to ensure high extract yields.

See **milling**.

Springmaischverfahren

See **jump-mashing**.

Spruce beer

Beer-like beverages that are flavoured with the buds or needles of spruce trees and associated with Europe and North America. The ingredients impart floral and resinous flavours and

aromas. Several variants may be encountered, both alcoholic and non-alcoholic. Alcoholic versions are made using sugar, either refined or molasses, as the source of fermentable material and the spruce extracts are added as flavourings.

The spruce flavourings introduce significant amounts of citric acid and for this reason spruce beer was given to the crew of the ship of Captain James Cook, the explorer, as a means of combating scurvy.

European versions use the Norway spruce where the extract provides an alternative flavouring to hops. In North America the red black or sitka spruce trees are used. In these cases most recipes also use hops.

Squalene

A triterpene metabolic intermediate (see diagram for structure) that in the presence of oxygen is epoxidised and via a further series of rearrangements used to synthesise sterols. It has a variety of commercial uses including pharmaceutical applications, possibly as an anti-tumour agent. In anaerobic yeast the lack of oxygen results in its accumulation and levels of around 1% of the total dry weight may be found.



Structure of squalene

Square

Shorthand term used to describe any fermenting vessel with a rectangular geometry.

See **open fermenting vessels**, **closed square**, **box fermenter**.

Squeeze malting

Name given to a procedure designed to malt grains using a low water content and thereby reduce the costs of the final kilning step. Grains are steeped to approximately 36% moisture after which water is removed by passing the grains through a series of rollers with a gap size of approximately 1.8 mm. In addition to dewatering, the squeezing treatment damages the surfaces of the grains such that the uptake of additives such as gibberellic acid is facilitated.

Stabilisation

Procedures used to improve the colloidal stability of beer and as a result increase the shelf life before haze formation occurs.

See **colloidal stability**.

Stabilisation in filter

Stabilisation in filter is the collective term given to those practices where the adjustment of the colloidal stability of beer and filtration are combined in a single or closely related set of processes. Several options are available but all share the use of chemical agents that are capable of precipitating or binding polyphenols and or proteins.

For comparatively small filtration runs, plate and frame filters can be used in which the filter sheets are impregnated with PVPP for the removal of polyphenols [see **polyvinyl-polypyrrolidone (PVPP)** for more details]. After use the sheets can be regenerated by back-flushing with hot caustic soda solution. For larger-scale operations PVPP is dosed in-line into the beer stream after filtration through a primary powder filter. The flow and dosage rates are arranged such that the required contact time of approximately 5 minutes is achieved. The PVPP plus bound haze-positive polyphenol is then removed using a second dedicated filter, usually of the horizontal leaf type. Prior to use the filter is pre-coated with PVPP. The PVPP is regenerated on the filter by treatment with caustic soda solution followed by water rinses and treatment with mild acid to achieve neutrality. After this the filter is emptied and the regenerated PVPP returned to the dose tank for reuse.

Removal of proteins via treatment with silica gel requires only a short contact time. Stabilisation can be achieved by incorporating a suitable grade of silica gel into the body feed of conventional powder filters.

A combined stabilisation and filtration system, which first removes proteins and polyphenols by passage through absorbers containing cross-linked agarose beads followed by cross-flow filtration, has been introduced by the Handtmann Company of Biberach, Germany.

See **cross-flow filtration**.

Stabilised hop pellets

See **hop pellets**.

Stabiquick

Stabiquick™ is the trade name given to a silica gel of the xerogel variety aimed at removing potential haze-forming proteins during beer filtration. It is made by the German company Stabifix Brauerei-Technik KG. The company manufactures a range of silica gels, both hydrogels and xerogels, the names of all of which contain the prefix 'Stabi'.

See **silica gel**.

Staling aldehydes

Group of aldehydes whose formation in packaged beer during ageing is considered partially responsible for the formation of stale aromas and tastes. Several compounds have been implicated including especially **trans-2-nonenal**. Many others may also be implicated, in particular, a group of Strecker aldehydes.

See **beer flavour stability**.

Standard Reference Method (SRM)

See **beer colour**.

Standard reference wort

The standard reference wort is defined as that which is obtained at the completion of boil and immediately before transfer from the kettle. The composition and quantity of the standard reference wort is product specific since it is dependent on the nature and quantities of raw

materials used and the conditions used in their subsequent processing. The efficiency of subsequent brewing operations is made with reference to this parameter.

Stange

A name given to a German beer glass, which is popular in the northern part of the country. The glass is tall and very narrow and the name, which translates as stem, rod or stick, is descriptive of this shape.

Star steam heater

A star steam heater is one of a variety of designs of internally mounted heaters designed to increase the efficiency of heat transfer and mixing in wort boiling kettles. It comprises a series of vertical vanes with a central feed pipe through which steam is introduced. Each vertical vane is a panel in which a steam jacket is located. The *raison d'être* of the device is principally that of increasing the surface area for heat transfer without introducing a large and difficult-to-clean internal structure.

See **wort kettle**.

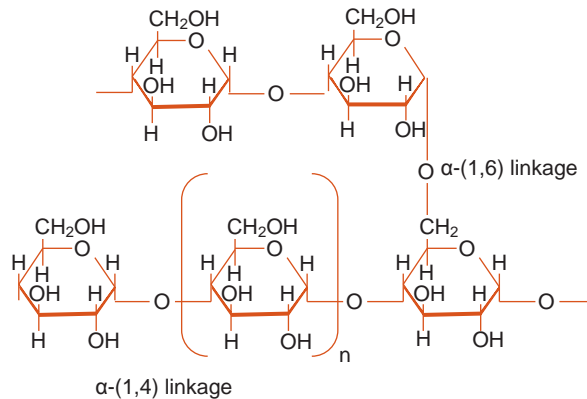
Starch

Starch is the major carbon storage material of green plants. Chemically it is a polymer of glucose in which maltose is the repeating unit. During wort production it is essential to treat raw materials in such a way that the starch reserves are converted into a form in which they may be degraded by enzymes to liberate fermentable sugars. The nature of this treatment is dependent on the type of raw material. This is in turn governed by the **gelatinisation** temperature of the particular type of starch. Starch gelatinisation describes the process by which a combination of heat and water cause starch reserves to swell and lose their organised structure and become susceptible to enzymatic degradation. In the case of milled malt grains this occurs during the mashing phase of wort production. With some adjuncts such as wheat, rye or oat flours, gelatinisation occurs at temperatures sufficiently low to allow the activity of malt amylases to carry out the process of starch breakdown and consequent formation of fermentable sugars. These adjuncts can be added to the mash without a heat pretreatment. With other adjuncts such as rice, maize and sorghum, starch gelatinisation temperatures are much higher, and these materials require to be treated in a **cereal cooker** in order to render the starch susceptible to malt amylases during the mashing phase. During gelatinisation the hydration step causes an irreversible breakdown of the hydrogen bonds which hold the component glucan chains to dissociate.

In barley, starch is deposited in the endosperm in plastids bound by double membranes, termed amyloplasts. The starch takes the form of relatively large granules. Two populations of granules occur, large (A type) and small (B type). The sizes of each are 22–48 and 1.7–2.5 μm , respectively.

The large starch granules are fewer in number compared with the smaller ones, amounting to approximately 10–20% of the total but they account for 85–90% of the total mass. The gelatinisation temperature of the large granules is lower than that of the smaller type. During starch biosynthesis the larger granules are formed first followed by the smaller variety.

Starch grains of various cereals differ in size, ultrastructure and composition. Barley starch granules contain some protein and lipid. The starch component consists of two fractions, **amylopectin** and **amylose**. The former is the major component accounting for roughly 76% of the total. Chemically, amylopectin consists of glucose units connected by α -(1,4) linkages. Branch points with α -(1,6) linkages occur at intervals of approximately 26 units. The molecular weight of amylopectin molecules is of the order 2×10^6 – 4×10^8 . The branch points account for approximately 6% of the total bonds. Each molecule has a single reducing end where the terminal chain end has a free C-1 position. In addition and because of the branched nature of the molecule, there are numerous non-reducing chain ends in which the terminal glucose residue is unsubstituted on position C-4.



Part of an amylopectin molecule showing glucose units joined by main α -(1,4) linkages and α -(1,6) branch points

The linear glucan chains of amylopectins are characterised in terms of length (long or short) and depending on whether or not the non-reducing end is free or bound to another chain.

Amylose is a largely linear molecule consisting of 1600–1900 residues of D-glucopyranose joined by α -(1,4) linkages. Although originally considered to be entirely linear molecules it is now known that occasional α -(1,6) linked branch points also occur. The number of branch points present in starch is species dependent and is referred to as the degree of polymerisation (DP_n). The relative lack of branch points means that each amylase molecule has both a single-reducing and non-reducing end.

The amylase and amylopectin molecules are arranged in an ordered manner within starch granules such that when subject to X-ray diffraction, a partial crystalline structure can be observed. The crystalline structure occurs because of the ability of the long chains to form intermolecular hydrogen bonds. Within each granule crystalline regions are interspersed with non-crystalline amorphous regions. These amorphous regions, where the constituent amylopectin molecules are arranged in a random fashion, are more susceptible to enzymolysis than the crystalline regions. The crystalline regions contain the relatively long unbranched chains of α -(1,4) linked molecules whereas the α -(1,6) linked branched areas appear to be concentrated within the amorphous regions. The long unbranched chains may be wound around each other to form double helices. The relative disposition of amylose and amylopectin molecules within

granules is unknown; however, it is likely that the amylose molecules are interspersed with those of amylopectin mainly in the amorphous regions. These regions may also contain polar lipids.

Amylose molecules can also form helical structures where there are six glucose residues per turn. In this form inclusion compounds can be formed. In the starch granules of barley grains these additional compounds include polar lipids such as lysophosphatidyl choline. In other cereals the inclusions may be free fatty acids. Where no inclusions are present the helices can form addition compounds with iodine. The addition compound formed with iodine has a characteristic blue-black colour. This colour reaction is used to assess the extent of starch degradation during mashing. The presence of other inclusions such as lipids prevents the formation of iodine complexes. In order to prevent underestimates of starch degradation when using the **iodine test** lipids must first be removed by prior treatment with butanol. The chains of amylopectins can also form helices and bind iodine. In this case the addition compounds are red in colour.

Amylose molecules that do not contain inclusions can crystallise and can form an insoluble precipitate. This process occurs via the reformation of hydrogen bonding between adjacent chains and is termed **retrogradation**. In this form the molecules are resistant to enzymic degradation and reductions in fermentability may result. The propensity of starch to undergo retrogradation has been shown to correlate negatively with the ratio of short to long glucan chains in the amylopectin fraction. Retrogradation may be avoided by careful control of mashing conditions and the use of appropriate malts and adjuncts. It is also important to ensure that enzymatic degradation of starches is allowed to proceed as soon as possible after gelatinisation has occurred. It may also be avoided by the addition of preparations of heat-stable α -amylases.

During gelatinisation swelling commences in the amorphous regions of starch granules. After this the process progresses into the crystalline regions, possibly because the glucan chains are removed from the double helices of the amylopectin chains from where they migrate into the amorphous regions. The swelling increases the surface area of the granule that is accessible to enzymic attack. In addition, the loss of structural coherence allows some amylose to be released. Under polarised light, starch granules show a characteristic birefringence. This takes the form of a dark '**maltose cross**', which can be readily distinguished from the lighter background. As gelatinisation proceeds the maltose cross disappears. This phenomenon can be used to identify the gelatinisation temperature of particular starches.

The mixture of enzymes present in malt that are capable of starch degradation is collectively termed **diastase**. Several activities appear to be involved principally α - and β -amylases, although others may also be active particularly in temperature-programmed mashes. α -Amylases attack α -(1,4) linkages, and depending on where the glucan chains are cleaved, a range of products can be formed. These include glucose, maltose and a range of branched and unbranched oligosaccharides and dextrans. β -Amylases hydrolyse the penultimate α -(1,4) linkages of amylose and amylopectin to liberate maltose. β -Amylases cannot hydrolyse α -(1,4) linkages that are close to α -(1,6) branch points; consequently when acting alone they degrade amylose molecules to the point where α -(1,6) linkages are encountered. Similarly, amylopectins are shortened until the residues consist of dextrans where all the non-reducing ends are within a couple of residues of a branch point. In concert, α -amylases are capable of breaking glucan chains such that new non-reducing chain ends are exposed and made available for

further degradation by β -amylases. Ultimately, further degradation requires the presence of **limit dextrinases**, also known as **debranching enzyme** or **R-enzyme**. These enzymes attack α -(1,6) linkages to release molecules of maltose, or maltotriose. The role of limit dextrinases during mashing depends on the conditions; however, they may be active in the early stages of temperature-controlled mashes. Other enzymes that contribute to diastase and which may be active at least for some portion of mashing include α -glucosidase and perhaps, phosphorylase. Several isozymes of α -glucosidase occur, which have differing substrate specificities. The enzymes preferentially not only hydrolyse α -(1,4) bonds but also show some activity against α -(1,6) linkages. Substrates include maltose, isomaltose, oligosaccharides, dextrans and starch at the ends of non-reducing chains.

Phosphorylase attacks terminal α -(1,4) linkages at the non-reducing ends. The glucose molecule is not liberated but instead is attached to inorganic phosphate to form glucose 1-phosphate. This may persist into finished wort or may be cleaved by a phosphatase to liberate glucose and free phosphate.

Starch granules

See **starch**.

Steam beer

The etymology of the term steam beer is uncertain, and it is possible that several diverse routes have culminated in the same name being applied to different beers. The perhaps common feature is that steam beers were those that were brewed under conditions under which precise temperature control was difficult. Thus, the steam beers of the western seaboard of the United States were produced under conditions where the climate was warm, ice and cold water was not readily available and consequently precise control of fermentation temperature was difficult. Under these conditions beers were sometimes produced with lager yeast stains at the comparatively warm fermentation temperatures more associated with ales. In consequence the beers were probably indifferent and had unbalanced flavour palates owing to the unusually high fermentation temperature. In addition, they became highly carbonated, and this is one suggested explanation for the name, in that the 'steam' referred to the sound made by the escaping gas. Alternatively, since the brewers had to seek methods for cooling worts which did not use conventional coolers, for example, open coolships, it is possible that the copious amounts of steam generated may have also been the basis of the name. These beers were probably of indifferent quality and were aimed at the labouring classes. They should not be confused with modern variants such as the well-regarded steam beer made by the Anchor Brewing Company. This company produces Anchor Steam Beer[®], a 5.0% abv lager produced by bottom fermentation. The beer has slight ester and moderate hop (30–45 IBU). It belongs to a group of beers now termed **California common beers**, which are characterised by the use of lager strains fermented at temperatures within the range of 14.5–20.0°C (58–68°F).

No doubt many of the early Californian brewers were German immigrants. Some of these may have had knowledge of the German *dampfbier*, which in German means steam beer. This beer style originated in Bavaria and is made from barley malt. It shares the characteristics of the North American variant in that it is fermented at a relatively high temperature (20–22°C); in this case though, the yeast is a *poj^f* ale type similar to those used for wheat beers. These

beers have a mildly phenolic character owing to the activity of the *POF* gene. In this case, the steam element of the name is thought to derive from the copious amounts of foam and fumes that evolve from very vigorous fermentations. *Dampfbier* has a heritage of many centuries, and it seems likely that most of these products were of variable and indifferent quality, the high fermentation temperature being a consequence of the lack of available economic cooling as opposed to an informed choice. As with the modern American variants these possible criticisms no longer apply, and modern *dampfbiers* are produced with the same degree of care and control as for any other beer type.

Steam stripper

Steam strippers are used for removing unwanted volatile materials from hot wort. They are used as an alternative approach to the more usual removal of volatiles during wort boiling in the kettle (see **wort boiling** for more details). By so doing it is possible to remove the unwanted materials without excessive evaporative losses (and concomitant expense), which are associated with prolonged wort boiling. In addition, such systems are needed where kettles are of the pressurised type and by design are aimed at low evaporation rates but at the expense of volatile stripping. Furthermore, additional unwanted volatile materials, particularly dimethyl sulphide (DMS) in the case of some beers, can be formed during the whirlpool stand. Use of a steam stripper, located after the whirlpool and before wort cooling, provides a useful additional method of control.

Steam strippers (see diagram) take the form of tall cylindrical vessels that are packed with a bed of material made up of numerous small stainless steel rings. These provide a large surface area for volatile stripping. The wort issuing from the whirlpool is heated and sprayed into the top of the column via a distribution system. This ensures that the wort is applied in an even manner. The hot wort passes down through the column in the form of a thin film. A counter-current of steam is allowed to pass up through the column, which strips and carries away the volatile material. The volatile material and steam are recovered in a condenser. The latter is also used to recover heat.

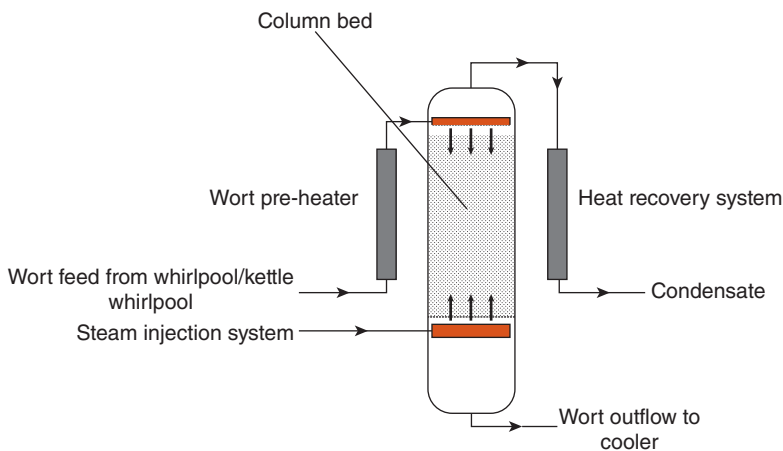


Diagram showing the principal features of a steam stripper suitable for the removal of unwanted volatile material from hot wort

Steeliness

A measure of barley or malt quality based on the appearance of the endosperm. It is a synonym of glassiness or vitreosity.

See **mealiness**.

Steel's mash mixer

Steel's mashers are used for the addition and mixing of grist into liquor at the commencement of mashing. They are most associated with traditional UK-style ale breweries. They were first introduced in the mid-nineteenth century. They are particularly suited for mixing and transferring the thick mashes associated with the use of ale mash tuns. However, they are unable to prevent ingress of oxygen.

The device consists of a length of cylindrical tubing, which is located between the base of the grist case and the entrance to the mash tun (see accompanying figure). Often the whole assembly is fitted onto a swivel device such that one Steel's masher is able to service a number of mashing-in vessels. Grist is delivered into the vertical part of the tube via a series of slide valves. These are used to control the rate of addition of grist and to prevent steam from entering the grist case and in so doing prevent the wetting of the contents. As the dry grist falls into the horizontal part of the masher, it is mixed with hot liquor. The wetted material is driven along the horizontal part of the masher by a rotating worm drive. As it progresses the wetted grist is mixed by a series of rotating beater rods. Eventually the mash reaches the end from which a spout delivers it to the mash conversion vessel.

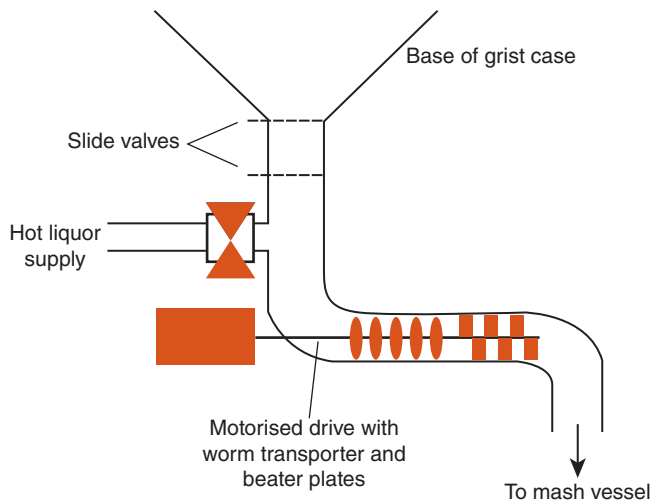


Diagram showing the principal features of a Steel's masher

Steep conditioning

Steep conditioning is the name given to the process in wort production in which the malt grains and other solid adjuncts, if used, are steeped in heated water immediately before milling. This pretreatment softens the grains such that their moisture content is increased to approximately 30%. After treatment the steep water is drained away and either discarded or retained and added to the mash. The wetted grains are then gently squeezed through two- or

four-type roller mills. This removes the contents of the grains but leaves the husks largely intact such that during the wort separation stage, they form well-draining filter beds.

The approach is now not well-favoured since the wetting stage is relatively uncontrolled and may be uneven leading to variable extract yields. This may be slightly improved by circulation of the water during the steeping phase. Although extract that is released during steeping may be recovered by adding the water to the mash, other grain components may also be added back with consequent undesirable effects on flavour. This method has now been superseded by spray steeping.

See **milling**.

Steeping

Steeping describes the stage in the **malting** process in which the grains, usually of barley or another cereal, are immersed in or sprayed with water. The exposure to water of the previously dry and quiescent grains results in the resumption of the metabolic processes associated with germination that were previously halted by drying following harvesting.

During steeping the grains swell and become softer as a result of the intake of steep water. Typically the weight of individual grains increases by some 40–50% as a consequence of water absorption. The precise regime used during steeping depends on the nature of the malting. However, it is usual to control the temperature of the water and periodically to allow it to drain away and replace it with a fresh supply. These changes allow the removal of unwanted floating solid detritus and dissolved materials. This purifies the malt grains, helps to reduce the concentration of contaminating microorganisms and prevents the formation of stale characters. The grains are exposed to oxygen during steeping either by forced aeration of the steep water or by providing an air-rest period during the intervals between draining and re-flooding the bed. The process is considered to be completed when sufficient water has been absorbed. In most modern maltings the grain at the end of steeping has already chitted (see **chit**).

During steeping the metabolic activity of the grains result in oxygen uptake and the consequent formation of CO₂ and ethanol. An important aim of steeping is to ensure that all grains become hydrated evenly such that the bed is as near as possible homogeneous. These processes are controlled by the application of air and the control of temperature. This is achieved by passing a stream of humidified and attemperated stream of air through the steep water. This aerates the bed, helps to control the temperature by removing excess heat and eliminates CO₂.

The steeping process both removes materials from malt grains and provides an opportunity to expose the grains to additives. For example, a proportion of malt phenols are removed during the steeping phase. The greater the amount that is removed, the beer will be commensurately less astringent and less likely to form hazes. The removal of phenols during steeping is favoured by adjusting steep water to an alkaline pH, a process favoured by some European maltsters. Similarly, steep waters may be supplemented with formaldehyde, which reduces anthocyanogen levels in malt probably via the formation of insoluble complexes with malt proteins that are not amenable to extraction during the mashing phase of brewing. At the end of steeping a dose of the plant hormone **gibberellic acid** may be added to the steep water to stimulate modification. In addition and where permitted sodium or potassium bromate may be added, typically at the end of steeping. This reagent reduces respiration and the growth of rootlets. The effect is to reduce malting losses. Bromate ions inhibit malt proteolytic enzymes

and thus their presence during malting tends to reduce levels of soluble nitrogen in malt, an undesirable side effect of gibberellic acid. For this reason bromate and gibberellic acid may be used in combination. Depending on the ratio of the two additives, the **hot water extract (HWE)** and **soluble nitrogen ratio** of the malt may be manipulated, as desired.

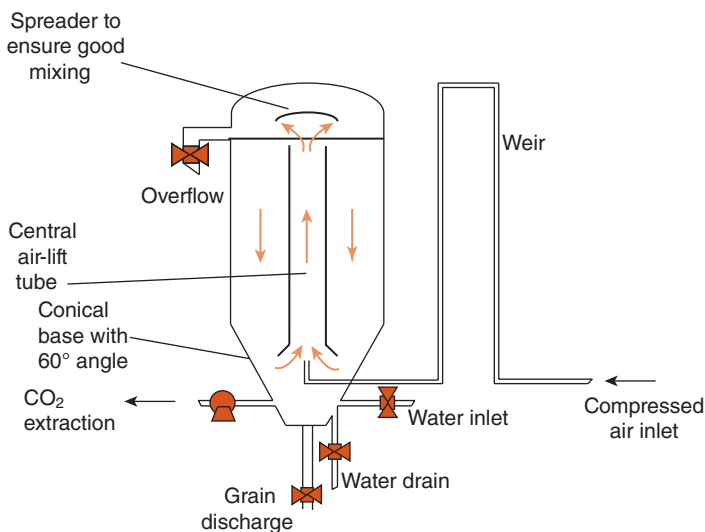
Steep water must be of potable quality and free from taints, pathogens and toxins. Typical temperatures for modern processes are 16–18°C. This is higher than more traditional processes in which the temperature was not controlled and might range between 5 and 20°C. The initial steep water was usually made alkaline by the addition of lime, sodium carbonate or NaOH. This favours extraction and solution of unwanted acidic, proteinaceous and phenolic materials, which are collectively referred to as **testinic acid**. In addition, alkaline conditions tend to be effective at reducing the load of microorganisms. After this first steep, which lasts for no longer than 3 hours, the bed is washed and suspended in fresh water. The addition of formaldehyde to steep water as a method of reducing the phenol content of malts has been mentioned already. Apart from the effect on phenols this compound also has an antiseptic effect. Historically a wide variety of other additives have been used for this latter purpose. These include various chlorine-containing agents such as hypochlorite salts and chlorine dioxide, potassium permanganate, sulphur dioxide, hydrogen peroxide, sodium hydrogen fluoride and salicylic acid. In addition to exerting an antiseptic effect, some of these agents also encourage the breaking of dormancy. Many of these can no longer be used because they are either toxic, dangerous to handle or induce taints. However, formaldehyde kills fungi such as *Fusarium* sp., which can be the source of mycotoxins and induce **gushing** in beer. Of all the potential additives hydrogen peroxide is probably the most effective. It is an efficient microbiocide, and it is known to accelerate germination of dormant grains. It has the advantage of degrading to harmless and undetectable products. Reduction of the microbial loading during steeping is desirable since the organisms compete with malt for the available oxygen. They can produce undesirable taints and odours. They render the spent steep water more difficult to treat and dispose of. Dead microorganisms derived from malt can persist through the brewing process and cause hazes in beers.

A variety of apparatus may be used for steeping. Typically, circular or more often rectangular tanks are used. A variety of materials are used for steep tank construction, currently stainless steel or epoxy-coated mild steel. In simple steep tanks the base is inclined and terminates in a gully, which allows water to drain away. Loss of grain is prevented by the presence of a metal grill. Addition of water to the grain bed is usually via top-mounted sprays. This arrangement allows the bed to be rinsed during changes of steep water. In early systems addition of and emptying of the grain was a manual operation. Latterly these steps have been automated. Modern flat-bottomed steeps have the largest capacity, typically with an upper limit of 50 tonnes. The high capacities are possible because the bed depth can be kept sufficiently small by increasing the vessel diameter. Grain is added via a top-mounted entry point and is allowed to settle onto a perforated false bottom. In the space between the true and false bottoms, a network of pipes supplies compressed air to aerate the bed. CO₂ is removed by a separate extraction pipe, which also runs from below the perforated false bottom. The grain is added to the vessel to give a depth of approximately 1–2 m. After loading, the surface of the bed is levelled using a device known as a **giracleur**. This consists of a series of rotating arms each of which is fitted with a number of blades. During fill the blades force the grains outwards. The rotating arms are gradually raised during filling ensuring that a flat bed is produced. After steeping is completed the giracleur

works in reverse and directs the grain towards an exit chute. The water entry and exit points are located below the false deck. In addition, water sprays may be fitted to the giracleur.

Several steep designs employ vessels fitted with conical bottoms. These are smaller than the flat-bottomed variety, a typical charge being approximately 25 tonnes. In these vessels water can be removed from the base the grain being retained on a perforated false bottom. The grain is added via top-mounted chutes and removed via operation of a valve fitted to the base. The conical bottom facilitates easy removal of the grain. During filling the dry grains are passed through an arrangement of water sprays to minimise dust generation. In some designs the bed is flooded with water during filling such that any floating material can be removed. Several approaches may be used to aerate and mix the steep. Commonly these take the form of air-lift tubes. These rely on a mixture of compressed air water and grain being pumped upwards through a vertically mounted tube. As the mixture exits the tube, fresh material is drawn in from the bed. In this way the grain is both mixed and aerated. The effectiveness of this can be further enhanced by the use of a spreader device, which distributes the grain over the surface of the bed as it exits from the tubes. In more complex designs the aeration tubes are rotated around the bed to ensure more efficient mixing and aeration. In others additional aeration coils comprising perforated pipes are immersed within the bed and may be used in conjunction with air-lift tubes. In yet other designs the grain bed may be circulated from one tank to another or circulated from bottom to top of the same vessel. These circulating types frequently incorporate devices which when required allow passage of water but retain the grains. This system permits rinsing and changes of water.

Some conical steep tanks are designed to facilitate periodic draining of the bed and the removal of CO₂ and addition of air during the dry rest period. The process tends not to be applied to shallow flat bed steeps because of the undesirable effects of uneven exposure of the bed to air. In conical steeps where it is used, the drained bed is retained on a mesh. CO₂ is removed via the application of suction at the base of the vessel. As the CO₂ is removed fresh air is drawn into the top of the bed.



Principal features of a conical steep tank

Many novel steep designs have been used by some practitioners. For example, drum steeps in which the grains are retained within drums made with perforated walls. The drums are mounted such that they are partially immersed in troughs of water. During use the drums are made to rotate such that the grain is mixed, wetted and regularly exposed to air. The high cost and complexity of such devices has tended to restrict their popularity.

When steeping is deemed to be completed the grains are discharged. This may be a wet or dry process. Wet casting in which the grain is suspended in water is easier and involves less soiling of pipework. However, dry casting results in faster chitting.

Steep water

Steep water, as the name suggests, is that in which barley grains are suspended in order for them to be hydrated to a desired level and thereby initiate germination. The water must be free from pathogenic microorganisms, taints and organic contaminants such as herbicides and fungicides. Low levels of salts are acceptable but highly saline water is not. Ferric ions must not be present as these will cause unsightly grey colouration of malt grains via interactions with polyphenols. The water must not be chlorinated since this will produce taints.

Several additions may be made to steep water to improve the malting process. Supplementation of the first steep water with lime in order to produce alkaline conditions is considered beneficial since it reduces microbial loadings and removes some proteinaceous and polyphenolic material from the husk, which reportedly results in beers with improved colloidal stability and a reduction in harshness. Other additives have been used also mainly with the aim of reducing microbial counts and thereby avoiding competition for oxygen with the developing embryo. These include various chlorine-containing antiseptics, oxidising agents such as sulphur dioxide, hydrogen peroxide, potassium permanganate and antimicrobial agents such as salicylic acid, or hydrogen fluoride. Many of these are no longer used since, as in the case of chlorine, as described already, they have other undesirable side effects.

See **steeping**.

Stein

The name given to a German mug, usually of 0.5- or 1-L capacity and used for drinking beer. Traditionally steins were made from stoneware and the name is considered to be a contraction of the German for this material, *steinzeug*. Steins are commonly made to be sold as souvenirs or commemorative items and such versions may be very ornate, often fitted with hinged lids and made from a variety of materials.

Steinfurth automatic foam stability tester

Proprietary device (<http://www.steinfurth.de>, last accessed 18 January 2013) that measures automatically the foam stability of beer, essentially based on the principles of the Ross and Clarke method. It features an automatic sampler, which conveys the beer sample directly from a bottle or can and into a cylinder. The operation is pressurised to prevent gas breakout and the foam is generated as the sample is forced through a nozzle. Optical sensors track the interface between the foam and the liquid formed by its collapse and use this information to compute the foam collapse time. An automatic washing system prepares the instrument for the next reading.

Stellar-ND

A six-row variety of malting barley that appears on the approved lists of Canada and the United States.

Sterling

Sterling is a US low alpha acid aroma hop released in 1998. It has Saaz as the principal parent and also contains Brewer's Gold, Early Green and Cascade in its ancestry. It contains 4.5–5.0% α -acids, of which 21–23% is cohumulone, and 0.8% β -acids. Total oils are 0.6–1.0% (20.0–22.0% caryophyllene, 13.0–15.0% farnesene, 6.0–8.0% humulene, 44.0–48.0% myrcene).

Stewed hops

See **reeked hops**.

Stewing

Stewing refers to a process stage in the manufacture of some speciality malts, notably crystal and caramel types. Thus, during the kilning phase the malts are held at a relatively high temperature whilst still moist. Under these conditions the endosperm liquefies which after cooling crystallises such that the grains take on a glassy appearance. These physical changes are accompanied by the development of characteristic sweet, toffee-like flavours and aromas.

See **kilning**.

Sticke Alt

Sticke alt is a generally strong and seasonal variant of the *Alt* style of German beer. The name translates as 'secret Alt', presumably a reference to the supposed arcane arts used for its production.

See **Altbier**.

Sticklebract

Sticklebract is a New Zealand high alpha triploid hop variety derived from First Choice. It was released in 1972. It contains 13–14% total α -acids of which 45% is cohumulone; β -acids are 7.5–8.5%. Total oils are 1.1% of which 5–6% is caryophyllene, 5.2% is farnesene, 10–10.5% is humulene and 52% is myrcene.

Stiefel

A glass drinking vessel made in the shape of a tall boot, hence the name. Capacities are comparatively large, usually in the region of 2 L, and the vessels are used in communal beer drinking 'games'.

Stillage

A stillage is the shaped rack on which casks of beer are stored, usually in a cellar, for the final stages of maturation, sedimentation and eventual dispense. Traditional stillages are made from stone, brick, wood or cast iron. The process of making cask-conditioned beers ready for dispense is referred to as stillaging. Modern stillages have been improved by the introduction of various innovations. These include the provision of rollers on which the cask sits and which

allow easy rotation in order to locate precisely the shive and keystone. Auto-tilting stillages are spring-loaded such that when full, the weight of the cask counterbalances the force of the spring. When beer is dispensed the weight decreases and the force applied by the spring allows the cask to tilt smoothly and automatically and thereby allow the maximum quantity of clear beer to be removed.

See **vertical stillage**.

Stingo

Stingo is a term associated with the United Kingdom and in particular Yorkshire. It refers to a strong ale, modern versions of which are usually sold in bottles and with an abv of 7–9%. The name apparently refers to the ‘sting’ associated with drinking the product.

Stirling

Stirling is a variety of malting barley that appeared on the Australian list of recommended varieties in 1982. It is no longer widely cultivated but still supplies a stable market for the production of the distilled spirit Schochu in Japan.

STIVA

The Dutch Foundation for Responsible Alcohol Consumption (*Stichting Verantwoord Alcoholgebruik*; <http://www.stiva.nl>, last accessed 18 January 2013). A non-profit-making organisation, funded by the major Dutch brewers and other producers of alcoholic beverages, that seeks to promote responsible advertising.

Stokes' Law

Stokes' law is a mathematical expression describing the relationships between parameters that govern the rates of sedimentation of particles suspended in fluids. Such separations are required to be carried out at several steps in the brewing process, for example, in wort clarification, recovery of yeast crops after fermentation and removal of precipitated non-yeast solid material after cold conditioning. The mathematical expression of Stokes' law is shown as follows:

$$V = \frac{2r^2 g(P_p - P_f)}{9\eta}$$

where

V = settling rate

r = Stokes' radius of particle

g = standard gravity

P_p = density of particles

P_f = density of suspending fluid

η = viscosity of suspending fluid.

Stokes' law demonstrates that the rate of settling of a particle (V) is governed by the radius and density of the particle and the density and viscosity of the suspending fluid. The practical implications of Stokes' law are that in tall vertical vessels, the natural rates of sedimentation will be very slow since the path is very long and the particles that are found have a very similar

density to that of beer. For example, the natural settling velocity of a yeast cell suspended in beer has been calculated as 2.37×10^{-6} m/s. In very large vertical vessels this implies that it could take several weeks for yeast cells and similarly sized particles to settle out. Clearly this is not an acceptable situation. An option would be to use shallow vessels, and indeed maturation tanks often have a horizontal orientation to minimise the problem of long sedimentation times. However, many brewers prefer to use vertical tanks and so alternative solutions have been sought. Sedimentation rates could be increased by reducing the viscosity of beer. In practice, this is not possible. The two variables described in Stokes' law that can be manipulated to the advantage of the brewer are the radius of the particle ($2r^2$) and gravitational force (g). Particle sizes can be increased by the use of agents, which cause the binding together of smaller particles into larger agglomerates. This occurs naturally with many yeast strains when the process of flocculation occurs at the end of fermentation. In maturation vessels the same end may be achieved via the use of fining agents. In the presence of isinglass, yeast and other negatively charged particles become bound to the positively charged collagen molecules with the result that very large particles are formed and sedimentation times are concomitantly much reduced. The gravitational force can be manipulated to the advantage of the brewer by means of centrifuges.

Stout

A beer style characterised as being well hopped, very dark in colour and either with a light smooth bitter palate (dry stouts as typified by Guinness) or those which also include priming sugars or other flavourings (sweet stouts).

Stouts were a later development of the original **porter** style of beer.

See **porter**.

Strainmaster

The Strainmaster is a device used for separating sweet wort from spent grains during the mashing stage of brewing. It is also known as a **Nooter tun** and was patented by the US brewer Anheuser Busch during the 1950s with the aim of achieving very rapid cycle times. They are now rare.

It comprises a cylindrical tank, the bottom of which is attached to a hopper that receives the spent grain. The main tank and hopper are separated by doors. Located within the tank are a number of pipes arranged at different heights (see illustration). The pipes inside the vessel are fitted with slots to allow passage of wort. The pipes exit from the vessel, and each is attached to a pump that allows clarified wort to be either re-circulated and returned to the vessel or directed towards the wort kettle. The exit points of each pipe run into a common collection point. In addition a mash transfer system allows the vessel to be filled and a supply of sparge liquor is also provided.

In operation a finely ground and thin mash is pumped into the pre-heated vessel. As soon as each pipe becomes submerged the appropriate pump is energised and the wort withdrawn and then re-circulated back into the vessel. During this operation the grains form a bed on the perforations such that the wort is filtered. When the wort achieves a desired degree of clarity the flow is directed towards the kettle. The multiplicity of run-off pipes provides a very rapid process. When the wort flow declines to a predetermined value, sparging commences.

In operation in commercial brewing the Strainmaster total cycle time is about 2 hours, probably about a third faster than a lauter tun. However, significant problems probably account for its demise. It was not suitable for the production of high-gravity worts. The spent grains were very wet and usually required an additional dewatering step. The recovered water might be used for subsequent mashings; nevertheless, levels of effluent were very high.

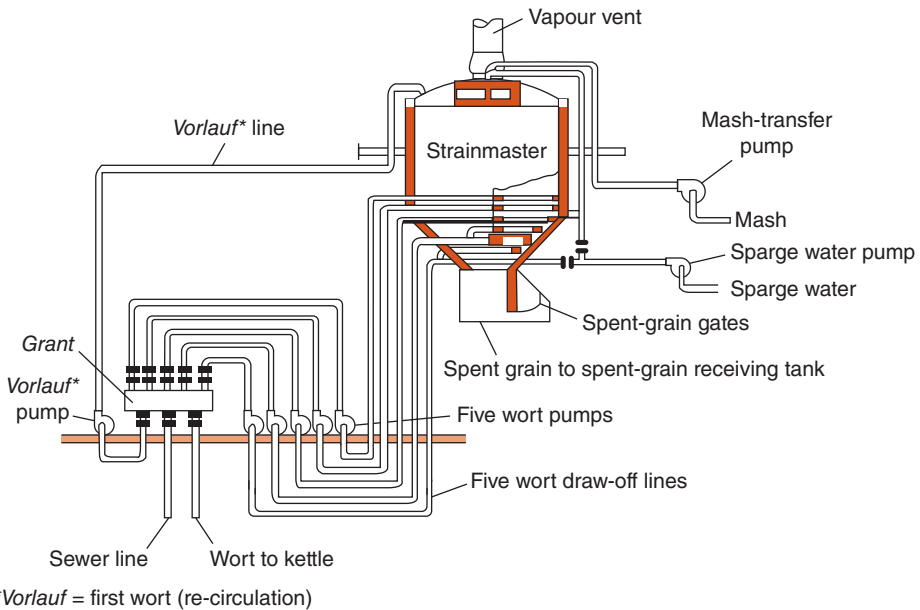


Diagram showing the principal features of a Strainmaster

Strecker degradation

Strecker aldehydes are intermediates formed during the kilning phase of malting and the boiling stage of wort production. In the Strecker reaction an amino acid and carbonyl react to give CO_2 and an aldehyde with one less carbon atom than the amino acid and an α -amino ketone.

The Strecker aldehydes have potent flavours and aromas; however, the majority are lost with other volatile compounds during wort boiling or reduced to alcohols during fermentation. Examples include acetaldehyde, isobutyraldehyde, isovaleraldehyde, methional and phenylacetaldehyde. At high concentrations these compounds have undesirable aromas and tastes.

The amino ketones can undergo further condensations and oxidations to yield pyrazines. These contribute the roast, coffee, burnt flavours associated with some kilned malts.

Strig

The central axis of the hop strobilus or cone.

See **hop plants**.

Striking heat

Striking heat is the term used for the temperature of the liquor measured at the point of addition in the mashing machine. The term **liquor heat** is also used as a synonym although strictly the latter term is used for the temperature of the hot liquor in the mashing machine feed tank.

See **mashing**.

Stripping

Term used in malting to describe the removal of grains after the completion of a stage in the process, for example, the removal of grains from a germination vessel and transfer to the kilning stage. The process may be manual or automatic. In the latter case the precise operation and means of accomplishing it is dependent on the type of equipment being used.

Strisselpalt

Strisselpalt is an aroma hop that derives from Alsace in France. It is susceptible to downy and powdery mildew and *Verticillium* wilt. The aroma is citrus/floral said to be similar to **Hersbrucker**. It contains 3.0–5.0% α -acids, of which 20–25% is cohumulone, and 3.0–5.5% β -acids. Total oils are 0.6–0.9% (8.0–10.0% caryophyllene, <0.1% farnesene, 15.0–25.0% humulene, 20.0–30.0% myrcene).

Strobile

The botanical term for the female inflorescence of the hop. A synonym for hop cone.

See **hop plants**.

Stromboli wort boiling system

The Stromboli wort boiling system was developed by the German fabricator of brewing plant Steineker. It comprises a kettle fitted with an internal heater and a novel double wort spreader. The wort passes through the heat exchanger using a thermosyphon. The very large surface area for heat exchange and vigorous rate of wort circulation gives, according to the company, very efficient volatile stripping and protein coagulation but at low thermal loads and with very low rates fouling.

See **wort kettle, wort boiling**.

Stuck fermentation

A fermentation that has arrested before the achievement of the expected attenuation gravity.

Styrian Goldings

Styrian Goldings, also known as **Savinja Goldings** or **Savinski Goldings**, is a hop variety grown in Slovenia. It is used primarily as an aroma hop (3–6% α -acids, 0.3–1.7% oils). It is used in UK-style ales, Belgian strong ales and some continental-style lagers.

It is the same variety as the UK cultivar **Fuggles** and in common with the latter is susceptible to wilt diseases, particularly *Verticillium* wilt. The name appears to have been an accident in that early imports of Fuggles hops from the United Kingdom to Slovenia were apparently labelled as being Fuggles Goldings based on a belief that Goldings were superior.

Sub-aleurone layer

Layer of cells found in barley grains that are situated immediately below the aleurone layer and situated towards the outer surface of the endosperm. The cells contain relatively few starch granules but relatively high levels of various proteins, including β -amylase.

See **barley grain**.

Sucellus

In ancient Gaul, the God of agriculture, forests and beer. The deity is usually pictured carrying a hammer with a long handle in one hand and a container or 'olla' in the other. In some interpretations the olla is associated with beer and for this reason Sucellus is also associated with the art of coopering.

Sucrase

See **invertase**.

Suffolk Jims

See **Norkies**.

Sulphur compounds, yeast and beer flavour

The metabolism of wort by yeast can generate sulphur-containing compounds with the potential to influence beer flavour from both organic and inorganic wort constituents. Examples of the former would be sulphur-containing amino acids such as cysteine and methionine whereas the principal source of inorganic sulphur in wort is sulphate.

A key intracellular metabolite is S-adenosylmethionine. When the pool size is low, sulphate uptake, via a specific permease, occurs where it is reduced to sulphite and sulphide, via a specific NAD⁺-linked reductase and in energy-requiring ATP-dependent reactions. Sulphide is used in the biosyntheses of S-containing metabolites. Under some circumstances both sulphide and sulphite may accumulate.

Reactions that lead to intracellular accumulation of S-adenosylmethionine result in the repression of genes involved in sulphate uptake and utilisation. Thus, the presence of exogenous methionine causes these effects presumably reflecting that the cell prefers to take up these ready-made intermediates in preference to the energy-intensive biosynthetic route from sulphate. Reactions that deplete the pool size of S-adenosylmethionine cause sulphite and sulphide to accumulate via reverse of the repression. For example, threonine inhibits the aspartokinase, the first enzyme in the pathway leading from aspartate to O-acetylhomoserine. The latter can combine with sulphide to form homocysteine, methionine and eventually S-adenosylmethionine. Under these conditions the first of these reactions is not possible and sulphide accumulates.

In active fermentation, with concomitant high rates of yeast growth, sulphate uptake is derepressed since the intracellular concentrations of sulphur-containing amino acids remain low as they are immediately utilised in anabolic reactions and the pool size of S-adenosylmethionine is also low. Sulphite or sulphide does not accumulate for it is entirely utilised in these biosyntheses. When metabolic rates decline in mid- to late fermentation, intracellular amino acid pool sizes also decline, including S-adenosylmethionine. Sulphite

reductase activity is also low, and provided that sufficient sulphate is available, it may be assimilated and sulphite accumulates.

Intracellular concentrations of sulphite are also influenced by the presence of carbonyls with which they are able to form adducts. Where fermentable carbohydrates, such as glucose, are in plentiful supply, the concomitant high levels of flux through pyruvate to acetaldehyde can lead to adduct formation between the latter and sulphite such that the effective intracellular concentrations of sulphite are available for the synthesis of S-adenosylmethionine. This causes derepression of the sulphate uptake pathway, and if sufficient sulphate is present in the medium continued operation of the pathway leads to the accumulation of additional sulphite.

The ability of sulphites to bind to aldehydes is also of significance with regard to beer staling since it can react with staling precursors such as *trans-2-nonenal*.

Summer Saaz

Summer Saaz is an Australian aroma hop produced in 1997. It is a seedless triploid variety bred from a tetraploid Czech Saaz mother. It has a pronounced sweet and fruity aroma. Analysis is 4.0–7.0% total α -acids of which 22.5–25.0% is cohumulone. Total β -acids are 1.1–1.5%. Total oil content is 0.9–1.3% of which 14.0–15.0% is caryophyllene, 0.1% is farnesene, 42.0–46.0% is humulene and 5.0–13.0% is myrcene.

Summit

Summit is a hop variety. It was released in 2003 and was the first commercial US dwarf variety. It contains 17.5–19.5% α -acids, of which 25.0–28.0% is cohumulone, and 4.7% β -acids. Total oils are 1.2–1.4% (14.0–15.0% caryophyllene, 22.0–22.2% humulene, 26.0–30.0% myrcene).

Sunstruck

See **light-struck character**.

Super Alpha

Super Alpha is, as the name suggests, a very high alpha hop variety. It is a triploid type bred in New Zealand from the **Smoothcone** cultivar. It was released in 1976. It contains 13–14% total α -acids of which 38% is cohumulone; β -acids are 8.4%. Total oils are 1.4% of which 6.2% is caryophyllene, <0.1% is farnesene, 21% is humulene and 51% is myrcene.

S

Super alpha hops

See **high alpha hops**.

Super-attenuation

Super-attenuation refers to a fermentation, or a beer which derives from it, in which the residual carbohydrate concentration is abnormally low compared with the majority of beers.

Brewing yeast strains are unable to utilise long-chain sugars and dextrans, and in consequence at the end of fermentation, these persist into the finished beer where they contribute to beer fullness and body (see **fermentation** for more details). Under some circumstances the dextrans may also be utilised, and hence, the residual gravity of the beer will be very low. This

is referred to as super-attenuation. The phenomenon may be deliberate or accidental. In the latter case certain microbial contaminants, particularly some wild yeasts, are able to utilise dextrins and contamination by these can produce this effect. In the former case, conversion of dextrins into ethanol has been viewed as a method for increasing yields and, in addition, as a route for producing low-carbohydrate beers. This is usually achieved, where permitted, by the use of appropriate exogenous enzymes such as dextrinases. The production of brewing yeast strains via genetic engineering that can utilise dextrins has been accomplished; however, for reasons of customer prejudice none are currently employed in commercial brewing.

Super Cascade

See **Centennial**.

Super Galena

Super Galena is a very high alpha disease-resistant hop variety released in 2006. Its parentage contains **Nugget** and **Galena**. It contains 13–16% total α -acids of which 35–40% is cohumulone; β -acids are 8–10.0%. Total oils are 1.5–2.5% of which 6–14% is caryophyllene, <0.1% is farnesene, 19–24% is humulene and 45–60% is myrcene.

Super Pride

Super Pride is an Australian very high alpha acid hop that was bred from the **Pride of Ringwood** cultivar. It contains 14.0–14.5% α -acids, of which *ca.* 28.0% is cohumulone, and *ca.* 7.0% β -acids. Total oils are *ca.* 1.2% (*ca.* 4.8% caryophyllene, 0% farnesene, *ca.* 9.0% humulene, 25.0–50.0% myrcene).

Super Styrian hops

Super Styrians is a generic name given to high alpha acid hop cultivars bred and grown in Slovenia. Originally four varieties, **Atlas**, **Apolon**, **Ahil** and **Aurora**, were released. The first three of these were seedlings of **Brewer's Gold**. Aurora was a seedling of **Northern Brewer**. The generic name has been a source of confusion since it does not imply any relation to **Savinski Goldings**, the true Styrian hop; instead it is simply a geographical reference indicating the areas of cultivation.

As a group the Super Styrians contain 10–12% α -acids, show reasonable disease resistance and have good storage properties.

Surface filter

A filter in which the sieving action is achieved solely at the surface of the filtration medium. Particles are trapped on the surface of the filter either based on size (entrapment) or by electrostatic interactions (adsorption). Membranes of the type that might be used for cold sterile filtration of beer fall into this category. This type of filter provides very predictable performance in the sense that the size cut-off point may be known with some degree of precision; however, they suffer from the disadvantage that they are very easily blinded. For this reason they tend not to be used for primary filtration but would normally be located at the end of a sequence of filters for final polishing or sterilising purposes.

Surface filters can take many forms. They can be simple rectangular or circular sheets that fit into supporting frameworks. They may be made part of cartridge types in which the membrane is folded or otherwise pleated to give a large surface area and the whole mounted within a stainless steel enclosure into which the process liquid is pumped.

Usually surface filters are used in the typical closed arrangement where the liquid is passed directly through the filter. They may also be used as part of **cross-flow filtration** systems.

See **filtration**.

Surfactants

Surfactants are amphiphilic molecules that confer properties that make them suitable for use as detergents, wetting agents, emulsifiers, foaming agents and dispersants. These properties are made use of in various roles within the brewing process. By definition the molecules bear both hydrophilic and hydrophobic components. The hydrophobic groups tend to adopt configurations in which they are pointing outwards, and this tends to prevent their adhering to surfaces, which lowers surface tension and explains their detergent action. At certain concentrations they form micelles in which large macromolecules form, which have a hydrophobic core and hydrophilic interior. The latter trap soil particles and prevent them from adhering to the surface that is being cleaned.

The amphiphilic nature is caused by the possession of a polar (hydrophilic) terminal group attached to a long hydrocarbon (hydrophobic) moiety. They are classified based on the nature of the polar group which may be neutral (non-ionic types), negatively charged (anionic types), positively charged (cationic types) or have both negative and positive charges (zwitterionic types). Water-insoluble types are non-foaming and are used as additives where foaming requires to be suppressed such as in bottle-washing operations. Water-soluble surfactants have an opposite behaviour and form very stable foams, which are used in spray cleaners such as the types used to clean and sanitise the surfaces of equipment such as small-pack filling machines. Cationic surfactants include the quaternary ammonium disinfectants, which are used in applications such as corrosion inhibitors and disinfectants in applications such as spray water for tunnel pasteurisers. Anionic surfactants are soap-like and used as conveyor belt lubricants. Zwitterionic types, also amphoteric in that the charge is dependent on the pH, are strong biocides and find use in soak baths. Neutral types are often added to **CIP** cleaning fluids.

Svenska Ölfrämjandet (SO)

The *Svenska Ölfrämjandet* is a Swedish-based consumer organisation formed in 1985 which champions for what are perceived as traditional beers and campaigns against the globalisation of the world brewing industry. It is a member of the EBCU.

Contact details are at <http://www.svenskaolframjandet.se> (last accessed 18 January 2013).

Swan neck

Component of a Burton Union system used to transfer beer and yeast from union cask to top trough.

See **Burton Union system**.

Sweet gale

Sweet gale is the common name for the plant *Myrica gale*, a resinous shrub extracts of which have been used as an alternative to hops.

See **gruit**.

Sweet water collect

Sweet water collect is the term used to describe the stage in operation of a lauter tun (or similar sweet wort clarification device) in which after sparging, the extract content has fallen to a level below which it is considered desirable to send forward to the kettle. The precise extract level will depend on the wishes of the individual operator and will be dictated by consideration such as the need to produce high-gravity worts.

The sweet water, or residual wort runnings, may be used in various ways, for example, in the next mashing-in cycle, as foundation water or sparge liquor.

Sweet wort

Sweet wort is the complex mixture of sugars, nitrogenous materials and the multitude of other soluble compounds that are both extracted from the grist and formed during the mashing stage of wort production. The term sweet is used to indicate that at this stage the wort has not been boiled and therefore does not contain any hop bitterness. The composition of sweet wort varies with the type of beer being made and the ingredients and plant used in its making. All contain many thousands of components, and complete characterisation has never been attempted. The dissolved solids typically consist of approximately 90% carbohydrates, 4–5% nitrogenous compounds and 1–2% ash.

See **mashing**.

Swing bend

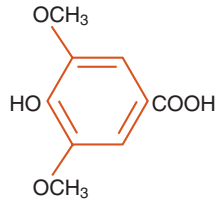
Name given to a device used for manually setting the routing for process fluids. It is analogous to a patch bay as used in the routing of electrical signals and is a more economic method compared with costly automatic valves. Process pipework that connects a series of related tanks or other pieces of brewery plant is directed to a common panel. The terminus of each pipe is fitted with a valve and a suitable male screw thread. The swing bend consists of a U-shaped piece of stainless pipe, each end of which terminates in a female screw thread fitting. The swing bends are sized so that they can be attached to the appropriate pipe terminuses and in so doing form a link.

Sybilla

Sybilla is a high alpha bittering hop variety of Polish origin. Analysis is 7.3% total α -acids of which 33.9% is cohumulone. Total oil content is 1.7% of which 9.5% is caryophyllene, 36.4% is humulene and 39.6% is myrcene.

Syringic acid

A simple phenolic compound, one of the series of substituted benzoic acid derivatives, which are found in worts (see accompanying diagram for structure). Concentrations in an unboiled lager wort are reported to be of the order of 0.6 mg/L.



Structure of syringic acid

See also **polyphenols**, **tannic acid**.

Systembolaget

The name of the Swedish state monopoly for the retail of alcoholic beverages. It translates literally as 'system company'. In Sweden the purchase of wines, spirits and stronger beers (Group III) are restricted to member shops of the *Systembolaget*. Swedish supermarkets can only sell Class II beers.

The current (2008) classification of beers is based on alcoholic strength, as follows:

Class I: 0–2.2% abv

Class II: 2.3–2.8% abv

Class III: 3.6% and above.

T

Taiwan Beverage Alcohol Forum (TBAF)

A non-profit-making organisation [<http://www.tbaf.org.tw> (last accessed 14 February 2013)] sponsored by major Taiwanese brewers and producers of other alcoholic beverages devoted to promoting safe alcohol consumption, responsible advertising and avoidance of alcohol abuse.

Takju

Takju is an alcoholic beer-like beverage from Korea. It is made via the fermentation of glutinous rice, barley or wheat. The product may be filtered to give a clear beverage called cheongju and this may be used as a base in the manufacture of a distilled product called soju. Takju is an opaque product as is reflected in the name (*tak* = cloudy). It has an alcohol content of 6–7% by volume and an astringent sour taste. It is also known as makgeolli. Ssal makgeolli is made entirely from rice. Dongdongju is another version which contains floating rice grains.

Talisman

Talisman is a US-bred hop variety. It is similar to Clusters but with a higher content α -acid content (8–9%) and oil (*ca.* 1.5%) and is derived from a late Clusters cross; however, it matures later than late Clusters. It is high yielding and used to be the dominant variety cultivated in Idaho until other cultivars with more desirable properties superseded it.

Talla

Talla is a traditional beer of Ethiopia made from barley, wheat, millet or sorghum. It is flavoured with spices and herbs. During its manufacture bread is used, which has been baked until dark. This, together with the use of wood fires to heat the infusion, imparts a smoky taste to the final product. The alcoholic strength is moderate at 2–4% by volume.

Tane-Koji

Name given to the mixture of rice and mycelium of the mould *Aspergillus oryzae*, which is used to conduct the amyolytic stage of saké production.

See **saké**.

Tankard

A vessel associated with beer drinking usually having a slightly tapered or straight-sided form often with a hinged lid. Historically they were made from wood using a coopered

construction. Very early versions sometimes had capacities of more than 2 L, perhaps suggesting communal use. Wooden tankards were replaced with pewter, ceramics or precious metals for higher-status examples. Early pewter tankards often had glass bottoms supposedly to alert the drinker to stealthy additions, such as the 'King's shilling' associated with the Press gangs of yore, or simply for early warning in the event of attack. Modern versions commonly retain the glass bottom and are often adorned or engraved as befits their use as gift items.

Tank bottoms

A term used to describe sediments which form in tanks, particularly fermentation or maturation vessels where beer is stored for any length of time. The formation of sediments at the base of tanks followed by removal and decantation is a convenient method of clarifying beers prior to final processing. The sediments include material such as yeast cells, various proteins, polyphenols and other break materials together with process aids where used. There is a downside in that where excessively large tank bottoms develop losses of entrained beer are commensurately high. Although many brewers seek to recover the beer, the storage and processing costs may be significant and the quality of the recovered beer is often questionable. For this reason it is helpful if the tank bottoms form a tight compact mass which is not readily re-suspended and which separates easily from beer. Where these goals are not achieved and there is a tendency for solids to re-suspend readily the term 'fluffy bottoms' may be encountered.

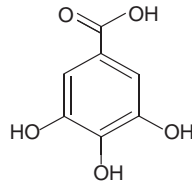
Tank farm

A number of brewing vessels, typically modern closed fermenters and conditioning tanks with a vertical configuration, which are grouped together in the same location. The close proximity allows all the vessels within the farm to be served by common services, thus producing cost savings. For example, multiple vessels can be served by a single wort main with a common cooling, yeast pitching and oxygenation system.

Tannic acid

A polyphenolic compound that can be used as a beer stabilizing agent via its ability to react with sensitive proteins and to form insoluble precipitates. Commercial preparations are prepared from oak galls and comprise high-molecular-weight glucose esters of gallic acid (see diagram for structure of the latter).

Tannic acid reacts with proteins which are rich in proline and therefore particularly liable to form hazes in beers. Dose rates are between 2 and 10 g/L. Crude preparations are used in the brewhouse either by addition to the mash or the copper. More purified preparations may be added to fermenter or to conditioning tank or even in-line between the conditioning tank and the filter. The latter option is favoured since providing the beer is chilled to between -1 and -3°C a contact time of less than 1 minute is sufficient for the precipitate to form. The precipitates can be problematic since they are very finely divided, and if the in-line approach is adopted poor filtration runs may be the result. In order to counter this it may be necessary to introduce a relatively costly high-speed centrifugation step between the dosage point and the filter.



Structure of gallic acid

Tannins

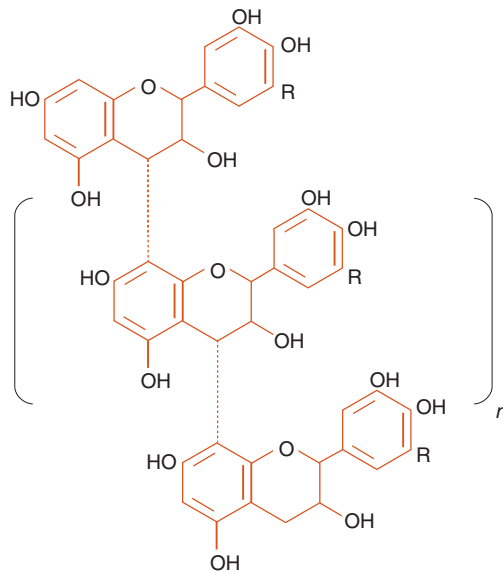
Tannins are polyphenols which are derived from plants. They are present in extracts of cereals such as malted barley and hops and therefore form components of worts and beers. They confer both negative and positive attributes (see **polyphenols** for a full discussion). They take their name from the Celtic word for oak, which makes reference to the fact that extracts of oak bark contain polyphenols which are capable of tanning leather. This property is a result of the ability of these polyphenols to bind and precipitate proteins present in animal hides, an essential part of the tanning process.

Extracts of plant tissues which contain tannins also contain other polyphenolic material which does not have tanning properties; however, somewhat confusingly, the term tannin is applied by some to all of these. Others prefer a more proscriptive approach and define tannins as polyphenolic compounds which are capable of forming precipitates with proteins.

See **colloidal stability**, **beer hazes**.

Tannoids

Tannoid is the name which has been applied to the polyphenol component of beers or worts which have undergone oxidation and polymerisation to form condensed polyphenols. Tannoids are the precursors of beer hazes via their ability to bind to sensitive proteins. The structure of a typical tannoid molecule is shown in the accompanying diagram.



Structure of a tannoid molecule

See **polyphenols** and **colloidal stability**.

Tannometer

The tannometer is a device used for a variety of analyses relating to beer colloidal stability. These include tannin content, sensitive proteins, saturated ammonium sulphate precipitation limit (SAPL), reducing substances and alcohol chill haze tests.

The device consists of an attemperated chamber which is fitted with a stirrer and a dosing system. The beer sample is placed in the chamber and a reactant appropriate for the test being conducted is dosed in via the injection system. The resultant reaction causes the formation of a haze and this is detected nephelometrically. An integrated plotter provides a record of the results. Alternatively the results are downloaded to a dedicated PC for logging.

Tap

With regard to cask-conditioned beer the tap is a valve made from brass, or now more usually plastic, which is driven into the keystone of a cask by the blow of a mallet made from rubber or ash. This process by which a cask is broached and made ready for beer dispense is termed tapping.

See **cask, cask-conditioned beer**.

Tapé Ketan

A beer-like beverage made from rice and native to Indonesia. The product is made by inoculating an aqueous suspension of steamed rice with a starter culture, called **ragi**, which contains a mixture of fungi, yeast and bacteria. Some of the fungal species present possess amylolytic enzymes and these are responsible for the formation of sugars, which are then used by the yeast species to form ethanol. At the point of consumption the ethanol concentration can be as high as 8% abv. In addition to ethanol the protein content is high as are various vitamins and starch, and therefore the beverage is both a stimulant and a foodstuff.

Tap heat

Tap heat is the generic term used to describe the temperature of wort during run-off. The temperature is usually taken 10–15 minutes after the taps have been opened. Where the taps are opened several times the term may be prefaced with the appropriate ordinal number as in first tap heat, second tap heat, and so on.

Tardif de Bourgogne

Tardif de Bourgogne is a French landrace hop variety with an unknown pedigree and is used for its aroma. It contains 3.0–5.5% α -acids, of which 17.0–22.0% is cohumulone, and 4.5–6.2% β -acid. Total oils are 0.5–1.8% (4.0–7.0% caryophyllene, >0.3% farnesene, 10.8–15.7% humulene, 31.0–51.0% myrcene).

Target

Target is a very high-yielding, medium-high alpha hop variety, one of the most commonly cultivated types in the United Kingdom. It was bred at Wye College in the early 1970s from a Northern Brewer, downy mildew-resistant male cross and a Kent Golding. For this reason it is also known as Wye Target. It contains 8.9–15.2% α -acids, of which 33.0–36.0% is

cohumulone, and 3.9–6.9% β -acids. Total oils are 0.8–2.3% (8.0–10.0% caryophyllene, >1.0% farnesene, 17.0–22.0% humulene, 45.0–55.0% myrcene).

Taurus

Taurus (also known as Hallertau Taurus) is a high alpha hop variety with good aroma and storage characteristics bred at the German Hüll Hop Research Institute. It is late ripening with good resistance to downy mildew and verticillium wilt. It contains 13.0–15% α -acids, of which *ca.* 21.0–24.0% is cohumulone, and 4.5–5.5% β -acids. Total oils are *ca.* 1.4% (45.0–48.0% caryophyllene, <0.1% farnesene, *ca.* 30.0% humulene, 30.0% myrcene).

T-bar beer dispense unit

A multi-beer dispense font that takes the form of a single vertical column, attached to the bar at the base, and which terminates at the top in the middle of a horizontal section (the tee) which bears the beer taps. The beer tubes run up through the interior of the column and via the horizontal section to each tap.

Tchouk

A beer made from millet and native to West Africa.

See **native African beers**.

TCW

See **one thousand corn weight**.

Tegestologist

A collector of beer drip mats or coasters.

Temperature-programmed infusion mashing

Temperature-programmed infusion mashing is a regime in which the process is carried out in a single stirred vessel. As opposed to decoction mashing where separate vessels are used to effect programmed increases in the overall temperature of the mash, in this technique direct heat is applied to the mash such that it is allowed to progress through a sequence of stands at a number of controlled and increasing temperatures.

The procedure is simpler than **decoction mashing** and uses few vessels. It is more controllable than **simple infusion mashing** and in consequence is becoming increasingly popular for the production of both ales and lagers. Compared with decoction mashing this approach requires approximately 40% less energy.

Many different variations are possible, dependent upon the nature of the grist and the style of beer being produced. Where large proportions of some adjuncts are used such as rice, maize and sorghum a separate **cereal cooker** may be needed.

With poorly modified malts a greater number of individual steps are required compared with a regime suitable for use with well-modified malt. The former might use a sequence of stands such as 30 minutes at 35°C, 30 minutes at 50°C, 30 minutes at 65°C, 30 minutes at 70°C and, finally, 15 minutes at 75°C. In the case of well-modified malt the initial temperature would usually be higher, around 50°C, and would use fewer individual stands.

The composition of the wort is dependent upon the conditions imposed. Lower initial temperatures and long stand times at lower temperatures favour proteolysis and therefore the formation of high concentrations of total soluble nitrogen. This is a consequence of the relatively low temperature optima of the proteases involved. Conversely, long stands at relatively high temperatures favour saccharification. Extensive proteolysis favours colour formation via the propensity of the released low-molecular-weight nitrogen-containing compounds to form melanoidins.

The heating might be applied via direct steam injection. In modern vessels heat is applied via external steam jackets. This is desirable since, although direct steam injection helps mix the mash, the condensation causes dilution.

Temporary hardness

See **water hardness**.

Temporary haze

Synonym for **chill haze**.

Terminal sterilant

Chemical disinfectants which are used in the last stage of cleaning regimes with the aim of sterilising the surfaces of the process plant being cleaned. Usually residues of the agents are left *in situ* after the plant is drained since this provides residual disinfecting activity in the interval between cleaning and reuse. This requires that the chemical agents have no effect on the process liquid which subsequently comes into contact with the cleaned plant. Obvious risks are introduction of taints or toxic effects on culture yeast. This risk may be avoided by introducing a terminal rinse with sterile water. Commonly used terminal sterilants are **chlorine dioxide** and **peracetic acid**.

Testa

Testa is a botanical term describing the outer coat of a seed. It derives from the integument of the ovary.

Testinic acid

Testinic acid is material associated with the husk of cereal grains such as barley. It is not a pure chemical and is relatively undefined. It is composed principally of a mixture of proteins and polyphenols. The composition of testinic acid is similar to that of the polyphenol protein hazes that can form in beers. It is extracted from grains when they are steeped in water. The efficiency of extraction is enhanced when the steep water is made alkaline. It is suggested that malts produced with alkaline steep water produce less astringent beers which are less prone to form hazes (see **steeping**).

The original definition described the fraction of barley husk that was soluble in dilute alkali but insoluble in acid. This definition was later extended to include all alkali-soluble but acid-insoluble substances obtained from treatment of the entire barley grain. The material has been found to contain by weight 35–56% protein, 21–38% lignin, 2–6.5% ash and a small amount

of carbohydrate [Stevens, R. (1958) Studies on the non-biological hazes of beer, IV, Testinic acid, *J. Inst. Brew.*, **64**, 470–476].

Tetra

Shorthand name used to describe tetra-iso- α -acids.

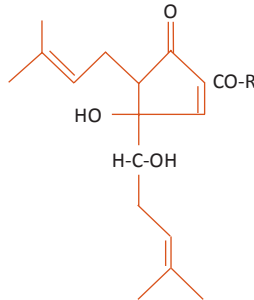
See **tetra-iso- α -acids**.

Tetradifon

Tetradifon (1,2,4-trichloro-5-(4-chlorophenyl)sulphonylbenzene) is an organochlorine pesticide which is used in the treatment of **red spider mite** infestations in hop plants. It is becoming of limited value because of concerns regarding the potentially harmful effects of pesticide residues and development of resistance by the target mites.

Tetrahydro-iso- α -acids

Tetrahydro-iso- α -acids are processed hop extracts formed by reduction of iso- α -acids. They are used both for imparting bitterness to beers and to enhance foam stability. They are not susceptible to the photolytic reaction which in the precursor iso- α -acids leads to the formation of the undesirable **light-struck character**; thus, these hop products may be used where the beers are packaged into green or clear glass bottles.



Generalised structure of tetra-iso- α -acids

T

Compared with iso- α -acids the tetra-iso- α -acids are nearly twice as bitter and very effective at stabilising foams. Commercial preparations comprise mixtures of both *cis*- and *trans*-isomers of tetrahydro-isohumulone, tetrahydro-iso-adhumulone and tetrahydro-iso-cohumulone.

Tetrazolium overlay test

The tetrazolium overlay test is used for the detection of respiratory-deficient (petite, rho⁻) mutants in populations of brewing yeasts. Tetrazolium salts (2,3,5-triphenyl tetrazolium chloride) is a chemical reagent that is used as the basis of several biochemical tests designed to provide a visual indication of metabolic activity. Oxidised forms of the reagent are colourless, but when reduced the resulting formazan takes the form of a bright red precipitate. Respiratory-sufficient cells are able to reduce tetrazolium salts and produce the colour change, whereas

respiratory-deficient cells are unable to carry out the transformation. This forms the basis of the test.

Yeast is cultivated aerobically on spread plates using a suitable nutrient medium in a manner that provides separate colonies. After incubation and colony formation the plates are overlaid with a cool molten medium containing glucose (2% w/v), phosphate buffer (50 mM, pH 7.0), agar (1.5%) and 2,3,5-triphenyl tetrazolium chloride (0.5% w/v). The plates are incubated for 1 hour in the dark after which the colonies are examined. Red colonies are respiratory sufficient, whereas white colonies are respiratory deficient.

Tetrazolium salts

Tetrazolium salt (2,3,5-triphenyl tetrazolium chloride) is a chemical reagent that is used as the basis of several biochemical tests designed to provide a visual indication of metabolic activity. Oxidised forms of the reagent are colourless, but when reduced the resulting formazan takes the form of a bright red precipitate. Living tissues are able to reduce tetrazolium salts and therefore the colour change can be used as a monitor of metabolic activity.

The reduction of tetrazolium salts is used as the basis of several tests used in brewing. In malting the reaction is used to determine **germinative capacity**. With regard to brewing yeast the reaction is used to determine the percentage of **petite mutants** that are present within a given population. In addition, the ability of yeast to reduce tetrazolium salts has been recommended as the basis of a **yeast vitality** test.

See **germinative capacity, petite mutants, yeast vitality, tetrazolium overlay test**.

Tettang

Tettang is a region in the Bodensee of Southern Baden-Württemberg in the region known as Swabia. It is a major hop-growing region and gives its name to a hop cultivar of the same name. It is one of the **noble hops** noted for relatively low bitterness and delicate flavour and aroma, although it is also cultivated in other parts of the world, particularly the United States.

The hop contains 3.5–4.5% each of alpha and beta acids. The total hop oil content is around 0.6 mL/100 g and contains (as a proportion of total oils) myrcene (40%), farnesene (15–20%), humulene (20%) and caryophyllene (6–7%).

Theodotus of Ancyra

An early fourth century Christian martyr who was an innkeeper in Ancyra, the capital of the Roman province of Galatia (modern Turkey). For obvious reasons he is claimed as one of the patron saints of innkeepers and publicans.

Thermal degradation unit

A measure used to quantify pasteurisation treatments expressed in units which reflect the predicted negative effects on beer flavour.

See **pasteurisation**.

Thermal mass flow meter

See **flow meter**.

Thermal vapour compression

Thermal vapour compression systems are used in brewing operations for energy recovery and conservation primarily in wort boiling. These systems depend upon the use of steam jet compressors. These comprise jets which are fed by a supply of high-pressure live steam. The vapours, or a proportion of them, from the kettle are fed via a lateral entry point into the jet of steam, the latter providing the motive force. The jet terminates in a chamber which is wider than the entry point and this causes the jet stream to decelerate, which results in an increase in pressure and a concomitant increase in temperature. The outflow from the jet is used to heat the kettle. Typically these systems also incorporate additional heat exchangers which recover heat from the kettle in the form of hot water, which may be used elsewhere in other brewing operations.

Thermosyphon

A thermosyphon is the phenomenon which is used to drive the flow of wort in some designs of wort kettle. Wort is heated as it passes through a bundle of vertically arranged cylindrical tubes enclosed within a chamber to which heat, in the form of steam, is applied. As the heated wort enters the base of the tubes it takes the form of a single liquid phase. Passage of the wort up through the tubes allows it to increase in temperature via heat transfer from the surrounding steam. This causes the wort to boil. At the top of the tubes boiling and concomitant separation of bubbles produce two-phase flow. In the latter condition the boiling wort is less dense than that at the base. This density differential produces an upward flow. At the surface the wort is directed back towards the periphery of the vessel from whence it flows back down the walls there to be drawn back in to the base of the heating tubes.

See **wort kettle**.

Thiobarbituric acid value

Value given to a test used to predict the staling potential of beer based on forced ageing and detection of carbonyls formed by reaction with 2-thiobarbituric acid. Beers are force aged by heating and after treatment with 2-thiobarbituric acid the concentration of the resultant complex is determined by reading the absorbance at 530 nm. Staling potential is determined by comparison with the result obtained with a control beer stored at 3°C to minimise staling.

Third beers

These are a type of non- or low-malt beer-like beverages developed and sold in Japan. The name derives from the fact that the beverages are beer-like but are neither true beers nor low-malt *happoshu* alternatives.

See *happoshu*.

Thrawl

An alternate name for a stillage associated with the counties of Yorkshire and Derbyshire in the United Kingdom.

Three '3 Cs' hop varieties

The 3 Cs are US hop varieties named **Cascade**, **Centennial** and **Columbus**. When used they are considered to produce the characteristic taste and aroma of US-style ales.

See entries for individual varieties for more details.

Three-glass taste test

Sensory method, also known as a **triangular test**, used to assess beer flavour and aroma by asking participants to identify one beer from another. The method is commonly used to test the effect on beer sensory characteristics of process or raw material changes. The test provides three portions of beer, two of which are identical and one other. Tests are performed in appropriate beer sensory booths and beers are served in identical dark glasses and as closely matched as possible in terms of dispense conditions. Beers are labelled in a manner that gives no indication of identify and they should be supplied in random order. Participants assess all three beers and indicate which glass is the odd one out. They must provide an answer even if they cannot discern any differences. Statistical analyses of the results indicate the sameness of the two beers. Controls using three identical beers assess the effectiveness of the test conditions.

See **sensory analysis**.

Three packers' rules

Basis of legislation used in the United Kingdom to regulate the quantity of product provided in a package. The rules apply to beers. The three rules are the following:

- (1) On average the actual contents of the package must not be less than the nominal stated value.
- (2) No more than 2.5% of the package may contain a volume lower than a given tolerance limit (T_1).
- (3) No packages will contain a volume which is less than the absolute tolerance limit (T_2).

The numerical values of T_1 and T_2 are defined for each pack type.

Three threads

An archaic UK brewing term supposedly referring to a mixture of ale, beer and twopenny (tuppenny).

See **porter**.

Thunaeus test

Test used to determine the germinative capacity of grains by immersion in a dilute solution of hydrogen peroxide.

See **germinative capacity**.

T'ien tsiou

A Chinese beer dating back to at least 2000 BC made from millet. The initial part of the name refers to the fact that the beer was designed to be consumed whilst immature, not fully fermented and therefore low in alcohol. A fully fermented higher-alcohol version also existed and was simply called **tsiou**.

Tilden drum malting system

An automated drum malting system developed in the United States in the early years of the twentieth century. It comprised two concentrically mounted perforated metal cylinders in which steeped grain was introduced into the gap between each. Moistened and attemperated

air was introduced into the inner cylinder and passed through the grain bed and thence to the outside. During this treatment the drums were rotated, which detached the culms. The latter passed through the perforations in the outer cylinder and accumulated under the drums from where they were collected. After germination was completed the grains were withered and kilned *in situ* by successive treatments with streams of dry and heated air.

See **drum malting, pneumatic malting**.

Tillicum

Tillicum is a high alpha hop variety bred in the United States from **Galena** and released in 1995. It is closely related to **Chelan hop** and is similar to both. The analytical profile is 12.0–14.5% total α -acids of which 31.5–38.5% is cohumulone. Total β -acids are 9.3–10.5%. Total oils are 1.5–1.9% of which 6.8–10.0% is caryophyllene, <1.0% is farnesene, 13.0–16.0% is humulene and 45.0–55.0% is myrcene.

Time to attenuation

A synonym for **time to PG**.

Time to diacetyl specification

Term used as a measure of fermentation performance defined as the time taken from the commencement of fermentation (usually the time the vessel is completely filled) to the point at which a specified threshold value for diacetyl concentration is achieved; also known as time to VDK.

Time to gravity

Synonym for **time to PG**.

Time to PG

Time to PG is a term used with reference to fermentation performance. It refers to the time taken from the start of fermentation to the point at which there is no further decrease in wort concentration, in this case expressed as present gravity. In the majority of commercial breweries the time taken to reach final gravity, as well as the actual recorded gravity, is recorded as an essential part of the quality system. Measured values are compared with specified values, and any deviation should trigger an investigation into cause and, where necessary, exercise of remedial measures.

Other terms are used which have the same meaning. These are **time to attenuation**, **time to racking gravity**, or simply **time to gravity**.

See **fermentation**.

Time to racking gravity

Term used as a measure of fermentation performance defined as the time taken from the commencement of fermentation (usually the time the vessel is completely filled) to the point at which the minimum desired wort concentration (measured as specific gravity or °Plato) is achieved.

Time to VDK

Time to VDK is a term used in relation to fermentation performance, typically commercial and usually large-scale lager types, where cycle time is an important consideration. It refers to the time taken from the start of fermentation to the point at which diacetyl concentration has fallen below a predetermined sub-flavour threshold.

See **fermentation, diacetyl stand, diacetyl cycle**.

Tiswin

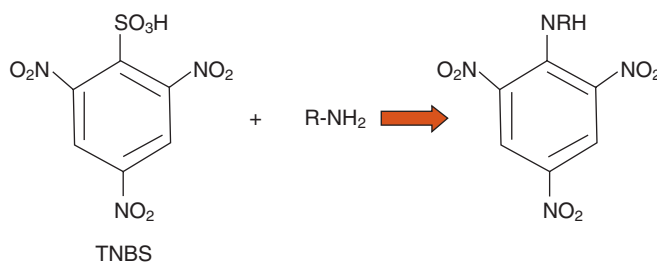
Tiswin is a type of maize beer associated with certain North American indigenous tribes, in particular the Apache. It is made by soaking the corns in water and after draining spreading them out in the sun and leaving them until they sprout. The corns are then boiled in water and the liquid is separated and retained in a container in which a spontaneous fermentation occurs. The mildly alcoholic product is consumed after a few days.

Titratable acidification power test

See **acidification power test (AP test)**.

TNBS

TNBS (2,4,6-trinitrobenzenesulphonic acid) is a reagent used for the determination of **free amino nitrogen (FAN)**. TNBS reacts with compounds which contain free amino groups to produce a trinitrophenylated amine complex. The complex is orange/yellow coloured and can be quantified spectrophotometrically by measuring the absorbance at 420 nm.



For information regarding the comparison of the TNBS procedure with other methods for determining FAN see **free amino nitrogen (FAN)** and **nitrogen**.

Toji

Name given in Japanese to a master brewer of saké.

See **saké**.

Tomahawk

Trade name for the US hop cultivar **Columbus**.

See **Columbus**.

Tomato juice broth (TJB)

Many early-developed media for lactic acid bacteria contain tomato juice as the presence of this additive was observed to be growth stimulatory (as were various other plant extracts). Apart from the general nutrients present studies indicated the presence of an additional factor

that was acid and heat resistant, suggesting an inorganic origin. Substitution tests have indicated that manganese may be the causative agent and several more refined lactic acid media contain the sulphate of this metal. Tomato juice-containing broths or agars designed for the growth and detection of lactic acid bacteria, especially *Pediococcus*, typically contain tomato juice, extracts of peptone and yeast, sulphates of magnesium and manganese, glucose as the principal carbon source and cysteine HCl to produce reducing conditions. Ethanol, or beer, may be added to increase the selectivity for beer spoilers.

Topaz

Topaz is an Australian high alpha bittering hop produced in 1985. It is a seedless triploid variety bred from a tetraploid female and a diploid male. Analysis is 15.5–18.0% total α -acids of which 47.0–49.5% is cohumulone. Total β -acids are 6.0–7.0%. Total oil content is 0.8–1.7% of which 10.0–11.0% is caryophyllene, 0% is farnesene, 11.0–13.0% is humulene and 25.0–43.0% is myrcene.

Top box-drum malting

A type of drum malting, now of historic interest only, in which the germinating grain was allowed to rest on a flat perforated metal deck located within a rotating drum. Conditioned and attemperated air was forced through the bed from underneath the deck and from there to an outlet at the upper part of the drum at the end distant to the inlet. Perforated plates covering the outlet prevented the grain from exiting during turning of the drum.

See **drum malting** and **pneumatic malting**.

Top cropping

The removal of yeast from the surface of fermenting wort. The formation of top crops is associated with ale fermentations using ale yeast strains, also known as top-cropping yeast, which, under appropriate conditions, rise to the surface to form a pellicle during fermentation.

See **crop**.

Top-cropping yeast

Term used for types of brewing yeast which during fermentation have a tendency to separate from the fermenting wort and rise to the surface to form a layer which comprises yeast and entrained non-yeast solids and bubbles of carbon dioxide. The term top-fermenting yeast is also used, although this is somewhat inaccurate since it is implicit that for fermentation to occur the yeast and wort must for much of the time be mixed intimately. This type of yeast is associated with the production of ales and for this reason the terms 'top cropping' and 'ale yeast' are used synonymously. This is an error since many ale strains can be made to form bottom crops in suitably designed fermenting vessels. Where top cropping is practised fermenting vessels are perforce designed to accommodate the removal of yeast from the surface of the fermenting wort. The traditional open square fermenting vessel fitted with a suction device or provision for **skimming** is a typical example.

The physiological basis for the tendency to form a top crop is unclear; however, the possession of a relatively hydrophobic cell surface and the ability of the yeast cells to flocculate and entrap CO₂ bubbles have been suggested as being implicated.

See **yeast**.

Top heat

A synonym for **top temperature**.

Top temperature

The term top temperature is used to describe the maximum temperature used in fermentation. For ease of control it is common to fill fermentation vessels at a temperature slightly below that at which the bulk of the fermentation is to be conducted. Thus, if a fermentation is to be conducted using, for the sake of example, an isothermal profile at 15°C, it would be common to collect the wort at 14°C. As the yeast begins to generate heat after pitching the temperature would rise until the set-point is reached and this would be maintained by the attenuation system. In this example the top temperature would be 15°C.

Many fermentations are conducted using a stepped temperature profile. For example, in large commercial modern lager fermentations a cool temperature might be used in primary fermentation, with a view to controlling ester formation. In the latter stages the temperature might be allowed to rise to a second plateau in order to encourage rapid reduction of diacetyl.

Top trough

A component part of a **Burton Union** system of fermentation.

Torrefied dextrins

Torrefied dextrins (also known as pyrodextrins) is the name given to the partially degraded and gelatinised starch granules which are formed when cereal grains are heat treated in the torrefaction process.

See **torrefied grains**.

Torrefied grains

Torrefied grains are used in brewing as solid adjuncts. The name is descriptive of the process used for their manufacture since it means to dry and roast by exposure to fire. Grains of cereals such as wheat or barley for use as brewing adjuncts are heated to 100–150°C. This causes the grains to swell and split. The enzymes present in the grains are denatured and therefore make no contribution to the mashing process; however, the starch granules are disrupted and partially gelatinised. In addition, depending upon the moisture content some sugars are caramelised and melanoidins are formed by reactions between sugars and amino acids. These changes in total cause changes in colour and flavor, and thus torrefied grains when used as adjuncts confer extract, colour and flavour. The heat treatment degrades some β -glucans and therefore torrefied grains are not a cause of over-viscous worts. The pretreatment removes the need for pre-cooking. The partially degraded starch granules are sometimes referred to as pyrodextrins or torrefied dextrins.

In the traditional torrefaction process grains were passed through a stream of red-hot sand. In more modern treatments the grains are pre-wetted to give 15–20% moisture and are heated to approximately 65°C before being passed before a stream of air heated to approximately 260°C.

See **adjuncts**.

Total loss CIP set

Cleaning system where the cleaning agents are used once and then disposed of.

See **CIP**.

Total soluble nitrogen (TSN)

The total soluble nitrogen is a measure of the total concentration of organic nitrogen compounds present in raw materials, worts or beers. It is an important measure since in the case of worts it provides information regarding the concentrations of nitrogen-containing nutrients available to yeast for growth during fermentation. Analyses are performed using the **Kjeldahl** or **Dumas procedures**. Results may be expressed in simple concentration terms in the case of worts or beers. Commonly, the result may be corrected to a nominal standardised gravity. In the case of raw materials such as malts the analysis is performed on wort produced under standardised conditions. The result is then referenced to the dry weight of the original sample.

In the case of yeast nutrition the nitrogen content is usually measured as the related parameter, **free amino nitrogen (FAN)**. However, total nitrogen analyses provide additional useful information. Nitrogen compounds contribute to beer mouthfeel and are important determinants of beer foaming ability.

The value obtained may be approximately converted to total protein concentration by multiplying the total soluble nitrogen value by 6.25.

Several other measures of the concentration of nitrogen and nitrogen-containing organic compounds are used in brewing.

See **nitrogen**.

Total VDK

Term applied to the results of analyses for diacetyl concentration in which fermentation samples have first been subjected to a heat treatment (typically 70°C for 30 minutes). The heat treatment converts α -acetolactate into diacetyl. The former is the immediate precursor in the pathway which leads to the formation of diacetyl. The conversion of α -acetolactate into diacetyl occurs in beer in a spontaneous oxidative decarboxylation reaction. In fermentation this reaction proceeds slowly and is the rate-determining step in the diacetyl cycle. For this reason the actual concentration of free diacetyl in fermentation samples is low and considerably less than the α -acetolactate concentration. The latter can be regarded as potential diacetyl.

The majority of analytical methods provide measures of the concentrations of both diacetyl and 2,3-pentanedione plus the α -acetohydroxy acid precursors. For this reason the results are expressed as total VDK.

See **diacetyl cycle**.

Tower brewery

A tower brewery is one in which the operating costs are defrayed by making use of gravity to facilitate transport of a batch of beer and its precursors through the individual stages of the brewing process.

The concept was developed in the nineteenth century as part of the industrialisation and scale-up of manufacturing processes characteristic of the Victorian Industrial Revolution and persisted until the mid part of the twentieth century when increases in scale and greater

concentration on costs demanded that large-volume brewers moved to a more economic horizontal layout.

Tower breweries comprised tall brick, concrete or steel-built structures. The foundations and walls required to be sufficiently robust to bear the considerable weight of the tanks and associated brewing equipment. The use of wood was avoided to minimise the risk of fire. The tower contained several floors in which the individual parts of the brewery were located. Usually individual vessels were situated between the floors to give convenient access to both the tops and bases. A centrally located shaft passed up the tower in which a hoist was housed and fire-proof doors provided access to each floor.

Brewing vessels were arranged spatially such that after the initial requirement to move raw materials to the top of the tower, the process flow was downwards, thereby minimising the need to use mechanical means to facilitate transport.

Water tanks were located on the flat roof of the building and the malt store and hot liquor tanks were placed on the top floor. Typically the mill was placed on the floor below directly above the mash tun and associated Steel's mixer. The kettle was placed on the top floor of the building and therefore it was necessary to pump the sweet wort upwards from the mash tun, the only major step requiring mechanical assistance.

From the kettle through to the fermenting vessels the wort proceeds downwards under the influence of gravity. Storage cellars, yeast handling facilities and racking tanks were all located on the ground or cellar floors of the building, thereby making use of the cooler ambient temperature and providing easy access for the transport of the finished product from the brewery.

Tower continuous fermenter

A continuous fermentation system introduced into the United Kingdom in the 1970s by the APV Company and used commercially by companies such as the erstwhile Bass Brewers Ltd. Unlike the majority of commercial continuous fermentation systems the tower system comprised a single vessel (see **continuous fermentation** for more details). The basis of the fermenter is that wort flows upwards at a defined rate. The yeast strain was a specially selected highly flocculent type which favoured retention in the vessel. The combination of flocculent yeast and upwardly moving wort stream produced a plug-flow arrangement which prevents substantial back-mixing and therefore produces a gradient the traverse of which mimics the changes which occur in a conventional batch fermentation.

The fermenter comprised a vertical cylindrical vessel made from stainless steel and provided with wall-mounted cooling jackets. Hot wort produced in a conventional brewhouse was subjected to continuous centrifugation to reduce solids loadings and was transferred whilst still hot to dedicated storage tanks. Wort was transferred from the storage tanks and sterilised by passage through a plate and frame heat exchanger. After cooling the wort was oxygenated and allowed to enter the fermenter via the base. Here it was subjected to rousing with a stream of CO₂ in order to prevent yeast compaction. Yeast retention in the body of the tower allowed the generation of very high yeast concentrations, in excess of 350 g/L wet weight, at the base. This promoted very rapid fermentation rates. The formation of the gradient along the vertical axis of the vessel was promoted by the provision of horizontally mounted baffles. Differences in density throughout the vertical axis of the vessel owing to the continuous addition of

relatively high-density fresh wort also tended to prevent back-mixing. At the top of the tower fully attenuated wort was allowed to exit via an overflow main. A system of baffles allowed separation of CO₂ and diverted some of the entrained yeast into a reservoir from which it could be recycled into the stream of in-flowing wort.

The high yeast concentrations achieved in the towers allowed high rates of productivity. At one UK brewery four tower fermenters each 8.5 m tall and 1 m in diameter were capable of producing 5000 hL of beer per week. This equated to a total fermentation time of 3–4 hours. Use of tower fermenters for commercial brewing ceased in the 1970s and reversion to batch fermentation took place. The reasons for this were lack of flexibility, restricted choice of yeast strain, the need for high levels of technical input and a tendency for uncontrolled wash-out of yeast.

Tower malting

A design of maltings, analogous to a tower brewery, in which the individual process steps of malting and their associated units of plant are arranged vertically, from top to bottom, within a dedicated building. The individual vessels are linked by appropriate grain conveying systems, and the building houses a water tank, located on the roof, air conditioning plant and facilities for CO₂ extraction and silos for holding the barley intake and finished malt. Operation of the individual stages of the malting process is integrated to minimise batch cycle times and to maximise the opportunities for automation.

By implication for most efficient operation, these types of malting are best suited to the production of a single malt quality since the whole needs to operate in a tightly integrated fashion and thereby with only a small opportunity for flexibility.

TPO

Acronym that stands for total in-pack oxygen, occasionally also written as TIPO. It is a measure of the oxygen content of both the liquid and headspace gas in a small-pack container such as a bottle or can. Several approaches have been devised with varying degrees of sophistication and ease of automation. The complication is that the oxygen concentration in the liquid and headspace gas may or may not be in equilibrium. Measurement of the dissolved oxygen content of the liquid phase, alone, may underestimate true values if the control of the packaging operation is insufficient to exclude air from the headspace of the package prior to sealing. If undetected poor flavour stability may result.

Dissolved oxygen meters are used together with a device which pierces the lid of the container making a gas-tight seal. A pump draws out a sample of the beer and delivers it to the oxygen meter. In early approaches it was necessary to subject the package to a process of controlled agitation to ensure equilibration of gas and liquid phases. This is the so-called **shake-out** approach. Filled containers are placed on a table shaker and shaken at *ca.* 180 rpm for 5 minutes and the dissolved oxygen content of the equilibrated liquid measured. The total bottle volume and liquid volumes are calculated and by subtraction the headspace volume. With this information, together with the beer temperature, it is possible to calculate the TPO using so-called Z factor tables. In modern approaches optical sensors allow simultaneous measurement of oxygen tension in both the headspace and liquid and from these the instrument calculates automatically the TPO. The advantages are that there is no sample preparation

time and it is possible to monitor the oxygen contents of both the beer and the headspace, which provides early identification of lack of proper process control.

Tradition (barley)

A variety of malting barley which appears on the approved lists of the United States and Canada. It was largest, in terms of acreage, in North Dakota in 2008.

Tradition (hop)

Tradition is a German aroma hop released in 1991 and bred at the Hüll Hop Research Institute. It is a verticillium wilt and downy mildew-resistant relative of **Hallertau Mittelfrüh**. It contains 5.0–7.0% α -acids, of which 26.0–29.0% is cohumulone, and 4.0–5.0% β -acids. Total oils are 1.0–1.4% (10.0–15.0% caryophyllene, >1.0% farnesene, 45.0–55.0% humulene, 20.0–25.0% myrcene).

Tramp iron

Tramp iron is the name given to pieces of stray metal that may be found as accidental contaminants of solid dry goods such as malts and other solid adjuncts. They must be removed by the use of screens and magnets before processing in the brewery in order to avoid damage to the plant.

Trans-2-nonenal

Aldehyde associated with cardboard flavour of stale beer with the following structure.



Structure of *trans*-2-nonenal

See **beer flavour stability**.

Trap filter

A trap filter is one which is incorporated into pipework carrying process fluids which prevents the passage of any extraneous suspended solids which might compromise the integrity of the liquid or downstream process equipment.

Trap filters are typically membrane cartridge types which are not tolerant of high solids loadings but are capable of providing process security. A typical application is the location of a trap filter after a powder filter used for primary beer filtration. In stages of their operation the latter may allow passage of kieselguhr powder fines which if not removed would give beer with unacceptable clarity. Other trap filters are intended to prevent damage to process plant. These take the form of relatively coarse stainless steel sieves. Their function is to prevent the

forward flow of any extraneous solid materials such as pieces of metal, screws and washers, which might accidentally find their way into process pipework which carries product. A typical location would be immediately before a filler on a packaging line where such pieces of debris would cause serious damage to relatively fragile filler tubes.

See **filtration**.

Trappist beers

Trappist beers are those associated mainly with Belgium and are brewed for commercial sale but entirely within monasteries either directly or under the supervision of monks (although bottling may be performed externally). This distinction allows the brewers to use the wording *trappiste* on bottle labels. Seven breweries, six in Belgium and one located in the Netherlands, fulfil this definition. These are Achel, Chimay, Orval, Rochefort, Westmalle and Westvleteren (Belgium) and Koningshoeven (the Netherlands).

The beers share nothing in common other than being brewed in these unique circumstances. In effect they represent a rump left over from the times when European monastic brewing, mainly for own use or the refreshment of guests, was commonplace.

Trappist beers are produced via top fermentation and most are bottled and are subjected to a further secondary fermentation after bottling. Although several different beer types are brewed by the Trappist monasteries, traditionally these were placed into one of three categories. This 'holy trinity' of beers was distinguished based on the proportion of malt used in the grist and termed *enkel* (single), *dobbel* (double) or *tripel* (triple). Alcoholic contents can be very high (in excess of 10% abv).

See **abbey beers**.

Treberin

Name given to one of the many substances which have been described as causes of premature yeast flocculation (PYF). It is a polysaccharide which was isolated from six-rowed barley which on hydrolysis yielded glucose, xylose and arabinose.

See **premature yeast flocculation (PYF)**.

Trehalose

Trehalose (α -D-glucopyranosyl-1,1- α -D-gluconopyranoside) is a disaccharide which comprises two molecules of D-glucose. It may serve as a storage carbohydrate in yeast, but most likely this role is performed by **glycogen**. The factors which modulate trehalose levels in yeast, together with its properties, suggest that it is a stress protectant.

In brewing yeast trehalose accumulates during fermentation typically up to 5% of the cell dry weight. In high-gravity fermentations much higher levels are formed, up to 25% of the dry weight. Similar levels are found in dried yeast preparations where its presence and concentration correlate with the ability to withstand the rigours of rehydration. These observations, coupled with the fact that trehalose is able to stabilise membranes, support its role in helping cells to survive applied stresses. Other stresses, such as heat shock and exposure to conditions of very high osmolality, also trigger trehalose accumulation, further supporting the view that formation of this compound forms part of a general stress response in yeast.

Trehalose is synthesised from glucose 6-phosphate via the concerted action of two enzymes, trehalose 6-phosphate synthase and trehalose 6-phosphatase. Mobilisation occurs via one of two trehalases, an inducible cytosolic neutral form and a constitutive vacuolar acidic enzyme. The former is activated by a reversible phosphorylation step catalysed by cyclic AMP-dependent protein kinase. The promoters of the synthetic enzymes contain the same sequences as other genes subject to expression in response to applied stresses such as heat shock.

See **glycogen, yeast growth and metabolism**.

Triangular test

See **three-glass taste test**.

Trim chiller

Trim chillers are heat exchangers, usually of the plate and frame type, which are used to make small adjustments to the temperature of process fluids. Commonly they are located in situations where processes may cause small pickups in temperature, for example, where in-line continuous centrifuges are used after maturation (conditioning) and before filtration. In this instance the temperature of the beer exiting the maturation tank will typically be less than 0°C. Depending on design some centrifuges generate sufficient heat to cause an increase of 1°C, or more. In order to prevent redissolving of cold break, which would therefore pass through the filter and compromise packaged beer colloidal stability, it is necessary to apply trim chilling to return the temperature of the beer, pre-filter, to the desired value.

See **plate and frame heat exchanger**.

Trinidad

A cultivar of the wheat and rye hybrid, triticale.

Tripel

Tripel, literally triple, is one of the traditional categories of Trappist beers made by top fermentation and usually bottled and subjected to a lengthy secondary fermentation. The name refers to the quantity of malt used in the grist and is distinguished from the weaker *dobbel* (double) and *enkel* (single) varieties.

See **Trappist beers**.

Triple decoction mashing

See **decoction mashing**.

Triploid hop varieties

Triploid hop varieties are hop cultivars which as a consequence of their genome are not able to set seed. This allows, if desired, male plants to be planted in the hop garden such that fertilisation of females may occur with concomitant increases in yield but without the formation of seed, which many brewers consider as a cause of rancid off-flavours. Conversely, sterile triploid males can be planted with conventional diploid cultivars with the same net result.

The development of triploid hops was pioneered in New Zealand and resulted in the introduction of several commercial super high alpha varieties. Breeding programmes in New

Zealand, the United States and Europe have resulted in the development of both high alpha and aroma triploid varieties.

Triploid hops (30 chromosomes) are produced from crosses between tetraploid (40 chromosomes) and diploid parents (20 chromosomes). The former occur in nature as rare mutations but more normally are induced by treatment with the plant alkaloid colchicine.

Tristimulus

See **beer colour**.

Triticale (triticosecale)

Triticale is a cereal plant that is a hybrid between wheat and rye, hence the name, which is derived from *Triticum* (barley) and *Secale* (rye). It has been considered to have much potential as a cultivated crop in that many cultivars possess useful characteristics of both parents, thus, high-yielding in the case of wheat and disease resistance and the ability to grow in low-fertility conditions associated with rye.

Triticale has been assessed for its use in brewing. Triticale malts have high **diastatic power (DP)**; worts produced from them contain high nitrogen concentrations, and they are darker and of higher pH than those made with conventional barley malt. Furthermore, ethanol yields after fermentation of triticale malt worts are less than those obtained from barley malts. Understandably this has tended to discourage the use of malted triticale in brewing. However, more favourable results have been obtained where the extracts of the unmalted grain have been used as an **adjunct**. For example, Glatthar *et al.* (2003, 2005) [Glatthar, J.H., Heinisch, J.J. & Senn, T. (2003) The use of unmalted triticale in brewing and its effect on wort and beer quality, *J. Am. Soc. Brew. Chem.*, **61**, 182–190; Glatthar, J.H., Heinisch, J.J. & Senn, T. (2005) Unmalted triticale cultivars as brewing adjuncts: effects of enzyme activities and composition on beer quality, *J. Sci. Food Agric.*, **85**, 647–654] tested three cultivars, Trinidad, Lamberto and Fidelio. They concluded that unmalted triticale was inferior to malted barley but was comparable to wheat when used as an adjunct. The Trinidad cultivar gave the most satisfactory results owing to its relatively low impact on wort viscosity.

Triumpf

See **Valtický**.

T

Trub

The term *trub* derives from the German for ‘cloudy’. It refers to the solid precipitate that forms in the kettle during wort boiling. It is a synonym for **hot break**. Occasionally the term may be applied to the sediments which form in the bottoms of tanks during other stages of brewing, for example, in fermentation or conditioning tanks. This usage is incorrect and trub should be applied solely to the solid material that is formed in the kettle during boiling and which is separated out during hot wort clarification, usually by the use of a whirlpool.

It is true that hot wort clarification does not remove all trub material from wort and therefore some will be carried forward into fermentation where it will co-sediment with yeast and cold break. In this sense the fermenter tank bottoms will contain some trub, but other solids will also be present.

See **hot break**.

Tsiou

See **t'ien tsiou**.

Tube and shell heat exchanger

Tube and shell heat exchangers are designed to change the temperature of process liquids. Typically they may be used for applications such as cooling of liquids such as hot wort (see **wort cooling** for more discussion), or for the application of heat as in a flash pasteurisation process. They comprise bundles of cylindrical tubes, which usually carry the process fluid, surrounded by a secondary chamber, the shell, through which the heat exchange medium is carried. For cooling operations the hot process liquid is allowed to pass through the tubes whilst the heat exchanging cooling fluid is pumped in countercurrent flow through the shell.

Tulipai

A mildly alcoholic beer made by certain indigenous tribes of North America, a synonym for **Tiswin**.

Tulip glass

Glass drinking vessel designed for beer consumption with a shape whose profile is reminiscent of a tulip flower and which typically have a circular base and stem. The shape is considered to both help trap delicate aroma notes and to favour good head retention by virtue of the flared lip. Branded versions are popular in Belgium for consuming strong ales.

Tun

A tun is a general term for a vessel. The term is associated particularly with the United Kingdom. Historically these were large coopered vessels made from wooden staves held together by metal hoops. In the brewing sense it may be preceded by another term descriptive of the use for which the vessel may be put, for example, **mash tun**. This usage persists to the modern day. It may also be used as a verb, as in *tunning*, in which case it is used in the sense of the transferring beer or other brewing process liquids into a tun. It is also descriptive of a volume of beer equal to 216 imperial gallons (983.04L).

The origin of the word is obscure. It may be derived from early English and possibly Celtic meaning 'enclosure' as in the sense of a tract of enclosed land or a compound. This etymological route resulted in the modern word 'town'. Whether or not this also accounts for the usage of tun as an enclosure for large volumes of liquid is uncertain.

Tunnel pasteurisation

Process and plant used to render small-pack beers microbiologically stable by subjecting them to a controlled heat treatment. A tunnel pasteuriser comprises a hollow elongated chamber fitted with internal devices for delivering a spray of heated water from above. Beer containers are exposed to the water sprays as they are transported through the pasteuriser via a motorised conveying system. The speed of the conveyor and the temperature of the water sprays control the extent of the heat treatment. Since the conveying rate is usually fixed control of temperature regulates the process (see **pasteurisation**).

Tunnel pasteurisers may have a single or two decks depending on the required rate of throughput. The tunnel is divided into a number of zones of differing temperature. These are a pre-heating zone, where the cold bottles are warmed, before passing into a superheating zone, where the temperature is increased to that required for pasteurisation (usually 60–65°C). Bottles then pass through the pasteurisation zone, where the bulk of the treatment is provided after which there are successive pre-cooling and cooling zones, where the temperature is reduced to room temperature. The conveying system usually takes the form of a walking beam where the containers rest on a series of metal bars parallel with the direction of movement. The bars are arranged in short overlapping rising and falling lengths such that the forward movement of individual sets moves the containers slowly forward in a series of cyclical steps. This arrangement is preferred to a simple continuous belt because it keeps individual sections of the walking beam in the same zone of the pasteuriser and therefore cannot contribute to heat pickup or loss. Typical residence times are of the order of 1 hour.

Tunnel pasteurisers attract high capital and revenue costs. The latter is kept to a minimum by recovering the heat energy for use elsewhere in the brewery. Usually the water is recovered from the cooling zone and recirculated for use in the pre-heating zone. The quality of the spray water must be carefully controlled in terms of salt composition, pH and microbial contamination. Sanitisers are added and values of around pH 8.0 maintained to avoid the growth of moulds and bacteria, and calcium levels must be kept low to avoid containers acquiring blooms of metallic salts. Precise regulation of the spray temperatures is vital to ensure proper heat treatments are achieved and continuous recording is usually maintained. In the event of a breakdown there are risks of both over- and under-pasteurisation. This eventuality requires the packaging line to have proper control procedures. Typically if the pasteuriser stops for longer than a given period of time the whole tunnel is cooled down to prevent over-pasteurisation of the product in the heating zones. Any product suspected of being under-pasteurised must be isolated and a decision taken as to how it will be treated. The packaging line must have accumulation facilities in the event of temporary stoppages. Modern high-throughput tunnel pasteurisers use very sophisticated control systems. Some have flexible speed controls where the speed of the conveying system is moderated in response to fluctuations in overall filling line velocity. Achievement of the desired pasteurisation treatment is controlled by modulating the spray temperature in response to the change in the rate of throughput. This allows more efficient line operation since it avoids the need for intermediate accumulation capacity. In addition, in the event of line stoppages, cooling systems reduce the temperature of packages in the heating zones to values just below the threshold for pasteurisation unit (PU) calculation. This ensures product quality and safety at minimum cost.

Monitoring of correct performance requires a consideration of the number of pasteurisation units supplied to actual filled containers. It is not sufficient to rely simply on monitoring spray temperatures. Several commercial devices are available, for example, the **Redpost**, probably the most well known, which provide measures of the pasteurisation units to which beer is exposed to during pasteurisation runs.

Tunnel pasteurisers attract greater costs than flash pasteurisers and they have a much larger footprint. In addition, they subject beers to a greater risk of thermal degradation; however, they have the great advantage that if operated correctly the microbial integrity of the beer is

guaranteed. Since flash pasteurisation and cold sterile filtration are applied to bulk beer prior to packaging they do not afford this luxury.

Turbidometry

A system of measurement in which the concentrations of suspended particles are determined by their ability to scatter light according to the Beer–Lambert law. The sample is held in a transparent cell, either online or as part of an offline test, and a beam of light is passed through it. A detector, located either directly opposite the light beam or at an angle to it, measures the extent to which the intensity of the light is reduced as a result of the particles present, and this can be related to the concentrations of particles present in the sample. The relation is not linear and depends on the shape and size of the particle. The relation between turbidometric readings and actual concentrations is determined using calibration curves.

The approach is used widely in brewing. In-line measurements are used to measure the clarity of process streams as in haze measurements. Since the output from the instrument can be used to control other brewing plant the method is often used to control dosing operations where there is a measurable change in turbidity such as adding filter powder and control of yeast pitching.

At laboratory scale it can be used to detect microbial growth in clear media. The limits of detection for bacteria are of the order of 1×10^6 cells per millilitre and compared with conventional culture techniques afford significant time savings for early detection of contamination.

Turbidometry relies on light scattering and is relatively insensitive to the wavelength of the incident light source (typically 400–800 nm is used). The related technique of **spectrophotometry** measures absorbance at a defined wavelength. This underpins many analytical techniques, much used in brewing, where a reaction takes place which involves a colour change, and the concentration of the analyte is inferred from the absorbance or optical density. In this case the wavelength of the incident radiation may range from the infrared down to the ultraviolet.

Turbidostat

A turbidostat is a type of continuous fermenter in which the population density within a culture vessel is maintained at a constant value by the regulation of the rate of addition of fresh growth medium in response to output from a device such as a nephelometer, which measures cellular populations by means of light scattering.

The turbidostat is the reverse of a chemostat, where population density is regulated by the rate of addition of fresh medium. It has the advantage over the latter in that it is possible to maintain steady-state conditions with an excess of all nutrients. In a brewing context this could be advantageous if this approach was used since it would provide a more flexible method of controlling beer composition.

See **chemostat** and **continuous fermentation**.

Tut

A tut is a small plug which seals the aperture in the **shive** of a cask and which is driven out when the **spile** is driven into the cask during the broaching process.

See **cask**, **cask-conditioned beer**.

Twopenny

A historic term used in the United Kingdom for a type of beer, also sometimes written as *tuppenny*. This was of a higher quality than the less expensive ale and beer categories.

See **porter**.

Two-spotted mite

See **red spider mite**.

Type 45 hop pellets

See **hop pellets**.

Type 90 hop pellets

See **hop pellets**.

Tyrothricin

An antibiotic, effective only against Gram-positive bacteria and reportedly *Candida* spp., which, before the realisation of the risks of the profligate use of such compounds, was suggested as a suitable agent for disinfecting pitching yeast.

U

Ukhamba

The name given to a woven basket made by the Zulu people of South Africa and designed to contain the native utshwala sorghum beer.

See **native African beers**.

Ullage

In the brewing sense the residues of beer which are returned to the brewery in casks, kegs or bottles and which must be removed and disposed of before cleaning and refilling, hence the verb de-ullage, to remove these residues. In the wider sense the term comes via the Latin *oculus*, meaning an eye, or the aperture through which casks are filled. In later Norman French this became *ouiller* as in to fill a cask brimful (up to the eye). By inference ullage became the term for any shortfall as in the headspace in a container or tank or as in any liquid lost in handling.

Ullmann continuous mashing system

This is a system designed to be used with continuous wort production systems, as became briefly popular during the 1970s and 1980s. It comprises a series of stirred mashing tanks each of which may be attemperated independently, for example, at 45, 52, 65 and 75°C, as might be used in a typical infusion mashing regime. In addition, a mash cooker vessel held at 100°C is also provided. The volume in each tank can also be regulated and, thus, the actual residence time in each tank and, by inference, the mashing regime can be controlled by a combination of the pumping rate and liquid level. After passage through the cascade of mashing tanks using a number of centrifugal pumps the sweet wort is separated from the spent grains using a continuous mash filter.

Ultra

Ultra is a triploid aroma hop variety released in 1995. It was bred in the United States from tetraploid **Hallertau Mittelfrüh** and diploid **Saaz hop** parental types. Ultra shares parentage with **Mount Hood**, **Liberty** and **Crystal hop**. It contains 4.5–5.0% α -acids, of which 25.0–30.0% is cohumulone, and 3.6–4.7% β -acids. Total oils are 0.8–1.2% (10.0–15.0% caryophyllene, 0% farnesene, 30.0–40.0% humulene, 25.0–35.0% myrcene).

Ultra-high-gravity brewing

Production and fermentation of very concentrated worts typically greater than 1080 (20°Plato), with subsequent dilution of the finished beer to sales strength as a means of increasing process productivity with minimal capital expenditure.

See **high-gravity brewing**.

Ultrasonic flow meter

See **flow meter**.

Ultraviolet (UV) radiation

Irradiation with UV radiation is used in brewing as a method of sterilisation. It exerts its effects by disrupting the nucleic acids of the target organisms. The latter show maximum absorption in the range of 260 nm and UV sterilisers are designed to generate radiation in the range of 200–280 nm, the so-called germicidal range. The result is cross-linking of the constituent bases of the nucleic acids such that lethal mutations occur. The dose rate must be sufficient; otherwise damaged cells can undertake repair steps and recover from the treatment. This is important since there is no residual activity.

UV irradiation is used principally in brewing for the sterilisation of water. Many biomolecules, as might be found in beer or wort, for example, are efficient absorbers of UV and, in such circumstances, entrained microorganisms can be shielded. Thus, the material to be treated must be relatively clear and must have low levels of suspended solids.

UV radiation is supplied by generators which take the form of low-pressure mercury lamps. These usually take a long tubular form and are designed to irradiate the stream of process fluid as it passes through a flow cell. The lamps have to be located behind quartz windows since glass is not transparent to UV. The power output of the lamp, the design and capacity of the flow cell, and the flow rate are all important determinants of efficiency.

The efficacy of sterilisation is much improved by the use of combinations of UV and other sterilising agents, in particular ozone. In this case apart from sterilisation of water complete oxidation of chlorinated hydrocarbons to CO₂ and hydrochloric acid with the concomitant removal of some taints also occurs.

Umqomboti

A native beer made in South Africa from maize grits and maize and sorghum malts. The name derives from the Xhosa language. It is an opaque sour beer with a modest alcohol content, typically up to 3% by volume. It is a valuable nutritional aid being very high in riboflavin vitamins. The proportions of maize and sorghum used influence the colour and taste of the beer. Sorghum gives a darker product, whereas maize imparts a lighter taste and colour. The latter is termed mealie meal and for this reason the beer is also known as mealie beer.

Underback

An underback is a vessel, usually associated with traditional ale production, which is used for the temporary storage of hot sweet wort. The underback is used where the kettle is not immediately available after the sweet wort has been separated from the spent grains in a mash tun. The wort is held at an elevated temperature, typically around 80°C, in order to deter microbial spoilage.

The holding time must not be prolonged since some thermophilic bacteria can tolerate these conditions, and as a result of their metabolism nitrate can be reduced to nitrite. This is undesirable principally since it increases the risk of formation of potentially carcinogenic nitrosamines via the action of other groups of beer spoilage organisms downstream of the brewhouse. In addition, prolonged storage of hot wort results in darkening.

Under-bar chiller

A refrigerated cabinet designed to be located behind or under a bar and used to hold supplies of chilled bottled beers and other small-pack beverages.

Under-bar cooler

See **remote beer cooler**.

Underletting

Underletting is a process used in mashing in which hot liquor is allowed to enter the mash via the false bottom of a mash tun. The hot liquor is added slowly such that it lifts the bed of grains off the false bottom such that they may be mixed and diluted. It is the most commonly used method for controlling the temperature of the mash during the course of UK-style ale infusion mashing. It may be used in conjunction with sparging. Underletting is also used to move the grains in the event of a **set mash**.

Union

Name given to the coopered casks which form the receptacles in which primary fermentation is conducted in the Burton Union system.

See **Burton Union system**.

Unionbirrai

Unionbirrai is an Italian consumer organisation founded in 1999 and with the aims of championing for what are perceived as traditional beers and campaigning against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Contact details are at <http://www.unionbirrai.com> (last accessed 4 April, 2013).

Union of Russian Brewers

The Union of Russian Brewers [<http://www.beer-union.com> (last accessed 14 February 2013)] is a trade organisation which represents the interests of the Russian Brewers Industry. It is a member of the **Worldwide Brewing Alliance**.

Uni-tanks

The term uni-tank is a contraction of 'universal tank'. It refers to brewery vessels which have been designed to carry out both primary fermentation and cold conditioning. Other terms with the same meaning are **dual-purpose tank** and **fermentation vessel conditioning tank** (FVCT).

Commonly these vessels are of the cylindroconical configuration but with the addition of the extra cooling capacity needed to reduce the temperature of green beer to the low values

needed for the cold-conditioning phase. Other tank designs have been developed for these duties; for example, see **Asahi vessel**, **Rainier uni-tank** and **sphericoconical dual-purpose vessel**.

Uni-tanking operations first became popular in the 1970s with commercial brewers who were seeking to maximise outputs. In this regard the combined operation allows a reduction in total process time compared to the more conventional two-tank approach since the time required for tank-to-tank transfers is eliminated. In addition, there are other cost savings in that the use of a single tank reduces the total number of cleans, losses associated with tank transfers and risks of oxygen pickup. Most importantly, fewer costly tanks are needed. The approach is more flexible in that it is possible to vary at any given time the fraction of the total tanks available which are dedicated to either fermentation or conditioning.

The uni-tank approach has significant drawbacks. Obviously the process requires that vessels are suitable for both primary fermentation and conditioning. This tends to lead to over-engineering and some degree of compromise. Essentially fermenting vessels are more complex compared with conditioning tanks since they must cater for operations such as yeast cropping and pitching and CO₂ collection. Conditioning tanks need only hold beer at a desired low temperature. Coolant supplies for conditioning must be at a lower temperature than that required for holding at fermentation temperatures. The large difference between beer and coolant on the latter case can lead to thermal shocks and stratification in poorly mixed vessels. The transfer between fermentation and conditioning vessels provides an opportunity to perform tasks which are more difficult in the single tank approach. Examples include application of cooling or addition of stabilisation agents in-line during the transfer.

For most brewers the disadvantages of uni-tanking probably outweigh the gains and for these reasons it is less common than it used to be. Nevertheless, it is suited to the operations of a few brewers. Generally these are those that use very large batch sizes producing one or a small number of beer qualities.

Universal beer agar

Non-selective medium containing metal salts, phosphate (medium buffered to pH 6.3 when made up), peptonised milk (source of lactose), yeast extract (vitamins especially B group), tomato juice (additional nutrients) and glucose (fermentable sugar). The medium is supplemented with hopped and de-gassed beer (25% v/v) before autoclaving. The medium supports the growth of both bacteria and yeast. The presence of hopped beer is selective for microorganisms associated with brewing. Incubation may be aerobic or anaerobic depending on which class of organisms is to be detected. Cycloheximide (1 mg/L added as a sterile filtered solution to molten tempered medium) may be added to prevent the growth of culture yeast.

Unterteig

This German term, literally the 'first paste', describes the shallow layer of solid material that is the first to settle out onto the false base of a **lauter tun**. It is usually about 1 cm in depth and consists principally of large grits and often contains relatively under-modified and starch-rich large fragments of malt. It is distinct from the **haupteig** (main paste) and **oberteig** (upper paste) layers.

See **lauter tun**.

Urbock

Urbock, literally 'original bock' is the forerunner of the bock style of beer. The former originated in the North German city of Einbeck from where it was exported to Bavaria and thence to the rest of the world.

See **bock**.

Urhell

See *Helles*.

Urwaga

A native beer of Kenya made from sorghum and an aqueous extract of ripe bananas.

See **native African beers**.

USDA hop cultivar collection

The United States Department of Agriculture (USDA) maintains an online catalogue of hop cultivars. Basic descriptions of each cultivar held in the collection together with dates of accession and origins may be found at <http://thehennings.com/beer/hops.html> (last accessed 12 February 2013). A repository of genetic material in the form of a collection of hop germ plasm is held at the USDA-run Agricultural Research Service located at Corvallis, Oregon (NCGR-Corvallis – *Humulus* germ plasm). Details of the collection and the various services provided may be found at <http://www.ars.usda.gov/Main/docs.htm?docid=11069> (last accessed 12 February 2013).

Utility water

Utility water is that which is used in the brewing process for purposes other than as a direct ingredient of beer. Several duties require the use of water; these include washing and rinsing of brewery plant, use as a slurring agent for process aids such as filter powders, as a coolant and as a raw material for the generation of steam. The composition of the water must be appropriate for the application for which it is to be used.

Where the water might come into direct contact with a product as in cleaning and rinsing it must be potable and free from all taints and suspended solids. For use in initial cleans the quality of the water need not be as high as that used in more sensitive parts of the process. Where it is used as a terminal rinsing agent of sterilised plant the water must be free from all microorganisms and it may contain an antimicrobial agent such as chlorine or now more usually chlorine dioxide.

Where the water is to be heated it is essential that its mineral content has been adjusted so that it will not form scales on the surfaces of metal work and it is not a source of corrosion. Thus, for these applications it will typically be softened, have pretreatments to control pH and may contain additives to prevent the formation of scales.

In the case of boiler water the specifications supplied by the manufacturers must be adhered to. The stringency of these specifications depends on the type of boiler and may range from relatively simple softening treatments, possibly with additions of chelating agents and polyphosphates to prevent deposition of scale, through to a requirement to use fully deionised water.

In the case of water used in cooling towers there is a risk of harbouring *Legionella* bacteria and to guard against this, appropriate biocides must be used in conjunction with a regime of sampling and microbiological analysis.

See **water**.

Utshwala

A beer made from sorghum and maize associated with the Zulu people of South Africa.

See **native African beers**.

V

Vacuum-relief valve

See **anti-vacuum valve**.

Vacuum sampler

This is a device used for removing samples of grains from a bulk source such as a lorry.

See **grain samplers**.

Valentine arm

A valentine arm is a device fitted to a mash tun which is used to regulate the flow of sweet wort during **run-off**. It comprises an inverted u-tube which forms a siphon through which the wort runs. It is fitted such that the height of the liquid head can be adjusted and this is used to regulate the rate of run-off and the pressure exerted on the bed of grains. The latter is important to prevent the grain bed from becoming compacted such that run-off is impeded or prevented.

See **mash tun**.

Valtický

An early Czech variety of malting barley. Valtický was used to develop new and improved varieties of malting barley using X-ray irradiation. This technique was responsible for the development of the **Diamant** variety, which was approved for use in brewing in Czechoslovakia 1965. Further breeding trials in the then German Democratic Republic gave rise to the variety named **Triumpf**. Over 150 new malting barley varieties developed since have Diamant and Triumpf in their pedigrees. In the modern Czech Republic these new varieties are referred to as Diamant type. They include **Ametyst**, **Hann**, **Favorit**, **Rapid**, **Spartan**, **Kořal**, **Safír**, **Rubin** and **Akcent**.

Until 1993 cultivation of malting barley in Czechoslovakia was largely restricted to domestic varieties and these accounted for 70% of the total acreage. These restrictions have now been eased, and as of the early part of the twentieth century Czech varieties accounted for only 30% of the total; Slovak varieties made up just 5% and the remainder, 65%.

In the Czech Republic assessment of new varieties is carried out the **Research Institute of Brewing and Malting (RIBM)** located in Brno. Formal accreditation of varieties is carried out by the **Central Institute for Supervising and Testing in Agriculture (CISTA)**.

Valve actuator

A device that allows regulation of the operation of a valve. Varying degrees of sophistication are possible. At its simplest the actuator can be a manually operated screw-threaded wheel, or similar, whereas more complex types are driven automatically. The operation can be simply open or closed, or with the appropriate valve type a controlled degree of flow can be achieved. In automatic types a feed-back system provides feedback of the status of the valve.

Two types of actuation are used, depending on the nature of the valve. For ball, butterfly or plug types, simple rotation, at an appropriate torque, through 90° is required. For those valve types which when manually operated require multiple turns, such as the globe or gate variety, the actuator takes the form of a rotating or non-rotating stem.

In multiple rotating types the stem is driven by a single or three-phase electrical motor. Torque is controlled using a gear box. A limit switch senses when the valve is either fully open or closed, and this regulates operation of the motor, controls the magnitude of the applied torque and provides feedback of the status of the valve. Usually a manual system for opening and closing the valve is provided in the event of power failure. The latter eventuality highlights the major drawback of this sort of actuation. For those valves which control critical process flows it is essential to have a fail-safe provision in order to ensure safety and product integrity. Unless there is an emergency power supply motor-driven actuators cannot fulfil this requirement.

A simple 90° rotation or non-rotating stems can be driven by hydraulically or pneumatically driven actuators. These are essentially very simple since no power is required and they tend to be very robust. In hydraulic types, rotation, where required, is obtained by converting the linear motion of a cylinder into a rotational movement using a converter such as a rack and pinion. Pneumatic actuators are controlled by solenoid switches. Position switches provide feedback of the valve status. A major advantage of this type of actuator is that it is relatively simple to provide a fail-safe mechanism. For example, a spring arrangement which opposes the usual movement of the actuator will ensure that the valve moves into a safe position in the event of failure of the actuating mechanism.

Remote operation of valves fitted with automatic actuation is usual. In this way, control of the operation of complex plant such as large tank farms can be managed from a control room using very few operatives. Where the rate of fluid flow is required to be modulated, apart from the need for a valve suitable for this purpose, a more sophisticated actuator is also required. This can take the form of a proportionating device which converts an applied electrical current, in the form of a 4- to 30-mA supply, into a corresponding valve position. Where the modulation of flow rates through many valves requires to be controlled and the rate of change if flow is rapid is more complex, actuating control systems are used. In these complex installations digital communication systems capable of supervising the operation and reporting on the status of multiple actuators are usual. Apart from providing a convenient method of operating these complex valve systems in an efficient manner, these digital approaches provide inputs suitable for global supervisory systems such as those used for predictive maintenance.

Van Caspel turner

See **grain turners**.

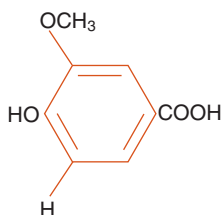
Vanguard

Vanguard is a US aroma hop, bred in the early 1980s and released in 1997. It has Hallertau in the pedigree. It contains 5.0–6.0% α -acids, of which 15.0–20.0% is cohumulone, and 5.0–7.0% β -acids. Total oils are 0.8–1.2% (10.0–15.0% caryophyllene, 0.3–0.5% farnesene, 45.0–50.0% humulene, 20.0–25.0% myrcene).

Vanillic acid

A simple phenolic compound, one of a series of substituted benzoic acid derivatives which are found in worts (see accompanying diagram for structure). Concentrations in an unboiled lager wort are reported to be of the order of 1.4 mg/L.

See **polyphenols, tannic acid**.



Structure of vanillic acid

van Leeuwenhoek, Antonie

Dutch amateur and self-taught scientist (1632–1723) born in Delft from a family of brewers on his maternal side who manufactured his own microscopes and, amongst many other observations, noted the presence of yeast cells in fermenting wort, the first known such record.

van Rijn continuous fermentation system

A system of continuous fermentation patented in 1906 in the United Kingdom by the eponymous L.R. van Rijn. It comprised a cascade of linked fermenting vessels in which an overflow system allowed fermenting wort to pass from one to another. Unlike many contemporary systems (see those of Schneible and Schalk) it was a truly continuous approach in which pitched and aerated wort was supplied as a constant feed to the base of the first vessel, and in response a stream of green beer issued from the overflow of the last vessel. Beer composition and system productivity was regulated by control of the rate of addition of fresh wort.

The approach was apparently not exploited at commercial scale.

VDK

Acronym that stands for vicinal diketone.

See **vicinal diketones**.

VDK analysis

As befits the importance of vicinal diketones (VDKs), in particular diacetyl, in beer flavour several analytical methods have been developed. The majority of methods rely on preheating at 50–70°C in order to ensure the conversion of all precursor acetoxy acids to free VDKs.

The earliest developed methods rely on the formation of coloured derivatives, thereby allowing quantification by spectrophotometric analysis. Examples of colourimetric procedures include reaction with dimethylglyoxime in the presence of hydroxylamine followed by reaction with ferrous sulphate to give a coloured complex. Another widely used procedure is a modification of the Voges–Proskauer procedure in which diacetyl is allowed to react with an alkaline mixture of α -naphthol and creatine and the absorbance measured of the resultant red complex.

More recently methods have been developed which rely on gas–liquid chromatography (GLC), gas–liquid chromatography in conjunction with mass spectroscopy (GCMS) or high-pressure liquid chromatography (HPLC). These methods also use an initial heat treatment, usually performed in sealed hypovials, and headspace analysis. These methods lend themselves to automation which suits the operational requirements of modern large commercial breweries where many fermenting vessels have to be serviced.

In the majority of breweries analyses are performed on samples removed from fermentation vessels for offline in the laboratory. The disadvantage of this approach is that there is a significant delay between sampling and obtaining the result, often several hours. In the case of diacetyl analyses this can result in a delay in moving on batches of green beer for processing. In order to avoid these delays attempts have been made to develop online sampling methods and automatic VDK analyses. Commercial systems designed to service tank farms have been developed which rely on individual fermenters being attached to a manifold system of capillary tubing, valves and pumps through which headspace samples can be delivered to a single GLC machine for analyses to be performed. As far as this author is aware no such systems are in operation seemingly because of the problems of keeping the complex tubing systems clean and operational.

VDK cycle

See **diacetyl cycle**.

VDK management

VDK management refers to those practices which are undertaken with a view to ensuring that the concentrations of those compounds, in particular diacetyl, which arise during fermentation and which are considered undesirable, are reduced to values below the flavour threshold for the particular beer.

The VDK, diacetyl, has a strong flavour and aroma of butterscotch, which is considered very objectionable in most beers, but especially the pilsner-type lagers. It is produced as a result of the growth and metabolism of yeast during primary fermentation. In the latter stages of fermentation it is assimilated by yeast and reduced to less flavour-active products. A key aspect of fermentation management is to ensure that these reactions are allowed to proceed such that in finished beers the concentrations of diacetyl and other VDKs are less than the flavour thresholds (see **diacetyl cycle** for a full description of the reactions involved).

The type of VDK management applied depends on the beer type and on the nature of the fermentation process used. Diacetyl is an essential contributor to the flavour of some beers, especially ales and stouts, and in such products no VDK management is necessary. In the case of lager beers produced using a long cool secondary fermentation where time is not of an

essence, the contact time between beer and yeast is very long. In such situations no additional treatments are needed to ensure that diacetyl concentrations are in specification in finished beers.

Specific measures are exercised with the aim of controlling diacetyl concentrations where there is a requirement for short fermentation cycle times. This is the case for the majority of the pale pilsener-type lagers which make up the bulk of the world's major brands.

Several approaches have been developed. The simplest is the need to hold beer in a fermenter at warm temperatures for a holding period after the completion of primary fermentation. Typically the beer is held at the same temperature, or occasionally slightly higher, as that used for primary fermentation. This phase is termed variously **diacetyl (VDK) rest** or **diacetyl stand, warm stand**. In order for diacetyl reduction to proceed it is essential that viable yeast cells remain suspended in the beer. Premature separation of yeast at this stage, as can happen in the case of flocculent strains fermented in tall vessels, can cause a cessation of diacetyl uptake and reduction. Typically, during the VDK stand, daily samples are removed from the fermenter, or more frequently, as desired and analysed for **total VDK**. When the concentration has fallen below a predetermined specified value the fermentation is judged complete and the beer can be moved to the next stage of processing.

More interventionist VDK management procedures may be applied with a view to obtaining more predictable vessel cycle times. Where permitted, preparations of a commercially available enzyme, α -acetolactate decarboxylase, can be added to the fermenter. This enzyme converts α -acetolactate directly into acetoin and, thus, prevents the formation of free diacetyl by the slower spontaneous oxidative decarboxylation.

Several methods have been devised which allow rapid VDK removal from green beer. The majority of these approaches use reactors which contain immobilised yeast cells. Green beer is removed at the end of primary fermentation and separated from yeast by continuous centrifugation. The beer is then heated for a short time at 90°C to ensure decomposition of all the precursor α -acetolactate. The green beer is then passed through the bioreactor where the very high concentration of yeast ensures rapid reduction of diacetyl to acetoin. This approach is used at commercial scale and it is claimed the beer is indistinguishable from that made using a conventional process. In order to avoid staling reactions it is essential to ensure that conditions are strictly anaerobic during the heating step.

VDK rest

Term used to describe a holding period at the end of primary fermentation where the temperature is held at the same value as that used in primary fermentation, or occasionally slightly higher, to allow the suspended yeast to take up and degrade diacetyl; also known as warm stand or diacetyl stand.

VDK stand

A synonym for **diacetyl stand**, also known as a VDK rest.

Verband der Brauereien Österreichs

The major trade association for brewers in Austria [<http://www.bierserver.as> (last accessed 12 February 2013)].

Veronus of Lambeek

A saint described as the patron saint of Belgian brewers. He is associated with the town of Lambeek in Belgium, the place which gives its name to the spontaneous fermented lambic beers. The name of the saint is used for eponymous beer festivals. Amongst his reported miracles was the appearance of a spring of pure water in response to his striking the ground with his staff. The relevance of this to brewing may be easily appreciated.

Vertical stillage

A vertical stillage is, as the name suggests, one in which beer is dispensed from a cask which has been stored vertically. The cask is located on its end and stored with two wedges placed under one side such that the keystone is raised. Venting of the cask and beer dispense is performed using a device termed an **ale extractor**. This comprises a body, similar to a standard tap which, after taking appropriate hygienic precautions, is driven into the keystone. The ale extractor is fitted with a valve through which gases may be vented. This should be partially open when fitting the extractor in order to prevent sudden ingress of air. During the conditioning phase the valve is used to control venting of carbon dioxide. When this is complete a blanking plug is removed and a tube is inserted into the bottom of the cask. This is sealed with a gas-tight gasket. The tube is connected to the beer dispense system and with the venting valve open beer can be withdrawn in the usual manner.

Vertical stillage is useful where cellar space is at a premium; it is claimed that ullage volumes are reduced and there is no need for tilting.

Verticillium wilt disease of hops

This wilt disease of hop plants is caused by species of the ascomycete mould, *Verticillium*. Two species have been implicated, *Verticillium albo-atrum* and *Verticillium dahliae*. There are geographical differences in the distribution of the two species. *Verticillium albo-atrum* is more important in temperate regions, whereas, although it is widespread, *V. dahliae* is dominant in tropical and subtropical regions.

Symptoms of the disease present in two ways. There is a mild, termed 'fluctuating', form and a much more serious 'progressive' form. As a consequence of the differences in severity these two forms were once considered distinct. Now they are thought to represent the two extremes of the same infection.

The disease is mainly soil-borne via infection from mycelium, which is found in the soil or on contaminated plant debris. Conidia are formed in the resting mycelium in the soil. The mycelium of *V. dahliae* contains resting structures termed microsclerotia which permit the organism to overwinter or survive harsh conditions. Dicotyledonous weeds can harbour latent infections and act as vectors. It is possible that transmission over long distances may be via infected seed, although in general passage over long distances is rare. Usually the disease is transmitted via human intervention in the form of contaminated soils or other materials.

Infection of hop plants occurs via the roots from whence the mycelium invades the vascular tissue. It is this which causes the wilting condition. Outbreaks are more likely to occur when the soil is excessively wet. Early symptoms are the yellowing of leaves at the base of the plant gradually spreading to those higher up. Those leaves showing the first signs of infection may die and fall off, whilst those which survive may bear necrotic spots. In the mild 'fluctuating'

manifestation of the disease symptoms appear relatively late in the year, typically July and August. A characteristic sign of infection is the swelling of the bine, known as 'fat bine'. This is a consequence of cambial activity, which gives rise to a corky appearance. This appears to be a host response to the fungal invasion. Sections through the lower portions of bine in this phase reveal a brownish discolouration of woody tissue.

In the progressive form of the disease the first symptoms occur earlier in the season, usually around May. As with the milder form the leaves begin to yellow and then turn brown and die from the lower part of the plant. The upper leaves may assume a characteristic 'tiger-stripe' effect owing to the development of black necrotic regions between the lighter yellow coloured veins. In this more serious form the woody tissue also appears stained, but stem swelling is not usually evident. Eventually the bine becomes defoliated and within a few weeks is usually dead.

The severity of outbreaks and consequent economic consequences is very variable. Outbreaks of the progressive disease in various parts of the world have in the past been responsible for effectively eliminating hop cultivation from some areas. There are no effective chemical remedies. However, there is a wide range of susceptibility to infection shown by different cultivars. The use of resistant strains of hop and good sanitary practices have in combination reduced the threat of this disease to acceptable levels.

Vibrating screen filter

Vibrating screen filters are used to separate solids materials from liquids. In brewing they are mainly used in operations such as the recovery of entrained wort from spent grains or from hot break. In addition, they may be used to recover beer from waste yeast streams.

They comprise a circular screen onto which the feed material is deposited. The mesh screen is mounted on a sprung bed which is weighted such that when it is rotated by an electric motor drive a vibrational moment is set up. This causes the solid material which accumulates on the surface of the screen to be transported in a spiral fashion such that it is directed towards an exit point located on the periphery. The clarified liquid passes through the screen where it is collected.

Vicinal diketones

VDKs are important and desirable flavour constituents in a number of foodstuffs, particularly dairy products such as butter, cheese and yoghurt. Their presence in some beers, particularly some ales and stouts, is also desirable; however, in the majority of beers, especially lagers, their presence at concentrations greater than the flavour threshold imparts objectionable toffee/butterscotch taste and aromas.

The nomenclature, vicinal (Latin, 'neighbours'), refers to the possession by these compounds of two ketone groups linked to two adjacent carbon atoms. With regard to beer several VDKs arise during fermentation, but the two most important are diacetyl ($\text{CH}_3\cdot\text{CO}\cdot\text{CO}\cdot\text{CH}_3$) and 2,3-pentanedione ($\text{CH}_2\cdot\text{CH}_3\cdot\text{CO}\cdot\text{CO}\cdot\text{CH}_3$). The flavour thresholds are low, 0.07–0.15 mg/L and 0.9 mg/L, respectively.

VDKs may arise in beers as a result of bacterial infection. In this case other symptoms of spoilage are usually evident such as non-standard fermentation performance and the formation of ropes or slimes. These compounds are also formed as a result of the activity of yeast

during conventional brewing fermentations. Diacetyl and 2,3-pentanedione are formed in beer as a consequence of the excretion by yeast and the spontaneous breakdown of intermediates of the biosynthesis of the amino acids valine and leucine. In mid- to late fermentation the free VDKs are assimilated by yeast and reduced to less flavour-active products. An essential part of fermentation management is to ensure that green beer is not separated from yeast until these reactions have occurred and VDKs are reduced to sub-flavour threshold concentrations.

See **diacetyl cycle, VDK management**.

Victoria

Victoria is an Australian high alpha bittering hop produced in 1985. It is a seedless triploid variety bred from a tetraploid female and introduced to widespread cultivation in the 1990s. Analysis is 11.5–14.8% total α -acids of which 38.0–41.0% is cohumulone. Total β -acids are 5.8–7.5%. Total oil content is 1.2–2.6% of which 10.0–16.0% is caryophyllene, 0% is farnesene, 0% is humulene and 13.0–47.0% is myrcene.

Vienna lager

Vienna-style lagers are beers produced by bottom fermentation and associated with Austria. They are characterised as having a sweet malty and slightly toasted character. The beers are dark brown or reddish in colour (16–24 EBC) and are made using dark **Vienna malts**. They are closely related to **Märzen**-type beers. Bitterness levels are low (22–28 IBU) and noble hops are used to impart delicate floral notes. Ethanol contents are within the range of 4.8–5.5% abv and the beers are made from worts of 11.5–14°Plato.

The style of beer has largely fallen from favour in its native Vienna; however, several examples are brewed in South and Central America, particularly Mexico, as a consequence of the presence of Austrian émigré brewers.

Vienna malt

Vienna malts are associated with European beers that are golden brown in colour, particularly **Märzen**-type and **Vienna lager** beers. The latter is described as reddish brown or copper coloured. The taste is described as slightly sweet, malty and toasted. The former is usually dark, although some variants are pale. **Märzen** beers are full bodied and usually have high bitterness.

Vienna malts are made from two-rowed barleys and usually have quite high protein concentrations and are quite well modified. The grains are produced using a kilning programme that is initially quite prolonged and at a cool temperature in order to favour the formation of high levels of reducing sugars and free amino nitrogen. At the end of kilning, when the grains are dry, the temperature is allowed to increase to approximately 90–105°C. During this latter phase the plentiful supply of precursor sugars and amino acids allows the formation of coloured melanoidins. Stewing must not be allowed to occur and in consequence these malts do not generate any caramel flavour. Kilning is discontinued when the desired degree of colour has formed (usually 6–10 EBC units).

Vital stains (dyes)

Biological stains that are used as the basis of tests used to determine the viability of microbial cells including yeast.

See **yeast viability**.

Vitaltitration yeast vitality test

See **acidification power test (AP test)**.

Vitreosity

Vitreosity is used as a measure of malt quality. It is the inverse of **mealiness** and refers to the appearance of the malt or barley grains where the endosperm has a hard steely or glassy appearance, which is characteristic of unmodified and immature grains. Vitreosity may be quantified by examining a representative sample of grains and scoring the endosperms as being totally glassy (score 1), half-glassy (score 0.5) or with glassy ends (score 0.25). For good quality brewing malt the total and averaged value should fall within the range of 0–0.25.

The test is at best subjective and is not a good indicator of malt quality.

See **mealiness**.

Vlamingh

An Australian variety of malting barley accredited for use in 2006. It is moderately early maturing and is described as plump grained and high yielding and suitable for cultivation in Western Australia, whose Department of Agriculture breeding programme is derived from. Protein levels are higher than Gairdner and Baudin but lower than Stirling and Hamelin.

VLB

Berlin-based brewing school (*Versuchs-und Lehranstalt für Brauerei*) [<http://www.vlb-berlin.org> (last accessed 12 February 2013)], founded in 1883 and providing education in brewing at all levels since that time. In addition, it is a centre for brewing research and a resource for the provision of brewing yeast cultures.

VLB S7 medium

Commercially available microbiological growth medium (*Versuchs-und Lehranstalt für Brauerei*, Berlin) aimed at the cultivation and detection of lactic acid bacteria, especially *Pediococcus*. It is a nutrient medium which contains liver extract, amino acids, vitamins, maltose and starch as principal sugar sources, sodium acetate (stimulatory to many species of *Pediococcus*), Tween 80 and the pH indicator Bromocresol Green to aid visualisation of colonies on solid media.

Vojvodina

Vojvodina is a scarcely grown hop variety bred in the 1970s in the former Yugoslavia from a cross with **Northern Brewer** and a male derived from **Savinski Goldings** and a wild male. It is resistant to downy mildew, high yielding and has very good storage properties.

Analysis is 6.0–10.0% total α -acids of which 30% is cohumulone. Total β -acids are 2.0–5.0%. Total oils are 0.6–1.5%.

Vorlauf

Vorlauf is the German term for ‘first runnings’. The term is used in relation to the operation of a lauter tun and refers to the practice of recirculating the first turbid worts from the wort outlet back onto the surface of the bed. The pump used to drive the liquid flow may be called the *vorlauf* pump.

Vortex mash mixer

The vortex mash mixer, or mash hydrator, is a device which is designed to mix grist with hot liquor prior to delivery of the resultant mash into the mashing vessel. The vortex mash mixer is designed for use with relatively thin mashes used for decoction or temperature-programmed infusion mashing. Their enclosed design favours exclusion of oxygen.

In the device the grist is allowed to fall from the grist case into a chamber contained within a section of vertically mounted pipework. Hot liquor is injected into the chamber via a tangentially mounted inlet such that the grist is mixed very efficiently into the mass of rotating and swirling liquor. The vortex mash mixer may also be referred to as a **mash (pre-)hydrator** since full hydration may not be completed until the mash enters the mashing vessel. Commonly an additional mixing chamber is located after the vortex mash mixers to ensure that this is accomplished.

VTT

Technical research institute in Finland [<http://www.vtt.fi> (last accessed 12 February 2013)] which was founded during January of 1942 as an independent but government-funded organisation charged with carrying out technical and scientific research for the benefit of the people. An additional income stream came from commercial research. The institute had close links to the University of Helsinki. A research brewery was opened in 1962 to support research work on brewing, yeast, microbiology, malting and related topics. In the 1990s a reorganisation resulted in the setting up of a number of independent research units including the VTT Biotechnology and Food Research. Further revisions and re-brandings have occurred, but a strong base in brewing research and microbiology remains. The institute curates a yeast culture collection.

W

Wanderhaufen system

A **semi-continuous malting** system.

Warm conditioning

See **condition**, **diacetyl stand**, **beer maturation**.

Warm cropping

The practice of removing surplus yeast from the fermenter before chilling has been applied.

See **crop**.

Warm rest

An alternative name for diacetyl rest or stand.

See **diacetyl stand**.

Warm stand

Synonym for 'warm rest.

See **diacetyl stand**.

Warm water steeping

This is a variant of the more usual process in which barley grains are first steeped in water attemperated to approximately 40–50°C. The intention of the process is to encourage very rapid uptake of water by the grains and thereby to shorten overall malting times. The process has not been adopted widely since ensuring the rapid and consistent attemperation of the wetted grains at the start is difficult to achieve. In addition, there is a further complication in that it is necessary to bring the warm phase to a rapid and controlled end by quickly transferring the grains to another usually conventional steep in which cold aerated water is admitted. This is also difficult to achieve.

Warrior

Warrior is a high alpha bittering hop which was bred at Yakima Chief Ranches in the United States. It contains 15.0–17.0% α -acids, of which 22.0–24.0% is cohumulone, and 4.5–5.5% β -acids. Total oils are 1.0–2.0% (8.0–10.0% caryophyllene, 0% farnesene, 15.0–20.0% humulene, 40.0–50.0% myrcene).

Water

Beer, depending on the type, contains approximately 90–98% water. Since water is the largest single component of beer it is predictable that its composition has a dramatic impact both on the finished product and on the brewing process. In a broader sense, aside from its use as an ingredient of beer, water is used as a process aid for duties such as generation of steam, as a coolant, as a method of de-aerating pipework and plant, as a suspending agent or solvent for the preparation of various slurries and solutions and in cleaning. Water usage by individual breweries is highly variable and in terms of the ratio of volumes of water used to beer produced, ranges of approximately 4:1–30:1 may be encountered. The cost of effluent disposal and the current heightened interest in environmental issues and sustainability have caused most brewers to look at methods of reducing water usage.

Traditionally the water used for brewing by any particular brewer, in the United Kingdom termed **liquor**, was that available locally. The ionic composition of the water used in brewing has a major impact on the operation of the process and on the palatability of the finished beer. For this reason the nature of local water supplies was a major controlling factor in the developments of the styles of beer associated with particular geographical areas. For example, pale lager beers require a supply of soft water, as occurs in areas such as Pilsen in the Czech Republic. Conversely, pale ales require hard water, and that which occurs in well water in Burton on Trent in the United Kingdom is particularly suitable for this style of beer. Other locales that are notable as being centres of brewing are Dublin, Munich and London, which also have relatively soft water but with an ionic composition particularly suitable for porters or stouts.

The precise composition of water from any area is variable and depends on the geology of the particular locale. In general, impermeable rocks tend to produce soft water, whereas permeable rocks provide opportunity for deep penetration of surface water, consequent solution of minerals, and as a result, the waters recovered from deep aquifers may be soft or hard depending on the solubility of the strata through which it passes. Some typical analyses of water local to some areas of brewing excellence are shown in the table.

Typical water analyses associated with areas of brewing excellence

Analyte (mg/L)	Burton on Trent	Dortmund	Pilsen	Munich	London
Calcium	250–350	200–250	5–8	80–100	80–100
Magnesium	20–35	20–30	3–4	18–22	4–6
Bicarbonate	300–350	150–200	12–15	150–180	100–120
Carbonate	130–150	–	–	–	12–130
Chloride	20–40	50–60	4–8	30–40	15–20
Nitrate	15–25	40–50	Trace	50–55	2–5
Chloride	15–20	50–55	4–6	30–40	15–20

Brewing has continued to be an important industry in many of the areas mentioned earlier and for these the composition of the local water continues to be an important determining factor in the styles of beers produced. However, the rise of international brewing companies and the need by several of these to produce whole ranges of different beer styles at the same location has resulted in a need to be able to manipulate water ionic composition as necessary. In consequence, many large-capacity brewers totally demineralise all water that is used for brewing purposes and then add back a cocktail of salts appropriate to the style of beer being made. This allows for the generation of water with a more consistent ionic composition free from any natural variation and removes the traditional geographical ties. Examples of the interesting consequences of these developments are that the vast majority of beer brewed now at Burton on Trent is pale pilsener-type lager and this requires the water to be softened. Conversely, the rise in popularity of brewing 'authentic' beer styles throughout the world, as for example exemplified by the craft brewing community, has resulted in a requirement to simulate the natural well water of Burton by addition of the requisite package of salts, a process termed 'Burtonisation'.

Natural water supplies are never pure. Water falls to earth in the form of a precipitate and in so doing becomes contaminated with atmospheric pollutants both natural and man-made. On the ground opportunities for further contamination occurs. There are several potential sources including naturally occurring materials, microorganisms, the results of plant and animal decomposition and pollutants derived from domestic and industrial wastes. Surface waters which accumulate in rivers, lakes, reservoirs, and so on, are most likely to be highly contaminated. A proportion of the surface water permeates through the soil and rock layers and becomes part of the water table. The permeation process acts as a filtration process and there is a reduction in the microbial loading and the removal of some surface contaminants. Whilst passing through the various strata soluble minerals can be leached out. When the water reaches an impermeable layer it will accumulate in the form of an **aquifer**. Common materials which hold water are sandstones, gravels and limestone. Water from these aquifers can be tapped in the form of boreholes, springs or wells to provide brewing water. These are favoured over sources of surface water such as lakes since the latter supply tends to be less pure. However, the rise of widespread industrialisation has resulted in a much increased risk of contamination of deep water supplies, and the use of some form of purification is more or less inevitable. For the majority of brewers with no access to borehole water the local municipal supply of water is used. There is no reason why seawater cannot be used apart from the fact that the current high costs of desalination tend to be prohibitive, although it is used by some (see **seawater**)

The supply of brewing water that is used has cost implications. Where possible it is preferable and less expensive to use a privately owned source of water such as a well or a borehole. Generally such supplies are more consistent and may require less processing to make them suitable for brewing. However, most authorities have regulations regarding how much water can be abstracted in order to prevent depletion of local supplies and will also usually charge a fee for the use of such water. In recent years many brewers have eschewed the use of boreholes because of the risks of contamination with industrial pollutants and the resulting costs of purification. On the other hand, most municipal water supplies are guaranteed to be potable; however, although this provides a guarantee of fitness for human consumption, it

does not imply fitness for brewing and some degree of further processing will be inevitable. A further complication is that municipal water supplies may be taken from several sources, each with a different mineral composition. The suppliers are under no obligation to inform brewers when changes are made and these may be abrupt.

Most water requires to be treated before it can be used in brewing. The type of treatment depends on the nature of the water and its intended use. Treatments take the form of purification, possibly sterilisation and adjustment of the salt contents and the pH. The aims of preliminary treatments are to remove suspended solids and dissolved components. As a group these undesirable water constituents have the potential to introduce spoilage microorganisms, to produce undesirable effects directly on brewing process streams or indirectly by the formation of scales or slimes, which would reduce the effectiveness of process plant. Various chemical treatments with flocculants or coagulants can be used with the aim of converting unwanted solutes into solid precipitates. Aeration steps can also be included to produce insoluble oxidised salts, or to oxidise salts such that they can be precipitated with chemical agents. Aeration in conjunction with passage of water through columns is used to remove undesirable volatile components. The unwanted solids can be removed by filtration, usually via relatively coarse beds, by sparging and flotation, via sedimentation or by the use of centrifuges or hydrocyclones.

Of particular concern are high concentrations of iron and manganese, which are particularly prone to generate slimes and scales in brewery plant. In addition, excessive concentrations of these metal ions in brewing liquor are implicated in the generation of excessive colour during wort production and as a causative agent of poor beer flavour stability. Both metal ions can be removed by treatment with oxidising agents such as ozone, chlorine or potassium permanganate in which the insoluble products are ferric hydroxide and manganese dioxide.

It may be desirable to reduce the microbial loading of water. Typical treatments include boiling, chlorination, **ozonisation**, exposure to ultraviolet (UV) radiation or use of an electrolytic silver process. Boiling is costly and rarely used. It has the advantage of removing **temporary hardness**. The use of chlorine gas also is now rare but can be accomplished by treatment with chlorine gas, hypochlorous acid, hypochlorite or chloramine. **Chlorine dioxide** is commonly used in preference to chlorine as a sterilising agent. It is produced by on-site generation and dosage systems which use hydrochloric acid and sodium chlorite as the starting materials. Dosage rates of approximately 0.4 ppm are recommended and a contact time of at least 10 minutes. Chlorine dioxide has the advantage of not reacting with chlorinated organic contaminants.

Ozone is a very powerful disinfectant and can be used to sterilise water using dosage rates of 0.5–3.0 mg/L and contact times of at least 15 minutes. It is toxic and corrosive so care must be taken with regard to handling and potential damage to pipework. In similar fashion to chlorine it degrades organic compounds and may destroy some taints.

UV radiation exerts its microbiocidal action via its effect on nucleic acids. Nucleic acids have a maximum absorption peak of around 260 nm and are therefore susceptible to disruption by irradiation with electromagnetic radiation in the UV range. Several companies supply flow cells through which water passes and in so doing is exposed to a beam of UV generated by a tubular mercury low-pressure discharge lamp. The treatment is effective providing the water is clear and free from suspended solids. There is no residual activity. Combinations of

UV and ozone provide very effective sterilisation and oxidation of chlorinated hydrocarbons to CO₂ and hydrochloric acid.

Secondary water treatments are designed to adjust the mineral content of water so that it is suitable for brewing the chosen style of beer. In addition further purification steps may be incorporated to remove undesirable contaminants. With regard to the latter it is common to pass beer through a bed of **activated carbon**. This process, usually referred to as carbon filtration, comprises specially prepared charcoal made via the pyrolysis of various high carbon-containing precursors such as coals or various woods. The finished product is treated such that it is converted into a granular or powdered form which has a very large surface area. Passage through beds of activated carbon removes many organic contaminants such as pesticides and trihalomethanes. In addition it adsorbs many waterborne contaminants such as humic and fulvic acids, soil components derived from humus and which confer undesirable colour and taste to water. Treatment with active carbon is commonly used with borehole water where contamination with surface pollutants is becoming an increasing problem in industrialised areas.

With regard to adjustment of mineral content it is usual to consider treatments in terms of water hardness. Traditional processes use various chemical treatments in which unwanted water components are converted into insoluble precipitates and thereafter are removed by flotation, sedimentation or filtration. Temporary hardness is caused principally by calcium bicarbonate. This can be converted to insoluble calcium carbonate by boiling. This is an expensive option and the same end can be accomplished by treatment with lime water (solution of calcium hydroxide) in which calcium bicarbonate is converted into insoluble calcium carbonate. In the case of some water supplies levels of magnesium bicarbonate may also be high and need to be reduced. Boiling is ineffective since the resultant magnesium carbonate is relatively soluble. In this case the water is treated with lime water, as described earlier, but in a two-stage process in which, firstly, the magnesium salt is precipitated as the insoluble hydroxide and, secondly, calcium bicarbonate is removed, as described already. This treatment also removes iron and manganese ions by converting them into insoluble hydroxides.

These treatments produce alkaline water, which must be further treated to reduce the pH to neutrality. This can be with mineral or lactic acids, where such treatments are permitted. Alternatively the pH may be reduced by treatment with carbon dioxide.

Permanent hardness is caused principally by calcium sulphate. This can be removed by treatment with sodium carbonate, which precipitates calcium as the carbonate leaving sodium sulphate in solution. However, where water is required to be softened it is now usual to use ion exchange resins and/or **reverse osmosis**. These treatments can remove all ions and produce totally demineralised water. Ion exchangers are artificial resins made in the form of spherical beads. They are used in the form of columns through which the water is passed. The resins have charged groups attached to them, which remove or 'exchange' with similarly charged groups present in the process stream. Different resins are designed to remove positively charged ions (cation exchangers) or negatively charged ions (anion exchangers). These may be used in separate columns or in a single bed as a mixture. Typically the beads are made from cross-linked polystyrene.

Where water is required to be softened ions of calcium and magnesium are exchanged for sodium ions. Where the water is required to be demineralised both cation and anion-exchange

resins are used. Cationic types contain sulphonic acid groups which bind positively charged metal ions and release hydrogen ions. Anionic resins contain quaternary ammonium groups which bind negatively charged anions and release hydroxyl ions. Ion-exchange resins are susceptible to chlorine degradation and this must be removed from water before treatment. Similarly iron and manganese ions require to be removed in pretreatments in order to prevent slime formation, which can block the beds. After use the resins must be regenerated by chemical treatments which remove the bound ions and replace them with the original exchange species. Ion-exchange treatments can generate off-flavours and these may be removed by filtration through activated carbon.

Reverse osmosis (RO), as the name suggests, utilises the phenomenon of osmosis. This utilises membranes that have a pore size sufficiently small to allow the passage of water molecules but not dissolved ions. By manipulation of the operating conditions water molecules can be made to migrate through the membrane, leaving behind the contaminating ions. RO treatment produces totally demineralised and sterile water but at a cost. Plants for water treatment are of modular design and incorporate membranes designed to provide a large surface area. In order to drive the process powerful pumps are required and the water must be free from solids, chlorine and manganese, and iron salts.

In many modern breweries the water treatment is finished by a de-aeration step. Older standards might be to less than 0.1 mg/L dissolved oxygen; more stringent modern specification would be less than 0.02 mg/L. Several methods are used to accomplish this which are based upon manipulation of partial pressures. Boiling, the most obvious method, is not used because of cost. Alternatives are the use of low pressure (vacuum de-aeration), passage down a column against a counter-flow of stripping gas, usually carbon dioxide (column de-aeration) and the use of hollow fibre semipermeable membranes (membrane de-aeration), where oxygen molecules are forced through the pores by the application of a vacuum on the gas side.

Water for use in brewing is required to be treated in a manner which renders it suitable for the chosen application. In the case of brewing liquor the mineral contents fulfil specific functions. These ions may be derived in part from the brewing water and also from other raw ingredients. The ions may have direct effects on beer flavour components or they may exert indirect effects on various parts of the brewing process. The latter effects are numerous. They are important in controlling wort pH, beer colour and removal of components which influence the propensity for the formation of beer hazes, and they are involved in reactions which regulate the concentration of compounds which affect beer flavour stability. Several ions are promoters or stabilisers of the activities of various enzymes, which play important roles in brewing. These enzymes may be those derived from malt and involved in the mashing stage of brewing. In addition they may influence the activities of yeast enzymes where several ions are required as growth factors. The action of these ions on yeast metabolism influences fermentation rates, degree of attenuation and the formation of yeast metabolites important in beer flavour. Since various ions have the potential to interact with each other or counteract or nullify their individual effects the ratios of each are of importance. In some ways this explains the attraction of starting the process with completely demineralised water and then adding back a cocktail of salts specifically designed to provide optimum performance.

Predictably the sum of the effects of ions on beer and brewing performance are complex and beyond the scope of this short article; however, some brief comments can be made. With regard to flavour, sulphate imparts dryness and bitterness. Chloride provides sweetness and fullness.

Too high a sulphate level may produce sulphury beers. The ratio of each is as important. Liquor for UK-style pale ales should contain a ratio of sulphate to chloride between 2:1 and 3:1; stouts and porters require low levels of sulphate and ratios of sulphate to chloride of 1:3. Mild ales are intermediate and ratios of approximately 1:2 for sulphate to chloride are recommended.

Individual metal ions also have a flavour impact; thus, sodium (>100 mg/L) is associated with metallic notes, potassium (>10 mg/L) imparts a soapy character and magnesium (>30 mg/L) dryness/astringency.

The multiple effects of ions are admirably illustrated by a consideration of the multiple roles of calcium. Calcium ions stabilise malt α - and β -amylases. They precipitate wort components such as phosphate, peptides and proteins and in so doing acidify the wort. With regard to phosphate, removal by precipitation reduces pH by the direct release of protons and also by virtue of the fact that these molecules are buffering agents with pK values at relatively high pH values. The addition of approximately 300 g calcium sulphate per 100 kg malt is sufficient to cause a reduction in wort pH of 0.1. β -Amylases have relatively low pH optima, typically around pH 4.7, and therefore acidification of wort is an advantage. Calcium ions react with oxalate in wort to produce a precipitate of calcium oxalate, known as beerstone. If not removed calcium oxalate can form hazes in packaged beer and provide nucleation sites for carbon dioxide breakout and concomitant **gushing**. Calcium ions are required for efficient flocculation of brewing yeast and therefore assist with separation of yeast crops at the end of fermentation. They also promote efficient fining. Calcium ions prevent over-extraction of anthocyanogens and prevent the formation of too much colour by reducing the precursors of melanoidin formation during the kettle boil. The pH lowering properties of calcium are important to ensure that the pH of sparge liquor is acidic. This prevents over-extraction of components such as silicates and tannins, which can impart astringency and a propensity to form hazes.

On the other hand, care must be taken to not extract too much phosphate since this is an essential nutrient for yeast in subsequent fermentation. Where water contains high levels of temporary hardness the presence of high bicarbonate levels counteracts the acidifying influence of calcium. General recommendations for upper limits for calcium are approximately 100–150 mg/L and for bicarbonate no more than 25–50 mg/L. Since significant quantities of calcium may be lost at the mashing stage it is common to add further doses to the kettle to ensure an adequate supply for the necessary precipitation reactions to occur.

With regard to other metal ions several are important for yeast nutrition, such as magnesium, manganese and zinc. With the exception of zinc a sufficient supply is provided by other beer raw materials. Copper is toxic to brewing yeast strains, but not some wild yeasts, and should be avoided. The presence of iron in brewing liquor is undesirable. Maximum concentrations are of the order of 0.1 mg/L. It is toxic to yeast; it can cause hazes in beers and slimes in brewery plant in the form of insoluble ferric hydroxide; it can react with hop iso- α -acids and impart an unattractive brown colouration to beer foam and very dark worts via interaction with phenolic components; and it confers metallic and astringent flavours to beer.

Nitrate has little, if any, effect on the brewing process; nevertheless concentrations should not exceed 25 mg/L since some bacteria, particularly *Obesumbacterium proteus*, sometimes found as a contaminant of pitching yeast, can reduce nitrate to nitrite. The latter is undesirable since it can be a precursor to the formation of carcinogenic nitrosamines. The presence of ammonium ions in water is indicative of contamination with sewage or other rotting organic matter. An acceptable maximum concentration is 0.5 mg/L.

Water is used in the brewing process for several duties other than wort production. Where it may come into contact with beer or wort similar attention to composition must be paid as is given to brewing liquor. Thus it must be free from any taints or aromas and must be of potable quality. Where it is to be mixed with beer, as in sparge liquor, or for yeast dilution and washing or for dilution of high-gravity beer, it should be of the same quality as that used for brewing. Where appropriate it should be sterile and de-aerated. Water used for duties such as heating or cooling should be softened to avoid the formation of scale. Where used in cooling towers biocides must be incorporated to comply with *Legionella* control legislation. Where used for cleaning and rinsing purposes it should be potable, softened to avoid scale formation and may incorporate terminal sterilants such as chlorine dioxide. If the water is chlorinated, levels should not exceed 0.1 mg/L in order to remove the risk of the formation of chlorophenols and concomitant taints. Water destined for use in boilers must conform to the specifications of the manufacturer. Where the steam is to be used in a direct injection process it must be made from potable water and softened and deoxygenated. In other applications boiler water might be treated with chelating agents to prevent the formation of scale.

Water alkalinity

The alkalinity of water is a measure of the buffering capacity that is produced by dissolved bicarbonate, carbonate and hydroxyl ions. It is an important characteristic of brewing water since it influences control of pH during wort production. It is related to the hardness of water (see water and water hardness for more details).

Alkalinity can be determined by titration with HCl. The amount of acid required to achieve an end point of pH 4.3, using methyl orange as indicator, gives a measure of the total bicarbonate content of the water (since bicarbonate is the principal ion present at pH values below pH 7.0). Alkalinity is usually expressed as milligram per litre of CaCO₃.

In practice the presence of other minerals in water also influence alkalinity as it is expressed in brewing. Vary hard waters, such as those found in Burton on Trent, have high alkalinity levels, as judged on the content of bicarbonate; however, it also contains high levels of calcium ions derived from dissolved gypsum (calcium sulphate) and moderate levels of magnesium. Both of these metal ions react with phosphates (organic and inorganic) present in the mash in reactions which liberate protons. The consequence is that the pH of mashes is reduced and the contrary effects of bicarbonates are ameliorated. This phenomenon is referred to as residual alkalinity. It explains why gypsum is often added to mashing or sparge liquors.

Residual alkalinity can be determined with a knowledge of total alkalinity (measured as milligram per litre of CaCO₃ and the concentrations in water of Ca²⁺ and Mg²⁺):

$$\text{Residual alkalinity} = \text{alkalinity} - 0.714 \text{ Ca}^{2+} \text{ (mg/L)} - 0.585 \text{ Mg}^{2+} \text{ (mg/L)}.$$

Where analyses for alkalinity and hardness only are available, an approximation for residual alkalinity can be obtained from

$$\text{Residual alkalinity} = \text{alkalinity} - 0.8 \times (\text{total hardness}/3.5) - 0.2 \times (\text{total hardness}/7).$$

Water hardness

The hardness of water is a measure of its mineral content, most usually the concentration of calcium and magnesium. It is of great relevance to brewing in that the presence of dissolved minerals has a direct impact on beer flavour and on the brewing process itself. With regard

to the latter, minerals influence the extraction of flavoured and coloured compounds or precursors thereof from raw materials. In addition, they influence the brewing process by modulating the rates of reactions of enzymes, those derived from cereals in the mash and those from yeast and involved in fermentation. Furthermore, calcium ions influence yeast technological behaviour via their effects on flocculence. Apart from the water used directly for brewing, hardness is important in utility water usually in a negative way via the propensity for the formation of scales or slimes. For example, total hardness can be determined by titration with the chelating agent, ethylenediaminetetracetic acid (EDTA), which removes calcium from the solution, the end point being determined using a suitable indicator.

Several minerals influence water hardness, principally calcium and magnesium bicarbonates or sulphates. Other cations (aluminium, iron and manganese) and anions (borate and phosphate) may also be important in some localities.

Hardness of water is easily assessed in a subjective manner by measuring the ease of formation of a lather when a sample is agitated with soap. Precise quantification is achieved by titrations designed to measure the actual mineral content usually based on calcium and magnesium.

Water hardness is expressed as being either temporary or permanent. **Temporary hardness** is so called because it can be removed by boiling. It is caused by the presence of calcium bicarbonate. Boiling causes the formation of calcium carbonate with the loss of CO_2 . The carbonate is relatively insoluble and forms a precipitate which can be removed by filtration leaving softened water. Alternatively and in a less energy-intensive process calcium hydroxide (lime) can be added with the same effect.

Permanent hardness is caused by the presence of the sulphates or chlorides of calcium or magnesium. It is permanent in the sense that boiling does not remove it. Softening of permanently hard water is achieved by chemical treatments that remove the causative minerals. For large-scale softening treatments **ion-exchange** resins are commonly used.

Several units of hardness are in use and they are not all the same. Units are based on the content of calcium, usually expressed as parts per million or milligram per litre of the carbonate or oxide (see accompanying table).

Other dissolved mineral will also contribute to the hardness value and, in this sense, they are additive.

In real terms soft water is considered to contain less than 140 mg/L total dissolved mineral. Very hard water contains more than 500 mg/L total dissolved minerals.

Units of water hardness

Unit	Abbreviation	Definition
Degree of general hardness	°GH	10 mg CaO per litre of water
German degree (<i>Deutsche Harte</i>)	°dH	As above
Clark degree	°Clarke; °E	1 grain calcium carbonate per imperial gallon of water (equivalent to 14.254 mg/L)
French degree	°f	10 mg carbonate per litre of water
US degree	°USA	1 mg/L calcium carbonate per litre of water

See **water**.

Water-heated kettle

The majority of modern kettles are heated by steam either via internal or external heat exchangers (see **wort kettle** for more details). Some kettles are designed to be heated via water as opposed to steam. In such cases the water must be held at high pressures (>16 bar) in order to prevent boiling and steam formation. Since such an approach is inherently expensive and difficult to control their choice over conventional steam systems may appear perverse. In fact they have the advantage of providing very short heat-up times, and this is useful where kettles which might otherwise have external steam jackets are required to provide very rapid turn-round times.

Water sensitivity

Water sensitivity refers to a phenomenon associated with the relationship of the availability of water and the germination of barley grains. Barley grains may be differentiated on the basis of a test in which the ability of 100 grains to germinate in the presence of 4 mL or 8 mL of water. Those which germinate less well in the presence of the higher water concentration are said to be water sensitive. In this case these more sensitive grains are deemed to require a suitably modified steeping regime.

Practically the occurrence of this phenomenon can be detected using the **4-mL and 8-mL test**. In this test triplicate (or more) samples of barley grains are spread out on a stack of three filter paper circles and these are placed within a Petri dish of 10-cm diameter. The requisite volume of water is added and after incubation in the dark for 24, 48 and 72 hours at 18–21°C. The percentage of grains which have germinated after these time intervals in the 4-mL test is taken as a measure of dormancy. The result of the 4-mL test is referred to as the germinative energy (% GE) of the grains. The results of the 8-mL test may be reported as water sensitivity [WS (8 mL) %]. In older reports the difference in percentage terms between the 4-mL test and the 8-mL test was taken as a measure of water sensitivity. If this difference is greater than 20% the sample of barley under test is deemed to be water sensitive. This practice was discontinued since the results could be misleading. Briggs [(1998) *Malts and Malting*, p. 109, Blackie Academic & Professional, London, UK, 1998] points out that as grains mature the results of both the 4-mL test and the 8-mL test improve until they are similar; however, those from the 4-mL test improve faster than the 8-mL test such that the difference actually increases. Other factors are also influential. Grains should be placed furrow-side downwards in the test and the grains should be equally spaced. This is related to the fact that the principal effect of the water film is that it forms a barrier to oxygen between the grain and the atmosphere. Hence, ensuring that the water is oxygenated or adding antiseptics which reduce the population of competing oxygen-scavenging microorganisms tends to reduce water sensitivity. With regard to the latter effect the addition of hydrogen peroxide is particularly effective since it is toxic to many microorganisms and after decomposition provides a source of oxygen. Nevertheless, there are differences since fully mature grains will germinate when fully suspended in aerated water, whereas water-sensitive types will not.

It is considered that grains will not begin to germinate until the surface film of moisture is absorbed by the grains. In water-sensitive grains this absorption is delayed. The occurrence of water sensitivity appears to have some genetic element, although it seems likely that heavy contamination of grains with microorganisms is the most significant factor.

The moisture content that is achieved during steeping is important and steeping regimes are altered to reflect this. Water-sensitive types will germinate if steeped to a moisture content of just 35%. However, this moisture content is insufficient for proper modification. The intermediate lower moisture content is controlled via the process termed as **air rest** or **dry steeping**. The grain is wetted to achieve a relatively low moisture content and then arrested at this stage by holding the grain for 8–24 hours in a current of dry air. During this time the surface film of water is absorbed and the metabolic changes that are necessary for germination occur. After this stage the grain is then wetted to normal levels of approximately 42–46% moisture, the water-sensitive effect is overcome, and germination and modification proceed normally. The practice of incorporating one or more air rests during steeping is also in more general use since it accelerates the germination of non-water-sensitive grains.

Wee Heavy

This is a colloquial name for **Scotch ale**.

See **Scottish ales**.

Weihenstephan School of Brewing

Weihenstephan is part of the town of Freising close to Munich in Germany and the location of the renowned brewing school. It is part of one of the three campuses of the *Technische Universität München*. The brewery, *Bayerische Staatsbrauerei Weihenstephan*, is reputedly the oldest in the world, dating back to the ninth century AD, and has close links with the university. Teaching in brewing and related sciences began in 1804 and in 1885 it became the Royal Bavarian Academy for Brewing and Farming. In 1928 it became associated with the Technical University of Munich, and the faculty of Brewing was founded in 1933 and programmes of teaching and research continue to flourish.

Weissbier

Weissbier is a type of wheat beer associated with Germany, in particular Bavaria, where the modern version was developed. The name in German means ‘white beer’ and is descriptive of its appearance. The beer is made from malted wheat, the grist of which must contain at least 50% by law, but typically contains 60–70%, the remainder being malted barley. The beers are made by top fermentation using a *pof^t* ale yeast. The beer is usually not filtered and in consequence has a golden opaque appearance. Most beers of this type are subject to a secondary fermentation in tank or in bottle and in consequence they develop a refreshing effervescence. The presence of yeast in the final product explains one of the synonyms for this type of beer, *hefeweizen*, literally yeast wheat. Similarly such beer styles are also referred to as *weizenbier*, which translates as ‘wheat beer’. The terms *weizenbier* and *weissbier* have not always been synonymous. In the early days of organised German brewing pale malts were rarities as were similar-hued beers made from them. For this reason any pale beer was referred to as ‘white’ irrespective of the sources of extract used in the grist. However, those made with malted wheat were called wheat beer (*wiezenbier*). Later when the malting process was more controlled other more descriptive names were introduced. The name *weissbier* was reserved for top-fermented wheat beers. The name *weizenbier* was also retained for this usage.

The beers are of various strengths, but the combination of ale yeast, the POF gene and the wheat gives the beers characteristics which are described as clove, spice, phenolic, bubblegum and banana.

Weissbiers originated in Bavaria and from there spread to the rest of Germany and other parts of the world. The use of wheat for brewing in Bavaria contradicts the original *Reinheitsgebot* since by that edict this cereal was reserved for baking. However, the forces of Mammon prevailed and the production of wheat beers was allowed, at a price. Wheat beers fell out of popularity at the end of the eighteenth century and were largely replaced by bottom-fermented lagers. This was greatly aided by the introduction of effective refrigeration, which allowed all year-round low-temperature fermentations to be conducted. In recent years there has been an upsurge in the popularity of wheat beers, and in consequence a renaissance in the brewing of such products has taken place. This has led to widespread brewing of wheat beers in many countries of the world. Not all of these adhere to the original minimum of 50% malted wheat in the grist.

Several variants are produced of the archetypal *weissbier*. Some types are carbonated in the brewery and are filtered to the same standards of brightness as non-yeast-containing beers. These are called *krystalweissen*. Other varieties are made with darker wheat malts and these are called *dunkelweissen*. Stronger wheat beers of the bock type are also made.

See **bock**.

Weizenbier

Weizenbier, literally German for wheat beer, is a style of beer made from a grist that contains predominantly wheat, the remainder being malted barley. The beers are usually unfiltered, made via top fermentation using a *pof*⁺ ale yeast and subjected to secondary fermentation in a tank or a keg.

See *weissbier*.

Weizenbock

Weizenbock is a variant of bock beer made from a combination of Vienna and Munich malts together with at least 50% wheat. A top-fermenting *pof*⁺ ale yeast is used and the beer is unfiltered.

See **bock**.

Weizendoppelbock

Weizendoppelbock is a strong (7–9% abv) variant of the bock beer style made from a combination of dark Vienna and Munich malts and at least 50% wheat. It is unfiltered and made with a top-fermenting *pof*⁺ ale yeast.

See **bock**.

Weizeneisbock

Weizeneisbock is a combination doppelbock, wheat beer and ice beer with a strength of around 12% abv. They are speciality beers not usually in general production.

See **bock**.

Weizen glass

Glass of German origin and designed for serving and consuming wheat beers. Usually they are tall and have a curved profile to give a comparatively narrow bottom and wide top. Various capacities are used, but all share the characteristic of having sufficient volume to allow for the large creamy heads typical of wheat beer.

Weizenmalzbier

Weizenmalzbier is a variant of *Malzbier*. It is a dark malt-based zero-alcohol beer produced by restricted fermentation of a wort made from a mixture of malted barley and malted wheat. It is sold as a health drink.

See **reduced-alcohol beer**.

Wellhoener continuous fermentation system

The Wellhoener system was a pilot scale combined continuous fermentation and maturation plant. It comprised six vessels. The first three vessels had capacities of 40, 30 and 20 hL, respectively, and were used for fermentation. In operation the temperature in these vessels was maintained at 10–12°C. After filling the first vessel with filtered pitched wort continuous flow was initiated by a supply of fresh aerated and filtered wort. The CO₂ formed as a result of the activity of yeast, was used to provide the motive force for pushing the fermenting wort between the vessels. By restricting the escape of CO₂ a pressure differential between the vessels was established and this, in addition to temperature, was used to control the rate of fermentation in the individual stages.

Green beer exiting from the third fermentation tank was filtered in-line and was transferred to the first of three maturation vessels each with a capacity of 15 hL. These were held in a separate room attemperated to 0°C. The bulk of maturation and adjustment of carbonation took place in the second maturation tank. The first maturation tank was essentially a receiver and the third provided a buffer.

Total residence time in the plant was of the order of 27 days and productivity was 5 hL/day.

Westmalle

One of the Trappist monasteries of Belgium that produce Trappist beers.

See **Trappist beers**.

Westminster

A spring variety of malting barley which appears on the fully approved for brewing list of the UK-based Institute of Brewing and Distilling.

Westvleteren

One of the Trappist monasteries of Belgium that produce Trappist beers.

See **Trappist beers**.

Wet milling

Wet milling describes the process of comminution where the grains and solid adjuncts, if used, are treated with water before milling. The process of moistening the grains before milling has

the intention of increasing the pliability of the husks such that they may be broken and of releasing their contents with a minimum of disruption. The consequent retention of relatively intact husk material provides a free-flowing filter bed during the mash separation step of sweet wort clarification. This allows for rapid cycle times and the use of deeper beds.

Several types of wet milling process may be used. In the best of these the degree of moisture pickup by the grains is controlled such that only the husk is affected. Providing the interior of the grains is kept dry the structures that are released when the grains are disrupted retain their brittle nature and so high yields of extract may be obtained.

See **milling**.

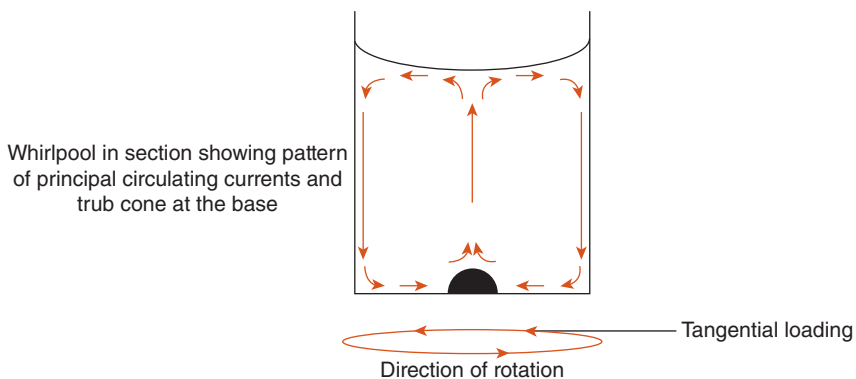
Wheat beer

See *weissbier*.

Whirlpool

Whirlpool tanks are devices used for the clarification of hot wort by the removal of trub. They are used by those brewers (the majority) who do not use whole hops. In the latter case a **hop back** is used (see entry for details). Whirlpools are hydrocyclones which rely on centrifugal forces to separate solid trub from wort.

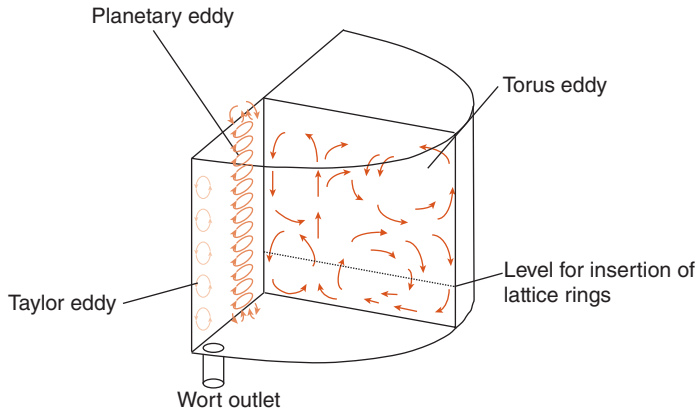
The whirlpool tank has a circular cross section. The entry point is a pipe which is mounted tangentially to the circular wall of the tank. Wort is pumped into the tank at a rate sufficient to impart a rapid circular motion in the mass of liquid. This sets up centrifugal forces which drive the suspended trub particles towards the wall. The actual forces involved in fluid flow in a whirlpool are complex and are not entirely characterised; however, the combination of centrifugal forces, frictional wall effects and pressure differentials set up by the liquid motion produce currents which cause the particles to slide down the walls, hit the base and spiral in towards the centre of the base (see diagram).



Principal patterns of fluid flow in a whirlpool

In practice the real patterns of fluid flow are much more complex than shown in the accompanying figure. This has fuelled much research into the development of whirlpools which are more efficient in operation. In practice various eddy currents are generated within the body

of the rotating wort and these can counteract the desired movement of trub particles (see diagram).



Eddy currents associated with fluid flow within a whirlpool which, if not counteracted, interfere with the formation of the trub cone

Devices, such as a lattice ring, as shown in the diagram, may be incorporated with the aim of disrupting the troublesome eddy currents. In addition, many novel modifications have been made to the base of the whirlpool. These include central structures such as sumps, gullies or cones. These serve as reservoirs in which the trub collects. The aim is to protect the trub cone which, once formed, is easily disrupted.

In practice, whirlpools have an aspect ratio of approximately 0.8:1. Wort is pumped into the vessel at a rate of approximately 3–4 m/s using a tangential entry point. Although the in-flow rate must be sufficiently rapid to impart rotational movement, it must be non-turbulent as this may disrupt the relatively delicate flocs of trub leading to the generation of difficult-to-remove fines. The entry point is usually located above the halfway line on the vertical wall. Vessel bases may be flat, slightly inclined or conical, with or without various other inclusions, as described already. The take-off point is placed at the base of the vessel. Additional take-off points located at various heights in the vertical wall may also be provided with the aim of allowing wort removal to commence as soon as it begins to clear from the top.

Once the whirlpool has been filled the wort is allowed to reside for a period of time during which the rotational movement slows and eventually ceases and the trub deposit forms. This period is termed the **whirlpool stand**. The precise time is controlled. This is important since apart from the formation of the trub cone other changes in wort composition possibly desirable or undesirable continue to take place. These include colour changes, hop isomerisation and the formation of important flavour compounds such as dimethyl sulphide (DMS). These reactions are terminated by wort cooling, which occurs at the end of the whirlpool stand. Other procedures which might be performed in the copper can also be moved into the whirlpool, for example, the addition of **kettle finings** or the addition of flavour hops.

After the whirlpool has been emptied the trub cone is removed, in modern vessels, usually automatically via a washing and rinse procedure. The trub may be simply discarded or more usually, in large commercial breweries, treated to recover entrained extract. Various pieces of

equipment may be used to accomplish this, for example, via centrifugation, rotary brush strainers or hydrocyclones; alternatively, the trub may be added to the next mash.

The duties of wort boiling and trub separation may be combined into a single vessel, termed a **kettle-whirlpool** (see entry). These have the advantage of economy in terms of the numbers of vessels that need to be used but perhaps at the expense of some flexibility.

Whirlpool stand

The whirlpool stand is the time during which hot wort is allowed to reside in the whirlpool before it is removed and cooled.

See **whirlpool**.

Whitbread Goldings

Whitbread Goldings is a UK aroma hop which dates from 1911. Owing to its lack of susceptibility to verticillium wilt it has been grown in areas where this disease is prevalent. It is considered to be not a true Goldings variety.

See **Goldings**.

White finings

A synonym for **isinglass** finings, in particular, preparations in which the cutting step is performed using a mixture of sulphurous and tartaric acids. In older brewing texts the former is claimed to provide superior cutting performance to tartaric acid alone since it prevents the growth of moulds.

White malt

The term white malt is applied to those types which are made in such a way that they retain sufficient enzyme activity that, when used alone, suitable wort is produced. They are also known as **base malts**. Since relatively low kilning temperatures are required in order to ensure that considerable enzyme activity persists into the finished product these malts tend to be fairly lightly coloured, hence the name white malts. Contrary to this, **speciality malts**, which are used principally to impart colour and flavour to beers, are made in such a way that little or no enzyme activity survives malting. These malts are usually darker and require to be blended into grists with white or base malts, the latter providing the bulk of the enzyme activity.

This distinction is somewhat arbitrary since not all speciality malts are dark (carapils) and not all white malts are pale (Munich dark malt).

White mould

A synonym for powdery mildew disease of hops.

See **powdery mildew**.

Whitsun-ales

A celebratory feast held in medieval England associated with raising funds, often by the sale of beer, for the upkeep and charitable services of parish churches.

See **ale**.

Widgets

Devices placed into small-pack beers, usually cans, which allow small-pack ales to have similar characteristics to their draught equivalents. The original concept was developed for canned Guinness with the intention of producing beer which when dispensed into a glass had the same appearance characteristic of the freshly poured draught equivalent. The idea has been widely copied in the United Kingdom by other brewers, each using their own bespoke in-pack device to deliver the effect. The beer is packaged into the can with a low level of carbonation, typically around 1.2 vol (2.4 g/L) and nitrogen, the latter usually being added at packaging in the form of a drop of liquid nitrogen. In this regard the beers that fall into the category are referred to as **smooth flow beers**.

The widget is a device, made of plastic or metal, which is hollow, the inner chamber being pierced by a small pore. When the can is filled nitrogen is forced into the chamber. On broaching the reverse happens and gaseous nitrogen is forced into the beer where it produces the characteristic boiling effervescence and thick creamy head. Widgets may be attached to the base of the can or allowed to float freely in the beer. The different designs represent bespoke approaches which suit the type of beer, which minimise the risk of oxygen entrainment and which avoid infringement of patents.

Wild yeast

From a brewing standpoint wild yeasts are defined as any yeast present within brewing process streams but not added deliberately. An alternative definition is yeasts not added deliberately and under full control. It follows that the group includes 'foreign' spoilage yeast strains and also inadvertent mixtures of brewing yeast strains as might occur where a brewery uses several strains. In the latter case the undesired contaminant would be considered wild. The risks of accidental contamination with wild yeast are high since many will thrive under the same conditions that favour culture yeasts. In addition, treatments designed to reduce microbial loadings of pitching yeast such as **acid washing** have no effect on wild yeasts.

Wild yeast strains are by convention divided into *Saccharomyces* and non-*Saccharomyces* types. The former represents the greatest risk since by definition they are the most closely related to culture strains, in particular the ability to tolerate anaerobic conditions. The effects of contamination by *Saccharomyces* wild yeasts range from comparatively subtle changes in beer flavour, altered patterns of flocculation, through to severe undesirable changes such as haze formation. Some strains cannot spoil beer, but osmophilic types can grow on raw materials such as sugar syrups. Diastatic wild yeast, formerly known as *Saccharomyces distaticus*, but now reclassified into *Saccharomyces cerevisiae*, possesses a glucoamylase and is able to assimilate dextrins. A consequence of this is that worts become super-attenuated. Diastatic strains, with others, often carry a gene, termed *POF*, an acronym for phenolic off-flavour, which codes for an enzyme that decarboxylates wort phenolic acids such as **ferulic acid** and cinnamic acid producing 4-vinyl-guaiacol and styrene, respectively. These confer clove, spicy or medicinal aromas and tastes, which are characteristic of some wheat beers but undesirable in most others. The characteristic clove-like aroma produced by these yeast strains is used as the basis of a sniff test for their detection.

Killer yeast strains, many of which are *Saccharomyces* wild yeasts, have the ability to compete with brewing strain and, in addition, produce exotoxins, termed zymocins, which

are lethal to brewing strains but to which they are immune. There are three groups and, in all cases, the property is conferred by a non-chromosomal cytoplasmic inheritable DNA plasmid. Types K1 and K2 produce ionophores which bind to host cell walls and penetrate the plasma membrane, rendering it permeable such that cellular ions are lost. Type K28 produces a toxin which binds to host cell wall mannoprotein and causes cell-cycle arrest. Killer strains also usually carry the POF gene. Occurrences of killer yeast infections in production brewing are reassuringly scarce; however, they were observed in some early continuous fermentation systems with predictably severe consequences.

Non-*Saccharomyces* wild yeast strains are a diverse group. Since most cannot tolerate anaerobic conditions they are as a group less able to spoil the later stages of fermentation and subsequent beer streams. The recent improvements made to the control of in-process oxygen have reduced the risks of such infections. Many yeast strains may be detected in process streams where, although they do not cause spoilage, they can cause false negatives in routine microbiological testing. A few may cause spoilage, particularly where accidental oxygen ingress occurs. For example, problems may occur in the initial aerobic stage of fermentation or in non-pasteurised cask beers where some air ingress is usually inevitable once the cask is broached.

Some genera of non-*Saccharomyces* wild yeasts which can cause spoilage are shown in the following table.

Genus	Comments
<i>Brettanomyces, Dekkera</i>	Common contaminant of bottle-conditioned beers and cask ales, found in spontaneous fermentations such as in lambic beers
<i>Kluyveromyces</i>	Osmotolerant and thermotolerant (up to 43°C) and capable of vigorous fermentation of glucose
<i>Pichia</i>	Pellicle and haze formed in the aerobic phase of fermentation and in draught cask ales
<i>Torulasporea</i>	Ferments glucose under aerobic conditions but poorly under anaerobic conditions, capable of spoiling cask ales
<i>Zygosaccharomyces</i>	Highly osmotolerant spoiler of sugar syrups

Willamette

Willamette is a triploid US aroma hop variety which derives from Fuggle. It was released in 1976 and rapidly became very popular and the most widely grown US aroma hop. It is resistant to downy mildew but susceptible to powdery mildew and verticillium wilt. It contains 4.0–6.0% α -acids, of which 30.0–35.0% is cohumulone, and 3.5–4.5% β -acids. Total oils are 1.0–1.5% (8.0–12.0% caryophyllene, 5.0–10.0% farnesene, 20.0–30.0% humulene, 20.0–30.0% myrcene).

Williams and Ramsden continuous fermentation system

A system of continuous fermentation designed for use with top-fermenting ale yeast strains which was developed during the 1960s when interest in such approaches for large-scale commercial brewers was at its height. It comprised a series of four linked vessels arranged in a

cascade via bottom-located infeeds and top-mounted overflows. The process was initiated by adding pitched aerated wort to the first vessel. Once fermentation had commenced fresh wort was introduced in a continuous stream to the first vessel and a gravity-fed cascade of flow was set up such that wort passed into the succeeding vessels. Good mixing and suspension of yeast was ensured by the provision of gas rousing to the second and third vessels. In addition, the third vessel was provided with means for the collection of CO₂. Primary fermentation was completed in the third vessel and this was provided with a means of collecting the yeast top crop and of preventing it from being transferred into the fourth and final vessel. The recovered yeast crop was transferred to a plate and frame filter from which entrained beer was recovered and returned to the infeed of the fourth vessel. The partially clarified green beer in the fourth tank was chilled and subject to adjustment of carbonation. A modification of the system as described earlier replaced the third tank with one of cylindroconical design and was suitable for use with bottom-cropping lager yeast strains.

See **continuous fermentation**.

Williamson and Brady continuous fermentation system

A system for continuous fermentation designed during the early 1960s as a joint initiative for the Carling Brewing Company in the United States and Canadian Breweries. It was implemented at commercial scale at the Forth Worth Brewery in the United States.

The design was similar to that of Coutts (see **Coutts, Morton W.**) and comprised an initial vertical pitching tank in which aerated wort was introduced and mixed with yeast recycled from a later stage in the process. Wort was provided by a continuous brewhouse. In the pitching tank the residence time was controlled such that the stages associated with the lag phase of a normal batch fermentation were allowed to proceed. After this the fermenting wort passed into the first of two fermentation vessels. Here a combination of relatively warm temperature, agitation and high yeast concentration ensured rapid fermentation rates. The final stage comprised a vertical yeast separation vessel into the conical base of which the flocculent yeast was allowed to settle. Partially clarified beer was removed from the upper part of the separation vessel and transferred to maturation vessels after in-line chilling and carbonation. Yeast recovered from the base of the separation tank was further concentrated by pressurisation in a separate smaller vessel designed for this purpose. A proportion of this yeast concentrate was recycled into the initial pitching tank.

The beer produced by this system was claimed to be indistinguishable from that made by conventional batch fermentation. Despite this the system was decommissioned probably in large part due to problems with infection.

Wind malts

Traditionally green malts were dried by spreading out the grains on perforated beds to give a thin layer and to allow moisture to be displaced by simple evaporation. This natural drying process was commonly carried out in well-ventilated lofts or in earlier practice in the open air. Such malts, for obvious reasons, were given the name wind malts. In countries with the benefit of clement weather, such as some in Africa, spreading out sorghum malts to dry in the sun was common practice. In Europe, as described by de Clerck ([1957] *A Textbook of Brewing*, Vol. 1, translated by Kathleen Barton-Wright, Chapman & Hall, UK) for the production of

traditional beers in Louvain, Belgium, 'the green malt is simply spread in a thin layer on screens or sieves in well-aerated lofts and left to dry'.

Windisch–Kolbach units

Windisch–Kolbach units are used to quantify the **diastatic power (DP)** of malts. It forms the basis of the method that is favoured by the European Brewing Congress and the American Society of Brewing Chemists. A Windisch–Kolbach unit is the quantity of maltose formed per 100 g of malt, milled under standard conditions and suspended in acetate buffer at pH 4.3 (± 0.1) for 20 minutes at 20°C.

Other units of diastatic power are **Lintner degree** and **maltose equivalent**. The relationship between these measures is given as

$$\text{Lintner degree} = \frac{^{\circ}\text{W-K} + 16}{3.5}$$

$$\text{Maltose equivalent} = ^{\circ}\text{L} \times 4.$$

Winge, Øjvind

Danish geneticist (1886–1964) who pioneered much groundbreaking work on yeast genetics whilst working at the Carlsberg Laboratory. He was the first to demonstrate a sexual cycle in yeast and the promulgation of traits via simple Mendelian segregation.

Withering

Withering is a stage in the malting process in which during the kilning phase the grains are subjected to an additional drying step intermediate between drying and curing. The aim of the process is to ensure that grains are sufficiently dry before curing in order to prevent stewing.

See **kilning**.

WLD medium

See **WLN medium**.

WLN medium

A general-purpose commercially available yeast and bacterial growth medium (Wallerstein Laboratory Nutrient Agar) which is probably the most widely used in the brewing industry. It comprises a buffered salt medium in which the carbon and nitrogen sources are glucose and casein hydrolysate and yeast extract, respectively. The pH indicator, bromocresol green (2.2 mg/L) is included, which is taken up by some colonies to give a green colouration. This can be useful as a relatively crude means of yeast strain identity based on colony size, shape and colour. Better discrimination is achieved by doubling the concentration of dye.

The addition of cycloheximide (15 mg/L) inhibits yeast growth and allows the detection of relatively low levels of bacterial contaminants in process samples which contain yeast cells. In this format the medium is termed WLD medium (Wallerstein Laboratory Differential Agar).

Woodruff

The plant woodruff (*Asperula odorata* or *Galium odorata*) has been used for flavouring beer before the widespread adoption of hops (see **gruit** for more details). It has a sweet scent and taste owing to the presence of coumarin (benzopyrone). The latter has a flavour reminiscent of freshly cut grass or, according to some, vanilla.

In modern Germany a sugar syrup containing an extract of woodruff is commonly added to *Berliner Weisse*.

Woodside automatic grain sampler

This is a device that is used to obtain representative samples whilst grains are transported along a conveyor belt.

See **grain samplers**.

Worldwide Brewing Alliance

The Worldwide Brewing Alliance is an organisation devoted to social responsibility and beer consumption. As its name suggests it represents brewing organisations from around the world. Collectively its subscribers include brewers responsible for more than 60% of total global beer production.

It is made up of national associations of the brewers of particular countries or geographical areas. Its constituent members are

Australasian Associated Brewers Incorporated

Beer Institute of the USA

Brewers Association of Canada

Brewers Association of Japan

British Beer and Pub Association

Cerveceros Latinoamericanos

The Brewers of Europe

Union of Russian Brewers.

The Worldwide Brewing Alliance collates and exchanges information between members which describe initiatives that seek to promote a positive image of the brewing industry and the responsible consumption of its products. It deals with issues such as the response of the industry to alcohol consumption and driving and alcohol consumption by young people.

Wort

The sterile aqueous solution that is formed in the brewhouse via the sequential processes of grist preparation, **mashing**, separation of spent grains, boiling, clarification and cooling. The origin of the word is obscure but may derive from the Old English *wyrt*, which carries the implication of being an extract of plant origin.

In the fermentation stage wort forms the growth medium for yeast (and any other microorganisms added intentionally). During fermentation, as a result of microbial activity, wort is transformed into beer. In most cases the grist will consist largely of milled malted barley, although a large variety of other solid raw materials can be used, including

malted and un-malted cereals. Liquid adjuncts, usually sugar syrups, may also contribute to the finished wort as will the minerals deriving from the brewing liquor. In the boiling stage hops are usually added and these contribute to bitterness and beer flavour and aroma.

Before the boiling stage the liquid is referred to as sweet wort. After boiling, because of the addition of hops and the effects of heat on the α -acids present within them, it is described as bittered wort.

Wort colour varies from a pale straw colour to almost black dependent on the type of malt (and other ingredients) used in its preparation. Typically it is slightly acid having a pH on the region of pH 4.8–5.2. It is slightly viscous and has a pleasant malty, sweet taste and aroma. Some suspended solids, **hot break** or **trub**, are always present, the amount being dependent on the extent to which efforts are made towards clarification. In a wort **sedimentation test** the solid material should settle out to form a compact sediment, leaving a brilliantly clear supernatant. Wort concentration, expressed as specific gravity relative to water at 20°C, varies between 1.030 for very low-strength types up to around 1.090 for very high-gravity examples. These are equivalent to values of approximately 7.5 and 22.5 using the **Plato** scale.

Wort boiling

Wort is subjected to a controlled heat treatment in the final stage of wort production immediately before clarification and cooling. The process is carried out in the kettle, also known in the United Kingdom as the copper, a name that is based on the original material of construction.

Wort boiling fulfils many functions. These are considered to be the following:

- (1) *Sterilisation.* During wort preparation it is not necessary to take any specific steps to avoid microbial spoilage other than to avoid deterioration of raw materials and to avoid the pickup of taints. After wort boiling such safeguards are mandatory. Boiling of wort ensures that it is sterile (at least up to the point where it is removed from the kettle, clarified and cooled).
- (2) *Denaturation of malt and any exogenous enzymes.* It is undesirable to allow the activities of malt and other enzymes to persist in finished wort since changes may continue to occur during and after fermentation. This would introduce inconsistency into the process and possibly result in unplanned and unexpected changes downstream of the brewhouse.
- (3) *Extraction and isomerisation of hops.* Hop α -acids and other flavour-active hop components are extracted during the boil. The α -acids are isomerised by boiling and the resultant hop iso α -acids produce their characteristic bitter taste.
- (4) *Coagulation of proteins and the formation of protein polyphenol complexes.* Complexes between proteins and polyphenols are important beer haze materials. The concentrations of either or both of these materials must be reduced during the brewing process to ensure that the finished beer has an appropriate colloidal stability. Wort boiling and subsequent clarification makes an important contribution to this requirement.
- (5) *Modification to beer flavour and colour.* Many compounds with significance for beer flavour and colour are produced during the boiling stage. The heating stage is required to

ensure that transformations such as Maillard reactions, which result in the formation of coloured compounds, occur.

- (6) *Relation to beer flavour stability.* The boiling stage results in the formation of reducing compounds which are important in preventing subsequent flavour staling oxidation reactions.
- (7) *Reduction in wort pH.* In order to ensure proper fermentation performance and subsequent beer quality the wort must have an appropriate acidic pH. Boiling wort is associated with a decrease in pH.
- (8) *Volatile evaporation.* The stripping effect induced by boiling is required to reduce the concentration or to eliminate many undesirable beer flavour compounds.
- (9) *Water evaporation.* Boiling wort provides an opportunity to reduce the volume and to concentrate the wort.

It may be appreciated that wort boiling represents one of the most significant usages of energy throughout the whole of the brewing process; apart from ensuring that the requirements of wort boiling, as described earlier, are achieved in an efficient and controlled manner, much effort has been directed towards the development of more cost-effective designs of kettle. It is, of course, true that many of the requirements for wort boiling, as outlined earlier, can be avoided or accomplished by alternative procedures, and it is sometimes proposed that the boiling step might be totally replaced. To date, this has not been achieved, but no doubt efforts will continue to be directed towards this end.

In early brewing operations the wort was boiled for two or more hours. During this process more than 10% of the water was lost to evaporation. This was considered desirable because of the ease with which unwanted volatile substances were lost with the water vapour, but at considerable cost. With modern kettle designs the loss of volatile materials is adequate, but since they are more volatile than water, evaporation rates have been reduced to less than 5% and boil times of 1–1.5 hours.

An important requirement of wort boiling is the coagulation and precipitation of proteins and polyphenols to form the solid trub material, which is largely removed during hot wort clarification. The more of these materials that are removed at this stage, the less that will need to be removed further downstream and the greater the colloidal stability of the resultant beer (with the caveat that the removal of excessive protein can have a negative effect on the head-forming ability of the beer). Another important facet of kettle design is that the vigour of the boil promotes the formation of flocs but does not generate shear forces which might subsequently disrupt them.

Many agents may be used during the boiling phase to promote the loss of potential haze-forming polyphenols and proteins. Collectively these are termed copper (or kettle) finings. Addition to the kettle is a convenience since the conditions favour sterility and good mixing. Agents include tannic acid, silica gel and Irish moss.

Many chemical changes occur in wort during the boil. The isomerisation of hop acids into the bitter iso-acid form has already been mentioned. Other examples include the development of coloured compounds typically via Maillard reactions between sugars and amino compounds and the conversion of S-methylmethionine into DMS.

Boiling of wort naturally results in a reduction in pH. This is desirable since it has benefits in terms of retaining a pale colour and giving beers with a clean palate. In addition, the

formation of hot break is favoured. The presence of Ca^{2+} ions favours the reduction in pH by reacting with wort components such as phosphates and liberating H^+ ions. If the brewing liquor is deficient in calcium more may be added to the kettle. Alternatively to ensure that the decrease in pH meets expectations many brewers add acids to the kettle. These may be simple mineral acids or lactic acid.

The sterilising conditions which arise as a consequence of boiling wort provide the ideal opportunity to add liquid adjuncts such as sugar syrups; however, there is no other good reason for this practice. The added material increases the total costs of wort boiling, and providing the microbiology of the syrup handling system is robust, there is no reason why such adjuncts should not be simply added directly to the fermenter.

For details regarding the design and operation of kettles, see **wort kettle**.

Wort collection

Wort collection is the term, most associated with the United Kingdom, which describes the process by which a fermenter is filled with wort and fermentation is initiated. The whole process would typically commence with wort cooling and incorporates addition of oxygen and inoculation with yeast. In the case of very large fermenting vessels several batches of wort might be needed to fill the vessel. It might be necessary to adjust the concentration of wort, in which case a system of blending sterile water, with an appropriate ionic composition (brewing liquor), might also be used. The time taken from the commencement of wort running to the completion of fermenter fill is termed the **collection time**. Somewhat confusingly it is usual to retain records of the timing of events which take place during fermenter fill; in particular the time when the fill is completed is noted and is taken to mean the point at which fermentation commences. This is also commonly referred to as the collection time and will usually be noted as the zero time on fermentation charts. A sample of wort may be taken at this point and analysed. The wort concentration at this time is referred to as the **collection gravity**. Of course, in the case of very large fermentation vessels, where filling times may be very long and the yeast is usually pitched very early in wort collection, yeast growth and metabolism will have commenced much earlier. This would be reflected in a lower than predicted collection gravity [see **original gravity (OG)** for more discussion of these effects].

The conditions which are established during wort collection have a profound effect on subsequent fermentation. Thus, the major variables are wort concentration, temperature, pitching rate and oxygen concentration. Once these are established the subsequent fermentation rate is controlled via attemperation. The application of additional control measures, in the event of less than ideal performance, such as the addition of more yeast and/or oxygen, is difficult to accomplish and usually with little effect. In this respect the precise control of wort collection is essential in order to ensure consistency of fermentation performance and beer quality. Good procedures and equipment for the regulation of the key parameters are now available, at a price; however, in the case of very large vessels with prolonged collection times, there remains a poor understanding of the need to consider the effects of the timing and nature of the application of control measures.

See **fermentation**.

Wort composition

Wort composition is complex and it is impossible to give a definitive analysis. Its composition is dependent on the nature of the raw materials; the soluble components of these are extracted at various brewhouse stages, and how they are modified chemically as a result of the conditions to which these are exposed (see **mashing** and **wort boiling** for more details). In gross terms the carbohydrate fraction is the biggest accounting for around 90–92% of the total solids. There is much variability depending on the recipe, but in an all-malt wort the most abundant carbohydrates are maltose (*ca.* 40% total solids) and higher saccharides such as maltotriose and maltotetraose (together *ca.* 20% total solids). Simpler fermentable sugars include glucose, fructose and sucrose (*ca.* 15% total solids). Longer-chain dextrans, glucans and pentosans account for around 20% of the total solids. A wide variety of other less commonly encountered carbohydrates may also be found in smaller quantities.

The nitrogenous fraction typically amounts to around 5% of the total solids and includes a wide variety of individual components. With regard to yeast nutrition and beer flavour development the free amino nitrogen (FAN) fraction is of importance, and free amino acids, peptides and proteins represent about 85% of the total nitrogenous solid matter. Many other organic nitrogen-containing compounds are also found (see **nitrogen**).

Vitamins have significance to yeast nutrition and small quantities are found, typically a few micrograms per millilitre up to milligrams per millilitre for others. Examples include in order of abundance: *myo*-inositol, nicotininc acid, pyridoxine, pantothenic acid, riboflavin, thiamine, folic acid and biotin.

Wort lipids are present in small quantities and in sweet worts are found mainly as free fatty acids but also in esterified form as mono-, di-, and triacylglycerols, phospholipids, glycolipids, carotenoids, tocopherols and sterols. Malt contains around 3–4% lipids on a dry weight basis and less than 5% of this is extracted into wort. The type of processing plant used is influential. More lipids are extracted with **lauter tuns** compared with **mash filters**. Some of the lipid fraction of sweet wort appears in the hot break and depending on the efficiency of clarification after boiling, a variable proportion will persist in cooled bittered wort. In addition to longer-chain fatty acids a wide variety of short-chain fatty and aliphatic acids are extracted from malts and other ingredients of the grist during mashing. Many of these are metabolic intermediates and include lactate, oxalate, succinate, fumarate, malate, citrate and pyruvate. Collectively they contribute to the buffering capacity of worts and contribute to yeast nutrition.

Malt and hops contain a wide variety of phenolic compounds usually considered as comprising two groups, substituted benzoic acids and substituted cinnamic acids. In unboiled worts typical concentrations of the total are around 5–6 mg/L. Examples include gallic acid, protocatechuic acid, 4-hydroxybenzoic acid, vanillic acid and syringic acid (benzoic acid derivatives); and caffeic acid, *p*-coumaric acid, ferulic acid and sinapic acid (cinnamic acid derivatives). In addition, many flavan-3-ols are found. These include catechin, epicatechin, gallo catechin and epigallocatechin. Collectively, in brewing terminology, these are termed anthocyanogens but more properly proanthocyanidins. These molecules have the ability to form polymers of various sizes. The structure of the polymers changes during wort production. Many are extracted from malt and hops into sweet worts. At this stage dimeric flavanols such as prodelpinidin B₃ and procyanidin B₃ and the monomer catechin predominate at

concentrations of around 20 and 5 mg/L, respectively. After boiling, the concentration of the polymeric forms declines, while that of the monomers increases (see **polyphenols** for more details).

The ash content of wort is around 1.5–2% of the total dry weight. It comprises inorganic ions which arise from the brewing liquor and grist ingredients. The ionic composition of the liquor is influential, generally making a small contribution towards lager worts but much greater for ale types. In the latter case sulphate may account for up to 400 mg/L (see **water** for a general discussion). In typical sweet worts the concentrations (mg/L) of some inorganic ions are calcium (40–100), copper (0.1–0.5), iron (0.08–0.4), manganese (0.1–0.2), magnesium (100–150), potassium (300–700), sodium (10–100) and zinc (0.07–0.12). Some metal ions may be lost with the hot break, for example, zinc, and an additional supplement of this metal, usually around 0.1 mg/L (as Zn^{2+}), may be added to cooled wort. Phosphate ions in sweet worts occur in concentrations of around 800 mg/L. The majority of this is formed via the degradation of nucleic acids and **phytic acid**.

Wort cooling

In preparation for fermentation the hot wort issuing from the brewhouse must be cooled to an appropriate temperature. The required temperature depends on the beer type but typically will be higher for ales (18–22°C) compared with lagers (6–12°C). It is true, however, that for many mainstream pale pilsener-type lager beers, the economic driver of shorter fermentation cycle times has resulted in the use of higher fermentation temperatures, and for many brands these are now approaching (or even exceeding) those used for ales.

Cooling wort to fermentation temperatures is accompanied by the formation of **cold break** (see entry for details). The cooling operations practised by some brewers allow for the separation and removal of this material (see **cold wort clarification**); others do not, and this material persists into fermentation. Before delivery to the fermenter the cooled wort must be aerated (or oxygenated), and in many modern breweries the cooling system incorporates equipment for accomplishing this (see **wort oxygenation**). Inoculation of wort with yeast (**pitching**) may also usually be performed during the transfer of wort from the brewhouse to the fermenter but, of course, in order to prevent loss of viability, the yeast cannot be added until after wort cooling.

A variety of pieces of equipment are used to cool wort. Historically, the process was via natural equilibration with the ambient temperature of the room in which the wort was cooled. This was accomplished by transferring the hot wort into shallow vessels known as **coolships**. These are rectangular open vessels made from wood or various metals such as iron, copper or aluminium. The liquid depth is not greater than 30 cm, thereby providing a large surface area for heat exchange with the atmosphere. The cooling process is lengthy, often more than 12 hours. The open arrangement and slow cooling allows the wort to become aerated and cold break settles to the bottom of the vessel. Careful decantation of the cooled wort allows much of the sediment of cold break to be left in the emptied vessel. In more modern incarnations of coolships the bottom of the vessel may be provided with a system of internal pipes through which cooling water may be circulated.

The use of coolships has been largely superseded by the use of more efficient methods of wort cooling. The major disadvantages of the former are high loss rates, slow cool times and

high risks of microbial contamination. In all subsequent cooling systems the process has been accelerated by the use of a circulating coolant enclosed within a heat exchange surface which is allowed to come into close contact with the hot wort. The first development was the introduction of **open vertical coolers**. These comprise an array of metal tubes arranged vertically and through which a coolant, usually water or brine, is circulated vertically, countercurrent to the wort flow. Hot wort is pumped into a trough mounted above the tubes. Cooling is effected by allowing the hot wort to trickle from the trough in the form of a thin film over the tubes.

Open vertical wort coolers allowed faster processing compared with coolships but failed to address the issue of hygiene. This disadvantage was overcome by the introduction of closed wort coolers. Two types may be used: **tube and shell heat exchangers** or **plate and frame heat exchangers**. In modern commercial breweries the latter are by far the most common. Both designs are entirely enclosed and therefore easy to clean and maintain aseptic conditions.

Shell and tube coolers comprise bundles of cylindrical tubes through which the wort is allowed to pass. The tubes are enclosed within a secondary container, also usually cylindrical, the shell, through which coolant is passed. The coolant may be air, water or a refrigerant (or a multistage combination) depending on the desired end temperature. Passage of air or oxygen in countercurrent to the wort flow allows control of the oxygen content of the cooled wort.

Plate and frame wort coolers (see **plate and frame heat exchanger**), commonly known as **paraflows**, are the most often used plant for wort cooling in high-throughput modern breweries. They comprise a series of thin stainless steel plates in which a series of grooves and gaskets provide channels for the flow of wort and coolant.

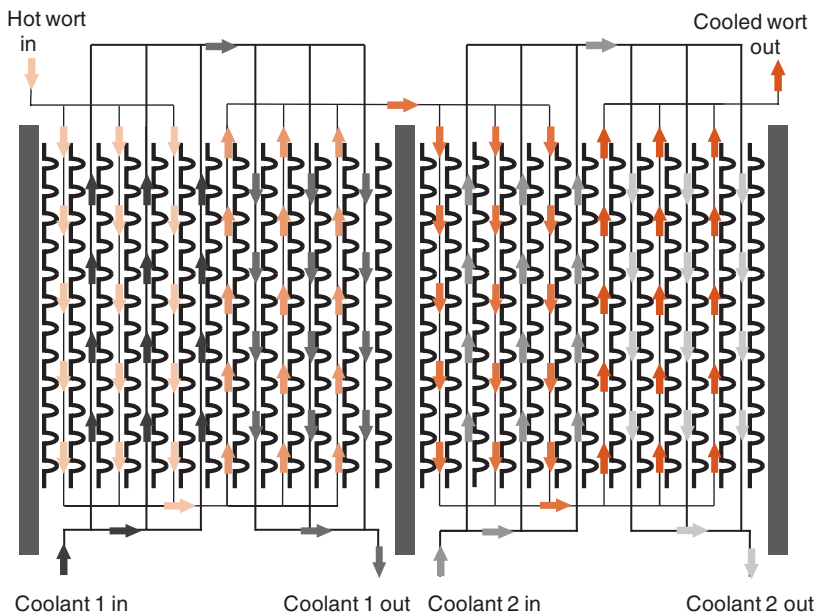


Diagram showing the fluid flow through a two-stage plate and frame heat exchanger suitable for cooling wort

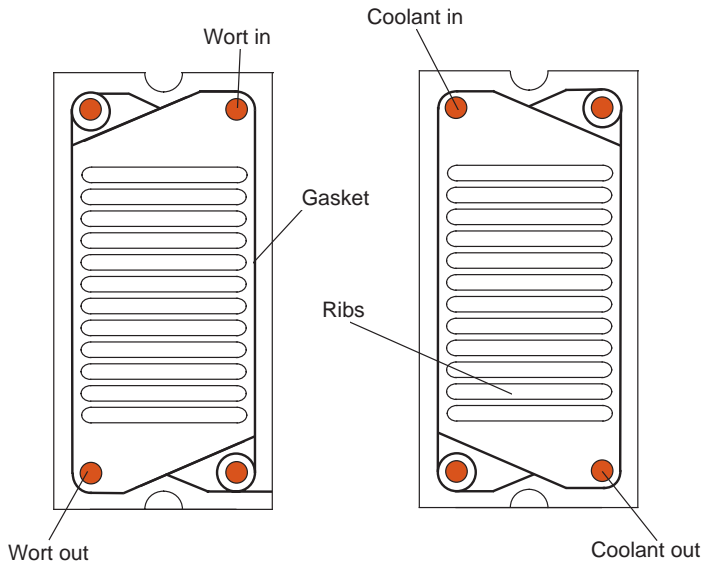


Diagram showing the arrangement of two adjacent plates in a plate and frame heat exchanger

The flow is arranged such that wort and coolant flow through alternate plates and provide a very large surface area for heat exchange. The number and size of individual plates is based on the required cooling load and flow rate. As with the shell and tube chillers, coolants are chosen based on the required cooling load and may be water, brines or refrigerants such as ethylene glycol. The individual plates in a paraflow are held together by screw clamps and the seals are dependent upon the integrity of the gaskets. In order to prevent leakage of the coolant into the wort flow and a possible contamination it is essential to manage the process such that the pressure in the wort line is higher than that of the coolant. Wort paraflows are commonly built in a number of stages, each of which is designed to reduce the wort temperature by a predetermined increment. The long tortuous pathway that the wort must traverse through the paraflow provides excellent mixing. In order to take advantage of this, oxygen or air may be added either at the start, or more usually, in between two of the stages.

Wort deflector

Synonym for **wort spreader**.

Wort fermentability

Wort fermentability is defined as the proportion of extract which can be utilised by yeast. It is expressed as a percentage according to the following equation:

$$\text{Fermentability (\%)} = \frac{\text{Original extract} - \text{final gravity}}{\text{Original extract}} \times 100.$$

Wort kettle

The kettle is the name applied to the piece of plant in which sweet wort is subjected to a controlled boil. It is also referred to as a **copper** (mainly United Kingdom) or occasionally a

hop boiler. During boiling wort composition is modified in several ways. These are described in the entry **wort boiling**.

An important aspect of kettle design is the method of application of heat. Originally this was via direct heating from the base using wood or coal fires. Such designs are inefficient since more than half of the calorific energy generated is lost. In addition, cycle times are relatively long since the fires required lighting before first use and extinguishing before reuse. The latter is an important consideration as application of heat to the empty kettle would result in charring or caramelisation when wort is admitted to the hot metal surface.

The use of direct gas or oil firing avoids some of the disadvantages of wood or gas; however, the most common method of heating is via the application of steam. In such applications steam is supplied to the kettle where at heat exchanging surfaces it condenses and in so doing gives up its latent heat to the wort (see **Fourier's law** for more details). The temperature of the steam is controlled by the application of pressure as these two parameters are positively correlated.

Operation and design of the kettle may be considered in terms of the required evaporation rate of a given volume of wort. The quantity of steam required to meet this target in a given time period is controlled by the pressure of the steam and the total surface area of heat transfer surface required to achieve the condensation of the steam within the desired time period. This figure can be calculated. Some practical factors are also important. A large difference between the temperature of the steam and that of the wort must be avoided since excessive colour changes in the wort may occur. For this reason, 3–4 bar (steam up to *ca.* 150°C) is the upper practical limit.

Heat transfer is influenced on the wort side by the boundary layer and, thus, the rate of wort flow over the surface is important, and this is influenced by the design and operation of individual kettles. Similarly any fouling on the surface of the heat exchanger will have a detrimental effect on heat transfer and, for this reason, the efficacy and frequency of the CIP system is critical.

Kettle design

The essence of good kettle design is that the wort must be heated in an efficient and cost-effective manner such that desirable changes occur in a controlled but as short a time as possible; however, the design and operation of the kettle must prevent undesirable changes such as overdevelopment of coloured products, excessive loss of foam-positive proteins and any adverse impact on beer flavour stability.

Very early kettles were simple open cylindrical vessels, usually made from iron and with rounded bases. Based upon its superior properties more modern but still traditional kettles were fabricated from copper. The vessel was mounted above a brick-built base in which the fire was contained. Use of these kettles was cumbersome since heat could not be applied until the vessel was charged with wort in order to avoid surface burning and charring. Subsequent developments resulted in the incorporation of an enclosing dome and chimney and mechanical stirrers (**rummagers**). The use of copper, which was easier to work compared with iron, facilitated the introduction of more complex designs which favoured improvements in the circulation of boiling wort. The enclosed design required fitting access doors in order to permit additions such as hops. Modern kettles are without exception fabricated from stainless steel.

In later designs the direct firing approach was superseded by the use of steam, which was introduced into a jacket covering the base of the vessel. Several designs of steam jacket have been devised with a view to increasing the productivity of the brewhouse. For example, the efficiency of wort circulation can be improved by the provision of steam jackets which cover only part of the base of the kettle. In this case the differential in density caused by the differential in temperature in different parts of the vessel sets up convection currents which drive mixing. This approach resulted in the development of kettles with non-cylindrical configurations, for example, rectangular vessels in which the base takes the form of two or more angled sheets of different lengths. One of the angled bases is provided with steam heating introduced via pipes running over the surface. The mixing in such systems may be augmented by the provision of mechanical agitators; nevertheless, they have the inherent disadvantage of a tendency for localised burning at the heating surface and loss of foam-positive proteins due to excessive foaming.

As with all brewing operations a decision must be made as to the optimum number and capacity of vessels used. In the case of the kettle a single large vessel minimises capital costs but at the expense of flexibility and cycle time. Conversely, multiple smaller vessels give a flexible solution and they may be operated sequentially thereby cutting the overall cycle time. These gains must be balanced against the capital and revenue costs of multiple vessels and usually the requirement to pool batches of boiled wort in an **underback**. An alternative is to use a vessel design which allows some flexibility in the volume of wort. This can be achieved by fitting a number of concentric steam jackets, the valves of which can be opened progressively as wort is admitted and the level rises. In any case such a development was necessitated by the need to provide sufficient heating surface in large kettles.

The efficiency of provision of heat via external steam jackets is improved further by modifications to the configuration of the base of the vessel, for example, the introduction of an inverted cone at the base of the kettle, the inner surfaces of which are fitted with steam jackets, in addition to those located at the base (see **high-efficiency kettle**). Loss of volatiles and evaporation of water may be further encouraged by incorporating **wort spreaders**. Several designs may be found; they are located close to the surface of the boiling wort where they capture the upward stream of flowing liquid and redistribute it over the surface. Common early designs take the form of inverted shallow cones and because of the visual similarity are often known as **Chinaman's hats**. More complex designs take the form of double spreaders mounted vertically above each other. In addition, Venturi tubes may be located below the spreaders. These are designed to channel and increase the velocity of the upward flow of wort into the spreader.

The need to control wort boiling at an acceptable economic cost has resulted in the development of several much more efficient kettle designs. The majority of these rely on heating chambers which are supplied with steam and through which the wort is circulated via a series of vertically mounted tubes. The heating chambers may be located inside the kettle (internal boiling system) or located externally and linked to the kettle via a pumped loop system (external boiling system).

In internal systems the heating chamber comprises a bundle of vertically arranged cylindrical tubes, the upper portions of which are narrowed. This increases the velocity of wort flow as it rises through the tubes. The wort exits the liquid surface where it is distributed over the

surface via a spreader. The heating chamber is located close to the bottom of the kettle since heat cannot be applied until it is submerged and, therefore, this arrangement favours rapid cycle times. Wort circulation takes the form of a thermosyphon which does not require pumping. This occurs because, owing to heat transfer during passage, the temperature of the wort exiting the top of the tubes is higher than that at the base. As the wort rises the boil becomes more vigorous and leads to a two-phase flow. In this state it is significantly less dense than the wort entering the base of the tubes. The latter is in a condition of turbulent single-phase flow and has a lower temperature. The differential in density drives the liquid flow. The principal features of an internal wort tube heater are shown in the following diagram.

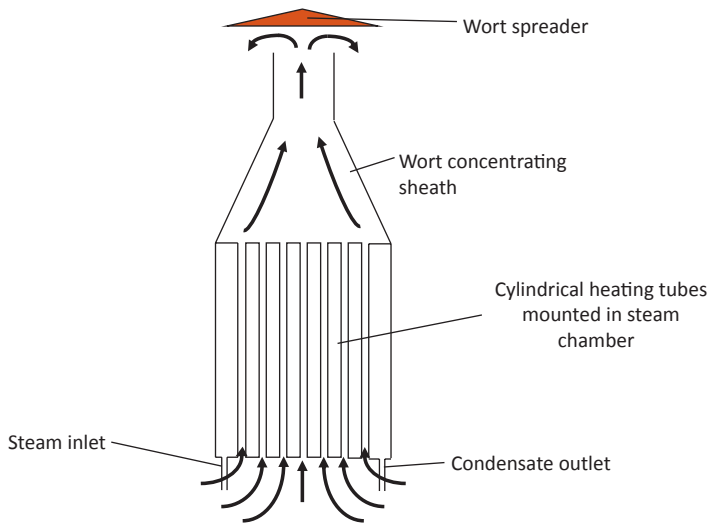


Diagram showing the key features of an internal wort heater. The tube assembly is located at the base of the kettle. The wort is discharged into the headspace where it hits the spreader and is dispersed over the surface and directed towards the walls from where it flows downwards, hits the circular bottom from where it re-enters the heating tubes.

Commonly the heating chamber is placed in a well at the base of the vessel such that it is rapidly submerged when wort is added. Wort pre-heaters provide more rapid cycle times and reduce operating costs. The thermosyphon generates sufficient flow to ensure that the turnover rate is equal to 5–10 times of the total wort volume per hour. In order to avoid over-foaming the spreader is designed to ensure that the wort does not splash onto the walls of the kettle.

Wort flow through the heating tubes should be controlled to ensure nucleate boiling. Nucleate boiling describes a condition in which bubbles which form at the interface between liquid and solid surfaces separate from the solid surface and pass back into the liquid phase. The efficiency of heat transfer in the tubes is influenced by the temperature of the steam, the pressure within the tubes, the nature of the tube material and the velocity of flow. As the wort enters the base of the tubes it begins to boil and bubbles form at nucleating sites, which take the form of minute cavities in the metal of the wall. The bubbles grow and eventually detach from the wall and are carried into the body of the liquid. Since the temperature of the bulk liquid is lower than that of the wall the bubbles collapse. In the case of wort boiling in a kettle

constructed from stainless steel the steam must be at a pressure of no more than 3 bar and wort flow must be turbulent. At higher steam pressures the relatively large temperature differential does not permit separation of bubbles from the wall. The resultant gas film impedes heat transfer. The tendency of bubbles to separate from the wall is influenced by the material of construction. Compared with stainless steel, bubbles are more easily detached from copper surfaces, and because of this difference with the latter metal it is possible to use steam pressures up to 5 bar.

When liquids flow through structures, such as the heating tubes, laminar flow may occur. This is where a relatively quiescent layer of liquid forms at the surface of the pipe and surrounding the flowing liquid. This impedes heat transfer. The boundary film layer is destroyed, providing the liquid flow is sufficiently turbulent.

With some systems employing internal heaters wort circulation rates may be accelerated using a pump located immediately below the heater. This is the basis of the Ecotherm kettle designed by the Steineker Company. The name, at least in part, refers to the fact that by using this system, it is claimed that the number of boiling cycles between cleans can be increased by more than twofold compared with thermosyphon-based internal heaters.

Dynamic low-pressure wort kettles utilise rapid pressure changes to induce very rapid boiling during which flash evaporation occurs with concomitant very efficient volatile stripping. In use, the kettle, which also uses an internal heater, is allowed to pass through a number of cycles of repeated pressurisation and depressurisation. During the depressurisation phase the wort boils and many small bubbles are released from the liquid. It is this phenomenon which gives the kettle design its name and is the mechanism by which volatiles are released from the wort. Typically the kettle is allowed to progress through six cycles during which the temperature fluctuates between 101 and 103°C. The total boil lasts for just under 1 hour and evaporation rates are of the order of 5%.

The **Merlin wort boiling system** (Steineker) relies on a thin film evaporator for volatile stripping. The system combines wort boiling, volatile stripping and trub removal in a two-vessel system. Evaporation rates are of the order of 4.5% and energy usage is very modest. Wort is pumped into the top vessel where it is allowed to pass over the surface of a large steam-heated stainless steel cone. The latter is provided with independent upper and lower steam heating zones. The wort passes over the cone surface in the form of a thin film which favours evaporation and volatile stripping. Water vapour and volatiles exit the vessel from a steam stack located above the evaporator. The falling film of wort re-enters the lower vessel either at the periphery or in the centre. The tangential and central entry stream favours good mixing and induces a rotational movement into the wort. This allows separation and removal of trub. During an initial heating phase both heating zones are used. Hops may be added at this stage and circulation through the lower reservoir allows continuous removal of trub. Pumping rates are of the order 4–6 tank volumes per hour during heat-up and four times per hour during the boil. The latter is allowed to proceed for approximately 1 hour. When the boil is completed circulation is discontinued and the remaining trub is removed during a short whirlpool stand. If required the clarified wort may be again passed over the cone whilst on route to the cooler. In this case only the lower heating zone is activated. This second treatment allows further volatile stripping, in particular removal of DMS formed during the whirlpool stand.

An inherent limitation of kettles fitted with internal heaters is that the size of the heating unit is limited by the capacity of the kettle. This restriction is obviated by using an external heating bundle through which the wort is circulated. Several systems are in use. They employ bundles of vertically oriented heating tubes enclosed within a chamber fitted with a steam supply. Wort is introduced from the base of the kettle into the base of the heating unit where it passes up through the vertical tubes after which it is returned to the top of the kettle. Commonly the heating unit is referred to as a **calandria**. Circulation may be via a thermosyphon or accelerated using a pump.

External heating systems have several advantages; principally, it is possible to use much bigger heat exchange surface areas, typically up to five times greater than internal heaters. This large surface area allows the use of low-temperature steam (113°C, 0.7 bar), which is beneficial for the retention of foam-positive proteins and, in addition, fouling is reduced. From a practical standpoint gains may be made with regard to cycle time since heating can commence as soon as sufficient wort has been pumped into the kettle. Since the complication of the internal heater is removed from the kettle it is much simpler to combine wort boiling and trub removal in a single vessel (see **kettle-whirlpool** for the diagram showing the principal features of a plant suitable for combined wort boiling and hot wort clarification).

Attempts have been made to introduce in-line continuous wort boiling. Although successful, these systems have seen little take-up. The advantage is claimed to be cost savings since the use of high pressures allows relatively high temperatures to be used with concomitant high rates of hop utilisation with short cycle times and modest energy usage. In one system a three-stage heat exchanger is used, which progressively raises the temperature of the wort in stages from 72 to 90°C, from 90 to 106°C and from 106 to 140°C. After holding for 3 minutes in the last heat exchanger the wort is cooled in two successive expansion chambers (120 and 100°C). In the cooling phase volatiles are removed and some of the heat recovered is used to supply heat to the two initial heating steps. The energy savings are claimed to be of the order of 65% compared to more conventional kettles; however, this is apparently at the expense of over-colouring of wort, possible loss of beer quality, and the plant pipework is complex and difficult to clean.

It is apparent from the foregoing discussion that wort boiling is an energy-intensive and, by inference, costly process. Typically wort boiling accounts for around a fifth of the total energy consumption of the whole brewing process. In a modern brewery it is essential to conserve this energy as much possible. For this reason several heat recovery systems have been devised, the aim of which is to capture the waste energy in a form in which it can be used elsewhere in the brewing process, for example, to preheat sweet wort as it passes from the mash separator to the kettle.

Heat recovery in this way requires the use of vapour condensers. In simple systems the steam vapour emitted from the kettle is allowed to pass through a main into which sprays of warm water are introduced. The vapour condenses and a proportion of the heat is transferred to the water spray. The hot water may be used immediately or stored in well-insulated tanks. Typically the latter are fed from the base such that the outlet is at the top where the hotter, less dense water is found.

Vapour compression systems allow the recovered heat to offset directly the cost of wort boiling. These systems rely on compression of the vapour such that its temperature rises

above 100°C. Two methods are used. **Mechanical vapour compression** systems use an electrically driven compressor to pressurise the vapour exiting from the kettle. At an over-pressure of 0.7bar the temperature of the vapour may be increased to approximately 112°C. This is fed back onto the heat exchanger of the kettle where it supplements the main steam feed. Alternatively **thermal vapour compression** systems depend upon the use of steam jet compressors. These comprise jets which are fed by a supply of high-pressure live steam. The vapours, or a proportion of them, from the kettle are fed via a lateral entry point into the jet of steam, the latter providing the motive force. The jet terminates in a chamber which is wider than the entry point, and this causes the jet stream to decelerate, which results in an increase in pressure and a concomitant increase in temperature. The outflow from the jet is used to heat the kettle. Typically these systems also incorporate additional heat exchangers which recover heat from the kettle in the form of hot water, which may be used elsewhere in other brewing operations. The choice of system depends on the availability of very high-pressure steam (>10bar) needed for the thermal vapour compression system or the relative cost of steam versus electricity (mechanical vapour compression system.)

Wort oxygenation

Processes used to ensure that pitched wort contains sufficient dissolved oxygen to satisfy the requirements of yeast during fermentation. Usually the process is performed as part of wort collection. Air-saturated wort contains approximately 8 mg/L dissolved oxygen. Oxygen-saturated wort can contain up to 35–40 mg/L dissolved oxygen. Oxygen solubility correlates negatively with wort concentration and temperature. Several levels of sophistication are possible. In the case of small-scale fermentations, particularly ale types using yeast strains that have small requirements for oxygen, it is often enough simply to make wort addition to the vessel sufficiently vigorous to ensure that it becomes air-saturated. A spreader device attached to the end of the wort main promotes good air solution. In the case of commercial fermentations it is necessary to use methods for the forced addition of gaseous air or pure oxygen during wort collection. In all cases the gas must first be passed through a suitable filter to ensure sterility. Simple systems inject gas into the wort stream usually via a rotameter to control the flow rate. Alternatively, the gas can be supplied at a given pressure. Large-scale commercial fermentations usually employ pure oxygen and require more sophisticated supply systems. In order to ensure good control of oxygen addition thermal mass flow meters are commonly used to dose a desired weight of gas into the wort. It is important to encourage high rates of gas transfer from the gaseous to liquid phases and for this reason, the gas inlet is often located between the last and penultimate stage of the wort heat exchanger. The long path length provided by the heat exchanger plates ensures good gas solution. Alternatively, in-line static mixers may be used to accomplish the same end. Where the process is controlled to a set-point value of wort dissolved oxygen concentration this parameter may be checked using a suitable dissolved oxygen probe placed upstream of the addition point.

Wort run-off

See **run-off**.

Wort sedimentation test

A qualitative test applied to boiled wort to assess wort clarity, the extent of protein coagulation and to provide a prediction of the ease with which **trub** separation will occur during the whirlpool stage of brewing. The test is performed in an insulated **Imhoff cone**, a transparent conical container in which a sample of wort (usually 1 L) is decanted and allowed to stand for 5 minutes. After this time the trub should have formed a compact layer at the base of the cone, leaving a clear supernatant. A cloudy wort and “fluffy” sediment is indicative of poor brew-house practises which require investigation and remedy.

Wort spreader

Wort spreaders (also known as wort deflectors) are devices incorporated into wort kettles which are designed to promote efficient evaporation of water and stripping of volatile constituents. The simplest design, often referred to as a Chinaman’s hat, comprises a shallow inverted cone which is located above the surface top of the upward flowing boiling liquid. The cone captures the stream of boiling wort and distributes it over the surface of the liquid. This increases the surface area of liquid from which evaporation and volatilisation can take place.

The vigour of the rolling boil in the wort kettle is vital for ensuring rapid loss of water and volatiles; however, the process must be controlled in order to avoid undue loss of foam-positive proteins and excessive colour development. These apparently contradictory needs have resulted in the development of several proprietary designs of wort spreader. These may take the form of double spreaders, mounted vertically above each other, or others in which a Venturi tube located below the spreader draws in the wort after which it is distributed over the liquid surface. In all cases the aim is to provide controlled conditions for loss of water and volatiles but avoiding undue splashing and foaming.

See **wort kettle**.

WS test

The WS test is applied to barley grains to assess the phenomenon of water sensitivity. The test is usually carried out simultaneously with the germinative energy (GE) test. Together these are referred to as the **4-mL and 8-mL test**. Triplicate samples of 100 grains are placed evenly spaced and furrow-side down on a stack of three sheets of 9-cm-diameter filter paper. These are placed within 9-cm glass Petri dishes. Water, either 4 or 8 mL, as appropriate, is added to each plate and these are incubated in the dark at 18–21°C. The numbers of chitted grains are counted at 24, 48 and 72 hours. Results are recorded as the germinative energy (% GE, 4 mL, 72 hours) and water sensitive (% WS, 8 mL, 72 hours). The results are a measure of the ability of grains to germinate and, hence, their fitness for malting and whether or not the grains are water sensitive. The values at each time period are indicative of rates of germination and are related to the vigour of the grain.

In acceptable samples approximately 50% of the grains should have germinated by 48 hours and >95% by day 3 in the GE test. A large discrepancy between the 4- and 8-mL tests indicates water sensitivity and the steeping regime for these grains should be modified to include one or more air rests.

See **water sensitivity and germination**.

Würze

German word for wort.

Wurzepfanne

German for copper.

Wye College

Wye College, more properly the College of St. Martin and St. Gregory at Wye, is a centre for agricultural studies, situated in Kent in the United Kingdom. In the brewing world it is known as a renowned centre for hop research. Numerous commercial hop cultivars owe their origin to the Wye College hop-breeding programme.

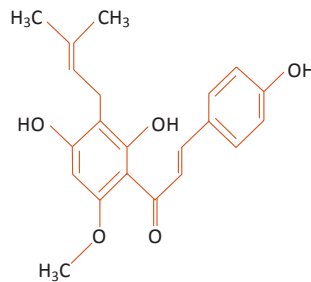
The college was founded in 1447, originally as a catholic seminary, but in 1898 became part of the University of London. In 2000 it became part of Imperial College, London, and was renamed Imperial College at Wye. Its closure was announced in 2005, for financial reasons.

X- α -Gal test

A test used to distinguish lager and ale brewing yeast strains. Lager strains, but not ale, possess α -galactosidase activity, which cleaves the chromagenic substrate X- α -Gal test (5-bromo-4-chloro-3-indoyl- α -D-galactoside) to form an insoluble blue green dye. When the chromagen is incorporated into solid media lager yeast colonies develop a green colour, whereas those of ale stains remain uncoloured. More recently the method has been adapted for use in a rapid test using microtitre plates where very low concentrations of lager yeast cells can be detected in a few hours.

Xanthohumol

Xanthohumol is the major prenylflavonoid component of the hard resin fraction of hops.



Structure of xanthohumol

The concentration of xanthohumol in hops lies within the range 0.1–0.8%. The concentration declines during kilning and storage. Xanthohumol is lost at various stages in the brewing process, with spent hops, with break in the whirlpool and with yeast cropped from fermentation; however, approximately 30% of the total persists into beer, mainly in the cyclised form, isoxanthohumol (up to 0.7 ppm xanthohumol and 3.44 ppm isoxanthohumol).

Xanthohumol serves no beneficial purpose in brewing; however, as a group the prenylflavonoids exhibit cytotoxic properties both against bacteria and cancer cells. This raises the

possibility that these compounds might have positive implications for the health of the consumer; however, whether or not these effects might have any significance at the concentrations at which they occur in beer is a moot point.

Xerogels

Xerogels are types of silica gel process aids which are used to improve beer colloidal stability via the removal of potentially haze-containing proteins.

See **silica gel**.

XMACS medium

Selective microbiological medium for wild yeast based on the principle of providing carbon sources that wild but not culture yeast can utilise for growth. The medium contains xylose, mannitol, adonitol, cellobiose and sorbitol, the first letters of these providing the acronymic name. It has been superseded by other media.

Y

Yakima Valley

Yakima Valley is a region in Washington State, USA. It is named after the River Yakima, a tributary of the Columbia River. It is a noted wine and fruit producing region. With regard to brewing it is the region responsible for the cultivation of approximately 80% of the total US hop crop. This accounts for around 40% of the world production of hops. It was established as a hop-growing area in the early 1870s following the devastation by downy mildew of crops cultivated in states on the eastern seaboard and Midwest, particularly New York and Wisconsin.

Yarake

Native manioc beer from Venezuela.

See **manioc beer**.

Yard of ale

A name of English origin given to a beer glass made in the shape of an elongated tube flared at one end and fitted with a spherical globe at the other. As the name suggests the whole glass is approximately 1 yard (0.91 cm) in length. The glasses are commonly used in drinking games in which the contestant has to finish the whole of the contents, usually around 1–2L, in a single draught without spillage. The latter test is made more difficult by the globed end, which, when the glass is almost drained, can empty with rapidity and disastrous consequences for the unwary imbiber.

The glasses are said to have their origin in coaching inns where the convenient shape allowed beer to be grasped and consumed by the coachman whilst on the hoof.

See **Kwak**.

Yarrow

The yarrow plant (*Achillea millefolium*) is common plant of pastures and waysides widely distributed throughout the United Kingdom and mainland Europe. It was introduced to North America, New Zealand and Australia. It has bitter astringent components which derive from volatile oils and various alkaloids.

The bitter nature of extracts of yarrow resulted in its use during the Middle Ages as a beer flavouring.

See **gruit**.

YCV

See **yeast storage vessel**.

Yeast

Yeast is the generic name given to a group of microorganisms that are classified within fungi and defined as having vegetative states in which asexual proliferation is via budding or fission. They grow predominantly as single cells, although many species exhibit dimorphism and have phases in their life cycles where they adopt a filamentous morphology and develop into a mycelium. Included is the genus *Saccharomyces* in which resides the yeast responsible for transforming wort into beer.

In brewing, the terms yeast and *Saccharomyces* are often, and incorrectly, used interchangeably. In fact there are approximately 100 genera of yeasts which are further classified into more than 700 individual species. These numbers will increase as new species are discovered. Each species can be further subdivided into numerous individual strains, the latter representing the smallest unit with a distinct genotype. It may be appreciated from the foregoing discussion that the term 'yeast' is imprecise since it simply describes fungi which can exist, either permanently or at least under certain conditions, as single cells. Even this definition is not strictly true since the single cells may occur as short chains or clusters. Similarly, from a physiological standpoint, the ability to catalyse ethanolic fermentation is a property of less than half of known yeast species. This diversity is reflected by the fact that yeasts occur in three of the fungal divisions: Ascomycota, Basidiomycota and Deuteromycota.

All brewing yeasts are ascomycetous, a group of fungi where a sexual stage occurs in which the resultant *ascospores* are borne within a sac-like body called an ascus. All brewing strains are members of the genus *Saccharomyces*. The term comes from the Latin word meaning 'sugar fungus', a name descriptive of the habitat where they may be commonly encountered.

For more details see specific entries related to yeast and its properties.

Yeast ageing

See **Hayflick limit**.

Yeast back

The name given to a tank and associated with UK ale brewing in which yeast cropped from primary fermentation is transferred and stored prior to re-pitching. Commonly the tanks were fabricated from slate and fitted with attemperators to assist with keeping the yeast cool.

Yeast cell composition

Yeast cells comprise approximately 80% water. The elemental composition of the dry fraction in order of abundance is C (*ca.* 50%), O (30–35%), N (5%), H (5%), P (1%), and trace elements (5–10%).

The macromolecular composition on a dry weight basis is protein (40–45%), carbohydrates (30–35%), nucleic acids (6–8%) and lipids (4–5%).

Yeast cell counts

See **yeast slurry analysis, haemocytometer, plate counts.**

Yeast cell cycle

In common with all living cells yeast have a requirement to undergo replication. In the case of brewing yeasts this is accomplished by the process of budding by which a mother cell produces a daughter. The cell cycle is defined as the series of events that have to occur in order for a complete round of vegetative (asexual) reproduction to occur. In yeast terms, the cell cycle includes all the processes that are required for the initiation of replication, the formation of a new daughter cell and its eventual release from the parent.

Five distinct phases of the cell cycle are recognised and by convention these are described using a coding system of letters and numbers. In reality the events which comprise the cell cycle should be viewed as a continuum.

In the context of brewing there are two opportunities for cells to enter the cell cycle: firstly, that which occurs during fermentation when cells are actively growing and undergoing successive rounds of replication; and secondly, where stored pitching yeast is first exposed to fresh wort and is moving from the stationary phase into active growth.

Yeast in the storage phase in between rounds of cropping and re-pitching is said to be in the G_0 state. In effect such cells are in a suspended state where the cell cycle is inoperative. Cells enter the G_0 stage when conditions preclude growth. This could be due to adverse stressful conditions or simply the exhaustion of an essential nutrient, as occurs at the end of brewery fermentation. The genome of such cells is structured towards survival. The cells are more resistant to environmental stresses compared with their actively growing counterparts. They rely on endogenous stores of carbohydrates, notably, glycogen for the provision of maintenance energy.

When pitched into fresh wort the availability of nutrients and the increase in temperature trigger the exit from G_0 and into the first stage of the cell cycle proper, termed G_1 . This is a gap phase where cellular growth occurs together with the synthesis of organelles. In this phase a number of cellular signalling systems are used to interrogate the status of the cell and environmental triggers. These include factors such as cell size, nutritional status and the satisfactory completion of a previous round of replication. These complex interacting signals reach an appropriate status which allows the replicative cell cycle to commence. At this point the cells pass through a gate which is termed START. In effect this commits the cells to division and, once passed, changes in external stimuli such as nutrient depletion cannot override the replication process. At the end of G_1 a ring of chitin appears on the cell surface, indicating where the new bud will emerge from. The precise position on the cell wall is usually ordered and the pattern of bud scars subsequently formed may be strain specific. Budding then commences as the cells pass into the S phase. In this phase DNA replication occurs and the nucleus migrates into the neck, which separates the mother and the emerging bud. A further resting stage now occurs, termed G_2 , during which growth and further development continue. This culminates in the M phase in which mitosis and nuclear division takes place and bud

emergence through the ring of chitin moves to completion. The process ends when the newly emerged bud becomes separated from the mother cell. This, together with cytokinesis, is considered to occur at the commencement of the next G_1 phase. The chitin-rich ring left on the mother cell leaves a visible bud scar. A similar ring is formed on the new daughter cell and this is termed the birth scar.

For some strains at the completion of the cell cycle the daughter may remain attached to the mother. A new cell cycle can be initiated and this may result in the formation of clusters or short chains of cells.

Providing the environmental conditions are favourable further rounds of the cell cycle can occur. This requires a certain amount of growth resulting in an increase in cell volume. This parameter is one of the signals which control passage from G_1 to START. In this regard the duration of the G_1 phase for mothers and virgin daughters is usually different, longer in the latter case since the daughters have to undergo a relatively large increase in cell mass before they attain the critical size necessary for the initiation of the cell cycle. By inference there is a positive correlation between cell size and replicative age (see **Hayflick limit** for more details).

At some point in batch culture the external conditions preclude further proliferation and the cells pass into the G_0 phase.

See also **yeast**.

Yeast collection vessel

See **yeast storage vessel**.

Yeast colonies

Single cells of yeast cultivated on the surface of nutrient media, solidified with a gelling agent such as agar or gelatin, proliferate and form groups of cells termed colonies. Depending on the medium and conditions of incubation these may assume characteristic shapes and colours which may be useful aids to identification. In addition, the consistency of the appearance of the colonies can provide some assurance of strain purity (see **yeast differentiation**). The nature of the yeast and the availability of nutrients to individual cells both influence colonial morphology. Colonies are usually roughly circular and grow in a radial fashion as cells at the periphery are able to utilise the relatively rich supply of nutrients. Cells in the centre or at the top of the colony depend on diffusion of nutrients from the underlying medium. Similar gradients will occur regarding the supply and dispersal of gases to and from the atmosphere surrounding the cells. The result is that for an aerobic cell in an atmosphere containing air there is an initial period of growth when no single factor is limiting and the colony expands in the form of a domed circle. As the total population size increases, cells at the bottom and centre become deprived of oxygen, and those in the centre and at the top become nutrient limited. In consequence, growth becomes predominantly annular and the colony may adopt a crater-type appearance.

The situation is more complex since the cells require the supply of many nutrients. Limitation for some of these, for example, nitrogen, can trigger complex reactions which may result in morphological changes such as the formation of pseudohyphae. This can trigger an uneven invasion of the agar such that the colony can adopt an irregular appearance. Further complications arise if the surface of the medium is overcrowded since the growth of individual colonies

can be influenced by close neighbours. Hence, where colonial morphology is used as a diagnostic tool, care must be taken when plating out to ensure these effects are minimised.

Yeast culture collections

Several organisations curate collections of yeast cultures, including brewing yeast strains. The organisations can be used, rather like a bank, as a storage facility where proprietary strains can be held, at a cost, by the third party culture collection, with the knowledge that they are being maintained in a way that ensures that a replacement culture for existing brewing yeast can be provided in a certified pure and highly viable condition. Some culture collections provide strain identification and other services. The strains may be part of private collections or they may be available for general purchase. With regard to the latter, where brewing strains with particular properties are required, online searchable databases can be used to facilitate selection.

The principal yeast culture collections are given as follows:

United Kingdom, National Collection of Yeast Cultures (NCYC) [<http://www.ncyc.co.uk> (last accessed 10 February 2013)]

United States, American Type Culture Collection (ATCC) [<http://www.atcc.org> (last accessed 10 February 2013)]

the Netherlands, Centraalbureau voor Schimmelcultures (CBS) [<http://www.cbs.knaw.nl> (last accessed 10 February 2013)]

Belgium, Belgium Co-ordinated Collections of Micro-organisms (BCCM) [<http://www.bccm.belspo.be> (last accessed 10 February 2013)]

Finland, VTT Biotechnology and Food Research (VTT) [<http://www.culturecollection.vtt.fi> (last accessed 10 February 2013)]

Germany, Versuchs-und Lehranstalt für Brauerei (VLB) [<http://www.vlb-berlin.org> (last accessed 10 February 2013)].

Other culture collections are devoted to the curatorship of cultures of other microorganisms, some of which are of interest to brewing as spoilage organisms. For example, in the United Kingdom, a resource for bacterial cultures is the National Collections of Industrial and Marine Bacteria (last accessed 10 February 2013)].

Yeast cytology

The ultrastructural features of an idealised yeast cell are shown in the accompanying figure. Yeasts are eukaryotes and possess the organelles characteristic of fungi such as a nucleus, mitochondria, vacuoles, ribosomes, endoplasmic reticulum and Golgi apparatus. The cell envelope comprises a thick outer wall which encloses the plasma membrane and the intervening **periplasmic space**. The latter is a functional part of the cell in that it contains several enzymes such as invertase, acid phosphatase and melibiase. In addition, its gel-like properties may afford protection to the relatively delicate plasma membrane.

The cell wall accounts for approximately 20% of the cell dry weight and is approximately 200 nm in thickness. It consists of approximately 90% carbohydrate, the remainder being protein. Of the carbohydrate fraction 30–50% comprises glucans. The glucan molecules form a matrix of long fibres joined by β -1,3 and β -1,6 linkages. The glucans are linked covalently to mannoproteins. These are made up of an inner core of mannose residues joined together

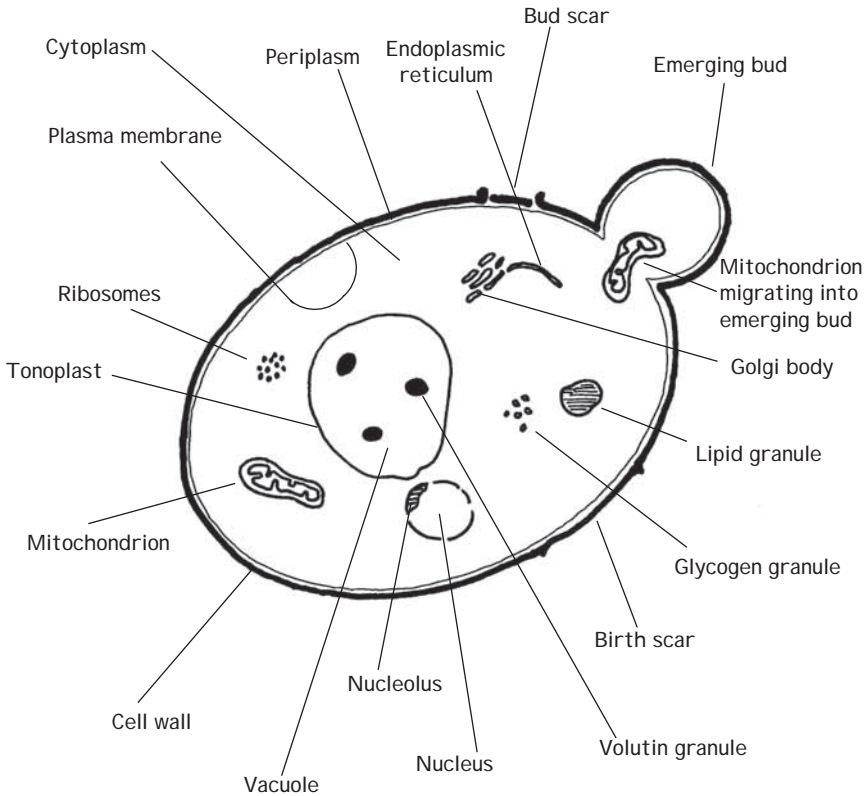


Diagram showing the principal features of a typical brewing yeast cell

by α -1,6 bonds. Short side chains are attached to the backbone via α -1,2 and α -1,3 linkages. This inner core is bound to an outer chain of approximately 100–150 mannose residues, also with α -1,6 mannose residues and short α -1,2 linked side chains. These side chains comprise dimers, trimers or tetramers of mannose, some of which contain phosphodiester linkages which confer an overall negative charge to the cell envelope. The quantity of phosphate present in the wall varies between ale and lager strains. Ale strains contain relatively fewer phosphate residues compared with lager types. The low phosphate cell wall of ale strains tends towards conferring a more hydrophobic surface, and this provides the explanation for the tendency of such strains to rise to the surface of fermenting worts (in conjunction with the ability of the yeast flocs to trap CO_2 bubbles). Protein molecules are attached to the mannans. The mannose and protein fractions of the cell wall constitute the receptors that are involved in **yeast flocculation** and sexual agglutination, and their particular structures are specific to individual strains.

From a structural standpoint the β -1,3 linked glucans form an interwoven network of fibrils which confer both strength and flexibility to the cell wall. The β -1,6 linked glucans link these fibrils to the mannoproteins and to other cell wall components such as glycogen and chitin. There are two pools of mannoproteins. Most are situated on the outer part of the wall and the degree of cross-linking regulates the size of molecules that can pass through the wall. The second pool of mannoproteins comprises molecules which are anchored in the plasma

membrane and project through the periplasm and across the glucan layer. It is this fraction which has both structural significance and importance in sexual and non-sexual agglutination.

Chitin, which is a linear polymer of β -1,4 linked N-acetyl glucosamine molecules, is distributed throughout the cell wall but is mainly found in the **bud scars**. It accounts for some 5% of the dry weight of the cell wall. Bud scars mark the point at which daughter cells have detached from the mother in the final stages of budding. The glycogen component of yeast cell walls is classified as being acid soluble and, unlike the alkali-soluble pool, does not function as a carbohydrate reserve material. Instead it appears to fulfil a structural role and is bound to the glucan fraction.

Yeast plasma membranes are similar to those of higher cells and comprise roughly equal quantities of lipids and proteins. The former fraction comprises mainly phospholipids, together with smaller concentrations of sterols, principally ergosterol. The fatty acids and sterols have both structural and functional roles. They are important components of the plasma membrane where they confer fluidity. Smaller concentrations are found in the membranes which enclose intracellular organelles. Yeast cells growing at low temperatures increase the proportion of unsaturated fatty acids found in the plasma membrane in order to maintain the appropriate degree of fluidity. In brewing yeast grown under fermentative conditions the total sterol accounts for approximately 0.1–0.2% of the total cell dry weight. Both sterols and fatty acids can be assimilated from the growth medium and both occur at low concentrations in hopped wort. They are also synthesised *de novo*; however, the pathways for both sterol and unsaturated fatty acids include steps that require the presence of molecular oxygen. In pitching yeast cropped from a previous fermentation, cellular proliferation under anaerobic conditions depletes these essential lipids and produces a requirement for oxygenation of wort in subsequent fermentation.

The plasma membrane encloses the cytoplasm, an aqueous colloidal liquid, in which many enzymes and metabolites are found. Several important enzyme systems are located in the cytoplasm. These include, amongst many others, those responsible for glycolysis, gluconeogenesis, the hexose monophosphate shunt and fatty acid synthesis. By convention such enzymes are described as being soluble since they may be isolated from the supernatants of the ultra-centrifugates of cell-free extracts; nevertheless, it is certain that the cytoplasmic enzyme systems are subject to spatial and functional organisation. The cytoplasm is acidic (*ca.* pH 5.2) and is particularly rich in RNA. RNA is found in the ribosomes, the sites of protein biosynthesis as directed in response to transcription of the genome. Ribosomes are abundant and may be found either freely suspended in the cytoplasm or attached to the outer membranes of organelles such as mitochondria, the nucleus and the endoplasmic reticulum. There are a few cytoplasmic inclusions or bodies which are not true organelles. These include glycogen granules which function as carbohydrate storage reserves and which can be visualised by staining with iodine. Lipid granules are present and these are mainly composed of triacylglycerols and esterified esters. The latter appear to function as sterol reserves and intracellular transport systems are available to mobilise these lipids and convey them to the plasma membrane for incorporation, when required.

The appearance and ultrastructure of the cell interior is subject to modification in response to the conditions to which the cell is exposed, for example, under conditions of active growth,

either aerobically, repressed or derepressed, anaerobically, or under starved, non-growing conditions. Thus, lipid particles are much more abundant when growth is aerobic and derepressed since these conditions favour lipid accumulation. Conversely, when cells are starved and are not actively growing, both glycogen and lipid granules become depleted.

There is an extensive intracellular membrane system and this is also highly dynamic. Under starvation or stressful conditions an extensive system of vacuoles may be seen, for example, during late fermentation or in yeast storage tanks after cropping. These bodies are bound by a membrane known as the tonoplast and are the sites for many catabolic pathways such as protein degradation. The resultant amino acids are stored temporarily in the vacuoles from which they may be transported when required for anabolic metabolism. Vacuoles contain stores of inorganic phosphate in the form of polymers joined by high-energy phosphoanhydride bonds. Under conditions of active balanced growth vacuoles are not very visible.

Within the cytoplasm there is an extensive system of microtubules and microfilaments which collectively are referred to as the cytoskeleton. This provides the mechanism by which cellular organisation is modified during the division and movement of chromosomes during meiosis and mitosis. Vesicular structures are used to enclose metabolites such as proteins and lipids in which form they may be transported across, into and out of the cell. A concentration of vesicles and stacked membranes, termed the Golgi body, or complex, is evident. This membranous structure is involved in metabolite trafficking between the vacuoles, the endoplasmic reticulum and the plasma membrane. It appears that the role of the Golgi body is to perform protein modification, sorting and direction to the appropriate site of need.

One or a small number of multi-branched mitochondria are present. From a structural standpoint yeast types are similar to those of higher organisms. In respiratory yeast cells the total mitochondrial volume, the chondriome, accounts for about 12% of the cell volume. Mitochondria are the sites of ATP generation via the respiratory pathways of oxidative phosphorylation and several other enzyme systems including those for fatty acid oxidation, the tricarboxylic acid (TCA) cycle, the synthesis of branched-chain amino acids and possibly some of the sterol biosynthetic pathway. Under the repressed conditions encountered in brewing the mitochondria remain poorly differentiated and difficult to visualise and the chondriome drops to around 3% of the total cell volume. These organelles are referred to as promitochondria. Many of the genes associated with electron transport and the TCA cycle are repressed and for this reason under fermentative conditions, energy transduction is via substrate-level phosphorylation and cellular redox balance via the formation of ethanol and glycerol. Promitochondria appear to perform several essential roles in brewing fermentation since cells without or with severely damaged mitochondria (termed ρ^0 and ρ^- , respectively) are deficient in several respects including flocculation, diacetyl metabolism, sterol synthesis and ability to withstand stress.

The nucleus is a roughly spherical structure approximately 1–2 μm in diameter and bound by a double membrane which is traversed by a number of pores. A nucleolus, which is the site of rRNA transcription, some of the stages of mRNA processing and ribosomal subunit assembly, is present and usually associated with the nuclear membrane. The nucleus of haploid cells contains 16 linear chromosomes which vary from 230 up to 1532 kb in length. In addition, several copies of a circular 2 μ plasmid are usually present. Chromosomes comprise complexes of double DNA helices bound to a core of histone proteins. Other proteins are also present,

the whole being termed chromatin, a name based on its ability to be stained with basic dyes. This association of DNA and proteins is structured into a complex super-coiled macromolecule. The extent of coil winding is less than that seen in higher eukaryotes.

Yeast-derived flavour compounds

Compounds produced by the metabolic activities of yeast during fermentation that persist in beer and contribute to flavour and aroma. The contributions made by raw ingredients to beer flavour, particularly malts and hops, are well recognised. Apart from the obvious conversion by yeast of wort sugars into ethanol and CO₂, which introduces warming notes and mouth tingle, respectively, other reactions occur during fermentation that result in the disappearance of many wort components and the formation of a multitude of new compounds which cumulatively contribute to the characteristic flavour and aroma of a beer. The release of CO₂ from beer helps propel volatile flavour compounds from beer into the mouth and nose of the consumer. The total number of compounds is not known but is certainly several hundred, possibly thousands. Many arise at concentrations close to their flavour threshold values and, in consequence, relatively small changes can have quite large effects on flavour. The range of compounds is similar for all strains of brewing yeast, although the concentrations of each may show significant variation. As a result, individual yeast strains are intimately linked with particular beer brands, and this is one reason why proprietary strains are jealously guarded by their owners. The concentrations of many of the compounds can be altered by differences in fermentation conditions, such as wort gravity, temperature, pitching rate and wort oxygenation. This implies that, for consistent results, it is necessary to apply strict control over these parameters, and by inference, the choice of appropriate values for them provides a route for manipulating beer flavour.

It is usual to consider the yeast-derived flavour compounds in groups based on their chemical similarity. The compounds that are found may be classified as carbonyls, alcohols, organic and fatty acids, esters and sulphur compounds. For more details of particular compounds, the pathways involved in their synthesis and the factors that influence their concentrations, individual group entries should be consulted. It may be appreciated that these classes of compounds for the most part represent different degrees of oxidation and, in this respect, they may be intermediates in common pathways. The sulphur compounds are a heterogeneous group with the sole common property of the possession of at least one sulphur atom.

Of course, green beer is, in effect, the spent medium left after yeast growth and metabolism have ended, and thus, although these compounds play a large role in beer flavour and aroma, they must be made by yeast for good metabolic reasons. Detailed knowledge of these underlying mechanisms would probably indicate routes towards better control regimes. In most cases there is little convincing evidence as to what these roles really are. Wort is a complex growth medium, yet one that is relatively unbalanced, being mainly sugar with only small concentrations of other nutrients. It may be, therefore, that yeast growth on wort is also unbalanced for much of fermentation and some metabolic intermediates are released by cells which, under other conditions, may be retained and used. This effect might be exacerbated by the relatively leaky membranes of yeast cells in late fermentation because of sterol depletion. It is also true that this group of compounds is found in beer at a low concentration.

Some metabolic roles have been suggested. Reactions involving many flavour compounds require oxido-reductase coenzymes and these reactions might represent mechanisms for

cellular redox control. This may be true, although the involvement of such large numbers of compounds appears slightly extravagant by the yeast cell, unless very broad-specificity enzymes are involved. It is likely that other functions may be involved.

Yeast differentiation

Methods used in brewery laboratories or by suppliers of yeast cultures which allow the positive identification and differentiation of yeast strains. These may be the brewing strains used to produce beer or potential beer spoiling wild yeast. In many cases the same or similar methods are applied to the identification of beer spoilage organisms.

Traditional tests rely on classical microbiological and biochemical techniques. Cultivation in liquid or solid nutrient media allows individual cells to be examined using microscopy, in all of its various forms, with or without the aid of various biological stains. This is of little value as a means of identification unless the strain in question has a very distinctive morphology; nevertheless, it can be a useful means of detecting gross contamination. Plating onto solid media allows the formation of colonies (see **colony**) and the appearance of these is also of diagnostic but limited value. It also provides a method of assessing the purity of samples since colonies with different morphologies are usually obvious, although very low levels of contamination may be more difficult to see. The use of differential and selective media allows yeast to be assigned to particular groupings, for example, brewing strain, *Saccharomyces* wild type and non-*Saccharomyces* wild type (see **microbiological media**). The conditions under which growth occurs, such as cardinal temperatures, absence or presence of oxygen, also provide useful discriminatory information. This may, for example, indicate if a brewing strain is an ale or lager type based on the growth of the former at higher temperatures. More definitive identification using these methods is not usually possible.

Numerous tests have been developed in which various properties of brewing strains can be assessed. These may, for example, rely on an examination of the flocculence characteristics of the yeast or its behaviour in laboratory-scale fermentations. The latter will provide information on growth rate and extent, attenuation profile, cropping behaviour, and so on. Beers may be recovered and may be subject to analyses. The results allow comparison with historical data which, whilst not providing proof of identity, at least indicate that behaviour falls within the usual boundaries for the particular yeast strain.

Biochemical tests of many types may be used to probe the yeast phenotype. These tests form the basis of the majority of classical taxonomic keys by which strains have been assigned to their appropriate taxon. Typical procedures investigate the spectrum of nutrients that individual yeast strains are able to assimilate and utilise under aerobic and anaerobic conditions. Any nutrient can be tested including sources of carbon and nitrogen. A minimal growth medium is used which is supplemented with the nutrient of choice, and after inoculation and incubation, the presence or absence of growth is recorded. Growth may be assessed by the appearance of turbidity, as a colour change using a pH indicator dye or via changes to enzyme-linked chromagenic dyes. The complete suites of tests used in taxonomic studies are usually very complex and are not applicable to routine use in a brewery. Commercially available kits, such as the **API test strips**, have been designed as shortened versions and typically assess the ability of the test organism to assimilate up to 20 substrates. Results may be obtained in a few hours.

For definitive identification it is necessary to use more precise techniques. Immunological methods rely on raising specific antibodies to cell surface antigens. Providing the latter are unique to the particular strain, visualisation of the interaction, typically using a fluorescent dye attached to the antibody, allows identification [see **enzyme-linked immuno-absorbent assay (ELISA)**, **direct epifluorescence filter technique (DEFT)**, **ChemScan RDI[™]**].

Several methods are available which utilise strain-specific differences in cellular composition. Care must be taken with some since changes may occur as a result of differences in physiological state. Pyrolysis mass spectrometry subjects a biomass sample to thermal degradation under carefully controlled conditions and subjects the low-molecular-weight volatile products to analysis via mass spectroscopy. The chemical fingerprint so produced has been shown to be of value in the identification of both yeast and bacteria. It is rapid and can be applied directly to a colony removed from an agar plate. Providing suitable reference analyses are available it can be used with any organism. The composition of whole cells can be assessed by Fourier transform infrared spectroscopy where unique fingerprints of individual strains are generated in the form of infrared spectra. Comparison of the results obtained with pre-developed data libraries provides positive identification. Determination of fatty acid profiles via extraction, esterification and capillary gas-liquid chromatography has proven useful as a means of identifying bacteria and some yeast strains as has the analysis of the fingerprints of whole cell protein extracts obtained via gel electrophoresis.

Undoubtedly methods based on genome analysis hold the greatest promise since by definition this feature must be unique to individual strains. Several methods have been devised which allow the generation of so-called genetic fingerprints. **Karyotyping** involves the extraction of whole chromosomes which are separated by pulsed-field electrophoresis and the resultant bands are visualised by staining with ethidium bromide. The patterns produced are strain specific. Pulsed-field electrophoresis is used since a uniform field is not able to resolve large DNA molecules. Other orientations are used, for example, a hexagonal ring of 24 electrodes surrounding the gel [clamped homogenous electric field (CHEF)] and an alternating field in which the two are transverse to the gel [transverse alternating field electrophoresis (TAFE)].

Several genetic analyses rely on DNA extraction and fragmentation followed by the identification of specific sequences using targeted probes. Restriction fragment length polymorphism (RFLP) relies on fragmenting extracted DNA or RNA using restriction enzymes that cleave nucleic acid chains at specific target sites. The fragments are separated, based on size, by electrophoresis on a gel. The separated DNA fragments are denatured to give single-stranded molecules, and these are transferred to nylon sheets in a process termed Southern blotting. A probe is added, which comprises single-stranded DNA bound to a system for visualisation, which may be a radioactive isotope or a fluorescent dye. The probe binds to complementary sites on the fragments and the resulting fingerprint can be visualised. **Polymerase chain reaction (PCR)** makes use of DNA polymerase to multiply small quantities of chosen fragments of DNA (or RNA) to give vastly increased quantities for subsequent analysis. This is achieved by denaturing the double strand followed by binding primers to opposite ends of the target nucleotide sequence and using the polymerase enzyme to construct additional complementary oligonucleotides. Further cycles of this process double the quantity of target DNA with each successive cycle. In this way reliable results can be generated from very small sample sizes. The fragments can be visualised as fingerprints by separation on gels.

Identification is made possible by the appropriate choice of primers which target highly conserved but species- or strain-variable sequences of DNA. Typically these are ribosomal RNA. Using fluorescent dye-linked probes the increase in signal strength during amplification can be used to quantify the cell concentration in the initial sample. Reduction of costs of DNA sequencing means that this approach can now be applied to amplified fragments as a means of strain identification. RPLC and PCR can be combined. In the process termed, random amplified polymorphic DNA PCR uses random mixtures of primers which bind at various sites which after amplification by PCR generate fragments that can be separated based on size to give a diagnostic fingerprint. Identification of both beer spoilage bacteria and yeast has proven possible with this technique. The **FISH (fluorescence *in situ* hybridisation)** technique utilises probes labelled with a fluorochrome specific for regions of rRNA in target cells which have a known taxonomic significance. Target cells are fixed, permeabilised and then allowed to hybridise with the probe. After washing to remove excess probes fluorescent cells can be visualised. Samples can be taken from pre-cultured isolates or directly from process streams.

Current best practice for genetic fingerprinting of brewing yeast strains suggests that the best method [recommended by the American Society of Brewing Chemists (ASBC)] is PCR of inter-delta regions of chromosomal DNA (regions of DNA which flank DNA associated with retrotransposons). This method can be used for testing stability, strain identification and detection of mutants. Both karyotyping using pulsed-field electrophoresis and random amplification of polymorphic DNA PCR (RAPD PCR) can also be used, although the latter technique is not recommended for assessing strain stability.

Yeast extract peptone dextrose (YPD) medium

Medium used for the routine cultivation of brewing and other yeast strains. It comprises yeast extract (5 g/L), peptone (10 g/L) and glucose (10 g/L). The medium is made up in distilled water; if desired, maltose may be substituted for glucose and agar (2% w/v) added to prepare a solidified form.

Yeast flocculation

Yeast flocculation is defined as the non-sexual reversible and calcium-dependent aggregation of yeast cells. It is of significance in the brewing industry since at the end of fermentation it is necessary to separate the crop from the green beer. This is facilitated by the phenomenon of flocculation whereby in late fermentation certain metabolic triggers, notably the exhaustion of fermentable sugars and other nutrients, induce the yeast cells to adhere and form flocs. The increase in particle size, coupled with the lack of convection currents due to the reduction in CO₂ generation, promotes efficient yeast separation from the green beer. This may be via sedimentation in the case of bottom-cropping lager strains, or by rising to the surface, in association with gas bubbles, in the case of top-cropping ale strains (where the vessel type is suitable for top cropping to occur).

Although yeast flocculation can be used to the advantage of the brewer, from the perspective of the yeast, it is probably a stress response. The cores of flocs provide a sheltered environment for starving cells which may be supplied with nutrients from the death and lysis of those in the outer layers. On pitching the presence of sugars in worts provides the signal for the inhibition of flocculation such that the freely borne cells are most able to take advantage of the fresh supply of nutrients.

Flocculence is an inherent characteristic of an individual yeast strain, whereas flocculation is the expression of this property. For flocculation to occur multiple conditions have to be met. These include having an appropriate genotype; the nutritional status of the medium, which influences the expression of the genotype; the physiological state of the cell, which can influence the extent to which flocculence is expressed; and physical parameters such as temperature, shear forces and pH, which affect the ability of cells to come into contact with each other and to form stable flocs. Some strains are non-flocculent under all conditions and, in general, these are not of great use in brewing. Other strains inhabit a continuum from slightly to heavily flocculent. Preferably strains do not express flocculence in primary fermentation since this ensures high suspended yeast counts and, in consequence, good rates of attenuation. When flocculation is triggered in late fermentation it is better if the majority of cells participate in order to minimise green beer yeast counts and to make downstream processing easier. On the other hand, early and very heavy flocculation can be a cause of sticking fermentation and/or prolonged vicinal diketone (VDK) stand times. Moderately flocculent strains are of value where beers are subjected to a secondary fermentation, either in lagering tanks or in casks for ales, where the presence of yeast is necessary.

Flocculation is dependent on the possession and concerted regulation of several genes. A family of 12 so-called *FLO* genes is of importance. The significance of all of these genes remains to be fully elucidated, but *FLO1*, *FLO5*, *FLO9*, *FLO10* and *FLO11* code for structural surface lectins involved in cell-to-cell interactions. *FLO1* is a dominant gene and *FLO5* and *FLO9* are highly homologous to it. *FLO8* is a transcriptional activator of *FLO1* and *FLO11*. Other genes also have significance, some of which may be mitochondrial since petite cells usually have altered flocculence characteristics.

Flocculation is considered to involve interactions between α -mannan residues of cell wall mannoproteins, present in all cells, with the N-terminal groups of lectin-like proteins, termed **flocculins**. Calcium ions are essential components in these interactions and are thought to ensure that the lectins are in the appropriate conformation for binding to occur. It is suggested that synthesis of flocculins requires the presence of *FLO* genes and these are inducible; however, the flocculent phenotype may not be expressed at all times since some wort sugars may bind to the lectins and block flocculation via inhibition of interactions with mannoproteins. Other interactions may also be of importance. The formation of fimbriae (projections on the cell surface) induced by nutrient limitation and associated with changes in cellular hydrophobicity has also been implicated in floc formation in some strains.

A number of flocculence genotypes have been recognised based on the conditions under which expression occurs or is inhibited. Mannose insensitive (MI) types are those where mannose does not block flocculation, possibly a result of an altered affinity of the lectin binding site. **NewFlo** types are typical of brewing strains and show the classic behaviour of flocculation only in late fermentation. In these strains flocculation is inhibited by mannose, glucose, maltose and sucrose. The lectin is possibly coded for by the *FLO10* gene and this is only expressed in late fermentation. Cells with the *flo1* phenotype produce a constitutive lectin whose binding activity is inhibited only by mannose and its derivatives.

In order for flocculation to occur it is necessary for cells to make contact. Perhaps counter-intuitively, it can be demonstrated that the vigour of flocculation is increased where suspensions of flocculating cells are subjected to mechanical agitation. The effect is a result of the

increased likelihood, under these conditions, of cell-to-cell collisions. Heavily flocculent yeast can pose some practical problems. Yeast crops are very concentrated, which makes attenuation in the cones of large fermenting vessels difficult such that death may occur if cropping is delayed. Such crops can be difficult to move with conventional pumps.

Variable flocculence is relatively common with some strains, which can place limits on the number of serial generations that can be used. It is assumed that these changes are a consequence of genomic instability to which the *FLO* genes seem particularly prone. Commonly, the flocculence character of pitching yeast is monitored in order to identify non-standard behaviour and to remove the deviant yeast line to avoid problem fermentation performance. Laboratory methods for assessment of flocculation, such as the **Helm's test**, assess the suspended cell count (single cell fraction) via measurement of light scattering and the sedimented fraction (flocculated cells) of a suspension of yeast of known concentration under a set of defined conditions.

Yeast flocculence

A term describing the innate ability of yeast cells of any strain to undergo the process of flocculation. It is reflective of the genome of the particular strain and is distinct from **yeast flocculation**, the phenotypic expression of flocculence.

Yeast food

Generic name given to nutritional supplements added to worts in order to correct for supposed nutritional imbalances. The precise composition differs with various proprietary brands, but typically they comprise mixtures of sources of nitrogen, both inorganic and organic (the latter often as part of a natural 'yeast extract'). Inorganic phosphate may be added as well as mixtures of metal ions (particularly Zn) and various growth factors and vitamins.

Such products should not be needed in an all-malt wort, apart from zinc, much of which is lost in the brewhouse with **trub**. The use of yeast foods may be necessary where worts with a high proportion of relatively pure sugar **adjuncts** are used, especially in high-gravity worts. With regard to the latter, there is a convincing body of evidence which suggests that ultra-high-gravity worts may be deficient in some metals, particularly Mg. It is likely that, if this practice is pursued, designer yeast foods containing a cocktail of metal ions and possibly unsaturated fatty acids and sterols may have to be developed.

Yeast generation number

The generation number is a term used in the management of yeast within a brewery. It refers to the number of times a particular yeast line has been serially cropped, stored and re-pitched.

See **serial fermentation**.

Yeast genetics

The genome of any organism is the totality of the genetic information present. It represents the whole of the potential activities of which the cell is capable. The expression of the genome at any given time is described as the phenotype.

The yeast nuclear genome is organised into 16 chromosomes, which range from just over 200 to more than 1500kb in length. The yeast genome was the first to be sequenced in its entirety. More than 6000 open reading frames have been identified of which approximately half of the potential proteins have been positively identified based on comparison with

known sequences from other sources. A further 20% have putative identification, leaving a residue of 30% so-called orphan genes whose function is yet to be determined. Each gene comprises around 500 codons and approximately 72% of the DNA of each chromosome code for genes. The genes occur in concentrated clusters throughout the chromosomes, and in haploid cells roughly half of the genes are duplicated. The latter observation has led to speculation that the genus *Saccharomyces cerevisiae* arose from a fusion event between two ancestral diploid cells each with 8 chromosomes, later reduced to a cell with 16 chromosomes via deletion.

In addition to the nuclear DNA approximately 0.5% of the total is located in the mitochondria; the latter codes for some 5% of mitochondrial proteins (25 positively identified and 7 putative open reading frames), the remainder being nuclear in origin. Cells with a normal complement of mitochondrial DNA are denoted ρ^+ . Mutant strains which lack some or all mitochondrial DNA may be viable but lack some functions. Those that are totally deficient in mitochondrial DNA are termed ρ^- strains. These lack the genes responsible for oxidative phosphorylation and are therefore incapable of respiratory growth. When grown on solid media the resultant colonies are much smaller than the wild types, and for this reason, these mutants are called petites (see **petite mutants** for more details).

Mobile genetic elements, termed Ty elements, are also present and more than 50 copies have been detected in haploid cells. These elements can move between chromosomal locations and, as a result, the genome can be rearranged.

Based on the total DNA content it has been demonstrated that brewing yeast strains are polyploid or aneuploid (containing multiple or partial multiple chromosomes). Although strains with copy numbers between one and seven have been observed, the majority are triploid or tetraploid. It has been suggested that this is advantageous in that multiple copies of genes involved in key activities such as sugar uptake may give a selective advantage compared to less capable haploid types. Polyploidy tends to suggest greater genetic stability and this may be one reason why such strains were originally inadvertently selected prior to the use of pure cultures.

From a genetic standpoint the genomes of ale and lager strains are distinct. It is generally agreed (albeit with much argument still in progress) that lager strains are hybrids of *S. cerevisiae* and the closely related *Saccharomyces bayanus* (see **yeast taxonomy** for more details), and for this reason, the genome of these hybrids is some 1.5–1.6× bigger than that of ale strains. Chromosomes of lager strains may be derived from each parental type or mosaics with contributions from both. This allows for much diversity in the genome of individual strains. In all lager strains the mitochondrial DNA appears to be derived from the *S. bayanus* parental type.

Brewing yeast strains do not appear to occur in nature, which presumably indicates that they arose as a consequence of the selective pressures present in the environment of an industrial brewery. Since they have a much more ancient lineage, *S. cerevisiae* ale strains were the first to evolve. The creation of lager strains was a much more recent event, probably occurring in Europe in the Middle Ages. Genetic analyses suggest that two distinct hybridisation events occurred, probably in different geographical locations. These equate to the ‘**Saaz yeast**’ and ‘**Frohberg yeast**’ lager types. The former (comparatively weakly attenuating) is associated with former Czechoslovakia and the Danish Carlsberg strains. The latter (strongly attenuating) is found in the Netherlands, non-Carlsberg Danish breweries and North America. It is assumed that the current distribution resulted in part from the diaspora of European brewers. In both

cases it is likely that the non-*Saccharomyces* ancestor was relatively cold tolerant, which provided the hybrid with a selective advantage compared to the other pure *Saccharomyces* parent. Genetically the two lager groupings are distinct and this forms the basis of the argument in favour of two separate hybridisation events. The ale-type ancestor was a brewing strain and different from other non-brewing *Saccharomyces* strains. The evidence suggests that the Froberg subgroup contains almost two relatively intact *S. cerevisiae* genomes plus a single *S. bayanus*-derived fragment, whereas in the Saaz subgroup, the genome contributions of the parental types are roughly equal. It is suggested that the Saaz group arose from a fusion event between haploid ale and *S. bayanus* strains to form a diploid strain that subsequently lost much of the ale strain genome as a result of the low-temperature selective pressures. The Froberg group derived from fusion of parents which comprised a homozygous diploid *S. cerevisiae* and a haploid *S. bayanus*.

Recently it has been reported that a new strain, christened *Saccharomyces eubayanus* and isolated from a forested region of Patagonia, has a genome that is 99.5% identical to the portion of lager yeast genome which is not *S. cerevisiae* in origin. It is suggested that this could be the wild parental ancestor of lager strains which at some point underwent hybridisation with a *S. cerevisiae*-type brewing strain. If this is so the method of transportation from South America to Europe requires explanation!

Yeast giant colonies

A now historical technique used to characterise brewing yeast strains as an aid to identification. Samples of a yeast culture are streaked onto a solid medium, comprising un-hopped malt extract and yeast extract solidified with gelatin, and incubated at 18°C. Plates are larger than usual (15-cm diameter and 2.5-cm depth) and each plate should have no more than five colonies. After approximately 3 weeks characteristic colonies are formed, the morphologies of which are diagnostic. The method is inexpensive and repeatable, providing consistency of media and technique; however, it is too lengthy for the needs of current brewing operations.

Yeast growth and metabolism

The following discussion is limited to brewing yeast strains and perforce is brief and generally restricted to those areas of direct relevance to brewing. Brewing yeasts are heterotrophic facultative anaerobes. More simply put, they are highly versatile and capable of rapidly adapting their genomes to permit growth under a wide variety of conditions including aerobic and anaerobic, and of using a wide variety of substrates to generate energy and new biomass. In addition, they are able to withstand a wide variety of stresses which, with care, renders them suitable organisms to survive within the environment of the modern brewing process.

The conditions under which brewing strains are used are unusual in that, although the medium, wort, is comparatively rich, it is also unbalanced since it contains large concentrations of sugars but relatively smaller concentrations of other essential nutrients. Oxygen is supplied at the start of fermentation in a single dose and thus the yeast must be capable of adapting its genotype and phenotype during the transition from aerobiosis to anaerobiosis. Furthermore, the yeast is commonly recovered from one fermentation and a portion of the crop retained and used to start the next. It follows that yeast must be capable of survival through periods of starvation in the fermenter, at the end of fermentation, and in the storage phase, and then adapt rapidly to growth mode when re-pitched.

Wort is a complex growth medium and yeast reacts to the various compounds present in different ways depending on their nature, their concentration and other prevailing conditions. Some are nutrients, some may be toxic or inhibitory; others fall into both of these groupings depending on their concentration. Some nutrients may be assimilated only under given conditions. The net result is that assimilation of many of the major classes of nutrients tends to be ordered throughout batch growth. This is of relevance to the operation of continuous fermentation processes in that it is usual to have to use multistage systems which separate spatially the steps which occur sequentially in a normal batch fermentation.

Many of the products of metabolism which are excreted by yeast as by-products of growth and which persist in beer are of significance with regard to flavour. An important aspect of fermentation management is to ensure that these various groups of flavour compounds are produced in the desired concentrations. Conversely, yeast metabolism removes from wort many components which are highly flavour active and undesirable in finished beers (see **beer flavour** and associated entries).

Predictably, given the complex nature of wort and the shift from aerobic to anaerobic conditions characteristic of fermentation, yeast have a multiplicity of mechanisms for controlling nutrient uptake. Uptake and efflux of some nutrients and products of metabolism may be via simple or facilitated diffusion. In addition, specific permeases are used which may be constitutive or inducible. A membrane-bound H^+ -ATPase provides the driving energy. Uptake of specific solutes may utilise proton symport or antiport systems, effects which influence the pH of the wort. Permeases for the same compound can be of low affinity (often constitutive and used where the nutrient is relatively abundant) or high affinity (often inducible and used where nutrient concentrations are low). In addition, membranes contain channels which are responsible for the transport of water, some organic molecules such as glycerol and various ions. The latter system controls the efflux of K^+ , which balances the uptake of protons during sugar assimilation. In some cases uptake and the initial stages of catabolism are linked, for example, where glucose is phosphorylated as part of the uptake process.

The outward manifestation of this multitude of systems is an ordered uptake of nutrients which reflects the ability of yeast to assimilate nutrients selectively. The sum total of the assimilation of nutrients from wort and the resultant production of extracellular metabolites represent the change from wort to green beer.

Uptake of sugars is ordered, and although there are strain-specific variations, sucrose is first cleaved to glucose and fructose using a periplasmic invertase. Glucose and fructose are assimilated very rapidly and when these are exhausted, the major wort sugar maltose is utilised followed by maltotriose. Dextrins are not utilised and these remain in beer where they contribute to mouthfeel and fullness. Lager strains contain multiple copies of the genes responsible for maltose uptake (*MAL* genes), probably an evolutionary adaptation which gives such strains an advantage in the conditions encountered in wort fermentation.

The assimilation of nitrogenous compounds is equally complex. There is a broad-specificity amino acid carrier termed general amino acid permease (GAP) and a number of constitutive or repressible high- and low-affinity amino acid permeases which are specific for one or a small group of amino acids. The narrow-specificity permeases appear to be active when the substrates are relatively plentiful. The relative activities of each are modulated according to which amino acids are present. The GAP permease is active when amino acid concentrations are low and

acts as a scavenger. The result is that, as with sugars, uptake of free amino nitrogen in wort is ordered. Group A amino acids (arginine, asparagine, aspartate, glutamate, glutamine, lysine, serine, threonine) are taken up from wort first, followed by Group B types (histidine, isoleucine, leucine, methionine, valine) then members of Group C (alanine, ammonia, glycine, phenylalanine, tryptophan, tyrosine). Proline, the sole member of Group D, is not assimilated supposedly since a repressible mitochondrial oxidase is required for its utilisation. Peptides up to around five amino acid residues may be utilised although more slowly than free amino acids.

Systems are available for the uptake and assimilation of the multitude of other classes of nutrients that yeast cells are capable of utilising. Although too much information is available to include here, there is again a tendency towards ordered uptake which commonly reflects ease of utilisation.

Sulphur can be assimilated by yeast from both organic and inorganic sources. Sulphate is taken up by a specific permease where it is reduced to sulphite and sulphide from where it is incorporated into sulphur-containing organic metabolites. Under some conditions both sulphite and sulphide can accumulate in beer. The latter is a characteristic of the pale bitter ales made in Burton on Trent and reflects the high gypsum content of the local water. The intracellular pool size of S-adenosylmethionine controls uptake of sulphate since when the former is high the genes required for uptake are repressed. Assimilation of exogenous sulphur-containing amino acids results in an increase in the pool size of S-adenosylmethionine and sulphate uptake is abolished. In active mid-fermentation sulphite concentrations in beer remain low because, although the pool of S-adenosylmethionine is low because of depletion of sulphur-containing amino acids via biomass formation, the inorganic sulphur is utilised for other biosynthetic reactions. In late fermentation, a decrease in these other biosyntheses can lead to a late burst of sulphite accumulation. This can be of significance in terms of beer flavour stability because of the ability of sulphites to form adducts with potentially beer staling carbonyls.

Under anaerobic conditions, brewing yeast is auxotrophic for sterols and unsaturated fatty acids. If these are not supplied in the medium molecular oxygen is required for their synthesis. **Yeast sterols** and unsaturated fatty acids are essential for proper membrane function and in brewing fermentations their synthesis occurs during the initial aerobic phase. Subsequent anaerobic growth dilutes the preformed lipids between mother cells and their progeny, and lipid depletion and the consequent lack of membrane competency may be the growth-limiting factors in fermentation. In this sense the quantity of oxygen supplied at the start of fermentation is the parameter that controls growth extent. The quantity of oxygen required for satisfactory fermentation is strain specific. Although imprecise and probably representing a continuum, for ale yeasts, four groups have been recognised: half-air saturated (Group 1), air saturated (Group 2), oxygen saturated (Group 3) and more than oxygen saturated (Group 4), equivalent to *ca.* 8–40 mg/L. Similar differences have been observed for lager strains. The reasons for the differences are obscure, although, in the case of sterols, it is possible that much of the additional oxygen charge needed by the Group 3- and Group 4-type yeasts might be used to synthesise steryl esters, as opposed to the free sterols needed for incorporation into membranes. On the basis of simple stoichiometry less than 50% of the oxygen supplied is used for lipid synthesis. The most abundant sterol and unsaturated fatty acids, respectively, are ergosterol, palmitoleic (16:1), oleic (18:1) and linoleic (18:2). In anaerobic pitching yeast the total sterol content amounts to less than 0.1% of the dry weight. At the onset of the anaerobic phase of fermentation this increases to 0.5–1.0% of the dry weight.

This compares with yeast grown under fully respiratory conditions, such as active dried brewing yeast, where sterol levels may be up to five times greater. This provides an explanation as to why wort oxygenation is not required for fermentations employing reactivated dried yeast.

Brewing yeast contains two potential storage carbohydrates, **glycogen** and **trehalose**. Up to 4% of wort sugars are channelled into glycogen synthesis and this material may account for up to 30% of the cellular dry weight. Trehalose concentrations in cropped brewing yeast are modest, typically less than 5% of the dry weight. Yeast recovered from high-gravity fermentation may contain up to 20% by dry weight, and the conditions used during the preparation of active dried yeast are manipulated to ensure that similar high levels of trehalose are produced. Both glycogen and trehalose are synthesised from glucose 6-phosphate. Both accumulate when growth is restricted by depletion of a nutrient other than carbon and the regulation of formation and mobilisation is complex. The evidence suggests that glycogen is a true reserve material which is used for maintenance during periods of starvation, as occurs in later fermentation and in the interval between cropping and re-pitching. The presence of oxygen stimulates the breakdown of glycogen, and there is much evidence supporting the view that sugar and energy derived from glycogen is used by yeast to support lipid synthesis in the aerobic phase of fermentation.

Trehalose does not appear to be a true storage carbohydrate. It accumulates in yeast in response to applied stresses, and in several organisms it is known that it promotes survival under stressful conditions, such as desiccation, via its ability to stabilise membranes. This explains why high levels occur in active dried yeast and that used for high-gravity fermentations.

The metabolism of brewing yeast is regulated by a number of global control systems which have a large impact on their performance in brewing and on beer composition. These are the outward manifestations of regulation at the enzyme level, generally rapid shifts made in response to sudden changes in external conditions and regulation at the genome level; longer-term global shifts in metabolism which persist over some time and by implication are triggered in response to large changes in external conditions. Many of these global control systems used metabolic cascades in which changes in the concentrations of relatively simple nutrients set in train complex sequences of steps, termed metabolic cascades, in which the up- and down-regulation of multiple sets of genes occurs.

For example, in the presence of glucose the transcription of several genes is repressed. In addition, the gene products of many of these genes are inactivated by post-transcriptional modification. These effects are termed glucose repression and glucose (catabolite) inactivation, respectively. Other variants of these terms exist which are either more general or relate to the effects of other metabolites. Examples would be the more general sugar repression (since other sugars may elicit similar effects although perhaps to a smaller degree) or nitrogen inactivation. Typically the control systems have a hierarchical dimension where a given set of exogenous conditions may override the effects of others, which allows a more subtle global regulation of metabolic activity.

There are several outward manifestations of these effects. They explain the ordered uptake of many nutrients such that the enzymes for maltose assimilation are not active when glucose is present. Similar mechanisms exist with regard to nitrogen assimilation such that the presence in the medium of certain nitrogen sources represses the transcription of genes responsible for the uptake of others.

In the presence of oxygen yeast can develop a fully respiratory metabolism where energy, in the form of ATP, is generated via the electron transport chain. However, in the presence of repressing concentration of a sugar such as glucose, metabolism is always fermentative and ATP is formed as a result of substrate-level phosphorylation via glycolysis, and redox control is maintained via the formation of ethanol, to a lesser extent glycerol and possibly many flavor-active compounds such as **vicinal diketones** and **higher alcohols, yeast and beer flavour**. This process overrides the presence of oxygen. In this respect all brewing yeast strains are strongly Crabtree positive (see **Crabtree effect**) and, even under permissive conditions, the dissimilation of no more than 10% of sugars is accounted for via respiration. The formation of ethanol as a major end product might confer some selective advantage because of its antibacterial properties. In addition, it can be viewed as a carbon store since in the presence of oxygen and in the absence of repressing concentrations of sugars it may be utilised as a carbon source. The change from repressing conditions (fermentation) to derepression (respiration) is termed **diauxie** and involves the coordinated expression of a multitude of genes as well as the repression of others. Yeast cells with a repressed phenotype lack fully developed mitochondria and peroxisomes. The TCA cycle becomes branched owing to the lack of 2-oxoglutarate dehydrogenase.

See **fermentation**.

Yeast head

The head is the layer of yeast, entrained solids and CO₂ bubbles that forms at the surface of wort during fermentation. The term is commonly modified with other adjectives to describe the appearance of the head and by inference the progress and vigour of the fermentation.

For example, see **rocky** (cauliflower) **yeast head**, *kräusen*.

Yeasting

Inoculation of wort with a predetermined concentration of yeast cells in order to initiate fermentation, a US term synonymous with pitching.

See **pitching yeast**.

Yeast intracellular pH (ICP test)

A yeast vitality test based upon the measurement of intracellular pH. Several variations of the method have been developed, although all are based on the use of pH-sensitive fluorescent dyes. Typically a dye such as an esterified form of 5,6-carboxyfluorescein diacetate is used, which is more easily taken up by viable cells compared with free fluorescein. Intracellular esterases cleave the molecule to yield the active fluorophore, and the pH can be monitored using spectrofluorimetry, either with a stand-alone instrument or in conjunction with **flow cytometry**.

The relation to vitality is based on the assumption that actively metabolising cells require to extrude protons in support of the symport transport reactions which fuel glycolysis. Proton efflux enables the cell to maintain a desired close to neutral intracellular pH. Should the latter deviate from expected values this is indicative of cells with compromised physiology.

See **yeast vitality**.

Yeast line

Yeast line is a term used to describe a culture of brewing yeast which is in use within a brewery. Typically this will be derived from a new culture of defined purity and composition introduced

into the brewery via the process of **yeast propagation** and then used in a sequence of serial pitchings, fermentations and croppings.

See **serial fermentation**.

Yeast morphology

There is considerable diversity in the shapes of individual yeast cells belonging to different genera. In the case of *Saccharomyces* individual cells are spheroidal or ellipsoidal, occurring singly or in pairs, short chains or small clusters. The ratio of long and short axes is of the order of 1.4:1. Cellular volumes are approximately $50\text{--}500\ \mu\text{m}^3$, and the dimensions of the long and short axes are $10.5\text{--}20\ \mu\text{m}$ and $2.5\text{--}4.5\ \mu\text{m}$, respectively.

The average cellular volume is characteristic for any given strain but shows much variation depending on external conditions and stage in the growth cycle. Thus, the cell wall is relatively flexible and this feature accommodates short-term fluctuations in volume as occurs, for example, when pitching yeast slurries, held in beer, are transferred to wort. This change in osmotic environment results in a transient increase in cell volume. Reductions in volume occur when cells are starved as a result of dissimilation of carbon stores such as **glycogen**. The latter can account for up to 40% of the total cell dry weight. For example, during the interval between cropping and re-pitching, the average volumes of cells have been observed to decrease by up to 20%. As yeast progress through the cell cycle growth-related fluctuations in cellular volume occur. During the budding phase the average volume decreases by up to 30%. There is a rough correlation between cell size and the generational age of individual cells. In one study virgin cells had a mean volume of $150\ \mu\text{m}^3$. After some 20 rounds of budding when cells were reaching the end of their typical lifespans, the volume had increased to approximately $850\ \mu\text{m}^3$. Brewing yeast cells are larger than laboratory strains, a consequence in the case of lager types of polyploidy.

Yeast nitrogen base (YNB)

A yeast nutrient medium which contains all essential nutrients other than a nitrogen source. It comprises a cocktail of vitamins and metal salts but with no principal carbon or nitrogen source. The latter are added as desired to make a complete medium suitable for the growth of selected organisms. For example, the addition of a nitrogen source and dextrin provides a medium suitable for detecting yeast with amyolytic activity.

Yeast nutrition

Yeast requires aqueous conditions for growth to proceed. The amount of available water (water activity) if too low can limit growth. This factor is related, in some ways, to the inverse factor of concentration of dissolved molecules (osmolality). This can be of significance where very concentrated worts are used in **high-gravity brewing**. The lower limit, in terms of water activity, at which yeast can grow, is determined genetically. Apart from the relevance to high-gravity brewing there is further significance in brewing in that highly osmotolerant strains such as *Zygosaccharomyces bisporus* can cause the spoilage of very concentrated sugar syrups.

Yeasts can utilise a wide range of organic nutrients. The precise spectrum that can be assimilated is of diagnostic significance. *Saccharomyces* strains can use several simple sugars but not pentoses. The precise range is strain specific. Rather more can be assimilated under aerobic conditions compared with anaerobic conditions. Brewing strains can use simple di-

tri- and tetrasaccharides but not dextrans or starches. Conversely, some **wild yeasts** can utilise dextrans and, in consequence, a symptom of some wild yeast wort infections is **super-attenuation**. There are some differences between lager and ale strains. The former possess multiple copies of the *MAL* genes responsible for maltose assimilation and in consequence tend to use this sugar more rapidly compared to ale types. Lager strains have α -D-galactosidase activity and can utilise the disaccharide melibiose, whereas ale strains cannot. Ale strains have a higher cardinal growth temperature (*ca.* 37–40°C) compared with lager strains (*ca.* 31–34°C).

Yeast can grow where ammonia is the sole source of nitrogen but not nitrate or nitrite. Several organic sources of nitrogen can support growth including amino acids, peptides, amines, pyrimidines and purines. As with sugars, the spectrum of organic nitrogen compounds capable of supporting growth can be of diagnostic significance. Proteins are not assimilated. Sulphur-containing amino acids are used as a source of this mineral, but glutathione and inorganic sources such as sulphate, sulphite, thiosulphate and even elemental sulphur can be utilised. Phosphorus is assimilated in the form of organic or inorganic phosphate. Several minerals, typically at concentrations less than 10 μ M, are essential nutrients and include B, Ca, Co, Fe, K, Mo, Mn, Mg, I, and Zn. All of these are provided in a typical wort with the exception of Zn, a proportion of which is removed as an insoluble precipitate in the brewhouse. Essential growth factors include biotin, thiamine, nicotinic acid, pyridoxine, *p*-aminobenzoic acid and pantothenic acid. The precise growth factor requirement is strain specific.

Various lipids can be assimilated. Of significance in brewing are unsaturated fatty acids and sterols. Brewing yeasts have an obligate requirement for these for anaerobic growth. They can be assimilated from wort, which typically contains small concentrations of each, but more usually they are synthesised in the aerobic phase of fermentation. Cell proliferation in the subsequent anaerobic phase of fermentation dilutes these lipids between mother and daughter cells, and via this mechanism oxygen is the growth-limiting substrate in many brewing fermentations. Brewing yeast cannot assimilate exogenous sterols under aerobic conditions, a phenomenon termed aerobic sterol exclusion.

Yeast oxygenation

The process, also known as yeast pre-oxygenation, in which pitching yeast is subjected to treatment with air or oxygen with a view to improving fermentation performance. The techniques have been practised in some form for many years, particularly in traditional German brewing, where it was used to provide a more vigorous fermentation with a shorter lag time when oxygenated yeast was pitched into aerated wort. The more recently developed process differs in that it totally replaces wort oxygenation. Cropped yeast, which has impaired membrane function as a result of depleted sterols and unsaturated fatty acids, is exposed to a controlled concentration of oxygen, at a defined temperature (usually around 20°C) and for a given period of time, typically 4–6 hours. During this treatment the yeast synthesises sterols and unsaturated fatty acids and proper membrane function is restored. The carbon and energy for these biosyntheses are provided by the concomitant mobilisation of glycogen reserves laid down during the previous fermentation. No additional exogenous supply of carbon is necessary. The yeast is pitched into anaerobic wort. The advantages of the approach are that sterol and unsaturated fatty acids are produced in consistent quantities such that yeast growth in fermentation is controlled by the selection of the appropriate pitching rate. The use of anaerobic wort avoids

excess oxygen, not utilised by yeast, being consumed in undesirable beer staling wort oxidation reactions. Oxygen tension during treatments is controlled at close to air saturation (*ca.* 8 mg/L) to avoid potential damage as a result of the generation of oxygen radicals.

Ensuring intimate contact between oxygen and yeast at a commercial scale is daunting. Equipment requires excellent oxygen transfer properties in order to guarantee an efficient process. The Meura company [<http://www.meura.com> (last accessed 13 February 2013)] has developed a yeast oxygenation system in which the gas is delivered via a membrane sparger located in an external pumped loop attached to an attemperated tank holding the reservoir of yeast. The company claims that the use of the system provides a shorter and more consistent fermentation performance.

Yeast propagation

The process in which, usually, a sequential series of cultures of brewing yeast strains of increasing volume, of defined purity and identity, are grown to a volume and cell concentration sufficient to pitch a production-scale fermentation.

Although all brewing fermentations yield an excess of yeast in quantities sufficient to start a number of subsequent fermentations, it is considered prudent by most brewers occasionally to introduce a new culture into the brewery. This is particularly the case in modern high-capacity intensive fermentations where some degree of deterioration of yeast with prolonged serial re-pitching is inevitable. Thus, repeated serial fermentation increases the risks of selection of genetic variants such as petites and/or the fraction of the crop containing the cells which are the oldest or with a compromised physiology. In addition, crops become increasingly contaminated with non-yeast solids, which can result in pitching rate errors, and the risks of microbial contamination are elevated.

Propagation occurs in two phases. The first takes place in the laboratory and begins with the preparation of a working culture, itself derived from the master culture (see **yeast supply** for a full description). The laboratory phase comprises a number of cultures of increasing volume initially using a standard nutrient medium such as yeast extract, peptone, glucose (YPG). Standard laboratory microbial procedures and apparatus are used. Cultures are incubated at room temperature and in the later stages, oxygen, in the form of air, is provided. Good rates of oxygen transfer to the growing cells are provided by the use of flask shakers or by agitation and direct addition of sterile air via sinters. The inoculation of each stage in the process represents the greatest risk of accidental contamination and good aseptic technique is essential. A typical regime would involve going from a slope, using the whole of the culture, into 1×10 mL YPD, followed by 1×100 mL YPD, 1×1 L and finally 1×20 L. For reasons of economy the terminal 20-L stage may use wort recovered from the brewery and sterilised in the laboratory. The apparatus used for this stage usually also serves as the receptacle in which the culture is transported into the brewery and therefore is constructed from stainless steel for robustness and is fitted with a means of making an aseptic connection to the brewery tank to facilitate inoculation of the first brewery propagation vessel (e.g. see **Carlsberg flask**).

The brewery phase comprises one or more tanks of increasing size, the number and capacity of which are chosen to suit the needs of the particular fermentation plant. Wort is used as the growth medium. The propagation plant is designed to provide conditions which are optimal

for yeast growth. It follows that the growth of potential contaminants would also be favoured. Tanks must be built to high standards of hygiene and must be supplied with a one-trip CIP system and preferably a steam supply for sterilisation. Gas inlet and outlet ports must be fitted with sterile filters and sample taps and inoculation ports should be steamable to allow aseptic operation.

A traditional brewery propagation plant usually comprises a series of tanks which in effect are little more than hygienic fermenters in that little provision is made for the addition of air or oxygen. As such terminal cell counts are little more than those obtained in fermentation (ca. $60\text{--}100 \times 10^6$ cells per millilitre). In addition, at each stage, it is common to ramp the operating temperature down to the fermentation temperature, the view being that it is necessary to condition the yeast so that it adapts to the conditions to which it will be exposed in fermentation. The consequence is that several sequential stages are required with small step-up ratios, usually not more than 1:5. Using such plant the brewery stage of propagation can last for several weeks. Even so, under-pitching of the first fermentation is common and suboptimal first fermentation plus blending of the first beers is the accepted price. A common work-round is to have small fermenters to take the new culture or to partially fill the standard bigger vessels and after 24 hours' fermentation add another aliquot of wort.

As a means of shortcutting these lengthy procedures **assimilation tanks** can be used. These are propagation vessels in which a proportion of the culture is retained after transfer of the bulk. The residual culture is mixed with fresh wort and a further period of incubation is carried out to allow the cell count to be replenished. This approach undoubtedly saves time but has the inherent risk that it provides ideal conditions for the selection of variants.

Modern commercial brewing characterised by the use of very large vessels fermenting high-gravity worts often at relatively high temperatures has increased the stress levels to which yeast is exposed. For these reasons the number of permissible generations of serial fermentation may be limited to less than five or fewer. This has increased the pressure on propagation and has fuelled the need for more efficient and high-yielding plants. This can be achieved by the use of relatively high operating temperatures (up to 30°C) and the provision of continuous oxygenation. High rates of oxygen transfer are provided by the use of in-tank agitation systems designed to deliver high $K_L a$. Feed-back systems monitor dissolved oxygen concentration and regulate addition and agitation rates to ensure constant positive but low levels of aerobiosis. By using such plant with a typical high-gravity malt wort, a terminal yeast count of $180\text{--}220 \times 10^6$ cells per millilitre can be achieved in 24–36 hours at an operating temperature of $20\text{--}25^\circ\text{C}$. Step-up ratios of at least 1:10 are possible and a simple two-tank seed vessel and principal growth vessel (operating volume of around 150 hL) is adequate to supply 1500- to 2000-hL fermentation vessels. Using such a system the brewery phase can be completed within 5 days. The use of wort as the feedstock and cessation of oxygenation when the primary growth phase has finished ensure that the yeast has a repressed physiology, similar to that cropped from a normal fermentation, albeit with enhanced levels of sterols and unsaturated fatty acids.

Y

Yeast redox control

Metabolic mechanisms which underpin some key aspects of cellular metabolism and which are relevant to the formation of many of the major products of yeast metabolism during fermentation, including ethanol.

Reactions involved in the catabolism of wort carbohydrates are catalysed by enzymes and at certain stages with the involvement of pyridine dinucleotide coenzymes, notably nicotinamide adenine dinucleotide (NAD⁺). The latter functions as an electron acceptor in oxidation reactions by accepting two hydrogen atoms from the substrate, one of which remains bound to the coenzyme as a hydride ion and the other is released. The product is the reduced coenzyme NADH. Since the cell has a finite pool of NAD⁺, it must replenish the oxidised form in order for the catabolic reactions associated with growth and energy generation to continue. This is termed redox balance and is accomplished by further reactions in which a substrate is reduced and NAD⁺ is thereby re-oxidised. In a fully aerobic respiratory metabolism NADH is re-oxidised in the mitochondrial electron transport chain. In brewing fermentations this route is not possible because the necessary genes are repressed and so other routes must be found. The majority of the necessary redox balancing is accomplished by the reduction of acetaldehyde to ethanol via alcohol dehydrogenases; however, since some carbon devolving from glycolysis is utilised in biomass formation additional routes are needed. There are many potential routes and several occur in the terminal steps of pathways that lead to the formation of important beer flavour compounds. Examples are the formation of higher alcohols via the reduction of precursor aldehydes, the reduction of diacetyl to acetoin and 2,3-butanediol, and the formation of glycerol from dihydroxyacetone.

See **yeast-derived flavour compounds**.

Yeast sexual cycle

Brewing yeasts are members of the Ascomycetae, which, by definition, under appropriate conditions, can undergo a sexual cycle the culmination of which is meiosis and the formation of ascospores borne in the fruiting body, the ascus. In fact, brewing strains rarely exhibit a sexual cycle probably as a consequence of their somewhat complex states of ploidy (see **yeast genetics**).

Non-brewing wild strains of *S. cerevisiae* may have a sexual cycle and this is initiated by conjugation between two haploid cells of opposite mating types. The latter produce pheromones, consisting of short peptides and termed *a* and α , and mating occurs in response to the binding of these to specific receptors on the cell walls of opposite mating types. For obvious reasons the mating types are termed MAT α and MAT*a*. The mating process is regulated by a MAPK signal transduction cascade [see **mitogen-activated protein kinase (MAPK) cascade systems**].

Binding of the initiator pheromone causes cells to arrest in the G₁ phase. Cells develop projections (schmoos) which grow and fuse with those of the opposite mating type. The fusion of plasma membranes provides the opportunity for nuclear fusion and formation of diploid cells. This diplophase can persist via subsequent growth and mitosis. Under conditions of nutrient starvation the diploid cells undergo meiosis and four haploid ascospores are formed, which will germinate in a suitable medium.

Mating type is controlled by an allele termed HO. Cells which lack this allele and which do not come into contact with cells of the opposite mating type develop into stable haploid clones via mitotic proliferation. HO⁺ cells are capable of changing the mating type. This does not occur in virgin daughter cells, but the ability is acquired once budding has occurred. The switch occurs in around 60% of such cells and allows mating to occur between siblings. Mating type is determined by the MAT locus on chromosome III. The latter possesses two silent loci

situated on each side of the centromere. These carry mating information, MAT α (HMR, right-hand side of the telomere) and MAT α (HML, left side of the telomere). Under some circumstances there is gene exchange between the MAT and silent HMR and HML loci, and the silent genes can be expressed. This can result in change in the mating type and the cells of the opposite type will fuse and develop diploids.

Yeast shock excretion

Phenomenon observed with brewing yeast where a variety of metabolites pass rapidly out of cells and into the medium following a shift from one medium to another, for example, as might occur when yeast held in barm ale is pitched into wort. The process can be observed when the new medium is simply water but is more pronounced in the presence of an exogenous fermentable sugar such as glucose or maltose. The effect produces acidification of the medium, as a result of extrusion of protons. The organic products are mainly amino acids and within 2–4 hours the bulk of these are reabsorbed. Other metabolites such as various nucleotides persist in the medium, and it has been suggested that these might make subtle contributions to beer flavour.

The effect is used as the basis of **yeast vitality** tests under the generic name **acidification power test (AP test)**. The physiological basis is not known, but it may simply represent a transient loss of membrane integrity when anaerobic pitching yeast, which by definition has impaired membrane function, is transferred to a new medium.

Yeast slurry analysis

In the majority of modern commercial breweries fermentation is initiated by the addition of yeast in the form of a slurry of cells suspended in beer. In order to calculate yeast pitching rates it is necessary to measure the concentration of yeast. This may be accomplished in a number of ways. The direct method is to determine the viable cell concentration, expressed as millions of cells per millilitre or gram of slurry. With this figure and a knowledge of the desired suspended viable yeast count in the pitched wort the quantity of slurry required can be calculated in terms of mass or volume. For example, the pitching yeast slurry contains 500×10^6 viable cells per gram and a pitching rate of 15×10^6 cells per millilitre of wort is required and the wort volume is 1500 hL.

The quantity of yeast slurry needed is

$$\frac{15 \times 10^6 \times 1000 \times 100 \times 15,000}{500 \times 10^6 \times 1000} = 4500 \text{ kg.}$$

Yeast cell counts are typically made using a light microscope and a **haemocytometer** using samples of slurry stained with a vital dye such as **methylene blue** in order to allow the viability and the viable yeast concentration to be determined. A representative sample of yeast slurry of known weight or volume is diluted and the viable cell content determined.

If the relationship between yeast count and yeast biomass, expressed either as a function of mass or volume, is known it is possible to simply determine the solid content of the yeast slurry. Representative duplicate samples of yeast slurry are decanted into centrifuge tubes, typically around 20 mL, and the precise volume or weight determined. The slurry is centrifuged, the barm ale decanted and the weight of packed yeast recorded. With these two figures the average solid content expressed as a percentage weight per weight or weight per volume

is determined. Using this figure the quantity of slurry needed to achieve the desired pitching rate can be computed. Commonly the relationship between yeast cell number and yeast mass or volume is assumed, for example, the common brewer's maxim that a pitching rate of 10 million cells per millilitre is roughly equivalent to 1 lb per barrel (*ca.* 2.8 g/L) pressed yeast.

Determination of the viable cell count per unit mass of yeast slurry is probably the best approach since it is independent of the non-yeast, trub content of yeast slurries; however, this needs to be tempered by the fact that the repeatability of microscopic cell counts is poor.

Automated yeast slurry analysis

Yeast slurry analyses can be automated and performed in the laboratory or online. Automatic counting devices such as the Coulter counter are simple particle counters which are useful where a rough analysis is needed such as a green beer cell count. They cannot distinguish viable from non-viable cells and are therefore less useful for analysis of pitching yeast slurries. Some online devices use optical light scattering measurements to quantify yeast concentrations in pitched worts. The operating range of these devices is not sufficient to allow direct analysis of concentrated yeast slurries, but they can control yeast dosing by the control of a set-point of turbidity in the pitched wort. Dual-beam systems also detect the turbidity in the un-pitched wort to allow correction for the presence of non-yeast solids.

The Aber system [<http://www.aber-instruments.co.uk> (last accessed 13 February 2013)] provides both off- and online yeast slurry analysis. The device makes use of the dielectric properties of yeast cells suspended in a conducting medium such as wort or beer. Yeast cells subject to a signal of radiofrequency wavelength act as capacitors, and after calibration the measured capacitance can be related to the usual measures of yeast concentration. The major advantages of the Aber instruments are that they have a very wide operating range allowing reliable measurements to be made in pitched worts and concentrated yeast slurries. More importantly, non-viable cells with a disrupted membrane do not act as capacitors and therefore do not contribute to the signal. Measured values for viable yeast concentration correlate very well against figures obtained via methylene blue staining. This means that separate viability measurements cannot be performed. Since calibration has to be made using yeast slurries in which the viable yeast concentration is measured by conventional means, as described earlier, the absolute precision cannot be better than these. On the other hand, the repeatability is excellent.

Yeast sphaeroplasts

Yeast cells which have had their cell walls removed by exogenous hydrolysing enzymes in the presence of an osmotically stabilising medium such that lysis does not occur. Sphaeroplasts can be used in genetic modification protocols.

See **yeast strain improvement**.

Yeast sterols

Sterols are lipids which are essential for proper control of cell membranes where with phospholipids they regulate membrane fluidity. They can be assimilated from the growth medium and incorporated into membranes or synthesised *de novo* from sugars. The latter requires the presence of molecular oxygen. The requirement for oxygen at the start of fermentation is explained in that it is partially used for the synthesis of sterols and unsaturated fatty acids (see **yeast growth and metabolism**).

In brewing yeast **ergosterol** is the most abundant sterol and accounts for around 90% of free sterols found in the plasma membrane. Smaller concentrations of lanosterol, zymosterol, 4,4-dimethylsterol, ergosta-7,22-dienol and dihydroergosterol are also found, although much of these may be simply intermediates of ergosterol synthesis. Smaller quantities of sterols are found in other cellular membranes and esterified forms occur in lipid granules, associated with triacylglycerols. Sterol esters may serve as a sterol store.

In cropped brewing yeast, the total sterol content is low, around 0.1% of the cell dry weight. At the end of the aerobic phase of fermentation this increases to around 0.5–1.0% dry weight. Derepressed respiratory yeast cells typically contain five times more sterol compared with anaerobic repressed cells.

Sterol synthesis proceeds via acetyl-CoA, leading at first to the formation of **squalene** in steps that require three molecules of ATP and reducing power in the form of NADPH. The early parts of the pathway are shared with steps leading to the formation of haem and ubiquinones. The epoxidation of squalene is the first committed step that requires oxygen. Subsequent rearrangements involving cytochrome P450 may also require oxygen.

Yeast storage vessel

A yeast storage vessel (YSV), also known as a yeast collection vessel (YCV), is used for the temporary holding of yeast slurry in the interval between cropping from the fermenter and re-pitching.

In the majority of commercial breweries yeast is cropped from a fermenter in the form of a concentrated slurry (typically 20–50% wet w/v, equivalent to *ca.* $0.4\text{--}1 \times 10^9$ cells per millilitre) in which the suspending fluid is beer. Commonly it is held in this form for a short period of time before being used to inoculate (pitch) the next fermentation. The function of the storage vessel is to ensure that during this interval the yeast remains in a condition in which it is fit for use. In other words, it meets necessary standards of purity, viability and physiological condition, which will ensure satisfactory fermentation performance when it is pitched into a subsequent fermentation.

The essential features of a modern YSV are shown in the accompanying diagram.

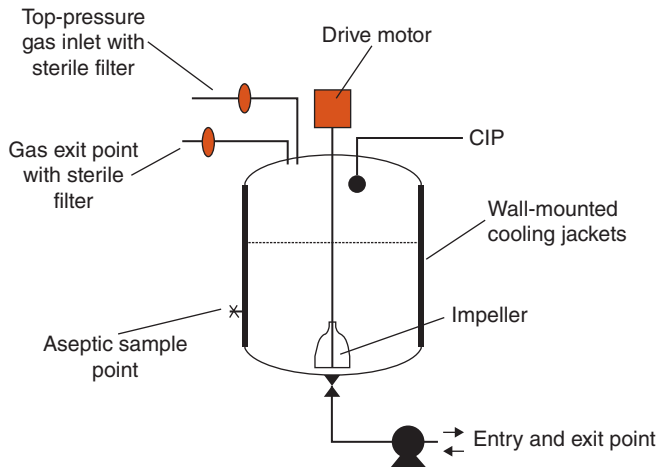


Diagram showing the features of a yeast storage vessel

They are constructed from stainless steel, of cylindrical design with dished tops and bottoms and are fitted with wall-mounted cooling jackets with sufficient capacity to hold the temperature at approximately 3°C ($\pm 1^\circ\text{C}$). The vessels are designed to maintain the holding temperature and not to cool warm yeast. Where yeast is cropped at relatively warm temperatures it is necessary to provide an external in-line chiller. In order to promote efficient attemperation a system of gentle agitation is also provided. This should be designed such that the agitation is sufficient to prevent yeast settling out but not too vigorous to generate excessive shear forces. Paddle-type impellers fitted to a top-mounted electrical drive system meet this need. A sample point mounted close to the base of the vessel allows removal of yeast for analysis. Since good hygiene is essential for the correct operation of these vessels the sample tap should preferably be of the type which can be sterilised by steam prior to use. In order to prevent ingress of microbes the vessels are top pressured with an inert gas such as nitrogen or CO₂. It is important to exclude air in order to prevent changes of yeast physiology such as dissimilation of glycogen reserves coupled to sterol synthesis, which would have the potential to produce inconsistent performance when the yeast is pitched into a subsequent fermentation. The gas exit point and top-pressurisation system must be fitted with appropriate sterile gas filters.

The majority of breweries have multiple YSVs, the individual sizes of which are chosen to meet the needs and capacity of the brewery. It is usual to size the vessels such that they can accommodate the total crop, which is required to be retained from a single fermentation. This arrangement allows individual yeast lines of varying generational ages to be segregated from each other.

Yeast strain

Term used to denote a specific variety of yeast. The term strain is used to denote the smallest taxonomic unit in which the possession of a distinct genotype can be demonstrated and is a subdivision of the species (see **yeast** for more details). In brewing terms many thousands of individual yeast strains are used and commonly they are the proprietary yeast types used, and jealously guarded, by individual brewers. Although all have genotypes which are sufficiently similar to allow them to be classified into the larger species groups (either *S. cerevisiae*, which include ale strains, or *Saccharomyces pastorianus*, lager strains), very small differences in genetic make-up can be detected, and when these are expressed, a phenotype is produced which provides a unique pattern of detectable and reproducible brewing properties.

Nomenclature at the strain level is unregulated and commonly either a name may be used which relates to the proprietary company, the beer quality for which they are used to produce, a description of a major brewing characteristic or simply a combination of letters and numbers.

Yeast strain improvement

Techniques which allow the isolation or generation of yeast strains with desirable brewing properties. The advent of the use of pure brewing yeast strains, pioneered by Hansen, provided a framework in which the properties of individual strains could be compared and contrasted, and this led to an appreciation that there was considerable diversity. It has always been possible to simply choose a brewing strain which possesses desirable properties; however, directed strain improvement provides a more focussed route to this end.

Properties which may be looked for relate to fermentation performance and beer quality. Examples include more efficient and/or more rapid conversion of extract into ethanol, the

ability to produce and survive in very high-gravity worts and to produce and tolerate the resultant high concentrations of ethanol, the ability to utilise a particular spectrum of carbohydrates, possession of flocculation characteristics which suit the type of fermentation and fermenter being used, the ability to outcompete potential contaminants and production of a particular spectrum of yeast-derived flavour compounds.

New strains can be identified by looking for natural variants within a population which have the desired property. The search can be made less hit and miss by the use of mutagenic agents and screening for desired variants. The development of genetic engineering extends the possibilities by providing a vehicle in which exogenous genes, from any source, can be introduced into brewing strains and thereby introducing characters that would not be normally be available.

Particular fermentation systems tend to be selective for certain yeast properties. For example, early crops formed in deep cylindroconical fermenters tend to be the most flocculent. Selection of this fraction of the crop can be used as a method of natural selection if a more flocculent strain is desired (and vice versa). Similar approaches can be used to select for other natural variants. Standard mutagens such as UV radiation have been used successfully to increase the frequency of natural variation and thereby to generate increased numbers of variants.

Classical mating techniques are problematic with brewing yeasts because of their polyploid/aneuploid genome, and the generation of hybrid diploids from the fusion of haploid spores is very difficult to achieve. The technique of rare mating has been used with some success. This method uses strong selective pressures to isolate rare hybrids. Typically an excess of usually respiratory-deficient parental strains is mixed with respiratory-sufficient haploid auxotrophs. Rare hybrids are selected as respiratory-sufficient prototrophs.

The technique of sphaeroplast fusion in which osmotically stabilised cells stripped of their cell walls are made to fuse by the application of a strong electric field has been used to form hybrids in which selected characters can be transmitted from donor to recipient cells.

Recombinant DNA genetic manipulations rely on the introduction of selected genes into recipient cells to generate individuals with altered genomes. Typically the foreign DNA is attached to a plasmid which also bears a dominant marker which allows selection of target cells. This approach is necessary because of the polyploid nature of the host brewing strains. Commonly used dominant markers include resistance to copper, herbicides such as sulphometuron-methyl and various antibiotics such as chloramphenicol and gentomycin. Multi-copies of the plasmids bearing genes of interest may be inserted into target cells and left in this form or they may be integrated into yeast chromosomes to provide more stable transformants.

Genetically manipulated brewing strains have been developed which are able to utilise dextrans (super-attenuating), possess killer factors, produce less than normal concentrations of diacetyl, possess β -glucanase activity, have constitutive maltose assimilating enzymes, produce reduced levels of H_2S and increased production of SO_2 . The current public aversion to the use of a genetically engineered organism for food production has resulted in a situation in which many major brewers have such strains but are not currently exploiting them commercially.

Yeast stress response

A term applied to yeast strains which describe the response of the genome and phenotype to applied stresses.

The commercial brewing process is inherently stressful to yeast. Examples include exposure to rapid changes in temperature (both upwards and downwards), low pH, high barometric pressure, low water activity, high osmotic pressure, exposure to high levels of ethanol shifts from anaerobiosis to aerobiosis (and the reverse) and periods of starvation. Modern brewing practices such as the use of very large batch sizes, very high-gravity worts and elevated fermentation temperatures exacerbate many of these stresses. Failure to manage these stresses can result in losses of yeast viability with concomitant undesirable effects on fermentation performance and beer quality.

Brewing yeast, in common with many other cells, are able to adapt their phenotypes in response to sudden changes in external conditions. Part of these responses is the ability to adapt the phenotype so that the cells are better able to survive stressful conditions.

The ability to withstand stress is to some extent strain specific and in absolute terms there is considerable variation. However, all strains exhibit a common stress response. Application of a sub-lethal stress triggers changes which result in the cellular adaptation such that the cells exhibit greater resistance to that and other stresses. The latter observation provides evidence that several different external triggers can elicit a common response.

When subject to an abrupt change in external conditions the cells typically move into a phase of apparent inactivity where growth ceases. During this time the adaptive changes occur, which constitute the stress response. The most studied response is that which occurs when cells are subject to a non-lethal heat shock. During a period of growth arrest some 70 heat shock proteins (hsps) are synthesised. Growth recommences and the hsps persist, and during this time the cells exhibit higher thermo-tolerance compared with the non-shocked cells. The functions of the hsps are mainly unknown; however, some of them are enzymes that repair partially denatured proteins, the ubiquitin system is activated, which degrades totally denatured proteins, and **trehalose** synthesis (a potent membrane stabiliser) is up-regulated.

A specific stress response element (STRE) has been identified in many genes which are involved in various stress-protecting duties. Some of these are specific for individual stresses; others are part of a common stress response. It appears that yeasts possess sensing systems which identify changes in external conditions. Where these changes are stressful specific genetic responses are elicited, which via signal transduction pathways feed into a common stress response mechanism. These responses are transmitted through the cell using mitogen-activated protein kinase (MAPK) cascades.

Yeast supply

The processes used to ensure that breweries have a timely supply of pitching yeast of the correct strain, of guaranteed purity, in an appropriate physiological condition and in the correct quantity.

Several levels of sophistication are possible depending on the nature of the brewery:

- (1) perpetual serial fermentation, cropping, brewery storage and re-pitching.
- (2) periodic supply of bulk pitching yeast slurry or cake from another brewer
- (3) third party supply of **active dried yeast** used in one-trip fermentation

- (4) third party supply of bespoke bulk culture of pitching yeast slurry
- (5) third party supply of pure laboratory cultures for in-house propagation
- (6) in-house storage of one or more proprietary yeast strains supplied to parent or group breweries for propagation.

Ultimately, apart from the perpetual serial fermentation approach, all supply systems share common features. These are

- (1) preservation of master cultures
- (2) recovery from storage
- (3) confirmation of strain purity and identity
- (4) preparation of working culture
- (5) laboratory propagation
- (6) brewery propagation.

Culture preservation and recovery

The master culture is one of guaranteed purity and identity and which when used in brewing has desired brewing properties. Master yeast cultures must be stored in a way that maintains viability and ensures freedom from contamination. The latter is achieved using appropriate containment and conventional aseptic technique. Viability is maintained by reducing metabolic activity. This can be achieved by storage at low temperature and/or by removal of cellular water. Several methods are used of varying efficacy. Cultures may be stored, usually on nutrient media solidified with agar, at 2–4°C or better at –80°C with a layer of oil covering the growing yeast to exclude air. Cultures may be freeze-dried (lyophilised) in which intracellular water is removed by sublimation by freezing under vacuum and the resultant powder is sealed in a glass vial. Freeze-dried cultures can be stored at cool temperatures for several months and after recovery yield viable cells. Although this method of preservation was very widely used, it is now known that overall viabilities may be very low, and in the case of brewing yeast strains the drying process may cause the generation of genetic variants. The gold standard method of preservation relies on storage under liquid nitrogen. Providing correct procedures are followed regarding the preparation of the culture and the method of freezing, cryopreservation in liquid nitrogen effectively provides an indefinite method of storage.

Cultures stored at refrigerator temperatures on solidified nutrient media do not require any special procedure for recovery; however, for the purposes of preservation a portion of the culture should be used to seed fresh medium approximately every 3 months. Freeze-dried or liquid nitrogen cultures are transferred aseptically into a sterile liquid nutrient medium and are incubated to produce an intermediary culture.

Confirmation of purity and identity

The purity of the intermediary culture is assessed using conventional microbiological techniques. A variety of differential media are used to check for the presence of potential bacterial and wild yeast contaminants. Typically streaking out onto a general yeast nutrient medium such as **WLN medium**, solidified with agar is used to check that the resultant colonies are uniform in appearance and have a colour and appearance characteristic for the particular strain. Definitive proof of identity is guaranteed by **genetic fingerprinting** techniques, the results of which are compared with historical records of that of the master culture.

Working cultures

The intermediate culture is used to inoculate working cultures which typically take the form of slopes (or slants). These are small glass tubes or bottles which contain a yeast nutrient medium solidified with agar. Whilst the medium is still molten the tubes are inclined such that when solid the surface area for yeast growth is maximised. After incubation for a few days at room temperature the slope cultures are stored at 2–4°C.

Propagation

The working culture is used to supply the initial inoculum for a series of serial cultures of ever-increasing volume, first within the laboratory and then in the brewery, with the aim of generating sufficient yeast to pitch the first production-scale fermentation (see **yeast propagation** for more details).

Documentation and management

It is essential that the yeast cultures supplied to the brewery have the correct purity and identity. Failure, particularly where multiple strains are used in one brewery, will have potentially severe consequences in terms of subsequent beer quality. Once a culture has been supplied to the production environment there is little or no chance to remedy any error before significant financial losses become inevitable. The design of the supply system must be sufficiently robust to avoid errors being made. In order to minimise the risk of human error it is essential that yeast supply is underpinned by a properly documented and traceable system which uses colour or number codes to assist checking culture identity. At critical steps the actions of the operator should be checked by an assistant. At regular intervals the whole of the process should be subject to scrutiny by a suitably trained audit team and any weaknesses identified and eliminated.

Yeast taxonomy

Yeast constitutes a diverse group of microorganisms which are classified within the fungi. Representatives are found in three of the major fungal divisions, Ascomycota (to which brewing strains belong), Basidiomycota and Deuteromycota. The discussion here is confined to brewing yeast.

The taxonomy of brewing yeast can be confusing. Parallel systems of nomenclature have arisen which reflect, on the one hand, the behaviour of individual strains in the context of brewing and, on the other, based on more rigorous genetic analyses. With respect to brewing properties yeasts are traditionally classified as being ale or lager types. On the basis of their behaviour in the fermenter these are also referred to as either top cropping (ale types) or bottom cropping (lager types). Historically these yeasts have been classified as *S. cerevisiae* (ale strains) and *Saccharomyces uvarum* or *Saccharomyces carlsbergensis* (lager strains). The term ‘*carlsbergensis*’, later changed to ‘*uvarum*’, reflects the fact that pure lager strains were isolated relatively recently at the Carlsberg Research Institute in Copenhagen and were shown to be distinct from the, in evolutionary terms, much older ale strains. These names continue to be used; however, the taxonomy of yeasts has been and is still subject to a process of continual revision as a result of the greater precision of recently developed genetic analytical techniques. These revisions have been accompanied by changes in nomenclature,

and unfortunately the older systems have remained in common use with the result that parallel naming systems, alluded to already, have arisen.

Early systems of yeast taxonomy relied on traditional descriptors using morphological and biochemical markers. These are useful since they describe features which are of practical relevance in commercial applications such as brewing. However, from a purely scientific standpoint, they have been superseded by more precise genetic analyses which provide a more reliable basis for differentiation and indicate evolutionary relationships. All *Saccharomyces* yeasts used in biotechnological applications are now classified within a subgroup termed *Saccharomyces sensu stricto*. As the name suggests all the species in this group are closely related. Strains from all member species can be crossed in any combination to produce hybrid ascospores. However, only those made between members of the same species are viable. Currently, six species are recognised within the *sensu stricto* group and these are *S. cerevisiae*, *Saccharomyces paradoxus*, *S. bayanus*, *Saccharomyces cariocanus*, *Saccharomyces kudriavzevii* and *Saccharomyces mikatae*, although further revisions are likely. Of these, members of *S. cerevisiae* are used for baking, brewing and winemaking. *Saccharomyces bayanus* strains are associated with winemaking and *S. pastorianus* includes those strains originally classified as *S. carlsbergensis* and used as bottom-fermenting lager strains. It has now been demonstrated that *S. pastorianus* is a hybrid species derived from a fusion event involving parental strains of *S. cerevisiae* and *S. bayanus*. Thus, the genome of the hybrids is larger than that of the parental types, typically 1.5–1.6× bigger, and is aneuploid. Considerable genetic diversity occurs since chromosomes may be pure *S. cerevisiae* or *S. bayanus* or may be mosaics containing genes identical to both parental types.

Yeast viability

Viability is defined as the percentage of live cells within a population. Within the context of brewing yeast viability measurements are made to allow corrections to be made when determining pitching rates. In addition, viability is used as a quantitative measure of the condition of pitching yeast. Commonly breweries use a specified viability value (typically >90%) below which yeast would be deemed unsuitable for use in fermentation.

From a scientific standpoint the concept of viability is contentious. It is usually defined as simply ‘the capacity for living’. In respect to yeast, it may be regarded as the ability to proliferate under appropriate conditions. In the case of those stages in brewing which require the presence of yeast such as primary and secondary fermentation it is possible that some yeast cells are not capable of progressing through the cell cycle but may still make a (desirable or undesirable) contribution to fermentation.

The viability of microorganisms is typically determined using **plate counts**, or variants thereof. Suspensions of microorganisms, with a known total cell concentration, are streaked onto a nutrient medium, solidified with agar, such that individual cells are separated spatially. Following a period of incubation colonies form, and it is assumed that each of these must have arisen from a single viable cell. With knowledge of the number of colonies and the original total cell count the viability can be calculated. In order to differentiate between cells capable of proliferation and those which cannot but still exhibit metabolic activity the term ‘**colony-forming unit (CFU)**’ is often used. Conversely, the term ‘viable but not culturable’, or simply,

'non-culturable' is used to describe cells which have detectable metabolic activity but which are not able to proliferate under the conditions where they are tested.

In order to use viability measurements to assess yeast quality and to determine pitching rates it is necessary to have a timely response. Plate count methods require one to a few days in order to generate a result and therefore such approaches are impractical for routine use. A result can be generated in several hours using a more rapid **slide culture** technique in which a layer of nutrient medium is layered onto a microscope slide and the development of micro-colonies is observed. Nevertheless, this is still too slow and other methods based on the use of so-called **vital stains (dyes)** are used routinely. These are reagents which when mixed with suspensions of cells produce differential staining reactions such that sub-populations of viable and non-viable cells can be distinguished.

The dye **methylene blue** is most commonly used in the brewing industry to determine the viability of yeast. This stain is taken up by dead cells such that they become stained blue. Viable cells are able to reduce the dye to the colourless leuco form and remain unstained. Although the method is the industry standard for yeast viability determination, justifiably it has some critics. Compared with colony counts it gives an overestimation of viability at values less than approximately 90%. The error increases with a decrease in the true viability. This is a result of the presence of increased proportions of severely stressed cells which tend to stain pale blue which may or may not be counted depending on the preference of the operator. For this reason alternative vital stains are used, which provide a more definite differentiation. These include **acridine orange**, **eosin Y**, **methylene violet 3-RAX**, **fluorescein diacetate**, **DiBAC₄**, **propidium iodide**, **Chemchrome Y**, **MgANS** and **Rhodamine 123**. The mechanisms which underpin these stains are various but generally involve exclusion by viable cells or uptake and modification by viable cells with an accompanying colour change. Many of the dyes are fluorescent, a property which, it is claimed, provides better discrimination, albeit at a cost in terms of the generally higher costs of reagents and the need for a fluorescence microscope. Many studies have been made in which correlations have been made between viability measured with vitality stains compared with other techniques such as plate counts. In general the fluorescent techniques appear to offer the best discrimination and Mg-ANS appears to be very suitable for application with brewing yeast. With regard to bright field stains, methylene violet is probably easier to use compared with methylene blue; however, it seems likely that many brewers will continue to favour the latter based on conservatism.

Measurement of viability can be automated using electronic cell counters, such as the flow cytometer (see **flow cytometry**), although at a cost at least an order of magnitude greater.

See also **yeast vitality**.

Yeast vitality

The term used to describe the basis of numerous tests that have been developed with the aim of probing yeast physiological condition and how this relates to fermentation performance. Traditionally the condition of yeast is assessed based on the determination of the proportion of living cells in the population (see **yeast viability**) using the reasoning that if the viability is low, it is likely that the viable fraction is not fit for purpose. Vitality tests extend this concept by assessing the physiological status of the viable fraction of yeast populations.

Ideal vitality tests are rapid, inexpensive, simple to perform and provide a result which can be used either as the basis of a decision on the fitness to pitch of a particular batch of yeast but preferably one which is predictive of subsequent fermentation performance such that an optimum pitching rate and/or wort oxygenation regime can be deduced.

It might be supposed that the rigorous application of quality assurance principles should preclude the need for such testing; however, the development of intensive fermentation techniques such as high- and ultra-high-gravity brewing, together with very large batch sizes, which undoubtedly increase the stresses to which yeast is exposed, has fuelled the perception that testing of pitching yeast condition should use techniques which provide more information than simple viability tests.

A plethora of tests has been suggested. These include simple microscope-based staining techniques (assessment of membrane integrity or visible changes brought about by intracellular processing of dyes), chemical analysis of cellular composition (ATP, NADH, sterols, glycogen, trehalose), ability to proliferate, assessment of the electrokinetic properties of cells and measurements of biochemical activities under defined conditions. The latter includes rapid and small-scale assessment of characters related to fermentation performance such as uptake of sugars and oxygen or the formation of heat, CO₂ or ethanol. Other physiological assessments rely on detection of intracellular pH, or the ability to acidify the medium or the degree to which cells can withstand an applied stress. In the case of the biochemical tests, a few specific pieces of bespoke equipment have been developed to make conducting the test less reliant on the skills of the operator and therefore possibly more suitable for use in a production environment. Should costs fall to levels within the reach of a typical brewery laboratory it is likely that **flow cytometry** will offer a powerful means of assessing the condition of yeast populations.

There is little consensus as to which tests should be adopted. Many brewers are content to use viability testing based on the pragmatic assumption that if this is low it may be assumed that the viable fraction of the population is compromised. The value of vitality tests is that they provide added value. This could be an automatic method for viability detection, or a related parameter, which is rapid and avoids the errors associated with manual microscopic counting techniques. Other tests may give additional information. This can be particularly useful where it is not just necessary to identify yeast with compromised physiology but to bring focus to the areas of yeast handling where problems are being introduced. In this regard many brewers will choose a single vitality test (the acidification power test and its variants seems to be particularly popular) for routine use. Providing this is applied in a consistent manner it is undoubtedly useful. A broader range of tests may be used for troubleshooting exercises.

Yeast washing

A generic term for the variety of treatments which are used to disinfect pitching yeast slurries. The most common is **acid washing** in which bacterial contaminants are killed based on their relative intolerance of low pH compared with brewing yeast. Several other selective biocides have been used. Antibiotics were used until this practice was precluded by the realisation of the risks associated with the selection of resistant strains. Most recently it has been suggested that **chlorine dioxide** could also find utility in this role.

YM medium

Yeast and mould medium (see **MYGP medium**).

Yorkshire square

Yorkshire squares are fermentation vessels traditionally made from slate or stone, which are variants of the more usual **open squares**. Traditional types are of modest capacity, usually >50 hL; more modern types are bigger, up to 900 hL, and are made from stainless steel. They were developed specifically to be used with flocculent ale strains.

The vessels comprise rectangular enclosures the top of which takes the form of an inclined deck located towards the top of the vertical sides but leaving a lip around the periphery of the vessel. The deck is pierced by a central manhole which has a rim on its upper surface about 15 cm in height. The upper and lower compartments, separated by the deck, are also connected by a number of circular pipes, termed organ pipes. Control of temperature is via external cooling jackets or submerged attempterators. The deck is also provided with an aperture for dipping to measure wort volume and an inlet to a drain for yeast removal.

At the start of fermentation pitched and aerated wort is pumped into the vessel to a height close to that of the deck. During primary fermentation the yeast rises through the central manhole where it is retained by the deck. Beer separates from the yeast and re-enters the lower compartment of the vessel via the organ pipes. Where very flocculent yeast strains are used a pumped recirculation system is provided, which takes wort from a drain point at the base of the vessel and returns it to the top of the deck.

When the primary fermentation is judged complete the recirculation loop is switched off and the yeast crop is allowed to settle on the surface of the deck from where it is collected by pushing into the exit drain provided for that purpose. The green beer is then removed from the bottom drain.

Proponents of these vessels claim that their disadvantages, namely, complexity and high beer losses, are outweighed by the quality of the beer produced. This has resulted in the installation of modern versions which have provision for automatic CIP and CO₂ collection. In addition, the removal of yeast crops and tank bottoms has been automated by the incorporation of an arrangement of sequentially operated water jets which force the solid products towards exit points attached to suction pumps.

YSV

See **yeast storage vessel**.

Žatec

Žatec is a town in what was Bohemia and now the Czech Republic. It has a long history, probably more than 700 years, of cultivating hops. It is the site of origin of the famous noble aroma hop cultivar, Saaz, which gives the Czech pilsner-type beers their characteristic delicate low bitterness, floral hoppy aromas and taste.

Zatecky Chmel

Zatecky Chmel, literally hops from Žatec, is the preferred name for Saaz hops grown in the Czech Republic. In some ways it reflects the wish by Czech nationals to dispense with older German nomenclature (as in ‘Saaz’) and to replace it with the native ‘Žatec’. The term is protected by laws of the European Union in which Zatecky Chmel is designated as a *Protected Designation of Origin* such that by statute (EU regulation 2081/92), from May 8, 2007, hops may only bear the mark Zatecky Chmel if they are aroma types of the Saaz variety or designated clones. The crops of 2007–2008 from this region were the first to be so protected.

Named clones of Žatec (Saaz) aroma hops grown in this region, together with the dates of their registration and covered by the legislation, are Lucan (1941), Blato (1952), Osvald’s Clones 31, 72, and 114 (all registered in 1952), Sirem (1969), Zlatan (1976), Podlesak (1989) and Blsanka (1993). These types derive from testing local landraces of the Saaz variety and as well as having desirable aroma properties were selected largely on the basis of yield.

See **Saaz hop**.

Zbyszko

Zbyszko is a high alpha bittering hop variety of Polish origin. Analysis is 8.5% total α -acids of which 25.6% is cohumulone. Total oil content is 1.9% of which 9.7% is caryophyllene, 23.9% is humulene and 53.3% is myrcene.

Zein

Zein is a **prolamin** protein obtained from the grains of maize (*Zea mays*). It is the equivalent to the **hordeins** in barley. Pure zein is water insoluble and edible but also hard, colourless and

odourless. These properties have favoured industrial applications such as use as various coatings. However, since maize grits and flours are also used as adjuncts in brewing, particularly in the case of sorghum beers, zeins must contribute to the nitrogenous contents of worts and the resultant beers.

Zeiss-Pulfrich nephelometer

An early beer haze meter based on the measurement of light scattering at 45°. It was used as a standard reference instrument in many breweries before the advent of modern apparatus.

Zenter

A measure of weight used in Europe for the quantification of hop yields. Numerically, 1 Zenter is equal 50 kg.

Zero-alcohol beers

See **reduced-alcohol beer**.

Zeta potential

Zeta potential is a parameter which is used to describe the electrostatic properties of colloidal particles suspended in a medium which contains charged ionic groups. It is of relevance to brewing in several ways. The zeta potential of haze particles suspended in beer and the ionic composition of the latter influence the rates at which these particles sediment. Process aids such as fining agents influence zeta potential and thereby accelerate the rates at which particles form sediments in tanks.

The colloidal particles suspended in beer or wort may include yeast cells. The zeta potential of yeast cells influences their behaviour in such media in that it affects rates of sedimentation, as described, and also the ability of cells to come together and form flocs. Yeast cells bear a net negative charge owing to the presence of phosphate and/or carboxyl groups on the cell surface. These tend to make the cells mutually repulsive. This repulsive force must be overcome in order for cells to come together and form flocs. It has been observed that in the later stages of fermentation the zeta potential of yeast cells decreases and this in part explains why flocculation occurs at this time (see **yeast flocculation** for more details). It is suggested by some that the zeta potential of yeast cells should be monitored as a routine test of condition.

Zeta potential is of importance in depth filtration. Many artificial filtration media, particularly those made from synthetic polymers, are made from fibres which carry a net positive zeta potential. This allows the filtration medium to bind and retain oppositely charged particles even though they may be smaller than the average pore size.

Zeta potential differs from simple surface charge. Charged particles suspended in an ionic medium become surrounded by a layer of articles of opposite charge. This is termed the fixed layer. Outside of this is a diffuse layer which forms a cloud-like region made up of ions of opposite polarity such that the whole is electrically neutral. The potential difference between the particles and surrounding medium is a function of the nature of the surface charge of the particle and the ionic composition of the medium.

Zeta potential is measured by assessing the mobility of particles when they are placed within an electrical field. In these circumstances the charged particles will migrate towards the

electrode of opposite charge. The particles migrate with the fixed layer and the inner part of the diffuse layer, termed the sliding surface. At the point of electrostatic neutrality the particles will form aggregates. The zeta potential is a measure of the potential difference of this sliding layer and that of the bulk suspending liquid.

Zeus

Zeus is a US super alpha hop variety developed in the Yakima Valley. It is very similar to **Columbus** (Tomahawk). It contains 12.0–16.5% α -acids, of which 27.0–35.0% is cohumulone, and 4.0–6.0% β -acids. Total oils are 1.0–2.0% (5.0–15.0% caryophyllene, <1.0% farnesene, 10.0–25.0% humulene, 25.0–65.0% myrcene).

Zlatan

Czech aroma hop variety which is a clone of Saaz.

See **Zatecky Chmel**.

Z value

Value used to calculate total in-pack oxygen concentrations (**TPO**) in bottled beers. TPO is calculated from the product of *Z* and the shake-out dissolved oxygen concentration (mg/L). The *Z* value is calculated from the following equations:

$$Z = 1 + \frac{HS(\%) \times 3777 \times (4.15 \times 10^{-7} \times T22 \times 10^{-4} \times T - 0.07)}{T}$$

$$HS(\%) = \frac{\text{Brimful volume} - \text{liquid volume} \times 100}{\text{Liquid volume}}$$

T = Temperature (Kelvin).

Zwickelbier

Name given to a German artisanal beer style which is characterised as being relatively low in ethanol content, typically less than 5% abv, with a high carbonation level and is sold unfiltered and unpasteurised. It's The name derives from the German *zwickel*, which is the name given to the sample tap from which beer is drawn for assessment from finishing tanks. Thus, implicit in the name is the suggestion that the beer is fresh when consumed. In practice the beer is held in finishing tanks from which the exit of CO₂ is restricted, hence the relatively high levels of carbonation.

Zygosaccharomyces bisporus

Species of osmotolerant yeast which has been identified as a spoilage organism in concentrated sugar syrups such as those commonly used in brewing.

Zymocin

Extracellular toxins produced by killer yeast strains to which they are self-immune but that are lethal to susceptible non-killer strains.

See **wild yeast**.

Zymomonas

Gram-negative bacteria which take the form of short rods occurring singly, in pairs or as chains or rosettes. Both motile and non-motile forms occur. Two species are recognised, *Zymomonas mobilis*, which is a beer spoiler, and *Z. mobilis* ssp. *Pomacae*, which is associated with cider spoilage. They are anaerobes but tolerant of microaerophilic conditions. They produce ethanol via the fermentation of glucose and fructose and are tolerant of relatively high concentrations of ethanol (up to 15% v/v). Maltose is not utilised. They are potent spoilers of UK-style ales but not lagers. The reasons for this are unclear but might reflect differences in wort carbohydrate spectrum and fermentation temperature. Sugar metabolism is via the Entner–Doudoroff pathway, which generates ethanol and acetaldehyde, acetate, acetoin, lactate and glycerol. In addition, hydrogen sulphide, dimethyl sulphide and dimethyl trisulphide are formed such that infected beers acquire a fruity, rotten apple aroma and taste.

Zythos

Zythos is a consumer organisation based in Belgium and founded in 2003 with the aims of championing for what are perceived as traditional beers and campaigning against the globalisation of the world brewing industry. It is a member of the European Beer Consumers Union (EBCU).

Contact details are at <http://www.zythos.be> (last accessed 11 February 2013).

Zythos (beer)

Name given to a beer-type beverage associated with ancient Egypt. The word may not be native Egyptian but possibly is of Greek origin.

Zythum

Name given to a beer-type barley wine beverage associated with ancient Egypt. In common with the majority of these beers which evolved in the ancient world, they appeared to be made from bread which was then broken up and suspended in water to allow the fermentation to take place. Additional herbs and spices were customarily added as flavourings. Xythum appears to have had a moderate alcohol content of approximately 5% by volume. A stronger version, apparently for the exclusive use of males, with an alcohol content of 10–15% by volume and called dizythum also existed.

The word may not be native Egyptian but possibly is of Greek origin as in zythos, the Greek equivalent.

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