Dairy processing handbook

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Chapter 1

Primary production of milk

Milk production began 6 000 years ago, or even earlier. The dairy animals of today have been developed from untamed animals which, over thousands of years, have lived at different altitudes and latitudes, at times exposed to natural and, many times, severe and extreme conditions.

Practically everywhere on earth man started domesticating animals. As a rule, herbivorous, multipurpose animals were chosen to satisfy his need of milk, meat, clothing, etc.

Herbivorous animals were chosen because they are less dangerous and easier to handle than carnivorous animals. The former did not compete directly with man for nourishment, since they ate plants which man could not use himself.

The herbivorous animals used were all ruminants with the exception of the mare and ass. Ruminants can eat quickly and in great quantities, and later ruminate the feed. Today, the same animals are still kept for milk production, milk being one of the essential food components for man.

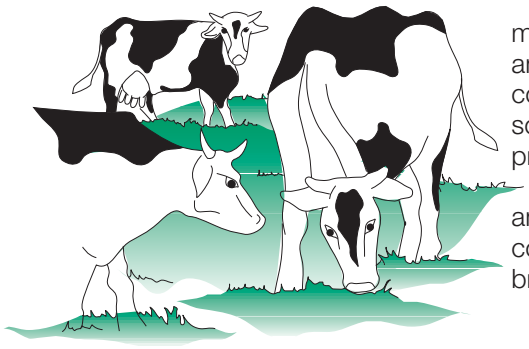
The most widespread milking animal in the world is the cow, which is found on all continents and in nearly all countries.

Table 1.1

Composition of milk from various animals.

Animal	Protein total %	Casein %	Whey protein %	Fat %	Carbo-hydrate %	Ash %
Human	1,0	0,5	0,5	4,5	7,0	0,2
Horse	2,2	1,3	0,9	1,7	6,2	0,5
Cow	3,5	2,8	0,7	3,7	4,8	0,7
Buffalo	4,0	3,5	0,5	7,5	4,8	0,7
Goat	3,6	2,7	0,9	4,1	4,7	0,8
Sheep	4,6	3,9	0,7	7,2	4,8	0,8

However, we should not forget the other milking animals, whose milk is of great importance to the local population, as a source of highly valuable animal protein and other constituents. Sheep are of exceptional importance among this group, especially in the Mediterranean countries and in large areas of Africa and Asia. The number of sheep in the world exceeds one billion, and they are thus the most numerous of all milk- and meat-producing domestic animals.



Sheep are often accompanied by goats, whose contribution to milk and meat production in the poorest areas should not be overlooked. Both sheep and goats are a source of cheap, high-quality protein and are mainly kept in conditions where climatic, topographical, economic, technical or sociological factors limit the development of more sophisticated protein production systems.

Table 1.1 shows the composition of milk from different species of animals. It should be noted that the figures given are only averages, as the composition for any species is influenced by a number of factors such as breed, feeding, climate, etc.

Cow milk

Milk is the only food of the young mammal during the first period of its life. The substances in milk provide both energy and the building materials necessary for growth. Milk also contains antibodies which protect the young mammal against infection. A calf needs about 1 000 litres of milk for growth, and that is the quantity which the primitive cow produces for each calf.

There has been an enormous change since man took the cow into his service. Selective breeding has resulted in dairy cows which yield an average of more than 6 000 litres of milk per calf, *i.e.* six times as much as the primitive cow. Some cows can yield 14 000 litres or more.

Before a cow can start to produce milk, she must first have a calf. Heifers reach sexual maturity at the age of seven or eight months but are not usually mated until they are 15 – 18 months old. The period of gestation is 265 – 300 days, varying according to the breed of the cow, so a heifer produces her first calf at the age of about 2 – 2,5 years.

- The heifer is bred (naturally or by insemination) before the age of two years.
- The gestation period is nine months and one week.
- After calving, the cow gives milk for 10 months.
- 1 – 2 months after calving the cow will again be bred.

Secretion of milk

Milk is secreted in the cow's udder, which is a hemispherical organ divided into right and left halves by a crease. Each half is divided into quarters by a shallower transverse crease. Because each quarter has one teat with its own separate mammary gland, it is theoretically possible to get milk of four different qualities from the same cow. A sectional view of the udder is shown in Figure 1.1.

The udder is composed of glandular tissue which contains milk-producing cells. The external layer of this tissue is muscular, thus giving cohesion to the body of the udder and protecting it against injury from knocks and blows.

The glandular tissue contains a very large number (about two billion) of tiny bladders called alveoli. The actual milk-producing cells are located on the inner walls of the alveoli, which occur in groups of between 8 and 120. Capillaries leading from the alveoli converge into progressively larger milk ducts which lead to a cavity above the teat. This cavity, known as the cistern of the udder, can hold up to 30 % of the total milk in the udder.

In the Irish village of Blackwater, Big Bertha died on 31 December 1993. She was probably the oldest cow in the world when she died at an age of 49 years. The owner, Mr Jerome O'Leary, announced that Big Bertha would have been 50 years of age on 15 March 1994.

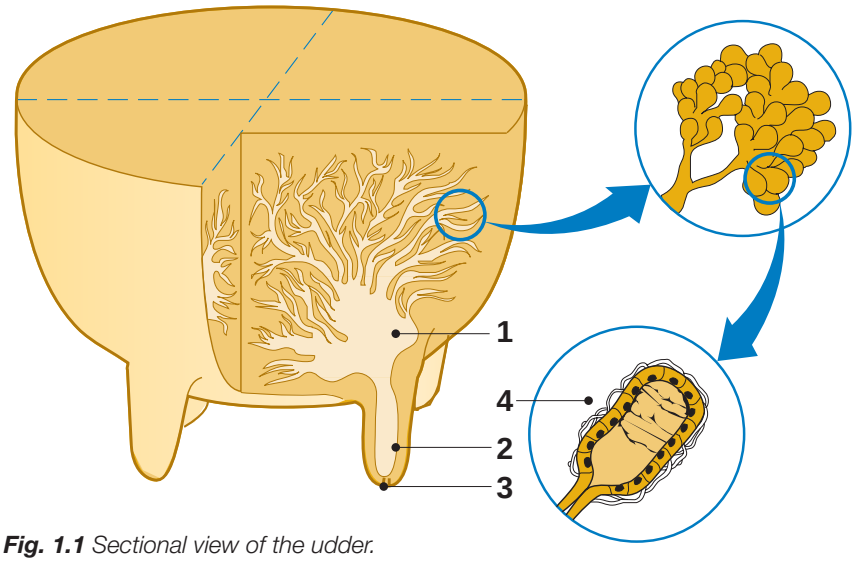


Fig. 1.1 *Sectional view of the udder.*
1 *Cistern of the udder*
2 *Teat cistern*
3 *Teat channel*
4 *Alveolus*

Large quantities of blood flow through the udder every day. Approx. 800 – 900 l of blood is needed for formation of one litre of milk.

The cistern of the udder has an extension reaching down into the teat; this is called the teat cistern. At the end of the teat there is a channel 1 – 1,5 cm long. Between milkings, the channel is closed by a sphincter muscle which prevents milk from leaking out, and bacteria from entering the udder.

The whole udder is laced with blood and lymph vessels. These bring nutrient-rich blood from the heart to the udder, where it is distributed by capillaries surrounding the alveoli. In this way, the milk-producing cells are furnished with the necessary nutrients for the secretion of milk. "Spent" blood is carried away by the capillaries to veins and returned to the heart. The flow of blood through the udder very high. It takes between 800 and 900 litres of blood to make one litre of milk.

As the alveoli secrete milk, their internal pressure rises. If the cow is not milked, secretion of milk stops when the pressure reaches a certain limit. Increase of pressure forces a small quantity of milk out into the larger ducts and down into the cistern. Most of the milk in the udder, however, is contained in the alveoli and the fine capillaries in the alveolar area. These capillaries are so fine that milk cannot flow through them of its own accord. It must be pressed out of the alveoli and through the capillaries into the larger ducts. Muscle-like cells surrounding each alveolus perform this duty during milking, see Figure 1.2.

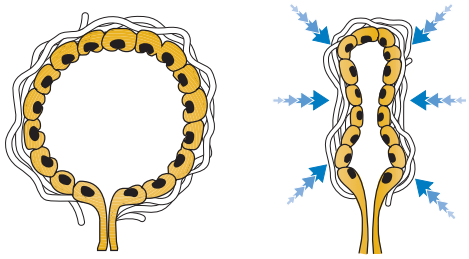


Fig. 1.2 *Squeezing of milk from alveolus.*

The lactation cycle

Secretion of milk in the cow's udder begins shortly before calving, so that the calf can begin to feed almost immediately after birth. The cow then continues to give milk for about 300 days. This period is known as lactation.

One to two months after calving the cow can be serviced again. During the lactation period, milk production decreases, and after approx. 300 days it may have dropped to only 25 – 50 % of its peak volume. At this stage milking is discontinued to give the cow a non-lactating period of up to 60 days prior to calving again. With the birth of the calf, a new lactation cycle begins. The first milk the cow produces after calving is called *colostrum*. It differs greatly from normal milk in composition and properties. See further in Chapter 2.

Milk production is somewhat lower during the first lactation period. A cow is normally productive for 3 – 5 years.

Milking

A hormone called oxytocin must be released into the cow's bloodstream in order to start the emptying of the udder. This hormone is secreted and stored in the pituitary gland. When the cow is prepared for milking by the correct stimuli, a signal is sent to the gland, which then releases its store of oxytocin into the bloodstream.

Fig. 1.3 *Milking takes 5 – 8 minutes.*

In the primitive cow, the stimulus is provided by the calf's attempts to suck on the teat. The oxytocin is released when the cow feels the calf sucking. A modern dairy cow has normally no calf present during milking. Stimulation of the milk let-down is done by the preparation of milking, *i.e.* the sounds, smells and sensations associated with milking.

The oxytocin begins to take effect about one minute after preparation has begun and causes the muscle-like cells to compress the alveoli. This generates pressure in the udder and can be felt with the hand; it is known as the let-down reflex. The pressure forces the milk down into the teat cistern, from which it is sucked into the teat cup of a milking machine or pressed out by the fingers during hand milking.

The effect of the let-down reflex gradually fades away as the oxytocin is diluted and decomposed in the bloodstream, disappearing after 5 – 8 minutes. Milking should therefore be completed within this period of time. If the milking procedure is prolonged in an attempt to "strip" the cow, this places an unnecessary strain upon the udder; the cow becomes irritated and may become difficult to milk.

Hand-milking

On many farms all around the world, milking is still done by hand in the same way as it has been done for thousands of years. Cows are usually milked by the same people every day, and are quickly stimulated to let-down just by hearing the familiar sounds of the preparations for milking.

Milking begins when the cow responds with the let-down reflex. The first jets of milk from the teats are normally rejected. A careful, visual inspection of the first milk enables the milker to detect the status of the udder health.

Two opposed quarters are milked at a time: one hand presses the milk out of the teat cistern, after which the pressure is relaxed to allow more milk to run down into the teat cistern from the udder cistern. At the same time milk is pressed out of the other teat. In this way the two teats are milked alternately. When two quarters have been emptied in this way, the milker then proceeds to milk the other two until the whole udder is empty.

The milk is collected in pails and poured through a strainer, to remove coarse impurities, into a churn holding 30 – 50 litres. The churns are then chilled and stored at low temperature to await transport to the dairy. Immersion or spray chillers are commonly used for cooling.

Fig. 1.4 *The milk should be poured through a strainer and then chilled.*

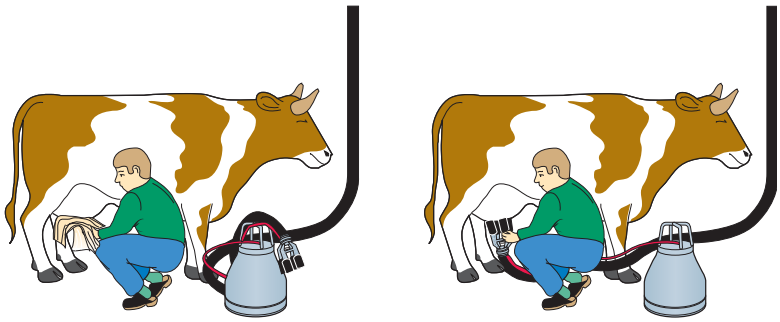


Fig. 1.5 *Preparing the cow for milking by cleaning and massaging the udders before the teat cups are placed on the udders.*

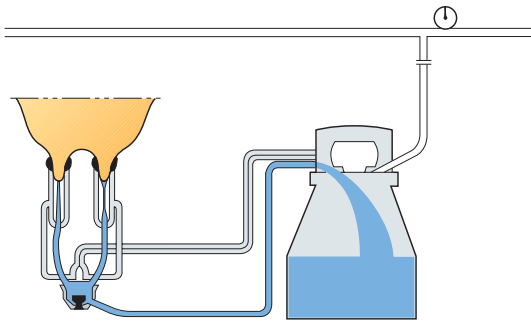


Fig. 1.6 *Machine milking equipment.*

Machine milking

The basic principle of the milking machine is shown in Figure 1.6. The milking machine extracts the milk from the teat by vacuum. A vacuum pump, a vacuum vessel, a vessel for collecting milk, teat cups and a pulsator are essential parts of the milking machine.

The teat cup unit consists of a teat cup containing an inner tube of rubber, called the teat cup liner. The inside of the liner, in contact with the teat, is subjected to a constant vacuum of about 50 kPa (50% vacuum) during milking.

The pressure in the pulsation chamber (between the liner and teat cup) is regularly alternated by the pulsator between 50 kPa during the suction phase and atmospheric pressure during the massage phase. The result is that milk is sucked from the teat cistern during the suction phase. During the massage phase, the teat cup liner is pressed together allowing a period of teat massage. This is followed by another suction phase, and so on, as shown in Figure 1.7.

Relief of the teat during the massage phase is necessary to avoid accumulation of blood and fluid in the teat. Such congestion in the teat can be painful to the cow, and milk let down and milking performance can be affected. Repeated congestion at successive milking sessions can even have an influence on the udder health. The pulsator alternates between suction and massage phases about 50 to 60 times per minute.

The four teat cups, attached to a manifold called the milk claw, are held on the cow's teats by suction and the friction between the teat and the teat cup liner. Vacuum is alternately (alternate pulsation) applied to the left and right teats or, in some instances, to the front teats and rear teats. The applying of vacuum to all four teats at the same time (simultaneous pulsation) is less common. The milk is drawn from the teats directly to the milk pail or via a vacuumised transport pipe to a receiver unit. An automatic

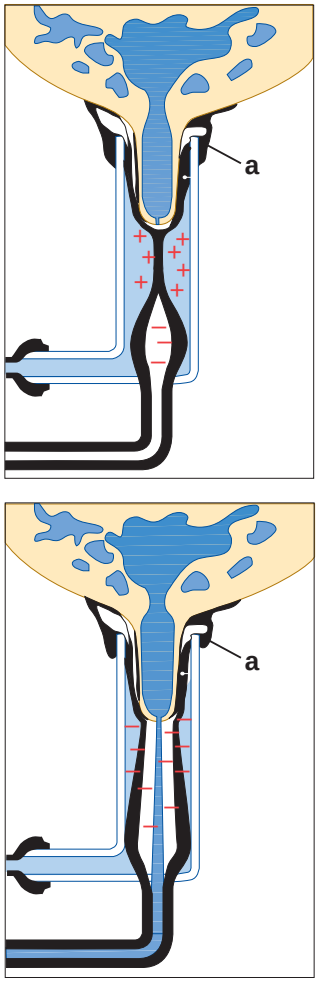


Fig. 1.7 *The phases of machine milking.*
a *Teat cup liner*

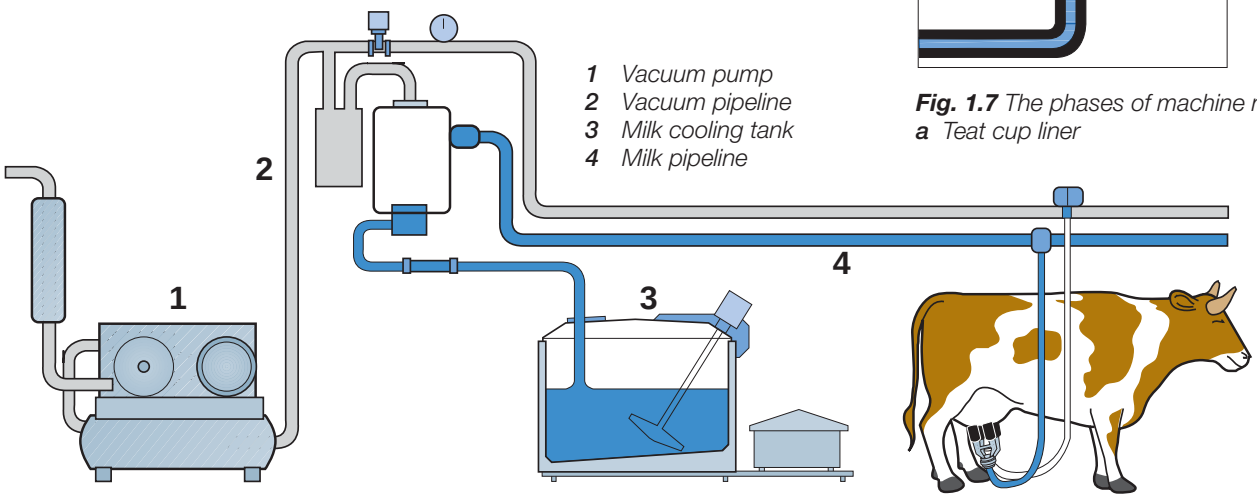


Fig. 1.8 *General design of pipeline milking system.*

shut-off valve operates to prevent dirt from being drawn into the system if a teat cup should fall off during milking. After the cow has been milked, the milk pail is taken to a milk room where it is emptied into a churn or a special milk tank for cooling.

To eliminate the heavy and time-consuming work of carrying filled pails to the milk room, a pipeline system may be installed for direct transport of the milk to the milk room (Figure 1.8). Such systems are most common today. It allow milk to be conveyed in a closed system straight from the cow to a collecting tank in the milk room. This is a great advantage from a hygienic point of view.

Regardless if the milking system is of bucket, pipeline or automatic type it is important that it is designed to prevent air leakage during milking. Excessive air leakage can influence the quality of the milk and cause elevated levels of free fatty acids.

The machine milking plant is also provided with *Cleaning-In-Place (CIP)* facilities.

Automatic milking systems

Automatic milking systems, Figure 1.9, have been installed on commercial farms at an increasing rate in recent years. The potential benefits are reduced labour requirements, higher milk quality, improved animal health and increased yield. Figure 1.11 shows a typically dairy farm layout including an automatic milking system.

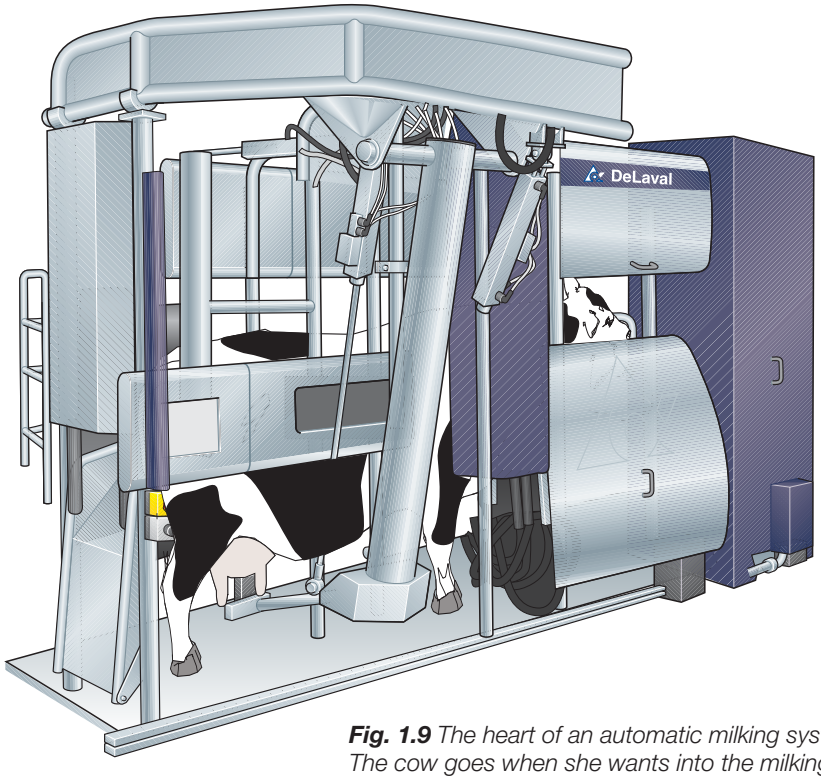


Fig. 1.9 *The heart of an automatic milking system. The cow goes when she wants into the milking station where the teats are cleaned and milked.*

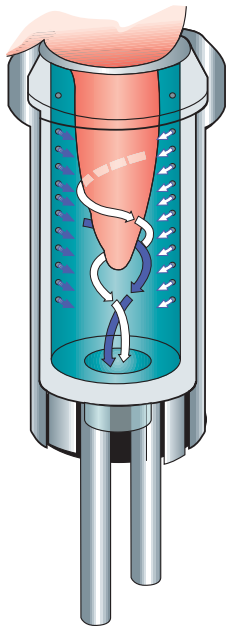
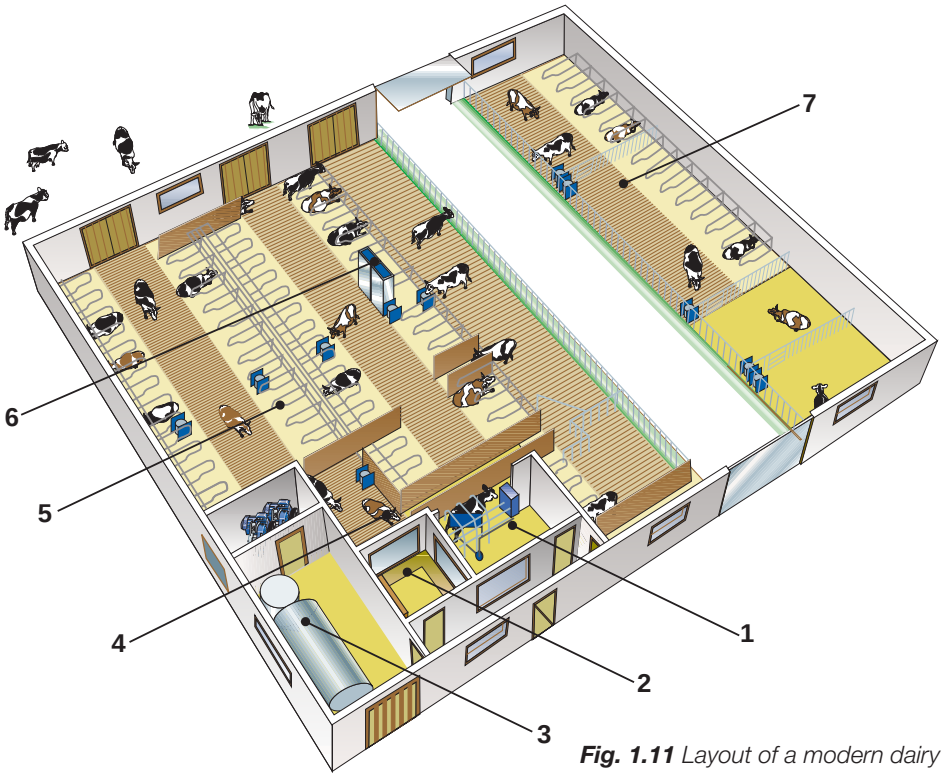


Fig. 1.10 *Teat-cup for cleaning, drying and pre-milking. The teat is flushed with tepid water for cleaning and finally dried with air. The pre-milk goes together with cleaning water to drain.*

In contrast to conventional milking, in which people bring the cows to be milked, automatic milking places emphasis on the cow's inclination to be milked in a self-service manner several times a day. The idea that cows like being milked is very attractive, and one of the main financial benefits from automatic milking is the increase in milk yield from more frequent milking.

When the cow wants to be milked, she walks to the milking station. A transponder on the cow identifies it, and if the cow was milked recently, she is directed back to the resting or feeding area.

The cow enters the automatic milking station and an individual amount of concentrate is served.



1 *Automatic milking station*
2 *Control room*
3 *Milk cooling and storage*
4 *Smart gate for preselecting the cows attempting the milking station*
5 *Living area*
6 *Feeding station*
7 *Calf section*

Fig. 1.11 *Layout of a modern dairy farm with an automatic milking system.*

In an automatic milking system the teats can be detected by a laser and vision camera. As an example, the teats can be cleaned separately by means of a teat-cup-like device, Figure 1.10, using tepid water applied intermittently at a certain pressure and turbulence to ensure efficient cleaning. Drying of the teats is carried out by compressed air in the same teat-cup.

Foremilking is carried out by the cleaning teat-cup, which applies vacuum at the end of the cleaning cycle. The cleaning teat-cups are finally flushed with water.

Sensors can detect whether foremilking has been carried out. Foremilking is applied for a few seconds to ensure that sufficient milk is evacuated and the let-down reflex is activated.

The teat-cups for milking are automatically attached sequentially. Milk from the four teats is kept separate until the milk meter records the amount from each quarter. Spraying each individual teat with disinfectant is the final stage of milking.

Milk yield, milking duration, milk flow rate, and certain characteristics of the milk are recorded during milking. In addition, data on cow movements, time of milking and time of concentrate feeding may also be available.

Milk leaving the milking station can be divided into different categories and being collected separately from the normal milk. The categories can be:

1 Treated cow
2 Freshly calved cow (colostrum)
3 Cow with less than one milking in the last 24 hours
4 A cow which, although healthy, has cell counts above a certain level

The fresh milk is forwarded to a buffer tank for cooling before being pumped to the storage tank.

Cooling of milk

Efficient cooling of the raw milk after milking is the best way to prevent bacterial growth. Various cooling systems are available; the choice depends on the produced volume of milk.

An *in-can* cooler, shown in Figure 1.13, is suitable for small producers. It is much favoured by users of chilled water units and producers using direct-to-can milking equipment.

An *immersion* cooler is designed for direct cooling of the milk in churns

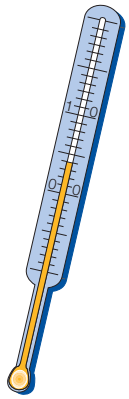


Fig. 1.12 *Milk must be cooled to 4 °C as soon as possible.*

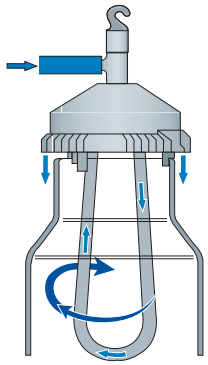


Fig. 1.13 *An in-can cooler is placed on top of the milking bucket or any type of milk can.*

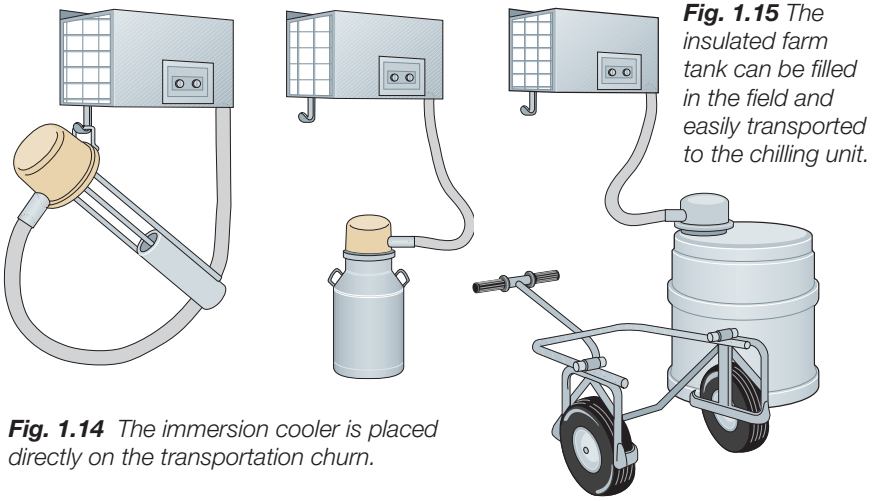


Fig. 1.14 *The immersion cooler is placed directly on the transportation churn.*

Fig. 1.15 *The insulated farm tank can be filled in the field and easily transported to the chilling unit.*

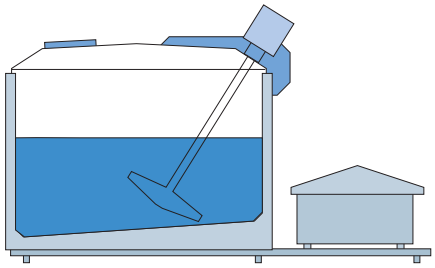


Fig. 1.16 *Direct expansion tank used for cooling and storage of milk.*

as well as in tanks. The condensing unit is mounted on a wall, Figure 1.14.

The evaporator is located at the lower end of the immersion unit.

The immersion cooler can also be used for indirect cooling, *i.e.* for cooling water in insulated basins. The milk is then cooled in transport churns immersed in the chilled water.

Insulated farm tanks for immersion coolers are available in both stationary and mobile types (Figure 1.15). When road conditions prevent access by tanker truck, a mobile tank can be used to bring the milk to a suitable collection point. Mobile tanks are easy to transport and thus suitable for milking in the fields.

Direct expansion tanks as shown in Figure 1.16 can as well be used for cooling and storage of the milk.

Cleaning and sanitising

Manual cleaning with brushes is a common method where hand milking or bucket machine milking systems are used.

Circulation cleaning is commonly performed in pipe line milking plants. The cleaning solution is circulated through the plant by vacuum and/or a pump.

Detergents, sanitisers, liquid temperatures and other cleaning conditions recommended by the milking machine supplier should be applied.

Cooling of milk on the farm

Milk leaves the udder at a temperature of about 37 °C. Fresh milk from a healthy cow is practically free from bacteria. It must be protected from

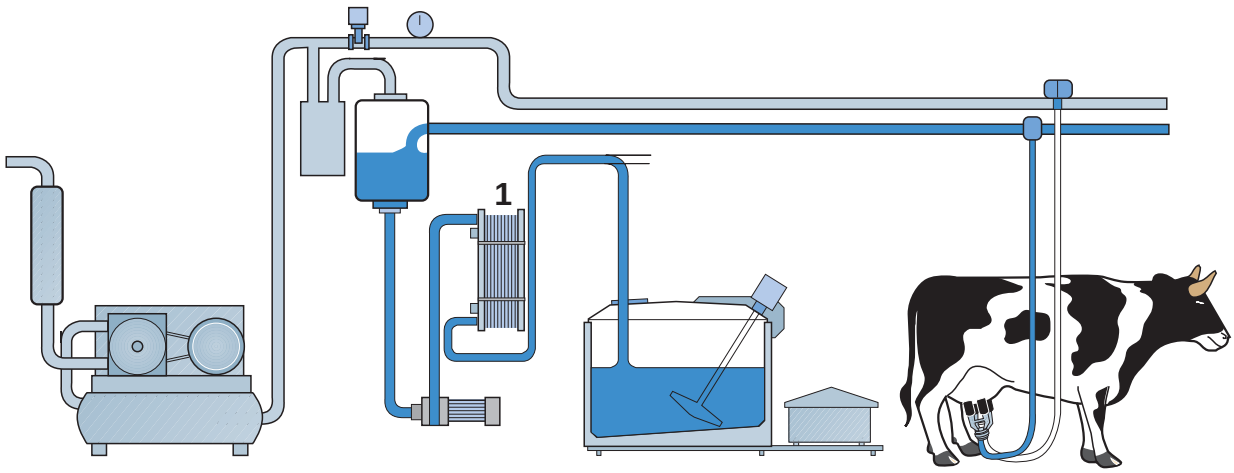


Fig. 1.17 *Milking equipment on a large farm with heat exchanger (1) for rapid cooling from 37 to 4 °C.*

being contaminated after it has left the udder. Micro-organisms capable of spoiling the milk are everywhere – on the udder, on the milker's hands, on airborne dust particles and water droplets, on straw and chaff, on the cow's hair and in the soil. It is common to filter the milk before it enters the milk tank.

Careful attention must be paid to hygiene in order to produce milk of high bacteriological quality. However, despite all precautions, it is almost impossible to completely exclude bacteria from milk. Milk is an excellent growth medium for bacteria; it contains all the nutrients they need. Thus, as soon as bacteria get into milk, they start to multiply. On the other hand, the milk leaving the teats contains certain original bactericides which protect the milk against the action of micro-organisms during an initial period after extraction. It also takes some time for infecting micro-organisms to adapt to the new medium before they can begin to grow.

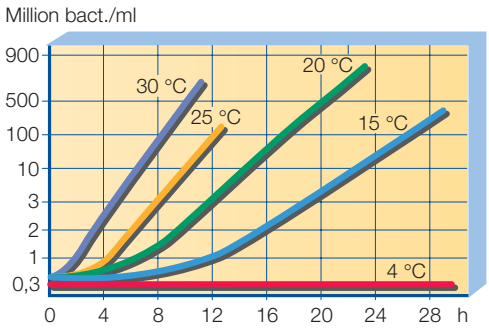


Fig. 1.18 *The influence of temperature on bacterial development in raw milk.*

Unless the milk is quickly cooled down after extraction, it may soon be spoiled by micro-organisms, which thrive and multiply most vigorously at temperatures around 37 °C. Milk should therefore be cooled immediately after it leaves the cow. At this temperature the level of activity of the micro-organisms is low. It is important to keep the milk at low temperature during storage. The activity of the micro-organisms will easily increase again if the temperature is allowed to rise some few degrees above recommended storage temperature. Figure 1.18 shows the rate of bacterial growth at different temperatures over time.

Under certain circumstances, *e.g.* with limited availability of water and/or electricity or when the quantity of milk is too small to justify the investment in cooling equipment on the farm, co-operative milk collecting centres with cooling facilities may be available.

Farm cooling equipment

Spray or immersion coolers are commonly used on farms, which deliver milk to the dairy in cans. In the spray cooler, circulating chilled water is sprayed on the outsides of the cans to keep the milk cool. The immersion cooler consists of a coil, which is lowered into the can. Chilled water is circulated through the coil to keep the milk at the required temperature (Figure 1.13 to 1.15).

Where milking machines are used, the milk is commonly collected in special milk tanks at the farm (Figure 1.16). A wide range of milk tanks of various sizes are available with built-in cooling equipment designed to guarantee cooling to a specified temperature within a specified time. These tanks are often in most cases equipped with equipment for automatic cleaning to ensure uniform high standard of hygiene.

On large farms, and in collecting centres where large volumes of milk (more than 5 000 litres) must be chilled quickly from 37 to 4 °C, the cooling equipment of the bulk tanks may be inadequate. In these cases the tank is mainly used to maintain the required storage temperature; a major part of the cooling is carried out by means of a heat exchanger in line in the delivery pipeline (Figure 1.17).

Frequency of delivery to the dairy

In former times, milk was delivered to the dairy twice a day, morning and evening. In those days the dairy was close to the farm. But as dairies became larger and fewer, their areas of collection increased and the average distance from farm to processing increased. This meant longer intervals between collections.

Collection on alternate days is common practice today in most of the large dairy countries with modern milk production. Collection every three or even four days is not entirely unknown.

Milk should preferably be handled in a closed system, to minimise the risk of contamination. It must be cooled to 4 °C as soon as it is produced

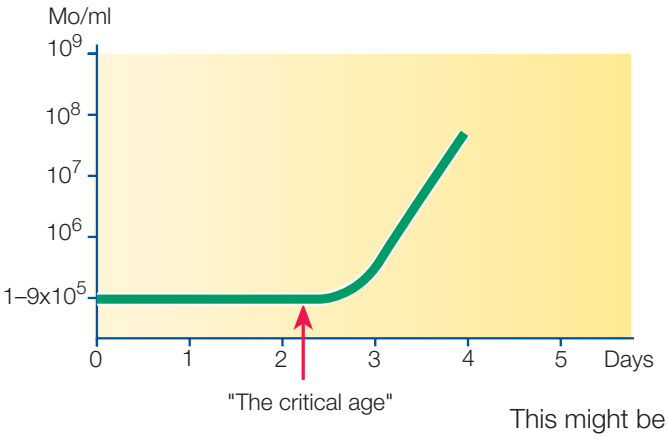


Fig. 1.19 *Bacteria growth at 4°C in raw milk.*

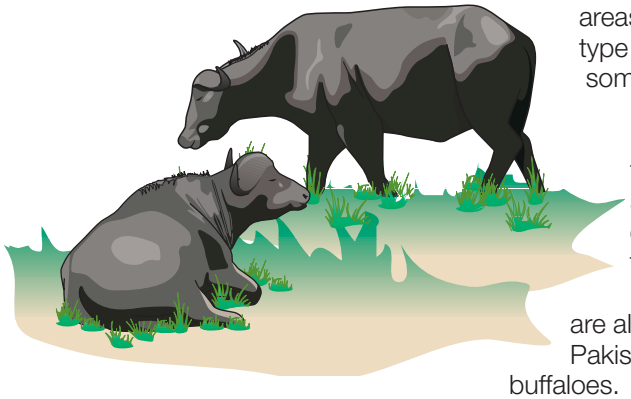
and then kept at that temperature until processed. All equipment coming into contact with milk must be cleaned and disinfected.

Quality problems may arise if the intervals between collections are too long. Certain types of micro-organisms, known as psychrotrophic, can grow and reproduce below +7 °C. They occur mainly in soil and water. Therefore, it is important that water used for cleaning is of high bacteriological quality.

Psychrotrophic bacteria will grow in raw milk stored at 4 °C. After an acclimatisation period of 48 – 72 hours, growth goes into an intense logarithmic phase (F igure 1.19). This results in breakdown of both fat and protein of the milk. This might be an important reason for off-flavours that may jeopardise the quality of products made from the milk.

This phenomenon must be taken into account in the planning of collection schedules.

Buffalo milk



Buffaloes are the most common milk producer in Asia and certain areas of Africa. There are many different species and the dominant type varies from region to region. The world population of buffaloes is some 150 million, of which 145 million live in Asia.

Most buffaloes are owned by farmers with small farms and are merely a source of a little extra income. In India, it is common that a family owns one or two buffaloes. In northern India, herd sizes of 10 to 15 animals are common. This area also has a well-developed milk collection system. Outside large Indian cities large farms with herds of 100 – 300 buffaloes are common.

Widespread in India, Pakistan and Southeast Asia, buffaloes are also common in Egypt, Romania, Turkey and Italy. In India, Pakistan and Egypt, some 50 – 65 % of all milk produced is from buffaloes.

It is estimated that 17 % of the world's total milk production comes from buffaloes. Only 6 % of the buffalo milk produced in India is processed, most is used by the farmer or sold untreated as "street milk".

Milk from buffaloes can be processed like milk from cows. However, its thermal stability is lower, so mixed milk, a mixture of buffalo and cow milk, is preferable for UHT treatment.

Yield and lactation period

The milk produced during a lactation period may differ due to regional and availability of feed. The buffaloes in India and China only produce 450 – 500 kg per lactation period, while others, *i.e.* specialised milking farms at Indian university farms produce more than 1 700 kg, and in Italy up to 3 000 kg.

The lactation period varies from 217 days in Egypt to 270 – 295 in India.

Secretion of milk

Lactating buffaloes secrete milk in the same way as other lactating domesticated animals. The anatomy of buffalo teats is slightly different from cow teats. The muscle around the streak channel is thicker, and more force is therefore required to open the canal. This is why the buffaloes are "hard milkers".

The milk is held in the upper, glandular part of the udder, in the alveoli and small ducts. Between milkings, there is no milk stored in the cistern. Hence, buffaloes have no cisternal milk fraction. The milk is expelled to the

cistern only during actual milk ejection. The same phenomenon is seen in Chinese yellow cows and yaks.

The composition of buffalo milk differs from that of cow milk. The biggest difference relates to fat, as buffalo milk from some breeds may contain up to 13 % fat. Buffalo milk fat has a higher melting point than cow milk, due to its higher proportion of saturated fatty acids. Phospholipids and cholesterol are lower in buffalo milk, and it is more resistant to oxidative changes compared to milk from cows.

Buffaloes produce colostrum during the first few days after calving. Colostrum from buffalo has a dry matter content of up to 30 % and contains valuable proteins. The colostral period usually lasts three days, during which the composition of the colostrum gradually changes, becoming more and more like ordinary milk. Colostrum, should not be delivered to dairy.

Some properties of buffalo milk

As can be seen from Table 1.1, buffalo milk is richer in most important constituents than cow milk.

The content of protein, lactose and ash is somewhat higher in buffalo milk than in cow milk. Buffalo milk contains vitamin A, but lacks β-carotene, which is present in cow's milk.

Milking

Buffaloes have been used in milk production for centuries. Milking buffaloes is not a difficult task. One should, however, take care not to simply apply cow-milking techniques, as buffaloes require slightly different milking methods.

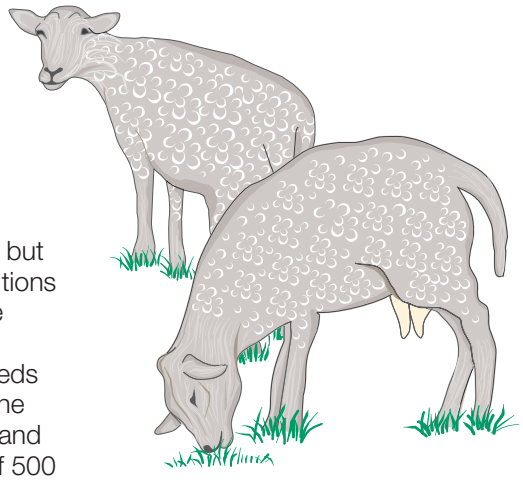
Hand-milking

Hand-milking is the method most often used on small, family-run farms. It is important to use a smooth and comfortable milking technique. In hand-milking, it is necessary to overcome the higher resistance in the teat sphincter.

Machine milking

Buffaloes have been successfully milked with machines for decades, in countries like Italy. Machine milking has during recent years become more interesting also for Asian and African farmers.

The udder and teats of buffaloes are different to those of cows, so a heavier cluster, higher operation vacuum and faster pulsation rate are required.



Sheep (ewe) milk

Among the numerous breeds of sheep, it may be difficult to define any particular dairy breeds, except by the purpose for which they are bred. Some breeds are mainly kept for production of meat and wool, but are occasionally also milked. There are breeds considered as dairy breeds, but their production per lactation does not exceed 100 kg due to the conditions under which they are kept. On the other hand, milk production of some meat breeds can be as much as 150 to 200 kg per lactation.

There are, however, some breeds that can be classified as dairy breeds due to their high production of milk and good milkability. They include the Lacaune of France, East Friesian of Germany, Awassi of the Near East and Tsigai in the CIS, Romania, Hungary and Bulgaria. Production figures of 500 to 1 000 kg of milk per lactation have been reported for East Friesian and Awassi ewes.

Yield and lactation period

Data on yields and lactation periods given by different authors show wide fluctuation between the various breeds as well as within the same breed. Figures of 0,4 to 2,3 kg per ewe per day for yield and 100 to 260 days for length of lactation should therefore be understood as a rough guide to low and high averages.

Flock size

It is estimated that, other factors equal, 8 to 10 dairy ewes correspond to one dairy cow.

Flock sizes of 150 to 200 ewes are appropriate for intensive family farms, while flock sizes of 300 to 400 ewes may be suitable as a production unit.

Large-scale enterprises may have many thousands of sheep each. The number of dairy animals kept in one flock, however, should not exceed about 1 200, because of the labour demanding milking. Well-functioning and robust milking equipment and high efficiency of milking are of utmost importance likewise as the quality of the management of the sheep.

An ewe is kept four to five years in a flock. The gestation period is about five months, and most breeds average 1,5 to 2 lambs a year – in poor areas less than one. Ewe lambs can be bred from the age of 6 to 8 months.

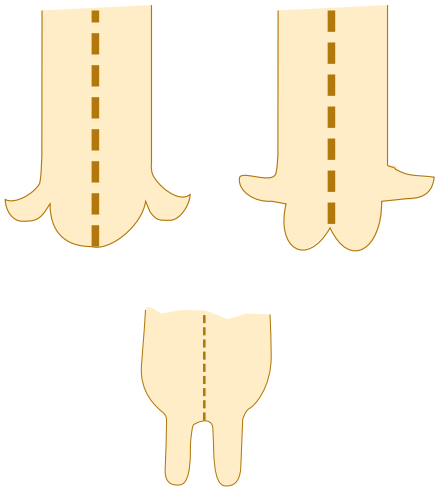


Fig. 1.20 *Typical locations of teats on udders of sheep. The ideal position is when the teats are located at the lowest points of the udder halves.*

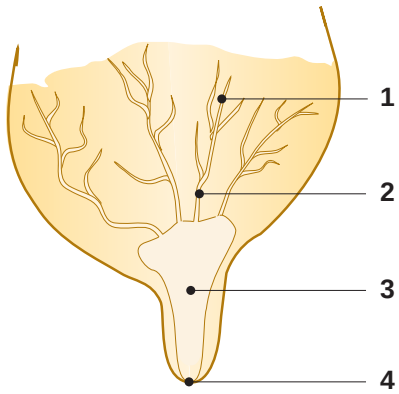


Fig. 1.21 *Cross-section of one half of a sheep's udder.*
1 *Alveolar tissue*
2 *Milk ducts*
3 *Teat cistern*
4 *Teat canal*

Secretion of milk

Lactating ewes secrete milk in the same way as other lactating domestic animals. Sheep milk is richer in all its important constituents as compared to cow milk (Table 1.1) and with nearly 30 % more dry matter. Variations in sheep milk composition are due to most of the same factors as for dairy cows, *i.e.* breeds, individuals and stage of lactation.

Ewes produce colostrum during the first few days after lambing. Colostrum has a dry matter content of up to 40 % and contains the important proteins, albumin and immunoglobulins. The colostral period usually lasts three to four days, during which the composition of the colostrum gradually changes, becoming more and more like ordinary milk. Colostrum should not be delivered to dairies.

Milk fat

Fat globules in sheep's milk range in size from 0,5 to 25 microns, but the largest fraction is between 3 and 8 microns, *i.e.* nearly twice as big as the fat globules in cow milk. The fat of sheep milk has a higher content of caprylic and capric acid than fat of cow milk. This is the main reason for the particular taste and aroma of milk products from sheep.

Protein

Sheep milk is typical casein milk. It contains on an average 4,5 % of casein and only around one per cent of whey proteins. The ratio casein/whey protein of sheep milk thus differs somewhat from that of cow's milk, viz 82 : 18 versus 80 : 20.

Some properties of sheep milk

Specific gravity is 1,032 – 1,040. This is due mainly to its high content of solids-non-fat. Acidity is high due to a high percentage of proteins. The pH normally varies between 6,5 and 6,8.

Milking

The anatomy of the udder of the ewe is different to that of the cow. The udder of the ewe consists of two halves with one teat each.

While the cow is normally easy to milk, both manually and by machine, sheep are more difficult to milk compared to cows, both manually and by

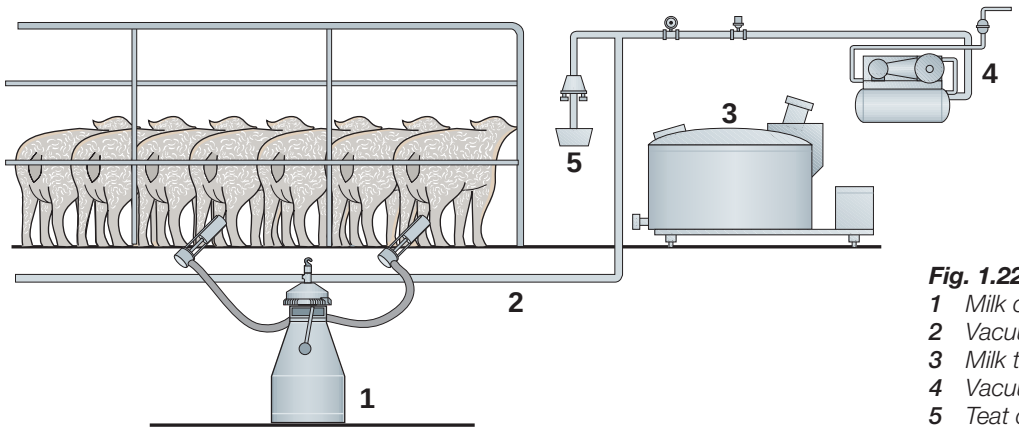


Fig. 1.22 *Churn milking system.*
1 *Milk churn with pulsator*
2 *Vacuum pipeline*
3 *Milk tank for cooling and storage*
4 *Vacuum pump*
5 *Teat cup cleaning unit*

machine. One important reason is that the teats of many ewes are horizontally oriented. An ideal udder is one with the teats at the lowest points of the udder halves. Figure 1.20 shows examples of various udder configurations of sheep.

Some breeds have a small percentage of cistern milk (Figure 1.21). The results of milking depend to a large extent of how well the let-down reflex works.

As with cows, the release of milk is initiated by a hormone, oxytocin, which causes the muscle-like cells to compress the alveoli. This generates pressure in the udder. The milk let-down of sheep lasts only for a short period, up to two minutes (as against up to 8 minutes for cows) depending on breed and stage of lactation.

Hand-milking

Hand-milking is the method of milking most often used in small herds. The efficiency of milking is very much dependent upon the milk let-down. A good milker may be able to milk 20 to 40 ewes with slow milk let-down (the Lacaune breed) in one hour, while the same milker may be able to milk 40 to 100 ewes per hour of sheep having fast milk let-down (the Manech breed).

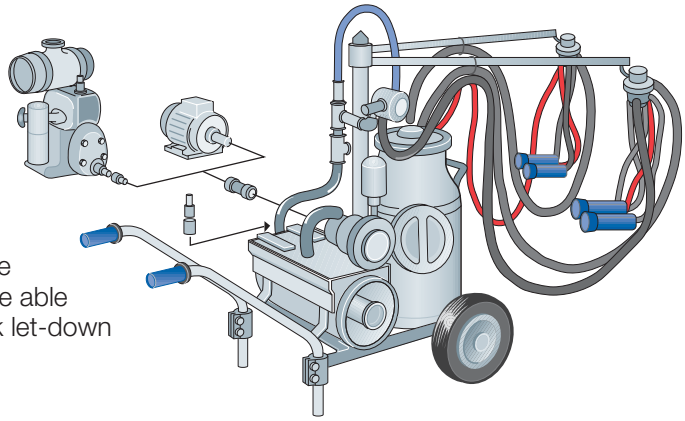


Fig. 1.23 *Mobile milking unit.*

Machine milking

Dairy farmers with more than 150 ewes generally install machine milking systems to take the hard labour out of milking.

The working principle of milking machines for ewes is similar to that described for cows, except that milking vacuum is lower, and the pulsation rates are much higher.

The most common types of machine milking installations are churn, mobile and pipeline systems (see Figure 1.22, 1.23 and 1.24).

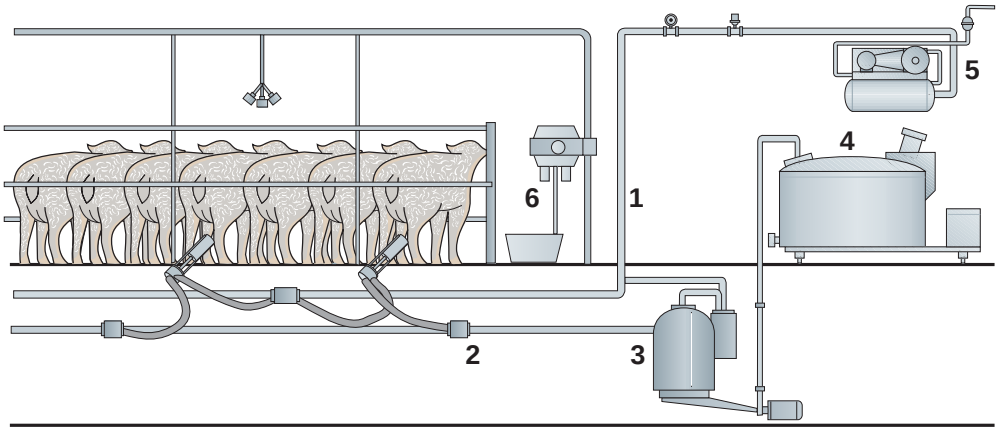


Fig. 1.24 *Pipeline milking system.*
1 *Milk pipeline*
2 *Vacuum pipeline*
3 *Receiver unit*
4 *Milk tank for cooling and storage*
5 *Vacuum pump*
6 *Teat cup cleaning unit*

In a *churn installation* the vacuum system is fixed and the churn unit is movable. The churn, which holds 20 to 40 litres, is used for manual transport of milk to the storage tank.

The pulsator can be mounted on the churn lid. A non-return valve in the lid allows air to be sucked from the pail.

A churn plant can have one to three churns per operator. The normal capacity of an operator with two churns is 70 ewes per hour. This type of installation is suitable for small flocks of up to 140 animals.

In a *pipeline milking installation* the milk line can be installed at high or low level in the parlour. Milking capacity depends on the design of the parlour.

The *mobile milking unit* is suitable for small flocks and outdoor milking, and when ewes must be milked in different places. The installation has the same capacity as that of a churn milking installation.

The unit consists of a complete vacuum system, power unit (electric motor or combustion engine), cluster assemblies, milk container for 20 to 40 litres and pulsation system, all mounted on a trolley.

During milking the trolley is placed behind four to eight ewes. The two pivoted bars are turned outwards behind the ewes, and the cluster assemblies are attached from the rear.

Goat milk

The goat was probably the first ruminant that was domesticated. Goats originate from Asia and are now spread almost all over the globe. Goats are very hardy animals. They thrive in areas where it may be difficult for other animals. Unlike sheep, goats are not flock animals.

There are numerous breeds of goat, but no specialised dairy breed. However, Saanen, Alpine, Toggenburg and Chamois breeds have been very successfully selected and bred for increased milk yields. Because of this, they have been exported all over the world for purpose of being crossed with local breeds.

Cashmere and Angora are breeds known for the special wool they produce.

Yield and lactation period

In a well-managed milk production herd, a goat can produce between 400 and 1 300 kg milk per lactation. The length of lactation varies from 200 to 300 days.

The hard, uncomfortable work of hand milking is eased by milking by machine. However, a certain volume of milk should be produced or a certain number of animals should be kept to justify change to mechanical milking. For a family-sized goat milking operation, depending upon local conditions at least 50 to 150 goats are required to reach an acceptable turnover. A business enterprise requires a larger number of animals, e.g. 200 to 1 000 goats. An intensive and feasible production unit, family sized operation or business enterprise, however, requires not only appropriate milking equipment but also effective management, feeding and breeding programmes.

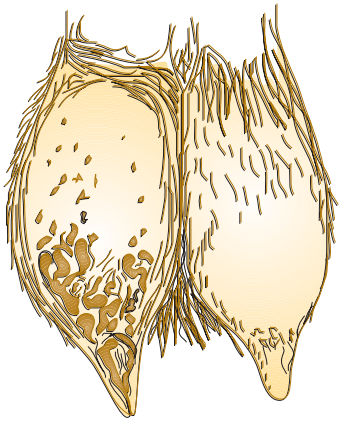


Fig. 1.25 *The shape of the goat's udders.*

Secretion of milk

Goats secrete milk in the same way as other lactating domestic animals.

The composition of goat milk, like that of other species, is influenced by several factors. From Table 1.1 it appears that gross composition of goat milk is almost similar to that of the cow. However, the ratio of casein to whey proteins in goat milk is narrower, 75:25, as compared to 80:20 for cow milk. The relative higher content of whey proteins may make goat milk more sensitive to heating.

The pH of goat milk normally varies between 6,5 and 6,7.

Milking

The female goat, like the ewe, has an udder with two halves (Figure 1.25) each with one teat. Compared with the ewe, the teats are in general somewhat longer and located at the lowest point of each half, and most of the milk is stored at the cysternal part of the udder, so both manual as well as machine milking is fairly easy to perform.

The duration of milk let-down of the goat may last for 1 to 4 minutes depending on stage of lactation and breed.

Hand milking

Milking by hand is still a common way of milking goats in many parts of the world, but machine milking is growing very fast.

Machine milking, cooling and storage

Machine milking greatly facilitates the work on large goat farms. Previous information about sheep and equipment for milking, cooling, cleaning and storage applies for the most part to goats as well.

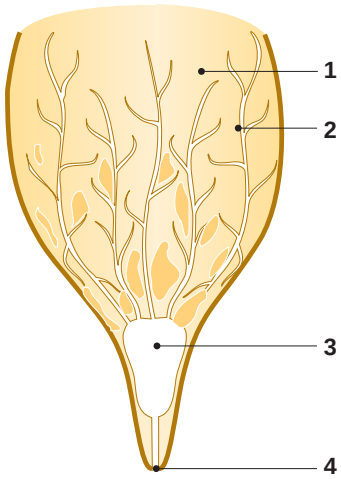
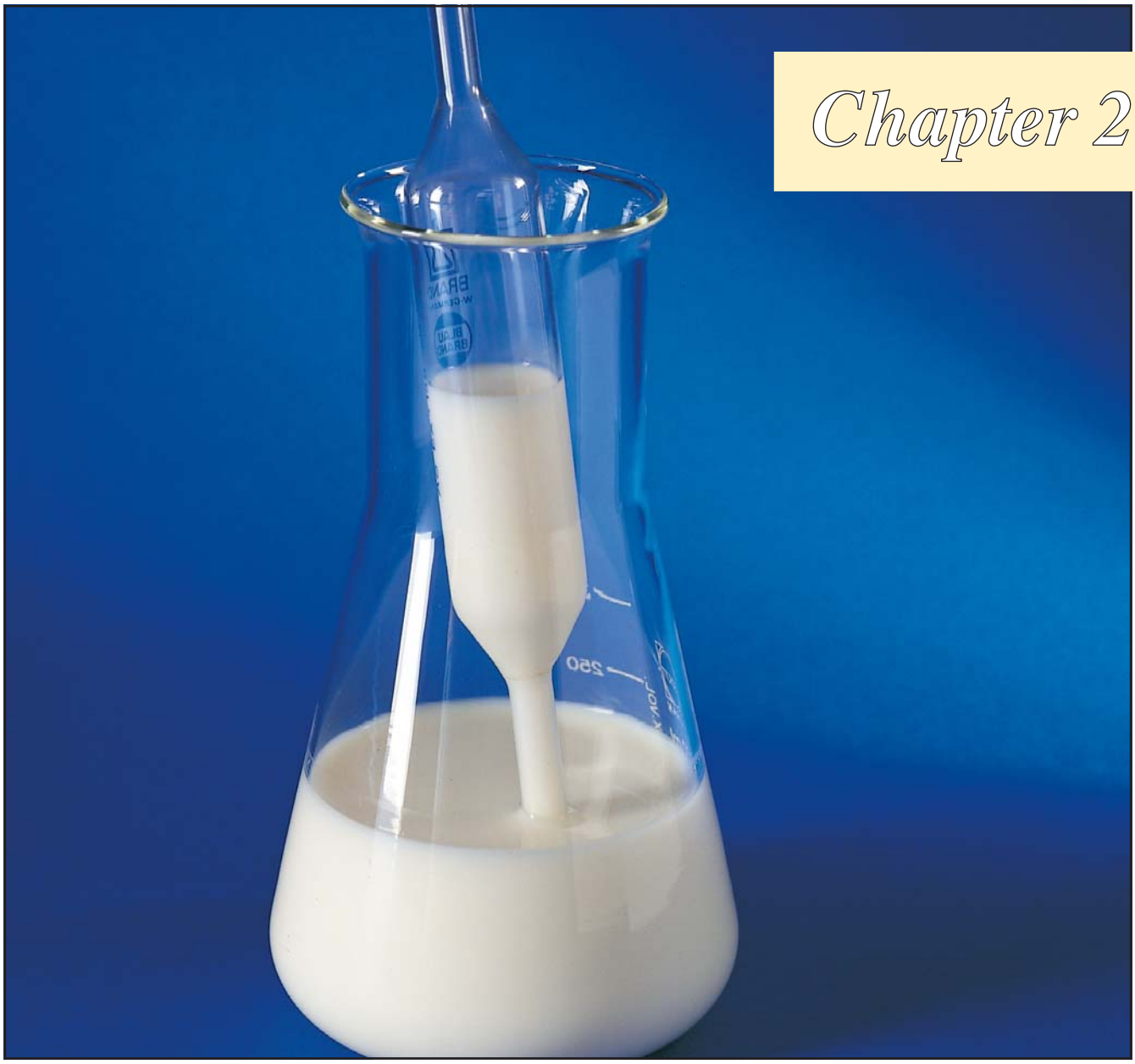


Fig. 1.26 *Cross-section of one half of the goat's udder.*
1 *Alveolar tissue*
2 *Milk ducts*
3 *Cistern*
4 *Teat canal*



Chapter 2

The chemistry of milk

The principal constituents of milk are water, fat, proteins, lactose (milk sugar) and minerals (salts). Milk also contains trace amounts of other substances such as pigments, enzymes, vitamins, phospholipids (substances with fatlike properties), and gases.

The residue left when water and gases are removed is called the *dry matter (DM)* or *total solids* content of the milk.

Milk is a very complex product. In order to describe the various constituents of milk and how they are affected by the various stages of treatment in the dairy, it is necessary to resort to chemical terminology. This chapter on the chemistry of milk therefore begins with a brief review of some basic chemical concepts.

Basic chemical concepts

Atoms

The atom is the smallest building block of all matter in nature and cannot be divided *chemically*. A substance in which all the atoms are of the same kind is called an element. More than 100 elements are known today. Examples are oxygen, carbon, copper, hydrogen and iron. However, most naturally-occurring substances are composed of several different elements. Air, for example, is a mixture of oxygen, nitrogen, carbon dioxide and rare gases, while water is a chemical compound of the elements hydrogen and oxygen.

The nucleus of the atom consists of protons and neutrons, Figure 2.1. The protons carry a positive unit charge, while the neutrons are electrically neutral. The electrons, which orbit the nucleus, carry a negative charge equal and opposite to the unit charge of the protons.

An atom contains equal numbers of protons and electrons with an equal number of positive and negative charges. The atom is therefore electrically neutral.

An atom is very small, Figure 2.2. There are about as many atoms in a small copper coin as there are seconds in a thousand million million years! Even so, an atom consists mostly of empty space. If we call the diameter of the nucleus one, the diameter of the whole atom is about 10 000.

Chemical symbols of some common elements in organic matter:

C	Carbon	**N**	Nitrogen
Cl	Chlorine	**Na**	Sodium
H	Hydrogen	**O**	Oxygen
I	Iodine	**P**	Phosphorus
K	Potassium	**S**	Sulphur

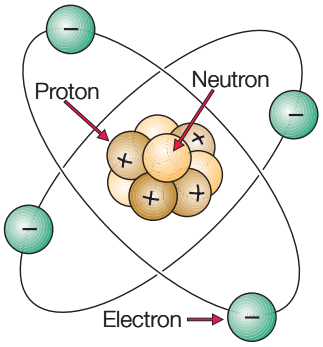


Fig. 2.1 *The nucleus of the atom consists of protons and neutrons. Electrons orbit the nucleus.*

Ions

An atom may lose or gain one or more electrons. Such an atom is no longer electrically neutral. It is called an ion. If the ion contains more electrons than protons it is negatively charged, but if it has lost one or more electrons it is positively charged.

Positive and negative ions are always present at the same time; *i.e.* in solutions as cations (positive charge) and anions (negative charge) or in solid form as salts. Common salt consists of sodium (Na) and chlorine (Cl) ions and has the formula NaCl (sodium chloride).

Molecules

Atoms of the same element or of different elements can combine into larger units which are called molecules. The molecules can then form solid substances, *e.g.* iron (Fe) or siliceous sand (SiO_2), liquids, *e.g.* water (H_2O), or gases, *e.g.* hydrogen (H_2). If the molecule consists mainly of carbon (C), hydrogen (H_2) and oxygen (O_2) atoms, the compound formed is said to be organic, *i.e.* produced from organic cells. An example is lactic acid ($C_3H_6O_3$). The formula means that the molecule is made up of three carbon atoms, six hydrogen atoms and three oxygen atoms.

The number of atoms in a molecule can vary enormously. There are molecules which consist of two linked atoms, and others composed of hundreds of atoms.

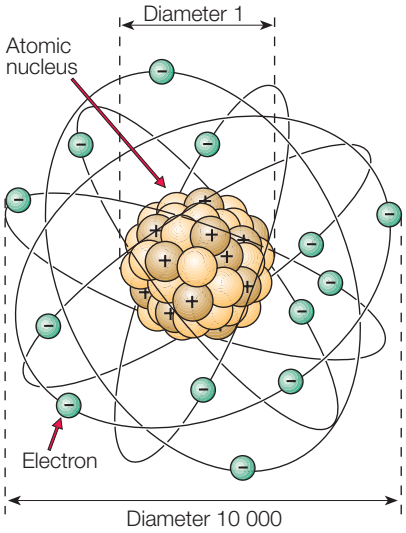


Fig 2.2 *The nucleus is so small in relation to the atom that if it were enlarged to the size of a tennis ball, the outer electron shell would be 325 metres from the centre.*

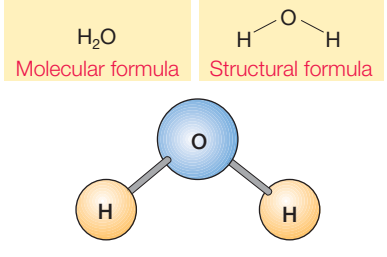


Fig 2.3 *Three ways of symbolising a water molecule.*

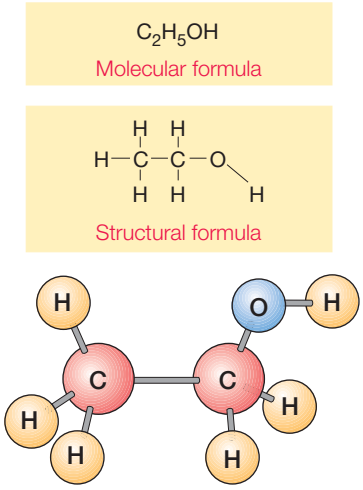


Fig 2.4 *Three ways of symbolising an ethyl alcohol molecule.*

Basic physical-chemical properties of cows' milk

Cows' milk consists of about 87 % water and 13 % dry substance. The dry substance is suspended or dissolved in the water. Depending on the type of solids, there are different distribution systems of them in the water phase.

Organic compounds contain mainly carbon, oxygen and hydrogen.

Inorganic compounds contain mainly other atoms.

Table 2.1
Physical-chemical status of cows' milk.

	Average composition %	Emulsion type oil/water	Collodial solution/ suspension	True solution
Moisture	87,0			
Fat	4,0	X		
Proteins	3,5		X	
Lactose	4,7			X
Ash	0,8			X

Definitions

Emulsion: a suspension of droplets of one liquid in another. Milk is an emulsion of oil in water (o/w), butter an emulsion of water in oil (w/o). The finely divided liquid is known as the dispersed phase and the other as the continuous phase.

Collodial solution: when matter exists in a state of division intermediate to true solution (*e.g.* sugar in water) and suspension (*e.g.* chalk in water) it is said to be in colloidal solution or colloidal suspension. The typical characteristics of a colloid are:

- Small particle size
- Electrical charge and
- Affinity of the particles for water molecules

In milk the whey proteins are in colloidal solution and the casein in colloidal suspension.

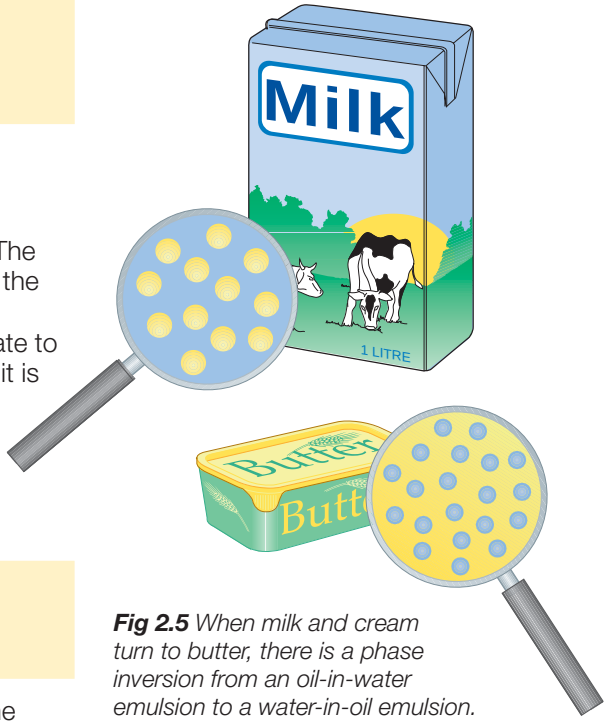


Fig 2.5 *When milk and cream turn to butter, there is a phase inversion from an oil-in-water emulsion to a water-in-oil emulsion.*

Substances such as salts destabilise colloidal systems by changing the water binding and thereby reducing protein solubility, and factors such as heat, causing unfolding of the whey proteins and increased interaction between the proteins, or alcohol which may act by dehydrating the particles.

Table 2.2
Relative sizes of particles in milk.

Size (mm)	Type of particles
10^{-2} to 10^{-3}	Fat globules
10^{-4} to 10^{-5}	Casein-calcium phosphates
10^{-5} to 10^{-6}	Whey proteins
10^{-6} to 10^{-7}	Lactose, salts and other substances in true solutions

Ref. *A Dictionary of Dairying* by J G Davis

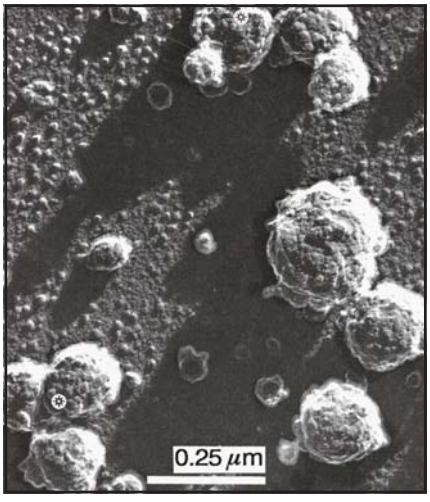


Fig 2.6 *Milk proteins can be made visible by an electron microscope.*

Ref. Miloslav Kaláb, Food structure, 1993.

True solutions: Matter which, when mixed with water or other liquids, forms true solutions, is divided into:

- *Non-ionic solutions.* When lactose is dissolved in water, no important changes occur in the molecular structure of the lactose.

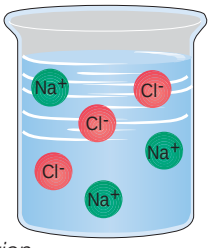


Fig 2.7 *Ionic solution.*

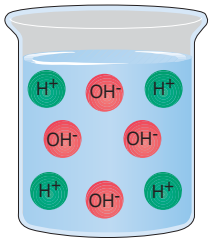


Fig 2.8 *Neutral solution with pH 7.*

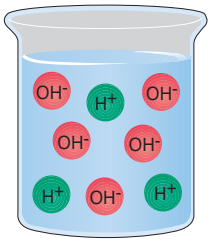


Fig 2.9 *Alkaline solution with pH higher than 7.*

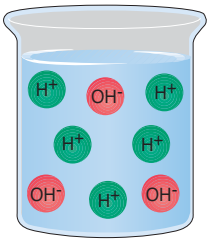


Fig 2.10 *Acid solution with pH less than 7.*

- *Ionic solutions.* When common salt is dissolved in water, cations (Na^+) and anions (Cl^-) are dispersed in the water, forming an electrolyte.

Acidity of solutions

When an acid (*e.g.* hydrochloric acid, HCl) is mixed with water it releases hydrogen ions (protons) with a positive charge (H^+). These quickly attach themselves to water molecules, forming hydrogen (H_30^+) ions.

When a base (a metal oxide or hydroxide) is added to water, it forms a basic or alkaline solution. When the base dissolves it releases hydroxide (OH^-) ions.

- A solution that contains equal numbers of hydroxide and hydrogen ions is neutral. Figure 2.8.
- A solution that contains more hydroxide ions than hydrogen ions is alkaline. Figure 2.9.
- A solution that contains more hydrogen ions than hydroxide ions is acid. Figure 2.10.

pH

The acidity of a solution is determined as the concentration of hydrogen ions. However, this varies a great deal from one solution to another. The symbol pH is used to denote the hydrogen ion concentration.

Mathematically, pH is defined as the negative logarithm to the base 10 of the hydrogen ion concentration expressed in molarity, *i.e.* $pH = -\log [H^+]$.

This results in the following scale at 25 °C:

$pH > 7$ – alkaline solution
$pH = 7$ – neutral solution
$pH < 7$ – acid solution

Neutralisation

When an acid is mixed with an alkali the hydrogen and hydroxide ions react with each other to form water. If the acid and alkali are mixed in certain proportions, the resulting mixture will be neutral, with no excess of either hydrogen or hydroxide ions and with a pH of 7. This operation is called neutralisation and the chemical formula:

$H_30^+ + OH^-$ results in $H_20 + H_20$

Neutralisation results in the formation of a salt. When hydrochloric acid (HCl) is mixed with sodium hydroxide (NaOH), the two react to form sodium chloride (NaCl) and water (H_20). The salts of hydrochloric acid are called chlorides, and other salts are similarly named after the acids from which they are formed: citric acid forms citrates, nitric acid forms nitrates, and so on.

Diffusion

The particles present in a solution – ions, molecules or colloids – are influenced by forces which cause them to migrate (diffuse) from areas of high concentration to areas of low concentration. The diffusion process continues until the whole solution is homogeneous, with the same concentration throughout.

Sugar dissolving in a cup of coffee is an example of diffusion. The sugar dissolves quickly in the hot drink, and the sugar molecules diffuse until they are uniformly distributed in the drink.

The rate of diffusion depends on particle velocity, which in turn depends on the temperature, the size of the particles, and the difference in concentration between various parts of the solution.

Figure 2.11 illustrates the principle of the diffusion process. The U-tube is divided into two compartments by a *permeable* membrane. The left leg is then filled with water and the right with a sugar solution whose molecules can pass through the membrane. After a while, through diffusion, the concentration is equalised on both sides of the membrane.

Osmosis

Osmosis is the term used to describe the spontaneous flow of pure water into an aqueous solution, or from a less to a more concentrated solution, when separated by a suitable membrane. The phenomenon of osmosis can be illustrated by the example shown in Figure 2.12. The U-tubes are divided in two compartments by a *semi-permeable* membrane. The left leg is filled with water and the right with a sugar solution whose molecules cannot pass through the membrane. Now the water molecules will diffuse through the membrane into the sugar solution and dilute it to a lower concentration. This process is called *osmosis.*

The volume of the sugar solution increases when it is diluted. The surface of the solution rises as shown in Figure 2.12, and the hydrostatic pressure, **a**, of the solution on the membrane becomes higher than the pressure of the water on the other side. In this state of imbalance, water molecules begin to diffuse back in the opposite direction under the influence of the higher hydrostatic pressure in the solution. When the diffusion of water in both directions is equal, the system is in equilibrium.

If hydrostatic pressure is initially applied to the sugar solution, the intake of water through the membrane can be reduced. The hydrostatic pressure necessary to prevent equalisation of the concentration by diffusion of water into the sugar solution is called the *osmotic pressure of* the solution.

Reverse osmosis

If a pressure higher than the osmotic pressure is applied to the sugar solution, water molecules can be made to diffuse from the solution to the water, thereby increasing the concentration of the solution. This process illustrated in Figure 2.13 is used commercially to concentrate solutions and is termed *Reverse Osmosis* (RO).

Dialysis

Dialysis is a technique employing the difference in concentration as a driving force to separate large particles from small ones in a solution, for example proteins from salts. The solution to be treated is placed on one side of a membrane, and a solvent (water) on the other side. The membrane has pores of a diameter which allows the small salt molecules to pass through, but is too small for the protein molecules to pass, see Figure 2.14.

The rate of diffusion varies with the difference in concentration, so dialysis can be speeded up if the solvent on the other side of the membrane is changed often.

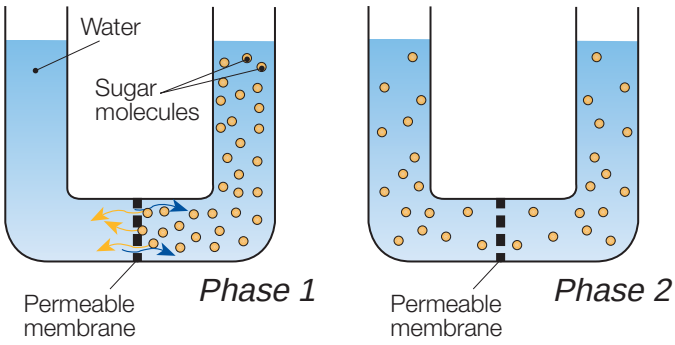


Fig 2.11 *The sugar molecules diffuse through the permeable membrane and the water molecules diffuse in the opposite direction in order to equalise the concentration of the solution.*

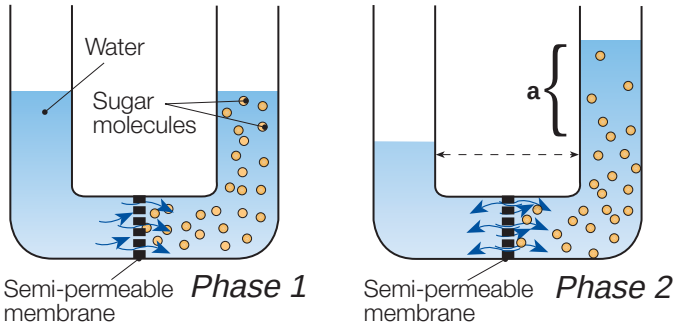


Fig. 2.12 *The sugar molecules are too large to diffuse through the semi-permeable membrane. Only the small water molecules can diffuse to equalise the concentration. "a" is the osmotic pressure of the solution.*

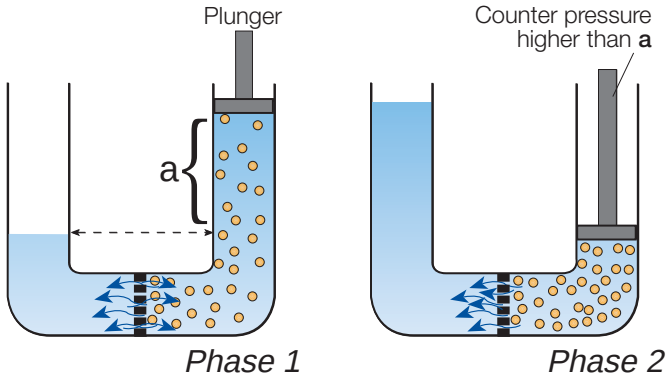


Fig. 2.13 *If a pressure higher than the osmotic pressure is applied to the sugar solution, water molecules diffuse and the solution becomes more concentrated.*

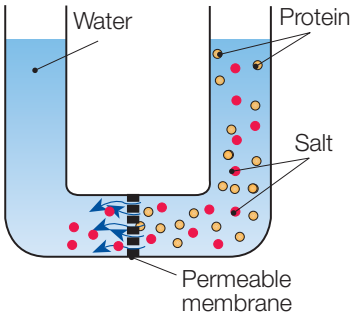


Fig 2.14 *Diluting the solution on one side of the membrane concentrates the large molecules as small molecules pass throught it.*

Composition of cows' milk

The quantities of the various main constituents of milk can vary considerably between cows of different breeds and between individual cows of the same breed. Therefore only limit values can be stated for the variations. The numbers in Table 2.3 are simply examples.

Besides total solids, the term solids-non-fat (SNF) is used in discussing the composition of milk. SNF is the total solids content less the fat content. The mean SNF content according to Table 2:3 is consequently 13,0 – 3,9 = 9,1 %. The pH of normal milk generally lies between 6,5 and 6,7, with 6,6 as the most common value. This value is true for pH measurement of milk of approximately 25 °C.

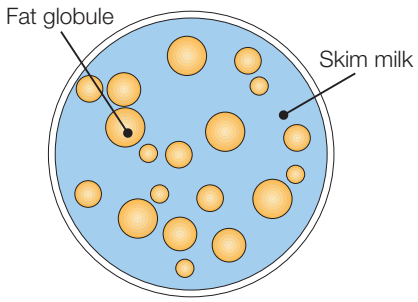


Fig 2.15 *A look into milk.*

Table 2.3
Quantitative composition of milk

Main constituent	Limits of variation	Mean value
Water	85,5 – 89,5	87,5
Total solids	10,5 – 14,5	13,0
Fat	2,5 – 6,0	3,9
Proteins	2,9 – 5,0	3,4
Lactose	3,6 – 5,5	4,8
Minerals	0,6 – 0,9	0,8

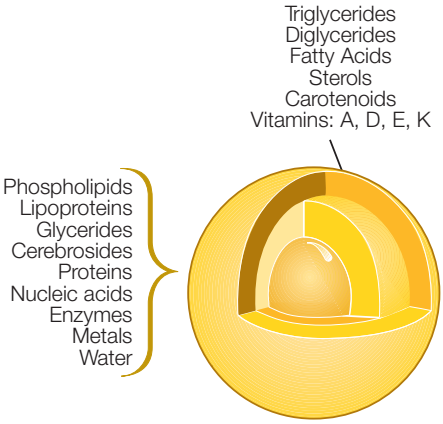


Fig 2.16 *The composition of milk fat. Size 0,1 – 20 µm. Average size 3 – 4 µm.*

Milk fat

Milk and cream are examples of *fat-in-water* (or oil-in-water) emulsions. The milk fat exists as small globules or droplets dispersed in the milk serum, Figure 2.15. Their diameters range from 0,1 to 20 µm (1 µm = 0,001 mm). The average size is 3 – 4 µm and there are some 15 billion globules per ml.

The emulsion is stabilised by a very thin membrane only 5 – 10 nm thick (1 nm = 10^{-9} m) which surrounds the globules and has a complicated composition.

Milk fat consists of triglycerides (the dominating components), di- and monoglycerides, fatty acids, sterols, carotenoids (giving the yellow colour of the fat) and vitamins (A, D, E, and K). Trace elements, are minor components. The composition of a milk fat globule is outlined in Figure 2.16.

The membrane consists of phospholipids, lipoproteins, cerebrosides, proteins, nucleic acids, enzymes, trace elements (metals) and bound water. It should be noted that the composition and thickness of the membrane are not constant, because components are constantly being exchanged with the surrounding milk serum.

As the fat globules are not only the largest particles in the milk but also the lightest (density at 15,5 °C = 0,93 g/cm^3), they tend to rise to the surface when milk is left to stand in a vessel for a while, Figure 2.17.

The rate of rise follows *Stokes' Law*, but the small size of the fat globules makes creaming a slow process. Cream separation can, however, be accelerated by aggregation of fat globules under the influence of a protein called *agglutinin.* These aggregates rise much faster than individual fat globules. The aggregates are easily broken up by heating or mechanical treatment. Agglutinin is denatured at time-temperature combinations such as 65 °C/10 min or 75 °C/2 min and the possibility of aggregation disappears.

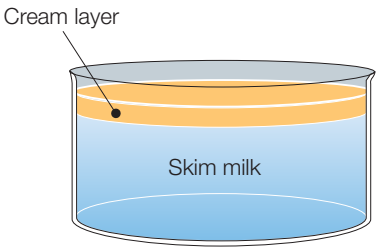


Fig 2.17 *If milk is left to stand for a while in a vessel, the fat will rise and form a layer of cream on the surface.*

Chemical structure of milk fat

Milk fat is liquid when milk leaves the udder at 37 °C. This means that the fat globules can easily change their shape when exposed to moderate mechanical treatment – pumping and flowing in pipes for instance – without being released from their membranes.

All fats belong to a group of chemical substances called esters, which are compounds of alcohols and acids. Milk fat is a mixture of different fatty-acid esters called triglycerides, which are composed of an alcohol called glycerol and various fatty acids. Fatty acids make up about 90 % of milk fat.

A fatty-acid molecule is composed of a hydrocarbon chain and a carboxyl group (formula RCOOH). In saturated fatty acids, the carbon atoms are linked together in a chain by single bonds, while in unsaturated fatty acids there are one or more double bonds in the hydrocarbon chain. Each glycerol molecule can bind three fatty-acid molecules, and as the three need not necessarily be of the same kind, the number of different glycerides in milk is extremely large.

Table 2.4 lists the most important fatty acids in milk fat triglycerides.

Milk fat is characterised by the presence of relatively large amounts of butyric and caproic acid.

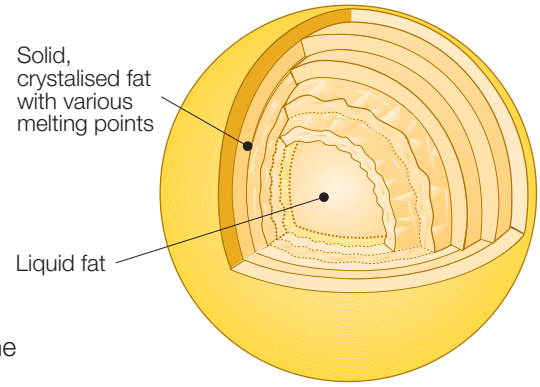


Fig 2.18 *Sectional view of a fat globule.*

Table 2.4
Principal fatty acids in milk fat

Fatty acid	% of total fatty-acid content	Melting point °C	Number of atoms H	C	O	
Saturated						
Butyric acid	3,0 – 4,5	–7,9	8	4	2	Liquid at room temp-erature
Caproic acid	1,3 – 2,2	–1,5	12	6	2	
Caprylic acid	0,8 – 2,5	+16,5	16	8	2	
Capric acid	1,8 – 3,8	+31,4	20	10	2	Solid at room temp-erature
Lauric acid	2,0 – 5,0	+43,6	24	12	2	
Myristic acid	7,0 – 11,0	+53,8	28	14	2	
Palmitic acid	25,0 – 29,0	+62,6	32	16	2	
Stearic acid	7,0 – 3,0	+69,3	36	18	2	
Unsaturated						
Oleic acid	30,0 – 40,0	+14,0	34	18	2	Liquid at room temp-erature
Linoleic acid	2,0 – 3,0	–5,0	32	18	2	
Linolenic acid	up to 1,0	–5,0	30	18	2	
Arachidonic acid	up to 1,0	–49,5	32	20	2	

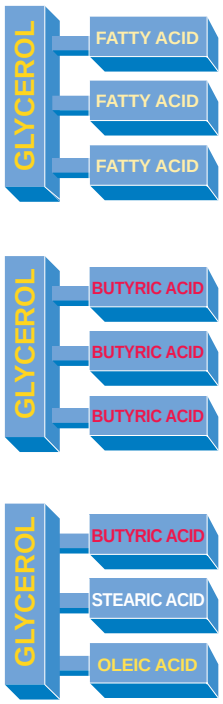


Fig 2.19 *Milk fat is a mixture of different fatty acids and glycerol.*

Melting point of fat

Table 2.4 shows that the four most abundant fatty acids in milk are myristic, palmitic, stearic and oleic acids.

The first three are solid and the last is liquid at room temperature. As the quoted figures indicate, the relative amounts of the different fatty acids can vary considerably. This variation affects the hardness of the fat. Fat with a high content of high-melting fatty acids, such as palmitic acid, will be hard; but on the other hand, fat with a high content of low-melting oleic acid makes soft butter.

Determining the quantities of individual fatty acids is a matter of purely scientific interest. For practical purposes, it is sufficient to determine one or more constants or indices which provide certain information concerning the composition of the fat.

Iodine value

Fatty acids with the same numbers of C and H atoms but with different numbers of single and double bonds have completely different characteristics. The most important and most widely used method of indicating

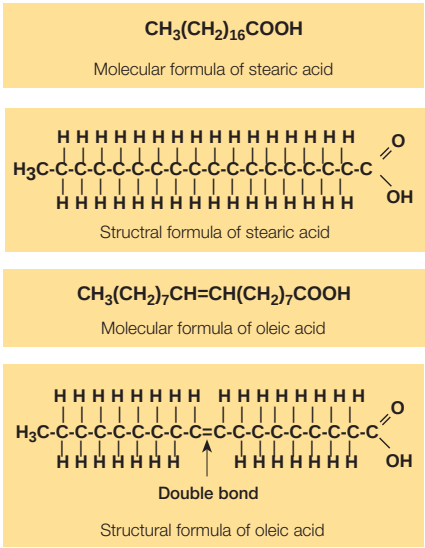


Fig 2.20 *Molecular and structural formulae of stearic and oleic acids.*

Fat with a high content of high-melting fatty acids is hard.

Fat with a high content of low-melting fatty acids is soft.

their specific characteristics is to measure the *iodine value* (IV) of the fat. The iodine value states the percentage of iodine that the fat can bind. Iodine is taken up by the double bonds of the unsaturated fatty acids. Since oleic acid is by far the most abundant of the unsaturated fatty acids, which are liquid at room temperature, the iodine value is largely a measure of the oleic-acid content and thereby of the softness of the fat.

The iodine value of butterfat normally varies between 24 and 46. The variations are determined by what the cows eat. Green pasture in the summer promotes a high content of oleic acid, so that summer milk fat is soft (high iodine value). Certain fodder concentrates, such as sunflower cake and linseed cake, also produce soft fat, while types of fodder such as coconut and palm oil cake and root vegetable tops produce hard fat. It is therefore possible to influence the consistency of milk fat by choosing a suitable diet for the cows. For butter of optimum consistency, the iodine value should be between 32 and 37.

Figure 2.21 shows an example of how the iodine value of milk fat can vary in the course of a year (Sweden).

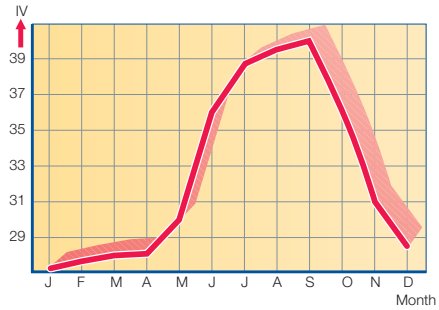


Fig 2.21 *Iodine value at different times of the year. The iodine value is a measure of the oleic acid content of the fat.*

Refractive index

The amount of different fatty acids in fat also affects the way it refracts light. It is therefore common practice to determine the *refractive index* of fat, which can then be used to calculate the iodine value. This is a quick method of assessing the hardness of the fat. The refractive index normally varies between 40 and 46.

Nuclear Magnetic Resonance (NMR)

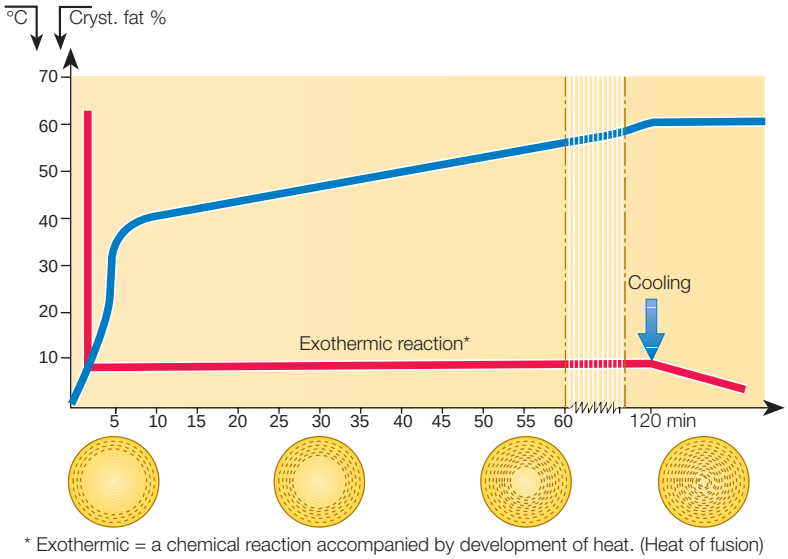
Instead of analysing the iodine value or refractive index, the ratio of saturated fat to unsaturated fat can be determined by pulsed NMR. A conversion factor can be used to transform the NMR value into a corresponding iodine value if desired.

The NMR method can also be utilised to find out the degree of fat crystallisation as a function of the time of crystallisation. Trials made at the SMR laboratory in Malmö, Sweden, 1979 to 1981, show that fat crystallisation takes a long time in a 40 % cream cooled from 60 °C to 5 °C. A crystallisation time of at least two hours was needed, and the proportion of crystallised fat was 65 % of the total.

It was also noted that only 15 to 20 % of the fat was crystallised two minutes after 5 °C was reached. The NMR value of butterfat normally varies between 30 and 41.

Fat crystallisation

During the crystallisation process, the fat globules are in a very sensitive state and are easily broken – opened up – even by moderate mechanical treatment.



* Exothermic = a chemical reaction accompanied by development of heat. (Heat of fusion)

Fig 2.22 *Milk fat crystallisation is an exothermic reaction, which means that the chemical reaction is accompanied by evolution of heat. The crystallisation curve is based on analysis made by the NMR method.*

Electron microscope studies have shown that fat crystallises in monomolecular spheres, see Figure 2.22. At the same time fractionation takes place, so that the triglycerides with the highest melting points form the outer spheres. Because crystallised fat has a lower specific volume than liquid fat, tensions arise inside the globules, making them particularly unstable and susceptible to breakage during the crystallisation period. The result is that liquid fat is released into the milk serum, causing formation of lumps where the free fat glues the unbroken globules together (the same phenomenon that occurs in butter production). Crystallisation of fat generates fusion heat, which raises the temperature somewhat (40% cream cooled from 60 °C to 7 – 8 °C grows 3 – 4 °C warmer during the crystallisation period).

It is important to bear this important property of milk fat in mind in production of cream for various purposes.

Proteins in milk

Proteins are an essential part of our diet. The proteins we eat are broken down into simpler compounds in the digestive system and in the liver. These compounds are then conveyed to the cells of the body where they are used as construction material for building the body's own protein. The great majority of the chemical reactions that occur in the organism are controlled by certain active proteins, the enzymes.

Proteins are giant molecules built up of smaller units called amino acids, Figure 2.23. A protein molecule consists of one or more interlinked chains of amino acids, where the amino acids are arranged in a specific order. A protein molecule usually contains around 100 – 200 linked amino acids, but both smaller and much larger numbers are known to constitute a protein molecule.

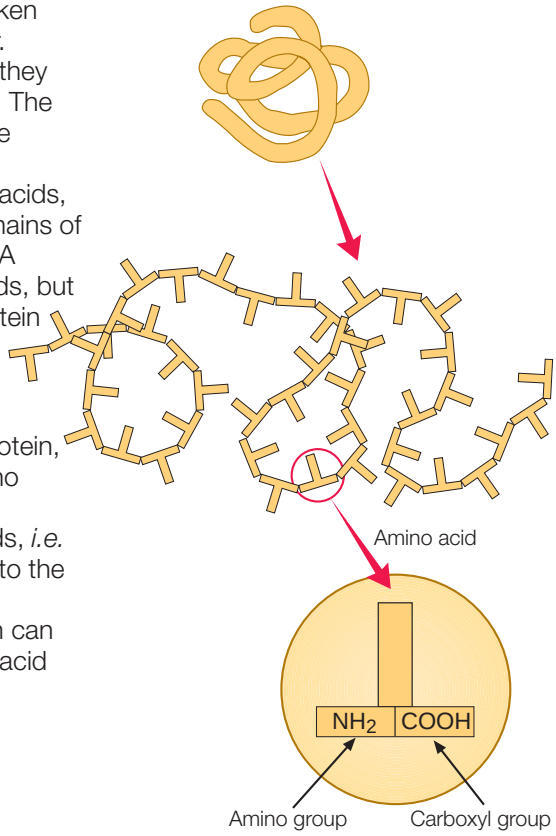


Fig 2.23 *Model of a protein molecule chain of amino acids, the amino and carboxyl groups.*

Amino acids

The amino acids in Figure 2.24 are the building blocks forming the protein, and they are distinguished by the simultaneous presence of one amino group ($–NH_2$) and one carboxyl group (–COOH) in the molecule. The proteins are formed from a specific kind of amino acids, α amino acids, *i.e.* those which have both an amino group and a carboxyl group bound to the same carbon atom, the α-carbon.

The amino acids belong to a group of chemical compounds which can emit hydrogen ions in alkaline solutions and absorb hydrogen ions in acid solutions. Such compounds are called amphotery electrolytes or ampholytes. The amino acids can thus appear in three states:

1 Negatively charged in alkaline solutions
2 Neutral at equal + and – charges
3 Positively charged in acid solutions

Proteins are built from a supply of approx. 20 amino acids, 18 of which are found in milk proteins.

An important fact with regard to nutrition is that *eight* (*nine* for infants) of the 20 amino acids cannot be synthesized by the human organism. As they are necessary for maintaining a proper metabolism, they have to be supplied with the food. They are called *essential amino acids*, and all of them are present in milk protein.

The type and the order of the amino acids in the protein molecule determine the nature of the protein. Any change of amino acids regarding type or place in the molecular chain may result in a protein with different properties.

As the possible number of combinations of 18 amino acids in a chain containing 100 – 200 amino acids is almost unlimited, the number of proteins with different properties is also almost unlimited. Figure 2.24 shows a model of an amino acid. As mentioned before, amino acids contain both a slightly basic amino group ($–NH_2$) and a slightly acid carboxyl group (–COOH). These groups are connected to a side chain, (R).

If the side chain is polar, the water-attracting properties of the basic and acid groups, in addition to the polar side chain, will normally dominate and

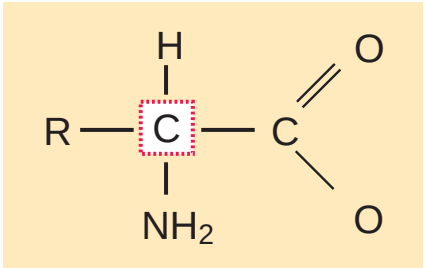


Fig 2.24 *The structure of a general amino acid. R in the figure stands for organic material bound to the central carbon atom.*

the whole amino acid will attract water and dissolve readily in water. Such an amino acid is named *hydrophilic* (water-loving).

If on the other hand the side chain is of hydrocarbon which does not contain hydrophilic radicals, the properties of the hydrocarbon chain will dominate. A long hydrocarbon chain repels water and makes the amino acid less soluble or compatible with water. Such an amino acid is called *hydrophobic* (water-repellent).

If there are certain radicals such as hydroxyl (–OH) or amino groups ($–NH_2$) in the hydrocarbon chain, its hydrophobic properties will be modified towards more hydrophilic. If hydrophobic amino acids are predominant in one part of a protein molecule, that part will have hydrophobic properties. An aggregation of hydrophilic amino acids in another part of the molecule will, likewise, give that part hydrophilic properties. A protein molecule may therefore be either hydrophilic, hydrophobic, intermediate or locally hydrophilic and hydrophobic.

Some milk proteins demonstrate very great differences within the molecules with regard to water compitability, and some very important properties of the proteins depend on such differences.

Hydroxyl groups in the chains of some amino acids in casein may be esterified with phosphoric acid. Such groups enable casein to bind calcium ions or colloidal calcium hydroxyphosphate, forming strong bridges between or within the molecules.

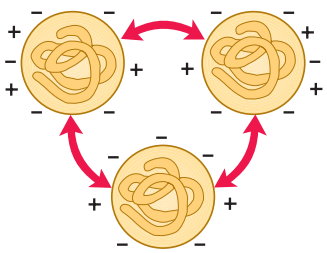


Fig 2.25 *A protein molecule at pH 6,6 has a net negative charge.*

The electrical status of milk proteins

The side chains of some amino acids in milk proteins carry an electric charge which is determined by the pH of the milk. When the pH of milk is changed by addition of an acid or a base, the charge distribution of the proteins is also changed. The electrical status of the milk proteins and the resulting properties are illustrated in the Figures 2.25 to 2.28.

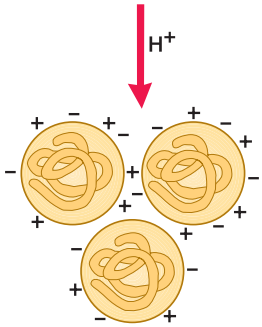


Fig 2.26 *Protein molecules at pH ≈ 4,6, the isoelectric point.*

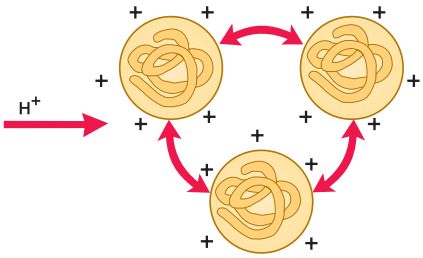


Fig 2.27 *Protein molecules at pH ≈ 1*

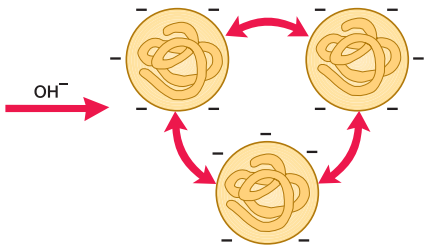


Fig 2.28 *Protein molecules at pH ≈ 14*

At the normal pH of milk, (≈ 6,6) a protein molecule has a net negative charge, Figure 2.25. The protein molecules remain separated because identical charges repel each other.

If hydrogen ions are added, Figure 2.26, they are adsorbed by the protein molecules. At a pH value where the positive charge of the protein is equal to the negative charge, *i.e.* where the numbers of NH_3^+ and $COO^–$ groups on the side chains are equal, the net total charge of the protein is zero. The protein molecules no longer repel each other, but the positive charges on one molecule link up with negative charges on the neighbouring molecules and large protein clusters are formed. The protein is then precipitated from the solution. The pH at which this happens is called the *isoelectric point* of the protein.

In the presence of an excess of hydrogen ions, the molecules acquire a net positive charge as shown in Figure 2.27. Then they repel each other once more and therefore remain in solution.

If, on the other hand, a strong alkaline solution (NaOH) is added, all proteins acquire negative charges and dissolve.

Classes of milk proteins

Milk contains hundreds of types of protein, most of them in very small amounts. The proteins can be classified in various ways according to their

chemical or physical properties and their biological functions. The old way of grouping milk proteins into casein, albumin and globulin has given way to a more adequate classification system. Table 2.5 shows an abridged list of milk proteins according to a modern system. Minor protein groups have been excluded for the sake of simplicity.

Whey protein is a term often used as a synonym for milk-serum proteins, but it should be reserved for the proteins in whey from the cheesemaking process. In addition to milk-serum proteins, whey protein also contains fragments of casein molecules. Some of the milk-serum proteins are also

Table 2.5
Concentration of proteins in milk

	Conc. in milk g/kg	% of total protein w/w
Casein		
α_{s1}-casein*)	10,0	30,6
α_{s2}-casein*)	2,6	8,0
β-casein**)	10,1	30,8
κ-casein	3,3	10,1
Total Casein	26,0	79,5
Whey Proteins		
α-lactalbumin	1,2	3,7
β-lactoglobulin	3,2	9,8
Blood Serum Albumin	0,4	1,2
Immunoglobulins	0,7	2,1
Miscellaneous (including Proteose-Peptone)	0,8	2,4
Total Whey Proteins	6,3	19,3
Fat Globule Membrane Proteins	0,4	1,2
Total Protein	32,7	100

*) Henceforth called α_s-casein
**) Including γ-casein

Ref: Walstra & Jennis

present in whey in lower concentrations than in the original milk. This is due to heat denaturation during pasteurisation of the milk prior to cheese-making. The three main groups of proteins in milk are distinguished by their widely different behaviour and form of existence. The caseins are easily precipitated from milk in a variety of ways, while the serum proteins usually remain in solution. The fat-globule membrane proteins adhere, as the name implies, to the surface of the fat globules and are only released by mechanical action, *e.g.* by churning cream into butter.

Casein

Casein is a group name for the dominant class of proteins in milk. The caseins easily form polymers containing several identical or different types of molecules. Due to the abundance of ionisable groups and hydrophobic and hydrophilic sites in the casein molecule, the molecular polymers formed by the caseins are very special. The polymers are built up of hundreds and thousands of individual molecules and form a colloidal solution, which is what gives skim milk its whitish-blue tinge. These molecular complexes are known as casein micelles. Such micelles may be as large as 0,4 microns, and can only be seen under an electron microscope.

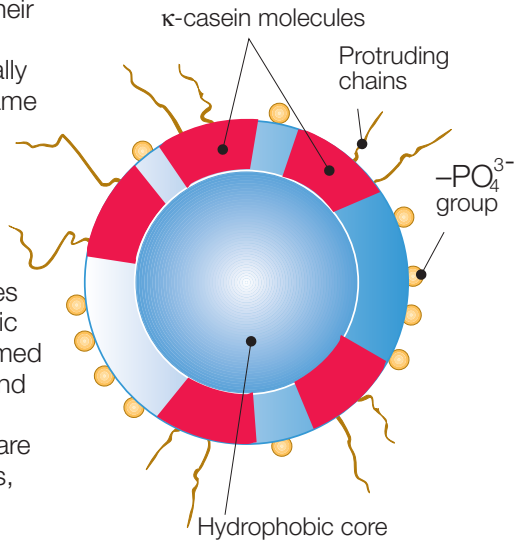


Fig 2.29 *Structure of a casein sub-micelle.*

Casein micelles

Casein micelles are fairly dense aggregates of sub-micelles with small regions of calcium phosphate, which links the sub-micelles together, giving the micelles an open, porous structure. Removal of calcium phosphate (CCP – colloidal calcium phosphate), *e.g.* by acidification or addition of EDTA or citrates, leads to disintegration of the micelles. Disintegration also occurs when pH becomes greater than 9.

There are three main subgroups of casein, α_s-casein, κ-casein and β-casein, which are all heterogeneous and consist of 2 – 8 genetic variants. Genetic variants of a protein differ from each other only by a few amino acids.

Casein micelles, shown in Figure 2.30, consist of a complex of sub-micelles, Figure 2.29, of a diameter of 10 to 15 nm (nanometer = 10^{-9} m). The content of α_s-, β- and κ-caseins is heterogeneously distributed in the different sub-micelles. The α- and β-caseins are mainly concentrated in the middle of the sub-micelles, while κ-casein predominates on the surface. It has been suggested that the hydrophilic protruding chain of the κ-casein protrudes from the surface of the sub-micelles forming a hairy layer (5 – 10 nm). However, a few α_s- and β- caseins can also be found at the surface. The current view is that the κ-casein content of the sub-micelles varies. The κ-casein-deficient sub-micelles are mainly located in the centre of the micelle, whereas the κ-casein-rich sub-micelles predominate on the surface, giving the whole micelle a hairy surface layer. The hairy layer of the κ-casein's protruding chain is partially responsible for the micelle's stability through a major contribution to the negative charge of the micelles (– 20 mV) and to their steric stabilisation. If the hairy layer is removed, *e.g.* by ethanol addition or rennet – induced hydrolysis, the colloidal stability of the micelle is destroyed and the micelles coagulate or precipitate.

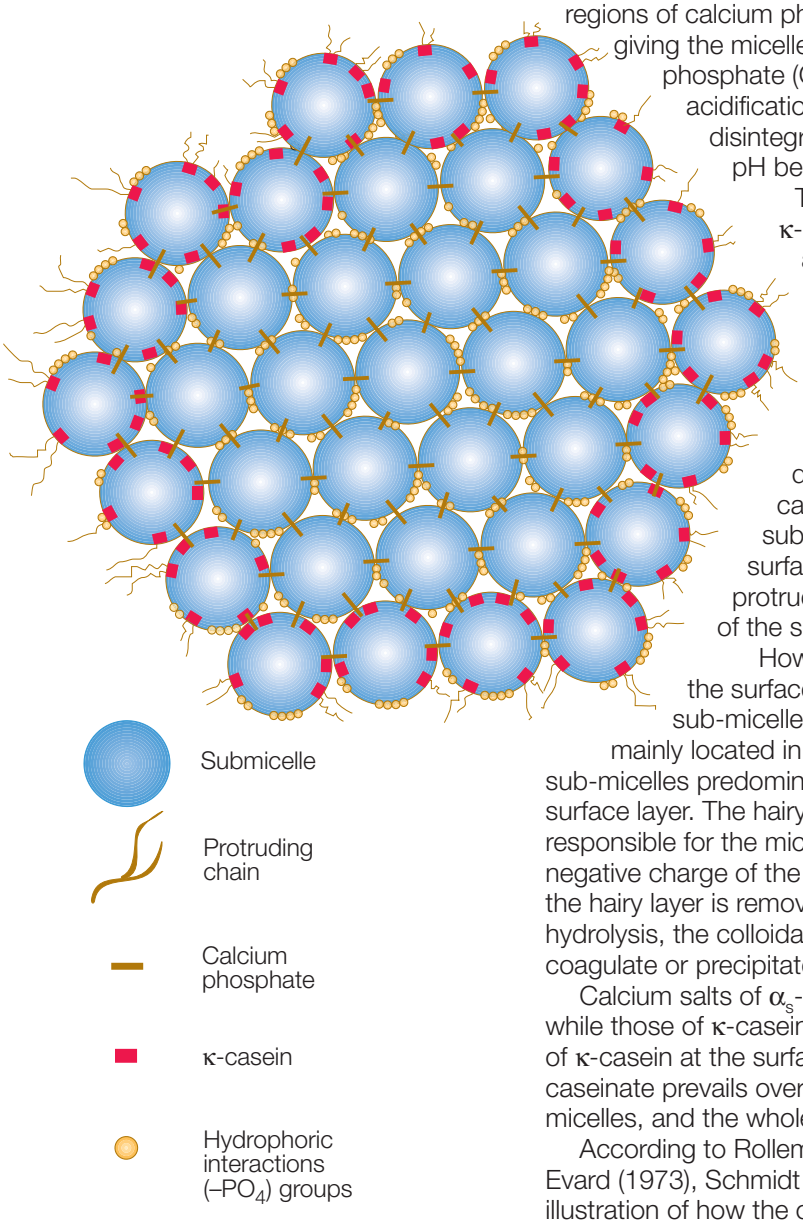


Fig 2.30 *Buildup and stabilisation of casein micelles.*

Ref: A digest of models by Slattery and Evard (1973), Schmidt (1982) and Walstra (1990) according to Rollema (1992). Rollema H.S. (1992) Casein Association and Micelle Formation p 63-111. Elsevier Science Publications Ltd.

Calcium salts of α_s-casein and β-casein are almost insoluble in water, while those of κ-casein are readily soluble. Due to the dominant localisation of κ-casein at the surface of the micelles, the solubility of calcium κ-caseinate prevails over the insolubility of the other two caseins in the micelles, and the whole micelle is soluble as a colloid.

According to Rollema (1992), a combination of the models of Slattery & Evard (1973), Schmidt (1982) and Walstra (1990) gives the best available illustration of how the casein micelles are built up and stabilised.

The calcium phosphate and hydrophobic interactions between sub-micelles are responsible for the integrity of the casein micelles. Adding an excess of Ca and phosphate results in aggregation of sub-micelles into larger units – micelles. The reason for this aggregation is presumably the deposition of Ca-phosphate in the sub-micelles, which lowers their electric charge and makes them more compact. They attract each other, causing aggregation. If two sub-micelles approach each other and the protruding peptide chains of at least one of them are in the way, they cannot agglomerate. This means that agglomeration goes on until roughly spherical particles are formed, fully covered by a more or less continuous layer of κ-casein with protruding chains that together form the hairy layer. Micelles are not uniform and vary in size. When measuring the size of casein particles, a great number of very small particles can be found. These are loose sub-micelles, but these normally form only a minor part of the total casein content.

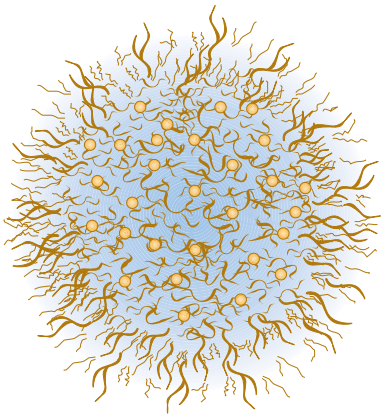


Fig 2.31 *A casein micelle.*

A casein micelle and its surroundings keep exchanging components, see Figure 2.31. The size of a micelle depends very much on the calcium ion (Ca^{++}) content. If calcium leaves the micelle, for instance by dialysis, the micelle will disintegrate into sub-micelles. A medium-sized micelle consists of about 400 to 500 sub-micelles, which are bound together as described above.

If the hydrophilic protruding chain end of κ-casein on the surfaces of micelles is split, *e.g.* by rennet, the micelles will lose their solubility and start to aggregate and form casein curd. In an intact micelle there is a surplus of negative charges, therefore they repel each other. Water molecules held by the hydrophilic sites of κ-casein form an important part of this balance. If the hydrophilic sites are removed, water will start to leave the structure. This gives the attracting forces room to act. New bonds are formed, one of the salt type, where calcium is active, and the second of the hydrophobic type. These bonds will then enhance the expulsion of water and the structure will finally collapse into a dense curd.

The micelles are adversely affected by low temperature, at which the β-casein chains start to dissociate and the CCP leaves the micelle structure, where it existed in colloidal form, and goes into solution. The explanation of this phenomenon is that β-casein is the most hydrophobic casein, and that the hydrophobic interactions are weakened when the temperature is lowered. Micelles appear to disintegrate into smaller ones, and the volume of the casein micelles increases. The loss of CCP causes a weaker attraction between sub-micelles and individual casein molecules in the sub-micelles. These changes make the milk less suitable for cheesemaking, as they result in longer renneting time and a softer curd.

β-casein is then also more easily hydrolysed by various proteases in the milk after leaving the micelle. Hydrolysis of β-casein to γ-casein and proteose-peptones means lower yield at cheese production because the proteose-peptone fractions are lost in the whey. The breakdown of β-casein may also result in formation of bitter peptides, causing off-flavour problems in the dairy products. The line graph in Figure 2.32 shows the approximate amount of β-casein (in %) that leaves a micelle at +5 °C during 20 hours' storing time.

In this context it should also be mentioned that when raw or pasteurised chill-stored milk is heated to 62 – 65 °C for about 20 seconds, the β-casein and calcium phosphate will revert to the micelle, thereby at least partly restoring the original properties of the milk.

On increasing the temperature, the micelles shrink somewhat and the amount of CCP increases. Serum proteins become largely associated with casein micelles during their heat denaturation bound to the micelle surface. One example is the association of β-lactoglobulin and κ-casein. Most of these associations cannot be reversed by cooling.

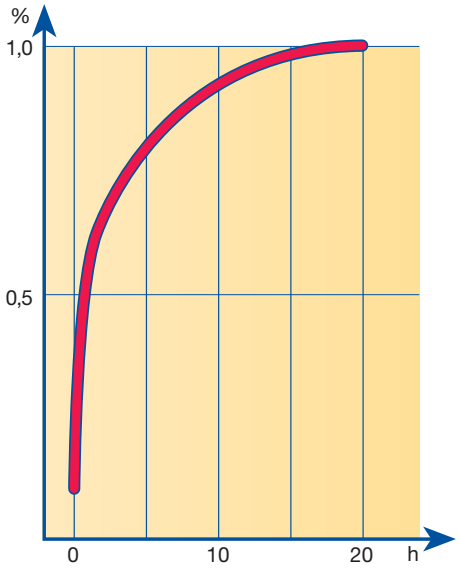


Fig 2.32 *β-casein in milk serum at +5 °C.*

Ref: Dr B Lindquist (1980), Arla Stockholm, Sweden.

Note: If a large excess of acid is added to a given coagulum, the casein will redissolve, forming a salt with the acid. If hydrochloric acid is used, the solution will contain casein hydrochloride, partly dissociated into ions.

Precipitation of casein

One characteristic property of casein is its ability to precipitate. Due to the complex nature of the casein molecules, and that of the micelles formed from them, precipitation can be caused by many different agents. It should be observed that there is a great difference between the optimum precipitation conditions for casein in micellar and non-micellar form, *e.g.* as sodium caseinate. The following description refers mainly to precipitation of micellar casein.

Precipitation by acid

The pH will drop if an acid is added to milk or if acid-producing bacteria are allowed to grow in milk. This will change the environment of the casein micelles in two ways. The course of events are illustrated in Figure 2.33. Firstly colloidal calcium hydroxyphosphate, present in the casein micelle, will dissolve and form ionised calcium, which will penetrate the micelle structure and create strong internal calcium bonds. Secondly the pH of the solution will approach the isoelectric points of the individual casein species.

Both methods of action initiate a change within the micelles, starting with growth of the micelles through aggregation and ending with a more or less dense coagulum. Depending on the final value of the pH, this coagulum will either contain casein in the casein salt form, or casein in its isoelectric state, or both.

The isoelectric points of the casein components depend on the ions of other kinds present in the solution. Theoretical values, valid under certain

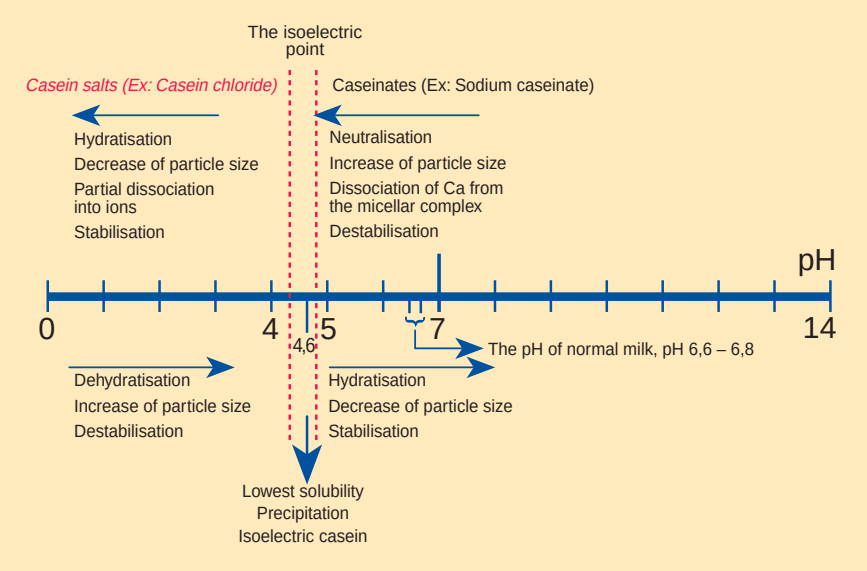


Fig. 2.33 *Three simplified stages of influence on casein by an acid and alkali respectively.*

conditions, are pH 5,1 to 5,3. In salt solutions, similar to the condition of milk, the range for optimum precipitation is pH 4,5 to 4,9. A practical value for precipitation of casein from milk is pH 4,6.

If a large excess of *sodium hydroxide* is added to the precipitated isoelectric casein, the redissolved casein will be converted into sodium caseinate, partly dissociated into ions. The pH of cultured milk products is usually in the range of 3,9 – 4,5, which is on the acid side of the isoelectric points. In the manufacture of casein from skim milk by the addition of sulphuric or hydrochloric acid, the pH chosen is often 4,6.

There are two ways to make caseinate particles flocculate and coagulate:
- Precipitation by acid
- Precipitation by enzymes

Precipitation by enzymes

The amino-acid chain forming the κ-casein molecule consists of 169 amino acids. From an enzymatic point of view the bond between amino acids 105 (phenylalanin) and 106 (methionin) is easily accessible to many proteolytic enzymes.

Some proteolytic enzymes will attack this bond and split the chain. The soluble amino end contains amino acids 106 to 169, which are dominated by polar amino acids and the carbohydrate, which give this sequence hydrophilic properties. This part of the κ-casein molecule is called the glycomacro-peptide and is released into the whey in cheesemaking.

The remaining part of the κ-casein, consisting of amino acids 1 to 105, is insoluble and remains in the curd together with α_s- and β-casein. This part is called para-κ-casein. Formerly, all the curd was said to consist of para-κ-casein.

The formation of the curd is due to the sudden removal of the hydrophilic macropeptides and the imbalance in intermolecular forces caused thereby. Bonds between hydrophobic sites start to develop and are enforced by calcium bonds which develop as the water molecules in the micelles start to leave the structure. This process is usually referred to as the phase of coagulation and syneresis.

The splitting of the 105 – 106 bond in the κ-casein molecule is often called the primary phase of the rennet action, while the phase of coagulation and syneresis is referred to as the secondary phase. There is also a tertiary phase of rennet action, where the rennet attacks the casein components in a more general way. This occurs during cheese ripening.

The durations of the three phases are determined mainly by pH and temperature. In addition the secondary phase is strongly affected by the calcium ion concentration and by the condition of micelles with regard to absence or presence of denatured milk serum proteins on the surfaces of the micelles.

Whey proteins

Whey protein is the name commonly applied to milk serum proteins.

If the casein is removed from skim milk by some precipitation method, such as the addition of mineral acid, there remains in solution a group of proteins which are called milk serum proteins.

As long as they are not denatured by heat, they are not precipitated at their isoelectric points. They are, however, usually precipitated by polyelectrolytes such as carboxymethyl cellulose. Technical processes for recovery of whey proteins often make use of such substances or of a combination of heat and pH adjustment.

When milk is heated, some of the whey proteins denature and form complexes with casein, thereby decreasing the ability of the casein to be attacked by rennet and to bind calcium. Curd from milk heated to a high temperature will not release whey as ordinary cheese curd does, due to the smaller number of casein bridges within and between the casein molecules.

Whey proteins in general, and α-lactalbumin in particular, have very high nutritional values. Their amino acid composition is very close to that which is regarded as a biological optimum. Whey protein derivatives are widely used in the food industry.

α-lactalbumin

This protein may be considered to be the typical whey protein. It is present in milk from all mammals and plays a significant part in the synthesis of lactose in the udder.

β-lactoglobulin

This protein is found only in ungulates and is the major whey protein component of milk from cows. If milk is heated to over 60 °C, denaturation is initiated where the reactivity of the sulphur-amino acid of β-lactoglobulin plays a prominent part. Sulphur bridges start to form between the β-lactoglobulin molecules, between one β-lactoglobulin molecule and a κ-casein molecule and between β-lactoglobulin and α-lactalbumin. At high temperatures, sulphurous compounds such as hydrogen sulphide are gradually released. These sulphurous compounds are responsible for the "cooked" flavour of heat treated milk.

The whey proteins are:

α-lactalbumin
β-lactoglobulin

Immunoglobulins and related minor proteins

This protein group is extremely heterogeneous, and few of its members have been studied in detail, Figure 2.34.

Immunoglobulins are antibodies synthesised in response to stimulation by specific antigens. They are specifically present in blood. Their content in cows' milk is low, but some of them are present in higher levels in colostrum and human milk. They can also act against "particles" such as bacteria, viruses and even fat globules, and flocculate them, a reaction called agglutination. In this way, bacteria can also be flocculated on fat globules and accumulate in the cream layer. When micro-organisms are flocculated, their growth and action can be significantly inhibited.

The agglutination reaction is specific with respect to a particular antigen. However, some of the agglutinates are non-specific, especially in the case of so called cryoprecipitation – agglutination, which takes place in cold milk at temperatures below 37 °C. The proteins involved are called cryo-globulines. The agglutinins are inactivated by heat treatment and their possibility to flocculate particles disappears. Because of that, agglutination does not occur in pasteurised milk.

In the future, many substances of importance will probably be isolated on a commercial scale from milk serum or whey. Lactoferrin and lactoperoxidase are substances of possible use in the pharmaceutical and food industries, and are now isolated from whey by a commercial process. Lactoferrin is also an inhibitor of bacteria including *B.stearothermophilus* and *B.subtilis*. The inhibition is caused by removal of iron from their serum.

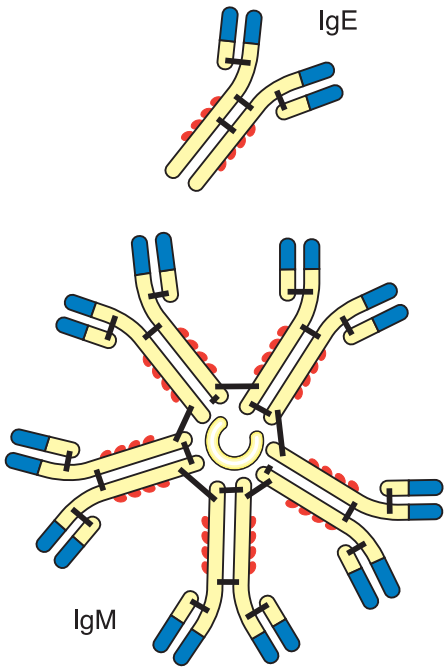


Fig. 2.34 *Schematic shape of two immunoglobulins.*

Ref. P.F. Fox and P.L.H. McSweeney, Dairy Chemistry and Biochemistry, 1998.

Membrane proteins

Membrane proteins are a group of proteins that form a protective layer around fat globules to stabilise the emulsion, Figure 2.35. Their consistency ranges from soft and jelly-like, in some of the membrane proteins, to rather tough and firm in others. Some of the proteins contain lipid residues and are called lipoproteins. The lipids and the hydrophobic amino acids of those proteins make the molecules direct their hydrophobic sites towards the fat surface, while the less hydrophobic parts are oriented towards the water.

Weak hydrophobic membrane proteins attack these protein layers in the same way, forming a gradient of hydrophobia from fat surface to water.

The gradient of hydrophobia in such a membrane makes it an ideal place for adsorption for molecules of all degrees of hydrophobia. Phospholipids and lipolytic enzymes in particular are adsorbed within the membrane structure. No reactions occur between the enzymes and their substrate as long as the structure is intact, but as soon as the structure is destroyed the enzymes have an opportunity to find their substrate and start reactions.

An example of enzymatic reaction is the lipolytic liberation of fatty acids when milk has been pumped cold with a faulty pump, or after homogenisation of cold milk without pasteurisation following immediately. The fatty acids and some other products of this enzymatic reaction give a "rancid" flavour to the product.

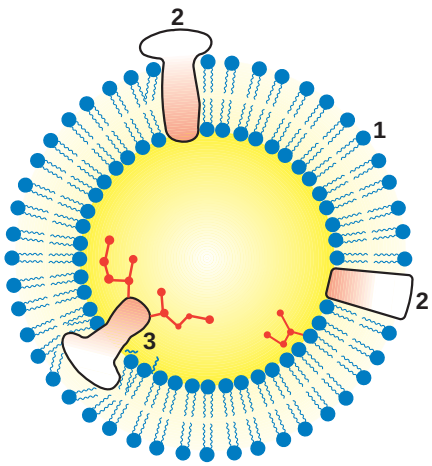


Fig 2.35 *Membrane proteins cover the surface of the fat globule.*
1 *Phospholipid*
2 *Protein*
3 *Glycoprotein*

Denatured proteins

As long as proteins exist in an environment with a temperature and pH within their limits of tolerance, they retain their biological functions. But if they are heated to temperatures above a certain maximum their structure is altered. They are said to be denatured, Figure 2.37. The same thing happens if proteins are exposed to acids or bases, to radiation or to violent agitation. The proteins are denatured and lose their original solubility.

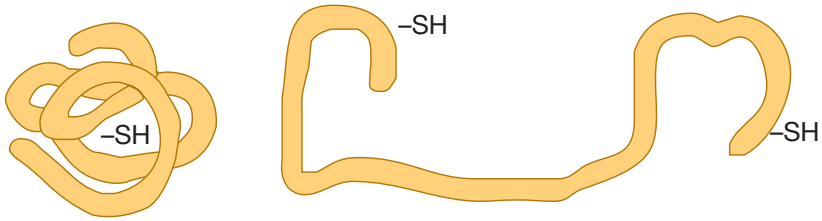


Fig 2.36 *Part of a whey protein in native (left) and denatured state.*

When proteins are denatured, their biological activity ceases. Enzymes, a class of proteins whose function is to catalyse reactions, lose this ability when denatured. The reason is that certain bonds in the molecule are broken, changing the structure of the protein. After a weak denaturation, proteins can sometimes revert to their original state, with restoration of their biological functions.

In many cases, however, denaturation is irreversible. The proteins in a boiled egg, for example, cannot be restored to the raw state.

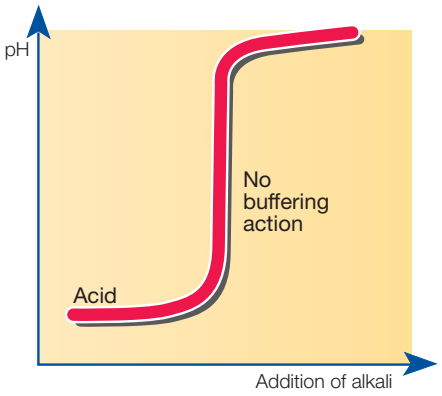


Fig 2.37 *If an alkali is added to acid the pH of the solution rises immediately – there is no buffering action.*

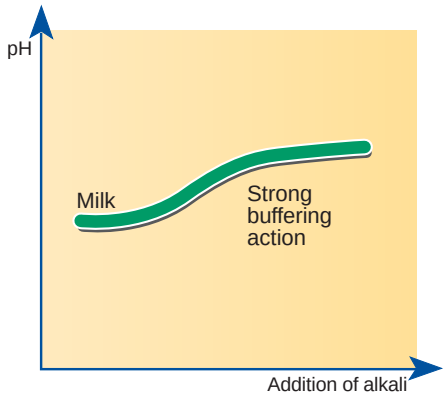


Fig 2.38 *If an alkali is added to milk the pH changes very slowly – there is a considerable buffering action in milk.*

Milk is a buffer solution

Milk contains a large number of substances which can act either as weak acids or as weak bases, *e.g.* lactic acid, citric acid and phosphoric acid and their respective salts: lactates, citrates and phosphates. In chemistry, such a system is called a buffer solution because, within certain limits, the pH value remains constant when acids or bases are added. This effect can be explained by the characteristic qualities of the proteins.

When milk is acidified, a large number of hydrogen ions (H^+) are added. These ions are almost all bound to the amino groups in the side chains of the amino acids, forming NH_3^+ ions. The pH value, however, is hardly affected at all, as the increase in the concentration of free hydrogen ions is very small.

When a base is added to milk, the hydrogen ions (H^+) in the COOH

groups of the side chains are released, forming a COO^- group. Because of this, the pH value remains more or less constant. The more base that is added, the greater the number of hydrogen ions released.

Other milk constituents also have this ability to bind or release ions, and the pH value therefore changes very slowly when acids or bases are added.

Almost all of the buffering capacity is utilised in milk that is already acid due to long storage at high temperatures. In such a case it takes only a small addition of acid to change the pH value.

Enzymes in milk

Enzymes are proteins having the ability to trigger chemical reactions and to affect the course and speed of such reactions. Enzymes do this without being consumed. They are therefore sometimes called *biocatalysts*. The functioning of an enzyme is illustrated in Figure 2.39.

The action of enzymes is specific; each type of enzyme catalyses only one type of reaction.

Two factors which strongly influence enzymatic action are temperature and pH. As a rule, enzymes are most active in an optimum temperature range between 25 and 50 °C. Their activity drops if the temperature is increased beyond optimum, ceasing altogether somewhere between 50 and 120 °C. At these temperatures the enzymes are more or less completely denatured (inactivated). The temperature of inactivation varies from one type of enzyme to another – a fact which has been widely utilised for the purpose of determining the degree of pasteurisation of milk. Enzymes also have their optimum pH ranges; some function best in acid solutions, others in an alkaline environment.

The enzymes in milk come either from the cow's udder or from bacteria. The former are normal constituents of milk and are called *original enzymes*. The latter, *bacterial enzymes*, vary in type and abundance according to the nature and size of the bacterial population. Several of the enzymes in milk are utilised for quality testing and control. Among the more important ones are peroxidase, catalase, phosphatase and lipase.

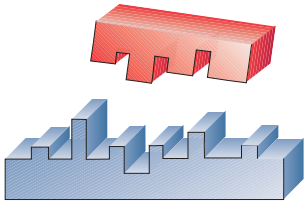
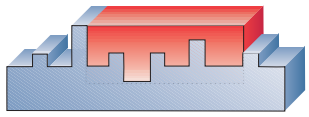
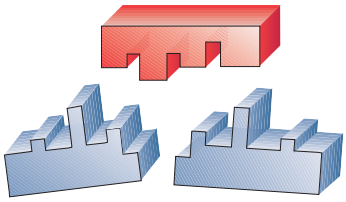


Fig 2.39 *A given enzyme will only split certain molecules, and only at certain bonds.*



The enzyme fits into a particular spot in the molecule chain, where it weakens the bond.



The molecule splits. The enzyme is now free to attack and split another molecule in the same way.

Peroxidase

Peroxidase transfers oxygen from hydrogen peroxide (H_2O_2) to other readily oxidisable substances. This enzyme is inactivated if the milk is heated to 80 °C for a few seconds, a fact which can be used to prove the presence or absence of peroxidase in milk and thereby check whether or not a pasteurisation temperature above 80 °C has been reached. This test is called Storch's peroxidase test.

Catalase

Catalase splits hydrogen peroxide into water and free oxygen. By determining the amount of oxygen that the enzyme can release in milk, it is possible to estimate the catalase content of the milk and learn whether or not the milk has come from an animal with a healthy udder. Milk from diseased udders has a high catalase content, while fresh milk from a healthy udder contains only an insignificant amount. There are, however, many bacteria which produce this kind of enzyme. Catalase is destroyed by heating at 75 °C for 60 seconds.

Phosphatase

Phosphatase has the property of being able to split certain phosphoric-acid esters into phosphoric acid and the corresponding alcohols. The presence of phosphatase in milk can be detected by adding a phosphoric-acid ester and a reagent that changes colour when it reacts with the liberated alcohol. A change in colour reveals that the milk contains phosphatase.

Phosphatase is destroyed by ordinary pasteurisation (72 °C for 15 – 20 seconds), so the phosphatase test can be used to determine whether the pasteurisation temperature has actually been attained. The routine test used in dairies is called the phosphatase test according to Scharer.

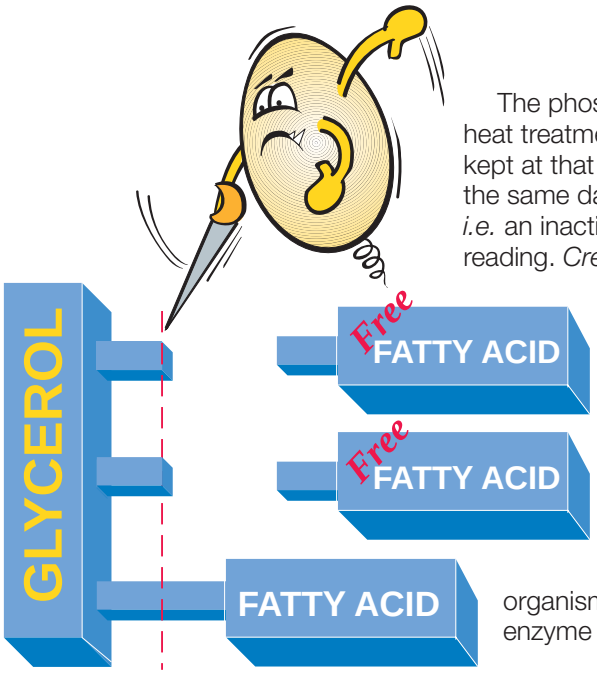


Fig 2.40 *Schematic picture of fat splitting by lipase enzyme.*

The phosphatase test should preferably be performed immediately after heat treatment. Failing that, the milk must be chilled to below + 5 °C and kept at that temperature until analysed. The analysis should be carried out the same day, otherwise a phenomenon known as reactivation may occur, *i.e.* an inactivated enzyme becomes active again and gives a positive test reading. *Cream is particularly susceptible in this respect.*

Lipase

Lipase splits fat into glycerol and free fatty acids. Excess free fatty acids in milk and milk products result in a rancid taste. The action of this enzyme seems, in most cases, to be very weak, though the milk from certain cows may show strong lipase activity. The quantity of lipase in milk is believed to increase towards the end of the lactation cycle. Lipase is, to a great extent, inactivated by pasteurisation, but higher temperatures are required for total inactivation. Many micro-organisms produce lipase. This can cause serious problems, as the enzyme is very resistant to heat.

Lactose in milk

Lactose is a sugar found only in milk; it belongs to the group of organic chemical compounds called *carbohydrates.*

Carbohydrates are the most important energy source in our diet. Bread and potatoes, for example, are rich in carbohydrates, and provide a reservoir of nourishment. They break down into high-energy compounds that can take part in all biochemical reactions, where they provide the necessary energy. Carbohydrates also supply material for the synthesis of some important chemical compounds in the body. They are present in muscles as muscle glycogen and in the liver as liver glycogen.

Glycogen is an example of a carbohydrate with a very large molecular weight. Other examples are starch and cellulose. Such composite carbohydrates are called polysaccharides and have giant molecules made up of many glucose molecules. In glycogen and starch the molecules are often branched, while in cellulose they are in the form of long, straight chains.

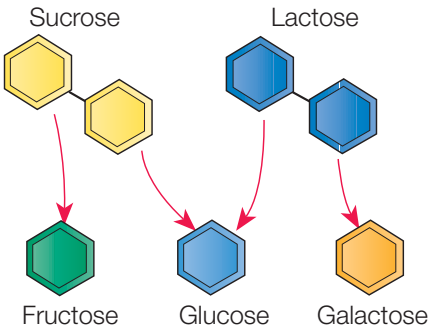


Fig 2.41 *Lactose and sucrose are split to galactose, glucose and fructose.*

Figure 2.41 shows some disaccharides, *i.e.* carbohydrates composed of two types of sugar molecules. The molecules of sucrose (ordinary cane or beet sugar) consist of two simple sugars (monosaccharides), fructose and glucose. Lactose (milk sugar) is a disaccharide, with a molecule containing the monosaccharides glucose and galactose.

Table 2.3 shows that the lactose content of milk varies between 3,6 and 5,5 %. Figure 2.42 shows what happens when lactose is attacked by lactic acid bacteria. These bacteria produce an enzyme called lactase, which attacks lactose, splitting its molecules into glucose and galactose. Other enzymes from the lactic-acid bacteria then attack the glucose and galactose, which are converted via complicated intermediary reactions into mainly lactic acid. The enzymes involved in these reactions act in a certain order. This is what happens when milk goes sour; lactose is fermented to lactic acid. Other micro-organisms in the milk generate other breakdown products.

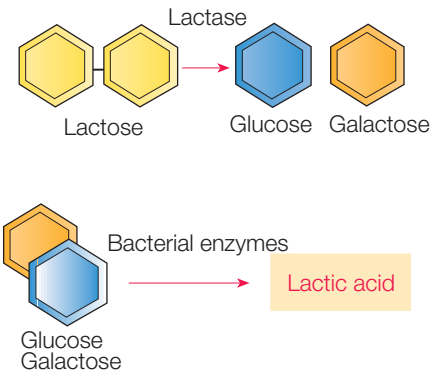


Fig 2.42 *Breakdown of lactose by enzymatic action and formation of lactic acid.*

If milk is heated to a high temperature, and is kept at that temperature, it turns brown and acquires a caramel taste. This process is called caramelisation and is the result of a chemical reaction between lactose and proteins called the Maillard reaction.

Maillard reactions are just initiated by heat treatment and will continue during storage of the product. The reaction kinetics is directly dependent on factors such as heat load and storage temperature.

Lactose is water soluble, occurring as a molecular solution in milk. In cheesemaking, most of the lactose remains dissolved in the whey. Evaporation of whey in the manufacture of whey cheese increases the lactose concentration further. Lactose is not as sweet as other sugars; it is about 30 times less sweet than cane sugar, for example.

Vitamins in milk

Vitamins are organic substances that occur in very small concentrations in both plants and animals. They are essential to normal life processes, but cannot be synthesised by the body. The chemical composition of vitamins is usually very complex, but that of most vitamins is now known. The various vitamins are designated by capital letters, sometimes followed by numerical subscripts, *e.g.* A, B_1 and B_2.

Milk is a good source of vitamins, which are present in varying amounts. Among the best known are A, the vitamin B group, vitamin C and D. Vitamins A and D are soluble in fat, or fat solvents, while the others are soluble in water.

In terms of fat-soluble vitamins, A and D are the most important. They affect eyesight and skin. For natural reasons, low-fat milk products contain less of these vitamins. In many countries this deficiency in low-fat milk is compensated for by enrichment with vitamins A and D, in order to achieve the same vitamin level as whole milk.

Table 2.6 lists the amounts of the different vitamins in one litre of market milk and the daily vitamin requirement of an adult person. The table shows that milk is a good source of vitamins. Lack of vitamins can result in deficiency diseases, see Table 2.7.

Table 2.6

Vitamins in milk and daily requirements

Vitamin	Amount in 1 litre of milk, mg	Adult daily requirement mg
A	0,2 – 2	1 – 2
B_1	0,4	1 – 2
B_2	1,7	2 – 4
C	5 – 20	30 – 100
D	0,002	0,01

Table 2.7

Vitamins deficiencies and corresponding diseases

Vitamin A deficiency	Night blindness, impaired resistance to infectious diseases
Vitamin B_1 deficiency	Stunted growth
Vitamin B_2 deficiency	Loss of appetite, indigestion
Vitamin C deficiency	Fatigue, pyorrhoea, susceptibility to infection (scurvy)
Vitamin D deficiency	Skeletal deformation (rickets)

Minerals and salts in milk

Milk contains a number of minerals. The total concentration is less than 1 %. Mineral salts occur in solution in milk serum or in casein compounds. The most important salts are those of calcium, sodium, potassium and magnesium. They occur as phosphates, chlorides, citrates and caseinates. Potassium and calcium salts are the most abundant in normal milk. The amounts of salts present are not constant. Towards the end of lactation, and even more so in the case of udder disease, the sodium chloride content increases and gives the milk a salty taste, while the amounts of other salts are correspondingly reduced.

Other constituents of milk

Milk always contains *somatic cells* (white blood corpuscles or leucocytes). The content is low in milk from a healthy udder, but increases if the udder is diseased, usually in proportion to the severity of the disease. The somatic cell content of milk from healthy animals is as a rule lower than 200 000 cells/ml, but counts of up to 400 000 cells/ml can be accepted.

Milk also contains *gases*, some 5 – 6 % by volume in milk fresh from the udder, but on arrival at the dairy, the gas content may be as high as 10 % by volume. The gases consist mostly of carbon dioxide, nitrogen and oxygen. They exist in the milk in three states:

1 Dissolved in the milk
2 Bound and non-separable from the milk
3 Dispersed in the milk

Dispersed and dissolved gases are a serious problem in the processing of milk, which is liable to burn on to heating surfaces if it contains too much gas.

Changes in milk and its constituents

Changes during storage

The fat and protein in milk may undergo chemical changes during storage. These changes are normally of two kinds: oxidation and lipolysis. The resulting reaction products can cause off-flavours, principally in milk and butter.

Oxidation of fat

Oxidation of fat results in a *metallic flavour,* whilst it gives butter an oily, tallowy taste. Oxidation occurs at the double bonds of the unsaturated fatty acids, those of lecithin being the most susceptible to attack. The presence of iron and copper salts accelerates the onset of auto-oxidation and development of metallic flavour, as does the presence of dissolved oxygen and exposure to light, especially direct sunlight or light from fluorescent tubes.

Oxidation of fat can be partly counteracted by micro-organisms in the milk, by pasteurisation at a temperature above 80 °C, or by antioxidant additives (reducing agents) such as DGA, dodecyl gallate. The maximum DGA dosage is 0,00005 %. Micro-organisms such as lactic-acid bacteria consume oxygen and have a reducing effect. Oxidation off-flavour is more liable to occur at low temperatures, because these bacteria are less active then. The solubility of oxygen in milk is also higher at low temperatures. High-temperature pasteurisation helps, as reducing compounds, ($^{-}$SH) groups, are formed when milk is heated.

It generally is assumed that oxygen molecules in singlet state ($^1O_2$) can oxidise a CH-group directly, while shifting the double bond and forming a hydroperoxide according the formula:

$$^1O_2 + -CH = CH - CH_2^- \longrightarrow -CHOOH - CH = CH -$$

The metallic oxidation off-flavour is more common in winter than in summer. This is partly due to the lower ambient temperature and partly to differences in the cows' diet. Summer feed is richer in vitamins A and C, which increase the amount of reducing substances in the milk.

In the presence of light and/or heavy metal ions, the fatty acids are further broken down in steps into aldehydes and ketones, which give rise to off-flavours such as oxidation rancidity in fat dairy products.

The above strongly simplified course of events at oxidation (really auto-

oxidation) of unsaturated fatty acids is taken from "Dairy Chemistry and Physics" by P. Walstra and R. Jennis.

Oxidation of protein

When exposed to light, the amino acid methionine is degraded to methional by a complicated participation of riboflavin (Vitamin B_2) and ascorbic acid (Vitamin C). Methional or 3-mercapto-methylpropionaldehyde is the principal contributor to *sunlight flavour,* as this particular flavour is called.

Since methionine does not exist as such in milk, but as one of the components of the milk proteins, fragmentation of the proteins must occur incidental to development of the off-flavour.

Factors related to sunlight flavour development are:

- Intensity of light (sunlight and/or artificial light, especially from fluorescent tubes).
- Duration of exposure.
- Certain properties of the milk – homogenised milk has turned out to be more sensitive than non-homogenised milk.
- Nature of package – opaque packages such as plastic and paper give good protection under normal conditions.

See also Chapter 8 concerning maintenance of the quality of pasteurised milk.

Lipolysis

The breakdown of fat into glycerol and free fatty acids is called *lipolysis.* Lipolysed fat has a rancid taste and smell, caused by the presence of low-molecular free fatty acids (butyric and caproic acid).

Lipolysis is caused by the action of lipases and is encouraged by high storage temperatures. But lipase cannot act unless the fat globules have been damaged so that the fat is exposed. Only then can the lipase attack and hydrolyse the fat molecules. In normal dairying routine, there are many opportunities for the fat globules to be damaged, *e.g.* by pumping, stirring and splashing. Undue agitation of unpasteurised milk should therefore be avoided, as this may involve the risk of widespread lipase action with the liberation of fatty acids that make the milk taste rancid. Lipase must be inactivated by high-temperature pasteurisation, to prevent it from degrading the fat. This completely destroys the original enzymes. Bacterial enzymes are more resistant. Not even UHT treatment can destroy them entirely. (UHT = Ultra High Temperature, *i.e.* heating to 135 – 150 °C or more for a few seconds.)

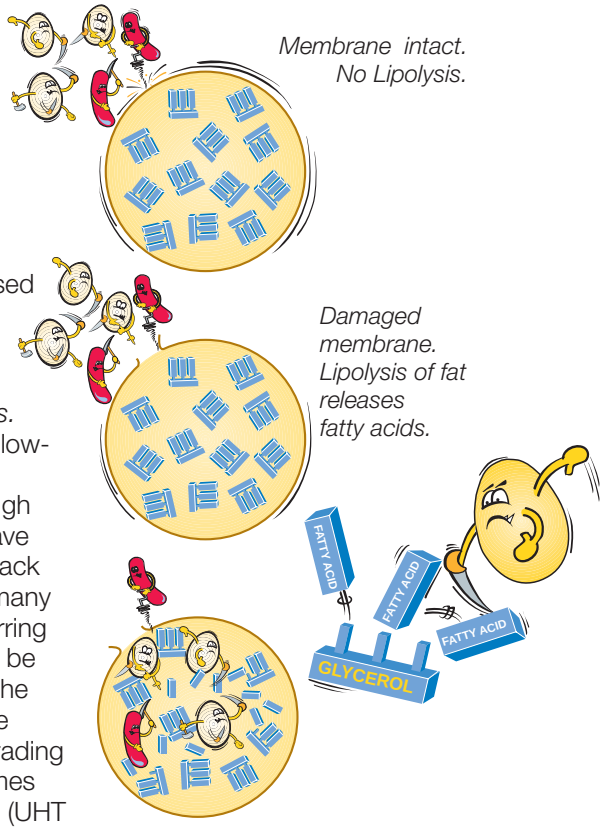


Fig 2.43 *When fat globule membranes are damaged, lipolysis can release fatty acids.*

Effects of heat treatment

Milk is heat treated at the dairy to kill any pathogenic micro-organisms that may be present. Heat treatment also causes changes in the constituents of the milk. The higher the temperature and the longer the exposure to heat, the greater the changes. Within certain limits, time and temperature can be balanced against each other. Brief heating to a high temperature can have the same effect as longer exposure to a lower temperature. Both time and temperature must therefore always be considered in connection with heat treatment.

Fat

It has been shown (Thomé et al, Milchwissenschaft 13, 115, 1958) that when milk is pasteurised at 70 – 80 °C for 15 seconds, the cream plug phenomenon is already evident at 74 °C (see Figure 2.44). Various theories have been discussed, but it appears that liberated free fat cements the fat globules when they collide. Homogenisation is recommended to avoid cream plug formation.

A. Fink and H.G. Kessler (Milchwissenschaft 40, 6-7, 1985) have shown that free fat leaks out of the globules in cream with 30 % fat, unhomogenised as well as homogenised, when it is heated to temperatures between

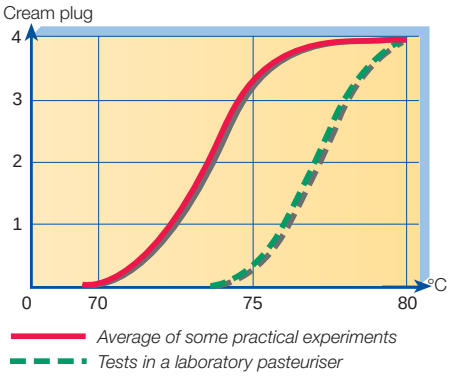


Fig. 2.44 *Cream plug formation in milk as a function of pasteurisation temperature. Scale from 0 (no effect) to 4 (solid cream plug). All pasteurisation was short-time (about 15 s).*
Ref: Thomé & al.

105 and 135 °C. This is believed to be caused by destabilisation of the globule membranes resulting in increased permeability, as a result of which the extractable free fat acts as a cement between colliding fat globules and produces stable clusters.

Above 135 °C, the proteins deposited on the fat globule membrane form a network which makes the membrane denser and less permeable. Homogenisation downstream of the steriliser is therefore recommended in UHT treatment of products with a high fat content.

Protein

The major protein, casein, is not considered denaturable by heat within normal ranges of pH, salt and protein content.

Whey proteins, on the other hand, particularly β-lactoglobulin which makes up about 50 % of the whey proteins, are fairly heat sensitive. Denaturation begins at 65°C and is almost total when whey proteins are heated to 90 °C for five minutes.

Whey protein heat denaturation is an irreversible reaction. The randomly coiled proteins "open up", and β-lactoglobulin in particular is bound to the κ-casein fraction by sulphur bridges. The strongly generalised transformation is shown in Figure 2.45.

Blockage of a large proportion of the κ-casein interferes with the renneting ability of the milk, because the rennet used in cheesemaking assists in splitting the casein micelles at the κ-casein locations. The higher the pasteurisation temperature at constant holding time, the softer the coagulum; this is an undesirable phenomenon in production of semi-hard and hard types of cheese. Milk intended for cheesemaking should therefore not be pasteurised, or at any rate not at higher temperatures than 72 °C for 15 – 20 seconds.

In milk intended for cultured milk products (yoghurt, etc.), the whey protein denaturation and interaction with casein obtained at 90 – 95 °C for 3 – 5 minutes will contribute to improved quality in the form of reduced syneresis and improved viscosity.

Milk heated at 75 °C for 20 – 60 seconds will start to smell and taste “cooked”. This is due to release of sulphurous compounds from β-lactoglobulin and other sulphur-containing proteins, inactive lipoproteins.

Enzymes

Enzymes can be inactivated by heating. The temperature of inactivation varies according to the type of enzyme.

There are some bacteria, *Pseudomonas spp*, (spp = species) nowadays very often cited among the spoilage flora of both raw cold-stored milk and heat-treated milk products, that have extremely heat-resistant proteolytic and lipolytic enzymes. Only a fraction of their activity is inhibited by pasteurisation or UHT treatment of the milk.

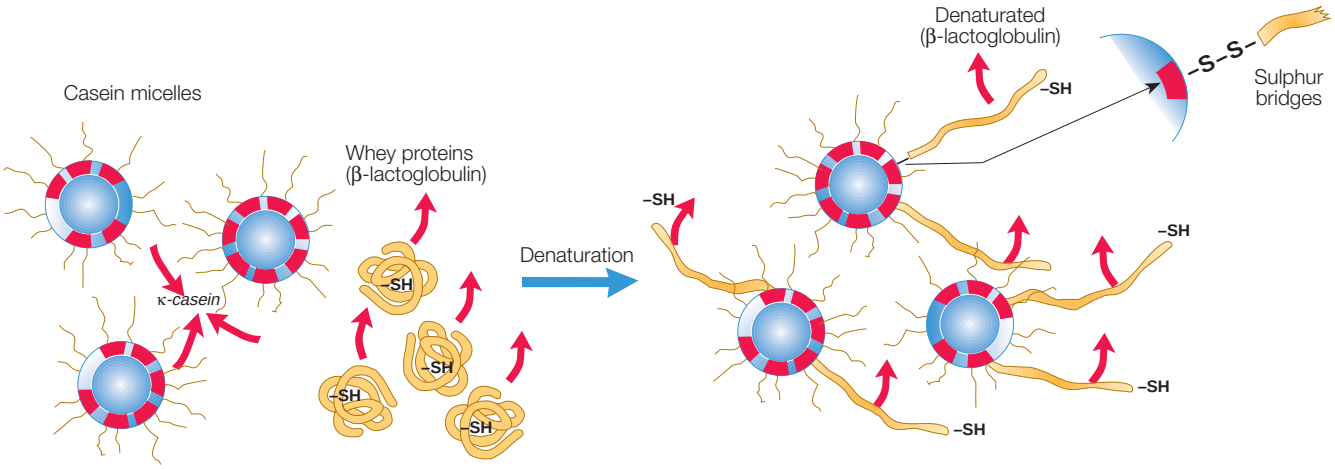


Fig. 2.45 *During denaturation κ-casein adheres to β-lactoglobulin.*

Lactose

Lactose undergoes changes more readily in milk than in the dry state. At temperatures above 100 °C, a reaction takes place between lactose and protein, resulting in a brownish colour. The series of reactions, occuring between amino groups of amino acid residues and aldehyde groups from milk carbohydrates, is called the Maillard reaction or browning reaction. It results in a browning of the product and a change of flavour as well as loss in nutritional value, particularly loss of lysine, one of the essential amino acids.

It appears that pasteurised, UHT and sterilised milks can be differentiated by their lactulose content. Lactulose is an epimer of lactose formed in heated milks (Adachi, 1958). It is thought to be formed by the free amino groups of casein (Adachi & Patton, 1961; Richards & Chandrasekhara, 1960) Martinez Castro & Olano, 1982, and Geier & Klostermeyer, 1983, showed that pasteurised, UHT and sterilised milks contain different levels of lactulose. The lactulose content thus increases with increased intensity of the heat treatment.

At temperatures above 100 °C, a reaction takes place between lactose and protein, resulting in a brownish colour.

Vitamins

Milk is an important source of A, D and group B vitamins. The fat-soluble vitamins are very thermostable and their level is not lowered by heat treatment. However, when milk is fortified with vitamin A, the relative loss seems to increase.

Losses of vitamins mainly concern vitamin C and some of the group B vitamins. The loss of vitamin C as such is generally of minor importance, as milk is not an important source of this vitamin, but it may influence the nutritional value anyway. The breakdown of vitamin C is connected with that of vitamin B_{12} and protects folic acid from oxidation.

The degradation of vitamins is not only related to the heat treatment, but also to storage of the final product. The loss of vitamins during storage can largely be avoided if oxygen and light penetration are excluded. Vitamin C and B_9 may completely disappear within a few days if a high level of oxygen is present. The reaction is catalysed by riboflavin (vitamin B_2) and accelerated by exposure to light. Most of the riboflavin disappears after long-term exposure to light.

Losses of some vitamins due to different treatments are presented in Table 2.8.

Table 2.8

Reduction of important vitamins in milk processed and stored in different conditions

	Pasteurised milk		UHT milk	
Vitamin	**Heat treatment**	**Chilled storage**	**Heat treatment**	**Ambient storage**
Ascorbic Acid, C	0 – 10 %	10 –100 %	0 – 100 %	up to 100 %
Thiamin, B_1	< 10 %	not investigated enough	< 10 %	no further loss*
Riboflavin, B_2	not significant	not significant*	< 10 %	no further loss*
Pyridoxine, B_6	< 10 %	not investigated enough	< 10 %	up to 50 %
Folic acid, B_9	not significant	not investigated enough	10 – 20 %	up to 100 %**
Cobulamin, B_{12}	< 10 %	not significant	0 – 30 %	up to 100 %
Retinol, B-carotene, A	not significant***	not significant***	not significant***	not significant***
Calciferols, D	not significant	not significant	not significant	not significant

* *When not exposed to light* ** *Dependent on oxygen content* *** *If not fortified*

Minerals

The solubility of calcium phosphate is very temperature-dependent. Unlike most compounds, the solubility of calcium phosphate decreases with temperature. This means that heating causes precipitation of calcium

phosphate in the form of CCP in the micelle, while cooling increases the concentration of soluble calcium phosphate. After cooling, the reaction is readily reversible, but after heating to high temperatures, the reversibility is more sluggish and incomplete.

The changes at high temperature imply that the milk becomes more acid and the pH drops as described in Table 2.9 below. The changes in pH can be explained as follows:
The shift in pH increases when milk is concentrated.

Physical properties of milk

Appearance

The opacity of milk is due to its content of suspended particles of fat, proteins and certain minerals. The colour varies from white to yellow, according to the coloration (carotene content) of the fat. Skim milk is more transparent, with a slightly bluish tinge.

$$3\,Ca^{2+} + 2\,HPO_4^{2-} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} Ca_3(PO_4)_2 + 2H^+$$

Table 2.9
Effect of temperature on the pH of milk

Temperature, °C	pH
20	6,64
30	6,55
40	6,45
50	6,34
60	6,23

Source: P.F.Fox and P.L.H. McSweeney: Dairy Chemistry and Biochemistry (1998)

Density

The density of cows' milk normally varies between 1,028 and 1,038 g/cm^3, depending on the composition.

$$d_{15,5°C} = \frac{100}{\frac{F}{0,93} + \frac{SNF}{1,608} + \text{Water}} \text{ g/cm}^3$$

F = % fat
SNF = % Solids Non Fat
Water % = 100 – F – SNF

The density of milk at 15,5 °C can be calculated according to the following formula on previous page and the example below.

Example: Milk of 3,2 % fat and 8,5 % SNF

$$d_{15,5°C} = \frac{100}{\frac{3,2}{0,93} + \frac{8,5}{1,608} + (100 - 3,2 - 8,5)} = 1,0306 \text{ g/cm}^3$$

Osmotic pressure

Osmotic pressure is controlled by the *number* of molecules or particles, not the weight of solute; thus 100 molecules of size 10 will have 10 times the osmotic pressure of 10 molecules of size 100.

It follows that for a given weight, the smaller the molecules the higher the osmotic pressure.

Milk is formed from blood, the two being separated by a permeable membrane, hence they have the same osmotic pressure, or in other words, milk is *isotonic* with blood. The osmotic pressure of blood is remarkably constant although the composition, as far as pigment, protein etc., are concerned, may vary. The same condition applies to milk, the total osmotic pressure being made up as in Table 2.10.

Table 2.10
Osmotic pressure in milk

Constituent	Molecular weight	Normal conc. %	Osmotic pressure atm	D °C	% of total osmotic pressure
Lactose	342	4,7	3,03	0,25	46
Chlorides, NaCl	58,5	≈ 0,1	1,33	0,11	19
Other salts, etc.	–	–	2,42	0,20	35
Total			**6,78**	**0,560**	**100**

Ref: A Dictionary of Daiyring, J.G. Davis.

Freezing point

The freezing point of milk is the only reliable parameter to check for adulteration with water. The freezing point of milk from individual cows has been found to vary from –0,54 to –0,59 0°C.

In this context it should also be mentioned that when milk is exposed to high temperature treatment (UHT treatment or sterilisation), precipitation of some phosphates will cause the freezing point to rise.

The internal or osmotic pressure also defines the difference in freezing point between the solution and the solvent (water) so that the freezing-point depression (D in Table 2.10) is a measure of this osmotic pressure. When the composition of milk alters due to physiological or pathological causes (*e.g.* late lactation and mastitis respectively), it is termed abnormal milk, but the osmotic pressure and hence the freezing-point remains constant. The most important change is a fall in lactose content and a rise in chloride content.

Acidity

The acidity of a solution depends on the concentration of hydrogen ions $[H^+]$ in it. When the concentrations of $[H^+]$ and $[OH^-]$ (hydroxyl) ions are equal, the solution is called neutral. In a neutral solution the number of $[H^+]$ per liter of the solution is 1:10 000 000 g or 10^{-7}.

pH represents the hydrogen ion concentration of a solution and can mathematically be defined as the negative logarithm of the hydrogen ion $[H^+]$ concentration.

$$pH = - \log [H^+]$$

Applied to the example above, the pH is $pH = - \log 10^{-7} = 7$ which is the typical value of a neutral solution. When $[H^+]$ is 1:100 000 g/l or 10^{-6}, the pH is 6 and the solution is acid. Thus the lower the exponent, the higher the acidity.

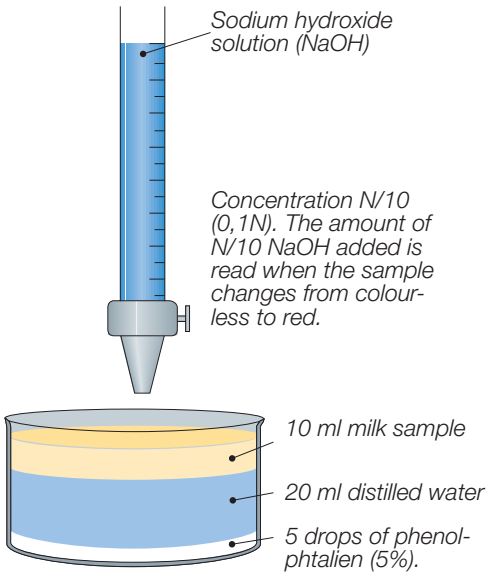


Fig 2.46 *Determination of acidity in Thörner degrees, °Th.*

The *pH value* of a solution or product represents the *present (true) acidity.* Normal milk is a slightly acid solution with a pH falling between 6,6 – 6,8 with 6,6 the most usual value, at a measurement about 25 °C. The pH is checked with a pH-meter.

Titratable acidity

Acidity can also be expressed as the *titratable acidity.* The titratable acidity of milk is the amount of a hydroxyl ion (OH^-) solution of a given strength needed to increase the pH of a given amount of milk to a pH of about 8,4, the pH at which the most commonly used indicator, *phenolphtalein*, changes colour from colourless to pink. What this test really does is to find out how much alkali is needed to change the pH from 6,6 to 8,4.

If milk sours on account of bacterial activity, an increased quantity of alkali is required, and so the acidity or titration value of the milk increases.

The titratable acidity can be expressed in a variety of units basically as a result of the strength of the sodium hydroxide (NaOH) needed at titration.

°**SH** = Soxhlet Henkel degrees, obtained by titrating 100 ml of milk with N/4 NaOH , using phenolphtalein as the indicator. Normal milks give values about 7. This method is mostly used in Central Europe.

°**Th** = Thörner degrees, obtained by titrating 100 ml of milk, thinned with 2 parts of distilled water, with N/10 NaOH, using phenolphtalein as the indicator. Normal milks give values about 17. Mostly used in Sweden.

°**D** = Dornic degrees, obtained by titrating 100 ml of milk with N/9 NaOH, using phenolphtalein as the indicator. Normal milks give values about 15. Mostly used in the Netherlands and France.

% l.a. = per cent lactic acid, obtained as °D with the result divided by 100. Frequently used in the UK, USA, Canada, Australia and New Zealand.

In Table 2.11 the various expressions for the titratable acidity are combined. The determination of acidity according to Thörner degrees is visualised in Figure 2.47.

Table 2.11
Acidity is often expressed in one of these ways

°SH	°Th	°D	% l.a.
1	2,5	2,25	0,0225
0,4	1	0,9	0,009
4/9	10/9	1	0,01

Example:
1,7 ml of N/10 NaOH are required for titration of a 10 ml sample of milk. 10 x 1,7 = 17 ml would therefore be needed for 100 ml, and the acidity of the milk is consequently 17 °Th.

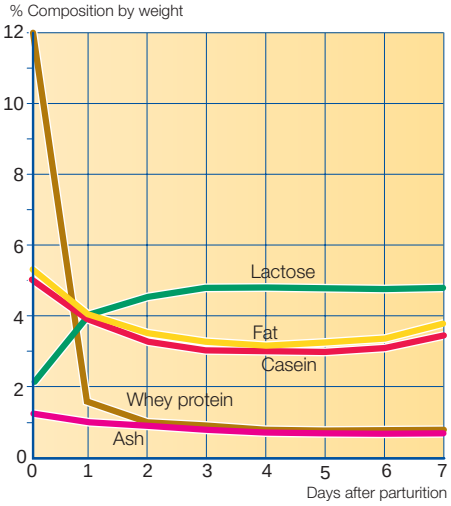


Fig 2.47 *Changes in the composition of cows' milk after parturition.*

Colostrum

The first milk that a cow produces after calving is called colostrum. It differs greatly from normal milk in composition and properties. One highly distinctive characteristic is the high content of whey proteins – about 11 % compared to about 0,65 % in normal milk, as shown in Figure 2.47. This results in colostrum coagulating when heated. A fairly large proportion of whey protein is immunoglobulins (Ig G, dominating in colostrum), which protect the calf from infection until its own immunity system has been established. Colostrum has brownish-yellow colour, a peculiar smell and a rather salty taste. The content of catalase and peroxidase is high. Four to five days after calving, the cow begins to produce milk of normal composition, which can be mixed with other milk.

Chapter 3

Rheology

Several important factors need to be taken into consideration in the design of food processing plants, in order to assure the quality of the end products. One of them is the question of rheology which concerns the flow behaviour of the products.

In the dairy industry in particular, there are cream and cultured milk products whose characteristics can be partially or completely spoiled if their flow behaviour is not understood. What follows here is a brief guide to the flow behaviour of some typical dairy industry products.

Definition

Rheology is defined as the *science of deformation and flow of matter.* The term itself originates from Greek *rheos* meaning 'to flow'. Rheology is applicable to all types of materials, from gases to solids.

A main issue is also the measurement, adaptation and application of viscosity data, which concerns the design calculations of processing equipment.

The science of rheology is young, only about 70 years of age, but its history is very old. In the book of Judges in the Old Testament, the prophetess Deborah declared "The mountains flowed before the Lord..." Translated into rheological terms by Professor M. Reiner, this expression means *everything flows if you just wait long enough*, a statement that is certainly applicable to rheology. It was also described by the Greek philosopher Heraclitus as "panta rei" – *everything flows*. Professor Reiner, together with Professor E. Bingham, was the founder of the science of rheology in the mid-1920s.

Rheology is used in food science to define the *consistency* of different products. Rheologically, the consistency is described by two components, the *viscosity* (thickness, lack of slipperiness) and the *elasticity* ('stickiness', structure). In practice, therefore, rheology stands for *viscosity measurements, characterisation of flow behaviour* and *determination of material structure.* Basic knowledge of these subjects is essential in process design and product quality evaluation.

Rheology is defined as the *science of deformation and flow of matter.*

The Deborah Number, **D**, named after the prophetess Deborah, is a way of characterising the flow behaviour of a material. The Deborah Number is the ratio between time of relaxation and the time of observation:

$$D = \frac{\text{time of relaxation}}{\text{time of observation}}$$

Consequently, the Deborah Number is large for materials of high viscosity and low for materials of low viscosity.

Characterisation of materials

One of the main issues of rheology is the definition and classification of materials. Normal glass, for instance, is usually defined as a solid material, but if the thickness of an old church window is measured from top to bottom, a difference will be noted. Glass does, in fact, flow like a liquid, albeit very slowly.

One way of characterising a material is by its *relaxation time, i.e.* the time required to reduce a stress in the material by flow. Typical magnitudes of relaxation times for materials are:

Gases	$<10^{-6}$	seconds
Liquids	$10^{-6} - 10^{2}$	seconds
Solids	$>10^{2}$	seconds

Another way of defining materials rheologically is by the terms *viscous, elastic* or *viscoelastic.* Gases and liquids are normally described as viscous fluids. By definition an ideal viscous fluid is unable to store any *deformation*

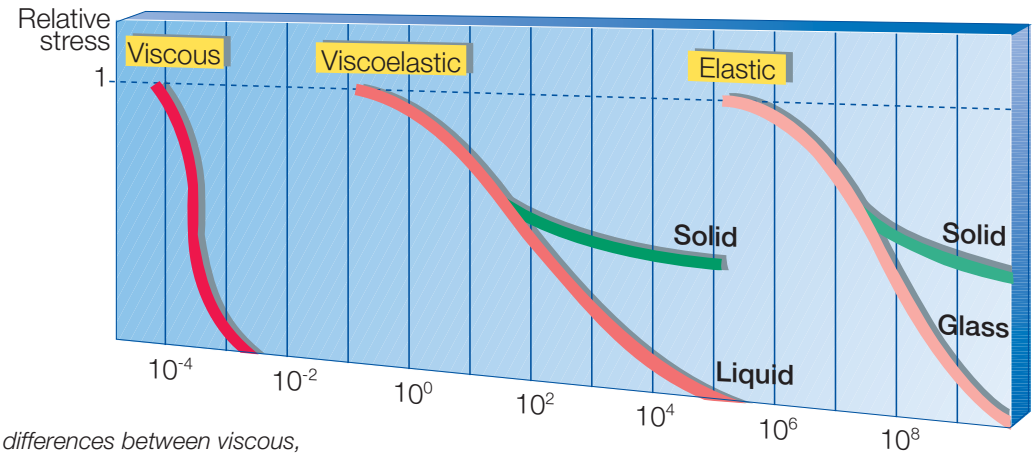


Fig. 3.1 *Curves showing the differences between viscous, viscoelastic and elastic materials when subjected to deformation.*

energy. Hence, it is irreversibly deformed when subjected to stress; it *flows* and the deformation energy is dissipated as heat, resulting in a rise of temperature.

Solids, on the other hand, are normally described as elastic materials. An ideal elastic material stores all imposed deformation energy and will consequently recover totally upon release of stress. A viscous fluid can therefore be described as a fluid which resists the *act of deformation* rather than the *state of deformation*, while an elastic material resists the act as well as the state of deformation.

A number of materials show viscous as well as elastic properties, i.e. they store some of the deformation energy in their structure, while some is lost by flow. These materials are called *viscoelastic*; there are many examples among foodstuffs such as starch-based puddings, mayonnaise and tomato purées.

Shearing

In rheology, *shearing* of a substance is the key to knowledge of flow behaviour and structure. A *sheared flow* is achieved through flow between parallel planes, *rotational flow* between coaxial cylinders where one cylinder is stationary and the other one is rotating, *telescopic flow* through capillaries and pipes, and *torsional flow* between parallel plates.

To enable study of the viscosity of a material, the shearing must induce stationary flow of the material. The flow occurs through rearrangement and deformation of particles and through breaking of bonds in the structure of the material.

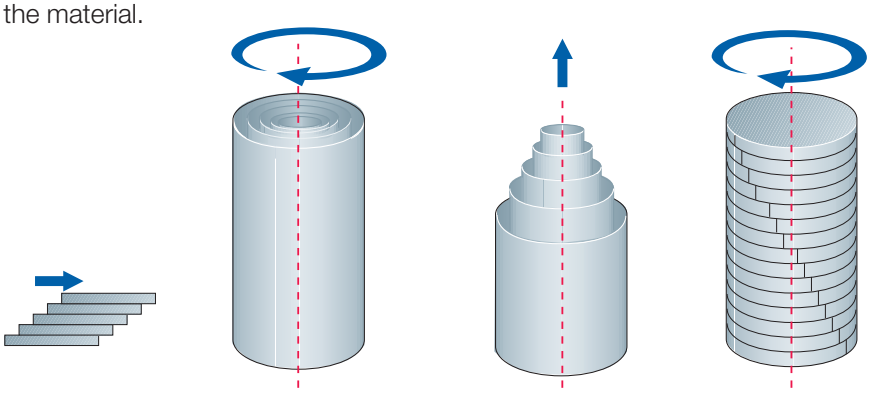


Fig. 3.2 *Different types of shearing.*

Shear stress is defined as

$$\sigma_{yx} = \frac{F}{A} \qquad [Pa]$$

F = Force, N
A = Area, m^2

shear rate as

$$\dot{\gamma} = \frac{d\gamma}{dt} = \frac{dv}{dy} \qquad [1/s]$$

and apparent viscosity of a fluid as

$$\eta_a = s / \dot{\gamma} \qquad [Pas]$$

If we want to study the elasticity (structure) of a material, the shearing must be very gentle so as not to destroy the structure. One way to achieve this is to apply an oscillating shear to the material, with an amplitude low enough to allow an unbroken structure to be studied.

Shearing between parallel planes is normally used for the basic definition of *shear stress* and *shear rate*, corresponding to how much deformation is applied to the material and how fast.

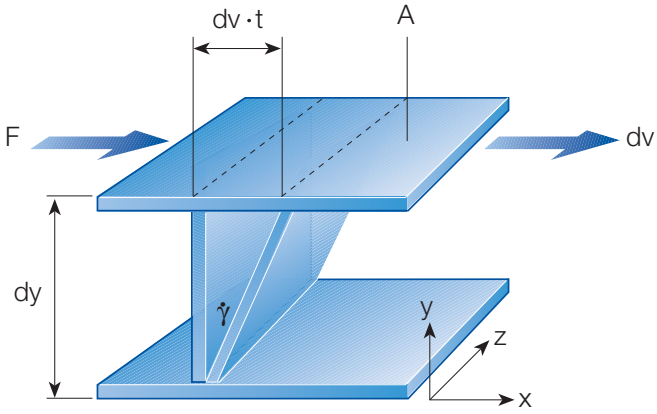


Fig. 3.3 *Definition of shear stress and shear rate is based on shearing between parallel planes.*

Newtonian fluids

Newtonian fluids are those having a constant viscosity dependent on temperature but independent of the applied shear rate. One can also say that Newtonian fluids have direct proportionality between shear stress and shear rate in laminar flow.

$$\sigma_{yx} = \eta \cdot \frac{dv}{dy} = \eta \cdot \dot{\gamma}$$

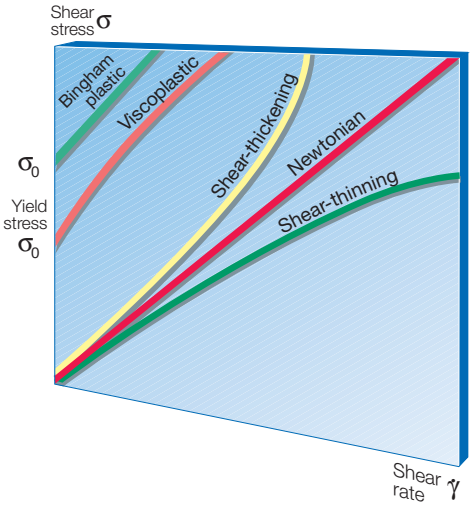


Fig. 3.4 *Flow curves for Newtonian and non-Newtonian fluids.*

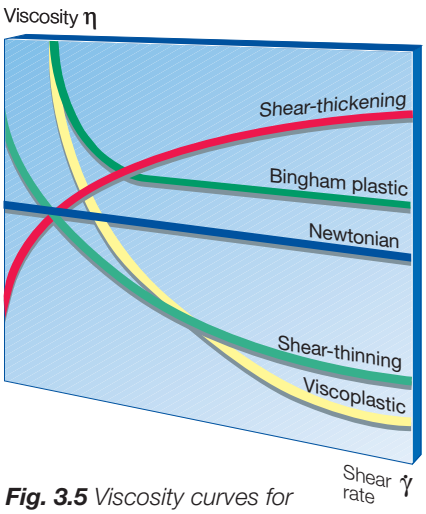


Fig. 3.5 *Viscosity curves for Newtonian and non-Newtonian fluids.*

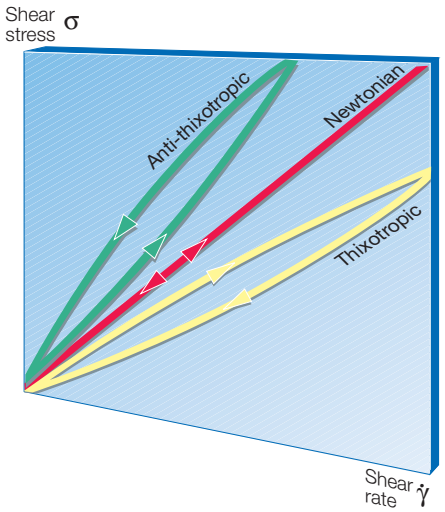


Fig. 3.6 *Flow curves for time-dependent non-Newtonian fluids.*

The proportionality constant is thus equal to the viscosity of the material. The *flow curve*, which is a plot of shear stress versus shear rate, will therefore be a straight line with slope η for a Newtonian fluid. The *viscosity curve*, which is a plot of viscosity versus shear rate, will show a straight line at a constant value equal to η.

A Newtonian fluid can therefore be defined by a single viscosity value at a specified temperature. Water, mineral and vegetable oils and pure sucrose solutions are examples of Newtonian fluids. Low-concentration liquids in general, such as whole milk and skim milk, may for practical purposes be characterised as Newtonian fluids.

Non-Newtonian fluids

Materials which cannot be defined by a single viscosity value at a specified temperature are called *non-Newtonian.* The viscosity of these materials must always be stated together with a corresponding temperature and shear rate. If the shear rate is changed, the viscosity will also change. Generally speaking, high concentration and low temperature induce or increase non-Newtonian behaviour.

Apart from being shear-rate dependent, the viscosity of non-Newtonian fluids may also be *time-dependent*, in which case the viscosity is a function not only of the magnitude of the shear rate but also of the duration and, in most cases, of the frequency of successive applications of shear. Non-Newtonian materials that are time independent are defined as *shear-thinning, shear-thickening* or *plastic*. Non-Newtonian materials that are time-dependent are defined as *thixotropic, rheopectic* or *anti-thixotropic.*

Shear-thinning flow behaviour

The viscosity of a shear-thinning fluid (also known as *pseudoplastic fluid*) decreases with increasing shear rate. Most liquid food systems belong to this category of fluids. The shear rate dependency of the viscosity can differ substantially between different products, and also for a given liquid, depending on temperature and concentration. The reason for shear thinning flow behaviour is that an increased shear rate deforms and/or rearranges particles, resulting in lower flow resistance and consequently lower viscosity.

Typical examples of shear-thinning fluids are yoghurt, cream, juice concentrates, and salad dressings. It should be noted that although sucrose solutions show Newtonian behaviour independent of concentration, fruit juice concentrates are always significantly non-Newtonian.

Hence a non-Newtonian fluid like yoghurt or fruit juice concentrate being pumped in a pipe shows decreased apparent viscosity if flow rate is increased. This means in practice that the pressure drop of a non-Newtonian fluid in laminar flow is not directly proportional to the flow rate as for Newtonian fluids in laminar flow.

Shear-thickening flow behaviour

The viscosity of a shear-thickening fluid increases with increasing shear rate. This type of flow behaviour is generally found among suspensions of very high concentration. A shear-thickening fluid exhibits dilatant flow behaviour, *i.e.* the solvent acts as a lubricant between suspended particles at low shear rates but is squeezed out at higher shear rates, resulting in denser packing of the particles. Typical examples of shear-thickening systems are wet sand and concentrated starch suspensions.

Plastic flow behaviour

A fluid, which exhibits a yield stress, is called a plastic fluid. The practical result of this type of flow behaviour is that a significant force must be applied before the material starts to flow like a liquid. This is often referred to as 'the ketchup effect'. If the force applied is smaller than the force corresponding to the yield stress, the material stores the deformation

energy, *i.e.* shows elastic properties, and hence behaves as a solid. Once the yield stress is exceeded, the liquid can flow like a Newtonian liquid and be described as a Bingham plastic liquid, or it can flow like a shear-thinning liquid and be described as a viscoplastic liquid.

Typical plastic fluids are quarg, high pectin pineapple juice concentrate, tomato paste and certain ketchups. Outside the liquid food world toothpaste, hand cream and greases are typical examples of plastic fluids.

A simple but still very effective way of checking a fluid's possible plastic properties is to just turn the jar upside down. If the fluid will not flow by itself it probably has a significant yield value. If it flows by itself, but very slowly, it probably has no yield value but a high viscosity. Information of this kind is of vital importance to process plant design regarding the dimensions and layout of storage and process tank outlets and pump connections.

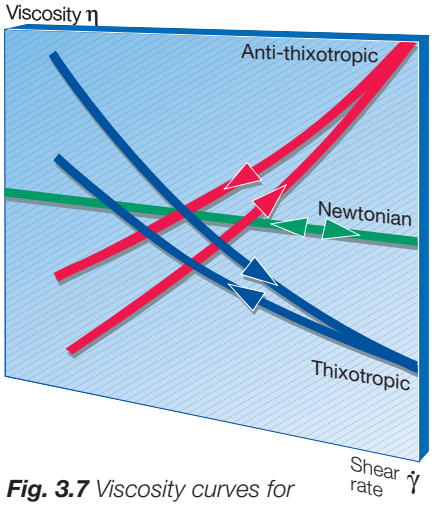


Fig. 3.7 *Viscosity curves for time-dependent non-Newtonian fluids.*

Time-dependent flow behaviour

Thixotropic fluids

A *thixotropic fluid* can be described as a shear-thinning system where the viscosity decreases not only with increasing shear rate but also with time at a constant shear rate. Thixotropic flow behaviour is normally studied in a *loop test*. In this test, the material is subjected to increasing shear rates followed by the same shear rates in decreasing order. The time-dependent thixotropic flow behaviour is seen from the difference between the ascending and descending viscosity and shear stress curves. To recover its structure, the material must rest for a certain period of time which is characteristic for the specific material. This type of flow behaviour is shown by all gel-forming systems. Typical examples of thixotropic fluids are yoghurt, mayonnaise, margarine, ice cream and brush paint.

Rheopectic fluids

A *rheopectic fluid* can be described as a thixotropic fluid but with the important difference that the structure of the fluid will only recover completely if subjected to a small shear rate. This means that a rheopectic fluid will not rebuild its structure at rest.

Anti-thixotropic fluids

An *anti-thixotropic fluid* can be described as a shear-thickening system, *i.e.* one where the viscosity increases with increasing shear rate, but also with time at a constant shear rate. As with thixotropic fluids, the flow behaviour is illustrated by a *loop test*. This type of flow behaviour is very uncommon among foodstuffs.

Flow behaviour models

For the adaptation of viscosity measurement data to process design calculations some kind of mathematical description of the flow behaviour is required. For that purpose several models are available for mathematical description of the flow behaviour of non-Newtonian systems. Examples of such models are *Ostwald, Herschel-Bulkley, Steiger-Ory, Bingham, Ellis* and *Eyring.* These models relate the shear stress of a fluid to the shear rate, thus enabling the apparent viscosity to be calculated, as always, as the ratio between shear stress and shear rate.

By far the most general model is the Herschel-Bulkley model, also called the *generalised power law equation*, which in principle is an extended Ostwald model. The main benefit of the generalised power law equation is its applicability to a great number of non-Newtonian fluids over a wide range of shear rates. Furthermore, the power law equation lends itself readily to mathematical treatment, for instance in pressure drop and heat transfer calculations.

The generalised power law equation is applicable to plastic as well as

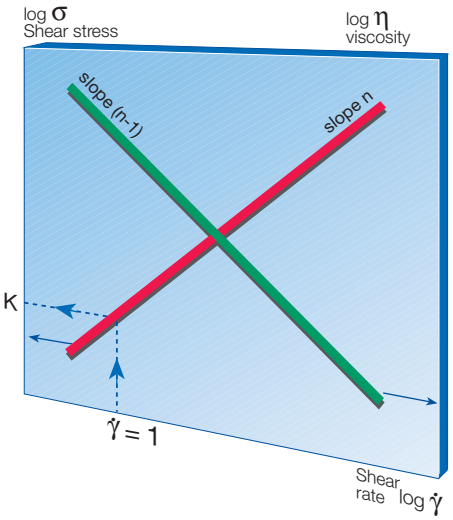


Fig. 3.8 *Logarithmic flow and viscosity curves for a shear-thinning power law fluid.*

shear-thinning and shear-thickening fluids according to the following:

$$(\sigma - \sigma_0) = K \cdot \dot{\gamma}^n$$

where
σ = shear stress, Pa
σ_0 = yield stress, Pa
K = consistency, Pas^n
$\dot{\gamma}$ = shear rate, s^{-1}
n = flow behaviour index

Suitable modification of the generalised power law equation makes it possible to rewrite it to express each type of flow behaviour.

For Newtonian fluids the power law equation looks like this: (K = h and n = 1):

$$\sigma = K \cdot \dot{\gamma}^n = \eta \cdot \dot{\gamma}$$

For a plastic fluid, the power law equation is used in the fully generalised form, with n < 1 for viscoplastic behaviour and n = 1 for Bingham plastic behaviour.

For a shear-thinning or shear-thickening fluid, the power law equation becomes:

$$\sigma = K \cdot \dot{\gamma}^n$$

with n < 1 and n > 1, respectively.

For time-dependent fluids, which in practice means thixotropic fluids, the mathematical models required for description of rheological behaviour are generally far more complex than the models discussed so far. These fluids are therefore often described by time-independent *process viscosities* normally fitted to the power law equation.

Typical data

Some typical data on shear rates, viscosities, power law constants (n and K values), and yield stress values at around room temperature (with the exception of molten polymers and molten glass), are shown in Table 3.1.

The unit of viscosity is Pas (Pascal second), which is equal to 1 000 mPas or 1 000 cP (centipoise). Please note also that all viscosity figures should be regarded as examples only (around room temperature) and should **NOT** be used for calculations.

Measuring equipment

The main types of viscometers are rotational and capillary. Rotational viscometers are of the spindle, cone-plate, plate-plate or concentric cylinder type. The latter may be of the Searle (rotating bob) or Couette (rotating cup) type. Capillary viscometers may be of the atmospheric or pressurised type. Generally speaking, rotational viscometers are easier to use and more flexible than capillary viscometers. On the other hand, capillary viscometers are more accurate at low viscosities and at high shear rates. However, for practical use in liquid food viscometry they are less applicable due to their sensitivity to even small particles like fruit juice fibres.

Instead, a special design of the capillary viscometer is the tubular

Table 3.1
Some shear rates, viscosities, power law constants, and yield stress values

Shear rates	sedimentation	10^{-6}	–	10^{-4}	s^{-1}	
	chewing	10^{1}	–	10^{2}	s^{-1}	
	stirring	10^{1}	–	10^{3}	s^{-1}	
	pumping	10^{2}	–	10^{3}	s^{-1}	
	spraying	10^{3}	–	10^{4}	s^{-1}	
	rubbing	10^{4}	–	10^{5}	s^{-1}	
Viscosities	air	10^{-5}	Pas			
	water	10^{-3}	Pas			
	olive oil	10^{-1}	Pas			
	glycerol	10^{0}	Pas			
	syrup	10^{2}	Pas			
	molten glass	10^{12}	Pas			
	glass	10^{40}	Pas			
n and K values	fruit concentrate	n=0,7	K	=	2	Pas^n
	molten chocolate	n=0,5	K	=	50	Pas^n
	sour milk	n=0,3	K	=	3	Pas^n
	quarg	n=0,3	K	=	4	Pas^n
	apple purée	n=0,3	K	=	10	Pas^n
	tomato paste	n=0,2	K	=	70	Pas^n
	grease	n=0,1	K	=	1000	Pas^n
Yield stress	ketchup	14	Pa			
	mustard	38	Pa			
	mayonnaise	85	Pa			

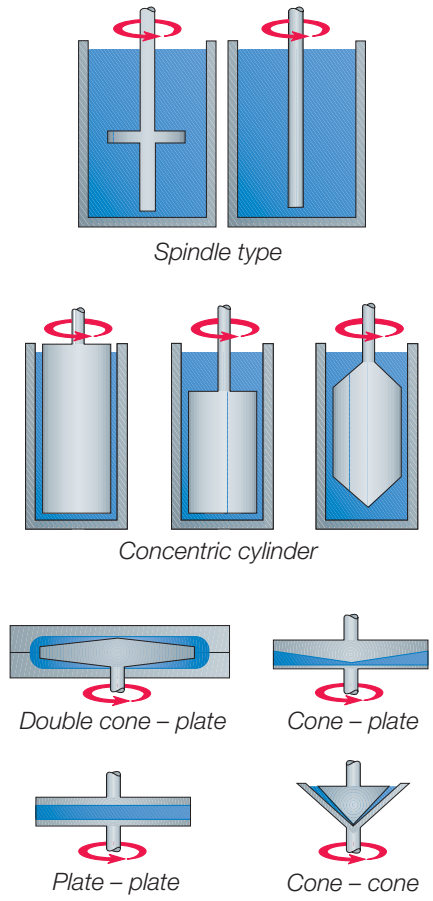


Fig. 3.9 *Operating principles of different types of viscometer.*

viscometer, with a diameter of *e.g.* 25 or 38 mm compared to a few mm for the capillary type. The tubular viscometer is used for the determination of the power law constants and is especially suitable for particulate products. The drawback of the tubular viscometer is that it often requires large product volumes and that the measuring system can be quite bulky and expensive.

Measurement of non-Newtonian fluids requires instruments where the applied shear rate is accurately defined, *i.e.* where the shearing takes place in a narrow gap with a small shear rate gradient. This fundamental requirement excludes viscometers where the gap is too big or even undefined, as it is in viscometers of spindle type. It must be strongly emphasised that viscosity measurements of non-Newtonian fluids carried out at undefined or out-of-range shear rates should not be used as a basis for quantitative analysis of viscosity figures or rheological parameters.

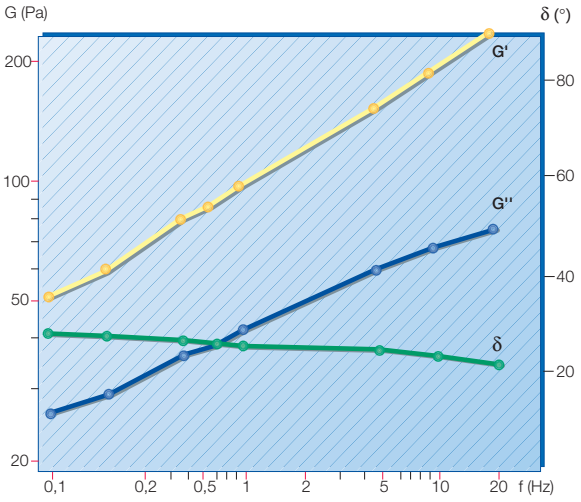
Rotational viscometers are available as portable as well as stationary instruments. Portable types usually come in a shockproof case equipped with all necessary accessories. They are basically manually operated, although some manufacturers provide connections for use with personal computers. Today many of the portable instruments are equipped with processors capable of running the viscometer according to the desired scheme and also of storing all measuring data for later download to a printer or a PC.

Stationary installations are normally computer controlled for automation of measuring sequences and data evaluation. The software usually includes possible fitting to a number of rheological models, plotting of flow curves, etc.

A rotational viscometer is normally insufficient for carrying out a complete

rheological analysis, for instance determination of structure breakdown in yoghurt. This type of analysis requires a more sophisticated instrument, generally called a rheometer. With a rheometer, operating with torsional vibration or oscillation rather than rotation, the fluid can be rheologically analysed without its structure being destroyed. Typical applications are viscoelastic fluids, for which a rheometer can be used to determine the viscous and elastic properties of the fluid separately.

Ordinary viscometers and rheometers should not be used for measurement of substances with very high viscosities, such as butter, cheese and vegetable fats. Certain types of penetrometers are available instead, but these cannot be used to obtain scientific rheological results since a penetrometer gives only empirical information. A special type of consistometer is preferably used within the tomato industry. This type of instrument gives the result in so-called ^{0}Bostwick, which is a unit applicable only to comparison of different products.



G' = *elastic modulus*
G'' = *viscous modulus*
δ = *phase angle*

Fig. 3.10 *Example of the result of a rheological analysis.*

Measuring techniques

Viscosity measurements should always be carried out for a representative range of shear rates and temperatures related to the process to be studied. The intended use of the measured data should therefore be considered before measuring takes place, for instance if the viscosity data are to be used in the design of a deep cooler or of the heating section of a steriliser.

Due to practical limitations the maximum applicable temperature for most viscometers is around 90 °C. At higher temperatures the risk of evaporation from the surface of the test sample followed by skin formation leading to increased momentum and hence false readings is significant. Hence a special type of pressurised measuring system has to be employed. With these systems temperatures up to 150 °C are possible, *i.e.* a typical sterilisation process up to 140 °C can be fully covered regarding viscosity data. It is also most important that the temperature is kept constant during the test period and, of course, that it is accurately measured. A temperature change of 3 °C can often cause a change in viscosity of 10 per cent.

To increase the accuracy of data evaluation, measurements should be made at as many different shear rates and temperatures as possible. In addition, heating effects must be considered. In a substance containing warm-swelling starch, for example, the viscosities before and after heating above swelling temperature will differ significantly.

Furthermore, storage conditions and time factors must be taken into consideration. The rheological properties of many products, *e.g.* fermented dairy products, change with time, and if the purpose of the viscosity measurement is to supply data for process design, the measurements should preferably be made in as close connection as possible to the actual processing stage.

When measurements are performed at a regular basis the results are preferably stored in a database in order to facilitate comparison of various products. In practice all varieties of liquid food products are unique regarding viscosity data, meaning that data measured on one type of vanilla pudding, one type of tomato purée or one type of yoghurt cannot be safely applied to another type or brand of a product with the same name or even with roughly the same composition. However, with access to a database containing data on a substantial amount of products there is always a possibility to extract a range of viscosities for a certain type of product in case no other information is available.

Pressure drop in pipes

Some useful equations are given below for manual calculation of pressure drop and shear rates for laminar pipe flow. All equations are based on the

power law expression, as most food systems in processing conditions can be described by this expression.

The equations are applicable to Newtonian as well as non-Newtonian fluids depending on the value of n used in the calculation: n<1 for shear-thinning (pseudoplastic) fluids, n=1 for Newtonian fluids, and n>1 for shear-thickening (dilatant) fluids.

The relationship between flow rate and pressure drop and between flow rate and wall shear rate in a circular channel is described as follows:

$$Q = \left(\frac{n}{3 \cdot n + 1}\right) \cdot \pi \cdot r^3 \cdot \left(\frac{r \cdot \Delta p}{2 \cdot L \cdot K}\right)^{1/n}$$

or

$$\Delta p = \left(\frac{3 \cdot n + 1}{n}\right)^n \cdot \left(\frac{Q}{\pi \cdot r^3}\right)^n \cdot \frac{2 \cdot L \cdot K}{r}$$

and

$$\dot{\gamma}_w = \left(\frac{3 \cdot n + 1}{n}\right) \cdot \left(\frac{Q}{\pi \cdot r^3}\right)$$

The parameters are:

Q	=	flow rate	m^3/s
r	=	duct radius	m
Δp	=	pressure drop	Pa
L	=	tube length	m
$\dot{\gamma}_w$	=	wall shear rate	s^{-1}
n	=	flow behaviour index	
K	=	consistency coefficient	Pas^n

The corresponding equations for rectangular channels are as follows:

$$Q = \left(\frac{n}{4 \cdot n + 2}\right) \cdot w \cdot h^2 \cdot \left(\frac{h \cdot \Delta p}{2 \cdot L \cdot K}\right)^{1/n}$$

$$\Delta p = \left(\frac{4 \cdot n + 2}{n}\right)^n \cdot \left(\frac{Q}{w \cdot h^2}\right)^n \cdot \frac{2 \cdot L \cdot K}{h}$$

$$\dot{\gamma}_w = \left(\frac{2 \cdot n + 1}{n}\right) \cdot \left(\frac{Q}{w \cdot h^2}\right)$$

The new parameters are:

w	=	duct width	m
h	=	duct height	m

Pressure drop in fittings

For calculation of pressure drop in fittings, *e.g.* valves, bends, expansions and tees, the following equation can be employed:

$$\Delta p = K_f \cdot \frac{r \cdot v}{2}$$

with the parameters

K_f	=	friction loss coefficient	–
ρ	=	density of fluid	kg/m^3
v	=	velocity of fluid	m/s

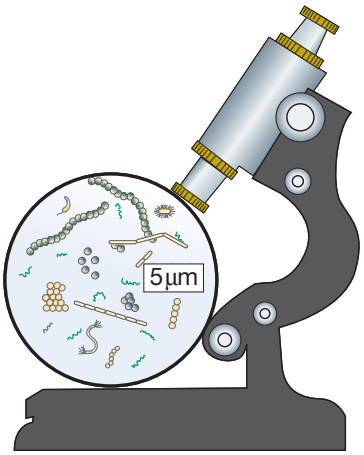
Values of the friction loss coefficient can be found in ordinary chemical or food engineering textbooks as well as in specialised rheological textbooks. For laminar flow, however, the data found are scarce and hence accurate estimation of pressure drop for typical liquid food flow conditions is difficult to make.

Since the actual pressure drop is dependent on the type of fluid as well as on the type and shape of the restriction and the friction loss, coefficients should therefore preferably be determined from experimental data.

Chapter 4

Microbiology

Microbiology is the study of living organisms of microscopic size, including bacteria, fungi (mould and yeast), algae, protozoa and viruses.



Some milestones in microbiological history

Antonie van Leeuwenhoek, 1632 – 1723, a self-taught Dutchman, constructed the microscope with which he could observe bacteria. Leeuwenhoek has been called the "father of microscopy".
Louis Pasteur, 1822 – 1895, a French chemist, invented the heat treatment method that is now called pasteurisation.
Robert Koch, 1843 – 1910, a German physician and 1905 Nobel Prize

winner for medicine, discovered pathogenic (disease-producing) bacteria such as the tubercle bacillus and cholera bacterium. In addition, he devised ingeniously simple methods to enable safe study of these organisms.
Alexander Fleming, 1881 – 1955, a British microbiologist, professor and 1945 Nobel Prize winner for medicine, discovered penicillin (1929), which is effective against many bacteria, but not tuberculosis.
Selman A. Waksman, 1888 – 1973, an American mycologist, microbiologist and 1952 Nobel Prize winner for medicine, discovered streptomycin, which is effective against many bacteria including tuberculosis.

Microbiology
Microbiology is the study of organisms that are so small, they can only be seen with the aid of a microscope. Size is measured in micrometer (µm).
1 µm = 0,001 mm

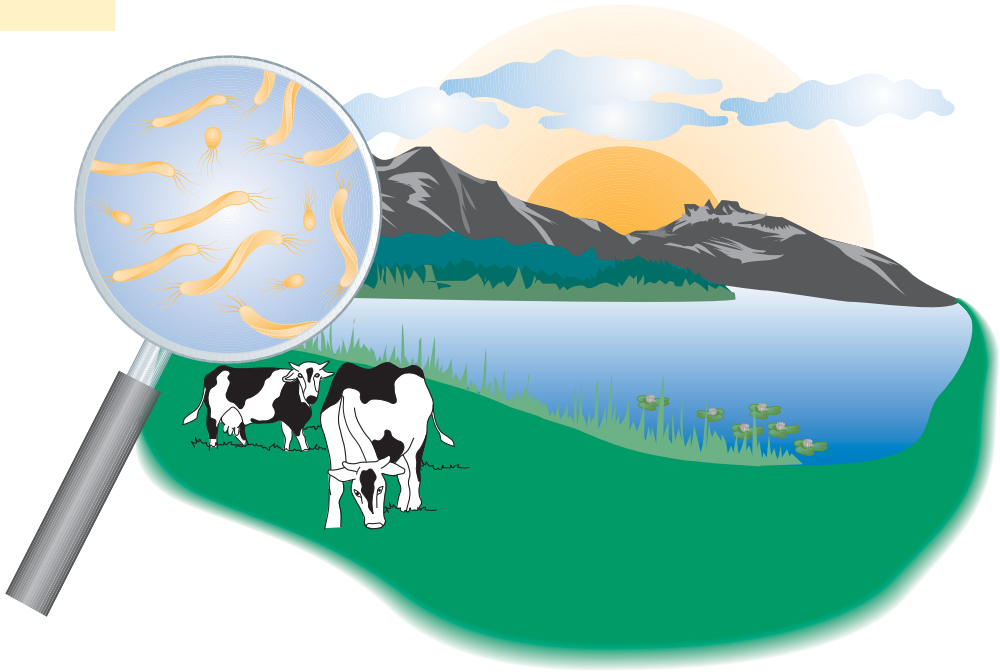


Fig. 4.1 *Micro-organisms can be found everywhere ... in the air ... in the soil ... and in water.*

Micro-organisms in nature

Micro-organisms are found everywhere - in the atmosphere, in water, on plants, animals and in soil. Because they break down organic material, they play an important role in the cycle of nature.

Micro-organisms occur most abundantly where they find food, moisture, and a temperature suitable for their growth. Since the conditions that favour the survival and growth of many micro-organisms are those under which people normally live, it is inevitable that we live among a multitude of microbes.

Listed below are the key characteristics of the different groups of micro-organisms, see Table 4.1.

Table 4.1
Micro-organisms

Groups	Range of size
Protozoa	5 – 200 µm
Algae	5 µm – a few metres
Fungie	
Yeast	5 – 10 µm
Mould	5 – 10 µm by metres
Bacteria	0,5 – 5 µm
Viruses	0,015 – 0,2 µm

Protozoa
- Unicellular, small aquatic organisms
- Can ingest solid food particles
- Ultimately become food for fish and larger animals
- Generally not food spoilage organisms
- A few protozoa are food-borne pathogens, transmitted by water
- Some protozoa are pathogens, transmitted by insects

Algae
- Uni- or multicellular organisms, frequently found in water
- Contain chlorophyll and are photosynthetic
- Used as food supplement and in pharmaceutical products
- Some are source of agar for microbiological media
- Some produce toxic substances
- Generally not food spoilage organisms

Yeasts
- Unicellular, oval or round in shape
- Frequently found in many environments: soil, plants and fruits
- Used as food supplement and in the production of alcoholic beverages
- Food spoilage organisms, especially of high acid foods

Moulds
- Multicellular with many distinctive features
- Always found in soil, but can also be found in water and air
- Responsible for the decomposition of many materials
- Useful for industrial production of many chemicals, including penicillin
- Can cause diseases in humans, animals, and plants
- Food spoilage organisms, especially of high acid foods

Bacteria
- A highly variable group of micro-organisms
- Found in almost all environments
- Some cause diseases, others perform important roles in the natural recycling of elements, and thus contribute to soil fertility
- Useful in industries for the manufacture of valuable compounds
- Some spoil foods and others are used in the manufacture of foods

Viruses
- Can only reproduce in living cells *i.e.* are parasites

Saprophytes = micro-organisms living on dead organic matter

Parasites = micro-organisms living on living animals and plants

Biotechnology

The concept of "biotechnology" is a fairly recently coined word for techniques utilising biological processes. Biotechnology has a history that predates the modern scientific disciplines of microbiology, biochemistry and process technology by thousands of years.

Until the end of the nineteenth century, these processes were associated with food, and above all with preservation of food.

Microbial processes still play a prominent part in the food industry, but biotechnology in the modern sense is largely associated with industrial utilisation of the properties of living cells or components of cells to obtain production of various products, such as hormones and certain vaccines. To accomplish this, it is necessary to utilise knowledge of the bio-sciences – biochemistry, microbiology, cell biology, molecular biology and immunology – as well as the technologies of apparatus design, process engineering, separation techniques, and analytical methods.

This chapter deals mainly with micro-organisms relevant to milk and milk processing, but specific viruses called bacteriophages are also described. These organisms cause serious problems in the manufacture of products where micro-organisms are needed for development of flavour, texture and other characteristics.

Bacteria

Bacteria are unicellular organisms that normally multiply by binary fission, *i.e.* splitting in two. Bacteria are classified partly by their appearance. However, to be able to see bacteria, they must be studied under a microscope at a magnification of about 1 000 times.

Bacteria may also be stained and the most widely used method of staining bacteria was introduced by the Danish bacteriologist Gram and is called Gram staining. Bacteria are divided into two main groups according to their Gram stain characteristics: Gram negatives are red and Gram positives are blue.

Morphology of bacteria

Morphology is the study of the form of bacteria. This covers morphological features such as shape, size, cell structure, motility (ability to move in a liquid), and spore and capsule formation.

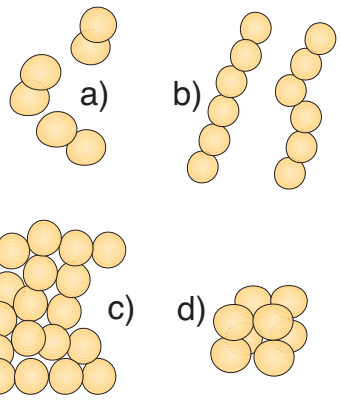


Fig. 4.2 *Spherical bacteria (cocci) occur in different formations.*

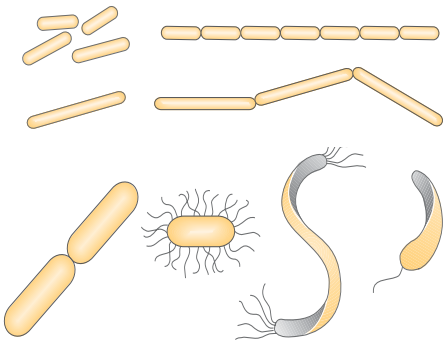


Fig. 4.3 *Rod- and spiral-shaped bacteria.*

Shape of bacteria

Bacteria come in many different shapes. However, three main characteristic shapes can be distinguished: spherical-, rod- and spiral-shaped.

The spherical bacteria are named cocci and when arranged in pairs they are called diplococci (Figure 4.2 a) and when arranged in chains they are called streptococci (b). Cocci can also be arranged in irregular clusters like grapes (c) and arranged in groups of four or as cubic arrangement (d).

Rod-shaped bacteria vary in both length and thickness. Some of them also form chains in the same way as many *Bacillus* species (Figure 4.3). The word bacilli means small rods.

Spiral bacteria can be of variable length and thickness, and the number of turns also differs. Spiral bacteria with many turns are among the largest bacteria, up to 20 µm are common.

Function of cell structures

Cell wall	gives the cell its specific shape
Cell membrane	active transport of nutrients and metabolites
Cytoplasm	place of production of cell constituents
Chromosome	carrier of genetic information

Cell structure and function of bacteria

The smallest basic unit of life, functionally and structurally, is a cell, and bacteria have the most simple cell organisation. The bacterial cell is procaryotic. All other cells, including fungi, algae, protozoa, plant and animal cells, are eucaryotic.

The minimum number of structural components in a bacterial cell is relatively small. The cell wall is the only rigid structural component. It gives the cell its shape. Bacteria with a thick cell wall are Gram-positive and bacteria with a thin cell wall are Gram-negative. The cell membrane determines what should be inside and outside of the cell. Only water-soluble substances can be transferred through the cell membrane. Thus no exchange between the cell and its environment or growth takes place if water is not present.

The contents of the interior of the bacterial cell are dispersed into two recognisable parts: the cytoplasm and the chromosome. The chromosome is the carrier of the genetic information in its DNA, deoxy-ribonucleic acid. In principle, a bacterium contains only one chromosome *i.e.* one molecule of DNA. Its information is transformed into enzymes in the cytoplasm. In electron microscope pictures, the cytoplasm most often appears granular. The actual sources of production of cell components are the ribosomes, which are big proteins, and RNA, ribonucleic acid. In addition to the recognisable structural components (Figure 4.4) there are many solutes in the cytoplasm: break down products, vitamins, co-factors and building blocks for the synthesis of cell components.

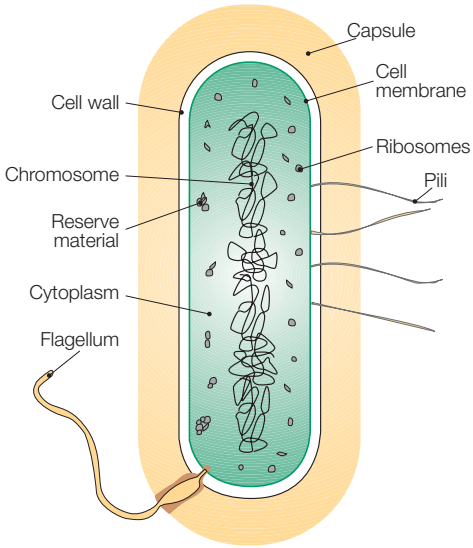


Fig. 4.4 *Schematic view of a bacterial cell.*

Motility of bacteria

Some cocci and many bacilli are capable of moving in a liquid nutrient medium. They propel themselves with the help of flagella, which are long, stiff-thread like appendages growing out of the cytoplasmic membrane (Figure 4.5). The length and number of flagella vary from one type of bacterium to another. The bacteria generally move at speeds of between one and ten times their own length per second. The cholera bacterium is probably one of the fastest; it can travel 30 times its length per second.

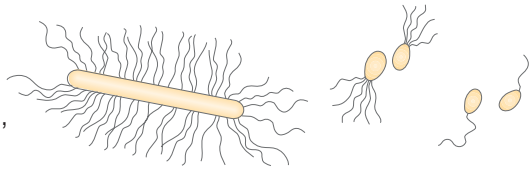


Fig. 4.5 *Flagella may be distributed all over the bacterium, or located at one or both ends.*

Spore formation

Only a few genera of bacteria form spores: *Bacillus* and *Clostridium* are the most well-known. The spore is a form of protection against adverse conditions, *e.g.* heat, disinfectants, dry condition or lack of nutrients. Some of the different types of spore formations are illustrated in Figure 4.6.

When the parent cell forms a spore, it may retain its original shape, or it may swell in the middle or at one end, depending on where the endospore is located. During spore formation the vegetative part of the bacteria cell dies. The cell eventually dissolves and the spore is released.

The spore germinates back into a vegetative cell and starts reproduction when conditions become favourable again.

Spores are resting cells with no metabolism and thus cannot multiply. They can survive for years in dry air, and they are more resistant than bacteria to chemical sterilants, antibiotics, drying and ultraviolet light. They are also resistant to heat: 20 – 30 minutes in hot water or steam at 120 °C will generally destroy spores. However, spore-forming bacteria in the vegetative state are killed in seconds by boiling at 100 °C just like any other bacteria.

Procaryotic are all bacteria
- Simple cell organisation
- No membrane around the genetic material, which is one DNA molecule

Eucaryotic are fungi, algae, protozoa, plant and animal cells
- Cell organisation complex
- Membrane around the genetic material (several DNA molecules) *i.e.* a true nucleus exists

Capsule formation

Some bacilli and cocci are surrounded by a capsule of strongly developed mucus. This makes them rather resistant against dry conditions. Growth of such bacteria in milk makes it viscous and slimy. In both cases this phenomenon gives ropy milk.

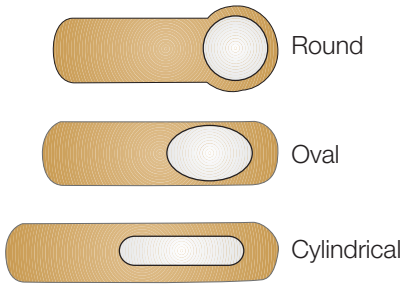


Fig. 4.6 *Various types of endospore formation in bacteria.*

Growth factors for bacteria

Nutrients

Bacteria require certain nutrients for their growth. The need for nutrients varies widely among different bacteria. The main sources of food are organic compounds, *e.g.* proteins, fats and carbohydrates. In addition, small amounts of trace elements and vitamins are necessary for growth.

As well as material for cell formation, organic matter also contains the necessary energy. Such matter must be soluble in water and have a low molecular weight, *i.e.* it must be broken down into very small molecules in order to be able to pass through the cytoplasmic membrane and be metabolised by the bacterium. Consequently, bacteria need access to water.

Some micro-organisms lack the ability to release enzymes for breaking down substances outside the cell. They have to utilise breakdown products created by other micro-organisms. Such a relationship is called symbiosis when both parties benefit from it. When one organism produces substances, which have an inhibiting effect on other organisms, this process is called antibiosis.

Symbiosis = permanent union between organisms, each of which depends for its existence on the other

Antibiosis = an antagonistic situation where one organism produces substances which inhibit the growth of other organisms

Water activity

The growth and metabolism of micro-organisms demand the presence of water in an available form. The most useful measurement of the availability of water is water activity, a_w. The a_w in a food may be reduced by increasing the concentration of solutes in the aqueous phase of the food, either by

a_w calculation
The a_w can be calculated according to the formula:

$$a_w = \frac{p}{p_o}$$

where p = vapour pressure of the food at t °C,
and p_o = vapour pressure of pure water at t °C

removing water or by adding solutes. Some water molecules are oriented around the solute molecules, and others become absorbed into insoluble food constituents. In both instances, the water becomes less available to enter into chemical reactions.

Dehydration is a method of food preservation that depends on the reduction of a_w by water removal. In salting and sugaring, the addition of a solute lowers the a_w and preserves the food. A small reduction in a_w often has sufficient effect to preserve a food when combined with other factors.

Definitions of water activity

The a_w of a food or solution equals the ratio of the water vapour pressure of the food (p) to that of pure water (p_o) at the same temperature. When a solution becomes more concentrated, vapour pressure decreases and the a_w drops from a maximum value of 1 for pure water.

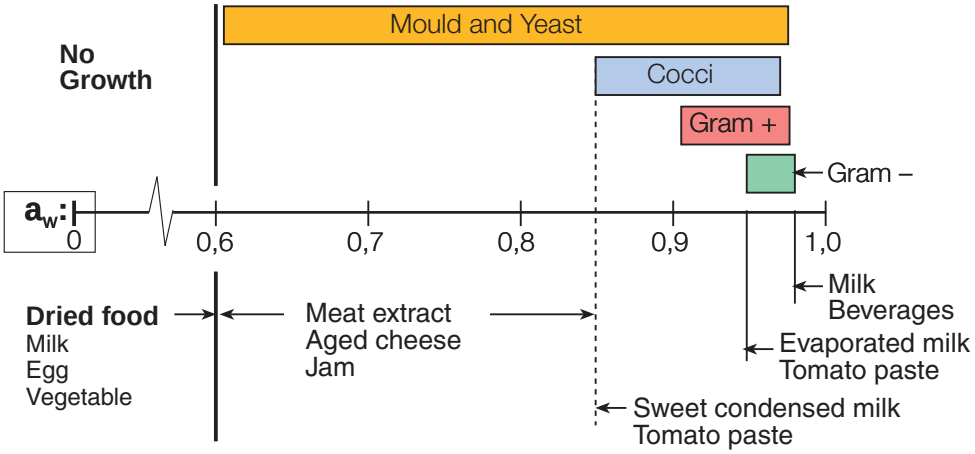


Fig. 4.7 *Effect of a_w on growth.*

Effect of water activity on growth

Many micro-organisms, including pathogenic bacteria, grow most rapidly at levels of a_w in the range of 0,99 – 0,98. Below this a_w the growth rate decreases and the length of the lag phase increases (Figure 4.7).

Most micro-organisms relevant to food have their optimum growth rate at an *a_w of 0,98 or higher*. This is also the range for a_w of milk and beverages in general. Several gram-negative bacteria are the most competitive due to growth rate, *i.e.* if present, they will dominate the microbial flora. In milk, for example, a gram-negative infection often hides an infection of gram-positive bacteria.

At an *a_w between 0,98 and 0,93* the gram-positive bacteria dominate, *i.e. Lactobacillus, Bacillus* and *Micrococcus*, but a few tolerant coliforms may be present. Food-borne bacterial pathogens (*Salmonella, C. botulinum* and *C. perfringens*) are prevented from multiplication. In contrast, *Staphylococcus* grow at 50 % of their maximum growth rate at $a_w = 0,94$. Within this range, spoilage of low-acid food by fungi is possible and they can compete with bacterial spoilage.

At an *a_w between 0,93 and 0,85* possible spoilage organisms are cocci, moulds and yeasts. The only bacterial pathogen growing within this range is *S. aureus*. Intermediate moisture food is designed to have an $a_w < 0,85$ in order to inhibit *S. aureus*.

At an *a_w between 0,85 and 0,60* a few moulds and yeasts can cause spoilage. Common foods in this range are jams and jellies preserved by a high concentration of sugar. There is no production of mycotoxin possible in this a_w range.

No micro-organisms can grow at an *$a_w < 0,60$*. Such food is safe from further microbial spoilage. It should be emphasised, however, that due to previous history, such food might contain viable micro-organisms including pathogens and/or toxins.

Temperature

Temperature is the greatest single factor affecting growth, multiplication and food deterioration (Figure 4.8). Bacteria can only develop within certain temperature limits, which vary from one species to another. In principle, bacteria can grow at temperatures between the freezing point of water and the temperature at which the protein in the cytoplasm coagulates. Somewhere between the maximum and minimum temperatures, *i.e.* the upper and lower limits, lies the optimum temperature. This is the temperature at which the bacterial strain multiplies most vigorously.

Temperatures below the minimum cause growth to stop, but do not kill the bacteria. The life functions of bacteria cease almost completely at a temperature close to the freezing point of water. As the cells have a high content of water, this will freeze at this temperature. When this happens, the bacteria can no longer absorb nutrients through the cell membranes.

If the temperature is increased above the maximum, the bacteria are quickly killed by heat. Most cells die within a few seconds of being exposed to 70 °C, but some bacteria survive heating to 80 °C for five minutes, even though they do not form spores.

It takes much more heat to kill bacterial spores, and dry heat is less effective than moist heat. Treatment with steam at 120 °C for 30 minutes ensures the destruction of all spores, but in dry heat, the bacteria must be kept at 160 °C for two hours to guarantee destruction of spores.

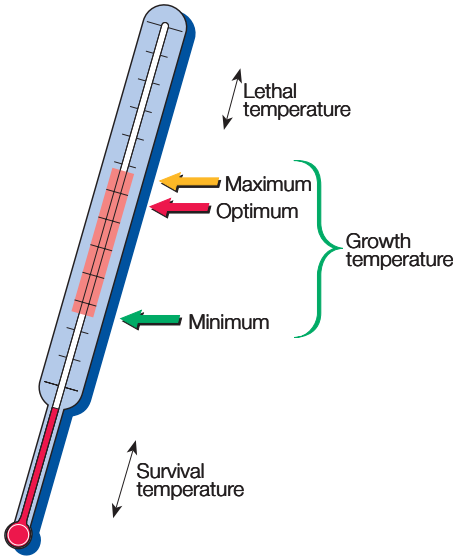


Fig. 4.8 *Temperature conditions for bacterial growth.*

Classification by temperature

Bacteria can be divided into the following categories (Figure 4.9) according to their preferred temperature range:

Psychrophilic (cold-loving) bacteria grow well at 0 °C with an optimum temperature about 12 – 15 °C and maximum below 20 °C.

Psychrotrophic (cold-tolerant) bacteria are mesophilic strains that can multiply at commercial refrigeration temperatures with an optimum temperature about 20 – 30 °C.

Mesophilic bacteria has a minimum temperature about 10 °C, and generally an optimum of 30 – 35 °C and maximum at about 50 °C. Without doubt, this is the most common range for bacterial growth. Approximately 90 % of all bacteria can grow in this temperature interval.

Thermophilic (heat-loving) bacteria have their optimum growth temperatures at 55 – 65 °C. Minimum temperature about 37 °C and maximum around 70 °C.

The psychrotrophic bacteria are of particular interest to the dairy industry, because microbiological activity in farm milk and market milk usually takes place at a temperature of 7 °C or below.

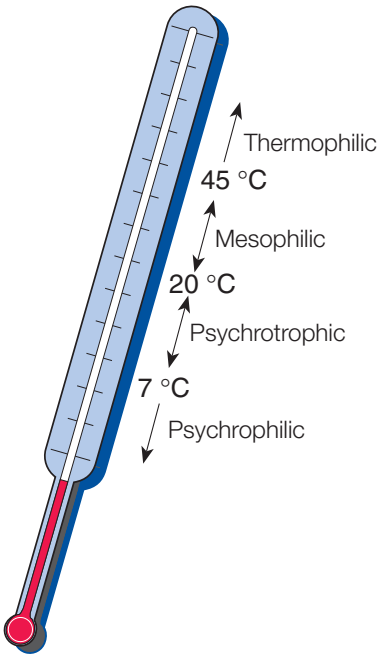


Fig. 4.9 *Classification of bacteria by temperature preference.*

Oxygen

Many micro-organisms need free oxygen to oxidise their food in order to produce energy and support their life processes. Complete oxidation of organic compounds forms CO_2 and water. Many micro-organisms can utilise air at atmospheric pressure, and these are called aerobic micro-organisms. Other types obtain energy from their food without need of free oxygen, and these are called anaerobic micro-organisms.

There are some bacteria that consume free oxygen if it is present, but which can grow in the absence of free oxygen. Such bacteria are called facultatively anaerobic. Anaerobic and facultatively anaerobic bacteria generally obtain their energy by fermentation of organic compounds. Chemically, this is an incomplete oxidation, whereby organic waste-products are formed, *e.g.* lactic acid from lactose, Table 4.2.

As most organisms obtain their oxygen from the air, *i.e.* they are aerobic, removal of oxygen/air is a means of controlling or preventing their growth. Examples of this are vacuum packing, gas packing and the use of materials acting as an air barrier.

Anaerobic bacteria die if exposed to atmospheric oxygen for any length of time.

Table 4.2
Bacterial relationship to oxygen

Bacterial group	Relationship to oxygen
Aerobe	Micro-organisms that use O_2 for growth and can tolerate O_2 at atmospheric level or higher *i.e.* 21 %.
Microaeraphile	Micro-organisms capable of using O_2 for growth but only at lower O_2 levels than in atmosphere.
Anaerobe	Micro-organisms incapable of O_2-dependent growth and can not grow in oxygen of atmospheric level. They obtain energy by fermentation.
Facultative anaerobe	Micro-organisms that can grow well both in the absence and presence of oxygen of atmospheric level. Some can grow aerobically with oxygen and anaerobically with fermentation.

Light

Light is only essential for photosynthetic cells, which capture energy from the light. Micro-organisms, including most bacteria, tend to be killed when exposed to direct sunlight. The ultraviolet part of the sunlight causes chemical changes in the DNA and cell protein.

Ultraviolet light is often used to disinfect atmospheres in starter rooms. However, it is not used to disinfect food, as chemical changes may also take place in the food.

pH – effect of acidity on growth

Most natural environments have pH values between 5 and 9, and the most common micro-organisms are optimised for growth in this range. Most moulds and yeasts grow best in slightly acidic media, around pH 5 to 6, while optimum conditions for bacteria are neutral or slightly alkaline environments.

Fresh milk normally has a pH between 6,5 and 6,7. Moulds and yeasts generally grow well at pH as low as 3, or even pH 2. Most non-processed foods have a pH slightly below neutral *i.e.* they are low acid foods. Fruit juices are generally high-acid foods (Figure 4.10).

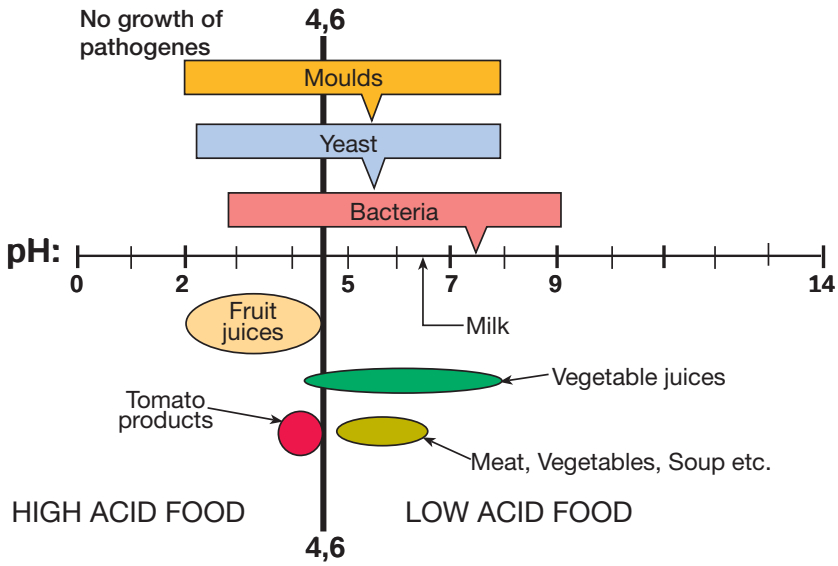


Fig. 4.10 *Effect of acidity on growth.*

Multiplication of bacteria

Bacteria normally multiply by binary fission. In Figure 4.11, multiplication is shown graphically. Each individual cell grows and after reaching a critical size, it divides into two identical cells. The type of cell arrangement, which results in a characteristic cell grouping, is usually constant for a given species of bacteria. Cell grouping can take the forms of chains, pairs and clumps. This characteristic is therefore used in the description of different species.

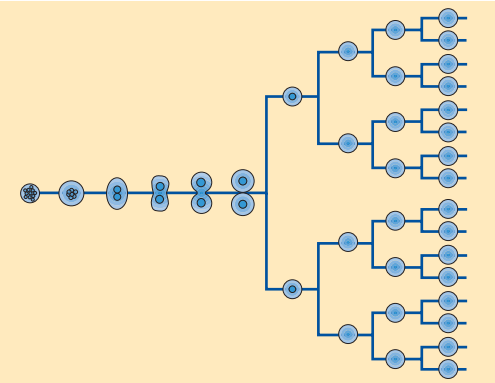


Fig 4.11 *Multiplication of bacteria.*

Rate of multiplication

In favourable conditions, multiplication of bacteria can occur at intervals of 20 – 30 minutes. The rate of multiplication can be calculated from the formula shown to the right. With a generation time of 0,5 hour, one bacterium/ml of milk will become about one million bacteria/ml within 10 hours.

Under optimal conditions in food, 100 million – 1 000 million bacteria/ml can be formed. At that stage, the growth rate will be inhibited by lack of nutrients and accumulation of toxic metabolic waste products. Reproduction finally stops, and large numbers of bacteria die. In reality, unfavourable conditions, such as low storage temperature or low pH will limit or delay the growth of bacteria in food.

Formula for rate of reproduction of bacteria

$$N = N_0 \times 2^{\frac{t}{g}}$$

N = number of bacteria/ml at time t
N_0 = number of bacteria/ml at time 0
t = the time of growth in hours
g = generation time in hours

Growth curve of bacteria

Figure 4.12 shows a curve of the growth of bacteria transferred to a substrate by inoculation. There is usually some delay before the bacteria start to reproduce, as they must first adapt to the new environment. This phase of development (a) is called the lag phase. The reason for the lag phase may also be that the culture has to be recovered. It may, for example, have been stored at a low temperature prior to inoculation.

The length of the lag phase varies according to how much the bacteria were inhibited at the moment of inoculation.

After the lag phase, the bacteria begin to multiply logarithmically. This phase (b) is called the log phase or the exponential phase.

After some time, toxic metabolic waste products accumulate in the culture. The rate of multiplication will therefore subsequently slow down, while at the same time bacteria are constantly dying, so that a state of equilibrium is reached between the death of some cells and the formation of new ones. This phase (c) is called the stationary phase.

In the next phase (d), formation of new cells ceases completely and the existing cells gradually die off. Finally the culture is almost extinct. This is called the death phase.

The shape of the curve, *i.e.* the length of the various phases and the gradient of the curve in each phase, varies with temperature, food supply and other growth parameters as well as species.

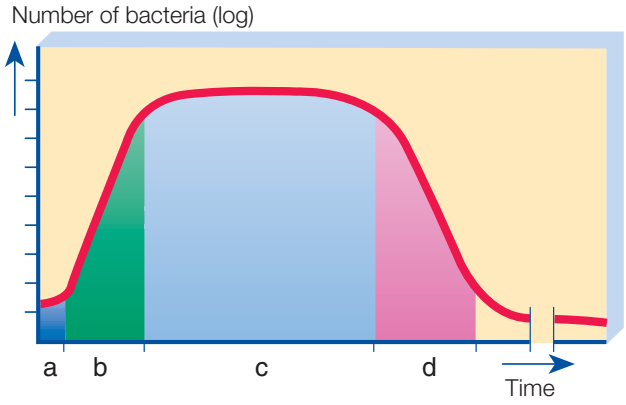


Fig. 4.12 *Growth curve of bacteria*
a *Lag phase*
b *Log phase*
c *Stationary phase*
d *Death phase*

Biochemical activity

Due to biochemical activity, micro-organisms can spoil food and cause diseases in animals and plants. Some micro-organisms have biochemical activities that are used in food processes i.e. the manufacture of cheese, yoghurt, butter, etc.

The activity of a specific micro-organism is governed by the enzymes it possesses, as these determine what it can feed on and break down, and consequently what end-products it produces.

There are many biochemical and enzymatic systems in micro-organisms. The following systems are the major ones concerned with milk and milk products. They can be sub-divided into which constituent they break down and their effects.

The most important biochemical and enzymatic systems of bacteria in milk products are those responsible for the following effects:

- Breakdown of carbohydrates
- Breakdown of protein
- Breakdown of fat
- Breakdown of lecithin
- Production of colour
- Production of mucus or slime
- Production of odours
- Reduction of oxygen
- Diseases

Breakdown of carbohydrates by:

- hydrolysis
- alcoholic fermentation
- lactic acid fermentation
- coliform type fermentation
- butyric acid fermentation

Breakdown of carbohydrates

Carbohydrates or sugars have the formula $(CH_2O)_n$ and were originally identified as hydrates of carbon. There are mono-, di- and polysaccharides. Polysaccharides are constituted of long chains of one or several sugars, for example, cellulose, starch and chitin. The enzymes of the micro-organism determine which carbohydrates they can break down, and to what extent. In milk, hydrolysis of the disaccharide lactose causes the breakdown to glucose and galactose. They can be completely degraded to carbon dioxide and water (oxidative metabolism), but in most cases fermentation occurs.

Fermentation usually results in various products such as organic acids (lactic acid, butyric acid, etc.), alcohols (ethyl alcohol, butyl alcohol, etc.) and gases (carbon dioxide, hydrogen, etc.), Table 4.3.

The most important forms of fermentation due to activity of micro-organisms are:

- Alcoholic fermentation of carbohydrates to alcohol and gas. One example is the break down of lactose to ethyl alcohol and carbon dioxide. Alcoholic fermentation usually takes place under anaerobic conditions and is mainly induced by yeasts.
- Lactic acid homofermentation of lactose, with lactic acid as the only end product. This reaction is used in the manufacture of cheese, yoghurt and other acidified products.
- Lactic acid heterofermentation of lactose, which produces lactic acid, acetic acid, carbon dioxide and ethyl alcohol.
- Coliform fermentation (mixed acid and butanediol) of lactose, which creates a wide variety of end products such as lactic acid, acetic acid, succinic acid, formic acid, butanediol, ethyl alcohol, carbon dioxide and hydrogen.
- Butyric acid fermentation under strict anaerobic conditions by one strain of *Clostridium* bacteria. In butyric fermentation, lactose is broken down to butyric acid, carbon dioxide, hydrogen and, in some cases, butyl alcohol.

As a general rule, carbohydrate fermentations in milk result in the production of acid (souring) and, in some cases, gas (depending on the organisms).

Breakdown of protein

The process in which protein is broken down is called proteolysis. Proteases such as rennin, pepsin and trypsin are the main enzymes involved in the process. These enzymes degrade proteins into peptides, which are then degraded by various peptidases to smaller peptides and free amino acids. Amino acids can be reutilised for protein synthesis by the cell; however, they can also be broken down oxidatively or fermentatively.

Proteins and their constituent amino acids have a wide combination of chemical elements and contain carbon, hydrogen, oxygen, sulphur, nitrogen and phosphorus. Breakdown of protein therefore results in a much larger range of acids, alcohols, gases (hydrogen, carbon dioxide, hydrogen

Table 4.3
Microbial degradation of carbohydrates

Prescence of oxygen	CO_2 + water + energy
Absence of oxygen	
Alcoholic fermentation	Ethanol + CO_2
Butyric acid fermentation	Butyric acid + CO_2 + H_2
Lactic acid fermentation	
Homofermentative	Lactic acid
Heterofermentative	Lactic acid + ethanol + acetic acid + CO_2

sulphide and ammonia) and other compounds. Breakdown of protein nearly always results in ammonia, which is alkaline and has a strong odour, Figure 4.13.

Three amino acids, cystine, cysteine and methionine, contain sulphur and result in hydrogen sulphide, which also gives off a strong smell of rotten eggs.

Breakdown of protein in liquid milk takes place in two major stages called peptonisation and consists of:

- Curdling (sweet as opposed to sour) or clotting of the milk by rennin-like enzymes. This fault in milk is called sweet curdling, a defect which is common in pasteurised milk that is stored warm.
- Proteolysis of the protein, resulting in production of ammonia, which is alkaline.

The degree of amino-free acids and ammonia in cheese gives an indication of its age and maturity as proteolysis progresses. Blue, or mould-ripened cheese has rapid proteolysis, resulting in production of large amounts of ammonia.

Proteolysis = breakdown of protein

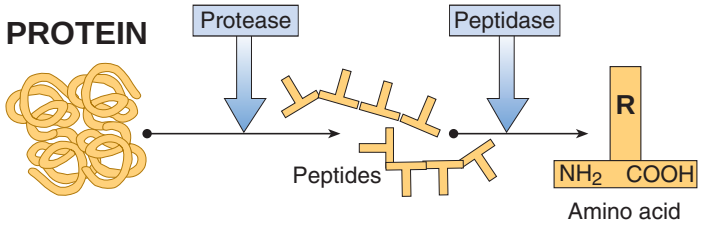


Fig. 4.13 *Protein is broken down to amino acid by the enzymes protease and peptidase.*

Breakdown of fat

The process in which fat is broken down by enzymes is called lipolysis. Lipase is the main enzyme involved in this process. During lipolysis, the fat is hydrolysed to glycerol and one, two or three separate fatty acids, Figure 4.14. Some of the fatty acids are volatile and give off strong smells. One example is butyric acid, which gives the characteristic rancid taste.

Pure fat cannot be broken down by micro-organisms, but fat in water emulsions, or fat in contact with water, are broken down by many micro-organisms. Water is essential for enzymatic split. Milk fat in the form of butter and cream is a water emulsion and contains protein, carbohydrate, minerals, etc., which sometimes makes it even more susceptible to enzymatic breakdown.

Many bacteria and moulds that break down proteins also break down fat oxidatively.

Lipolysis = breakdown of fat

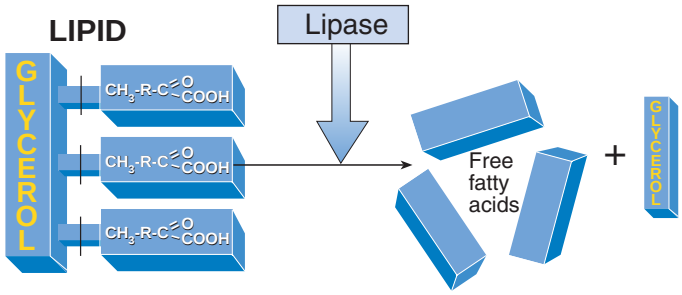


Fig. 4.14 *Lipid is broken down to free fatty acids and glycerol by the lipase enzyme.*

Breakdown of lecithin

Lecithin, the phospholipid contained in the membranes round the fat globules, is a chemical combination of glycerol, two fatty acids, phosphoric acid and choline, an organic alkali. Strains of *Bacillus cereus* produce enzymes, lecithinases, which hydrolyse the lecithin into diglyceride and phosphoryl choline. The membranes of the fat globules are split, resulting in an unstable fat emulsion often seen in the form of flocs or lumps floating on the surface of the milk or cream. This fault in milk or cream is called bitty or broken cream.

Further break-down of the choline into trimethyl amine will result in a fishy smell and taste.

Pigment and colour production

The process of colour production is called chromogenesis and the organism causing the production is referred to as chromogenic.

This process of metabolism is a feature of certain micro-organisms. It is greater in some foods than others and takes place only at ambient or lower temperatures. Aerobic conditions are also favourable for chromogenesis.

There are two types of pigment:

- Endo-pigment, which stays in the cell
- Exo-pigment, which diffuses out of the cell into the surrounding food

There are three basic colour groups:

- Carotenoids, (yellow, green, cream or golden)
- Antho cyanins, (red)
- Melanins, (brown or black)

The name of an organism often refers to the colour it produces. Example: *Staphylococcus aureus* = the golden *Staphylococcus*.

Chromogenesis = colour production caused by chromogenic bacteria

The species of an organism is often named after the colour it produces, for example:

Albus	=	white
Luteus	=	yellow
Citreus	=	citrus yellow
Roseus	=	pink or red
Aureus	=	golden
Violaceum	=	violet
Nigra	=	black or brown

Mucus production

A number of bacteria produce a mucus (or slime) of polysaccharides, which dramatically increase viscosity, as they are highly water-soluble and dissolve in the medium. This is utilised in certain cultured products such as yoghurt and "långfil", a Swedish ropy milk.

Odour production

Some organisms produce strong odours or smells. Below is a list of some organisms and their associated smells:

- Moulds – musty
- Actinomycetes – earthy
- Yeasts – yeasty
- Pseudomonadaceae – fruity/fishy
- Coliforms – manure
- Lactococcus lactis var. maltigenes – malty

Pathogens in raw milk

Pathogenic bacteria
cause disease in human beings, animals and plants.

Some micro-organisms may cause food poisoning (pathogenic micro-organisms), either by intoxication and/or infection. Intoxication implies the production of poisons in the food prior to its consumption. Infection means the establishment, active growth, and multiplication of such micro-organisms in the human body. Often rather large numbers are needed to cause an infection, but sometimes, as in the case of *Salmonella* typhimurium, the MID (minimum infection dose) may be as small as one bacterium.

Table 4.4
Pathogens in milk

Infectious	Toxin formers
• *Mycobacterium bovis*	• *Bacillus cereus*
• *Mycobacterium tuberculosis*	• *Clostridium perfringens*
• *Escherichia coli* (some strains)	• *Staphylococcus aureus* (some strains)
• *Listeria monocytogenes*	
• *Salmonella*	
• *Campylobacter*	
• *Corynebacterium diphteriae*	

Study of bacteria

Study of bacteria
- Pure culture
- Sterile technique
- Cfu, colony forming unit
- Colony count

Bacteria occur in nature in extremly large populations made up of many different species. In order to study the characteristics of a particular species it is necessary to separate it from all other species. Laboratory procedures exist for this purpose.

The growth of a mass of cells of the same species in a laboratory vessel (such as a test tube) is called a pure culture. To keep the culture pure, continuous precautions have to be taken to prevent entrance of other species. This is done by applying sterile technique.

Bacteria are cultivated in nutrient broth or on nutrient agar. The type of nutrients depends on the species. Typical nutrients are a mixture of proteins, peptides, sugar, mineral salts and co-factors. To obtain nutrient agar, a jelly-like, semi-hard substance called agar is added to the broth.

Micro-organisms cultivated on or in agar substrates grow as colonies. Under favourable conditions, one cell will multiply into a mass of cells called a cfu (colony forming unit), which can be seen with the naked eye. By making dilutions of the original sample, plating on agar and counting the colonies, it is possible to enumerate the bacteria. This well-established technique for enumeration of bacteria, yeast and mould is called a Colony count.

By using selective agar media, which allows only specific groups of bacteria to grow, the presence of various types of bacteria can be demonstrated.

Identification and classification of bacteria

In an attempt to classify the many different groups of bacteria that exist, they were previously divided into families, genera and species in the same way as higher plants and animals.

In zoology and botany, this is done according to the external characteristics of the individual (appearance). The same principle was originally applied to the classification of bacteria, but it was soon found that it was not enough to group bacteria simply by size, shape, appearance and motility. Apart from these external characteristics, it was also necessary to consider the metabolism of the organisms (their relationship to various carbohydrates, proteins, fats, etc.) and their strain characteristics. With information on these matters, it was possible to group similar organisms in a bacterial classification system.

The Latin names of bacteria according to this system are now internationally used. Every bacterium has two names. The first represents the genus and the second describes the species, often indicating a certain property or origin. See the Pigment and colour production section above.

Identification of bacteria to the genus level is done by a combination of various biochemical tests and morphological analysis, including gram-reaction.

A lot of new techniques based on DNA composition have been introduced to identify bacteria. The most important of these is PCR, polymerase chain reaction. This method can directly identify bacteria at the species level. Today the method is in regular use to identify pathogens. The FTIR (Fourier Transform infrared) method compares several bacterial components at a molecular level with a databank of type-species.

The most authoritative literature on identification of bacteria is Bergey´s Determinative Bacteriology. The 9th edition, (1994), identifies several thousand species. However, these represent only a fraction of those existing in nature. Much work remains to be done and future editions of BDB will undoubtedly become more extensive.

Bergey's Determinative Bacteriology, 9th edition

Number of bacteria detected

- Groups 35
- Genera 550
- Species 4 500

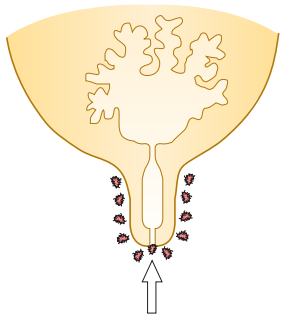


Fig. 4.15 *Bacteria enter through the teat canal.*

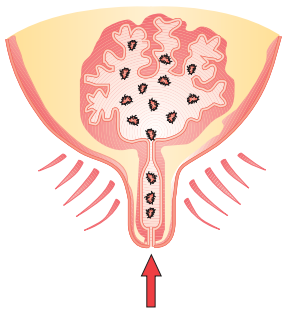


Fig. 4.16 *During udder inflamation the milk is heavily infected by bacteria.*

Fig. 4.17 *Collect the first bacteria-rich jets of milk from each teat in a separate vessel with a black cover.*

Bacteria in milk

From the cow

Milk is virtually sterile when it is secreted in the udder. However, even before it leaves the udder, milk is infected by bacteria that enter through the teat canal. These bacteria are normally harmless and few in number, up to a few hundred per ml.

However, in cases of bacterial udder inflammation (mastitis), the milk is heavily contaminated with bacteria and may even be unfit for consumption. This condition also causes the cow to suffer.

There are always concentrations of bacteria in the teat canal, but most of them are flushed out at the beginning of milking. It is advisable to collect the first bacteria-rich jets of milk from each teat in a separate vessel with a black cover. Flocculated milk from diseased animals shows up readily against the black background.

Infection at the farm

In the course of handling at the farm, milk is liable to be infected by various micro-organisms, mainly bacteria. The degree of infection and the composition of the bacterial population depend on the cleanliness of the cow's environment and the cleanliness of the surfaces with which the milk comes into contact, *e.g.* the pail or milking machine, the strainer, the transport churn or the tank and agitator. Milk-wetted surfaces are usually a much greater source of infection than the udder.

When cows are milked by hand, bacteria can get into the milk via the milker, the cow, the litter and the ambient air. The magnitude of the influx depends largely on the skill and the hygiene-consciousness of the milker and the way the cow is managed. Most of these sources of infection are eliminated in machine milking, but another one is added, namely the milking machine. A very large number of bacteria can enter the milk this way if the milking equipment is not cleaned properly.

Bacteria in raw milk

Milk is very nutrious and is susceptible to contamination and hereby growth of a wide variety of bacteria.

Farm milk may contain anything from a few thousand bacteria per ml, if it comes from a hygienic farm and up to several millions if the standard of cleaning, disinfection and chilling is poor. Daily cleaning and disinfection of all milk equipment is therefore the most decisive factor in the bacteriological quality of milk. Under optimal condition it should be possible to achieve a bacteria count of less than 20 000 CFU (Colony Forming Units) per ml.

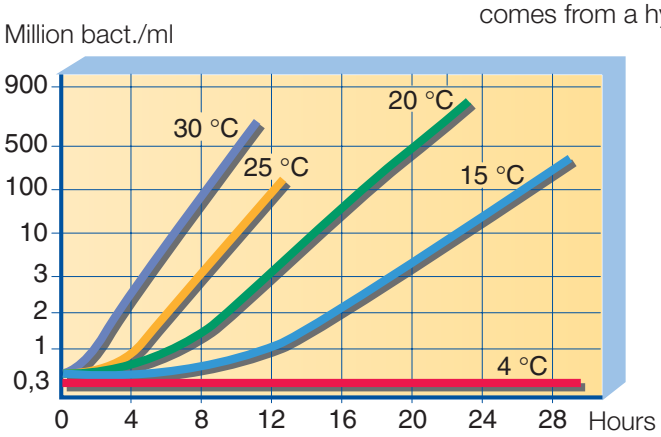


Fig. 4.18 *Influence of temperature on bacterial development in raw milk.*

Rapid chilling to below 4 °C contributes greatly to the quality of the milk at the farm. This treatment slows down the growth of the bacteria in the milk, thereby greatly improving its keeping qualities.

The influence of temperature on bacterial development in raw miilk is shown in the graph in Figure 4.18. Starting from 300 000 CFU/ml the speed of development at higher temperatures and the effect of cooling to 4 °C is striking. Cooling to 4 °C or even lower to 2 °C, in conjunction with milking makes it possible to deliver milk at two-day intervals provided that the milk container/tanker is insulated.

There are principally three sources of infection: inside the cow, the udders and everything the milk comes into contact with. The most common micro-organisms in raw milk of good quality (<20 000 CFU/ml) is restricted to a few groups of bacteria, Table 4.5.

Table 4.5

Incidence of main groups of bacteria in low count raw milk.

Group	Incidence, %
Micrococcus	30 – 99
Streptococcus	0 – 50
Asporogenous gram-pos. rods	<10
Gram-neg. rods	<10
Sporeformers	<10
Miscellanous	<10

Bacteria in pasteurised milk

HTST (High Temperature Short Time) pasteurisation of milk kills heat-sensitive micro-organisms. Survivors are spore formers, Corynebacteria and a few other Gram-positive rods and cocci. This relatively heat-resistant flora is called the thermoduric group.

Occurrence of Gram-negative bacteria in HTST milk depends on water-borne re-infection such as leakage or some other unhygienic condition. As many Gram-negative bacteria can grow at refrigeration temperatures quite well, they spoil the HTST milk in a few days. Therefore, routine laboratory control of Gram-negatives is necessary.

Fungi

Fungi are a group of micro-organisms that are frequently found in nature among plants, animals and human beings. Different species of fungi vary a great deal in structure and method of reproduction. Fungi may be round, oval or threadlike. The threads may form a network, visible to the naked eye, in the form of mould on food, for example. Fungi are divided into yeasts and moulds.

Fungi are divided into:
- yeasts
- moulds

Yeasts

Yeasts are single-cell organisms of spherical, elliptical or cylindrical shape. The size of yeast cells varies considerably. Brewer's yeast, *Saccharomyces cerevisiae*, has a diameter of 2 – 8 µm and a length of 3 – 15 µm. Some yeast cells of other species may be as large as 100 µm.

Yeasts, like moulds, have a more complex internal structure than bacteria. They contain cytoplasm and a clearly discernible nucleus surrounded by nuclear membrane, Figure 4.19. The cell is enclosed by a wall and a cell membrane, which is permeable to nutrients from the outside of the cell and waste products from the inside.

The cell contains a vacuole that serves as storage space for reserve nutrition and for waste products before they are released from the cell. Fat globules and carbohydrate particles are embedded in the cytoplasm. In the cytoplasm there is also a fine network of membranes named endoplasmic reticulum, mitochondria (where energy for cell growth is generated), as well as ribosomes.

Yeast can cause defects in cheese and butter.

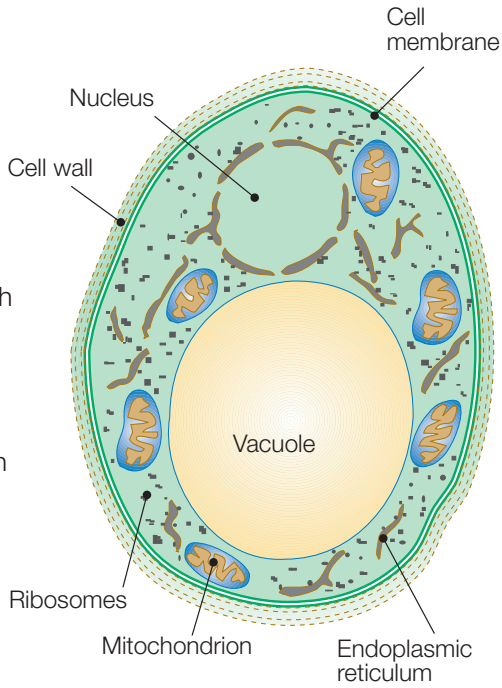


Fig. 4.19 *The structure of a yeast cell.*

Reproduction of yeast

Yeast cells normally reproduce by budding, as shown in Figure 4.20, although other methods of reproduction can also be found. Budding is an asexual process. A small bud develops on the cell wall of the parent cell. The cytoplasm is shared for a while by parent and offspring. Eventually the bud is sealed off from the parent cell by a double wall.

The new cell does not always separate from its parent and may remain attached to it while the latter continues to form new buds. The offspring cell may also form fresh buds of its own. This can result in large clusters of cells attached to each other.

Some types of yeast reproduce sexually, as in Figure 4.21, by forming spores, ascospores and basidiospores (not to be confused with bacterial spores). Two cells fuse together and the two nuclei also fuse. Following division of the nuclear material, eight ascospores are formed within the cells, each containing a similar set of DNA. When the spores are mature, they are released and germinate, forming new cells, which then reproduce asexually by budding.

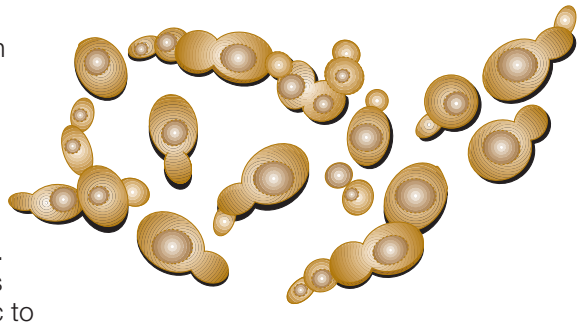


Fig. 4.20 *Budding yeast cells.*

Conditions for the growth of yeast

Environment and nutrients

Yeasts have the same need for nutrients as other living organisms. They usually flourish in habitats where sugars are present, such as fruits, flowers, and the bark of trees. A few species are pathogenic to animals and humans. Yeasts are the predominant spoilage organism of fruit juices. Like bacteria, they have a system of intracellular and extracellular enzymes capable of breaking down large molecules in the substrate to manageable size for the metabolism of the cells. In the laboratory, yeasts are cultivated in sugar-rich substrates with pH 5 to 6.

Moisture

Like bacteria, yeasts must have access to water in order to live, but yeasts require less water than bacteria. Some species can grow in media with very low water content, such as honey or jam.

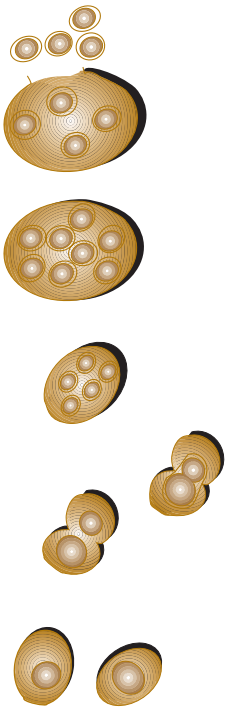


Fig. 4.21 *Sexual reproduction of yeast..*

Important factors for yeast growth
- nutrients
- moisture
- acidity
- temperature
- oxygen

Yeasts grow best in acid media.

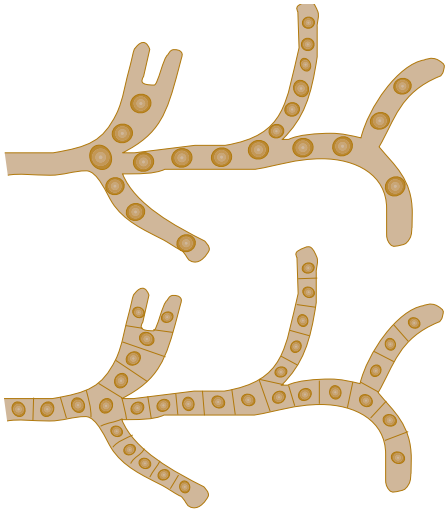


Fig 4.22 *Depending on the group, moulds have either hyphae with or without crosswalls.*

Acidity
Yeast can grow in media with pH values ranging from 3 to 7,5. The optimum pH is usually 5 – 6.

Temperature
Yeast cells do not usually grow at temperatures below the freezing point of water or above about 47 °C. The optimum temperature is normally between 20 and 30 °C. Many genera contain psycrotrophic strains; *Candida, Cryptococcus, Rhodotorula* and *Torulopsis*, for example.

Growing cells are normally killed within 5 to 10 minutes at temperatures of 52 – 58 °C. Spores (ascospores) are more resistant, but are killed when exposed to 60 – 62 °C for a few minutes.

Oxygen
Yeasts have the ability to grow both in the presence and in the absence of atmospheric oxygen, *i.e.* yeast are facultatively anaerobic. In the absence of oxygen, yeast breaks down sugar to alcohol and water while, in the presence of oxygen, it breaks down sugar to carbon dioxide and water. Yeast cells grow faster in the presence of oxygen.

Classification of yeasts
Yeasts are divided into three groups, according to their ability to produce spores (ascospores and basidiospores). The strains that form spores belong to the groups Ascomycetes and Basidiomycetes. Those that do not produce spores, but reproduce mainly by budding, belong to the group of Fungi imperfecti.

Importance of yeast
Yeasts are generally undesirable organisms from the dairy point of view, with one exception. Kefir, a Russian cultured product, is fermented with a mixed culture of yeasts and lactic acid bacteria in a grain-shaped aggregate. Otherwise, yeast organisms can cause serious faults in culture dairy products, including cheese and butter. In the brewing, wine, baking and distilling industries, on the other hand, they make a valuable contribution.

Moulds
The category of moulds comprises a fairly heterogenous group of multicellular, threadlike fungi.

The moulds consist of threadlike strands of cells called hyphae. The mass of hyphae that can be seen with the naked eye is called mycelium. The hyphae may or may not have crosswalls between the cells and are usually branched. The hyphae are the vegetative part of the mould, often colourless, and secrete enzymes by which they degrade food (Figure 4.22).

As the mould colony grows, the hyphae and mycelium radiate outwards from the centre.

Reproduction of moulds
Moulds reproduce by means of spores of various types. Both sexual and asexual reproduction may occur in the same species. The asexual spores usually have thick walls and are relatively resistant to desiccation. Some strains have very heat-resistant sexual spores. A mould can remain dormant in spore form for quite a long time.

The asexual spores, conidia, represent the most common method of mould reproduction, and they are usually produced in enormous numbers. They are very small and light and can be carried by air currents, spreading the mould from place to place. This is a common, everyday occurrence, and often presents a problem in the dairy industry.

Metabolism of moulds

Mould fungi metabolise in much the same way as yeasts. They are well equipped with enzymes, which they use to break down a variety of organic substances. From the dairy point of view, the action of mould on fat and protein is of particular interest. The growth of mycelium mould is illustrated in Figure 4.24.

Moisture

Moulds can grow on materials with a very low water content and can extract water from moist air.

Water activity (a_w)

Moulds are more tolerant to low a_w than any other group of micro-organisms. Some can tolerate concentrations of sugar and salt with high osmotic pressure, *e.g.* fruit preserves and sweetened condensed milk.

Oxygen

Moulds normally grow in aerobic conditions. Oxygen is necessary for the formation of conidia, and for the growth of mycelia.

Temperature

The optimum growth temperature for most moulds is between 20 and 30 °C.

Acidity

Moulds can grow in media with pH values from 3 to 8,5. Many species, however, prefer an acid environment, *e.g.* cheese, yoghurt, citrus fruit and fruit juices.

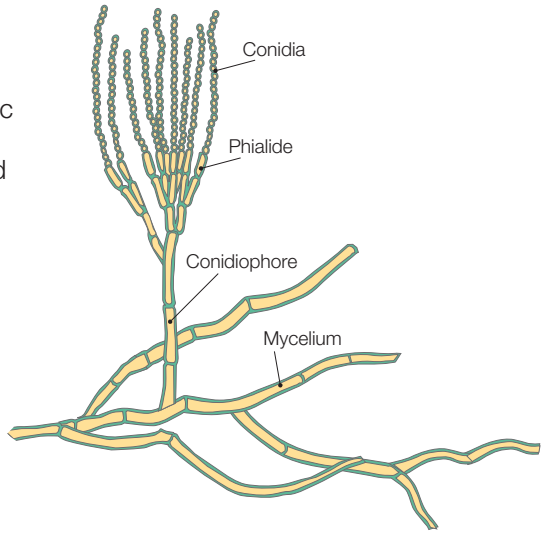


Fig 4.23 *Penicillium sp. Mycelium with conidiophores producing chains of conidia.*

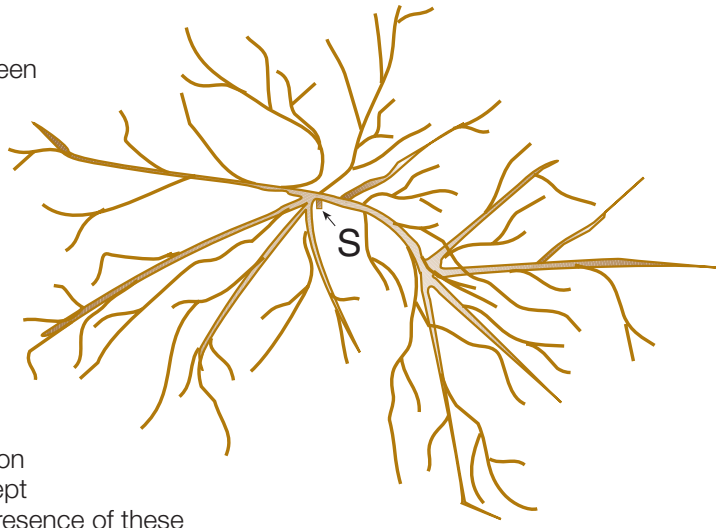


Fig 4.24 *Growth of mould mycelium on malt agar derived from one spore (S) after one day's growth at 20°C.*

Importance of moulds in the dairy

As with yeasts, moulds do not survive ordinary pasteurisation temperatures, 72 – 74 °C for some 10 to 15 seconds, except moulds with heat-resistant sexual spores. The unwanted presence of these organisms is therefore a sign of re-infection.

There are many different families of moulds. Some groups that are of importance in the dairy industry are Penicillium and milk mould, Geotrichum candidum.

Penicillium

The genus Penicillium is one of the most common types of mould. The spore-forming hyphae of this family are branched at the tip, resembling a brush. Green mould, which occurs very widely in nature, belongs to this family. Some species of penicillia play an important part in dairy processes. Their powerful protein- and fat-splitting properties make them the chief agents in the ripening of Blue cheese, Camembert, etc. The Blue-cheese mould is called Penicillium roqueforti and the Camembert mould, Penicillium camemberti. See Figure 4.23.

Milk mould

The milk mould Geotrichum candidum is on the borderline between yeast and mould. Its reproduction is similar to that of yeast organisms; the outer part of the hyphae is tied off in a process that resembles budding. Its structure is shown in Figure 4.25. The mould occurs on the surface of cultured milk as a fine, white velvety coating. This mould contributes to the ripening of semisoft and soft cheeses. It may cause rancidity in butter.

Moulds on the surfaces of cheese and butter can cause discoloration and also give the product an off flavour. Strict hygiene is necessary in the

Yeasts are facultative anaerobic organsims

Moulds are strictly aerobic organisms
(with a few exceptions)

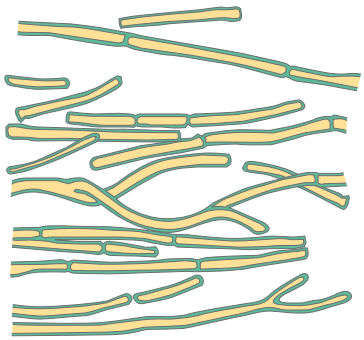


Fig 4.25 *Structure of the Geotrichum candidum moulds.*

dairy in order to prevent products from being affected by moulds during processing. Walls and ceilings, for example, must be kept scrupulously clean in order to prevent moulds from settling there.

Bacteriophages

Twort, an English scientist, discovered as early as 1915 that certain cultures of staphylococci were disrupted and broken down. A couple of years later d'Herelle, a Canadian scientist, after having made similar observations, postulated that the phenomenon was caused by invisible organisms feeding on the bacteria. He called them bacteriophages.

Bacteriophages are thus viruses, *i.e.* bacterial parasites. By themselves they can persist, but they cannot grow or replicate except within bacterial cells. They have very specific hosts, *e.g.* single species or strains of bacteria.

Structure of bacteriophages

Bacteriophages, or phages, vary considerably in size, and an electron microscope is needed to see them. One of the biggest is the T-phage, which infects *Escerichia coli* and closely related bacteria. The T-phages have a "head" and a "tail" and a size of 0,03 to 0,3 µm. A schematic drawing of a phage is shown in Figure 4.26.

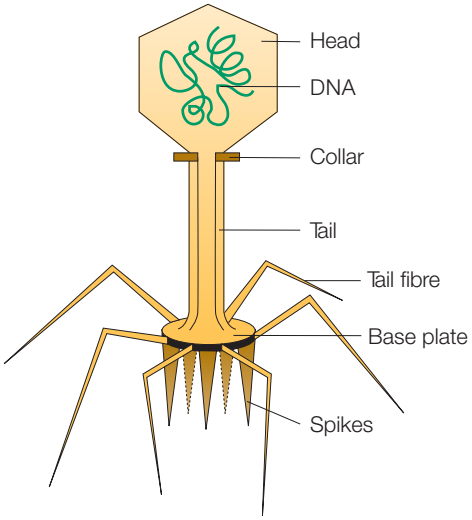


Fig. 4.26 *A schematic drawing of a phage.*

Reproduction of phages

Phages attack actively growing bacteria, within which they can replicate. The bacteria subsequently disintegrate, releasing a group of 10 to 200 phages per bacterium to attack new victims. The scenario is shown in Figure 4.27.

The phage attaches to the surface of its host (1), and the DNA is injected into the cell. The cellular "machinery" then produces new phage DNA and phage proteins (2; 3). The new phages are assembled inside the bacterial cell (4), which is then lysed (5) and the mature phages are released.

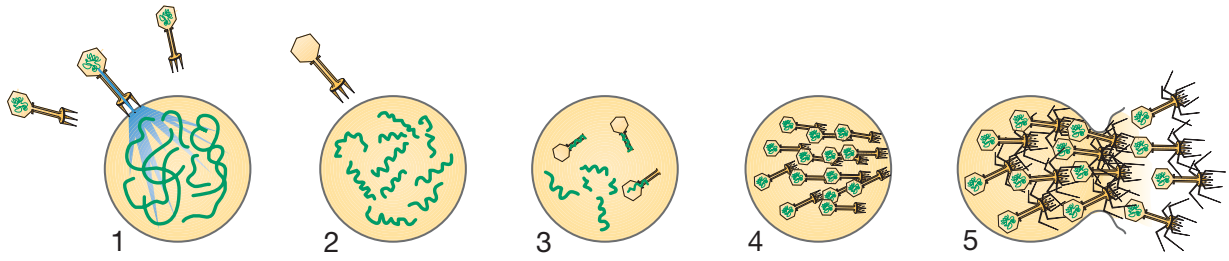


Fig. 4.27 *Schematic picture of the propagation of bacteriophages.*

Concluding notes

The great variety of bacteria, yeasts and moulds, and their wide range of activities, are of the utmost importance to life on earth in general, and to humanity in particular.

Micro-organisms in soil and water are responsible for degrading available sources of nutrients into forms that plants can assimilate. By doing so, they also perform an indirect service to the animal kingdom, including Man.

Human beings also benefit more directly from micro-organisms. Lactic acid-forming micro-organisms, for example, can be used to preserve fodder (silage) for livestock. The same principle is applied to the preparation of certain foods such as sauerkraut, green olives and cucumbers.

Micro-organisms are of paramount importance in the manufacture of many dairy products, such as yoghurt, cheese and cultured butter. Selection of the right types of micro-organism is an important factor in maximising the quality of these products.

Micro-organisms used in the manufacture of dairy products are normally

supplied by companies that specialise in developing and propagating them under strictly-controlled hygienic conditions. The micro-organisms used in the dairy industry are called starter cultures. A starter culture is, for example, a mixture of organisms that form lactic acid by fermenting the lactose in milk. However, it is important that the quality of the starter cultures is preserved after arrival at the dairy by maintaining high standards of hygiene, and that when used, sterile technique is applied in critical steps of the processing chain.

In this context, it should be mentioned that the milk may contain residues of antibiotics emanating from treatment of cows suffering from mastitis; the most commonly occurring one is penicillin. In spite of regulations saying that milk from cows treated with antibiotics must not be sent to the dairy, you may find sufficiently high levels of antibiotics in bulk tank milk to stop or

Levels of penicillin that inhibit some micro-organisms

Micro-organism	Penicillin (I.U) */ml
Lactococcus lactis	0,1 - 0,25
Lactococcus cremoris	0,05 - 0,1
Streptococcus thermophilus	0,01 - 0,05
Lactobacillas bulgaricus	0,25 - 0,5
Starter (mixed culture)	0,25 - 0,5

**/ I.U = International unit. (Penicillin causes lysis of bacterial cells.)*

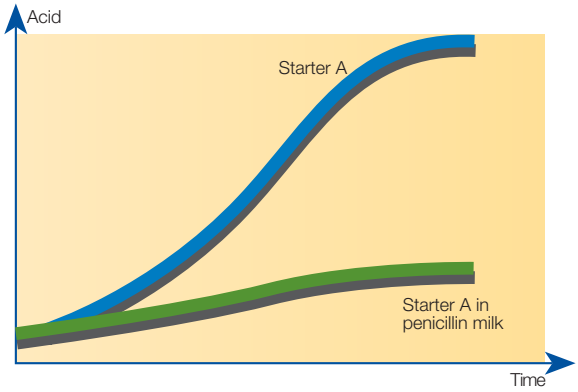


Fig. 4.28 *Effect of penicillin in milk on acid production.*

retard growth of the starter cultures to be used. Figure 4.28 illustrates the influence of even small residues of penicillin on the most commonly used starter cultures.

As raw milk is usually contaminated with bacteriophages, it is important that the milk used for starter cultures, generally skim milk, is heated to at least 90 °C for 30 minutes to inactivate the phages. Figure 4.29 shows what will happen if this is not done or if the milk is re-contaminated by phages afterwards. The time it takes for one "non-infected" bacterium to produce four new bacteria is two generations. In the same period, one phage infects one bacterium, which releases 150 new phages in one generation's time. These phages infect 150 new bacteria and in a further one generation's time, 22 500 phages are released. This is the reason why a phage-infected starter culture suddenly collapses after a while.

It would be a false idealisation of micro-organisms to omit to mention that some of them – the pathogenic micro-organisms – are regarded as mankind's worst enemies. The threat against Man is becoming more and more serious due to the use of antibiotics. Some pathogens are today resistant against all antibiotics. It is also true that without the many harmless micro-organisms, life would not be possible for Man and many other living organisms.

In most countries, governments have passed laws requiring pasteurisation of milk produced at a dairy and intended for consumption. A typical temperature/time combination for pasteurisation is 72 °C for 15 – 20 seconds, which kills all pathogens. In order to avoid recontamination it is of utmost importance that good hygiene practise prevails.

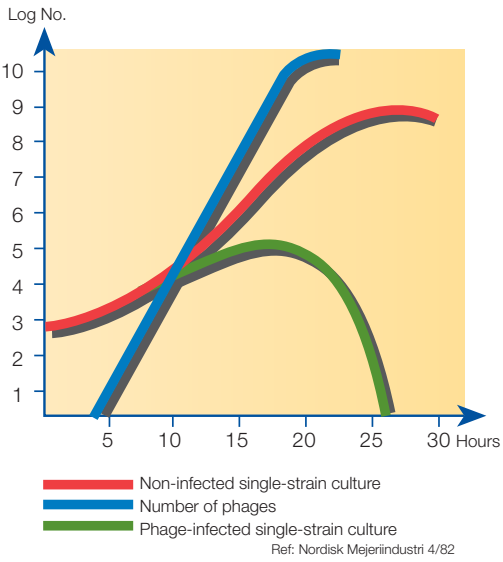


Fig. 4.29 *Growth of starter bacteria and phages and influence on infected starter culture.*

Chapter 5

Collection and reception of milk

The milk is brought from the farm (or collecting centre) to the dairy for processing. All kinds of receptacles have been used, and are still in use, throughout the whole world, from 2 – 3 litre calabashes and pottery to modern bulk-cooling farm tanks for thousands of litres of milk.

Formerly, when dairies were small, collection was confined to nearby farms. The micro-organisms in the milk could be kept under control with a minimum of chilling, as the distances were short and the milk was collected daily.

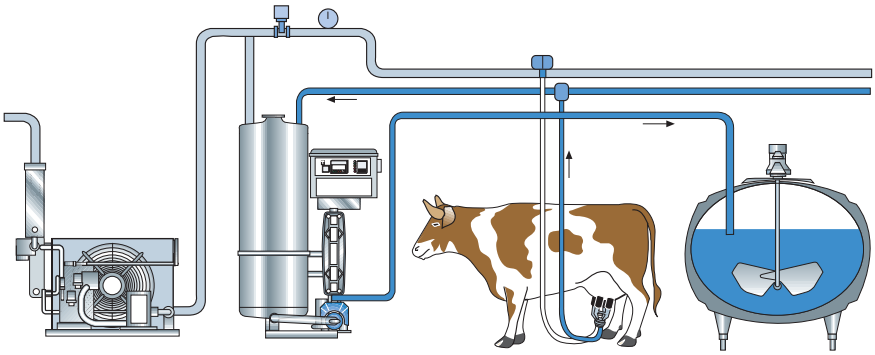


Fig. 5.1 *The milk flow in an instant cooling system from cow to cooling tank.*

Today the trend is towards progressively larger dairy units. There is a demand for a higher production and increased quality of the finished product. Milk must be brought from farther away and this means that daily collection is generally out of the question. Nowadays, collection usually takes place every other day, but the interval can sometimes be three days and even four.

Keeping the milk cool

The milk should be chilled to + 4 °C immediately after milking and be kept at this temperature all the way to the dairy.

If the cold chain is broken somewhere along the way, *e.g.* during transportation, the micro-organisms in the milk will start to multiply. This will result in the development of various metabolic products and enzymes. Subsequent chilling will arrest this development, but the damage will already be done. The bacteria count is higher and the milk contains substances that will affect the quality of the end product.

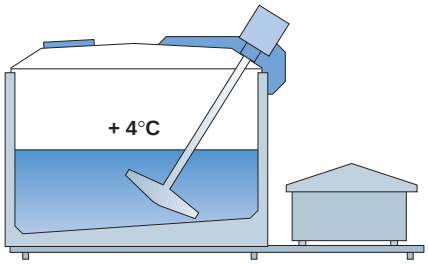


Fig. 5.2 *Bulk cooling tank with agitator and chilling unit.*

Design of farm dairy premises

The first steps in preserving the quality of milk must be taken at the farm. Milking conditions must be as hygienic as possible; the milking system designed to avoid aeration, the cooling equipment correctly dimensioned.

To meet the hygienic requirements, dairy farms have special rooms for refrigerated storage. Bulk cooling tanks are also becoming more common. These tanks (Figure 5.2) with a capacity of 300 to 30 000 litres, are fitted with an agitator and cooling equipment to meet certain stipulations – for example that all the milk in the tank should be chilled to +4 °C within two hours after milking.

Larger farms, producing large quantities of milk, often install separate plate coolers for chilling the milk before it enters the tank (Figure 5.1). This saves mixing warm milk from the cow with the already chilled contents of the tank.

The milk room should also contain equipment for cleaning and disinfecting the utensils, pipe system and bulk cooling tank.

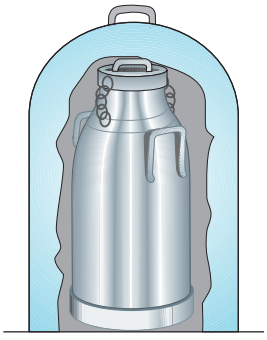


Fig. 5.3 *An insulating cover protects the milk from heat and cold.*

Delivery to the dairy

The raw milk arrives at the dairy in churns or in insulated road tankers, the latter being used only in combination with bulk cooling tanks at the farm. The requirements are the same for both methods – the milk must be kept well chilled and free from air and treated as gently as possible. For example, churns and tanks should be well filled to prevent the milk from sloshing around in the container.

Churn collection

Milk is transported in churns of various sizes, the most common being of 30 or 50 litres capacity. The churns are taken from the farm to the roadside.

This should be done just before the arrival of the collecting lorry. The churns should be protected from the sun by a tarpaulin or a shelter (Figure 5.4), or even better by a loose insulating cover of polystyrene (Figure 5.3).

Milk collecting centres should be established in certain regions where there is no good road to the dairy farm, when water and/or electricity are not available on the farm, or when the milk quantities are too small to justify investment in cooling facilities. The centres can be organised in different ways and in accordance with the prevailing situation. The farmers have several alternatives. Uncooled milk in churns or cooled milk in insulated tanks can be delivered at certain road junctions, directly to tankers. Uncooled milk can also be delivered in churns to centrally placed milk collecting centres (Figure 5.5). Another alternative is that neighbouring farmers deliver their uncooled milk in churns to a larger farm.

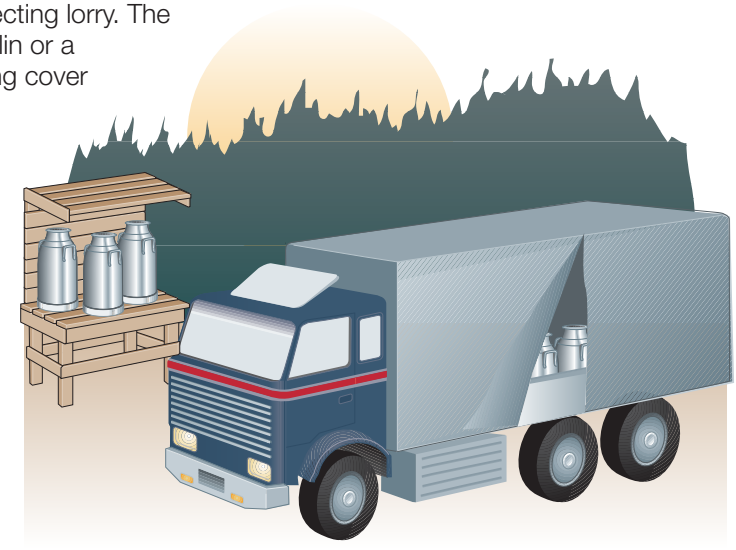


Fig. 5.4 *Churn collection.*

The churn-collecting lorry follows a carefully planned schedule so that it always arrives at each collection point at the same time. After having been loaded onto the platform of the lorry, the churns should always be covered with a tarpaulin for protection against the sun and dust. The lorry returns to the dairy as soon as the churns have been collected from all the farms on its route.

Each farm usually has a code number, which is stamped on the churns. It is used by the dairy when calculating how much money the farmer should be paid.

Milk from diseased cows or cows treated with antibiotics must not be supplied to the dairy. Such milk cannot be used for products based on bacteria cultures, as the antibiotic strain will kill the bacteria. This applies to cultured milk products, cheese and butter, etc. Minute amounts of milk containing antibiotics can render enormous quantities of otherwise suitable milk unusable.

Fig. 5.5 *Farmers deliver uncooled milk in churns to centrally placed cooling stations.*

Bulk collection

When milk is collected by tanker, it must be possible to drive all the way to the farm milk room. The loading hose from the tanker is connected to the outlet valve on the farm cooling tank. The tanker is usually fitted with a flow meter and pump so that the volume is automatically recorded. Otherwise, the volume is measured by recording the level difference which, for the size of the tank in question, represents a certain volume. In many cases, the tanker is equipped with an air-eliminator.

Pumping is stopped as soon as the cooling tank has been emptied. This prevents air from being mixed into the milk. The tank of the bulk collection vehicle is divided into a number of compartments to prevent the milk from sloshing around during transportation. Each compartment is filled in turn, and when the tanker has completed its scheduled round, it delivers the milk to the dairy.

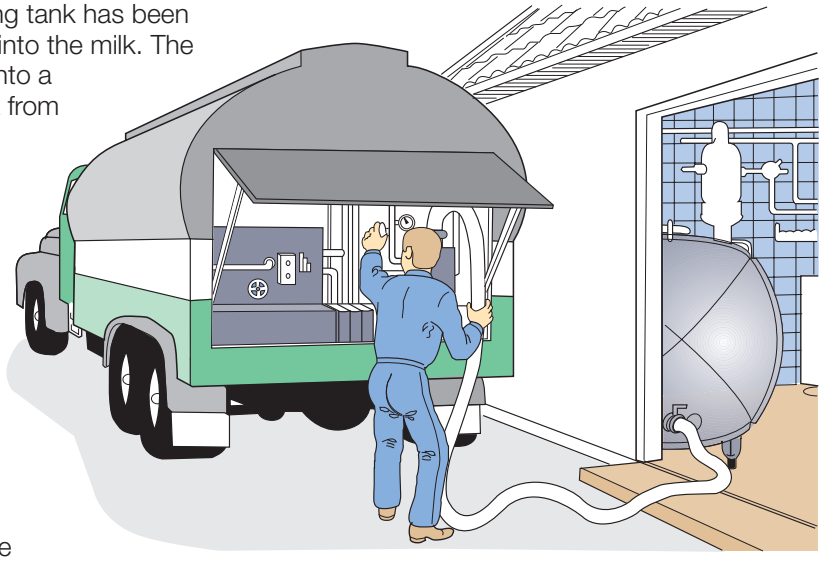


Fig. 5.6 *Bulk collection at the farm.*

Testing milk for quality

Milk from sick animals and milk which contains antibiotics or sediment must not be accepted by the dairy. Even traces of antibiotics in milk can render it unsuitable for the manufacture of products which are acidified by the addition of bacteria cultures, *e.g.* yoghurt and cheese.

Normally, only a general assessment of the milk quality is made at the farm. The composition

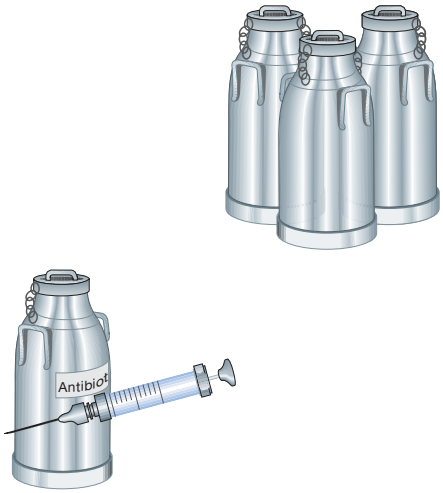


Fig. 5.7 *Milk from animals treated with antibiotics must be kept separate from other milk.*

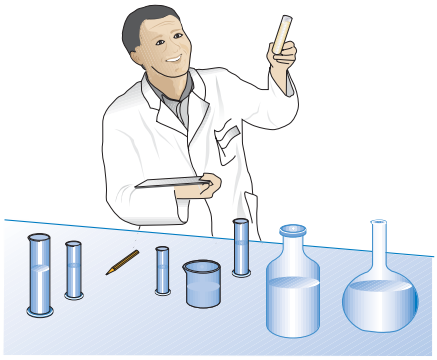


Fig. 5.8 *Analysing milk samples.*

The common tests carried out on milk supplies are:

- Taste and smell
- Cleaning
- Sediment
- Hygiene
- Somatic cell count
- Bacteria count
- Protein content
- Fat content
- Freezing point

and hygienic quality is usually determined in a number of tests on arrival at the dairy. The outcome of some of these tests has a direct bearing on the money paid to the farmer.

The most common tests carried out on milk supplies are detailed below.

Taste and smell

In the case of bulk collection, the driver takes a sample of the milk at the farm for testing at the dairy. Churn-collected milk is sampled at the churn reception department. Milk that deviates in taste and smell from normal milk receives a lower quality rating. This affects the payment to the farmer. Milk with significant deviations in taste and smell should be rejected by the dairy.

Cleaning checks

The inside surfaces of farm tanks and churns are carefully inspected. Any milk residue is evidence of inefficient cleaning and will result in a deduction in accordance with a quality payment scheme.

Sediment tests

This applies only to churns. A sample is taken with a pipette from the bottom of a churn and is then passed through a filter. A quality deduction is made if visible impurities are retained by the filter.

Hygiene or Resazurin Tests

The bacteria content of the milk is a measure of its hygienic quality. The Resazurin Tests are used frequently. Resazurin is a blue dye which becomes colourless when it is chemically reduced by the removal of oxygen. When it is added to the milk sample, the metabolic activity of the bacteria present has the effect of changing the colour of the dye at a rate which bears a direct relationship to the number of bacteria in the sample.

Two hygiene tests use this principle. One is a quick-screening test, which may form the basis for the rejection of a bad churn supply. If the sample starts to change shade immediately, the consignment is considered unfit for human consumption.

The other test is a routine test and involves storage of the sample in a refrigerator overnight, before a Resazurin solution is added. The sample is then incubated in a water bath and held at 37,5 °C for two hours.

Somatic cell count

A large number (more than 500 000 per ml of milk) of somatic cells in the milk indicates that the cows are suffering from udder diseases. The cell content is determined with specially designed particle counters *e.g.* (Coulter counter).

Bacteria count

A simplified form of bacteria count can also be used to assess the bacteria content. In this, the Leesment method, the bacteria are cultivated at 30 °C for 72 hours in a 0,001 ml milk sample with a nutritive substrate. The bacteria count is determined with a special screen.

Protein content

Many dairies pay the farmers according to the protein content of the milk. This is analysed by means of instruments operating with infrared rays. Up to 300 analyses per hour can be performed.

Fat content

Various methods can be used to determine the butterfat content. The Gerber test is the most widely used method for whole milk.

Freezing point

Many dairies check the freezing point of the milk to determine whether or

not it has been diluted with water. Milk of normal composition has a freezing point of –0,54 to –0,59 °C. The freezing point will rise if water is added to the milk. Special instruments are used for this check.

Milk reception

Dairies have special reception departments to handle the milk brought in from the farms. The first thing done at reception is to determine the quantity of the milk. The quantity is recorded and entered into the weighing system that the dairy uses to weigh the intake and compare it with the output.

The quantity of the intake can be measured by volume or by weight.

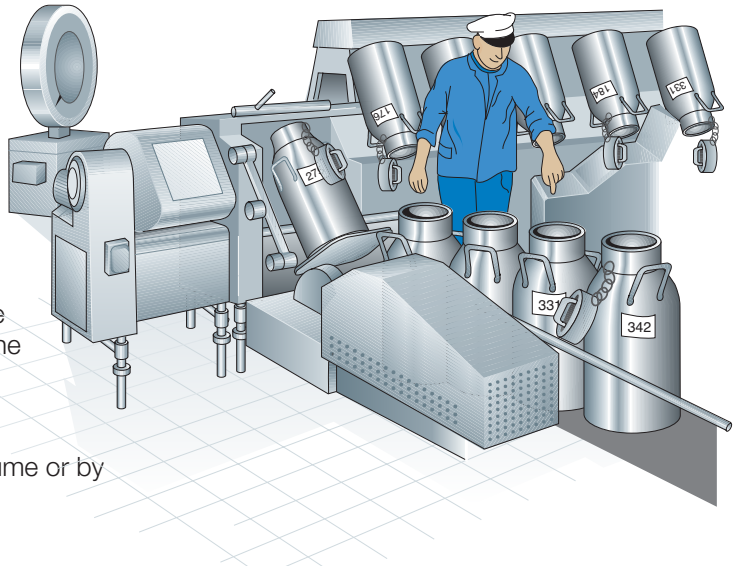


Fig. 5.9 *Churn reception. Weighing and recording of milk.*

Churn reception

The milk in the churns is weighed in. The churns arrive from the lorry on a conveyor. On the way, the lids are automatically removed. At the weighing station the milk is automatically emptied into a weighing bowl which indicates the quantity. The weighing machine operator enters the quantity against the identification number of the producer. The weighing-in system is often designed so that the operator enters the producer identification number on a keyboard before weighing in all the churns from that producer (Figure 5.9). The weights are then automatically totalled and recorded against the identification number. The identification for the next supplier is then entered by the operator, and the process is repeated until all the milk has been weighed in.

The weighing equipment must be well maintained and checked every day to ensure accuracy.

From weighing-in, the raw milk is pumped to storage tanks to await processing.

The empty churns are conveyed to a cleaning station, where they are washed with water and detergent to remove all traces of milk. In some cases, the clean churns continue to another station to be filled with by-products from the dairy process, which may be skim milk, buttermilk or whey. Finally the churns continue to a loading dock to await return to the farm.

Tanker reception

Tankers arriving at the dairy drive straight into a reception hall, often large enough to accommodate several vehicles.

The milk is measured either by volume or by weight.

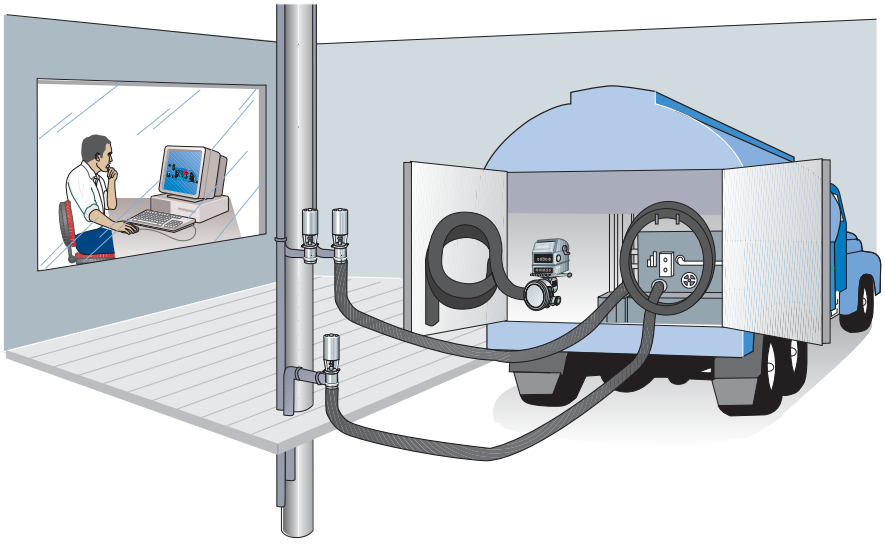


Fig. 5.10 *Measuring milk intake in a tanker reception hall.*

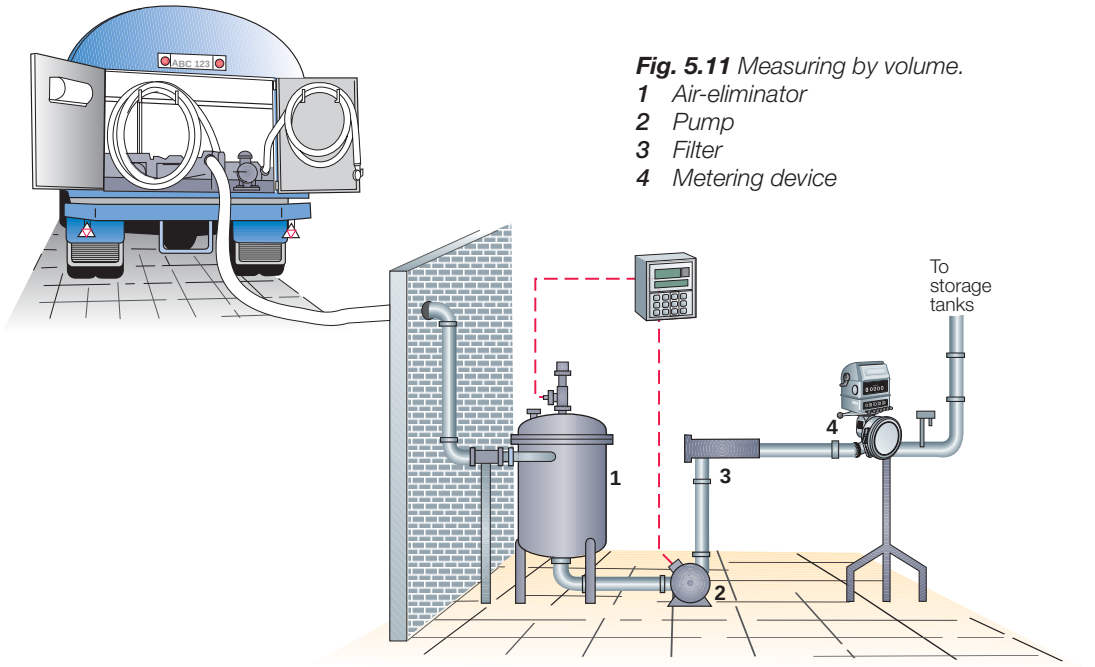


Fig. 5.11 *Measuring by volume.*
1 *Air-eliminator*
2 *Pump*
3 *Filter*
4 *Metering device*

Measuring by volume

This method uses a flowmeter. It registers the air in the milk as well as the milk, so the results are not always reliable. It is important to prevent air from entering with the milk. Measuring can be improved by fitting an air-eliminator before the flowmeter (Figure 5.11).

The tanker outlet valve is connected to an air-eliminator and from this the milk – free from air – is pumped through the flowmeter, which continuously indicates the total flow. When all the milk has been delivered, a card is placed in the meter for recording the total volume.

The pump is started by the control equipment which senses when the milk in the air-eliminator has reached the preset level for preventing air from being sucked into the line. The pump is stopped as soon as the milk level drops below a certain level.

After measuring, the milk is pumped to a storage (silo) tank.

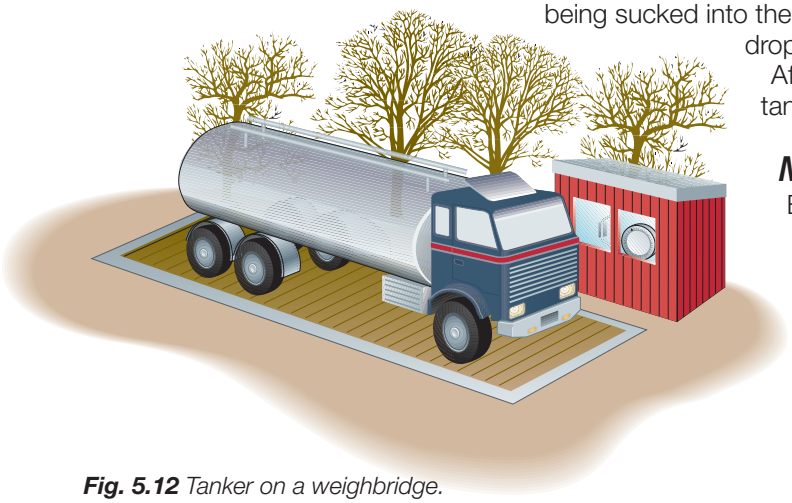


Fig. 5.12 *Tanker on a weighbridge.*

Measuring by weight

Bulk-collected milk can be measured in in two ways:

1 Weighing the tanker before and after unloading and then subtracting one value from the other (Figure 5.12).

2 Using special weighing tanks with load cells in the feet (Figure 5.13).

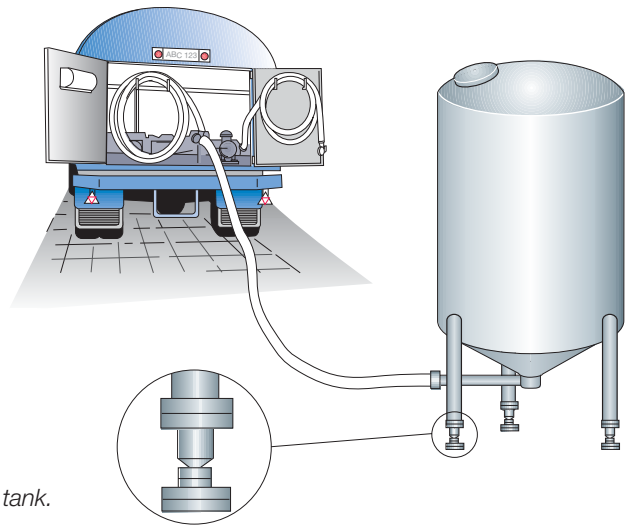


Fig. 5.13 *Milk reception via a weighing tank.*

In the first alternative, the tanker is driven onto a weighbridge at the dairy. Operation may be manual or automatic. If manual, the operator records the weight against the driver's code number. Where operation is automatic, the necessary data are recorded when the driver places a card in a card scanner. Before being weighed the tanker normally passes a vehicle washing station. This is of special importance when the weather is bad.

When the gross weight of the tanker has been recorded, the milk is delivered into the dairy. This may take place in line with a de-aerator but not a flowmeter. When empty, the tanker is weighed again and the tare weight is deducted from the previously recorded gross weight.

When the weighing-tank method is used, the milk is pumped from the tanker into a special tank with load cells built into the feet. The cells supply an electric signal that is always proportional to the weight of the tank. The strength of the signal increases with the weight of the tank as the milk enters the tank. The weight of the contents in the tank can be recorded when all the milk has been delivered. After this the milk is pumped to a silo tank.

Tanker cleaning

Tankers are cleaned every day, as a rule at the end of a collection round. If the tanker makes several rounds a day, cleaning should take place after each round. Cleaning can be carried out by connecting the tanker to a cleaning system while in the reception area, or by driving it to a special cleaning station.

Many dairies also clean the outside of their tankers every day so that they always look clean when they are on the road. In more and more countries new rules are introduced about desinfection of tankers to avoid spreading animal diseases.

Chilling the incoming milk

Normally, a temperature increase to slightly above + 4 °C is unavoidable during transportation. Therefore, the milk is usually cooled to below + 4 °C in a plate heat exchanger, before being stored in a silo tank to await processing.

Raw milk storage

The untreated raw milk – whole milk – is stored in large vertical tanks – silo tanks – which have capacities from about 25 000 litres up to 150 000 litres. Normally, capacities range from 50 000 to 100 000 litres. Smaller silo tanks are often located indoors while the larger tanks are placed outdoors to reduce building costs. Outdoor silo tanks are of double-wall construction, with insulation between the walls. The inner tank is of stainless steel, polished on the inside, and the outer wall is usually of welded sheet metal.

Agitation in silo tanks

These large tanks must have some form of agitation arrangement to prevent cream separation by gravity. The agitation must be very smooth. Extreme agitation causes aeration of the milk and fat globule disintegration. This exposes the fat to attack from the lipase enzymes in the milk. Gentle agitation is therefore a basic rule in the treatment of milk. The tank in Figure 5.14 has a propeller agitator, often used with good results in silo tanks. In very high tanks it may be necessary to fit two agitators at different levels to obtain the required effect.

Outdoor silo tanks have a panel for ancillary equipment. The panels on the tanks all face inwards towards a covered central control station.

Tank temperature indication

The temperature in the tank is indicated on the tank control panel. Usually, an ordinary thermometer is used, but it is becoming more common to use an electric transmitter, which transmits signals to a central monitoring station.

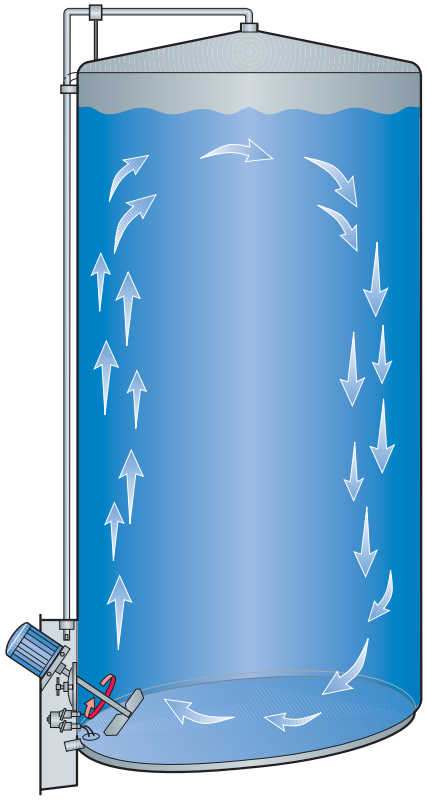


Fig. 5.14 *Silo tank with propeller agitator.*

Level indication

There are various methods available for measuring the milk level in a tank. The pneumatic level indicator measures the static pressure represented by the head of liquid in the tank. The higher the pressure, the higher the level in the tank. The indicator transmits readings to an instrument.

Low-level protection

All agitation of milk must be gentle. The agitator must therefore not be started before it is covered with milk. An electrode is often fitted in the tank wall at the level required for starting the agitator. The agitator stops if the level in the tank drops below the electrode. This electrode is known as the low-level indicator (LL).

Overflow protection

A high-level electrode (HL) is fitted at the top of the tank to prevent overfilling. This electrode closes the inlet valve when the tank is full, and the milk supply is switched to the next tank.

Empty tank indication

During an emptying operation, it is important to know when the tank is completely empty. Otherwise, any milk remaining when the outlet valve has closed will be rinsed out and lost during the subsequent cleaning procedure. The other risk is that air will be sucked into the line if emptying continues after the tank is dry. This will interfere with later treatment. Consequently an electrode, lowest low level, (LLL) is often located in the drainage line to indicate when the last of the milk has left the tank. The signal from this electrode is used to switch to another tank or to stop emptying.

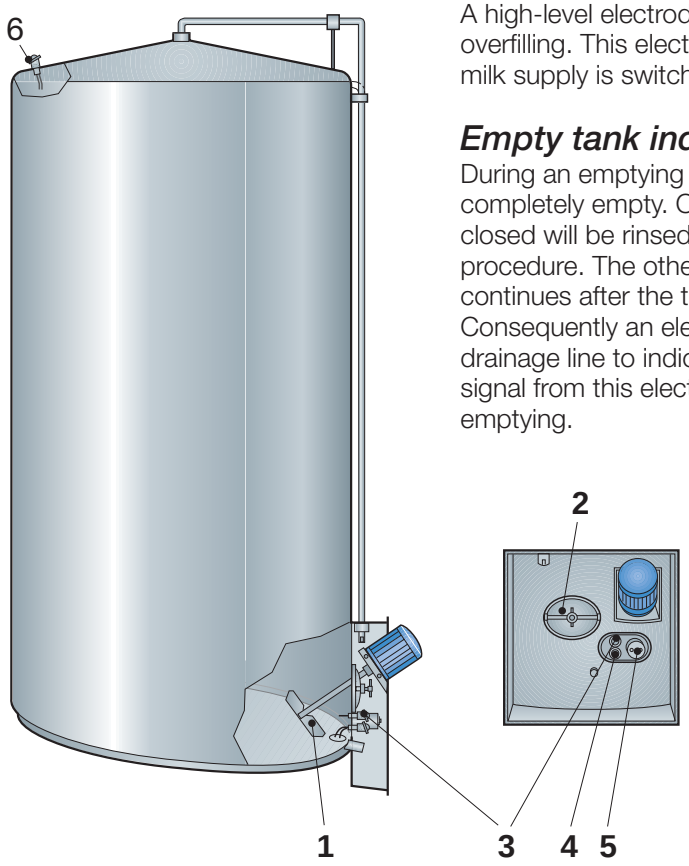


Fig. 5.15 *Silo tank with alcove for manhole, indicators, etc.*

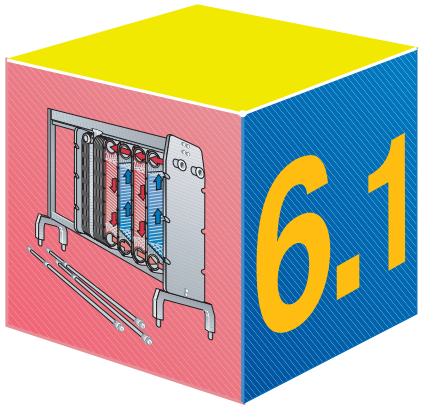
1 *Agitator*
2 *Manhole*
3 *Temperature indicator*
4 *Low-level electrode*
5 *Pneumatic level indicator*
6 *High-level electrode*

Chapter 6

Building-blocks of dairy processing

The following chapter describes the frequently used components in dairy processing. It covers only those components which are used in liquid milk processing. Cheesemaking equipment, buttermaking machines, etc. are described in chapters on the respective processes.

Heat exchangers



The purposes of heat treatment

By the end of the 19th century, heat treatment of milk had become so commonplace that most dairies used the process for some purpose or another, such as for milk intended for cheese and butter production.

Before heat treatment was introduced, milk was a source of infection, as it is a perfect growth medium for micro-organisms. Diseases such as tuberculosis and typhus were sometimes spread by milk.

The term “pasteurisation” commemorates Louis Pasteur, who in the middle of the 19th century made his fundamental studies of the lethal effect of heat on micro-organisms and the use of heat treatment as a preservative technique. The pasteurisation of milk is a special type of heat treatment which can be defined as “any heat treatment of milk which secures the certain destruction of tubercle bacillus (T.B.) without markedly affecting the physical and chemical properties of the milk”.

In considering the history of pasteurisation it is worth mentioning that although scientists everywhere agreed fairly closely on the necessary degree of heat treatment, the process was very loosely controlled in commercial practice for a long time. Milk was frequently either overheated or underheated, so that it either had a cooked flavour or was found to contain viable T.B.

In the middle of the 1930s (*JDR*:6/191), Kay and Graham announced the detection of the *phosphatase enzyme*. This enzyme is always present in raw milk and is destroyed by the temperature/time combination necessary for efficient pasteurisation. In addition, its presence or absence is easily confirmed (Phosphatase test). The absence of phosphatase indicates that the milk has been adequately heated.

Fortunately, all common pathogenic organisms likely to occur in milk are killed by relatively mild heat treatment which has only a very slight effect on the physical and chemical properties of milk. The most resistant organism is the tubercle bacillus (T.B.), which is considered to be killed by heating milk to 63 °C for 10 minutes. Complete safety can be assured by heating milk to 63 °C for 30 minutes. T.B. is therefore regarded as the index organism for pasteurisation: any heat treatment which destroys T.B. can be relied upon to destroy all other pathogens in milk.

It is extremely fortunate that none of the major pathogens in milk form spores.

Apart from pathogenic micro-organisms, milk also contains other substances and micro-organisms which may spoil the taste and shorten the shelf life of various dairy products. Hence, a secondary purpose of heat treatment is used to destroy as many as possible of these other organisms and enzymatic systems. This requires more intense heat treatment than is needed to kill the pathogens.

This secondary purpose of heat treatment has become more and more important as dairies have become larger and less numerous. Longer intervals between deliveries mean that, despite modern cooling techniques,

micro-organisms have more time to multiply and to develop enzymatic systems. In addition, the constituents of the milk are degraded, the pH drops, etc. To overcome these problems, heat treatment must be applied as quickly as possible after the milk has arrived at the dairy.

Time/temperature combination

The combination of temperature and holding time is very important, as it determines the intensity of the heat treatment. Figure 6.1.1 shows lethal effect curves for *Coliform bacteria, Typhus bacteria* and *Tubercle bacilli*. According to these curves, coliform bacteria are killed if the milk is heated to 70 °C and held at that temperature for about one second. At a temperature of 65 °C it takes a holding time of 10 seconds to kill coliform bacteria. These two combinations, 70 °C/1 s and 65 °C/10 s, consequently have the same lethal effect.

Tubercle bacilli are more resistant to heat treatment than coliform bacteria. A holding time of 20 seconds at 70 °C or about 2 minutes at 65 °C is required to ensure that they are all destroyed. There might also be heat-resistant micrococci in milk, but as a rule, they are completely harmless.

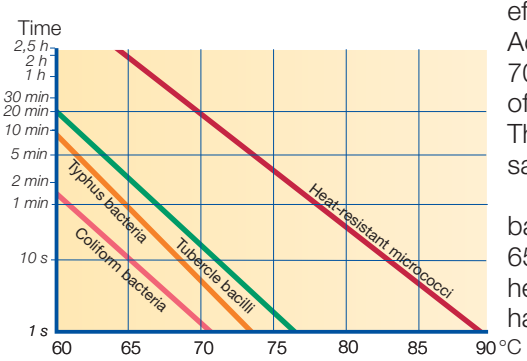


Fig. 6.1.1 *Lethal effect on bacteria.*

Limiting factors for heat treatment

Intense heat treatment of milk is desirable from the microbiological point of view. But such treatment also involves a risk of adverse effects on the appearance, taste and nutritional value of the milk. Proteins in milk are denatured at high temperatures. This means that the cheesemaking properties of milk are drastically impaired by intense heat treatment. Intense heating produces changes in taste; first cooked flavour and then burnt flavour. The choice of time/temperature combination is therefore a matter of optimisation, in which both microbiological effects and quality aspects must be taken into account.

Since heat treatment has become the most important part of milk processing, and knowledge of its influence on milk better understood, various categories of heat treatment have been initiated, as shown in Table 6.1.1.

Table 6.1.1

The main categories of heat treatment in the dairy industry

Process	Temperature, °C	Time
Thermisation	63 – 65	15 s
LTLT pasteurisation of milk	63	30 min
HTST pasteurisation of milk	72 – 75	15 – 20 s
HTST pasteurisation of cream etc.	> 80	1 – 5 s
Ultra pasteurisation	125 – 138	2 – 4 s
UHT (flow sterilisation) normally	135 – 140	a few seconds
Sterilisation in container	115 – 120	20 – 30 min

Thermisation

In many large dairies, it is not possible to pasteurise and process all the milk immediately after reception. Some of the milk must be stored in silo tanks for hours or days. Under these conditions, even deep chilling is not enough to prevent serious quality deterioration.

Many dairies therefore pre-heat the milk to a temperature below the pasteuration temperature, to temporarily inhibit bacterial growth. This process is called *thermisation*. The milk is heated to 63 – 65 °C for about 15 seconds, a time/temperature combination that does not inactivate the

phosphatase enzyme. Double pasteurisation is forbidden by law in many countries, so thermisation must stop short of pasteurisation conditions.

To prevent aerobic spore-forming bacteria from multiplying after thermisation, the milk must be rapidly chilled to 4 °C or below and it must not be mixed with untreated milk. Many experts are of the opinion that thermisation has a favourable effect on certain spore-forming bacteria. The heat treatment causes many spores to revert to the vegetative state, which means that they are destroyed when the milk is subsequently pasteurised.

Thermisation should be applied only in exceptional cases. The objective should be to pasteurise all the incoming milk within 24 hours of arrival at the dairy.

LTLT pasteurisation

The original type of heat treatment was a batch process in which milk was heated to 63 °C in open vats and held at that temperature for 30 minutes. This method is called the *holder method* or *low temperature, long time (LTLT) method*.

Nowadays milk is almost always heat treated in continuous processes like thermisation, HTST pasteurisation or UHT treatment.

HTST pasteurisation

HTST is the abbreviation of *High Temperature Short Time*. The actual time/temperature combination varies according to the quality of the raw milk, the type of product treated, and the required keeping properties.

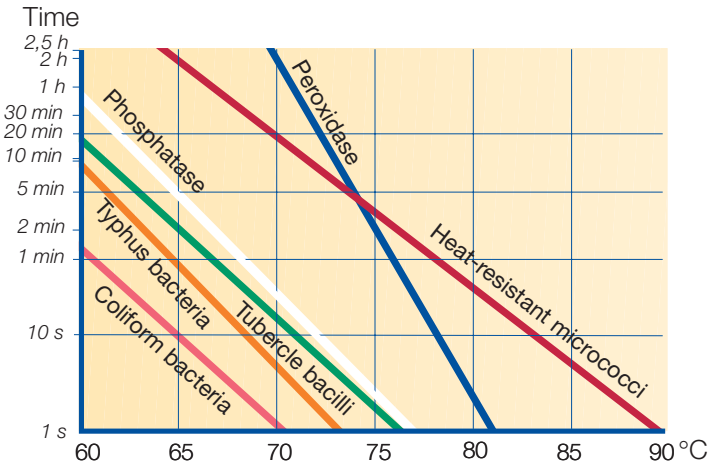


Fig. 6.1.2 *Lethal effect curves and time/temperature curves for destruction of some enzymes and micro-organisms.*

Milk

The HTST process for milk involves heating it to 72 – 75 °C with a hold of 15 – 20 seconds before it is cooled. The phosphatase enzyme is destroyed by this time/temperature combination. The phosphatase test is therefore used to check that milk has been properly pasteurised. The test result must be negative; there must be no detectable phosphatase activity (Figure 6.1.2).

Cream and cultured products

Phosphatase tests should not be used for products with fat contents above 8%, as some reactivation of the enzyme takes place a fairly short time after pasteurisation. The heat treatment must also be stronger, as fat is a poor heat conductor.

Peroxidase, another enzyme, is therefore used for checking the pasteurisation results for cream (Peroxidase test acc. to Storch). The product is heated to a temperature above 80 °C, with a holding time of about five seconds. This more intense heat treatment is sufficient to inactivate peroxidase. The test must be negative – there must be no detectable peroxidase activity in the product (Figure 6.1.2).

As the phosphatase test cannot be used for acidified products either, heating control is based on the peroxidase enzyme. Milk intended for cultured milk production is normally subjected to intense heating to coagulate whey proteins and increase its water-binding properties *i.e.* prevent formation of whey.

Ultra pasteurisation

Ultra pasteurisation can be utilised when a particular shelf life is required. For some manufacturers, two extra days are enough, whereas others aim for a further 30 – 40 days on top of the 2 – 16 days which is traditionally associated with pasteurised products. The fundamental principle is to reduce the main causes of reinfection of the product during processing and packaging, so as to extend the shelf life of the product. This requires extremely high levels of production hygiene and a distribution temperature

of no more than 7 °C; the lower the temperature, the longer the shelf life.

Heating milk to 125 – 138 °C for 2 – 4 seconds and cooling it to < 7 °C is the basis of extended shelf life. ESL, *Extended Shelf Life*, is a general term for heat treated products which have been given improved keeping qualities by one means or another. Nevertheless, ESL products must still be kept refrigerated during distribution and in retail stores.

UHT treatment

UHT is the abbreviation for *Ultra High Temperature*. UHT treatment is a technique for preserving liquid food products by exposing them to brief, intense heating, normally to temperatures in the range of 135 – 140 °C. This kills micro-organisms which would otherwise destroy the products.

UHT treatment is a continuous process which takes place in a closed system that prevents the product from being contaminated by airborne micro-organisms. The product passes through heating and cooling stages in quick succession. Aseptic filling, to avoid reinfection of the product, is an integral part of the process.

Two alternative methods of UHT treatment are used:

- Indirect heating and cooling in heat exchangers,
- Direct heating by steam injection or infusion of milk into steam and cooling by expansion under vacuum.

Sterilisation

The original form of sterilisation, which is still in use, is in-container sterilisation, usually at 115 – 120 °C for some 20 – 30 minutes.

After fat standardisation, homogenisation and heating to about 80 °C, the milk is packed in clean containers; usually glass or plastic bottles for milk, and cans for evaporated milk. The product, still hot, is transferred to autoclaves in batch production or to a hydrostatic tower in continuous production.

Heating and cooling are the most important operations in the dairy.

Pre-heating

Normally, the desired processing temperatures are reached directly after pasteurisation, but sometimes it is necessary to cool and store the milk temporarily, before the final processing is done. Some examples are given below.

Cheese milk is pre-heated to 30 – 35 °C prior to the vat, where a final temperature adjustment is made before the rennet is added. Hot water is used as the heating medium. Warm whey from a previous batch can also be utilised for a first pre-heating step, in order to cut the heating costs.

Yoghurt milk is pre-heated to 40 – 45 °C prior to the fermentation tank, where the addition of culture takes place. Hot water is used as the heating medium.

Milk can also be pre-heated before addition of other ingredients, (such as chocolate powder, sugar or fats), in the manufacture of different milk-based food products.

Heat transfer processes in the dairy

One of the most important requirements of modern dairying is to be able to control the temperature of products at every stage in the process. Heating and cooling are therefore very common operations in the dairy.

Heating

Hot water, or occasionally low-pressure steam, is used as the heating medium to heat milk. A certain amount of heat is transferred from the heating medium to the milk so that the temperature of the latter rises and the temperature of the heating medium drops correspondingly.

Cooling

Directly after arrival at the dairy, the milk is often cooled to a low temperature (5 °C or lower), to temporarily prevent growth of micro-organisms. Following pasteurisation, the milk is also cooled again to about 4 °C.

If naturally-cold water is at hand, it may be utilised for pre-cooling after pasteurisation and regenerative heat exchange. In all cases, heat is transferred from the milk to the cooling medium. The temperature of the milk is reduced to the desired value and the temperature of the cooling medium rises correspondingly. The cooling medium may be cold water, ice water, brine solution or an alcohol solution, such as glycol.

Regenerative heating and cooling

In many cases, a product must first be heated for a certain treatment and then cooled. Pasteurisation of milk is an example. Chilled milk is heated from, perhaps, 4 °C to a pasteurisation temperature of 72 °C, held at that temperature for 15 seconds and then chilled to 4 °C again.

The heat of the pasteurised milk is utilised, to warm the cold milk. The incoming cold milk is pre-heated by the outgoing hot milk, which is simultaneously pre-cooled. This saves heating and refrigeration energy. The process takes place in a heat exchanger and is called *regenerative heat exchange* or, more commonly, *heat recovery*. As much as 94 – 95% of the heat content of the pasteurised milk can be recycled.

Fig. 6.1.3 *Heat transfer by conduction. Example: Heat is transferred from the bowl of the spoon to the handle.*

Heat transfer theory

Two substances must have different temperatures in order to transfer heat from one substance to another. Heat always flows from the warmer substance to the colder. The heat flow is rapid when the temperature difference is great. During heat transfer, the difference in temperature is gradually reduced and the rate of transfer slows down, ceasing altogether when the temperatures are equalised.

Heat can be transferred in three ways: by conduction, convection and radiation.

- **Conduction** means transfer of thermal energy through solid bodies and through layers of liquid at rest (without physical flow or mixing in the direction of heat transfer). Figure 6.1.3 shows an example of heat conduction to a teaspoon in a cup of hot coffee. Heat is transferred by conduction to the handle, which then becomes warmer.
- **Convection** is a form of heat transfer that occurs when particles with a high heat content are mixed with cold particles and transfer their heat to the latter by conduction (Figure 6.1.4). Convection consequently involves mixing. If the teaspoon is rinsed with running cold water, heat is transferred from the spoon to the water, which is heated in the process. The heated water is replaced by cold water, which in turn absorbs heat from the spoon. Heat transfer by convection continues until the spoon and the running water have the same temperature.
- **Radiation** is the emission of heat from a body which has accumulated thermal energy (Figure 6.1.5). The thermal energy is converted into radiant energy, emitted from the body and absorbed by other bodies which it strikes. Almost all substances emit radiant energy.

Fig. 6.1.4 *Heat transfer by convection. Example: The spoon is rinsed in running cold water. Heat is absorbed by the water and the spoon gets cooler, until the spoon and the water are at the same temperature.*

Heat transfer principles

All heat transfer in dairies takes place in the form of convection and conduction. Two principles are used: direct and indirect heating.

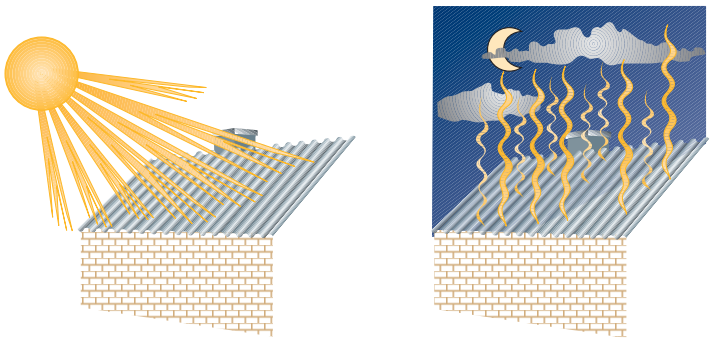


Fig. 6.1.5 *Heat transfer by radiation. Example: A roof accumulates solar heat during the day and radiates the heat at night.*

Direct heating

Direct heating means that the heating medium is mixed with the product. This technique is used to:

- Heat water, where steam is injected directly into the water and transfers heat to the water by both convection and conduction.
- Heat products, such as curd in the manufacture of certain types of cheese (by mixing hot water with the curd) and to sterilise milk by the direct method (steam injection or infusion of milk into steam).

The direct method of heat transfer is efficient for rapid heating. It offers certain advantages which will be considered in Chapter 9 on long life milk production. It does, however, involve mixing the product with the heating medium, and this necessitates certain steps in the subsequent process. It also makes strict demands on the quality of the heating medium. Direct heating is forbidden by law in some countries on the grounds that it introduces foreign matter into the product.

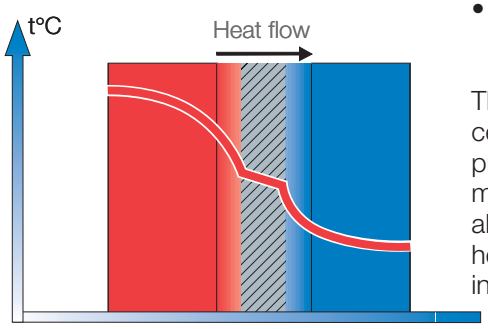


Fig. 6.1.6 *Heat is transferred from a heating medium to a cold product on the other side of the partition.*

Indirect heating

Indirect heat transfer is therefore the most commonly used method in dairies. In this method, a partition is placed between the product and the heating or cooling medium. Heat is then transferred from the medium through the partition into the product (Figure 6.1.6).

We assume that the heating medium is hot water, flowing on one side of the partition, and cold milk on the other. The partition is consequently heated on the heating-medium side and cooled on the product side. In a plate heat exchanger, the plate is the partition.

There is a boundary layer on each side of the partition. The velocity of the liquids is slowed down by friction to almost zero at the boundary layer in contact with the partition. The layer immediately outside the boundary layer is only slowed down by the liquid in the boundary layer and therefore has a low velocity. The velocity increases progressively, and is highest at the centre of the channel.

Similarly, the temperature of the hot water is highest in the middle of the channel. The closer the water is to the partition, the more it is cooled by the cold milk on the other side. Heat is transferred, by convection and conduction, to the boundary layer. Transfer from the boundary layer through the wall to the boundary layer on the other side is almost entirely by conduction, while further transfer to the milk in the central zone of the channel is accomplished by both conduction and convection.

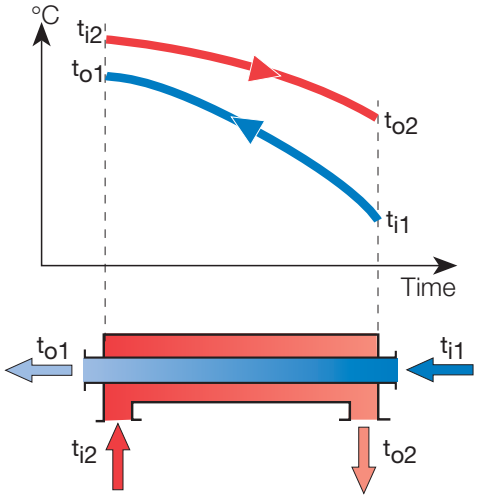


Fig. 6.1.7 *Temperature profiles for heat transfer in a heat exchanger.*

The heat exchanger

A heat exchanger is used to transfer heat by the indirect method.

Several different types will be described later. It is possible to simplify heat transfer by representing the heat exchanger symbolically as two channels separated by a tubular partition.

Hot water (red) flows through one channel and milk (blue) through the other. Heat is transferred through the partition. The hot water enters the channel at a temperature of t_{i2} and is cooled to a temperature of t_{02} at the outlet. Milk enters the heat exchanger at a temperature of ti1 and is heated by the hot water to an exit temperature of t_{01}. The temperature changes during passage through the heat exchanger are shown by the curves in Figure 6.1.7.

Dimensioning data for a heat exchanger

The necessary size and configuration of a heat exchanger depend on many factors. The calculation is very intricate and is nowadays normally done with the aid of a computer. The factors that must be considered are :

- Product flow rate
- Physical properties of the liquids
- Temperature program
- Permitted pressure drops

- Heat exchanger design
- Cleanability requirements
- Required running times

The general formula for calculating the required size (heat transfer area) of a heat exchanger is:

$$A = \frac{V \times \rho \times c_p \times \Delta t}{\Delta t_m \times k}$$

A = Required heat transfer area
V = Product flow rate
ρ = Density of the product
c_p = Specific heat of the product
Δt = Temperature change of the product
Δt_m = Logarithmic mean temperature difference (LMTD)
k = Overall heat transfer coefficient

Product flow rate

The flow rate, V, is determined by the planned capacity of the dairy. The higher the flow rate, the larger the heat exchanger needed.

Example: If the product flow rate in a plant is to be increased from 10 000 to 20 000 l/h, the heat exchanger must be extended to twice the original size, provided the flow rates of the service media are also doubled, other factors being constant.

Physical properties of the liquids

The density figure, ρ, is determined by the product.

The figure for specific heat, c_p, is also determined by the product. The specific heat tells how much heat must be supplied to a substance in order to increase its temperature by 1 °C.

Another important physical property is viscosity. This will be discussed in the section on overall heat transfer coefficient below.

Temperature program

The object of heat transfer is to heat or cool a given quantity of a product, such as milk, from a given inlet temperature to a given outlet temperature. This is accomplished in a heat exchanger with the help of a service medium, such as water. In the case of heating, milk is heated with hot water, the temperature of which drops correspondingly.

Several aspects of the temperature program must be considered: the change of temperatures, the differential temperature between the liquids and the flow direction of the liquids.

Temperature change

Inlet and outlet temperatures of the product are determined by preceding and subsequent process stages. The change of product temperature is marked Δt in the general formula above. It can be expressed as: $\Delta t_1 = t_{o1} - t_{i1}$. See also Figure 6.1.7.

The inlet temperature for the service medium is determined by processing conditions. The temperature for outgoing service medium can be calculated by an energy balance calculation.

For a modern heat exchanger the energy losses to the surrounding air can be neglected, as they are very small. Thus the heat energy given off by the hot liquid is equal to the heat energy absorbed by the cold liquid, *i.e.* an energy balance. It can be expressed as the following formula:

$$V_1 \times \rho_1 \times c_{p1} \times \Delta t_1 = V_2 \times \rho_2 \times c_{p2} \times \Delta t_2$$

Example: 20 000 l/h cheese milk (V_1) is to be heated from 4 °C to 34 °C by 30 000 l/h hot water (V_2) at 50 °C. Density (ρ) and specific heat (c_p) for milk are about 1 020 kg/m^3 and 3,95 kJ/kg, K and for water 990 (at 50°C) and 4,18 kJ/kg.

The temperature change for the hot water can then be calculated:
20 000 x 1 020 x 3,95 x (34 – 4) = 30 000 x 990 x 4,18 x Δt_2
Δt_2 = 19,5 °C. The hot water temperature will drop by 19.5 from 50 to 30,5 °C.

Logarithmic mean temperature difference (LMTD)

It has already been mentioned that there must be a difference in temperature between the two media for heat transfer to take place. The differential temperature is the driving force. The greater the difference in temperature, the more heat is transferred and the smaller the heat exchanger needed. For sensitive products there are, however, limits to how great a difference can be used.

The differential temperature can vary through the heat exchanger. A mean value, LTMD, is used for calculation. It is called Δt_m in the general formula above. It can be calculated by the following formula, using the denominations in Figure 6.1.8.

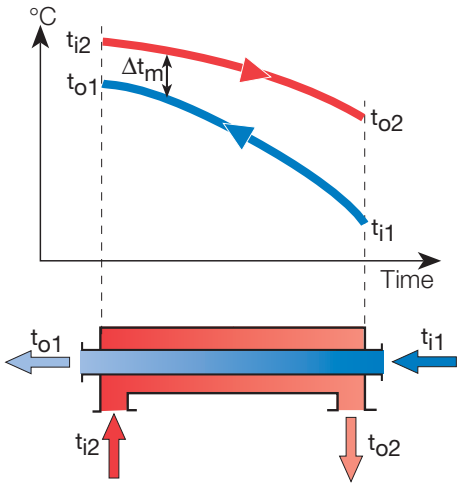


Fig. 6.1.8 *Temperature profiles for heat transfer in a heat exchanger with countercurrent flow.*

$$\Delta t_m = \frac{(t_{i2} - t_{o1}) - (t_{o2} - t_{i1})}{\ln \dfrac{(t_{i2} - t_{o1})}{(t_{o2} - t_{i1})}}$$

In the example with the cheese milk heater, the logarithmic mean difference temperature, Δt_m, can be calculated as 20,8 °C.

An important factor in determining the mean temperature differential is the directions of the flow in the heat exchanger. There are two main options: *countercurrent* or *concurrent* flow.

Countercurrent flow

The temperature difference between the two liquids is best utilised if they flow in opposite directions through the heat exchanger (Figure 6.1.8). The cold product then meets the cold heating medium at the inlet, and a progressively warmer medium as it passes through the heat exchanger. During the passage, the product is gradually heated so that the temperature is always only a few degrees below that of the heating medium at the corresponding point. This type of arrangement is called countercurrent flow.

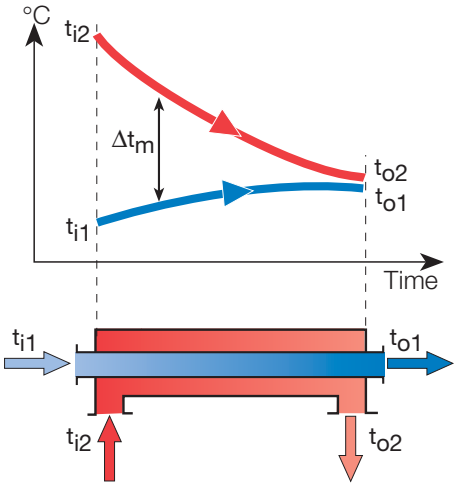


Fig. 6.1.9 *Temperature profiles for heat transfer in a heat exchanger with concurrent flow.*

Concurrent flow

With the opposite arrangement, concurrent flow (Figure 6.1.9), both liquids enter the heat exchanger from the same end and flow in the same direction. In concurrent flow, it is impossible to heat the product to a temperature higher than that which would be obtained if the product and the heating medium were mixed. This limitation does not apply in countercurrent flow; the product can be heated to within two or three degrees of the inlet temperature of the heating medium.

Overall heat transfer coefficient

This factor, k, is a measure of how efficient the heat transfer is. It tells how much heat passes through 1 m^2 of the partition per 1 °C of differential temperature. The same factor is used to calculate insulation for buildings, although in that case, the object is to make k as small as possible, whereas in a heat exchanger it should be as high as possible.
This factor depends on:

- Permitted pressure drops for the liquids
- The viscosities of the liquids
- The shape and thickness of the partition

- The material of the partition
- Presence of fouling matter

Permitted pressure drops

In order to increase the value of k, and improve the heat transfer, it is possible to reduce the size of the channel through which the product flows. This reduces the distance over which heat must be transferred from the partition to the centre of the channel.

At the same time, however, the cross section area of flow is reduced. This has two results:

a. the flow velocity through the channel increases, which in turn means
b. the flow becomes more turbulent.

The greater the pressure drops for product and service media, the more heat is transferred and the smaller the heat exchanger needed.

Products which are sensitive to mechanical agitation (*e.g.* milk fat) may, however, be damaged by violent treatment. The pressure drop across the heat exchanger also rises, so the product pressure before the heat exchanger must be increased to force the product through the narrower channels. It may then be necessary to install a booster pump. In some countries, installation of a booster pump is specified in legal requirements, basically to secure a higher pressure on the product side, and thus to prevent leakage of unpasteurised product into pasteurised product.

Viscosity

The viscosities of the product and the service medium are important to the dimensioning of a heat exchanger. A liquid with high viscosity develops less turbulence when it flows through the heat exchanger compared to a product with lower viscosity. This means a larger heat exchanger is needed, assuming everything else remains constant. For instance, a larger heat exchanger is needed for cream than for milk, if capacities and temperature programs are identical.

Special attention must be paid to products with non-Newtonian flow behaviour. For these products, the apparent viscosity depends not only on the temperature, but also on the shear rate. A product which seems rather thick in a tank may flow much more readily when it is pumped through pipes or a heat exchanger. The flow behaviour of such products must be measured with special instruments so that correct calculations can be made. (See also Chapter 3, *Rheology*.)

Shape and thickness of the partition

The partition is often corrugated to create a more turbulent flow, which results in better heat transfer. Figure 6.1.10 shows three different designs.

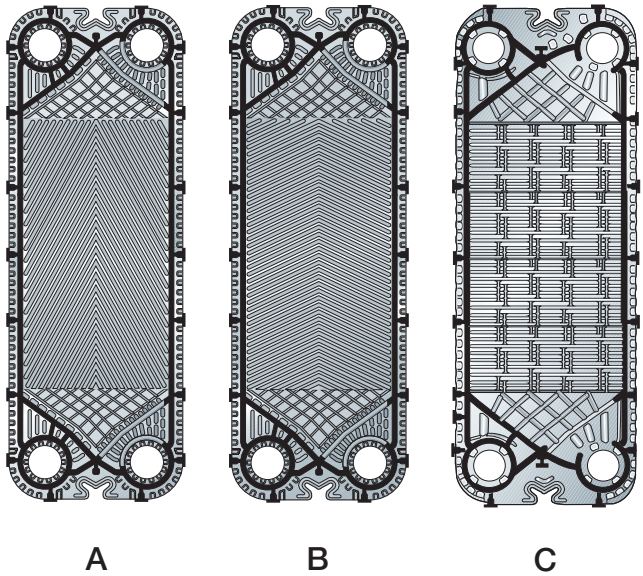


Fig. 6.1.10 *The shape of the partition in a plate heat exchanger may differ depending on the product to be treated and thermal efficiency requirements.*

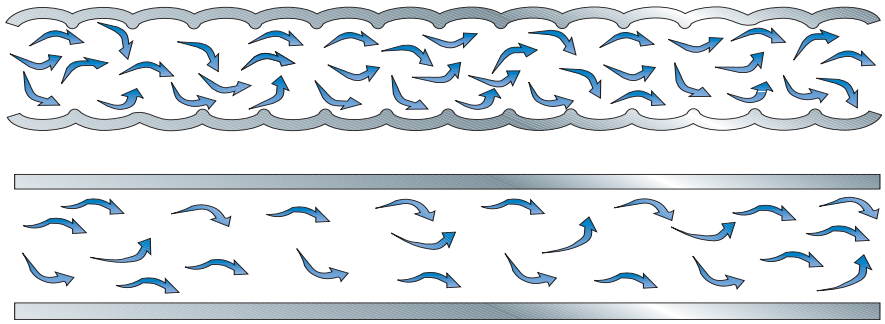


Fig. 6.1.11 *Turbulence will be much more intense when the surface is corrugated compared to a smooth surface.*

Plates with different corrugations according to **A**) and **B**) in the figure, have different thermal properties and pressure drops. With these two plate types, three different channels can be formed. This gives the possibility to optimise the heat transfer/pressure drop relation for a certain duty.

Figure **C**) shows a plate with a completely different corrugation. The number of contact points is reduced to make it possible to run liquids with particles or fibres of limited size.

The thickness is also important. The thinner the partition, the better the heat transfer. But this must be balanced against the need for the partition to be strong enough to withstand the pressure of the liquids. Modern plates are designed with metal to metal contact points that gives a good pressure resistance also for thin plates.

The heat transfer in tubular heat exchangers can be improved by corrugation of the inner tubes (Figure 6.1.11). This will however also give a higher pressure drop. Smooth or corrugated tubes are chosen in order to optimise the heat transfer/pressure drop relation.

Material of the partition

For food processing, the normal material is stainless steel, which has fairly good heat transfer characteristics.

Presence of fouling matter

Most dairy products are sensitive to heating, which must therefore be done very carefully to avoid changes in the products. Proteins will coagulate and encrust the inside of a hot saucepan, if it is used to heat milk. The same thing happens in heat exchangers if the heat transfer surface is too hot.

The differential temperature between heating medium and product should therefore be as small as possible, normally 2 – 3 °C above the pasteurisation temperature. If the surface is too hot, in relation to the product, there is a risk that proteins in the milk will coagulate and be deposited in a thin layer on the partitions. Heat must then also be transferred through this layer, which will cause the value of the overall heat transfer coefficient k to drop.

The differential temperature between heating medium and product will then no longer be sufficient to transfer the same amount of heat as before, and the temperature at the product outlet will drop. This can be compensated for by increasing the temperature of the heating medium, but this also raises the temperature of the heat transfer surface so that more protein coagulates on the surface, the thickness of the crust increases and the value of k drops still more.

The value of k is also affected by an increase or decrease of the flow rate through the heat exchanger, as this affects the flow characteristics. Increasing the flow rate makes the flow more turbulent and increases the value of k. Throttling the flow makes it less turbulent and reduces the value of k. It is therefore normally desirable to avoid variations in the flow rate through a heat exchanger, but for economic reasons, it might be necessary to accept some variations in certain types of production.

Example: In the previously considered case of the cheese milk heater, the heat transfer coefficient can be assumed to be about 5 000 W/m^2, K, if a plate heat exchanger made of thin stainless steel is used and the plates are not much fouled.

The other factors in the formula shown on page 89 are:

Flow rate, l/h	=	20 000
Density, kg/m^3	=	1 020
Specific heat, kJ/kg, K	=	3,95
Temperature change, °C	=	30
Temperature difference, °C	=	20,8
Heat transfer coefficient, W /m^2, K	=	5 000

The necessary heat transfer surface can be calculated as:

$$A = \frac{20\,000 \times 1\,020 \times 3{,}95 \times 30}{3\,600 \times 20{,}8 \times 5\,000} = 6{,}5 \text{ m}^2$$

This is to be considered as a theoretical value. In actual practice the sensitive nature of the product and the process demands must also be considered. Two such factors, not included in the formula, are requirements for cleanability and running time.

Cleanability requirement

A heat exchanger in a dairy must be cleaned at the end of a production cycle. This is done by circulating detergents the same way as the milk. The cleaning process is described separately in Chapter 21.

To achieve efficient cleaning, the heat exchanger must be designed not only to meet the required temperature program, but also with cleaning in mind.

If some passages in the heat exchanger are very wide, *i.e.* have several parallel channels, the turbulence during cleaning may not be enough to remove fouling deposits effectively. On the other hand, if some passages are very narrow, *i.e.* few parallel channels, the turbulence may be so high that the pressure drop will be very great. Such a high pressure drop may reduce the flow velocity of the cleaning solution, thereby reducing its effectiveness. A heat exchanger must thus be designed to allow effective cleaning.

When liquids with particles or fibres have been run, back flush is normally needed during cleaning. Back flush means that the flow is reversed during some phases of the cleaning programme.

Running time requirement

Some fouling always occurs when milk products are heated to a temperature above 65 °C. This means that there will always be a limited running time before the pasteuriser must be stopped for cleaning.

The length of the running time is difficult, not to say impossible, to predict, as it is determined by the amount of fouling formed.

The rate of buildup of fouling depends on many factors such as:

- Temperature difference between product and heating medium
- Milk quality
- Air content of the product
- Pressure conditions in the heating section

It is especially important to keep the air content as low as possible. Excess air in the product will greatly contribute to increased fouling. Under certain conditions, the running time may also be limited by growth of micro-organisms in the downstream part of the regenerative section of a plate heat exchanger. This is however rare; when it occurs it is usually related to the pre-treatment of the milk.

All this together makes it important to allow for cleaning at regular intervals when making production plans for pasteurisers.

Regeneration

The method of using the heat of a hot liquid, such as pasteurised milk, to pre-heat cold incoming milk is called regeneration. The cold milk also serves to cool the hot, thus economising on water and energy. Regeneration efficiencies of up to 95 % can be achieved in efficient, modern pasteurisation plants.

We can take the simplest operating profile – heat treatment of raw milk – as an example. Using the formula:

$$R = \frac{(t_r - t_i) \times 100}{(t_p - t_i)}$$

where		Values in this example
R	= regenerative efficiency, %	
t_r	= milk temperature after regeneration, °C	68
t_i	= temperature of raw incoming milk, °C	4
t_p	= pasteurisation temperature, °C	72

we obtain: $R = \frac{(68 - 4) \times 100}{(72 - 4)} = 94{,}1\ \%$

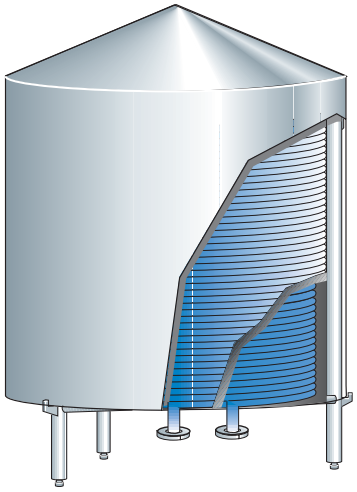


Fig. 6.1.12 *Shrouded, spiral holding tube for long holding time.*

Fig. 6.1.12 *Zig-zag holding tube.*

Holding

Correct heat treatment requires that the milk is held for a specified time at pasteurisation temperature. This is done in an external holding cell.

A holding cell usually consists of a pipe arranged in a spiral or zig-zag pattern and is often covered by a metal shroud to prevent people from being burned if they touch it. The shroud will also reduce the heat losses to the surrounding air. The length of the pipe and flow rate are calculated so that the time in the holding cell is equal to the required holding time.

Accurate control of the flow rate is essential because the holding equipment is dimensioned for a specified holding time at a given flow rate. The holding time changes in inverse proportion to the flow rate in the holding cell.

Holding sections built into the plate heat exchanger were used earlier, but external holding cells are used almost exclusively nowadays.

Calculation of holding time

The appropriate tube length for the required holding time can be calculated when the hourly capacity and the inner diameter of the holding tube are known. As the velocity profile in the holding tube is not uniform, some milk molecules will move faster than the average. To ensure that even the fastest molecule is sufficiently pasteurised, an efficiency factor must be used. This factor depends on the design of the holding tube, but is often in the range of 0,8 – 0,9 if the flow is turbulent. For more viscous fluids, the flow might be laminar and then the efficiency factor is lower.

Formula

1. $V = \frac{Q \times HT}{3\,600 \times \eta}\ dm^3$

2. $L = \frac{V \times 4}{\pi \times D^2}\ dm$

Data required for calculation:

Q = flow rate at pasteurisation, l/h
HT = holding time in seconds
L = length of holding tube in dm, corresponding to Q and HT
D = inner diameter of holding tube in dm, to be known or adapted to the other pipework
V = volume of milk in l or dm^3 corresponding to Q and HT
η = efficiency factor

Example: A holding time (HT) of 15 sec is required in a pasteurisation plant with a capacity (Q) of 10 000 l/h. The inner diameter (D) of the pipe to be used is 48,5 mm = 0,485 dm. Calculate the length (L) of the holding tube, with the efficiency factor of 0,85.

$$1.\ V = \frac{10\,000 \times 15}{3\,600 \times 0{,}85} = 49{,}0\ dm^3$$

$$2.\ L = \frac{49{,}0 \times 4}{\pi \times 0{,}485^2} = 265{,}5\ dm \text{ or } 26{,}5\ m$$

The length of the holding tube should be about 26,5 m.

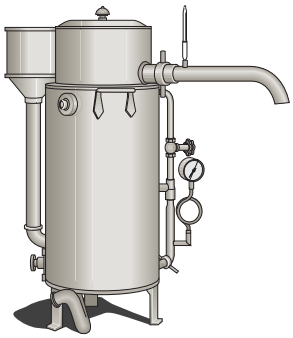


Fig. 6.1.14 *This type of flash pasteuriser with a turbine-driven stirrer was manufactured and sold by AB Separator between 1896 and 1931.*

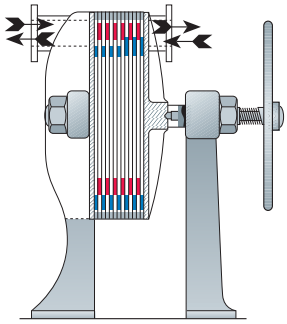


Fig. 6.1.15 *The plate heat exchanger was patented in 1890 by the German inventors Langen and Hundhausen.*

Different types of heat exchangers

The most widely used type of equipment at the end of the 19th century was the heater, one type of which is shown in Figure 6.1.14. Despite its many shortcomings, this heat exchanger model was still in use in some dairies even in the 1950s.

In 1878 a German, Albert Dracke, was granted a patent on an apparatus in which one liquid could cool another by each flowing in a layer on opposite sides of series of plates. It is not known whether any such patents, one of which covers the heat exchanger shown in Figure 6.1.15, ever left the drawing board. However, at the beginning of the 1920s, the old German ideas were reappraised, and a regenerative heat exchanger, based on these concepts, was launched. Since then, plate heat exchangers have assumed a predominant role for heating and cooling purposes in the dairy industry.

The following three types of heat exchangers are the most widely used nowadays:

- Plate heat exchanger
- Tubular heat exchanger
- Scraped-surface heat exchanger

Plate heat exchangers

Most heat treatment of dairy products is carried out in plate heat exchangers. The plate heat exchanger (often abbreviated PHE) consists of a pack of stainless steel plates clamped in a frame.

The frame may contain several separate plate packs – sections – in which different stages of treatment, such as pre-heating, final heating and cooling take place. The heating medium is hot water, and the cooling medium cold water, ice-water or propyl glycol, depending on the required product outlet temperature.

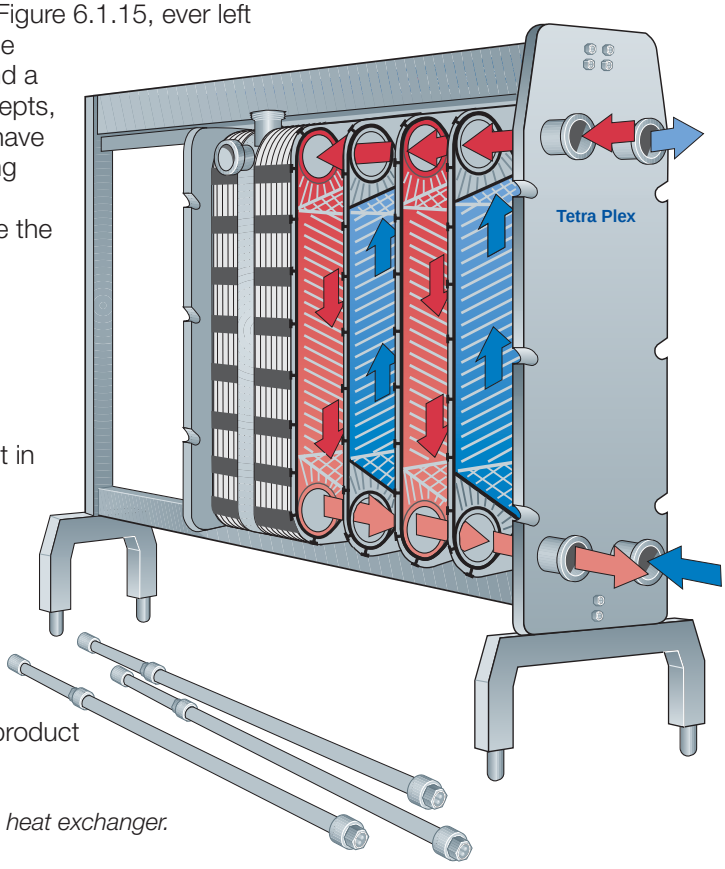


Fig. 6.1.16 *Principles of flow and heat transfer in a plate heat exchanger.*

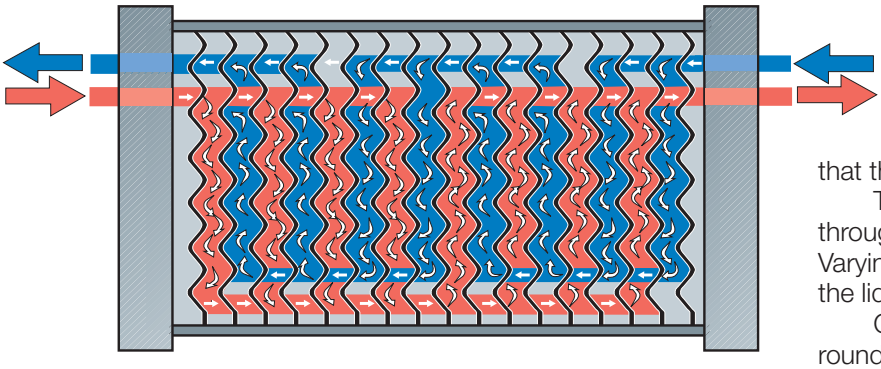


Fig. 6.1.17 *The system of parallel flow pattern for both product and heating/ cooling medium channels. In this example the combination is written 4 x 2 / 2 x 4.*

The plates are corrugated in a pattern designed for optimum heat transfer. The plate pack is compressed in the frame. Supporting points on the corrugations hold the plates apart, so that thin channels are formed between them.

The liquids enter and leave the channels through holes in the corners of the plates. Varying patterns of open and blind holes route the liquids from one channel to the next.

Gaskets round the edges of the plates and round the holes form the boundaries of the channels and prevent external leakage and internal mixing.

Flow patterns

The product is introduced through a corner hole into the first channel of the section and flows vertically through the channel. It leaves at the other end through a separately gasketed corner passage. The arrangement of the corner passages is such that the product flows through alternate channels in the plate pack.

The service (heating or cooling) medium is introduced at the other end of the section and passes, in the same way, through alternate plate channels. Each product channel consequently has service medium channels on both sides.

For efficient heat transfer, the channels between the plates should be as narrow as possible; but both flow velocity and pressure drop will be high if a large volume of product must pass through these narrow channels. Neither of these effects is desirable and, to eliminate them, the passage of the product through the heat exchanger may be divided into a number of parallel flows.

In Figure 6.1.17 the blue product flow is divided into two parallel flows, which change direction four times in the section. The channels for the red heating medium are divided into four parallel flows, which change direction twice.

This combination is written as 4 x 2 / 2 x 4, *i.e.* the number of passes, the number of parallel flows for the blue product, the number of passes, and the number of parallel flows for the red service medium. This is called the grouping of the plates.

Tubular heat exchangers

Tubular heat exchangers (THE) are in some cases used for pasteurisation and UHT treatment of dairy products. The tubular heat exchanger (Figure 6.1.18), unlike plate heat exchangers, has no contact points in the product channel and can thus handle products with particles up to a certain size. The maximum particle size depends on the diameter of the tube. The tubular heat exchanger can also run longer between cleanings than the plate heat exchanger in UHT treatment.

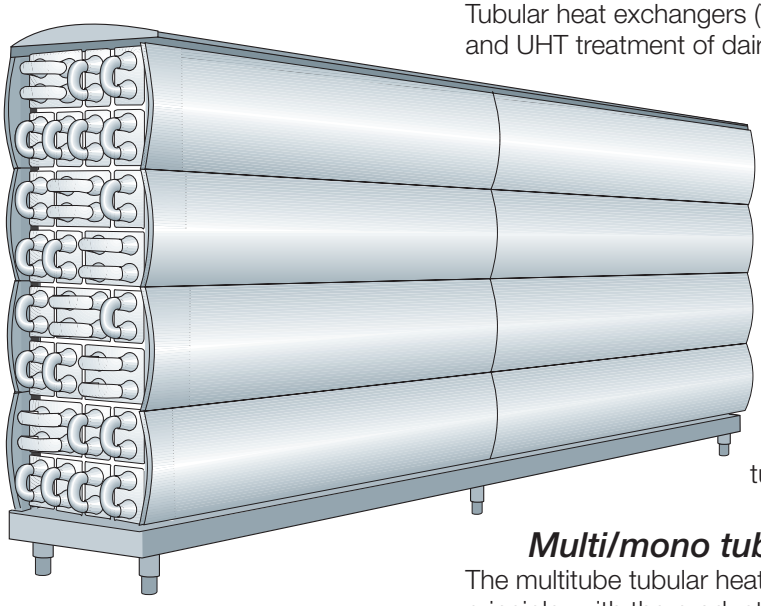


Fig. 6.1.18 *The tubular heat exchanger tubes are assembled in a compact unit.*

Compared to a plate heat exchanger, a higher flow velocity is needed to create efficient heat transfer in a tubular heat exchanger.

Tubular heat exchangers are available in two fundamentally different types; multi/mono tube and concentric tube.

Multi/mono tube

The multitube tubular heat exchanger operates on the classic shell and tube principle, with the product flowing through a group of parallel tubes and the service medium between and around the tubes. Turbulence for efficient heat

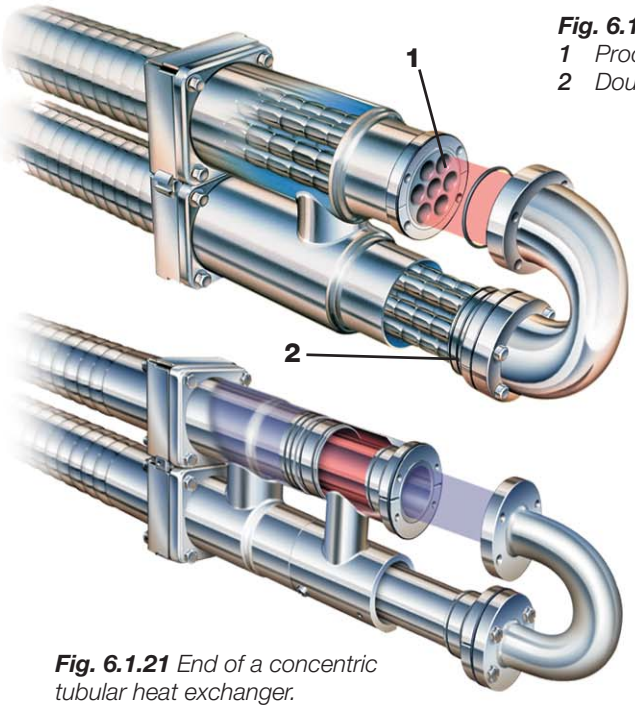


Fig. 6.1.19 *End of a multitube tubular heat exchanger.*
1 Product tubes surrounded by cooling medium
2 Double O-ring seal

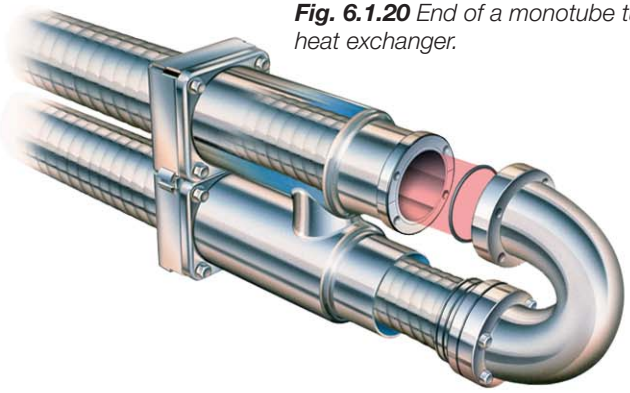


Fig. 6.1.20 *End of a monotube tubular heat exchanger.*

Fig. 6.1.21 *End of a concentric tubular heat exchanger.*

transfer is created by helical corrugations on the tubes and shell.

The heat transfer surface consists of a bundle of straight corrugated or smooth tubes (1) welded into tube plates at both ends (Figures 6.1.19 and 6.1.20). The tube plates are in turn sealed against the outer shell by a double O-ring construction (2) (floating design). This design allows the product tubes to be taken out of the shell by unscrewing the end bolts. This makes the unit strippable for inspection.

The floating design absorbs thermal expansion and the product tube bundles in the shell can be changed, allowing different combinations to be used for different applications.

Direct product to product heat recovery can be utilised in a multitube with special design. This is due to the fact that the tube inserts can be taken out for inspection also on the shell side.

The monotube is a version with only one inner tube, which will permit particles with a diameter up to 50 mm to pass.

Multi/mono tubes are well suited for processes operating at very high pressures and high temperatures.

Concentric tube

The heat exchanger surface of a concentric tubular heat exchanger, shown in Figure 6.1.21, consists of straight tubes of different diameters concentrically located. This design gives an efficient heating or cooling as there is heating/cooling media on both sides of the annular product channel. The product channel is available with different depth to meet the requirements for products with particles.

The concentric tube is designed with floating tubes to absorb thermal expansion and to make it possible to inspect both product and media channels.

A concentric tube is specially well suited for high viscous fluids with strong non-Newtonean flow behaviour.

Scraped-surface heat exchanger

The scraped-surface heat exchanger (Figure 6.1.22), is designed for heating and cooling of viscous, sticky and lumpy products and for crystallisation of products. All products that can be pumped can also be treated.

A scraped surface heat exchanger consists of a cylinder (1) through which the product is pumped in countercurrent flow to the service medium

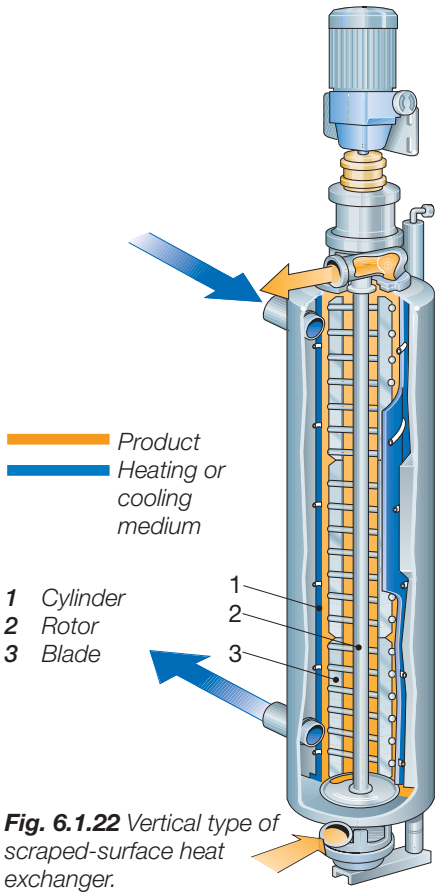


Fig. 6.1.22 *Vertical type of scraped-surface heat exchanger.*

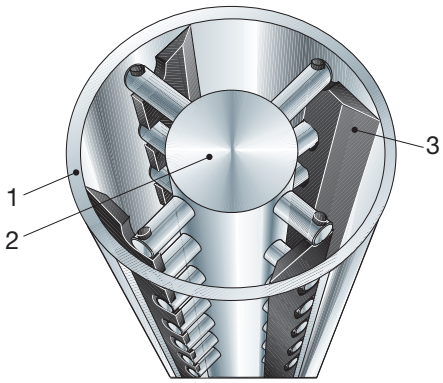


Fig. 6.1.23 *Section through a scraped-surface heat exchanger.*
1 *Cylinder*
2 *Rotor*
3 *Blade*

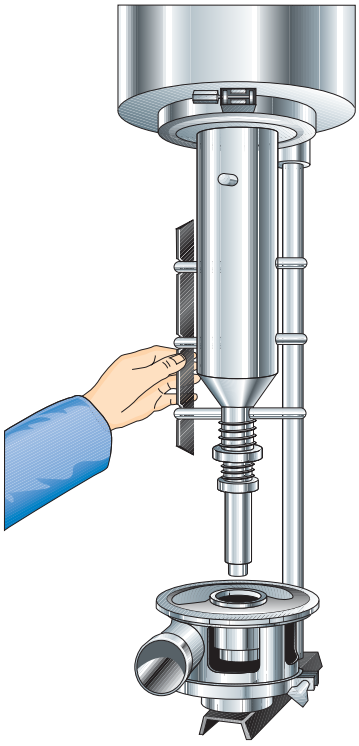


Fig. 6.1.24 *Removal of blades from the rotor assembly in lowered position.*

in the surrounding jacket. Exchangeable rotors (2) of various diameters, and varying pin/blade (3) configurations allow adaptation to different applications. Smaller diameter rotors allow larger particles to pass through the cylinder, while larger diameter rotors result in shorter residence time and improved thermal performance.

The product enters the vertical cylinder through the lower port and continuously flows upwards through the cylinder. At process start-up, all the air is completely purged ahead of the product, allowing complete and uniform product coverage of the heating or cooling surface.

The rotating blades continually remove the product from the cylinder wall (Figure 6.1.23), to ensure uniform heat transfer to the product. In addition, the surface is kept free from deposits.

The product exits the cylinder via the upper port. Product flow and rotor speed are varied to suit the properties of the product flowing through the cylinder.

At shut-down, thanks to the vertical design, the product can be displaced by water with minimum intermixing which helps assure product recovery at the end of every run. Following this, complete drainage facilitates CIP and product changeover.

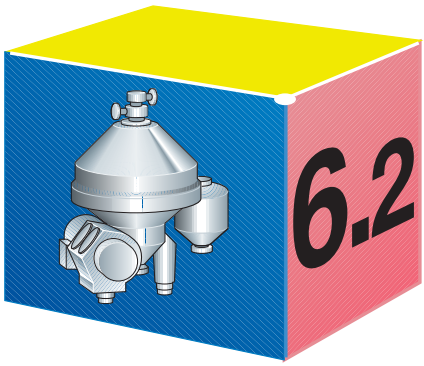
As mentioned above, rotor and blades are exchangeable, an operation which is possible due to the automatic hydraulic lift that facilitates raising and lowering the rotor/blade assembly, (Figure 6.1.24).

Typical products treated in the scraped-surface heat exchanger are jams, sweets, dressings, chocolate and peanut butter. It is also used for fats and oils for crystallisation of margarine and shortenings, etc.

The scraped-surface heat exchanger is also available in versions designed for aseptic processing.

Two or more vertical-type scraped-surface heat exchangers can be linked in series or parallel to give a greater heat transfer surface depending on the processing capacity required.

Centrifugal separators and milk standardisation



Centrifugal separators

Some historical data

A newly invented appliance for separating cream from milk was described in the German trade journal "Milch-Zeitung" dated the 18th of April 1877. This was "a drum which is made to rotate and which, after turning for a time, leaves the cream floating on the surface so that it can be skimmed off in the usual fashion".

After reading this article, a young Swedish engineer, Gustaf de Laval, said, "I will show that centrifugal force will act in Sweden as well as in Germany." The daily newspaper "Stockholms Dagblad" of 15th January 1879 reported: "A centrifugal separator for cream skimming has been on show here since yesterday and will be demonstrated every day between 11 a.m. and 12 noon on the first floor of the house of number 41, Regeringsgatan. The machine can be likened to a drum which is driven round by a belt and pulley. The cream, which is lighter than the milk, is driven by centrifugal force to the surface of the milk and flows off into a channel from which it is led into a collection vessel. Under it, the milk is forced out to the periphery of the drum and is collected in another channel, whence it is led to a separate collecting vessel."

From 1890, the separators built by Gustaf de Laval were equipped with specially-designed conical discs, the patent on which had been granted in 1888 to the German Freiherr von Bechtolsheim and had been acquired in 1889 by the Swedish company AB Separator, of which Gustaf de Laval was part-owner.

Today, most makes of similar machines are equipped with conical disc stacks.

Fig 6.2.2 *One of the very first separators, the Alfa A 1, manufactured from 1882.*

Fig 6.2.1 *Gustaf de Laval, inventor of the first continuously working centrifugal separator.*

Sedimentation by gravity

Historically speaking, the centrifugal separator is a recent invention. Up to a hundred years ago, the technique used for separating one substance from another was the natural process of sedimentation by gravity.

Sedimentation takes place all the time. Clay particles moving in puddles will soon settle, leaving the water clear. Clouds of sand stirred up by waves or by the feet of bathers do the same. Oil that escapes into the sea is lighter than water, rises and forms oil slicks on the surface.

Sedimentation by gravity was also the original technique used in dairying to separate fat from milk. Milk fresh from the cow was left in a vessel. After some time the fat globules aggregated and floated to the surface where they formed a layer of cream on top of the milk. This could then be skimmed off by hand.

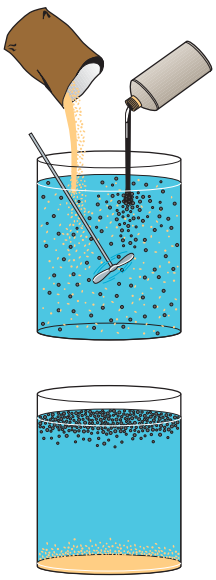


Fig. 6.2.3 *Sand and oil sink and float respectively after mixing with water.*

Requirements for sedimentaion

The liquid to be treated must be a dispersion; a mixture of two or more phases, one of which is continuous. In milk it is the milk serum, or skim milk, that is the continuous phase. Fat is dispersed in the skim milk in the form of globules with variable diameters up to some 15 μm. Milk also contains a third phase, consisting of dispersed solid particles such as udder cells, pulverised straw and hair, etc.

The phases to be separated must not be soluble in each other. Substances in solution cannot be separated by means of sedimentation.

Dissolved lactose cannot be separated by means of centrifugation. It can, however, be crystallised. The lactose crystals can then be separated by sedimentation.

The phases to be separated must also have different densities. The phases in milk satisfy this requirement; the solid impurities have a higher density than skim milk, and the fat globules have a lower density.

Substances in solution cannot be separated by means of sedimentation.

How does sedimentation work?

If a stone is dropped into water, we would be surprised if it did not sink. In the same way, we expect a cork to float. We know by experience that a stone is heavier and a cork is lighter than water.

But what happens if we drop a stone in mercury, a liquid metal with a very high density? Or if we drop a piece of iron into mercury? We have no experience to help us predict the result. We might expect the piece of iron to sink. In actual fact, both the stone and the piece of iron will float.

Density

Every substance has a physical property called density. Density is a measure of how heavy a substance is and can be expressed as kg/m^3. If we weigh a cubic metre of iron, we will find that the scale shows 7 860 kg. The density of iron is 7 860 kg/m^3. The density of water at room temperature is 1 000 kg/m^3 and those of stone (granite), cork and mercury at room temperature are 2 700 kg/m^3, 180 kg/m^3 and 13 550 kg/m^3 respectively.

When an object is dropped into a liquid, it is basically the density of the object, compared with the density of the liquid, that determines whether it will float or sink. If the density of the object is higher than that of the liquid, it will sink, but it will float if the density of the object is lower.

Density is usually denoted by the Greek letter ρ. With a density of a particle ρ_p and the density of the liquid ρ_l, it is possible to form the expression ($\rho_p - \rho$), *i.e.* the difference in density between the particle and the liquid. If we drop a stone into water, the difference in density will be (2 700 – 1 000) = 1 700 kg/m^3. The result is a positive number, as the density of the stone is higher than that of water; the stone sinks!

The expression for cork in water is (180 – 1 000) = – 820 kg/m^3. This time, the result is negative. Because of the low density of a cork, it will float if it is dropped into water; it will move against the direction of the force of gravity.

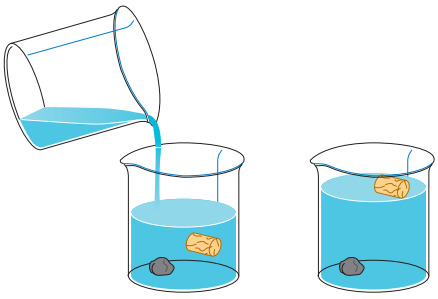


Fig. 6.2.4 *Cork is lighter than water and floats. Stone is heavier than water and sinks.*

Sedimentation and flotation velocity

A solid particle or liquid droplet moving through a viscous fluid medium under the influence of gravity will eventually attain a constant velocity. This is called the *sedimentation velocity*. If the density of the particle is lower than the fluid medium the particle will float at a flotation velocity. These velocities are denoted v_g (g = the force of gravity). The magnitude of the sedimentation/flotation velocity is determined by the following physical quantities:

- Particle diameter d m
- Particle density ρ_p kg/m^3
- Density of the continuous phase ρ_l kg/m^3
- Viscosity of the continuous phase η kg/m,s
- Gravitational attraction of the earth g = 9,81 m/s^2

If the values of these quantities are known, the sedimentation/flotation velocity of the particle or droplet can be calculated by means of the following formula, which is derived from *Stokes' law*:

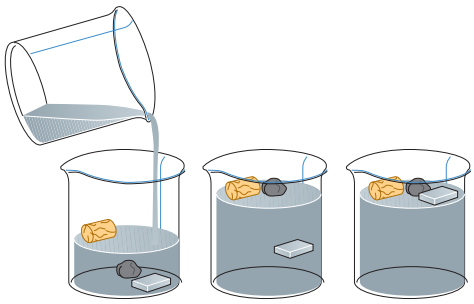


Fig. 6.2.5 *Iron, stone and cork all have lower densities than mercury and will therefore float.*

$$1) \qquad v_g = \frac{d^2\ (\rho_p - \rho_l)}{18\ \eta}\ g$$

The formula above (Equation 1) shows that the sedimentation/flotation velocity of the particle or droplet:

- Increases as the square of the particle diameter; this means that the particle of d = 2 cm will settle/rise four times faster ($2^2 = 4$) than a particle of d = 1 cm.
- Increases with increasing differential density between the phases.
- Increases with diminishing viscosity of the continuous phase.

Flotation velocity of a fat globule

With fresh milk in a vessel, the fat globules will begin to move upwards, towards the surface. The flotation velocity can be calculated with the help of the formula above. The following average values apply at an ambient temperature of about 35 °C:

d = 3 µm = 3 x 10^{-6} m
($\rho_p - \rho_l$) = (980 – 1 028) = – 48 kg/m^3
h = 1,42 cP (centipoise) = 1,42 x 10^{-3} kg/m, s

Substituting these values in the formula:

$$1) \quad v_g = \frac{(3 \times 10^{-6}) \times 48}{18 \times 1{,}42 \times 10^{-3}} \times 9{,}81 = \frac{9 \times 10^{-12} \times 48}{18 \times 1{,}42 \times 10^{-3}} \times 9{,}81 =$$

$$= 0{,}166 \times 9{,}81 = 10^{-6}\ \text{m/s} = 0{,}166^{-3}\ \text{mm/s} = 0{,}597\ \text{mm/h}$$

As indicated above, fat globules rise very slowly. A 3 µm diameter fat globule moves upwards at a flotation velocity of 0,6 mm/h. The velocity of a fat globule which is twice the size will be 2^2 x 0,6 = 2,4 mm/h. In reality, fat globules cluster into larger aggregates and flotation therefore takes place much more rapidly.

Figure 6.2.6 shows schematically how fat globules of different diameters move through the milk serum under the influence of gravity. At zero time, the fat globules are at the bottom of the vessel. After t minutes, a certain amount of sedimentation has taken place, and after 3 t minutes, the largest fat globule has reached the surface. By this time, the medium-sized globule has risen to a point halfway to the surface, but the smallest globule has only covered one quarter of the distance.

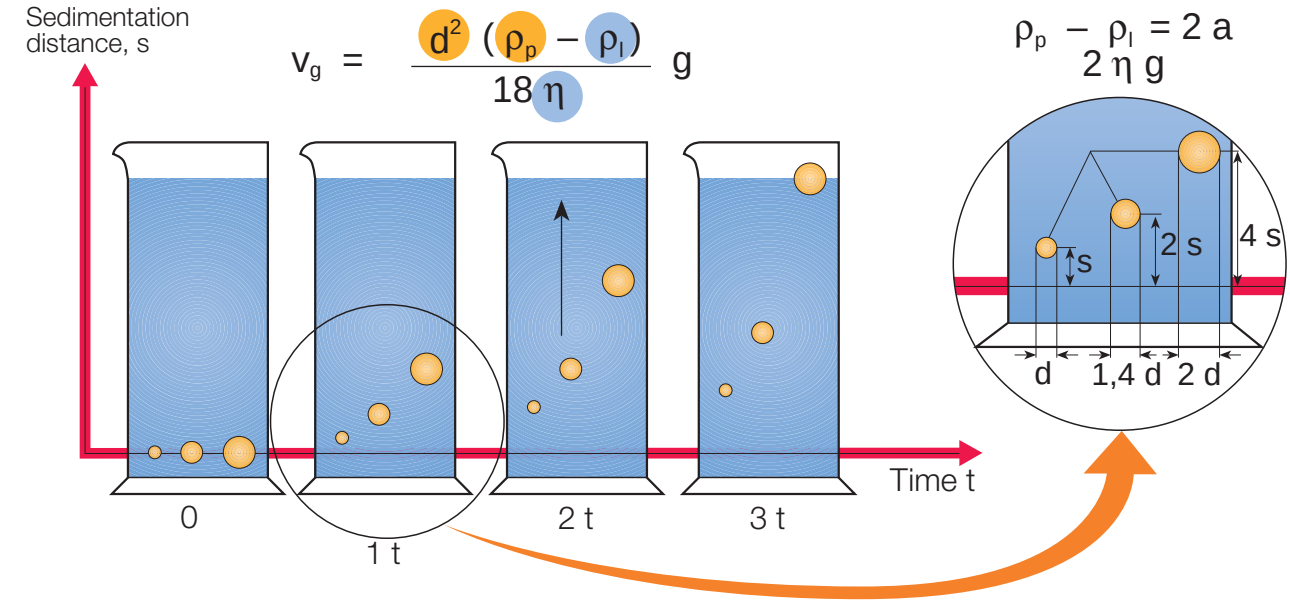


Fig. 6.2.6 *Flotation velocities of fat globules with different diameters.*

The medium-sized globule will reach the surface in 6 t minutes, but the smallest globule will need 12 t minutes to get there.

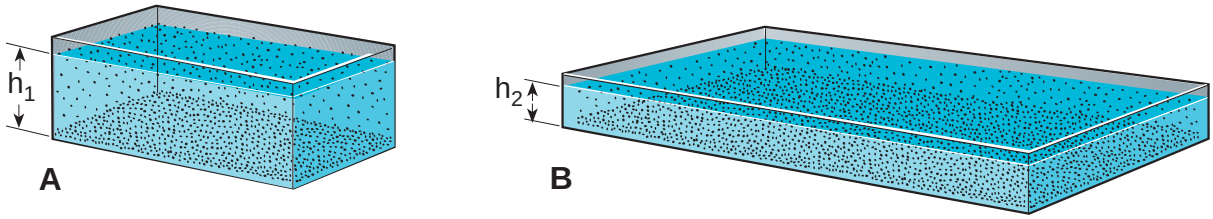


Fig. 6.2.7 *Sedimentation vessels holding the same volume but with different sedimentation distances (h_1 and h_2; $h_1 > h_2$).*

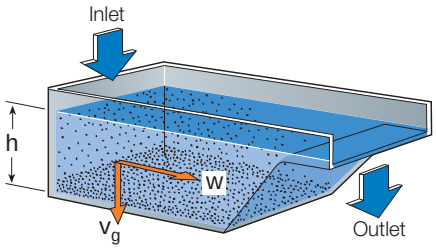


Fig. 6.2.8 *Vessel for continuous separation of solids from a liquid.*

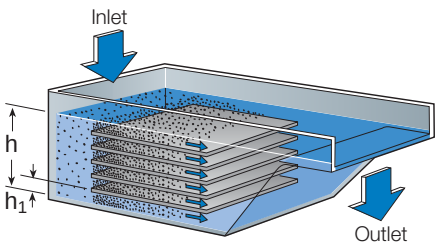


Fig. 6.2.9 *Horizontal baffle plates in the separation vessel increase sedimentation capacity.*

Batch separation by gravity

In the vessel A in Figure 6.2.7, containing a dispersion in which the dispersed phase consists of solid particles with a uniform diameter *d* and a density higher than that of the liquid, the suspension must be left long enough for particles starting from the surface to reach the bottom. The sedimentation distance in this case is h_1 m.

The time to complete separation can be reduced if the sedimentation distance is reduced. The height of the vessel (B) has been reduced and the area increased so that it still has the same volume. The sedimentation distance (h_2) is reduced to 1/5 of h_1 and the time required for complete separation is therefore also reduced to 1/5. However, the more the sedimentation distance and time are reduced, the greater the area of the vessel.

Continuous separation by gravity

A simple vessel which can be used for continuous separation of particles of non-uniform diameter from a liquid is shown in Figure 6.2.8. The liquid containing the slurried particles is introduced at one end of the vessel and flows towards an overflow outlet at the other end at a certain capacity. On the way, the particles settle at different rates, due to their different diameters.

Baffles increase the capacity

The capacity of the sedimentation vessel can be increased if the total area is increased, but this makes it large and unwieldy. It is instead possible to increase the area available for separation by inserting horizontal baffle plates in the vessel, as illustrated in Figure 6.2.9.

There are now a number of “separation channels”, in which sedimentation of particles can proceed at the same rate as in the vessel in Figure 6.2.8. The total capacity of the vessel is multiplied by the number of separation channels. The total area available (*i.e.* the total number of baffle plate areas) for separation, multiplied by the number of separation channels, determines the maximum capacity that can flow through the vessel without loss of efficiency, *i.e.* without allowing any particles, larger than the designated limit size to escape with the clarified liquid.

When a suspension is continuously separated in a vessel with horizontal baffle plates, the separation channels will eventually be blocked by the accumulation of sedimented particles. Separation will then come to a halt.

If the vessel has inclined baffles instead, as in Figure 6.2.10, the particles that settle on the baffles under the influence of gravity will slide down the baffles and collect at the bottom of the vessel.

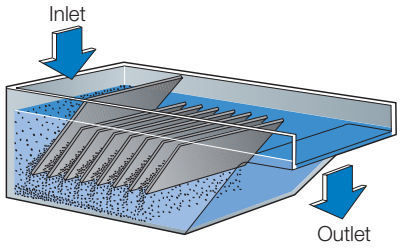


Fig. 6.2.10 *Inclined baffle plates within the sedimentation vessel give laminar flow and allow the particles to slide down.*

Why are particles that have settled on the baffles not swept along by the liquid that flows upwards between the baffles? The explanation is given in Figure 6.2.11, which shows a section through part of a separation channel. As the liquid passes between the baffles, the boundary layer of liquid closest to the baffles is braked by friction so that the velocity drops to zero.

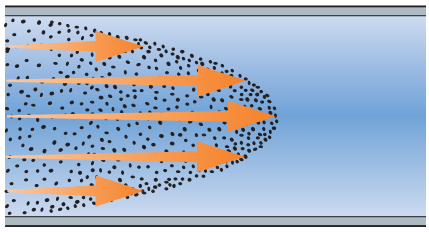


Fig. 6.2.11 *Particle velocities at various points in a separation channel. The length of an arrow corresponds to the velocity of a particle.*

This stationary boundary layer exerts a braking effect on the next layer, and so on, towards the centre of the channel, where the velocity is highest. The velocity profile shown in the figure is obtained – the flow in the channel is laminar. The sedimented particles in the stationary boundary zone are consequently subjected only to the force of gravity.

The projected area is used when the maximum flow through a vessel with inclined baffle plates is calculated.

In order to utilise the capacity of a separation vessel to the full, it is necessary to install a maximum amount of surface area for particles to settle on. The sedimentation distance does not affect the capacity directly, but a certain minimum channel width must be maintained, to avoid blockage of the channels by sedimenting particles.

Continuous separation of a solid phase and two liquid phases

A device similar to the one shown in Figure 6.2.12 can be used for separation of two mixed liquids from each other, by means of gravity, and also for separating slurried solid particles from the mixture at the same time.

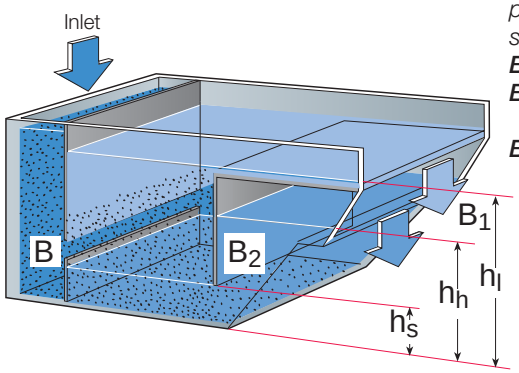


Fig. 6.2.12 *Vessel for continuous separation of two mixed liquid phases and simultaneous sedimentation of solid phases.*
B *Inlet*
B $_1$ *Overflow outlet for the light liquid*
B $_2$ *Baffle preventing the lighter liquid from leaving through the outlet for the heavier liquid*

The dispersion passes downwards from the inlet through the opening B. An interface layer then flows horizontally at the level of B. From this level, the solid particles (which have a higher density than both liquids) settle to the bottom of the vessel. The less dense of the two liquid phases rises toward the surface and runs off over overflow outlet B_1. The denser liquid phase moves downward and passes below baffle B_2, out of the lower outlet. Baffle B_2 prevents the lighter liquid from going in the wrong direction.

Separation by centrifugal force

Sedimentation velocity

A field of centrifugal force is generated if a vessel is filled with liquid and spun, as shown in Figure 6.2.13. This creates a centrifugal acceleration, *a.* The centrifugal acceleration is not constant like the gravity ***g*** in a stationary vessel. The centrifugal acceleration increases with distance from the axis of rotation (radius, r) and with the speed of rotation, expressed as angular velocity ω, (Figure 6.2.14).

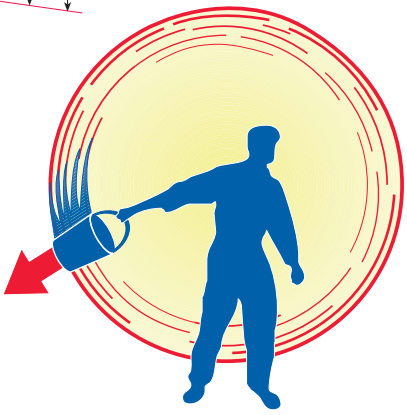


Fig. 6.2.13 *Centrifugal force is generated in a rotating vessel .*

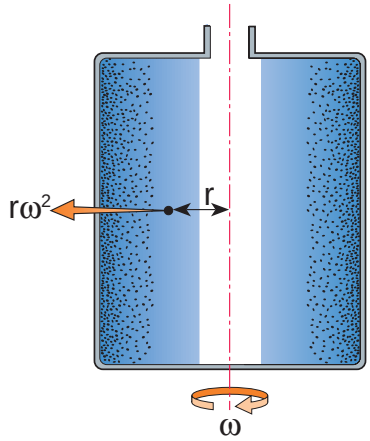


Fig. 6.2.14 *A simple separator*

The acceleration can be calculated by the formula 2).

2) $$a = r\,\omega^2$$

The following formula 3) is obtained if the centrifugal acceleration, ***a,*** expressed as $r\omega^2$, is substituted for the gravitational acceleration, g, in the aforementioned Stokes' law equation 1.

Equation 3) can be used to calculate the sedimentation velocity, ***v***, of each particle in the centrifuge.

3) $$v_c = \frac{d^2\,(\rho_p - \rho_l)}{18\eta}\,r\omega^2$$

Flotation velocity of a fat globule

Equation 1) was previously used and it was found that the flotation velocity of a single fat globule 3 µm in diameter was 0,166 x 10^{-6} m/s or 0,6 mm/h under the influence of gravity.

Equation 3) can now be used to calculate the flotation velocity of a fat globule of the same diameter at a radial position of 0,2 m in a centrifuge rotating at a speed of n = 5 400 rpm.

The angular velocity can be calculated as

$$\omega = \frac{2\,\pi \times n}{60}\ \text{rad/s (radians per second)}$$

giving 2π = one revolution and
n = revolutions per minute (rpm)
with a rotating speed (n) of 5 400 rpm the angular velocity (ω) will be:
ω = 564,49 rad/s

The sedimentation velocity (v) will then be:

$$v = \frac{(3 \times 10^{-6})^2 \times 48}{18 \times 1{,}42 \times 10^{-3}} \times 0{,}2 \times 564{,}49^2 = 0{,}108 \times 10^{-2}\ \text{m/s}$$

i.e. 1,08 mm/s or 3 896,0 mm/h.

Dividing the sedimentation velocity in a centrifugal force field by the sedimentation velocity in a gravity field gives the efficiency of centrifugal separation, compared with sedimentation by gravity. The sedimentation velocity in the centrifuge is 3 896,0/0,6 ≈ 6 500 times faster.

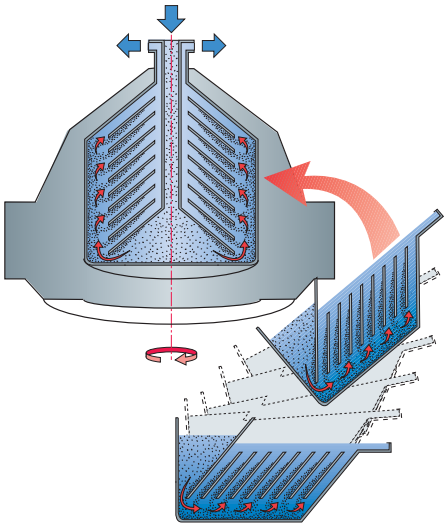


Fig. 6.2.15 *The baffled vessel can be turned 90° and rotated, creating a centrifuge bowl for continuous separation of solid particles from a liquid.*

Continuous centrifugal separation of solid particles – Clarification

Clarification = separation of solid particles from a liquid.

Figure 6.2.15 shows a centrifuge bowl for continuous separation of solid particles from a liquid. This operation is called clarification. Imagine the sedimentation vessel in Figure 6.2.10 turned 90° and spun round the axis of rotation. The result is a sectional view of a centrifugal separator.

Separation channels

Figure 6.2.15 also shows that the centrifuge bowl has baffle inserts in the form of conical discs. This increases the area available for sedimentation. The discs rest on each other and form a unit known as the disc stack.

Radial strips called *caulks* are welded to the discs and keep them the correct distance apart. This forms the separation channels. The thickness of the caulks determines the width.

Figure 6.2.16 shows how the liquid enters the channel at the outer edge (radius r_1), leaves at the inner edge (radius r_2) and continues to the outlet. During passage through the channel, the particles settle outward towards the disc, which forms the upper boundary of the channel.

The velocity w of the liquid is not the same in all parts of the channel. It varies from almost zero, closest to the discs, to a maximum value in the centre of the channel. The centrifugal force acts on all particles, forcing them towards the periphery of the separator at a sedimentation velocity, v. A particle consequently moves simultaneously at velocity w with the liquid, and at sedimentation velocity, v radially towards the periphery.

The resulting velocity, v_p, is the sum of these two motions. The particle moves in the direction indicated by vector arrow v_p. (For the sake of simplicity it is assumed that the particle moves in a straight path as shown by the broken line in the figure.)

In order to be separated, the particle must settle on the upper plate before reaching point B', *i.e.* at a radius equal to or greater than r_2. Once the particle has settled, the liquid velocity at the surface of the disc is so small that the particle is no longer carried along with the liquid. It therefore slides outwards along the underside of the disc under the influence of the centrifugal force, is thrown off the outer edge at B and deposited on the peripheral wall of the centrifuge bowl.

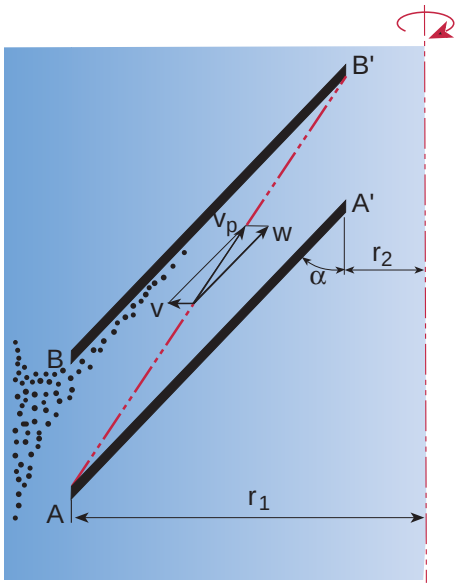


Fig. 6.2.16 *Simplified diagram of a separation channel and how a solid particle moves in the liquid during separation.*

The limit particle

The limit particle is a particle of such a size that if it starts from the least favourable position, *i.e.* point A in Figure 6.2.17, it will only just reach the upper disk at point B'. All particles larger than the limit particle will be separated.

The figure shows that some particles smaller than the limit particle will also be separated if they enter the channel at point C somewhere between A and B. The smaller the particle, the closer C must be to B in order to achieve separation.

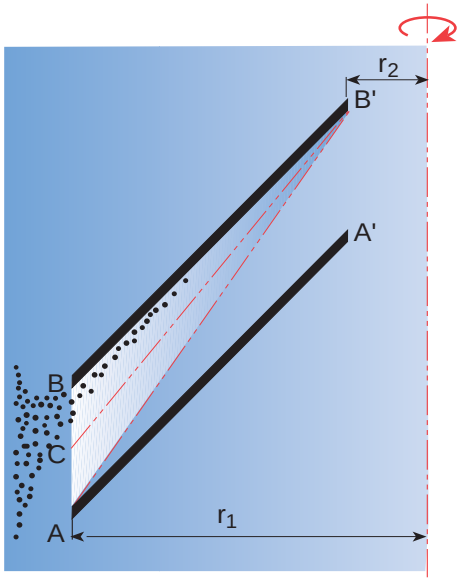


Fig. 6.2.17 *All particles larger than the limit particle will be separated if they are located in the shaded area.*

Continuous centrifugal separation of milk

Clarification

In a centrifugal clarifier, the milk is introduced into the separation channels at the outer edge of the disc stack, flows radially inwards through the channels towards the axis of rotation and leaves through the outlet at the top as illustrated in Figure 6.2.18. On the way through the disc stack, the solid impurities are separated and thrown back along the undersides of the discs to the periphery of the clarifier bowl. There they are collected in the sediment space. As the milk passes along the full radial width of the discs, the time of passage also allows very small particles to be separated. The most typical difference between a centrifugal clarifier and a separator is the design of the disk stack. A clarifier has no distribution holes or open holes at the periphery. The number of outlets also differs – a clarifier has one and a separator has two.

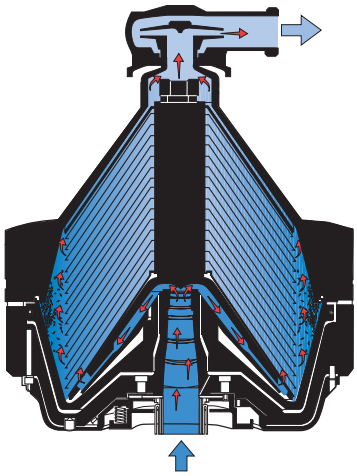


Fig. 6.2.18 *In a centrifugal clarifier bowl, the milk enters the disc stack at the periphery and flows inwards through the channels.*

Separation

In a centrifugal separator, the disc stack is equipped with vertically-aligned distribution holes. Figure 6.2.19 shows schematically how fat globules are separated from the milk in the disc stack of a centrifugal separator. A more detailed illustration of this phenomenon is shown in Figure 6.2.20.

The milk is introduced through vertically-aligned distribution holes in the

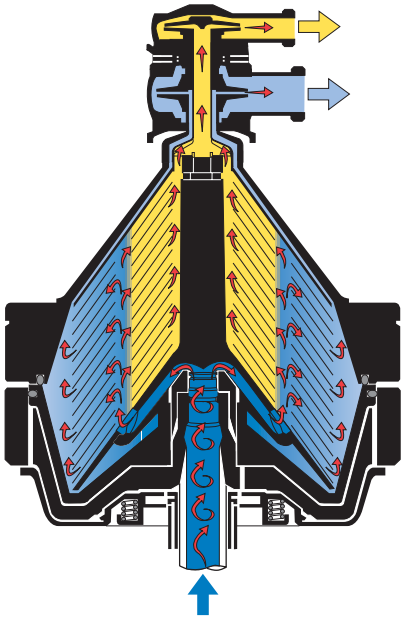


Fig. 6.2.19 *In a centrifugal separator bowl, the milk enters the disc stack through the distribution holes.*

The size of fat globules varies during the cow's lactation period, *i.e.* from parturition to going dry. Large globules tend to predominate just after parturition, while the number of small globules increases towards the end of the lactation period.

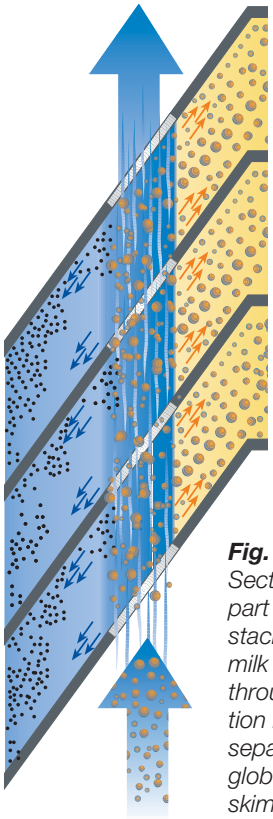


Fig. 6.2.20 *Sectional view of part of the disc stack, showing the milk entering through the distribution holes, and separation of fat globules from the skim milk.*

discs at a certain distance from the edge of the disc stack. Under the influence of centrifugal force, the sediment and fat globules in the milk begin to settle radially outwards or inwards in the separation channels, according to their density relative to that of the continuous medium (skim milk).

As in the clarifier, the *high-density solid impurities* in the milk will quickly *settle outwards* towards the periphery of the separator and collect in the sediment space. Sedimentation of solids is assisted by the fact that the skim milk in the channels in this case moves outwards towards the periphery of the disc stack.

The *cream*, *i.e.* the fat globules, has a *lower density* than the skim milk and therefore *moves inwards* in the channels, towards the axis of rotation. The cream continues to an axial outlet.

The *skim milk moves outwards* to the space outside the disc stack and from there through a channel between the top of the disc stack and the conical hood of the separator bowl to a concentric skim milk outlet.

Skimming efficiency

The amount of fat that can be separated from milk depends on the design of the separator, the rate at which the milk flows through it, and the size distribution of the fat globules.

The smallest fat globules, normally < 1 µm, do not have time to rise at the specified flow rate but are carried out of the separator with the skim milk. The remaining fat content in the skim milk normally lies between 0,04 and 0,07 %, and the skimming ability of the machine is then said to be 0,04 – 0,07.

The flow velocity through the separation channels will be reduced if the flow rate through the machine is reduced. This gives the fat globules more time to rise and be discharged through the cream outlet. The skimming efficiency of a separator consequently increases with reduced throughput and vice versa.

Fat content of cream

The whole milk supplied to the separator is discharged as two flows, skim milk and cream, of which the cream normally represents about 10 % of the total throughput. The proportion discharged as cream determines the fat content of the cream. If the whole milk contains 4 % fat and the throughput is 20 000 l/h, the total amount of *fat* passing through the separator will be

$$\frac{4 \times 20\,000}{100} = 800 \text{ l/h}$$

Assume that cream with a fat content of 40 % is required. This amount of fat must be diluted with a certain amount of skim milk. The total amount of liquid discharged as 40 % cream will then be

$$\frac{800 \times 100}{40} = 2\,000 \text{ l/h}$$

800 l/h is pure fat, and the remaining 1 200 l/h is skim milk.

Installation of throttling valves in the cream and skim milk outlets makes it possible to adjust the relative volumes of the two flows to obtain the required fat content in the cream.

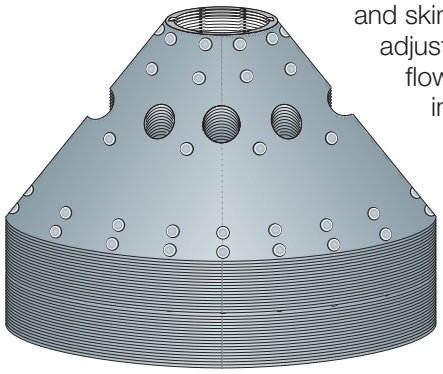


Fig. 6.2.21 *Disc stack with distribution holes and caulks.*

Solids ejection

The solids that collect in the sediment space of the separator bowl consist of straw and hairs, udder cells, white blood corpuscles (leucocytes), red blood corpuscles, bacteria, etc. The total amount of sediment in milk varies but may be about 1 kg/10 000 litres. The sediment space volume varies depending on the size of the separator, typically 10 – 20 litres.

In milk separators of the solids-retaining type it is necessary to dismantle the bowl manually and clean the sediment space at relatively frequent intervals. This involves a great deal of manual labour.

Modern self-cleaning or solids-ejecting separator bowls are equipped for automatic ejection of accumulated sediment at pre-set intervals. This eliminates the need for manual cleaning. The system for solids discharge is described at the end of this chapter under "The discharge system".

Solids ejection is normally carried out at 30- to 60-minute intervals during milk separation.

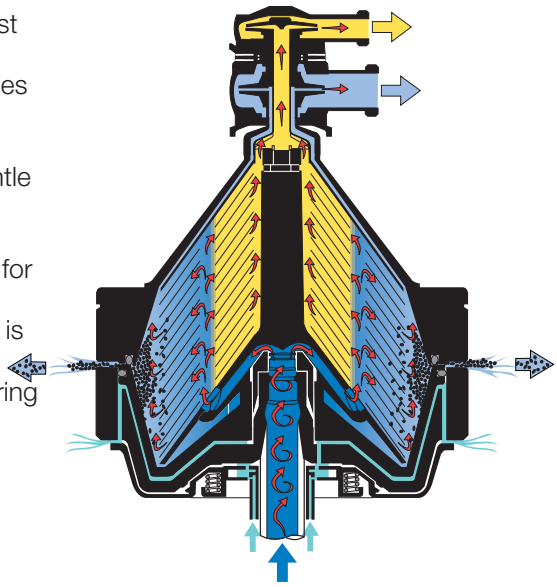


Fig. 6.2.22 *Solids ejection by short opening of the sedimentation space at the periphery of the bowl.*

Basic design of the centrifugal separator

A section through a self-cleaning separator, Figures 6.2.25 and 6.2.26, shows that the bowl consists of two major parts, the body and the hood. They are held together by a threaded lock ring. The disc stack is clamped between the hood and the distributor at the centre of the bowl.

Modern separators are of two types: semi-open and hermetic.

Semi-open design

Centrifugal separators with paring discs at the outlet, (Figure 6.2.23), are known as semi-open types (as opposed to the older open models with overflow discharge).

In the semi-open separator, the milk is supplied to the separator bowl from an inlet, normally in the top, through a stationary axial inlet tube.

When the milk enters the ribbed distributor (4), it is accelerated to the speed of rotation of the bowl, before it continues into the separation channels in the disc stack (3). The centrifugal force throws the milk outwards to form a ring with a cylindrical inner surface. This is in contact with air at atmospheric pressure, which means that the pressure of the milk at the surface is also atmospheric. The pressure increases progressively, with increasing distance from the axis of rotation, to a maximum at the periphery of the bowl.

The heavier solid particles settle outwards and are deposited in the sediment space. Cream moves inwards towards the axis of rotation and passes through channels to the cream paring chamber (2). The skim milk leaves the disc stack at the outer edge and passes between the top disc and the bowl hood to the skim milk paring chamber (1).

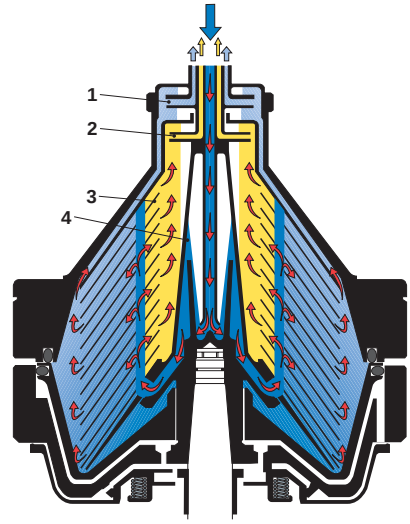


Fig. 6.2.23 *Semi-open (paring disc) self-cleaning separator.*
1 *Skim milk paring chamber*
2 *Cream paring chamber*
3 *Disc stack*
4 *Distributor*

Paring disc

In the semi-open separator, the cream and skim milk outlets have special outlet devices – paring discs, – one of which is shown in Figure 6.2.24. Because of this outlet design, the semi-open separators are usually called – paring-discs – separators.

The rims of the stationary paring discs dip into the rotating columns of liquid, continuously paring out a certain amount. The kinetic energy of the rotating liquid is converted into pressure in the paring disc, and the pressure is always equal to the pressure drop in the downstream line.

An increase in downstream

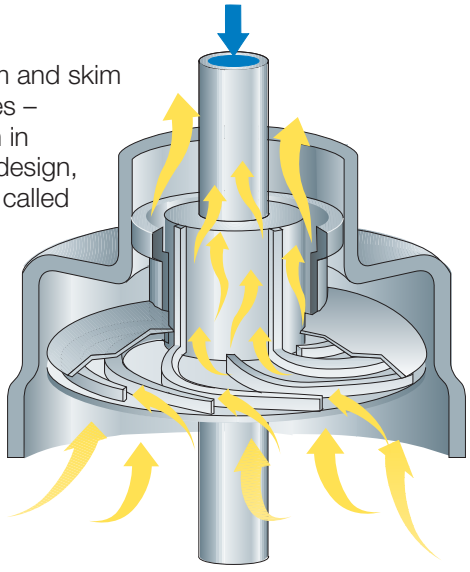


Fig. 6.2.24 *The paring disc outlet at the top of the semi-open bowl.*

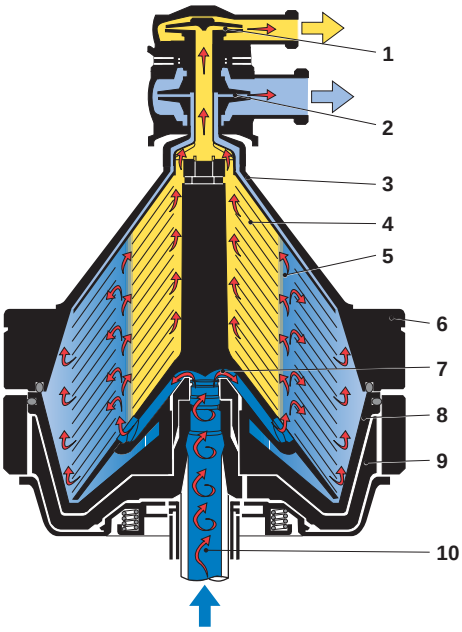


Fig. 6.2.25 *Section through the bowl with outlets of a modern hermetic separator*

1 *Outlet pump cream*
2 *Outlet pump skim milk*
3 *Bowl hood*
4 *Distribution hole*
5 *Disc stack*
6 *Lock ring*
7 *Distributor*
8 *Sliding bowl bottom*
9 *Bowl body*
10 *Hollow bowl spindle*

Fig. 6.2.26 *Sectional view of a modern hermetic separator.*

11 *Frame hood*
12 *Sediment cyclone*
13 *Motor*
14 *Brake*
15 *Gear*
16 *Operating water system*
17 *Hollow bowl spindle*

pressure means that the liquid level in the bowl moves inwards. In this way, the effects of throttling at the outlets are automatically counteracted. In order to prevent aeration of the product, it is important that the paring discs are sufficiently covered with liquid.

Hermetic design

In the hermetic separator, the milk is supplied to the bowl through the bowl spindle. It is accelerated to the same speed of rotation as the bowl and then continues through the distribution holes in the disc stack.

The bowl of a hermetic separator is completely filled with milk during

operation. There is no air in the centre. The hermetic separator can therefore be regarded as part of a closed piping system.

The pressure generated by the external product pump is sufficient to overcome the flow resistance through the separator to the discharge pump at the outlets for cream and skim milk. The diameter of the pump impellers can be engineered to suit the outlet pressure requirements.

Control of the fat content in cream

Paring disc separator

The volume of cream discharged from the paring disc separator is controlled by a throttling valve in the cream outlet. Increasingly larger amounts of cream, with a progressively diminishing fat content, will be discharged from the cream outlet, if the valve is gradually opened.

A given rate of discharge consequently corresponds to a given fat content in the cream. If the fat content of the whole milk is 4% and cream with 40% fat is required, the discharge from the cream outlet must be adjusted to 2 000 l/h (according to the previous calculation). The pressure on the skim milk outlet, (1) in Figure 6.2.27, is set by means of a regulating valve at a certain value, according to the separator and the throughput. The throttling valve (2) in the cream outlet is then adjusted to give the flow volume corresponding to the required fat content.

Any change in the cream discharge will be matched by an equal (and opposite) alteration in the skim milk discharge. An automatic constant pressure unit is fitted in the skim milk outlet to keep the back pressure at the outlet constant, regardless of changes in the rate of cream flow.

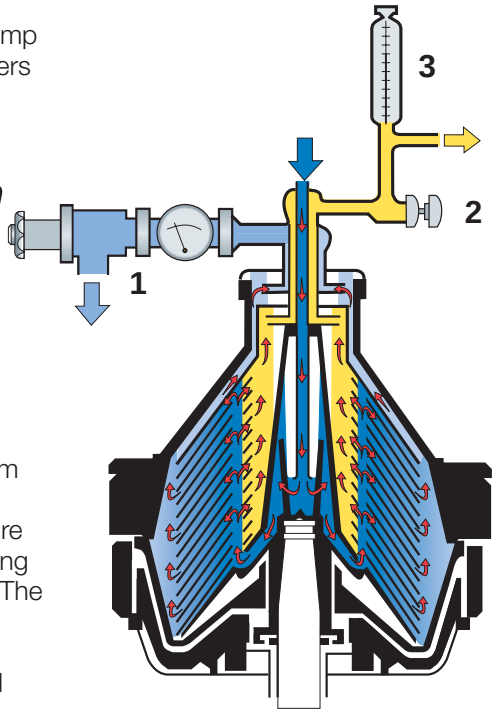


Fig. 6.2.27 *Paring-disc separator with manual control devices in the outlets.*
1 *Skim milk outlet with pressure-regulating valve*
2 *Cream throttling valve*
3 *Cream flow meter*

Cream flow meter

In paring-disc separators, the volume of cream discharged is controlled by a cream valve (2) with a built-in flow meter (3). The size of the valve aperture is adjusted with a screw, and the throttled flow passes through a graduated glass tube. A spool-shaped float, within the tube, is lifted by the cream flow to a position on the graduated scale, varying according to the flow rate and viscosity of the cream.

By analysing the fat content of the incoming whole milk and calculating the volume of the cream flow at the required fat content, it is possible to arrive at a coarse setting of the flow rate and to adjust the throttling screw accordingly. Fine adjustment can be made when the fat content of the cream has been analysed. The operator then knows the float reading when the fat content of the cream is correct.

The fat content of the cream is affected by variations in the fat content of the incoming whole milk and by flow variations in the line. Other types of instruments are used, (*e.g.* automatic in-line systems) to measure the fat content of cream in combination with control systems which keep the fat content at a constant value.

Hermetic separator

An automatic constant pressure unit for a hermetic separator is shown in Figure 6.2.28. The valve shown is a diaphragm valve and the required product pressure is adjusted by means of compressed air above the diaphragm.

During separation, the diaphragm is affected by the constant air pressure above and the product (skim milk) pressure below. The pre-set air pressure will force the diaphragm down if the pressure in the skim milk drops. The valve plug, fixed to the diaphragm, then moves downwards and reduces the passage. This throttling increases the skim milk outlet pressure to the pre-set value. The opposite reaction takes place when there is an increase in the skim milk pressure, and the pre-set pressure is again restored.

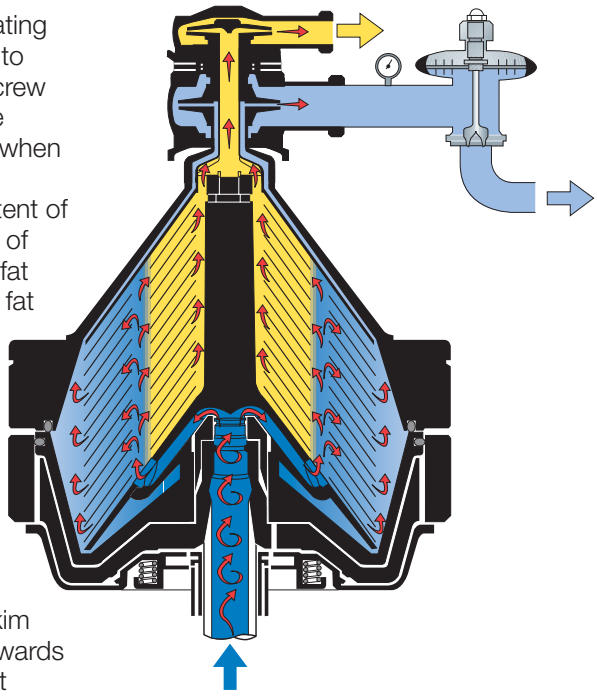
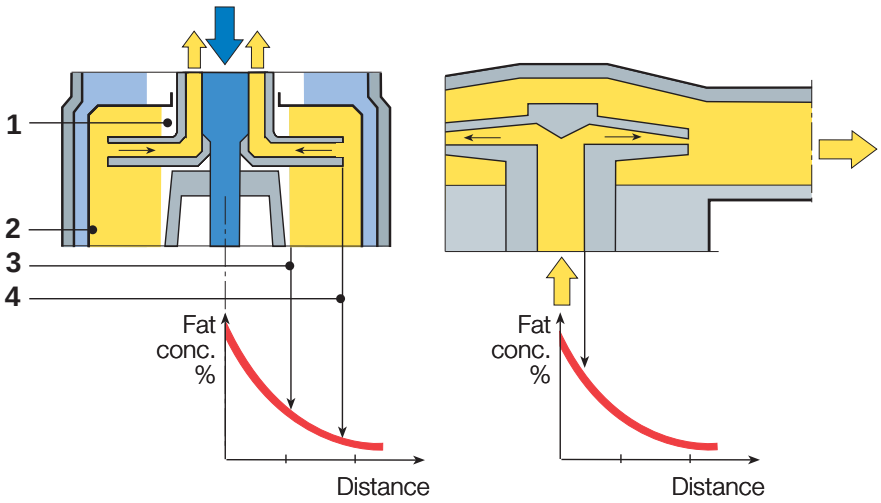


Fig. 6.2.28 *Hermetic separator bowl with an automatic constant pressure unit on the skim milk outlet.*



1 *Air column*
2 *Outer cream level*
3 *Inner cream level*
4 *Level of required cream fat content*

Fig. 6.2.29 *The cream outlet of a paring disc and a hermetic separator and corresponding cream fat concentrations at different distances.*

Differences in outlet performance of hermetic and paring-disc separators

Figure 6.2.29 is a simplified picture of the cream outlets on a paring-disc and a hermetic separator. It also shows an important difference between these two machines. In the paring-disc separator, the outer diameter of the paring disc must penetrate into the rotating liquid column. The distance is determined by the fat content of the cream. The fat content is highest at the inner, free cream level in the separator. From there, the fat content is gradually reduced, as the diameter increases.

An increased fat content in the cream from the separator increases the distance from the inner, free-liquid level of the cream to the outer periphery of the paring disc by the cream level being forced inwards. The fat content at the inner, free-cream level must consequently be considerably higher if, for instance, 40 % cream is to be discharged. The cream must be over-concentrated – to a higher fat content – compared with the cream leaving the separator. This could cause destruction of the fat globules in the innermost zone facing the air column, as a result of increased friction. The outcome will be disruption of fat globules causing sticking problems and increased sensitivity to oxidation and hydrolysis.

Cream from the hermetic separator is removed from the centre, where the fat content is highest. Over-concentration is therefore not necessary.

When removing cream that has a high fat content, the difference in outlet performance is even more important. At 72 %, the fat is concentrated to such an extent that the fat globules are actually touching each other. It would be impossible to obtain cream with higher fat content from a paring-disc separator, as the cream would have to be considerably over-concentrated. The required pressure cannot be created in a paring-disc separator. High pressures can be created in the hermetic separator, which makes it possible to separate cream with a fat content exceeding 72 % globular fat.

The discharge system

Production and CIP

During separation, the inner bottom of the bowl – the sliding bowl bottom – is pressed upwards against a seal ring in the bowl hood by the hydraulic pressure from water beneath it. The position of the sliding bowl bottom is given by the difference in pressure on the top of it, from the product, and on the bottom of it, from the water.

Sediment from the product and the CIP solutions are collected in the sediment space at the periphery of the bowl, until a discharge is triggered.

To clean the larger surfaces in the bowl of bigger centrifuges efficiently, a larger volume of sediment and liquid is discharged during water rinsing in the cleaning cycle.

Discharge

A sediment discharge sequence may be triggered automatically by a pre-set timer, a sensor of some kind in the process, or manually by a push button.

The details in a sediment discharge sequence vary, depending on centrifuge type, but basically a fixed water volume is added to initiate drainage of the balance water. When the water is drained from the space below the sliding bowl bottom, it drops instantly and the sediment can escape at the periphery of the bowl. New balance water is automatically supplied from the service sytem, to close the bowl. The water moves the sliding bowl bottom upwards, to tighten against the seal ring. A sediment discharge has taken place, in tenths of a second.

The centrifuge frame absorbs the energy of the sediment leaving the rotating bowl. The sediment is discharged from the frame by gravity to a vessel, pump or to sewage.

Drive units

In a dairy separator, the bowl is mounted on a vertical spindle, supported by a set of upper and lower bearings. In most centrifuges, the vertical shaft is connected to the motor axis by a worm gear on a horizontal axis, giving an appropriate speed, and a coupling. Various types of friction couplings exist, but friction is inconsistent, so direct couplings with a controlled start sequence are often preferred.

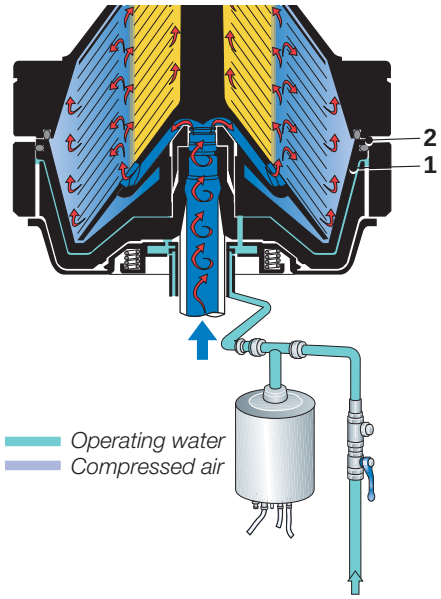


Fig. 6.2.30 *The valve system supplying operating water to a separator guarantees proper discharge performance.*

1 *Sliding-bowl bottom*
2 *Sediment discharge port*

Standardisation of fat and protein

Principle calculation methods for mixing of products

Standardisation involves adjustment of the fat content of milk, or a milk product, by addition of cream or skim milk as appropriate to obtain a given fat content.

Various methods exist for calculating the quantities of products with different fat contents that must be mixed to obtain a given final fat content. These cover mixtures of whole milk with skim milk, cream with whole milk, cream with skim milk and skim milk with anhydrous milk fat (AMF).

One of these methods, frequently used, is taken from the Dictionary of Dairying by J.G. Davis and is illustrated by the following example:

How many kilograms of cream of A % fat must be mixed with skim milk of B % fat to make a mixture containing C % fat? The answer is obtained from a rectangle (Figure 6.2.31) where the given figures for fat contents are placed.

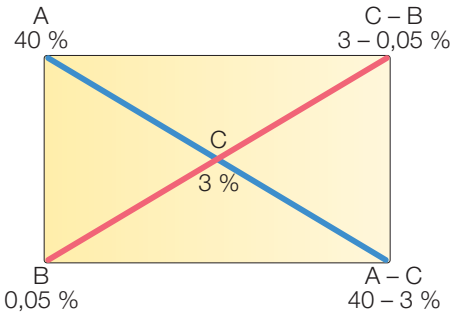


Fig. 6.2.31 *Calculation of the fat content in product C.*

A	Cream fat content, %	40
B	Skim milk fat content, %	0,05
C	Fat content of the end product, %	3

Subtract the fat content values on the diagonals to give C – B = 2,95 and A – C = 37.

The mixture is then 2,95 kg of 40 % cream and 37 kg of 0,05 % skim milk to obtain 39,95 kg of a standardised product containing 3 % fat.

From the equations below, it is then possible to calculate the amounts of A and B needed to obtain the desired quantity (X) of C.

$$1)\ \frac{X \times (C - B)}{(C - B) + (A - C)}\ \text{kg of A and}\qquad 2)\ \frac{X \times (A - C)}{(C - B) + (A - C)}\ \text{kg of B}$$

[also (X – equation 1)]

Principle of standardisation

The cream and skim milk leaving a separator have constant fat contents, if all other relevant parameters remain constant. The principle of standardisation – regardless of whether control is manual or computerised – is illustrated in Figure 6.2.32.

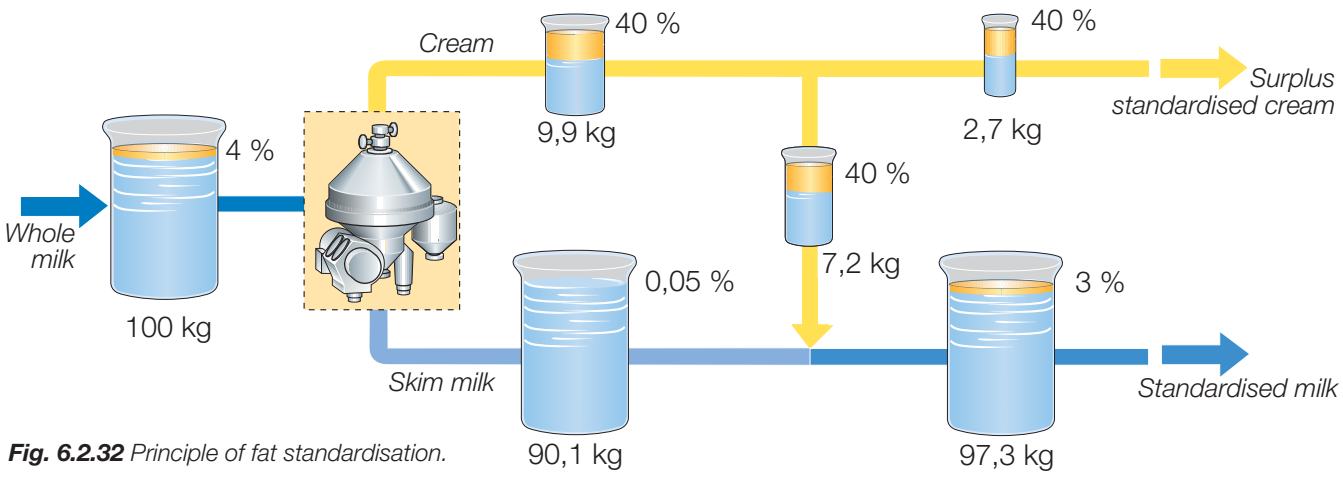


Fig. 6.2.32 *Principle of fat standardisation.*

The figures in the illustration are based on treatment of 100 kg whole milk with 4 % fat. The requirement is to produce an optimal amount of 3 % standardised milk and surplus cream containing 40 % fat.

Separation of 100 kg of whole milk yields 90,35 kg of skim milk with 0,05 % fat and 9,65 kg of cream with 40 % fat.

The amount of 40 % cream that must be added to the skim milk is 7,2 kg. This gives a total of 97,55 kg of 3 % market milk, leaving 9,65 – 7,2 = 2,45 kg surplus 40 % cream.

Direct in-line standardisation

In modern milk processing plants with a diversified product range, direct in-line standardisation is usually combined with separation. Previously, standardisation was done manually, but, along with increased volumes to process, the need for fast, accurate standardisation methods, independent of seasonal fluctuations of the raw milk fat content, has increased. Control valves, flow and density meters and a computerised control loop are used to adjust the fat content of milk and cream to desired values. This equipment is usually assembled in units (Figure 6.2.33).

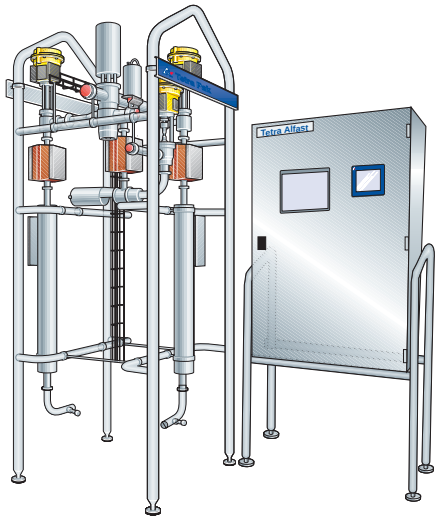


Fig. 6.2.33 *Direct in-line standardisation systems are pre-assembled as a process unit.*

The pressure in the skim milk outlet must be kept constant in order to enable accurate standardisation. This pressure must be maintained, regardless of variations in flow or pressure drop caused by the equipment after separation, and this is done with a constant-pressure valve located close to the skim milk outlet.

For precision in the process, it is necessary to measure variable parameters such as:

- Fluctuations in the fat content of the incoming milk
- Fluctuations in throughput
- Fuctuations in pre-heating temperature

Most of the variables are interdependent; any deviation in one stage of the process often results in deviations in all stages. The cream fat content can be regulated to any value within the performance range of the separator, with a standard deviation based on repeatability of 0,15 % fat. For standardised milk, the standard deviation based on repeatability should be less than 0,02 %.

Usually, whole milk is heated to 55 – 65 °C in the pasteuriser before being separated. Following separation, the cream is standardised to a pre-set fat content. To achieve this, the calculated amount of cream intended for standardisation is routed and remixed with an adequate amount of skim milk. The surplus cream is directed to the cream pasteuriser. The course of events are illustrated in Figure 6.2.34.

Under certain circumstances, it is also possible to apply an in-line standardisation system to a *cold milk centrifugal separator*. However, it is then very important that all fat fractions of the milk fat are given enough time at the low temperature (10 – 12 hours) for complete crystallisation. The

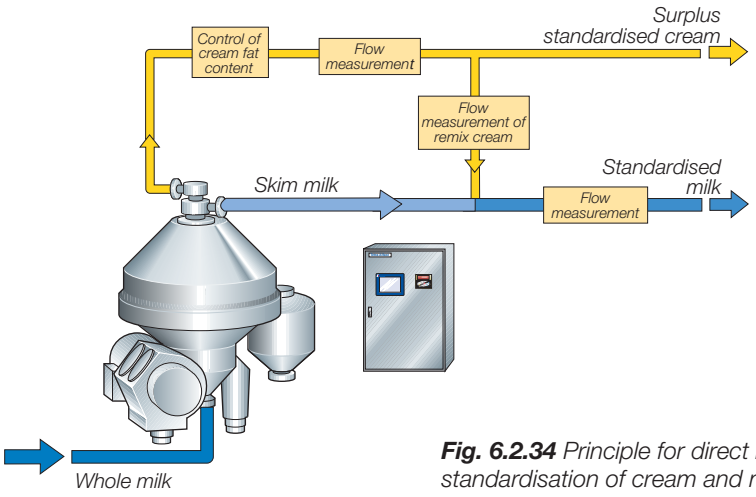


Fig. 6.2.34 *Principle for direct in-line standardisation of cream and milk.*

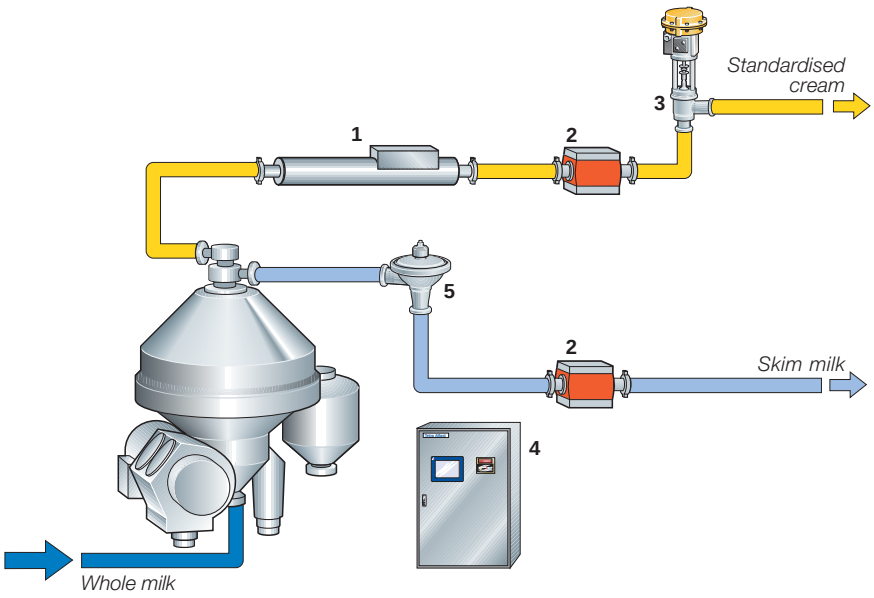


Fig. 6.2.35 *Control loop for keeping a constant cream fat content.*
1 *Density transmitter*
2 *Flow transmitter*
3 *Control valve*
4 *Control panel*
5 *Constant-pressure valve*

reason is that the density will vary with the degree of crystallisation and will thus affect the measuring accuracy of the density transmitter, which is always calibrated after installation.

Cream fat control system

The fat content of the cream in the outlet from the separator is determined by the cream flow rate. The cream fat content is inversely proportional to the flow rate. Some standardisation systems therefore use flow meters to control the fat content. This is the quickest method and – as long as the temperature and fat content in the whole milk before separation are constant – also an accurate method. The fat content will be wrong if these parameters change.

Various types of instruments can be used for continuous measurement of the fat content in cream. The signal from the instrument adjusts the cream flow so that the correct fat content is obtained. This method is accurate and sensitive to variations in the temperature and fat content of the milk. However, the control is slow and it takes a long time for the system to return to the correct fat content when a disturbance has occurred.

There are two transmitters in Figure 6.2.35 measuring the flow of standardised cream and skim milk respectively. With these two flow data, the control system (4) calculates the flow of whole milk to the separator. A density transmitter (1) measures the cream density and converts this value into fat content. Combining fat content and flow rate data, the control system activates the modulating valve (3), to obtain the required cream fat content.

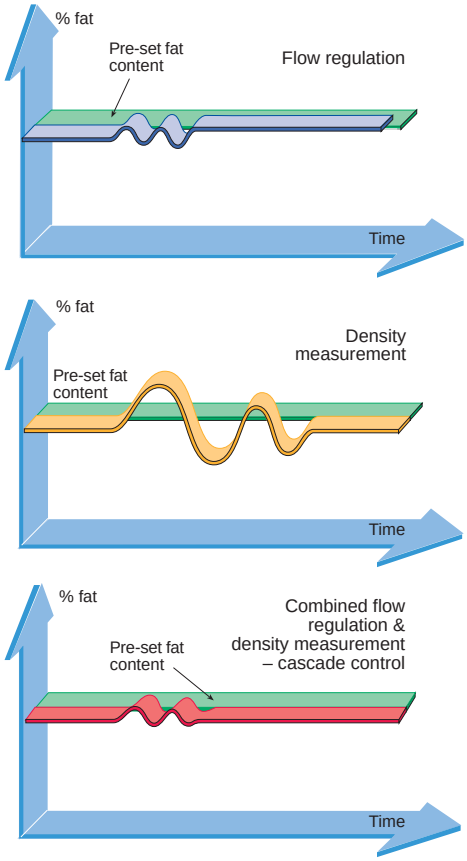


Fig. 6.2.36 *Differences in reaction time between different control systems.*

Cascade control

A combination of accurate measurement of the fat content and rapid flow metering, known as *cascade control*, offers great advantages, as illustrated in Figure 6.2.36.

When disturbances occur, caused for example by the recurrent partial discharges of the self-cleaning centrifuges or changes in the temperature of the cream or the fat content of the incoming milk, the diagram shows that

- The flow control system alone reacts fairly quickly, but the fat content of the cream deviates from the pre-set value after stability is restored
- The density measurement system alone reacts slowly, but the fat content of the cream returns to the pre-set value
- When the two systems are combined in cascade control, a rapid return to the pre-set value is achieved

The cascade control system thus results in fewer product losses and a more accurate result. The computer monitors the fat content of the cream, the flow rate of the cream and the setting of the cream regulating valve.

The density transmitter (See 1 in Figure 6.2.35) in the circuit measures the density of the cream continuously (mass per unit of volume, *e.g.* kg/m^3), which is inversely proportional to the fat content as the fat in cream has a lower density than the milk serum. The density transmitter transmits continuous density readings to the computer in the form of an electric signal. The strength of the signal is proportional to the density of the cream. Increasing density means that there is less fat in the cream and the signal will increase.

Any change in density modifies the signal from the density transmitter to the computer; the measured value will then deviate from the setpoint value which is programmed into the computer. The computer responds by changing the output signal to the regulating valve by an amount corresponding to the deviation between measured and set-point values. The position of the regulating valve changes and restores the density (fat content) to the correct value.

In Figure 6.2.35 the flow transmitter (2) in the control circuit measures the flow in the cream line continuously and transmits a signal to the microcomputer. The transmitters in the control circuit measure the flow and density in the cream line continuously and transmit a signal to the microcomputer.

Cascade control is used to make necessary corrections due to variations in the fat content in the incoming whole milk. Cascade control works by comparing:

- The flow through the flow transmitter, which is proportional to the cream fat content, and
- The density measured by the density transmitter, which is revised according to the cream fat content.

The microcomputer in the control panel (4) then calculates the actual whole milk fat content and alters the control valves to make the necessary adjustments. The standardised milk fat content is recorded continuously.

Fat control by density measurement

Measurement of the cream fat content is based on the fixed relationship which exists between fat content and density. The fat content varies inversely with density because the fat in cream is lighter than the milk serum.

In this context, it is important to remember that the density of cream is also affected by temperature and gas content. Much of the gas, which is the lightest phase in the milk, will follow the cream phase, reducing the density of the cream. It is therefore important that the amount of gas in the milk is kept at a constant level. Milk can contain varying levels of air and gases, but 6 % can be taken as an average figure. More air than that can cause problems such as inaccuracy in volumetric measurement of milk, increased fouling of equipment during heating, etc. More about air in milk is mentioned in Chapter 6.6, *Deaerators*.

The simplest and most common way of doing this is to let the raw milk stand for at least one hour in a tank (silo) before it is processed. Otherwise, a deaerator should be integrated into the plant, ahead of the separator.

The density of the cream is reduced if the separation temperature is increased, and vice versa. To bridge moderate variation of the separation temperature, the density transmitter is also provided with a temperature sensor (Pt 100) for signalling the pre-sent temperature to the control module.

The density transmitter continuously measures the density and temperature of the liquid. Its operating principle can be likened to that of a tuning fork. As the density of product being measured changes, it in turn changes the vibrating mass and thus the resonant frequency. The density value signals are transmitted to a control module.

The density transmitter consists of a single straight tube through which the liquid flows. The tube is vibrated by excitation coils on the outside, which are connected to the instrument casing and thus to the pipeline system, via bellows.

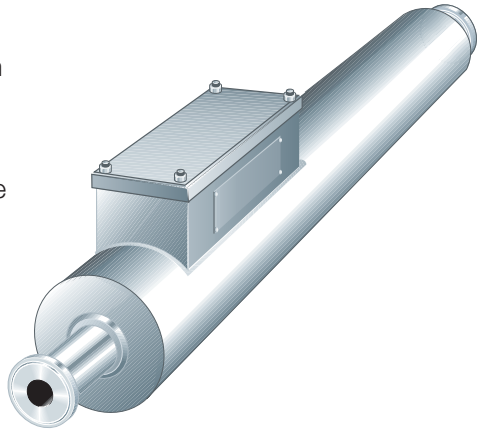


Fig. 6.2.37 *Density transmitter.*

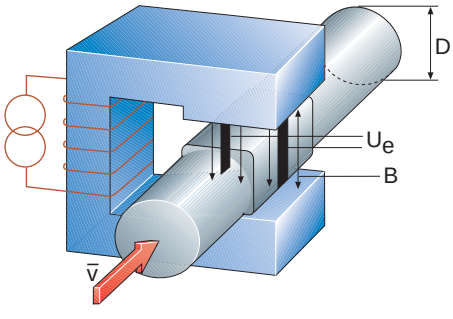


Fig. 6.2.38 *Flow transmitter.*

$U_e = K \times B \times v \times D$

where

U_e *= Electrode voltage*
K *= Instrument constant*
B *= Strength of magnetic field*
$\bar{v}$ *= Average velocity*
D *= Pipe diameter*

The density transmitter is installed as part of the pipeline system and is light enough to require no special structural support.

Flow transmitter

Various types of meters are used for flow control. Electromagnetic meters (Figure 6.2.38) have no moving parts that wear. They are often used, as they require no service and maintenance. There is no difference in accuracy between the meters.

The meter head consists of a metering pipe with two magnetic coils. A magnetic field is produced, at right angles to the metering pipe, when a current is applied to the coils.

An electric voltage is induced and measured by two electrodes mounted in the metering pipe, when a conductive liquid flows through the pipe. This voltage is proportional to the average velocity of the product in the pipe and therefore to the volumetric flow.

The flow transmitter contains a microprocessor, which controls the current transformer that maintains a constant magnetic field. The voltage of the measuring electrodes is transmitted, via an amplifier and signal converter, to the microprocessor in the control panel.

Flow control valves for cream and skim milk

The microcomputer compares the measured value signal from the density transmitter with a pre-set reference signal. As shown in Figure 6.2.35, if the measured value deviates from the pre-set value, the computer modifies the output signal to the control valve in the line after the density transmitter. This resets the valve to a position which alters the cream flow from the separator to correct the fat content.

Control circuit for remixing of cream

The control circuit in Figure 6.2.39 controls the amount of cream to be continuously remixed into the skim milk to obtain the required fat content in the standardised milk. It contains two flow transmitters (2). One is located in the line for the cream to be remixed, and the other in the line for standardised milk, downstream of the remixing point.

The signals from the flow transmitters are conveyed to the micro-computer, which generates a ratio between the two signals. The computer compares the measured value of the ratio with a pre-set reference value and transmits a signal to a regulating valve in the cream line.

Too low fat content in the standardised milk means that too little cream is being remixed. The ratio between the signals from the flow transmitters will therefore be lower than the reference ratio, and the output signal from the computer to the control valve changes. The valve closes, creating a higher pressure drop and a higher pressure which forces more cream through the remixing line. This affects the signal to the computer; the adjustment

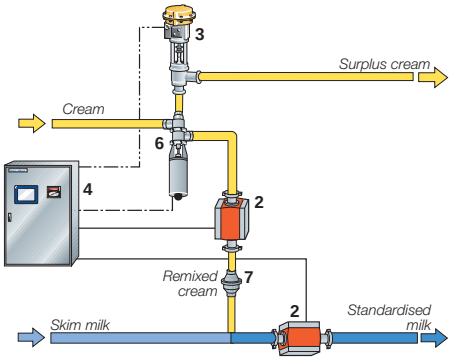


Fig. 6.2.39 *Control circuit for remixing cream into skim milk.*

2 Flow transmitter
3 Control valve
4 Control panel
6 Change-over valve
7 Check valve

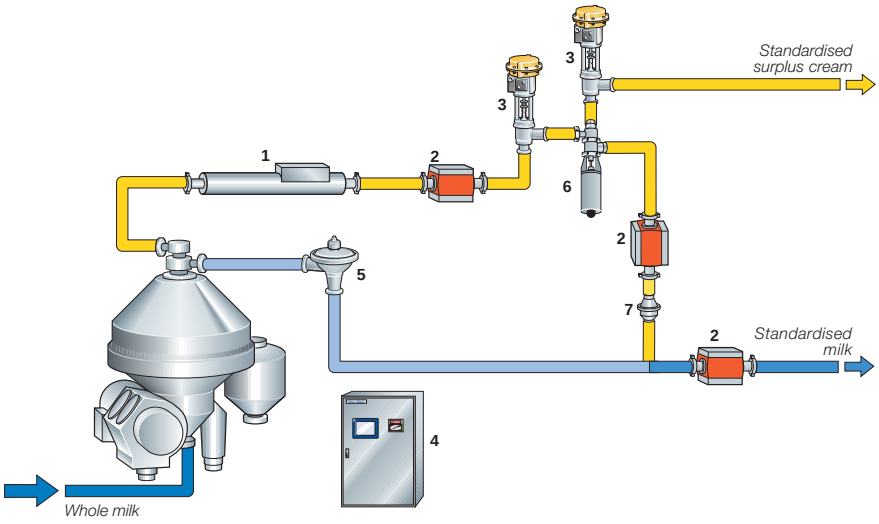


Fig. 6.2.40 *The complete process for automatic, direct standardisation of milk and cream.*

1 Density transmitter
2 Flow transmitter
3 Control valve
4 Control panel
5 Constant-pressure valve
6 Shut-off valve
7 Check valve

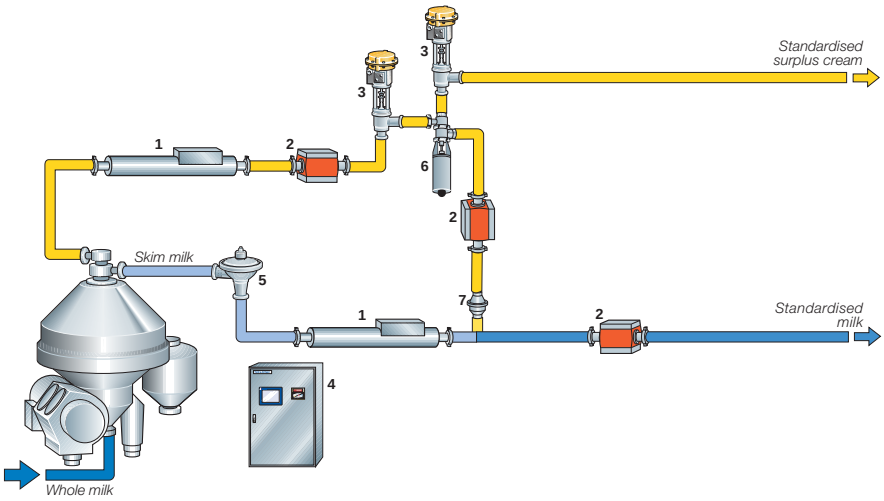


Fig. 6.2.41 *System for standardisation of fat to SNF ratio with an extra density meter in the skim milk line.*

1 *Density transmitter*
2 *Flow transmitter*
3 *Control valve*
4 *Control panel*
5 *Constant-pressure valve*
6 *Change-over valve*
7 *Check valve*

proceeds continuously and ensures that the correct quantity of cream is remixed. The electric output signal from the computer is converted into a pneumatic signal for the pneumatically-controlled valve.

Remixing is based on known constant values of the fat content in the cream and skim milk. The fat content is normally regulated to a constant value between 35 and 40 % and the fat content of the skim milk is determined by the skimming efficiency of the separator.

Accurate density control, combined with constant pressure control at the skim milk outlet, ensures that the necessary conditions for remixing control are satisfied. Cream and skim milk will be mixed in the exact proportions to give the pre-set fat content in the standardised milk, even if the flow rate through the separator changes, or if the fat content of the incoming whole milk varies.

The flow transmitter and the regulating valve in the cream remixing circuit are of the same types as those in the circuit for control of the fat content.

The complete direct standardisation line

The complete direct standardisation line is illustrated in Figure 6.2.40. The pressure control system at the skim milk outlet (5) maintains a constant pressure, regardless of fluctuations in the pressure drop over downstream equipment. The cream-regulating system maintains a constant fat content in the cream discharged from the separator, by adjusting the flow of cream discharged. This adjustment is independent of variations in the throughput or in the fat content of the incoming whole milk. Finally, the ratio controller mixes cream of constant fat content with skim milk in the necessary proportions to give standardised milk of a specified fat content. The standard deviation, based on repeatability, should be less than 0,02 % for milk and 0,15 % for cream.

Some options for fat standardisation

In cheese production, for example, there is sometimes a requirement to standardise fat to SNF. Introducing a second density transmitter, located in the skim milk pipe connected with the separator, satisfies this requirement. This arrangement is illustrated in Figure 6.2.41, where the density transmitters serve two functions:

1 To increase the accuracy of fat standardisation
2 The density value is the base for the calculation of the SNF content

The control system converts the density of the skim milk into SNF content, a value which is then used to control the ratio of fat to SNF.

If, on the other hand, the fat content of the incoming milk is *lower* than the content specified for the standardised milk, a calculated volume of skim milk is leaked from the stream leaving the separator, and the remaining volume is mixed with the cream.

Note that the warm surplus skim milk must be collected, cooled and pasteurised as soon as possible.

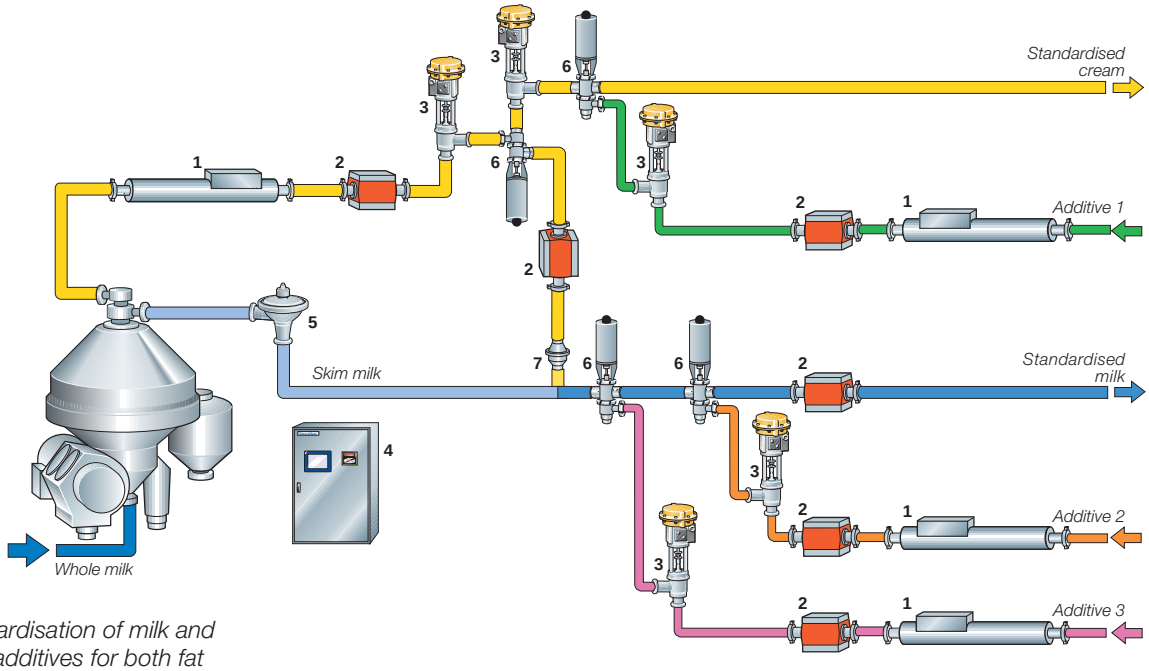


Fig. 6.2.42 *Standardisation of milk and cream with three additives for both fat and protein standardisation.*

1 *Density transmitter*
2 *Flow transmitter*
3 *Control valve*
4 *Control panel*
5 *Constant-pressure valve*
6 *Change-over valve*
7 *Check valve*

Protein standardisation

It is also possible to connect a protein sensor to analyse the actual protein content in the standardised milk. With this option, it is possible to standardise with a fat to protein ratio. By combining this sensor with an extra additive with a protein concentrate, it is possible to standardise both the fat and the protein content at the same time.

For production of cheese milk this installation is a fully automatic process to achieve the correct fat to protein ratio. In order to have the flexibility to produce high and low fat cheeses with different protein content, it is possible to connect three independent additive lines to the standardised milk pipe. This arrangement is illustrated in Figure 6.2.42.

Additives

Other options are also possible, such as addition of cream and whey cream, which is sometimes needed in standardisation of milk intended for cheese making. The fat content of the cream additive can be measured automatically with a density meter. In order to utilise the cream obtained from separation of whey, a corresponding volume of ordinary cream is “bled” off. This arrangement allows cream of better quality to be utilised for production of quality butter and various types of cream, such as whipping cream. This arrangement is illustrated in Figure 6.2.42.

The Bactofuge®

Bactofugation is a process in which a specially designed centrifuge called a Bactofuge is used to separate micro-organisms from milk.

Originally, the Bactofuge was developed to improve the keeping quality of market milk. However, until recently the Bactofuge has mainly been used as a complement to pasteurisation or thermisation on cheese milk. It has also been used on milk for milk powder and whey for baby food. Lately, a renewed interest has been seen for bactofugation of market milk in order to meet the supermarket demands for a few days longer shelf life.

Bacteria, especially heat-resistant spores, have a significantly higher density than the milk. A Bactofuge is therefore a particularly efficient means of ridding milk of bacteria spores. Since these spores are also resistant to heat treatment, the Bactofuge makes a useful complement to thermisation, pasteurisation and sterilisation.

The original Bactofuge was a solid bowl centrifuge, with nozzles in the periphery of the bowl. It was long considered necessary to have a continuous flow of the heavy phase, either through a peripheral nozzle or over the heavy phase outlet of the Bactofuge, to achieve efficient separation. This was possibly true of the old solid-bowl centrifuges with vertical cylindrical walls, but in modern self-cleaning separators with a sludge space outside the disc stack, bacteria and spores can be collected over a period of time and intermittently discharged at pre-set intervals.

There are two types of modern Bactofuge:

- The *two-phase Bactofuge* has two outlets at the top: one for continuous discharge of bacteria concentrate (bactofugate) via a special top disc, and one for the bacteria-reduced phase. Figure 6.2.43.
- The *one-phase Bactofuge* has only one outlet at the top of the bowl for the bacteria-reduced milk. The bactofugate is collected in the sludge space of the bowl and discharged at pre-set intervals. Figure 6.2.44.

The amount of bactofugate from the two-phase Bactofuge is about 3 % of the feed, while the corresponding amount from the one-phase Bactofuge can be as low as 0,15 % of the feed.

Bactofugate always has a higher dry matter content than the milk from which it originates. This is because some of the larger casein micelles are separated out together with the bacteria and spores. Higher bactofugation temperature increases the amount of protein in the bactofugate. The optimal bactofugation temperature range is 55 to 60 °C.

The reduction effect on bacteria is expressed as a percentage.

Bacteria belonging to the genus Clostridium – anaerobic spore-forming bacteria – are among the most feared by cheesemakers, as they can cause late blowing of cheese, even if present in small numbers. This is why cheese milk is bactofugated.

The arrangements for integration of bactofugation into a cheese milk pasteurisation plant are discussed in Chapter 14, *Cheese*.

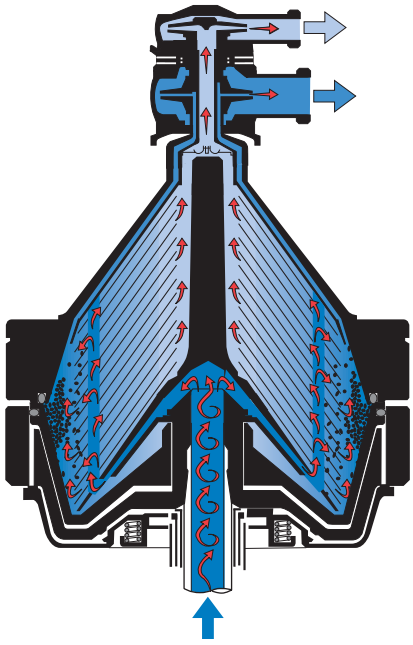


Fig. 6.2.43 *Bowl of two-phase Bactofuge for continuous discharge of bactofugate.*

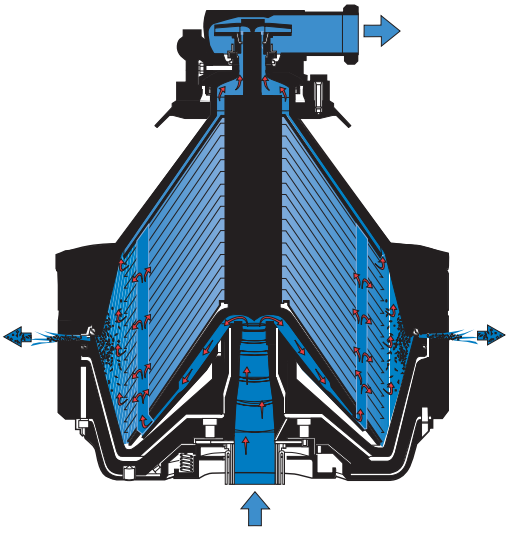


Fig. 6.2.44 *Bowl of one-phase Bactofuge for intermittent discharge of bactofugate.*

Decanter centrifuges

Centrifuges are used in the dairy industry to harvest special products like precipitated casein and crystallised lactose. The previously described disc-bowl centrifugal clarifiers, however, are not suitable for these duties due to the high solids content of the feed.

The types most often used are sanitary basket centrifuges and decanter centrifuges (Figure 6.2.45). Decanters, which operate continuously, have many applications. They are also used, for example, in plants producing soya milk from soybeans, and specially adapted models are widely used to dewater sludge in waste water treatment plants.

A decanter centrifuge is a machine for continuous sedimentation of suspended solids from a liquid by the action of centrifugal force in an elongated rotating bowl. The characteristic which distinguishes the decanter from other types of centrifuge is that it is equipped with an axial screw

conveyor for continuous unloading of separated solids from the rotor. The conveyor rotates in the same direction as the bowl, but at a slightly different speed to give a "scrolling" effect. Other characteristic features of the decanter include:

1 A slender conocylindrical bowl rotating about a horizontal axis,
2 Countercurrent flow, with solids discharge from the narrow end and discharge of liquid phase from the wide end.

A decanter centrifuge is a machine for continuous sedimentation of suspended solids from a liquid, by the action of centrifugal force in an elongated, horizontal rotating bowl.

The function of the decanter centrifuge

The feed suspension is introduced through an inlet tube to the feed zone of the conveyor, where it is accelerated and directed into the interior of the spinning rotor (Figure 6.2.46).

The solids, which must have a higher specific gravity than the liquid, settle out at the inner wall of the bowl almost instantaneously, due to the intense centrifugal acceleration – normally in the range of 2 000 – 4 000 g – leaving a clear inner ring of liquid.

Solids discharge

The compact solids phase is transported axially towards the narrow end of the rotor by means of the screw conveyor, which is geared to turn at a slightly different speed than the bowl. On the way to the discharge ports, the solids are lifted out of the liquid pool by the flights of the screw conveyor up along the dry beach. On the beach, more liquid drains off and flows back into the pool. The dry solids are then finally discharged from the bowl through the discharge ports into the collecting chamber of the vessel that surrounds the rotor. From there, they are removed by gravity from the machine through an outlet funnel.

Liquid discharge (open)

The liquid phase, forming a hollow cylinder due to the centrifugal force, flows in a helical channel between the flights of the conveyor towards the large end of the rotor. There the liquid overflows radially-adjustable weirs into the centre chamber of the collecting vessel and is discharged by gravity.

Liquid discharge (pressurised)

Some decanter centrifuges are equipped for pressurised discharge of the liquid phase by a paring disc (4) in Figure 6.2.46. The liquid overflowing the weirs enters a paring chamber where it once more forms a hollow rotating cylinder. The channels in the stationary paring disc are immersed in the rotating liquid, which causes a pressure differential. The liquid travels down the channels, converting the energy of rotation into a pressure head, sufficient to pump the liquid out of the machine and to succeeding processing steps.

Continuous process

In a decanter centrifuge, the three stages of the process – inflow, sedimentation into concentric layers and separate removal of the liquid and solid phases – proceed in a fully continuous flow.

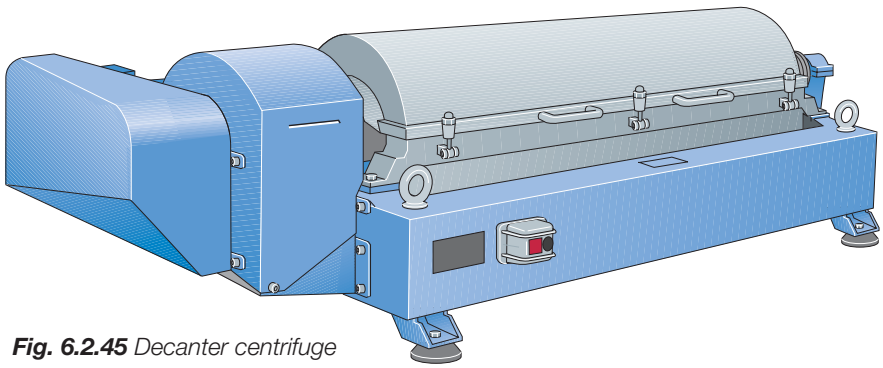


Fig. 6.2.45 *Decanter centrifuge*

Principal components

The principal components of a decanter centrifuge are the bowl, conveyor and gearbox (together comprising the rotor) and the frame, with hood, collecting vessels, drive motor and belt transmission.

The bowl

The bowl normally consists of a conical section and one or more cylindrical sections flanged together. The cylindrical part provides the liquid pool and the conical part the dry beach.

The shell sections are usually ribbed or grooved on the inside to prevent the solids from sideslipping as the conveyor rotates.

The conical section terminates in a cylindrical stub with one or two rows of solid discharge ports depending on machine type. These ports are, in most cases, lined with replaceable bushings of stellite or ceramic material, to prevent abrasion.

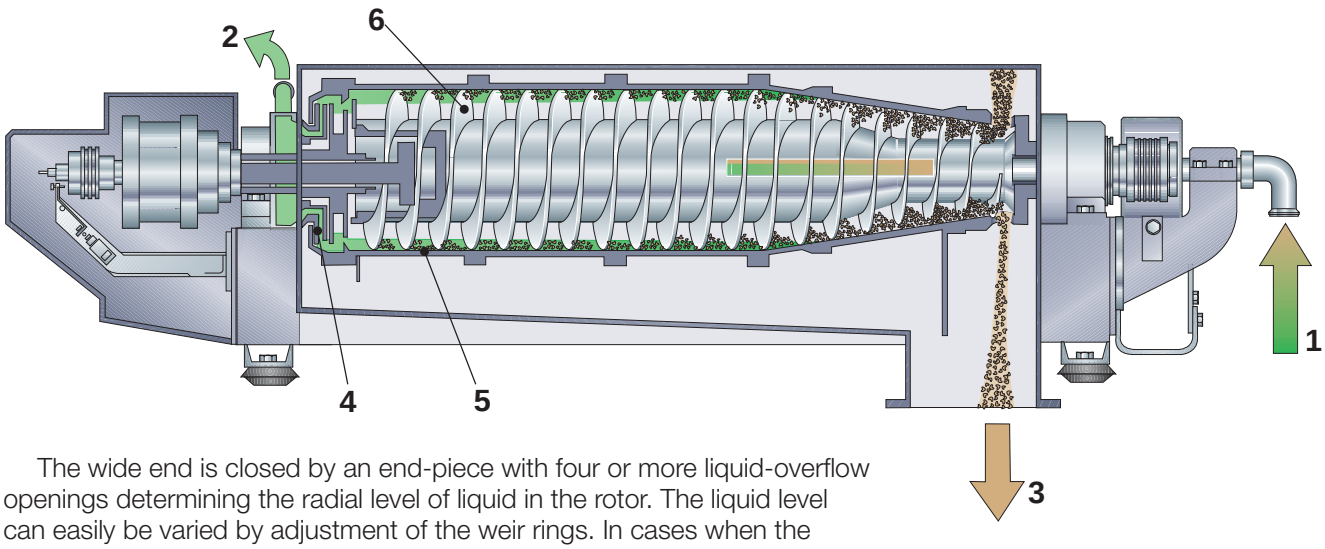


Fig 6.2.46 *Section through the rotor of a decanter centrifuge with pressurised discharge.*

1 *Feed suspension*
2 *Liquid phase discharge*
3 *Solid phase discharge (by gravity)*
4 *Paring chamber and disc*
5 *Bowl*
6 *Screw conveyor*

The wide end is closed by an end-piece with four or more liquid-overflow openings determining the radial level of liquid in the rotor. The liquid level can easily be varied by adjustment of the weir rings. In cases when the clarified liquid phase discharge is by means of a paring disc (4), the adjustable weirs lead into the paring chamber.

The rotor is driven by an electric motor via V-belts and pulleys.

The conveyor

The conveyor is suspended in the bowl on bearings and rotates slowly or fast relative to the bowl, pushing the sediment towards the sludge ports at the narrow end. The configuration of the conveyor screw flights varies according to application: the pitch (spacing between flights) may be coarse or fine, and the flights may be perpendicular to the axis of rotation or perpendicular to the conical part of the bowl mantle. Most models are equipped with single-flight conveyors, but some have double flights.

The gearbox

The function of the gearbox is to generate the scrolling effect, *i.e.* the difference in speed between bowl and conveyor. It is fitted to the hollow shaft of the bowl and drives the conveyor through a coaxial spline shaft.

An extension of the sunwheel shaft, *i.e.* the central shaft of the gearbox, projects from the end opposite the bowl. This shaft can be driven by an auxiliary motor, enabling the conveyor speed to be varied, relative to the speed of the bowl.

The gearbox may be of planetary or cyclo type; the former produces a negative scrolling speed (conveyor rotates slower than bowl), while the latter, equipped with an eccentric shaft, gives a positive scrolling speed.

Frame and vessel

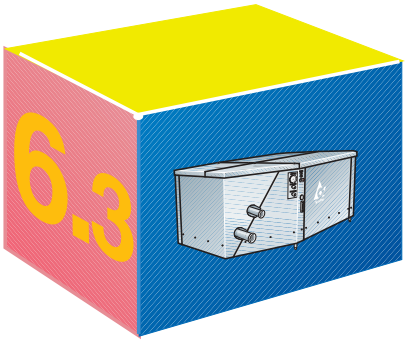
There are various designs of frame and vessel, but in principle, the frame is

a rigid mild steel structure carrying the rotor parts and resting on vibration insulators.

The vessel is a welded stainless steel structure with a hinged hood which encloses the bowl. It is divided into compartments for collection and discharge of the separated liquid and solid phases.

Liquid may be discharged by gravity or under pressure by a paring disc. (4) in Figure 6.2.46. Solids are discharged by gravity, assisted by a vibrator if necessary, into a collecting vessel or onto a conveyor belt. for onward transport.

Homogenisers



The technology behind disruption of fat globules

Homogenisation has become a standard industrial process, universally practised as a means of stabilising the fat emulsion against gravity separation. Gaulin, who invented the process in 1899, described it in French as “fixer la composition des liquides”.

Homogenisation primarily causes disruption of fat globules into much smaller ones (Figure 6.3.1). Consequently, it diminishes creaming and may also diminish the tendency of globules to clump or coalesce. Essentially, all homogenised milk is produced by mechanical means. Milk is forced through a small passage at high velocity.

The disintegration of the original fat globules is achieved by a combination of contributing factors such as turbulence and cavitation. The homogenisation reduces fat globule size from an average of 3,5 µm in diameter to below 1 µm. This is accompanied by a four- to six-fold increase in the fat/plasma interfacial surface area. The newly created fat globules are no longer completely covered with the original membrane material. Instead, they are surfaced with a mixture of proteins adsorbed from the plasma phase.

Fox et al.[1)] studied a fat-protein complex produced by the homogenisation of milk. They showed that casein was the protein half of the complex and that it was probably associated with the fat fraction through polar bonding forces. They postulated further that the casein micelle was activated at the moment it passed through the valve of the homogeniser, predisposing it to interaction with the lipid phase.

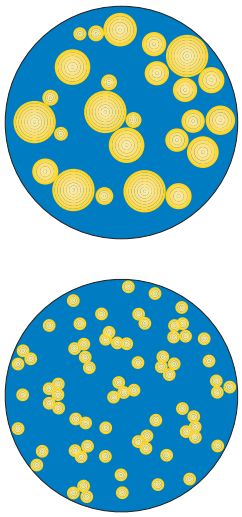


Fig. 6.3.1 *Homogenisation causes disruption of fat globules into much smaller ones.*

Process requirements

The physical state and concentration of the fat phase at the time of homogenisation contribute materially to the size and dispersion of the ensuing fat globules.

Homogenisation of cold milk, in which the fat is essentially solidified, is virtually ineffective. Processing at temperatures conducive to the partial solidification of milk fat (*i.e.* below 40 °C) results in incomplete dispersion of the fat phase.

Products of high fat content are more difficult to homogenise and also more likely to show evidence of fat clumping, because the concentration of serum proteins is low in relation to the fat content. Usually, cream with higher fat content than 20 % cannot be homogenised at high pressure, because clusters are formed as a result of lack of membrane material (casein). Increasing the homogenisation temperature decreases the visocity of milk and improves the transport of membrane material to the fat globules.

Homogenisation temperatures normally applied are 55 – 80 °C, and homogenisation pressure is between 10 and 25 MPa (100 – 250 bar), depending on the product.

1) Fox, K.K., Holsinger, Virginia, Caha, Jeanne and Pallasch, M.J., J. Dairy Sci, 43, 1396 (1960).

Flow characteristics

When the liquid passes the narrow gap, the flow velocity increases (Figure 6.3.2). The speed will increase until the static pressure is so low that the liquid starts to boil. The maximum speed depends mainly on the inlet (homogenisation) pressure. When the liquid leaves the gap, the speed decreases and the pressure increases again. The liquid stops boiling and the steam bubbles implode.

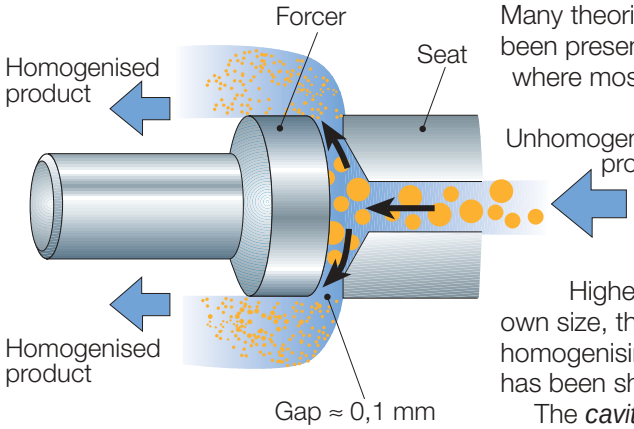


Fig. 6.3.2 *At homogenisation, the milk is forced through a narrow gap where the fat globules are split.*

Homogenisation theories

Many theories of the mechanism of high pressure homogenisation have been presented over the years. For an oil-in-water dispersion like milk, where most of the droplets are less than one µm (10^{-6} m) in diameter, two theories have survived. Together, they give a good explanation of the influence of different parameters on the homogenising effect.

The theory of globule disruption by ***turbulent eddies*** ("micro whirls") is based on the fact that a lot of small eddies are created in a liquid travelling at a high velocity. Higher velocity gives smaller eddies. If an eddy hits an oil droplet of its own size, the droplet will break up. This theory predicts how the homogenising effect varies with the homogenising pressure. This relation has been shown in many investigations.

The ***cavitation*** theory, on the other hand, claims that the shock waves created when the steam bubbles implode disrupt the fat droplets. According to this theory, homogenisation takes place when the liquid is leaving the gap, so the back pressure which is important to control the cavitation is important to homogenisation. This has also been shown in practice. However, it is possible to homogenise without cavitation, but it is less efficient.

Single-stage and two-stage homogenisation

Homogenisers may be equipped with one homogenising device or two connected in series, hence the names single-stage homogenisation and two-stage homogenisation. The two-stage system is illustrated in Figure 6.3.5.

In both single-stage homogenisation and two-stage homogenisation, the whole homogenisation pressure (P_1) is used over the first device. In single-stage homogenisation, the back pressure (P_2) is created by the process. In two-stage homogenisation the back pressure (P_2) is created by the second stage. In this case the back pressure can be chosen to achieve optimal homogenisation efficiency. Using modern devices, the best results are obtained when the relation P_2/P_1 is about 0,2. The second stage also reduces noise and vibrations in the outlet pipe.

Single-stage homogenisation may be used for homogenisation of products with high fat content demanding a high viscosity (certain cluster formation).

Two-stage homogenisation is used primarily to reach optimal homogenisation results and to break up fat clusters in products with a high fat content. The formation and break-up of clusters in the second stage is illustrated in Figure 6.3.3.

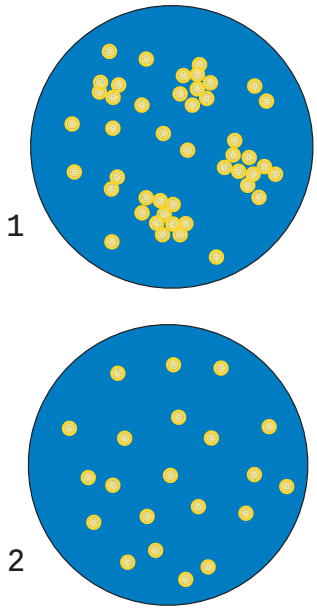


Fig. 6.3.3 *Disruption of fat globules in first and second stages of homogenisation.*
1 After first stage
2 After second stage

Effect of homogenisation

The effect of homogenisation on the physical structure of milk has many advantages:

- Smaller fat globules leading to less cream-line formation
- Whiter and more appetizing colour
- Reduced sensitivity to fat oxidation
- More full-bodied flavour, and better mouthfeel
- Better stability of cultured milk products

However, homogenisation also has certain disadvantages:

- Somewhat increased sensitivity to light – sunlight and fluorescent tubes – can result in "sunlight flavour" (see also Chapter 8, *Pasteurised milk products*).
- The milk might be less suitable for production of semi-hard or hard cheeses because the coagulum will be too soft and difficult to dewater.

The homogeniser

A high-pressure homogeniser is a pump with a homogenisation device. A homogeniser is generally needed when high-efficiency homogenisation is required.

The product enters the pump block and is pressurised by the piston pump. The pressure that is achieved is determined by the back-pressure given by the distance between the forcer and seat in the homogenisation device. This pressure P_1 (Figure 6.3.8) is always designated the homogenisation pressure. P_2 is the back-pressure to the first stage.

The high-pressure pump

In Figure 6.3.4, the piston pump is driven by a powerful electric motor (1), via belts (2) and pulleys through a gearbox (3) to the crankshaft (10) and connecting-rod transmission, which converts the rotary motion of the motor to the reciprocating motion of the pump pistons (9).

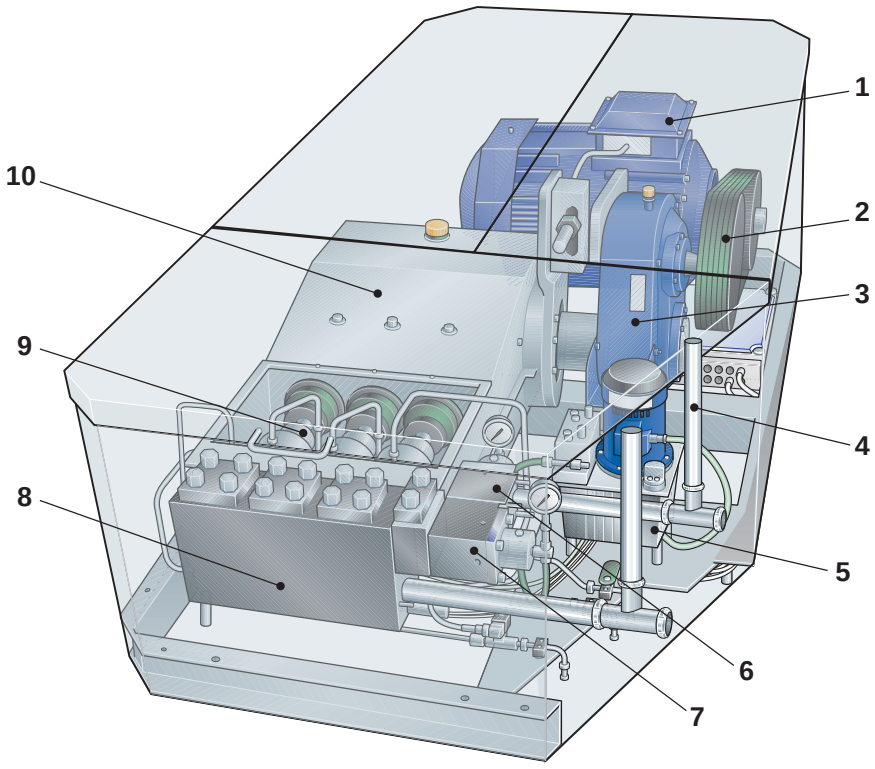


Fig. 6.3.4 *The homogeniser is a large high-pressure pump with a homogenising device.*

1 Main drive motor
2 V-belt transmission
3 Gearbox
4 Damper
5 Hydraulic pressure setting system
6 Homogenising device, second stage
7 Homogenising device, first stage
8 Solid stainless steel pump block
9 Pistons
10 Crankcase

A piston pump is a positive pump and its capacity can only be adjusted by changing the speed of the motor or changing the size of the pulleys. To handle higher pressures, pistons with smaller diameter are installed. This will reduce the maximum capacity, as each machine size has a maximum crankshaft speed. A larger machine has a longer stroke length and/or more pistons. In many cases these pistons also have a larger diameter.

A high-pressure pump has normally three to five pistons (9), running in cylinders in a high-pressure block (8). They are made of highly resistant materials. The machine is fitted with double piston-seals. Water is supplied

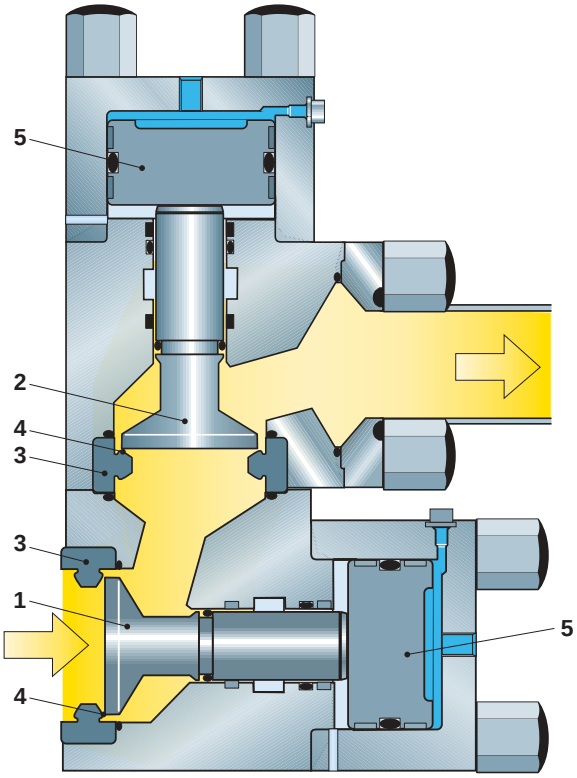


Fig.6.3.5 *The components of a two-stage homogenisation device.*
1 First stage forcer
2 Second stage forcer
3 Seat
4 Gap
5 Hydraulic actuator

to the space between the seals to lubricate the pistons. A mixture of hot condensate and steam can also be supplied to prevent reinfection when the homogeniser is placed downstream in aseptic processes.

A pistonpump will always generate a pulsating flow. The acceleration and decelerationof the liquid will create a pulsating pressure in the suction pipe. To avoid cavitation in the pump, there is always a damper on the suction pipe to reduce the pulsation. On the outlet side, the pulsation might create vibrations and noise, why the outlet pipe is also equipped with a damper.

As it is a positive pump, a piston pump should not operate in a series of other positive pumps, unless there is a bypass – otherwise the result can be extreme pressure variations and damaged equipment. If the flow can be stopped downstream of a high-pressure pump, a safety device must be installed that opens before the pipe bursts.

The homogenisation device

Figure 6.3.5 shows the homogenisation and hydraulic system. The piston pump boosts the pressure of the milk from about 300 kPa (3 bar) at the inlet to a homogenisation pressure of 10 – 25 MPa (100 – 250 bar), depending on the product. The pressure to the first stage before the device (the homogenisation pressure) is automatically kept constant. The oil pressure on the hydraulic piston and the homogenisation pressure on the forcer balance each other. The hydraulic unit can supply both first and second stage with an individually set pressure. The homogenisation pressure is set by adjusting the oil pressure. Actual homogenisation pressure can be read on a pressure gauge.

Note that the homogenisation pressure is the pressure before the first stage, not the pressure drop.

Homogenisation always takes place in the first stage. The second stage basically serves two purposes:

- Supplying a constant and controlled back-pressure to the first stage, giving best possible conditions for homogenisation
- Breaking up clusters formed directly after homogenisation as shown in Figure 6.3.3.

The parts in the homogenisation device are precision-ground. Its seat is at an angle that makes the product accelerate in a controlled way, thereby reducing the rapid wear and tear that would otherwise occur.

Milk is supplied at high pressure to the space between the seat and forcer. The distance between the seat and the forcer is approximately 0,1 mm or 100 times the size of the fat globules in homogenised milk. The velocity of the liquid is normally 100 – 400 m/s in the narrow annular gap. The higher the homogenisation pressure, the higher the speed. Homogenisation takes 10 – 15 microseconds. During this time, all the pressure energy delivered by the piston pump is converted into kinetic energy. Part of this energy is converted back to pressure again after the device. The other part is released as heat; every 40 bar in pressure drop over the device gives a temperature rise of 1 °C. Less than 1 % of the energy is utilised for homogenisation, but nevertheless, high-pressure homogenisation is the most efficient method available.

Homogenisation efficiency

The purpose of homogenisation varies with the application. Consequently the methods of measuring efficiency also vary.

According to Stokes' Law, the rising velocity of a particle is given by:

v_g = velocity
g = force of gravity
p = particle size
ρ_{hp} = density of the liquid
ρ_{lp} = density of the particle
t = viscosity
in the formula:

$$v_g = \frac{p^2 \times (\rho_{hp} - \rho_{lp})}{18 \times t} \times g$$

or $$v_g = \text{constant} \times p^2$$

It can be seen that reducing the particle size is an efficient way of reducing the rising velocity. Therefore, reducing the size of fat globules in milk reduces the creaming rate.

Analytical methods

Analytical methods for determining homogenisation efficiency can be divided into two groups:

Studies of creaming rate

The straight forward way of determining the creaming rate is to take a package, store it at the recommended storage temperature until the last day of consumption, open it and check if the cream layer is acceptable or not.

The *USPH* method is based on this. A sample of, say, 1 000 ml is stored for 48 hours, after which the fat content of the top 100 ml is determined, as well as the fat content of the rest. Homogenisation is reckoned to be sufficient if 0,9 times the top fat content is less than the bottom fat content.

The *NIZO* method is based on the same principle, but with this method, a sample of 25 ml is centrifuged for 30 minutes at 1 000 rpm, 40 °C and a radius of 250 mm. The fat content of the 20 ml at the bottom is divided by the fat content of the whole sample, and the ratio is multiplied by 100. The resulting index is called the NIZO value. The NIZO value of pasteurised milk is normally 50 – 80 %.

Size distribution analysis

The size distribution of the particles or droplets in a sample can be determined in a well defined way by using a laser diffraction unit (Figure 6.3.6), which sends a laser beam through a sample in a cuvette. The light

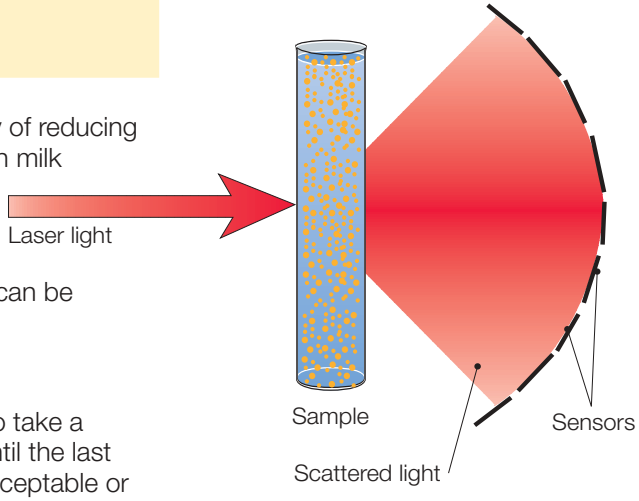


Fig. 6.3.6 *Particles analysis by laser diffraction.*

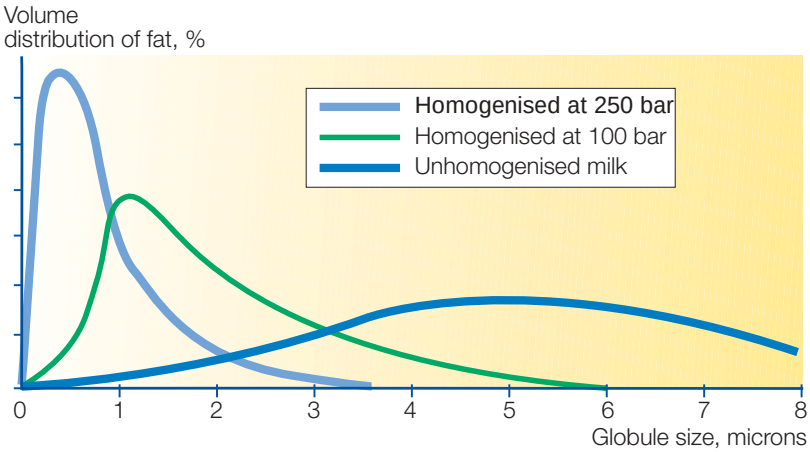


Fig. 6.3.7 *Size distribution curves.*

will be scattered, depending on the size and numbers of particles in the sample.

The result is presented as size distribution curves. The percentage of the volume (fat) is given as a function of the particle size (fat globule size). Three typical size distribution curves for milk are shown in Figure 6.3.7. It can be seen that the curve shifts to the left as a higher homogenisation pressure is used.

Note that fat globules can aggregate during storage and that this can increase the creaming rate.

Energy consumption and influence on temperature

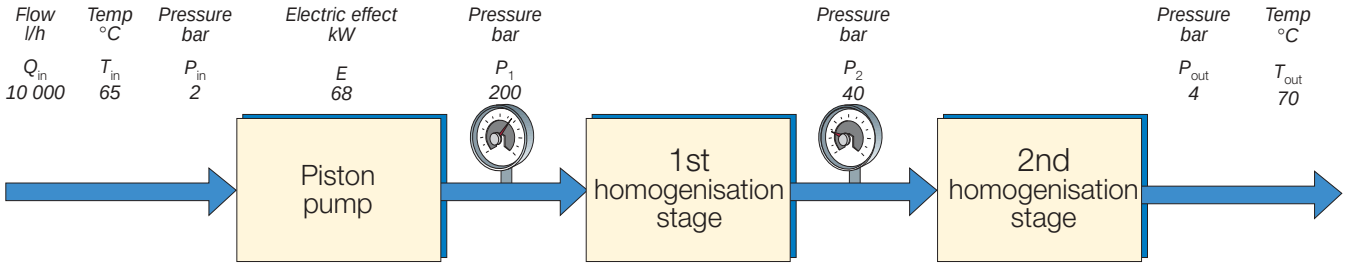


Fig. 6.3.8 *Energy, temperature and pressure in a homogenisation example.*

The electrical power input needed for homogenisation is expressed by the formula:

			Example:
E	=	Electrical effect, kW	
Q_{in}	=	Feed capacity, l/h	10 000
P_1	=	Homogenisation pressure, bar	200 (20 MPa)
P_{in}	=	Pressure to the pump, bar	2 (200 kPa)
η_{pump}	=	Efficiency coefficient of the pump	0,85
$\eta_{el.\ motor}$	=	Efficiency coefficient of the electrical motor	0,95

$$E = \frac{Q_{in} \times (P_1 - P_{in})}{36\,000 \times \eta_{pump} \times \eta_{el.\ motor}} \quad kW$$

The efficiency coefficients are typical values. From the figures for feed capacity and pressures given on the right above, the electric power demand will be 68 kW. Of this, 55 kW is used for pumping and converted to

heat in the homogenisation device, and 13 kW is released as heat to the cooling water and to the air.

As was mentioned above, part of the pressure energy supplied is released as heat. Given the temperature of the feed, T_{in}, the homogenisation pressure, P_1, the pressure after homogenisation, P_{out}, and that every 4 MPa (40 bar) in pressure drop raises the temperature by 1 °C, the following formula is applicable:

$$T_{out} = \frac{P_1 - P_{out}}{40} + T_{in}$$

The energy consumption, temperature increase and pressure decrease are illustrated in Figure 6.3.8.

T_{in} = 65 °C
P_1 = 200 bar (20 MPa)
P_{out} = 4 bar (400 kPa)
resulting in
T_{out} = 70 °C

The homogeniser in a processing line

In general, the homogeniser is placed upstream, *i.e.* before the final heating section in a heat exchanger. In most pasteurisation plants for market milk production, the homogeniser is usually placed after the first regenerative section.

In production of UHT milk, the homogeniser is generally placed upstream in indirect systems but always downstream in direct systems, *i.e.* on the aseptic side after UHT treatment. In the latter case, the homogeniser is of aseptic design with special piston seals, sterile steam condenser and special aseptic dampers.

However, downstream location of the homogeniser is recommended for indirect UHT systems when milk products with a fat content higher than 6 – 10 % and/or with increased protein content are going to be processed. The reason is that with increased fat and protein contents, fat clusters and/or agglomerates (protein) form at the very high heat treatment temperatures. These clusters/agglomerates are broken up by the aseptic homogeniser located downstream.

Split homogenisation

An aseptic homogeniser is more expensive to operate. In some cases it is sufficient if just the second stage is placed downstream. This arrangement is called split homogenisation.

Note that the whole section, including the heat exchanger, between the first and the second stage in the homogeniser, has to withstand a fairly high pressure.

Full stream homogenisation

Full stream or total homogenisation is the most commonly used form of homogenisation of UHT milk and milk intended for cultured milk products.

The fat content of the milk is standardised prior to homogenisation, as is the solids-non-fat content in certain circumstances, *e.g.* in yoghurt production.

Partial homogenisation

Partial stream homogenisation means that the main body of skim milk is not homogenised, but only the cream together with a small proportion of skim milk. This form of homogenisation is mainly applied to pasteurised market milk. The basic reason is to reduce operating costs. Total power

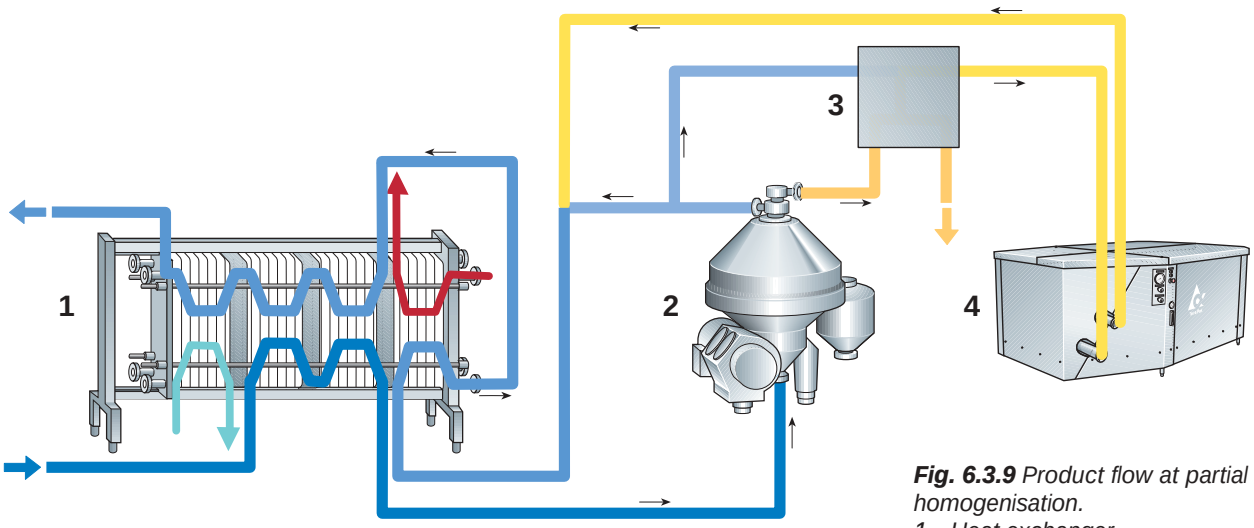


Fig. 6.3.9 *Product flow at partial stream homogenisation.*
1 Heat exchanger
2 Centrifugal separator
3 Automatic fat standardisation device
4 Homogeniser

consumption is cut by some 80 % because of the smaller volume passing through the homogeniser.

As sufficiently good homogenisation can be reached when the product contains at least 0,2 g casein per g fat, a maximum cream fat content of 18 % is recommended. The hourly capacity of a homogeniser used for partial homogenisation can be dimensioned according to the following example.

The formulae for the calculations are:

1. $$Q_{sm} = \frac{Q_p \times (f_{cs} - f_{rm})}{f_{cs} - f_{sm}}$$

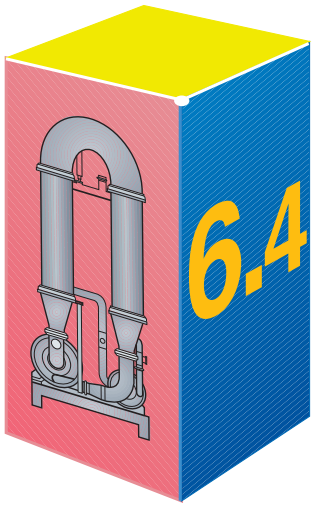
2. $$Q_h = \frac{Q_{sm} \times f_{sm}}{f_{ch}}$$

			Example:
Q_p	=	Plant input capacity, l/h	10 000
Q_{sm}	=	Output of standardised milk, l/h	
Q_h	=	Homogeniser capacity, l/h	
f_{rm}	=	Fat content of raw milk, %	4,0
f_{sm}	=	Fat content of standardised milk, %	3,5
f_{cs}	=	Fat content of cream from separator, %	35
f_{ch}	=	Fat content of cream to be homogenised, %	18

The hourly output of pasteurised standardised milk, Q_{sm}, will be approx. 9 840 l. Inserted into Formula 2, this gives an hourly homogeniser capacity of approx. 1 915 l, *i.e.* about one-fifth of the output capacity.

The flow pattern in a plant for partially homogenised milk is illustrated in Figure 6.3.9.

Membrane filters



Membrane technology is a proven separation method used on the molecular and ionic levels. Since the beginning of the 1970s, this technique has been adapted for the dairy industry.

Definitions

Definitions of some frequently used expressions :

Feed = the solution to be concentrated or fractionated.

Flux = the rate of extraction of permeate measured in litres per square meter of membrane surface area per hour (l/m^2/h)

Membrane fouling = deposition and accumulation of feed components on the membrane surface and/or within the pores of the membrane. Causes an irreversible flux decline during processing

Permeate = the filtrate, the liquid passing through the membrane

Retentate = the concentrate, the retained liquid

Concentration factor = the volume reduction achieved by concentration, *i.e.* the ratio of initial volume of feed to the final volume of concentrate/retentate

Diafiltration = a design to obtain better purification. Water is added to the feed during membrane filtration with the purpose to wash out low molecfular feed components which will pass through the membranes, basically lactose and minerals.

Membrane technology

In the dairy industry, membrane technology is principally associated with

- **Reverse Osmosis (RO)**
  – concentration of solutions by removal of water
- **Nanofiltration (NF)**
  – concentration of organic components by removal of part of monovalent ions like sodium and chlorine (partial demineralisation)
- **Ultrafiltration (UF)**
  – concentration of large and macro molecules, for example proteins
- **Microfiltration (MF)**
  – removal of bacteria, separation of macro molecules

The spectrum of application of membrane separation processes in the dairy industry is shown in Figure 6.4.1.

All the above techniques feature pressure driven membrane filtration processes, in which the feed solution is forced through the membrane under pressure. The membranes are categorised by their NaCl retention (RO and NF) molecular weight cut-off (NF and UF), or nominal pore-size

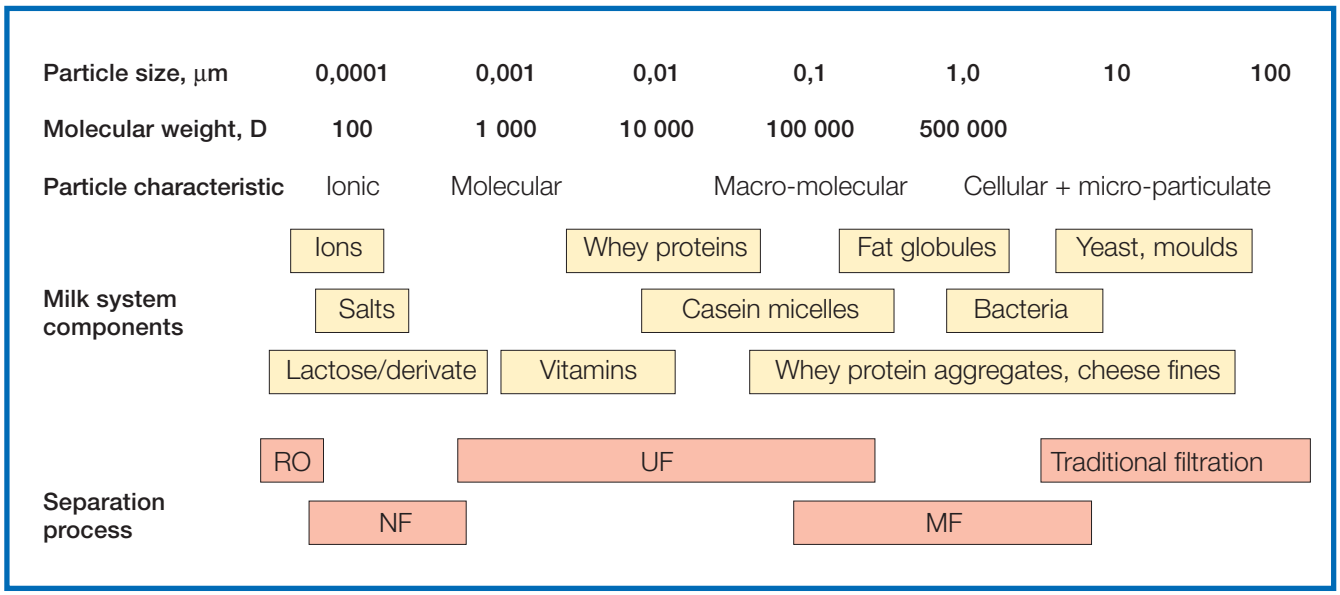


Fig. 6.4.1 *Spectrum of application of membrane separation processes in the dairy industry.*

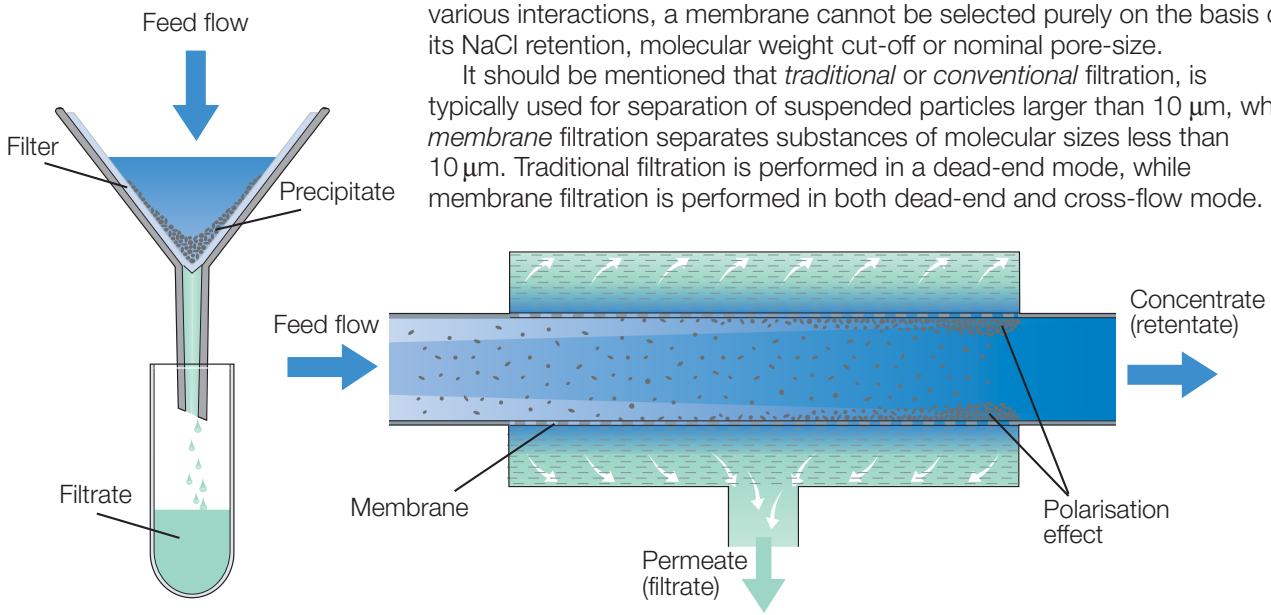


Fig. 6.4.2 *Basic differences between conventional dead-end filtration and cross-flow membrane filtration.*

(MF). The cut-off is, supposedly the molecular weight of the smallest molecule that will not pass through the membrane. However, owing to various interactions, a membrane cannot be selected purely on the basis of its NaCl retention, molecular weight cut-off or nominal pore-size.

It should be mentioned that *traditional* or *conventional* filtration, is typically used for separation of suspended particles larger than 10 µm, while *membrane* filtration separates substances of molecular sizes less than 10 µm. Traditional filtration is performed in a dead-end mode, while membrane filtration is performed in both dead-end and cross-flow mode.

The basic difference between conventional filtration and cross-flow membrane filtration is illustrated in Figure 6.4.2.

Several differences can be noted between conventional and membrane filtration.

- **Conventional** filters are thick with open structures.
  Filter material is typically paper.
  Gravity is the main force affecting particle separation. Pressure may be applied only to accelerate the process. The flow of feed is *perpendicular* to the filter medium, and filtration can be conducted in open systems.
- **Membrane** filters are thin and of fairly controlled pore size.
  Filter material is polymers and ceramics, nowadays more rarely cellulose acetate.

In membrane filtration, the use of a pressure difference across the membrane, a trans membrane pressure, TMP, is essential as driving force for separation and in *cross-flow* or *tangential* membrane filtration a flow design is followed. The feed solution runs parallel to the membrane surface

and the permeate flows perpendicular to the membrane surface. The filtration must be carried out in a closed system.

Principles of membrane separation

The membrane separation techniques utilised in the dairy industry serve different purposes:

RO – used for dehydration of whey, UF permeate and condensate.

NF – used when partial desalination of whey, UF permeate or retentate is required.

UF – typically used for concentration of milk proteins in milk and whey and for protein standardisation of milk intended for cheese, yoghurt and some other products. It is also used for clarification of fruit- and berry-juices.

MF – basically used for reduction of bacteria in skim milk, whey and brine, but also for defatting whey intended for whey protein concentrate (WPC) and for protein fractionation.

The general flow patterns of the various membrane separation systems are illustrated in Figure 6.4.3.

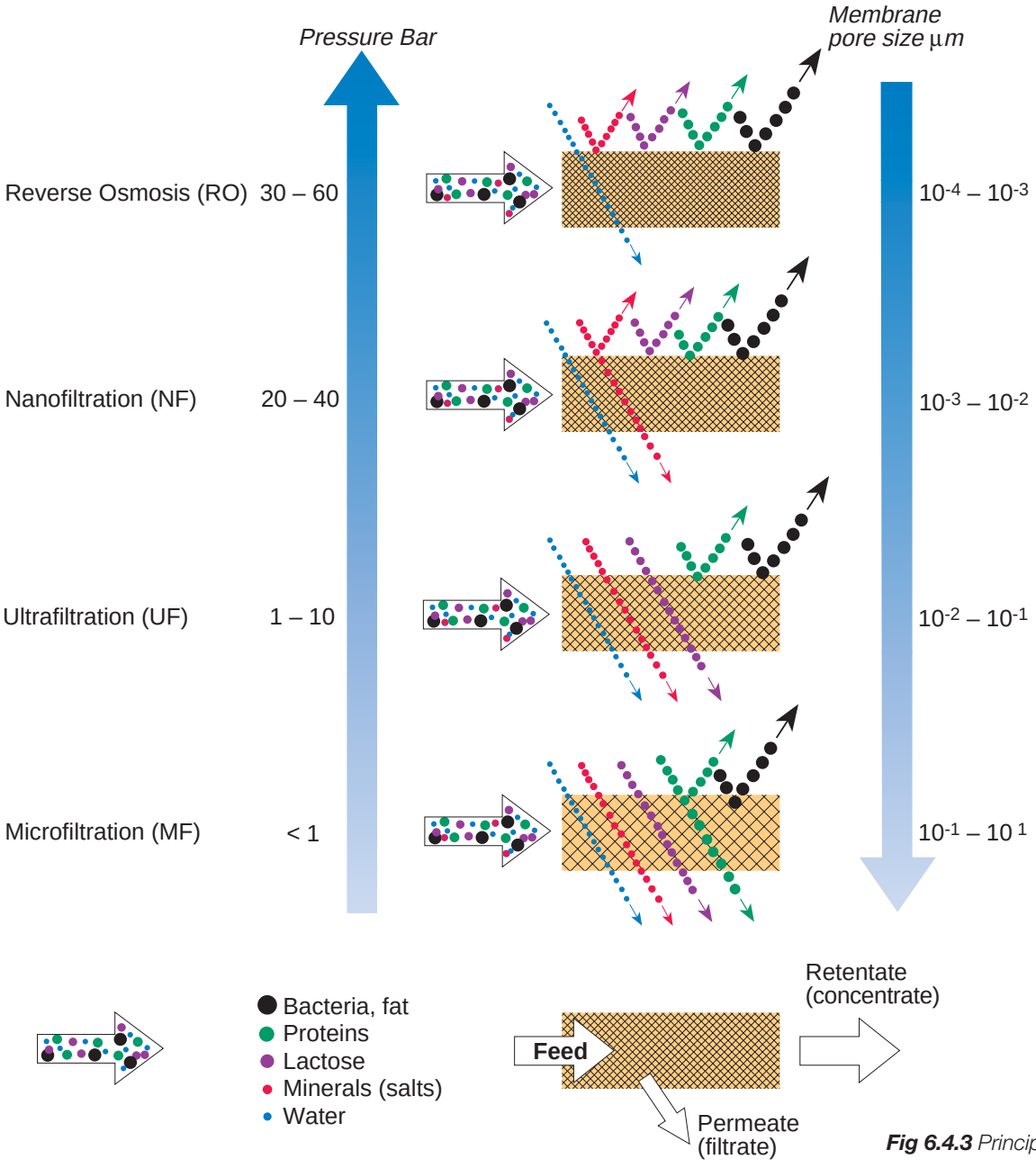


Fig 6.4.3 *Principles of membrane filtration.*

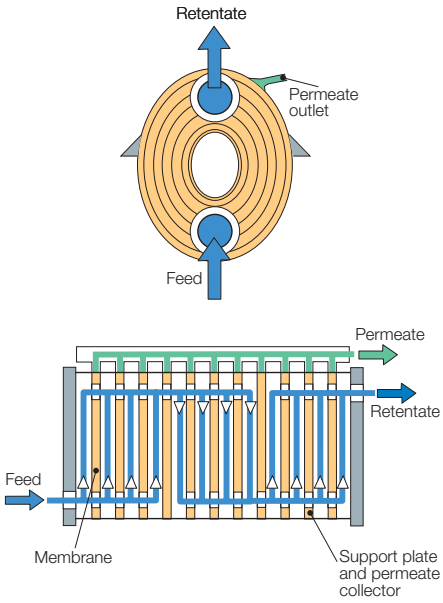


Fig. 6.4.4 *Example of a plate and frame system (DDS) for UF.*

Filtration modules

The filtration modules used may be of different configurations.

Design	Typical application
Plate and frame	UF, RO
Tubular, based on polymers	UF, RO
Tubular, based on ceramics	MF, UF
Spiral-wound	RO, NF, UF
Hollow-fibre	UF

Plate and frame design

These systems consist of membranes sandwiched between membrane support plates, which are arranged in stacks, similar to ordinary plate heat exchangers. The feed material is forced through very narrow channels that may be configured for parallel flow or as a combination of parallel and serial channels. A typical design is shown in Figure 6.4.4.

A module is usually divided into sections, in each of which the flow between pairs of membranes is in parallel. The sections are separated by a special membrane support plate in which one hole is closed with a stop disc to reverse the direction of flow, giving serial flow between successive sections. Modules are available in various sizes.

Membrane material: typical polymers.

Tubular design – polymers

The system made by Paterson and Candy International Ltd, PCI, is an example of tubular systems used in the dairy industry.

The PCI module for UF is illustrated in Figure 6.4.5. The module has 18 x 12,5 mm perforated stainless steel tubes assembled in a shell-and-tube-like construction. All 18 tubes are connected in series. A replaceable membrane insert tube is fitted inside each of the perforated stainless steel pressure support tubes. Permeate is collected on the outside of the tube bundle in the stainless steel shroud. The module can readily be converted from UF to RO.

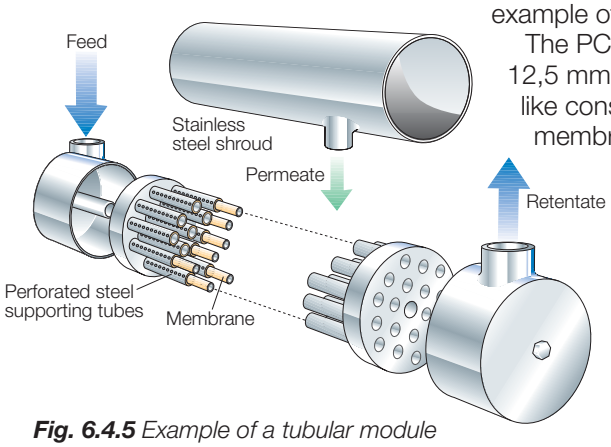


Fig. 6.4.5 *Example of a tubular module to be integrated into a UF (or RO) system (PCI).*

Tubular design – ceramic

A tubular concept with ceramic membranes is steadily gaining ground in the dairy industry, especially in systems for reduction of bacteria in milk, whey, WPC and brine.

The filter element (Figure 6.4.6) is a ceramic filter manufactured by the company Pall Exekia.

The thin walls of the channels are made of fine-grained ceramic and constitute the membrane. The support material is coarse-grained ceramic.

In MF for bacteria removal, the system is fed with skim milk, because with whole milk, the fat would also be concentrated, which is undesirable in applications for bacteria reduction.

Most of the feed (about 95 %) passes through the membrane as permeate, in this case bacteria-reduced skim milk. The retentate, some 5 % of the feed, is bacteria-rich skim milk.

The filter elements (1, 7, 19 or 37 in parallel) are installed in a module. Figure 6.4.7 shows a module with 19 filter elements, one of which is exposed to the left of the module. For industrial purposes, two modules are put together in series, forming a filter loop together with one retentate circulation pump and one permeate circulation pump (Figure 6.4.10).

Depending on the required

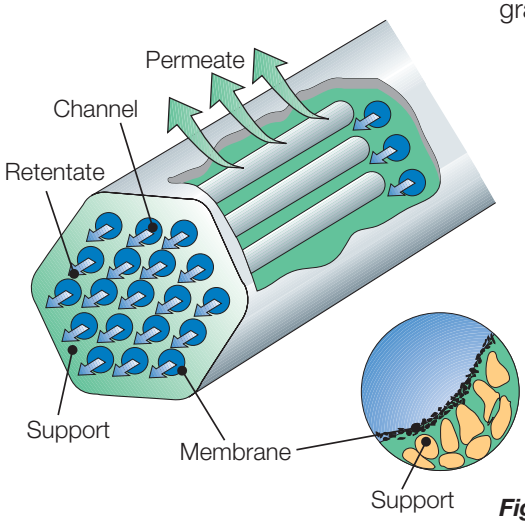


Fig.6.4.6 *Cross-flow filtration in a multichannel element (19 channels).*

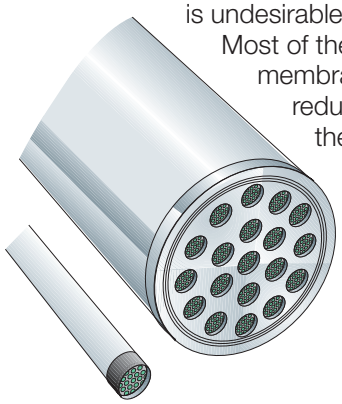


Fig 6.4.7 *The filter elements,1, 7 or 19 (shown) in parallel, are installed in a stainless steel module.*

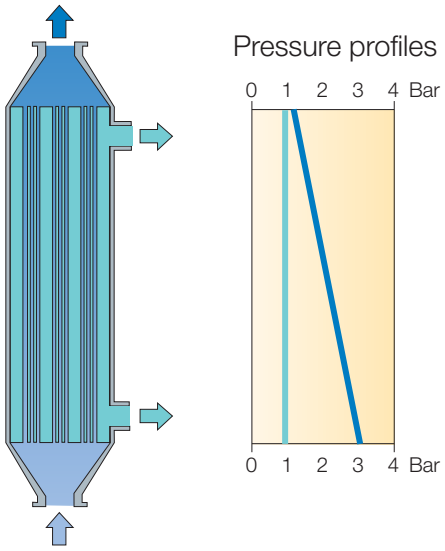


Fig 6.4.8 *Pressure drop during conventional cross-flow microfiltration.*

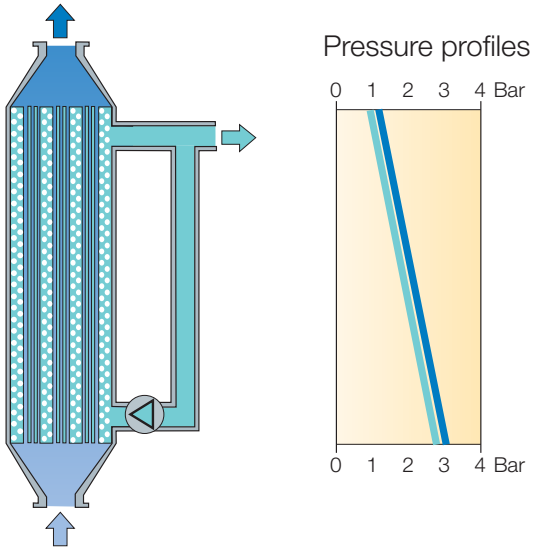


Fig 6.4.9 *Pressure drop at the Uniform Transmembrane Pressure system.*

capacity, a number of filter loops can be installed in parallel.

The feed is pumped into the modules from below at a high flow rate. The high flow rate causes a high pressure drop along the membrane elements which leads to an uneven transmembrane pressure (TMP), the TMP being higher at the inlet than at the outlet. The very high TMP at the inlet quickly causes clogging of the membrane. This phenomenon is illustrated in Figure 6.4.8, which shows conventional cross-flow microfiltration. Experience shows that a low transmembrane pressure gives much better performance, but in conventional cross-flow microfiltration, a low transmembrane pressure occurs only at the outlet, *i.e.* on a very small part of the membrane area.

A unique Uniform Transmembrane Pressure (UTP) system has been introduced to achieve optimum conditions on the entire area. The patented system, illustrated in Figure 6.4.9, involves high-velocity permeate circulation concurrently with the retentate creating a pressure drop on the permeate side which is equal to the pressure drop on the retentate side. This gives a uniform TMP over the whole of the membrane area, with optimum utilisation of the membrane.

The latter system is possible because the space between the elements inside the module, *i.e.* on the permeate side, is normally empty, but in the UTP version, it is filled with plastic grains. The pressure drop on the permeate side is regulated by the permeate pump and is constant during operation of the plant.

Today membrane elements of special design which have this so called UTP system built-in in their structure are available. When using this type of membranes there is no need for a circulation on the permeate side. These membranes have a flow resistance which differs along the element.

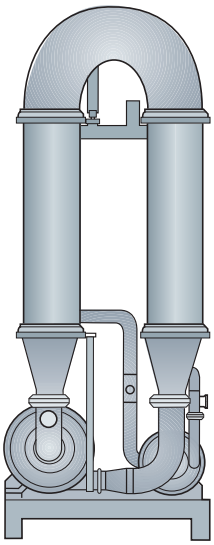


Fig. 6.4.10 *An industrial membrane filter loop consists of:*
- *two filter modules connected in series*
- *one retentate circulation pump*
- *one permeate circulation pump*

Spiral-wound design

As the spiral-wound design differs from the other membrane filtration designs used in the dairy industry, it calls for a somewhat more detailed explanation.

A spiral-wound element contains one or more membrane envelopes, each of which contains two layers of membrane separated by a porous permeate conductive material. This material, called the *permeate channel spacer*, allows the permeate passing through the membrane to flow freely. The two layers of membrane with the permeate channel

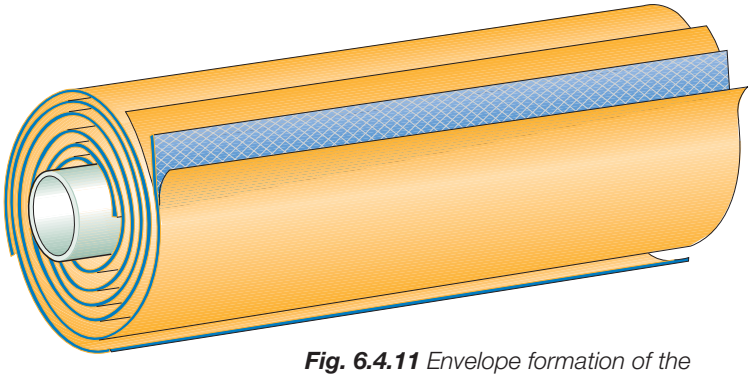


Fig. 6.4.11 *Envelope formation of the spiral-wound filter design.*

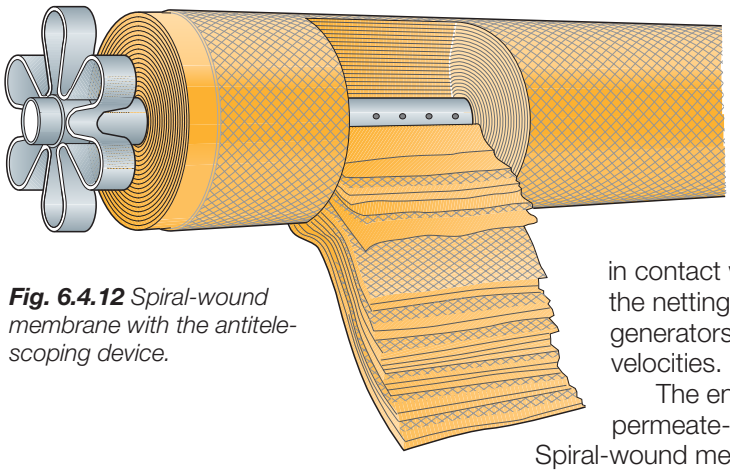


Fig. 6.4.12 *Spiral-wound membrane with the antitelescoping device.*

spacer between them are sealed with adhesive at two edges and one end to form the membrane envelope. The open end of the envelope is connected and sealed to a perforated permeate-collecting tube. The envelope configuration is illustrated in Figure 6.4.11.

A plastic netting material, serving as a channel for the flow of feed solution through the system and known as the feed channel spacer, is placed in contact with one side of each membrane envelope. Due to the netting design the feed spacers also act as turbulence generators to keep the membrane clean at relatively low velocities.

The entire assembly is then wrapped around the perforated permeate-collecting tube to form the spiral-wound membrane.

Spiral-wound membranes are equipped with an antitelescoping device (Figure 6.4.12) between the downstream ends of the membrane elements to prevent the velocity of treated fluid from causing the layers to slip.

Several elements – normally three – can be connected in series inside the same stainless steel tube as shown in Figure 6.4.13.

Membrane and permeate spacer material: polymer.

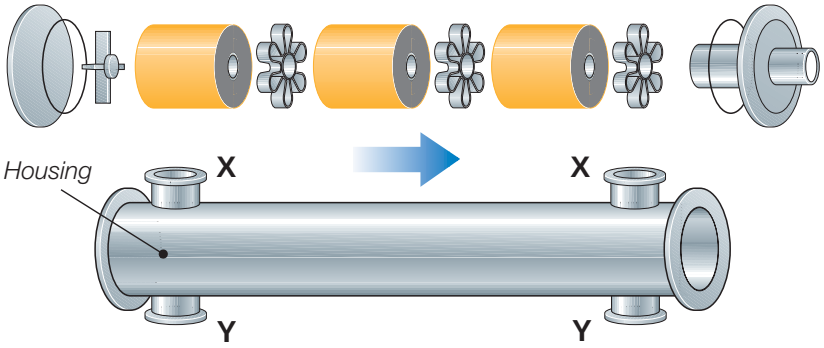


Fig.6.4.13 *Spiral-wound module assembly. Either or both of the pairs of connecting branches (X and Y) can be used for stackable housing, specially used in UF concepts.*

Hollow-fibre design

Hollow-fibre modules are cartridges which contain bundles of 45 to over 3 000 hollow-fibre elements per cartridge. The fibres are oriented in parallel; all are potted in a resin at their ends and enclosed in the permeate collecting tube of epoxy.

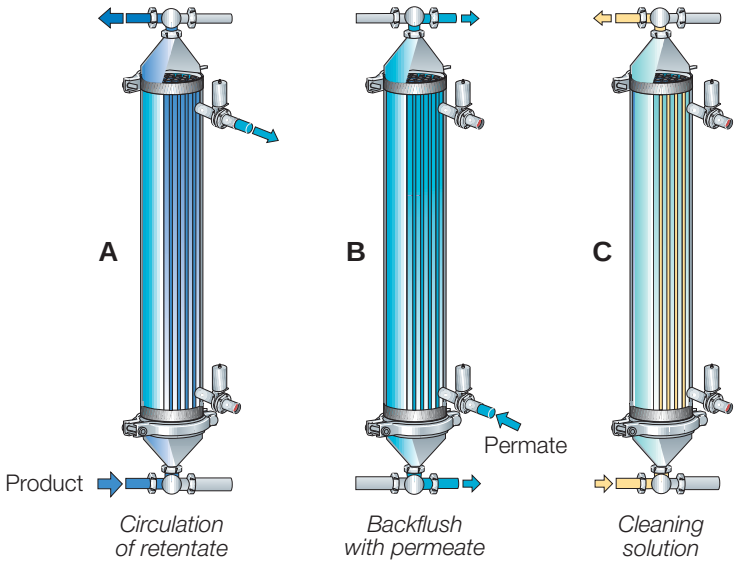


Fig. 6.4.14 *UF cartridge during filtration (A), backflushing (B) and cleaning (C).*

The membrane has an inner diameter ranging from 0,5 to 2,7 mm, and the active membrane surface is on the inside of the hollow fibre. The outside of the hollow-fibre wall, unlike the inner wall, has a rough structure and acts as a supporting structure for the membrane. The feed stream flows through the inside of these fibres, and the permeate is collected outside and removed at the top of the tube.

A special feature of this design is its backflushing capability, which is utilised in cleaning and with permeate recirculated through the outer permeate connection to remove product deposits on the membrane surface. Various modes of operation of a hollow-fibre module are illustrated in Figure 6.4.14.

Membrane material: polymers.

Separation limits for membranes

The separation limit for a membrane is determined by the lowest molecular weight that can be separated. The membrane can have a definite or a diffuse separation limit, as illustrated in Figure 6.4.15 for two UF membranes. The same phenomena occur in other types of membrane separators, but the slope of the curves may be different. Membranes with a definite separation limit separate everything with a definitely lower molecular weight, while membranes with a diffuse limit let some material with a higher molecular weight through and stop some with a lower molecular weight.

The separation accuracy of a membrane is determined by pore size and pore size distribution. Because it is not possible to carry out an exact fractionation according to molecular mass or molecular diameter, the cutoff is more or less diffuse.

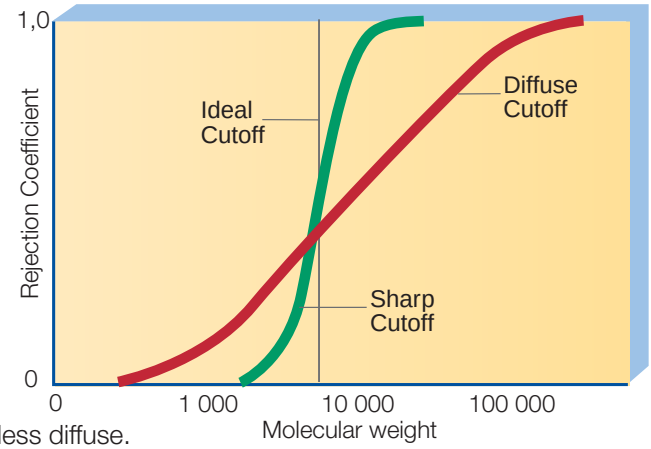


Fig. 6.4.15 *Typical rejection characteristics of ultrafiltration membranes showing ideal, sharp and diffuse molecular weight cutoffs.*

The definition that the molecular weight determines the separation limit should be taken with some reservations, as the shape of the separated particles also has an influence. A spherical particle is easier to separate than a chain-shaped particle. In addition comes the build-up of a "secondary membrane" by macromolecules, *e.g.* proteins, which may constitute the membrane that really determines the molecular cutoff value.

Material transport through the membrane

Separation capacity depends on a number of factors:

- Membrane resistance, which is characteristic for each membrane and is determined by
  – the thickness of the membrane
  – the surface porosity
  – the pore diameter
- Transport resistance, *i.e.* the concentration polarisation and fouling effects are phenomenon which occurs at the surface or in the porous structure of the membranes as filtration proceeds.

The formation of a layer which increase the resistance can be explained as follows:

- Large molecules (*i.e.* protein and fat) are transported by convection to the membrane at right angles to the direction of flow. Due to the retention the concentration of particles will increase at the membrane surface.
- This concentration gradient produces a back diffusion in the opposite direction, back to the bulk.
- Parallel to the membrane, the proteins present in the layer close to the membrane surface move at velocities which vary according to the increase in axial flow rate.

- The fouling effect is not uniformly distributed along the membrane, especially when the pressure drop gives different transmembrane pressures (TMP) along the membrane surface. The upstream end of the membrane is therefore clogged first. The fouling gradually spreads over the whole surface, reducing capacity and eventually making it necessary to stop and clean the plant.
- The main effect of fouling is that the removal of permeate decreases as filtration proceeds.
- The fouling effect can be reduced in certain concepts by using backflush, reverse flow or UTP (possible when ceramic membranes are used).

Pressure conditions

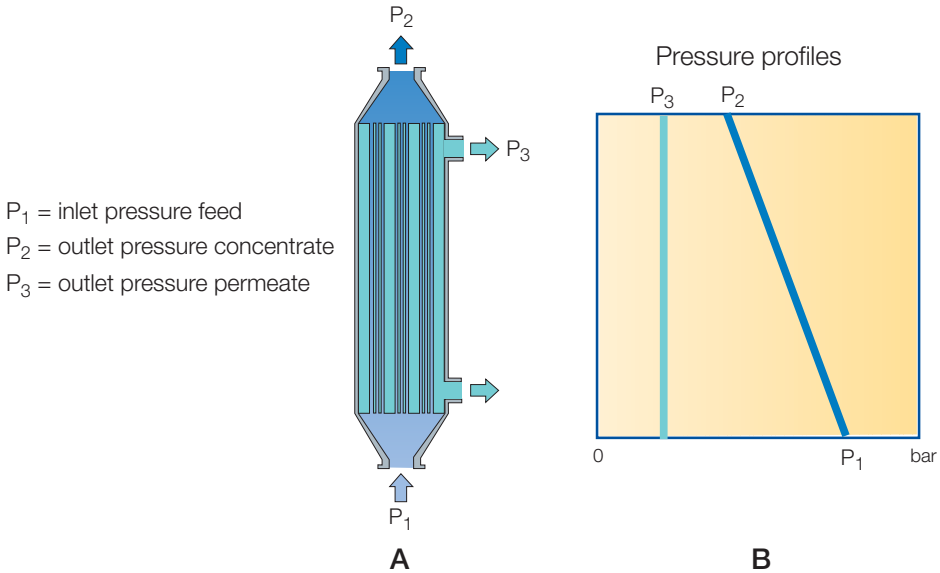
Pressure is the driving force of filtration, and an important distinction must be made between:

1 The hydraulic pressure drop along the module $P = P_1 - P_2$.
The higher the velocity through the module the higher the value of P. A higher velocity results in a higher shear at the membrane surface and a lower polarisation effect. However, there are constraints such as the resistance to pressure of the membrane and the price of pumps capable of delivering both high flows and high pressure.

2 The transmembrane pressure (TMP) is the pressure drop between the retentate and the permeate sides of the membrane at a particular point along the membrane. The main criterion of the efficiency of a membrane system is expressed as the flux – the flow per membranes area and hour, $l/m^2/h$, and is a function of TMP.

The TMP, *i.e.* the force which pushes the permeate through the membrane, is greatest at the inlet and lowest at the discharge end of the module. Since the decrease in TMP is linear, an average TMP is given by:

$$TMP = \frac{P_1 + P_2}{2} - P_3$$



$$P = P_1 - P_2 \qquad TMP = \frac{P_1 + P_2}{2} - P_3$$

Fig. 6.4.16 *Hydraulic (A) and transmembrane (B) pressure drops over a membrane*

The hydraulic pressure drop over the membrane (A) and the transmembrane pressure profile (B) are illustrated in Figure 6.4.16.

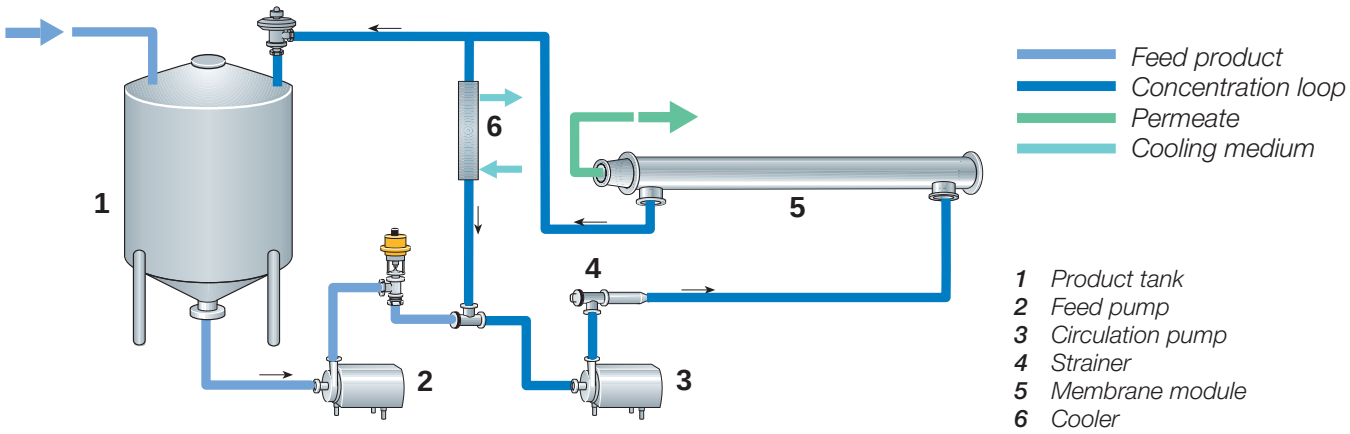


Fig. 6.4.17 *Batch membrane filtration plant*

Principles of plant designs

The operation of membrane filtration plants depends basically on the pressure generated by the pumps used. The following guides should be taken into consideration:

1 The capacity of the pump(s) should match the required flow rate and the characteristics of the module(s), which vary widely according to module design and size.
2 The pump(s) should be insensitive to changes in the viscosity of the processed stream up to the viscosity limit of the module. It/they should also operate efficiently at the temperatures used for processsing and cleaning.
3 The pump(s) must satisfy the sanitary standards for dairy equipment.

Pumps of several types are used, including centrifugal pumps and positive displacement pumps. Sanitary centrifugal pumps are normally used as feed and circulation pumps, but sanitary positive displacement pumps are occasionally used as high-pressure feed and circulation pumps for high-viscosity liquids, *e.g.* in the final stages of ultrafiltration of acidified milk.

Membrane separation plants can be used for both batch and continuous production. The feed solution *must not contain coarse particles*, which can damage the very thin filtration layer/active layer. A fine-meshed strainer is therefore often integrated into the feed system.

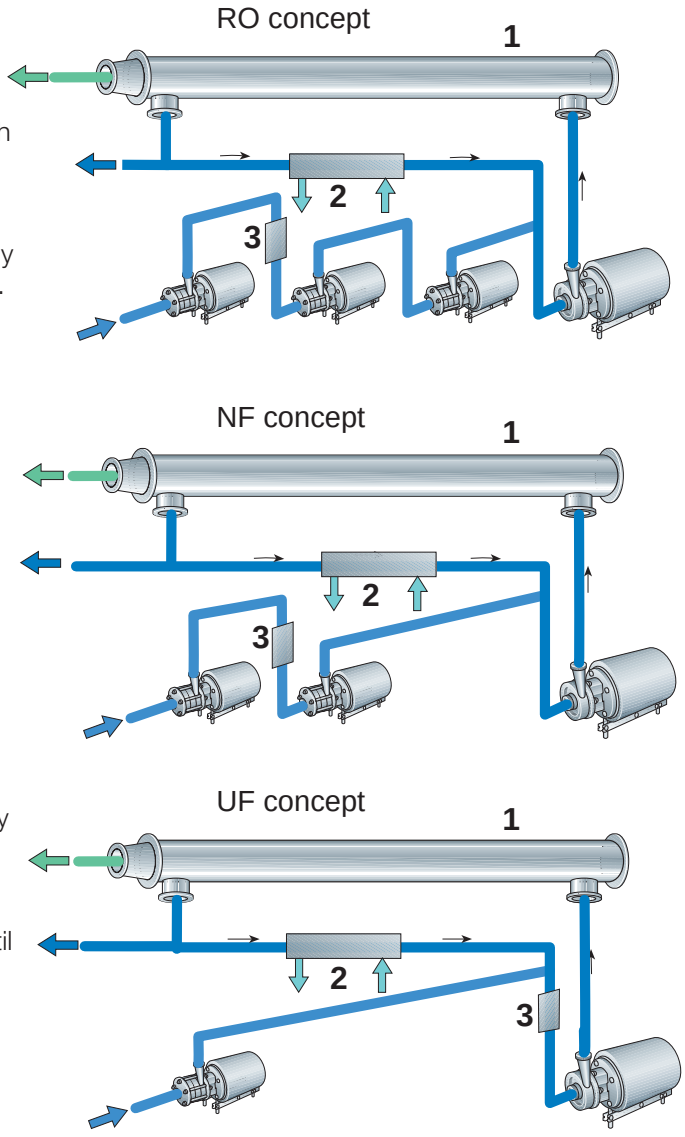


Fig. 6.4.18 *Design principles for different filter loops.*
1 Membrane
2 Cooler
3 Strainer

Batch production

Plants for batch production (Figure 6.4.17) are used mainly for filtration of small volumes of product, for example in laboratories and experimental plants. A certain amount of the product to be treated is kept in a buffer tank. The product is circulated through the membrane separator until the required concentration is obtained.

Continuous production

Schematic designs of the membrane filtration plants referred to are collected in Figures 6.4.18. and 6.4.19. The plants illustrated in Figure 6.4.18 represent spiral-wound concepts for RO, NF and UF applications, with polymer membranes of different pore sizes, while Figure 6.4.19 shows a MF plant with ceramic membranes.

As the RO membranes are much tighter than those of the two other systems, a higher inlet pressure is required for production. This is main-

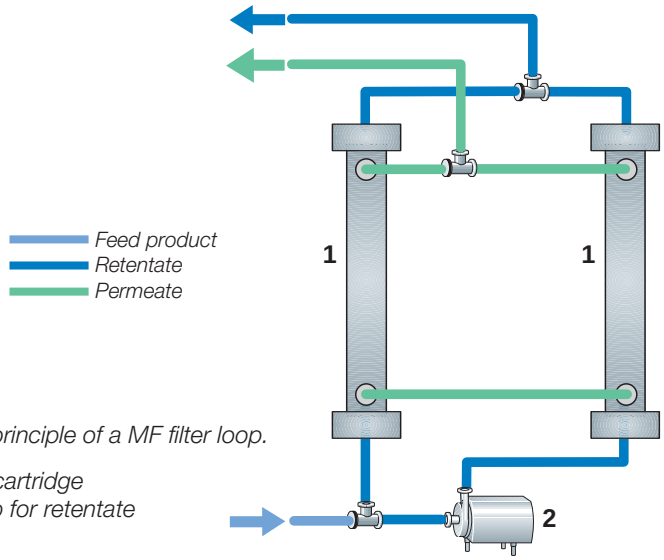


Fig. 6.4.19 *Design principle of a MF filter loop.*

1 *MF membrane cartridge*
2 *Circulation pump for retentate*

tained by three sanitary centrifugal feed pumps in series and one sanitary centrifugal circulation pump.

The other two filtration plants, NF and UF, have more open membranes and can therefore manage with two feed pumps and one feed pump respectively.

As was mentioned earlier, the MF concept is based on two filter modules operated in series in a filter loop system which also contains one centrifugal pump for circulation of the retentate and one for circulation of the permeate.

The feed solution may be supplied from a separation plant with a system for constant pressure at the outlet, or from a balance tank equipped with a pump and a system for capacity regulation.

Processing temperature in membrane filtration applications

In most cases, the processing temperature is about 50 °C for dairy applications. Filtration plants are normally supplemented with a simple cooling system integrated into the internal circulation loop to compensate for the slight rise in temperature that occurs during operation and to maintain a constant processing temperature.

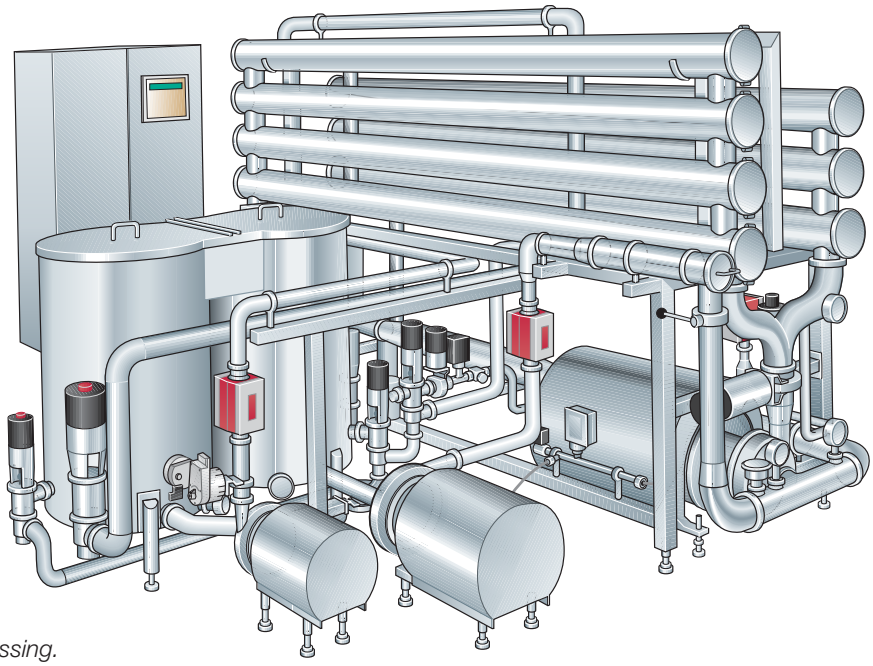


Fig. 6.4.20 *Production module for UF processing.*

Evaporators

Removal of water

Concentration of a liquid involves evaporation of a solvent, in most cases water. Concentration is distinguished from drying in that the final product – the concentrate – is still liquid.

There are several reasons for concentrating food liquids:

- Reduce costs for storage and transportation
- Induce crystallisation
- Reduce the cost of drying
- Reduce water activity to increase microbiological and chemical stability
- Recover valuable substances and by-products from waste streams.

Concentration of a liquid by evaporation under vacuum was introduced in 1913. The process was based on a British patent by E.C. Howard, which covered a steam-heated double-bottomed vacuum pan with condenser and vacuum pump.

Concentration

In the dairy industry, evaporation is used to concentrate whole milk, skim milk, whey, whey protein concentrate and permeate from membrane filtration modules. Water is evaporated by means of indirect heating. Product and heating medium (steam) are kept separate from one another by means of a sheet of special steel. The heat released during the condensing of the steam is transferred to the product via the partition.

Evaporation also constitutes the preliminary stage of the drying of the said products.

How far the concentration process can be forced is determined by product properties such as viscosity and heat stability.

Heat treatment is often an integral process step of an evaporator in order to achieve specific properties in the finished powder. As some products are sensitive to heat, the design of these systems has to be considered carefully with respect to temperature and holding time in order to achieve the desired effects on the one hand but, on the other, without causing heat damage.

To minimise the thermal impact on the products from the heat applied,

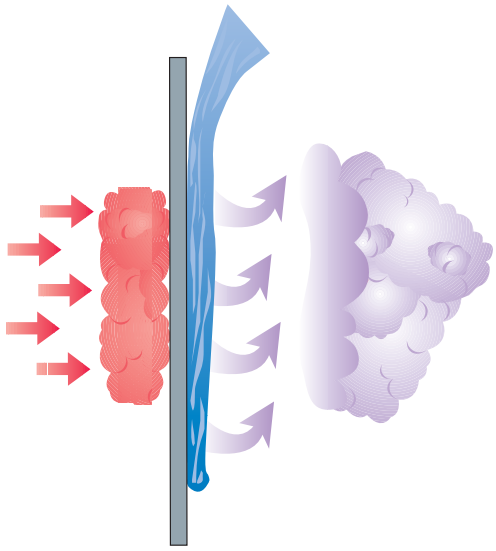


Fig. 6.5.1 *General principle of evaporation. A partition is heated by hot steam and vapour evaporates from the liquid on the other side.*

Table 6.5.1

Typical solids content after evaporation for dairy products

Whole milk and skim milk	48 – 50 %
Whey	58 – 65 %
Whey protein concentrate	35 – 48 %
Permeate	70 – 75 %

evaporation takes place in a vacuum at pressures of 160 – 320 hPa, equivalent to water boiling temperatures of 55 – 70 °C.

The following aspects must be taken into account when planning an evaporator station:

- Quality of the final product
- Energy costs
- Heat treatment
- Heat recovery
- Condensate quality
- Cleaning duration and cleaning costs
- Cost of premises
- Environmental conditions
- Investment costs

Evaporator design

It takes a large amount of energy to boil off water from a solution. This energy is often supplied as steam. To reduce the amount of steam needed, the evaporator is normally designed as a multiple-effect evaporator. Two or more effects operate at progressively lower vacuums and thus with progressively lower boiling points. In such an arrangement, the vapour produced in the first effect can be used as a heating medium in the next effect. The result is that the amount of steam needed is approximately equal to the total amount of water evaporated, divided by the number of effects.

Evaporators with four to seven effects are used in the dairy industry. Nowadays, electricity is used extensively as the energy source; particularly in the case of what is known as pre-concentrators, which are used to concentrate milk and whey to 32 – 36 % solids content. To do this, an electric compressor is used which compresses the vapour evolved in the effect, thus bringing it to a temperature level 3 – 5 °C higher and using it as a heating medium in the heater. This mechanical vapour recompression (MVR) offers clear benefits in terms of operating costs.

Table 6.5.2

Typical consumptions per kg evaporated water for falling-film tubular evaporators with thermal recompression in the dairy industry

2-effect	0,32 kg steam
3-effect	0,25 kg steam
4-effect	0,18 kg steam
5-effect	0,13 kg steam
6-effect	0,11 kg steam
7-effect	0,09 kg steam
1-effect MVR	0,012 kWh

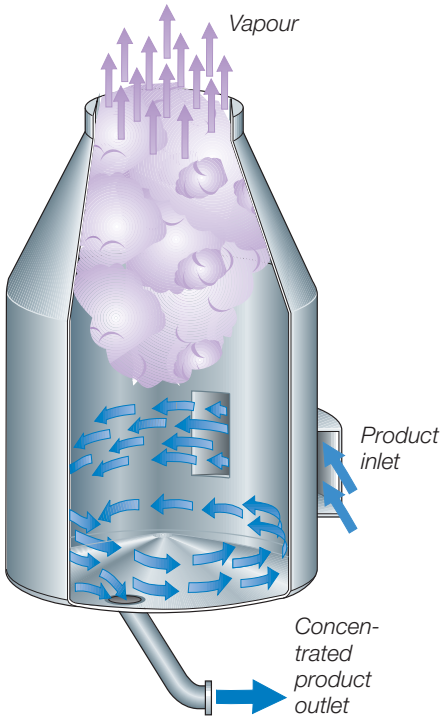


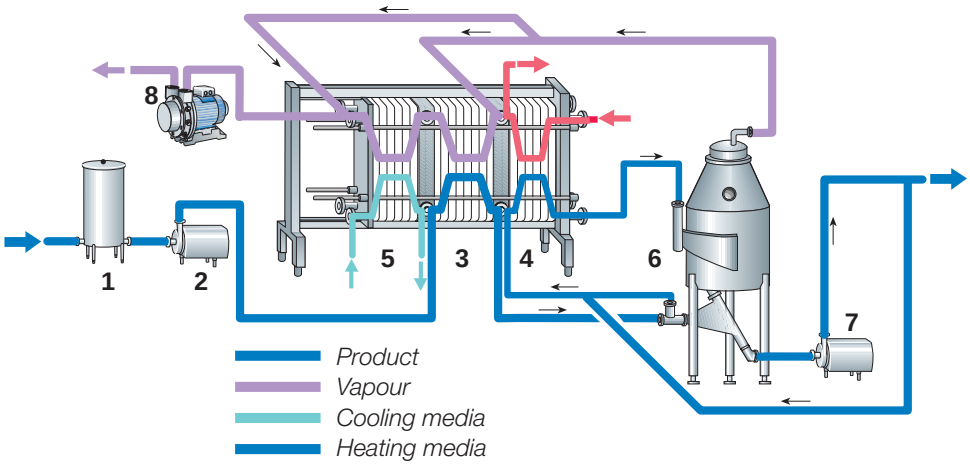
Fig. 6.5.2 *Product flow in a circulation evaporator.*

Circulation evaporators

Circulation evaporators can be used when a low degree of concentration is required or when small quantities of product are processed.

In yoghurt production, for example, evaporation is utilised to concentrate milk 1,1 – 1,25 times, or from 13 to 14,5 or 16,25 % solids content respectively. This treatment simultaneously deaerates the product and rids it from off-flavours.

The circulation evaporation process line is shown in Figure 6.5.3. The milk is heated to 90 °C and enters the vacuum chamber tangentially at a high velocity and forms a thin, rotating layer on the wall surface (Figure 6.5.2). As it swirls around the wall, some of the water is evaporated and the



1 *Balance tank*
2 *Feed pump*
3 *Pre-heating section/condenser*
4 *Temperature adjustment section*
5 *Cooling section/condenser*
6 *Vacuum chamber*
7 *Recirculation pump*
8 *Vacuum pump*

Fig. 6.5.3 *Process line for a circulation evaporator.*

vapour is drawn off to a condenser. Air and other non-condensable gases are extracted from the condenser by a vacuum pump.

The product eventually loses velocity and falls to the inwardly-curved bottom, where it is discharged. Part of the product is recirculated by a centrifugal pump to a heat exchanger for temperature adjustment, and then to the vacuum chamber for further evaporation. A large amount of product must be recirculated, to reach the desired degree of concentration. The flow through the vacuum chamber is four to five times the inlet flow to the plant.

Plate-type evaporator

Distribution in a plate-type falling-film evaporator can be arranged with two pipes running through the plate pack. For each product plate (in Figure 6.5.4), there is a spray nozzle in each product pipe, spraying the product in a thin, even film over the plate surface. In this case, the product enters at evaporation temperature to avoid instant flash evaporation during the distribution phase.

The water component of the thin product film evaporates rapidly as the

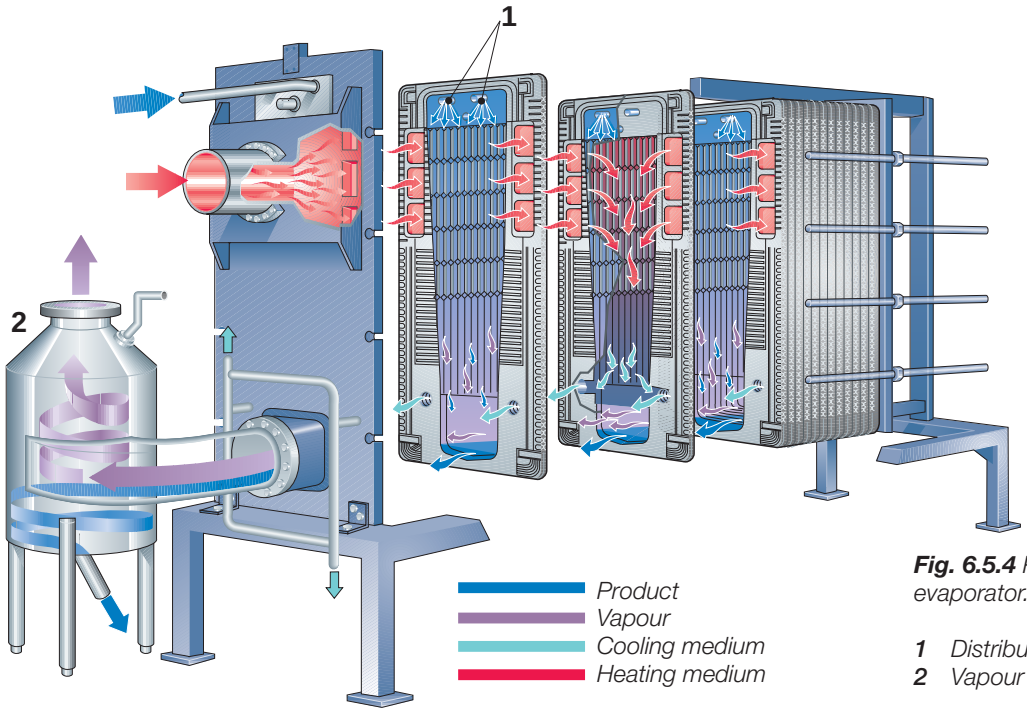


Fig. 6.5.4 *Plate-type cassette falling-film evaporator.*

1 *Distribution pipes with spray nozzles*
2 *Vapour separator*

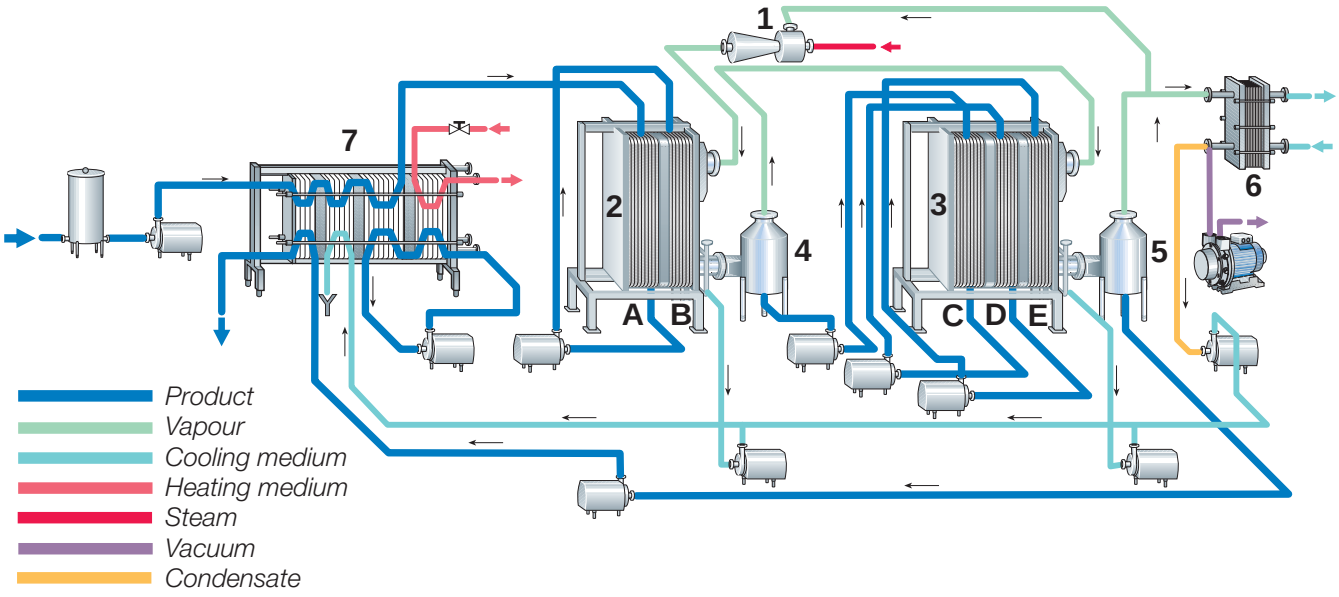


Fig. 6.5.5 *Two-effect cassette evaporator with thermocompressor.*

1 *Thermocompressor*
2 *First evaporation effect*
3 *Second evaporation effect*
4 *Vapour separator for first effect*
5 *Vapour separator for second effect*
6 *Plate condenser*
7 *Pre-heater*

A *First passage of first effect*
B *Second passage of first effect*
C *First passage of second effect*
D *Second passage of second effect*
E *Third passage of second effect*

product passes over the heating surface. A vapour cyclone separator (2) is fitted at the outlet of the evaporator. This separates the vapour from the concentrated liquid.

As evaporation proceeds, the volume of liquid decreases and the volume of vapour increases. If the vapour volume exceeds the available space, the velocity of the vapour will rise, resulting in a higher pressure drop. This will require a higher temperature difference between the heating steam and the product. To avoid this, the available space for vapour must be increased as vapour volume increases.

To achieve optimum evaporation conditions, the product film needs to have approximately the same thickness over the length of the heating surface. Since the volume of available liquid steadily decreases as the product runs down the heating surface, the perimeter of the heating surface must be decreased to keep the film thickness constant. Both these conditions are fulfilled by the plate design of the falling-film cassette evaporator shown in Figure 6.5.4. This unique solution makes it possible to evaporate using very small temperature differences at low temperatures.

The residence time in a falling-film evaporator is short, compared to other types. The combination of temperature and time in the evaporator determines the thermal impact on the product. Using a falling-film evaporator with a low temperature profile (low evaporation temperatures, small temperature differences, low heat load) is a considerable advantage for the concentration of dairy products which are sensitive to heat treatment.

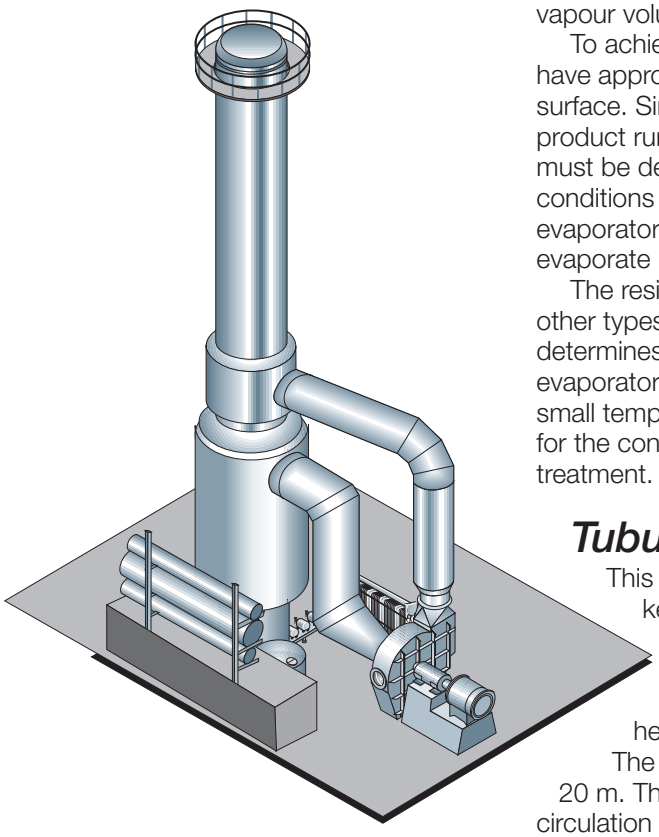


Fig. 6.5.6 *Tubular falling-film evaporator with mechanical recompressor. (CPS)*

Tubular evaporators

This is the evaporator type most often used in the dairy industry. The key to success with falling-film evaporators is to obtain uniform distribution of the product over the heating surfaces. Vertically arranged tubes are used for the most part, where the product flows downwards on the inner surface of the tubes and the heating steam condenses on the outer surface of the tubes.

The length of the tubes may vary between 15 m and more than 20 m. The length of the tubes is selected in order to promote good circulation of the heating steam around the tubes. The tubes are encased and provided with insulation.

The overall heating surface is divided into a number of sections and the

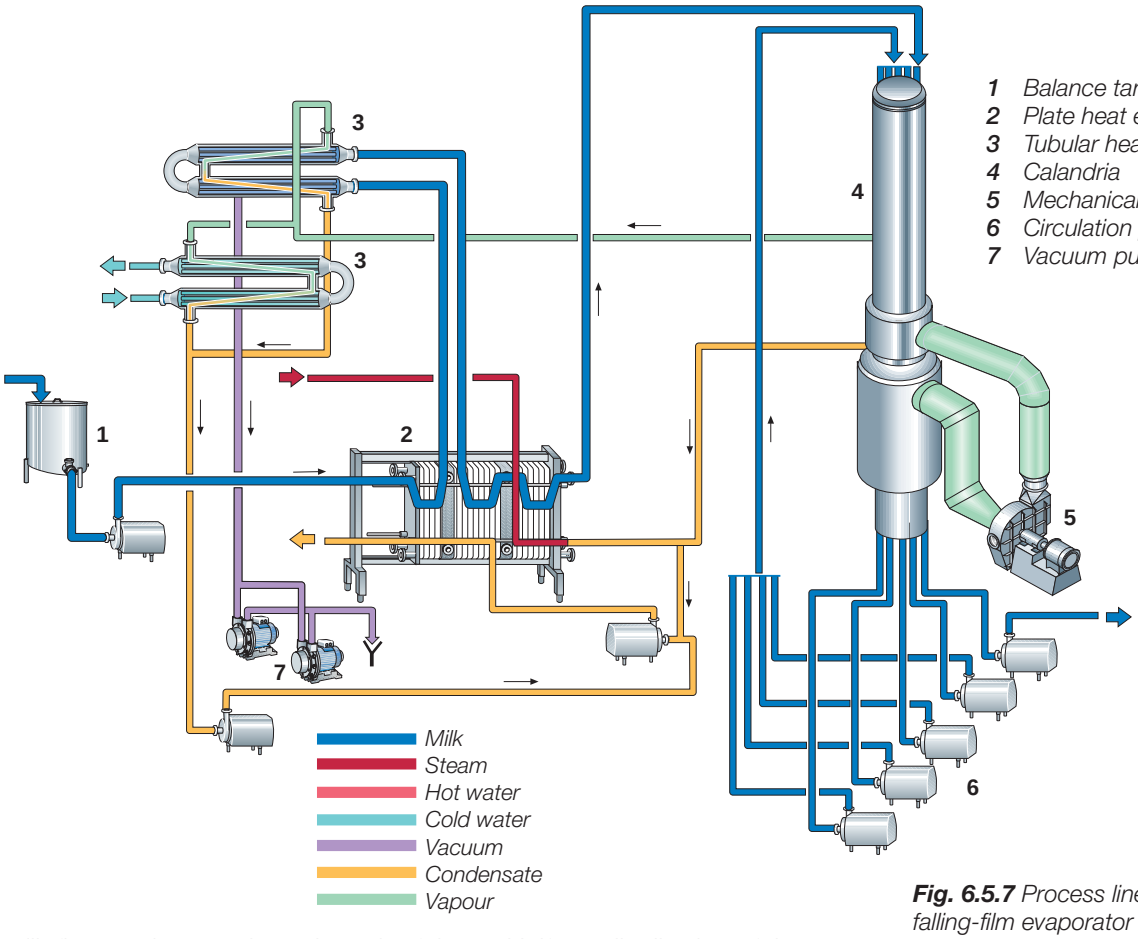


Fig. 6.5.7 *Process line for a tubular falling-film evaporator with mechanical recompression, MVR. (CPS)*

milk flows only once through each of these. Uniform distribution of the product over the heating surface is very important for economical operation of an evaporator. Gaps in the distribution lead to local overheating. This causes the product to stick, thereby impairing the transfer of heat into the product and impeding cleaning. This reduces production uptime.

Uniform product spreading in the head section (Figure 6.5.8) of the evaporator is required for good distribution, as is correct calculation of the sections. This is achieved by means of a horizontal spreader plate beneath the cover of the heater. Holes drilled concentrically around the downpipes lead the product into the tubes as a uniform film. Slightly superheating the product when feeding it into the spreader section makes it expand and thus ensures immediate partial evaporation and good distribution. The vapour forces the product to the inner surface of the evaporator tubes, where it flows away as a thin film.

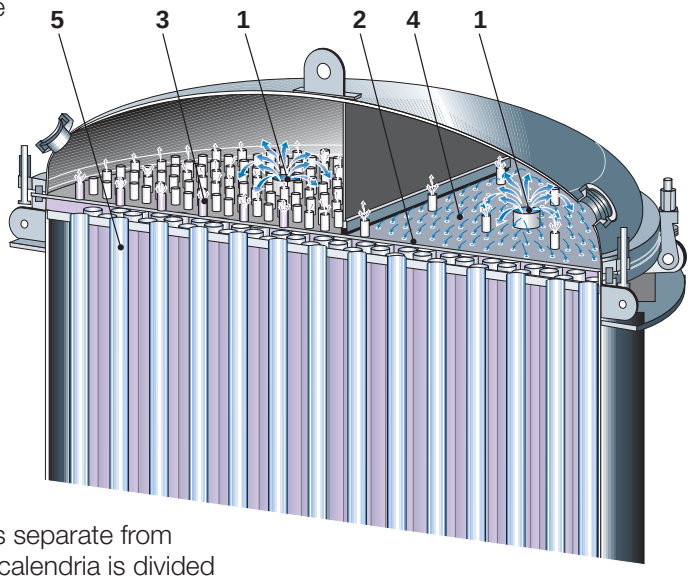


Fig. 6.5.8 *Upper section of the calandria in a falling-film tubular evaporator. (CPS)*

1 *Product feed tube*
2 *Distribution plate*
3 *Vapour tubes*
4 *Distribution holes*
5 *Falling-film tubes*

Pre-concentrators

Nowadays, falling-film tubular evaporators are mainly used for high capacity concentration in the dairy industry. The complete calandria heating unit is made of stainless steel, and it is divided into a number of sections separate from each other. Depending on the nature of the process the calendria is divided into 5 – 7 sections in a pre-concentrator.

The product is pumped to the top end of the first heating section and distributed to its tubes. The volume of the product is reduced by the evaporation of water that takes place during the downflow. At the bottom end of the section, the vapour evolved is removed and the product is collected in a sump. The product is pumped into the next section and back to the top end of the calandria.

The heat transfer surfaces of the sections arranged one after the other

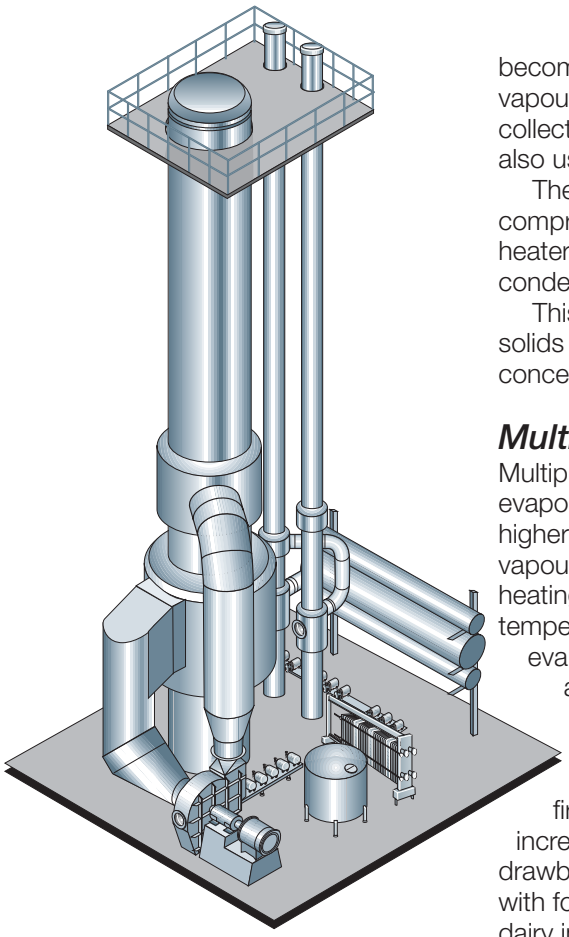


Fig. 6.5.9 *Falling-film tubular evaporator with MVR and finisher with thermocompressor. (CPS)*

become smaller and smaller due to the increasing concentration. The vapour evolved is usually kept separate from the product by an annular collector which is integrated in the calandria. External vapour separators are also used.

The compressor fan draws off the vapour from the collector and compresses it. The compressed vapour is forced into the casing of the heater, where it then condenses on the outer surface of the tubes. The condensate is pumped out and used for pre-heating the feed product.

This structure allows whey, for example, to be concentrated from a solids content of 6 % to a solids content of 32 %, and skim milk to be concentrated from a solids content of 9 % to a solids content of 36 %.

Multiple-effect evaporators

Multiple-effect evaporators are usually used. The theory is that if two evaporators are connected in series, the second effect can operate at a higher vacuum (and therefore at a lower temperature) than the first. The vapour evolved from the product in the first effect can be used as the heating medium for the next effect, which operates at a lower boiling temperature due to the higher vacuum. One kilogram of water can be evaporated from a product with a primary steam input of 0,6 kg, even allowing for heat losses.

It is also possible to connect several evaporator effects in series to further improve steam economy. However, this makes the equipment more expensive and involves a higher temperature in the first effect. The total volume of product in the evaporator system increases with the number of effects connected in series. This is a drawback in the treatment of heat-sensitive products. However, evaporators with four to seven effects and additional finishers have been used in the dairy industry for a long time now in order to save energy.

Thermal vapour recompression (TVR)

The vapour evolved from the product can be compressed and used as a heating medium. This improves the energy balance of the evaporator. A thermocompressor is used for this purpose.

Figure 6.5.10 shows a two-effect evaporator with a thermocompressor

1 *Balance tank*
2 *Plate heat exchanger*
3 *Tubular heat exchanger*
4 *Calandria, first effect*
5 *Collector*
6 *Calandria, second effect*
7 *Thermal recompressor*
8 *Circulation pumps*
9 *Vacuum pumps*
10 *Discharge pump*

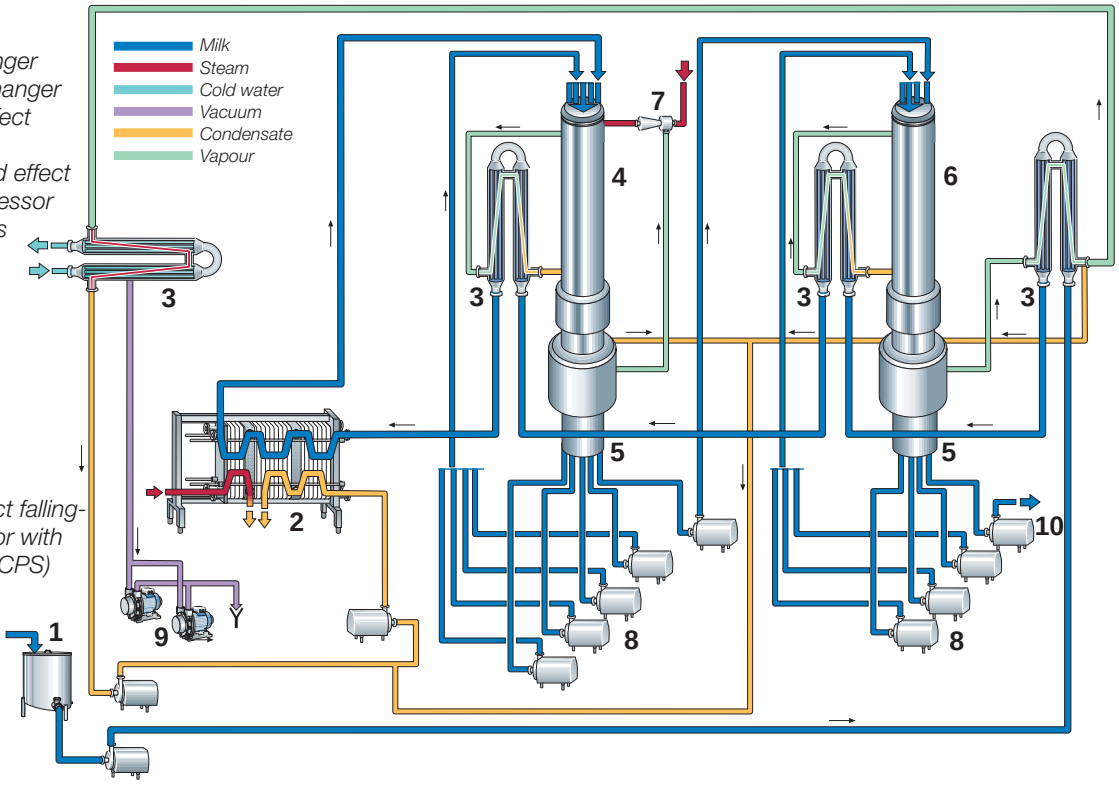


Fig. 6.5.10 *Two-effect falling-film tubular evaporator with thermocompressor. (CPS)*

for the evaporation of milk. Part of the vapour is supplied to the thermocompressor, to which high-pressure steam (600 – 1 000 kPa) flows. The compressor uses the high steam pressure to increase the kinetic energy, and the steam is ejected at high speed from the nozzle. This jet effect mixes the steam and the vapour from the product and compresses the mixture to a higher pressure. Using a thermocompressor together with a multiple-effect unit optimises the energy balance.

Process flow

The milk is pumped from a balance tank (1) to the pasteuriser (2), where it is pasteurised and heated to a temperature slightly above the boiling point of the first evaporator effect. The milk then continues to the first effect (4) of the evaporator, which is under a vacuum corresponding to a boiling temperature of 60 °C. The water evaporates and the milk is concentrated as the thin film of milk flows downwards in the tubes.

The concentrate is separated from the vapour in the collector (5) and pumped to the second effect (6). In this effect, the vacuum is lower, corresponding to a boiling temperature of 50 °C. After further evaporation in the second effect, the concentrate is again separated from the vapour in the collector (5) and pumped out of the system for further treatment (10).

The injection of high-pressure steam into the thermocompressor (7) increases the pressure of the vapour from the second effect. The live steam/vapour mixture is then used to heat the first effect (4).

Evaporation efficiency

A two-effect falling-film evaporator with thermocompressor requires about 0,32 kg of steam to evaporate 1 kg of water, and a five-effect evaporator requires 0,13 kg of steam. Without the thermocompressor, the specific steam consumption would be approx. 0,55 and 0,2 kg respectively per kg of water evaporation.

A five-effect evaporator with thermocompressor needs about 0,13 kg of steam to evaporate 1,0 kg of water.

Demand for lower energy consumption has led to the development of facilities with more than six effects, but certain limits must be observed in this instance. The maximum boiling temperature on the product side is normally no more than 70 °C in the first effect and 40 °C in the last.

Thus a temperature range of between 40 °C and 70 °C makes 30 °C available for the dimensioning of the evaporator. The greater the number of effects, the lower the temperature difference in each individual effect. Potential temperature differences are also reduced in the form of pressure drops and increased boiling temperatures. The sum of these in a multi-effect evaporator station may lead to restriction of the temperature difference of 5 – 15 °C. This requires larger heat transfer surfaces and results in higher capital costs. Larger heat transfer surfaces then mean greater difficulties in ensuring uniform distribution of the liquid over the heat transfer surfaces. Another disadvantage is the longer residence time of the product in the system. In a seven-effect evaporator with thermocompressor, it is possible to evaporate 12 kg of water with 1 kg of steam. This is equivalent to a specific steam consumption of 0,09 kg of steam per kg of water evaporation.

How far the concentration process can be forced is determined by product properties such as viscosity and sensitivity to heat. The solids content of skim milk and whole milk can be increased to 48 % and 52 % respectively. If concentrates with higher solids contents are required, the evaporator must have a special finishing effect (thickener).

Mechanical vapour recompression (MVR)

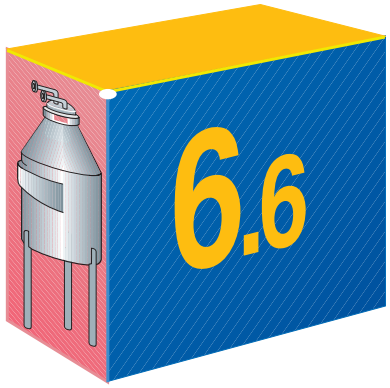
Unlike a thermocompressor, a MVR, mechanical vapour recompression system (fan), draws all the vapour out of the evaporator and compresses it before returning it to the heating side of the evaporator. Increasing the pressure of the vapour requires mechanical energy which drives the compressor. Thus during production, the evaporator requires no additional thermal energy, or only very little thermal energy towards the end of a

production cycle, apart from for the steam used for heat treatment before the first effect. Thus there is no residual vapour to be condensed.

Figure 6.5.9 shows an evaporator with mechanical vapour recompression and 2-stage finisher with thermocompressor. The compressed vapour is returned from the compressor to the pre-concentrator to heat the product. In the finisher, the vapour evolved from the second effect is then used to heat the first effect. A thermocompressor can be used to boost the steam pressure/temperature to the required level.

A pasteuriser heated with live steam is installed before the MVR effect in the system. Excess vapour is condensed in a separate condenser. Mechanical vapour recompression makes it possible to evaporate 80 – 100 kg of water with 1 kWh. Using an evaporator with mechanical vapour recompression can halve the operating costs compared to a conventional seven-effect evaporator with a thermocompressor.

Deaerators



Air and gases in milk

Milk always contains greater or lesser amounts of air and gases. The volume of air in milk in the udder is determined by the air content of the cow's bloodstream. The oxygen (O_2) content is low, being chemically bound to the hæmoglobin in the blood, while the carbon dioxide (CO_2) content is high because the blood carries large volumes of CO_2 from the cells to the lungs. The total volume of air in milk in the udder can be from around 4,5 to 6 %, of which O_2 constitutes about 0,1 %, N_2 (nitrogen) about 1 % and CO_2 3,5 to 4,9 %.

Milk is exposed to air in several ways during milking. Atmospheric oxygen dissolves in the milk, while CO_2 is released from it. Part of the air does not dissolve in the milk but remains in a finely dispersed form, often adhering to the fat.

After milking and collection in a churn or cooling tank, the milk may contain 5,5 to 7,0 % air by volume, with 6 % as an average figure (see Table 6.6.1).

The equilibrium that prevails between those three states of aggregation is determined by temperature and atmospheric pressure. When the temperature rises, during pasteurisation for instance, dissolved air goes from solution to dispersion. It is the dispersed air that causes problems in milk treatment.

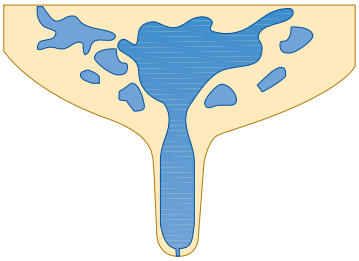


Fig. 6.6.1 *Milk in the udder contains 4,5 to 6 % gases.*

Table 6.1
Gas content (volume %) of commercial mixed raw milk

	Oxygen	Nitrogen	Carbon dioxide	Total gas
Minimum	0,30	1,18	3,44	4,92
Maximum	0,59	1,63	6,28	8,50
Average	0,47	1,29	4,45	6,21

Air in milk occurs in three states:
1 Dispersed
2 Dissolved
3 Chemically bound

Further air admixture

More air is introduced into the milk during handling at the farm and transportation to the dairy, and during reception at the dairy. It is not unusual for incoming milk to contain 10 % air by volume, or even more. Finely and coarsely dispersed air predominates at this stage. The basic problems caused by dispersed air are:

- Inaccuracy in volumetric measurement of milk.
- Incrustation of heating surfaces in pasteurisers (fouling).
- Reduced skimming efficiency in separators.
- Loss of precision in automatic in-line standardisation.

Dispersed air causes problems.

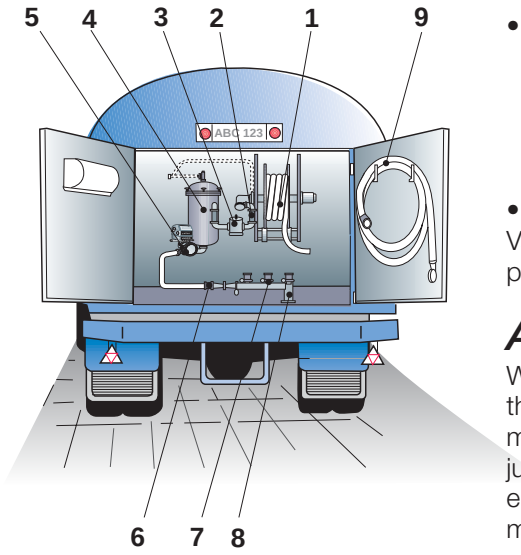


Fig. 6.6.2 *Back of a milk tanker.*

1 *Hose for collecting milk at the farm*
2 *Strainer*
3 *Pump*
4 *Air eliminator*
5 *Measuring device*
6 *Check valve*
7 *Valve cluster*
8 *Tank outlet*
9 *Hose for milk delivery at the dairy*

- Concentration of air in cream, causing
  - inaccurate in-line fat standardisation,
  - incrustation of cream heaters,
  - 'pre-churning' resulting in
    - loss of yield in butter production,
    - adhesion of free fat to the tops of packages.
- Reduction of the stability of cultured milk products (expulsion of whey).

Various methods of deaeration are therefore used to avoid jeopardising production and the quality of the products.

Air elimination at collection

When milk is collected in road tankers, from churns or bulk cooling tanks, the milk from each farm is normally measured by a volumeter. To optimise measuring accuracy, the milk should be passed through an air eliminator just before being measured. Most tankers are therefore provided with an air eliminator through which the farmer's milk must pass before being measured and pumped aboard the tanker.

One system (Wedholms, S) is shown in Figure 6.6.2. The pump equipment is placed in a cabinet at the rear end of the tanker. The equipment strains, pumps, eliminates air and measures the volume of the milk, before it enters the collecting tanks of the tanker.

The suction hose (1) is connected to the farmer's churns and/or bulk cooling tanks. The milk is sucked through a strainer (2) and pumped to the air eliminator (4). The positive displacement pump (3) is self-priming.

While the level of milk rises in the air eliminator, the float inside also rises; at a certain level the float closes the valve at the top of the vessel. The pressure inside the vessel increases and the check valve (6) is released. The milk flows via the measuring unit (5) to the valve cluster (7) and the tanks in the tanker. The tanker is emptied through the outlet (8) by the hose (9).

Milk reception

On arrival at the dairy, the milk will again contain dispersed air as a result of the jolting of the road tankers en route. Normally, the milk is measured as it is pumped to the reception tanks. Here again, the milk should first pass an air eliminator of the same type to ensure accurate measurement, (Figure 6.6.3).

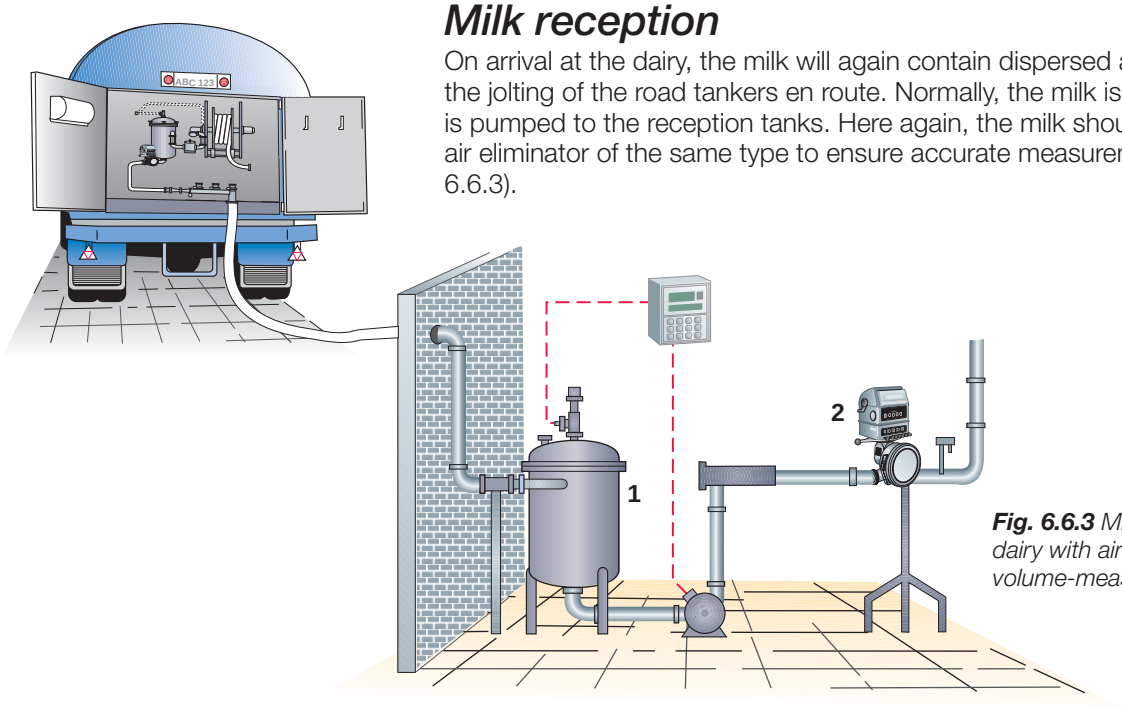


Fig. 6.6.3 *Milk reception at the dairy with air eliminator (**1**) and volume-measuring device (**2**).*

The inlet of the cylindrical vessel must be located at a lower level than the outlet pipe of the milk tank(s) on the vehicle, as the milk should not be pumped into the vessel, but transferred to it by gravity. The system can be manually or automatically operated.

In both cases, the efficiency of air elimination depends very much on how finely dispersed the air is. The smallest air bubbles cannot be removed.

Vacuum treatment

Vacuum deaeration has been used successfully to expel dissolved air and finely dispersed air bubbles from milk. Pre-heated milk is fed to an expansion vessel, (Figure 6.6.4), in which the vacuum is adjusted to a level equivalent to a boiling point about 7 to 8 °C below the pre-heating temperature. If the milk enters the vessel at 68 °C, the temperature will immediately drop to 68 – 8 = 60 °C. The drop in pressure expels the dissolved air, which boils off, together with a certain amount of the milk.

The vapour passes a built-in condenser in the vessel, condenses, and runs back into the milk, while the boiled-off air, together with non-condensable gases (certain off-flavours) is removed from the vessel by the vacuum pump.

For production of yoghurt the vacuum vessel is not provided with a condenser, as milk intended for yoghurt is often also slightly (15 – 20 %) concentrated. Condensation of vapour is arranged separately.

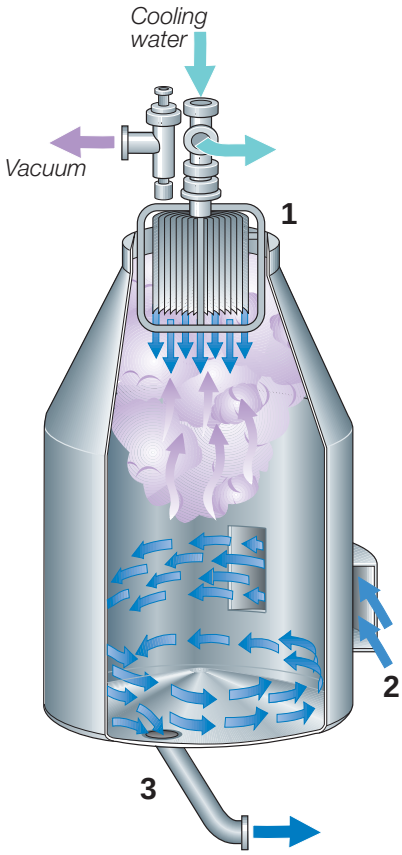


Fig. 6.6.4 *Flow of milk and air in the vacuum deaerator with built-in condenser.*

1 Built-in condenser
2 Tangential milk inlet
3 Milk outlet with level control system

Deaeration in the milk treatment line

Whole milk is supplied to the pasteuriser and heated to 68 °C. It then proceeds to the expansion vessel for vacuum treatment. To optimise the efficiency, the milk enters the vacuum chamber tangentially through a wide inlet, which results in exposure of a thin film on the wall. Expansion of the vapour flashed off from the milk at the inlet accelerates the flow of milk down the wall.

On the way down towards the outlet, which is also located tangentially, the velocity decreases. The feed and discharge capacities are thus identical. The deaerated milk, now at a temperature of 60 °C, is separated, standardised and homogenised before returning to the pasteuriser for final heat treatment.

With a separator integrated in the processing line, a flow controller must be placed before the separator to maintain a constant flow through the dearator. In this case, the homogeniser must be provided with a circulating loop. In a process line without a separator, the homogeniser (without a circulation loop) will maintain the constant flow through the deaerator.

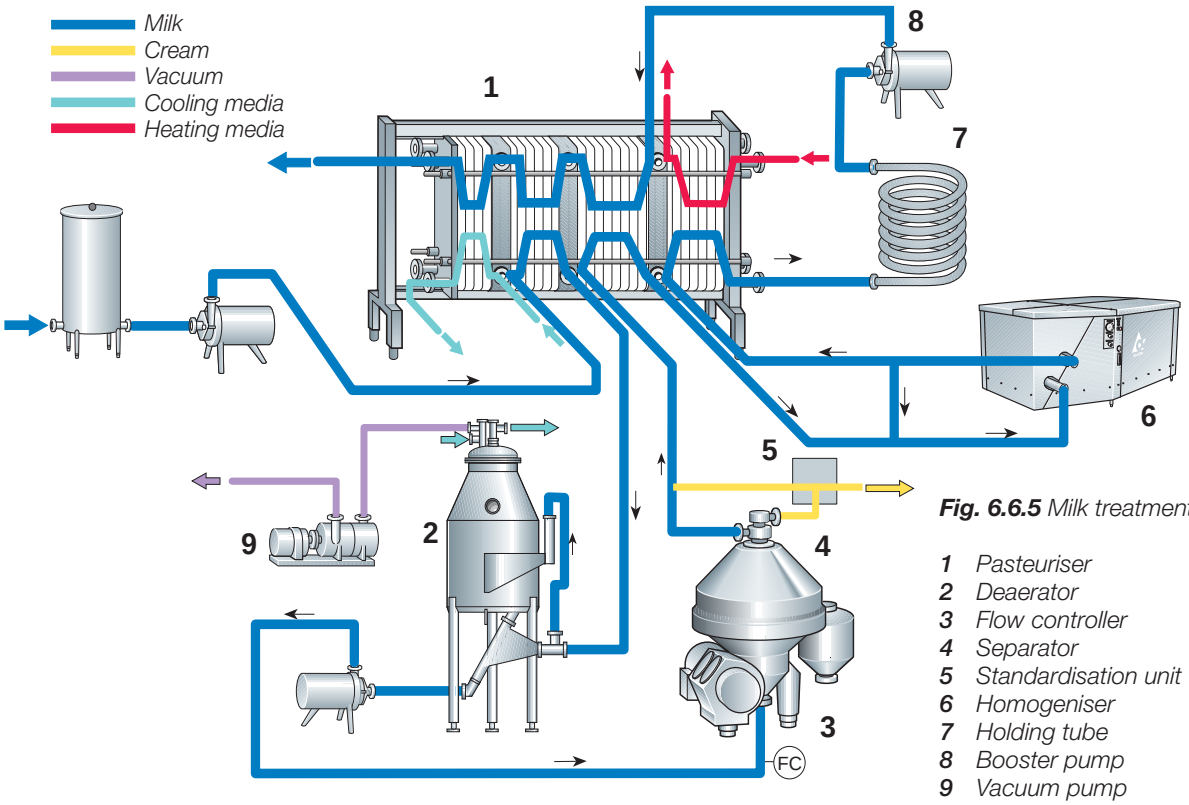
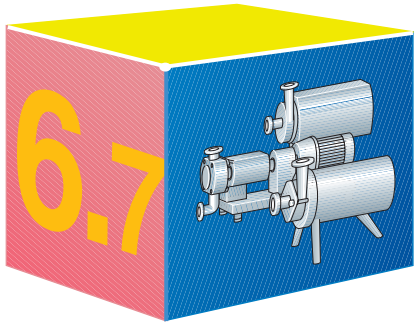


Fig. 6.6.5 *Milk treatment plant with deaerator.*

1 Pasteuriser
2 Deaerator
3 Flow controller
4 Separator
5 Standardisation unit
6 Homogeniser
7 Holding tube
8 Booster pump
9 Vacuum pump

Pumps



Pumping demands

Demands on the quality of products, and the profitability of manufacturing processes, have grown steadily heavier over the years. Formerly, it was often possible to allow liquids to flow through a plant by gravity. Nowadays, they are forced through long pipelines with many valves, through heat exchangers, filters and other equipment which often have high pressure drops. The flow rates are frequently high. Pumps are therefore used in numerous parts of a plant, and the need to have the right pump in the right place has become increasingly important. Many problems may arise; they can be summarised under the following headings:

- Pump installation
- Suction and delivery lines
- Type and size of pump required should be selected with regard to:
  - flow rate
  - product to be pumped
  - viscosity
  - density
  - temperature
  - pressure in the system
  - material in the pump

Typical dairy pumps are the centrifugal, liquid-ring and positive displacement pumps. The three types have different applications. The centrifugal pump is the type most widely used in dairies.

The centrifugal pump, shown in Figures 6.7.1 and 6.7.2, is mainly used for low-viscosity products, but it cannot handle heavily-aerated liquids. The liquid-ring pump is used when the air content is high. The positive displacement pump is used for gentle treatment and high viscosities.

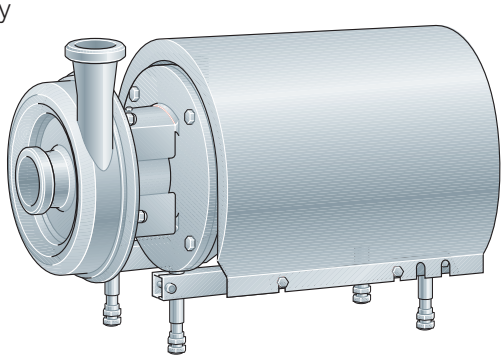


Fig. 6.7.1 *The most common type of sanitary pump in the dairy is the centrifugal pump.*

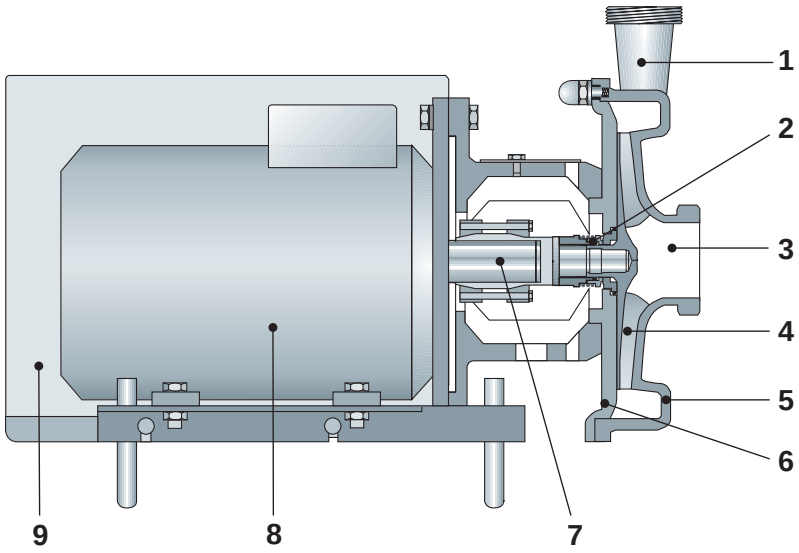


Fig. 6.7.2 *Main parts of a centrifugal pump.*

1 *Delivery line*
2 *Shaft seal*
3 *Suction line*
4 *Impeller*
5 *Pump casing*
6 *Back plate*
7 *Motor shaft*
8 *Motor*
9 *Stainless steel shroud and sound insulation*

Suction line

Before we discuss the pumps themselves, it is important to understand the facts and problems connected with pumping.

The pump should be installed as close as possible to the tank or other source from which the liquid is to be pumped, and with as few bends and valves as possible in the suction line. This should have a large diameter in order to reduce the risk of cavitation.

Delivery line

Any throttling valve must be fitted in the delivery line, possibly together with a check valve. The throttling valve is used to adjust the flow rate of the pump. The check valve protects the pump from water hammer and prevents liquid from flowing back when the pump has stopped. Normally, the check valve is situated between the pump and the throttling valve.

Cavitation

Cavitation can be detected by a crackling sound in the pump. It occurs when the pressure drops locally below the vapour pressure and small vapour bubbles form in the liquid. The pressure increases as the liquid continues further into the impeller, and the vapour condenses very rapidly. The vapour bubbles collapse at a very high velocity and at a local pressure, which can be as high as 100 000 bar. This is repeated with a high frequency and can cause pitting damage to the surrounding material, particularly if it is brittle.

Cavitation occurs when the pressure in the suction line is too low relative to the vapour pressure of the pumped liquid. The tendency to cavitate increases when viscous or volatile liquids are pumped.

Cavitation in pumps results in reduced head and efficiency. As cavitation increases, the pump gradually stops pumping.

Cavitation should be avoided. However, should the pumping conditions be very difficult, and the pump cavitates slightly but is otherwise operating well, it is still possible to use the pump. This is because dairy pumps have impellers of acidproof steel, which is very resistant to wear caused by cavitation. Some damage to the impeller may occur when the pump has been in operation for a long time.

The possibility of cavitation occurring in a pump can be predicted by calculation. See NPSH (Net Positive Suction Head) on the following page.

How to avoid cavitation

The general rule of thumb is:

- Low pressure drop in the suction line (large pipe diameter, short suction pipe, few valves, few bends, etc.)
- High inlet pressure to the pump, for example a high liquid level above the pump
- Low liquid temperature

Pump chart

Pump charts are invaluable for selecting a pump for a given application. Three curves are needed to select the correct pump.

- Flow rate and head, QH curve
- Required motor power, kW
- NPSH (net positive suction head)

The charts are drawn on the basis of tests with *water*. The data in the chart must be recalculated if liquids with other physical properties are to be pumped.

The required flow rate, Q, is usually known when a pump is going to be selected. In the example shown in Figure 6.7.3, the flow rate, Q, is 15 m^3/h. The required head must usually be calculated. Here we assume 30 m.

Locate the flow rate on the bottom Q scale. Start from this point and follow a vertical line upwards until it intersects a horizontal line indicating the required head, 30 m, on the H scale. This point does not meet any of the QH curves indicating the impeller diameter. The nearest larger impeller size, in this case 160 mm, should be chosen. The resulting head will be 31 metres liquid column.

The next step is to follow the vertical 15 m^3/h line downwards, until it intersects the power curve for the 160 mm impeller. A horizontal line to the left of the intersection indicates a power consumption of 2,3 kW. To this figure a safety margin of approximately 15 % must be added, giving a total

of around 2,6 kW. Therefore, a 3 kW motor can consequently be used.

If the pump is fitted with a motor of a certain size, always check that the motor is not overloaded. There should always be a safety margin for excess load.

Finally, the 15 m^3/h vertical line is followed to the NPSH curve, to the right in the top diagram. Following the horizontal line to the right, shows that the required NPSH value is 1 metre.

Head (pressure)

When selecting a pump, it should be remembered that the head, H, in the flow chart is the head of the pump when the liquid flows into the pump without suction lift or inlet pressure.

To obtain the actual pressure after the pump, it is necessary to consider the conditions on the suction side of the pump. If there is a vacuum in the suction line, the pump must do part of its work before the liquid reaches it. The pressure at the outlet is then lower than that given in the chart.

On the other hand, if the suction line is flooded to give positive pressure at the pump inlet, the outlet pressure will be higher than that shown in the chart.

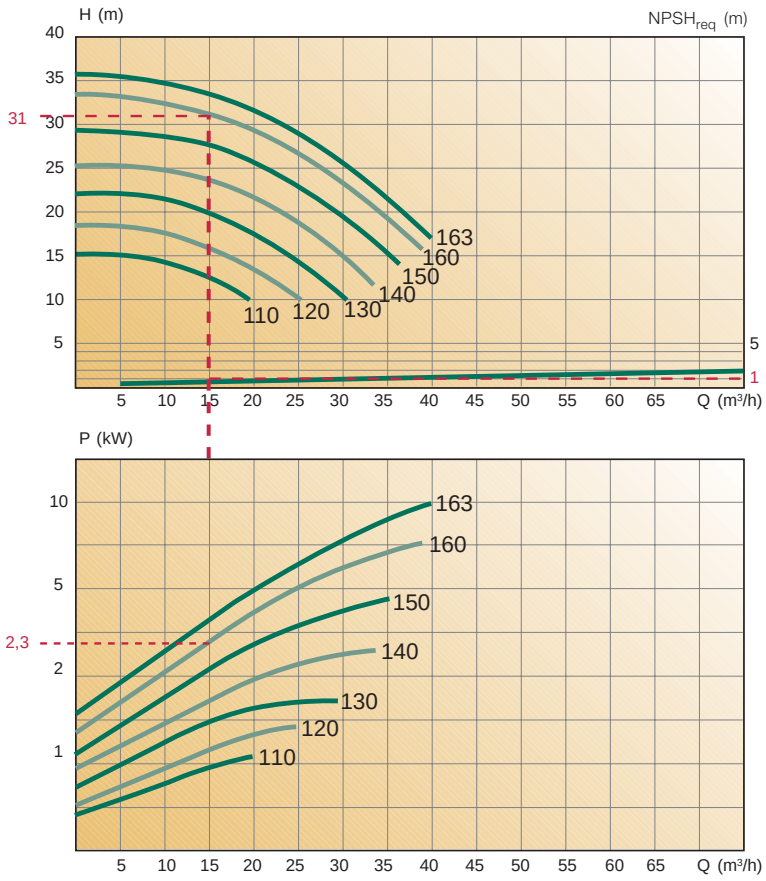


Fig. 6.7.3 *Pump chart for a centrifugal pump.*

NPSH (Net Positive Suction Head)

As previously mentioned, in planning a pump installation, it is important that the suction line is laid out so that the pump does not cavitate. An NPSH curve is included in the flow charts (Figure 6.7.3). The NPSH of a pump is the necessary excess pressure above the vapour pressure of the liquid required to avoid cavitation. This is called $NPSH_{req}$.

Before this can be used, the available NPSH of the suction line in prevailing operation conditions must be calculated. This figure, $NPSH_{av}$, should be equal to or higher than the required NPSH, which is the value in the chart.

The following formula is used to calculate $NPSH_{av}$ in the system:

p_a = pressure in bar abs at the liquid surface
p_v = vapour pressure in bar abs
d_r = relative density
h_s = static suction lift in metres liquid column
h_{fs} = pressure drop in suction line, metres liquid column

$$NPSH_{av} = h_s - h_{fs} + \frac{p_a}{d_r} \times 10 - \frac{p_v}{d_r} \times 10 \text{ m liquid column}$$

Note that h_s is negative for suction lift and positive for inlet pressure.

Shaft seals

The shaft seal is often the most sensitive component in a pump, as it must seal between a rotating part, impeller or shaft, and a stationary part, the pump casing. Normally a mechanical seal is used.

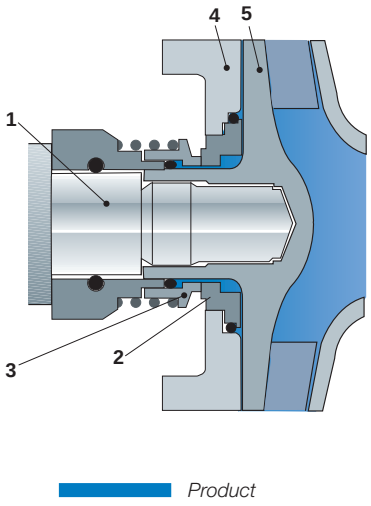
A rotating seal ring has a lapped sealing surface which rotates against a lapped stationary seal ring. A liquid film is formed between the sealing surfaces. The film lubricates the seal and prevents direct contact between the two seal rings. This means minimum wear and long life for the seal. If the pump runs dry, the lubricating liquid film in the seal is destroyed and wear on the sealing rings is increased.

The mechanical seal is usually balanced. This means that it is insensitive to the pressure in the pump. The sanitary mechanical seal needs no adjustment and causes no wear on the shaft. It is available in single or flushed versions.

Single mechanical shaft seal

Single mechanical seals, Figure 6.7.4, are standard in most sanitary pumps for the dairy industry.

In a mechanical seal the stationary seal ring is fastened to the back plate of the pump casing. The rotating ring can be fitted inside or outside the pump and is sealed with an O-ring. The rotating ring can move along the shaft and is pressed against the stationary ring by a spring.



1 Shaft *2* Stationary ring *3* Rotating ring *4* Back plate *5* Impeller

Fig. 6.7.4 *Single mechanical shaft seal.*

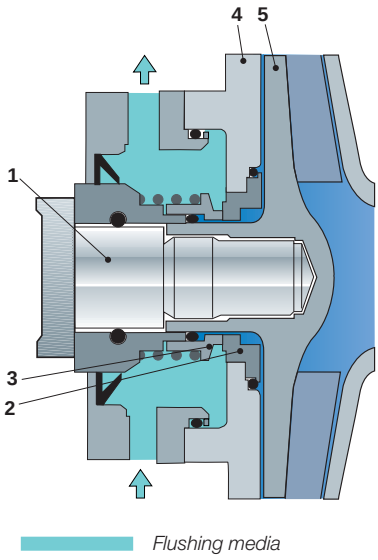


Fig. 6.7.5 *Flushed mechanical shaft seal.*

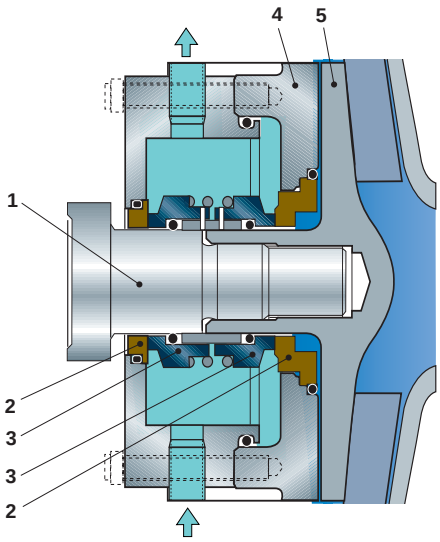


Fig. 6.7.6 *Double mechanical shaft seal with flushing media.*

Flushed shaft seal

The flushed seal, Figure 6.7.5, consists of two seals. Water or steam is circulated through the space between the two seals to cool or clean the seals or to create a barrier between the product and the atmosphere.

The flushed shaft seal is recommended for the following applications:

- With barrier steam for pumping sterilised products when reinfection must be avoided.
- Water flushing for pumping sticky solutions or products which crystallise, for example sugar solutions.
- Water cooling of the seal when matter may be deposited on the shaft at the seal and burn on because of the higher temperature at the sealing surfaces. An example is the booster pump in pasteurisers.
- Water barrier to exclude air from the product when pumping at a very low inlet pressure, *e.g.* from a vacuum vessel.

The barrier steam pressure must not exceed the atmospheric pressure at 100 °C, as the steam may then become dry. This would result in the seal running dry and the sealing surfaces being damaged. The steam and water supply is regulated at the inlet to the seal, and there must be no

obstructions in the outlet pipe. The barrier is always supplied through the lower connection.

Double mechanical shaft seal

The double mechanical seal, Figure 6.7.6, is similar to the flushed seal. However, the lip seal is replaced by a stationary/rotating seal arrangement similar to the single seal and the primary sealing parts of the flushed and double mechanical seals – hence the name "double mechanical".

The double mechanical seal can be used instead of a flushed seal and is recommended for the following applications:

- As a steam barrier for pumping sterilised products to avoid possible contamination
- For cleaning of abrasive products that may damage a lip seal arrangement
- To handle aggressive flushing fluids, such as those used in certain pharmaceutical or chemical processes, as these may damage a lip seal arrangement
- As a high-pressure flushing barrier (up to 5 bar) if a lip seal arrangement is not suitable

Internal shaft seal

Most pumps have external shaft seals, as the design is simple and they are the optimum solution from a hygienic point of view. The external seal is suitable for most applications.

For the external seal, the processed product is located inside the seal and product pressure forces the product out between the seal faces. This means that the external seal has a limitation regarding maximal product pressure, typically 10 bar.

Therefore, high inlet pressure and multi-stage centrifugal pumps need an internal shaft seal.

For the internal seal, the processed product is outside, surrounding the seal. This principle, together with heavy-duty designed seal parts, means that the internal seal can handle inlet pressures of up to 40 bar, see Figure 6.7.7.

The internal seal is available as a single seal or a flushed seal. Handling and suitability of the flushed seal is the same as for the external flushed seal.

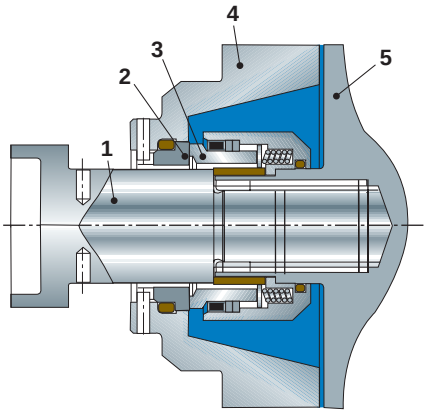


Fig. 6.7.7 *Internal shaft seal.*
1 *Shaft*
2 *Stationary ring*
3 *Rotating ring*
4 *Back plate*
5 *Impeller*

Material for shaft seals

A commonly used combination of materials is carbon for the rotating seal ring and stainless steel for the stationary ring. A better combination is silicon carbide against carbon. For abrasive liquids, seals with very hard faces are recommended. Silicon carbide against silicon carbide is commonly used for such applications.

Centrifugal pumps

Pumping principle

The liquid entering the pump is directed to the centre (eye) of the impeller and is set in circular motion by the impeller vanes, as in Figure 6.7.8. As a result of the centrifugal force and the impeller motion, the liquid leaves the impeller at a higher pressure and velocity than at the impeller eye. The velocity is partly converted into pressure in the pump casing before the liquid leaves the pump through the outlet connection.

The impeller vanes form channels in the pump. The vanes are normally curved backward, but may be straight in small pumps.

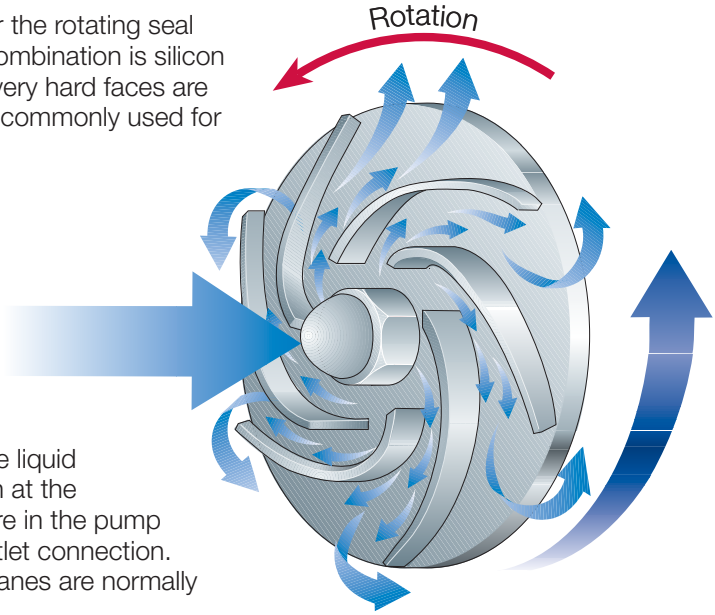


Fig. 6.7.8 *Flow principle in a centrifugal pump.*

Centrifugal pump types

Different types of centrifugal pump are available, depending on the application requirements.

These types are:

- Standard centrifugal pump
- High inlet pressure centrifugal pump
- Multi-stage centrifugal pump
- Self-priming centrifugal pump

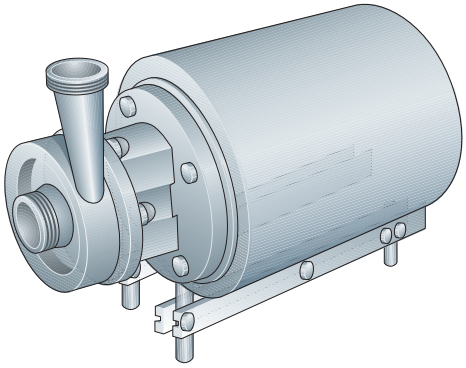


Fig. 6.7.9 *Centrifugal pump adapted for high inlet pressure.*

Standard centrifugal pump

This is the cheapest and most commonly used centrifugal pump, as it is suitable for most non-viscous applications.

The standard pump has some limitations regarding high inlet and system pressures, as well as aerated applications. In these cases other centrifugal pump types should be used.

High inlet pressure centrifugal pump

This pump is specially designed for applications with high inlet pressure requirements, such as filtration systems.

The special-purpose parts in this pump are a specialised motor, heavy-walled pump casing, thick backplate and a hygienic internal mechanical shaft seal to withstand the high inlet pressure, Figure 6.7.9.

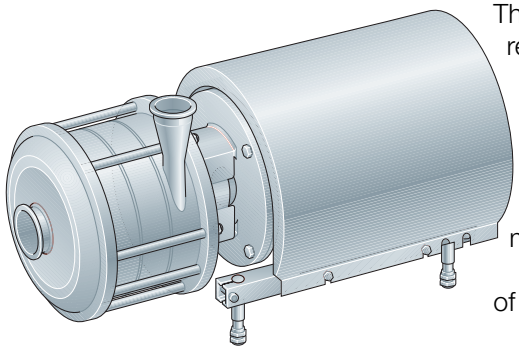


Fig. 6.7.10 *Multi-stage centrifugal pump for high outlet pressure.*

Multi-stage centrifugal pump

This pump is specially designed for high outlet pressure requirements at relatively low capacities. Pumps of this type are typically used as booster pumps.

The pump consists of several stages and it works in a similar way to several pumps coupled in series.

Its special-purpose pump design includes several impellers and intermediate casings, thick backplate and a hygienic internal mechanical shaft seal, Figure 6.7.10.

The motor is either standard or special purpose, depending on the level of inlet pressure.

Self-priming centrifugal pump

This self-priming pump is specially designed for aerated applications, such as CIP return systems.

The pump is a standard centrifugal pump that is equipped with a tank, two non-return valves and a tee.

If it is only pumping fluids, the pump works as a normal centrifugal pump. However, if air/gases enter the pump, the special tank/non-return valve design will create a vacuum and separate and expel the air/gases through the pump discharge until only fluids remain. The pump will then resume work as a normal centrifugal pump.

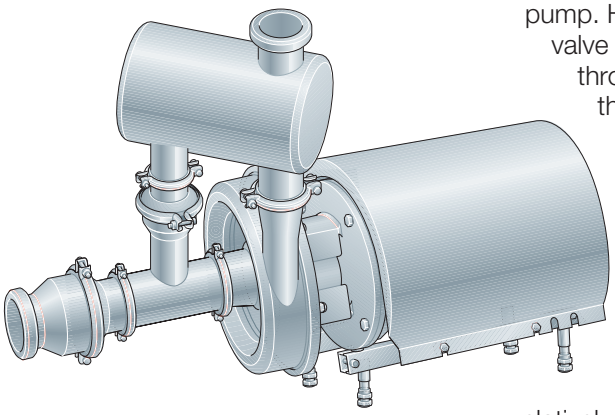


Fig. 6.7.11 *Self-priming pump equipped with tank and valves.*

Centrifugal pump applications

The centrifugal pump is the most commonly used pump in the dairy industry and should be selected if it is suitable for the application in question. The reason for this is that a centrifugal pump is usually cheaper to purchase, operate and maintain, and is also the most adaptable pump for different operating conditions.

The centrifugal pump can be used for pumping of all liquids of relatively low viscosity which do not require particularly gentle treatment. It can also be used for liquids containing relatively large particles, provided of course that the particle size does not exceed the dimensions of the impeller channel.

A disadvantage of the centrifugal pump is that it cannot pump aerated liquids; it loses prime and stops pumping. It must then be stopped and

primed – filled with liquid – and started again before it can continue pumping. Consequently, *the centrifugal pump is not self-priming* and the suction line and pump casing must be filled with liquid before it can operate. The installation should therefore be carefully planned.

Flow control

It is seldom possible to select a standard pump that fits the required capacity exactly. Some sort of adaptation must therefore be made by:

- throttling – highly flexible but uneconomical
- reducing the impeller diameter – less flexible but more economical
- speed control – flexible and economical

The three alternatives are illustrated in Figure 6.7.12.

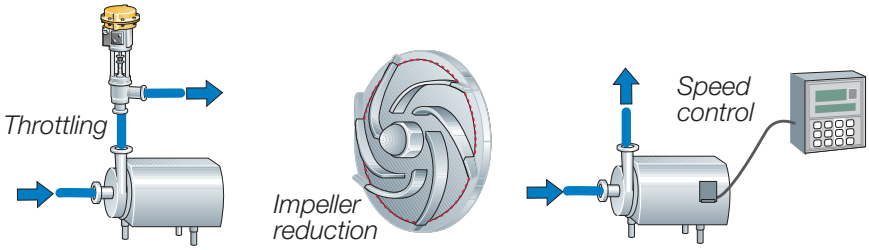


Fig. 6.7.12 *Methods of flow control in a centrifugal pump.*

Throttling

The most simple flow control is to fit a throttling valve in the pump outlet line. It is then possible to adjust the pump exactly to the required pressure and flow rate. This is the correct method if the pump is used for varying pressures and flow rates. The disadvantage is that throttling is uneconomical when pressure and flow are constant.

Throttling can be carried out with orifice plates in the pipe, with manual or automatic control valves or with a mechanical flow controller, which is often fitted in milk treatment lines.

Reducing impeller diameter

A lower pump curve than the maximum curve is obtained by reducing the original impeller diameter D to D_1 (Figure 6.7.13). The new diameter D_1 can be roughly determined by drawing a straight line from O on the chart through the required operating point A to the standard curve B, for impeller diameter D. Read pressure H and the required new pressure H_1. The new impeller diameter D_1 is obtained from the formula:

$$D_1 = D \times \sqrt{\frac{H_1}{H}}$$

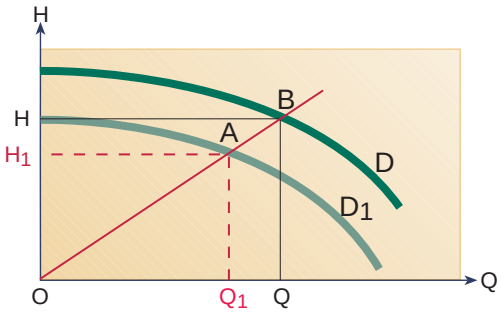


Fig. 6.7.13 *Flow reduction when the impeller diameter is reduced from D to D_1.*

The most economical pump installation is obtained if the impeller diameter is reduced to diameter D_1. Most pump charts have curves for different impeller diameters.

Speed control

Changing the speed will change the centrifugal force created by the impeller. Pressure and capacity will then also change – up for higher speed and down for lower.

Speed control is the most efficient way of regulating a pump. The speed of the impeller is always exactly right for the performance of the pump, and therefore also the power consumption and the treatment of the liquid.

A frequency converter can be used, together with standard three-phase motors. They are available for manual or automatic control of flow and pressure.

Pumps for 60 Hz

Most centrifugal pumps are designed for 50 Hz, which means 3 000 rpm (revolutions per minute) for a two-pole motor. The power supplies in some countries operate at 60 Hz, which means that the speed increases by 20 % to 3 600 rpm. Pump curves for 60 Hz are available from pump manufacturers.

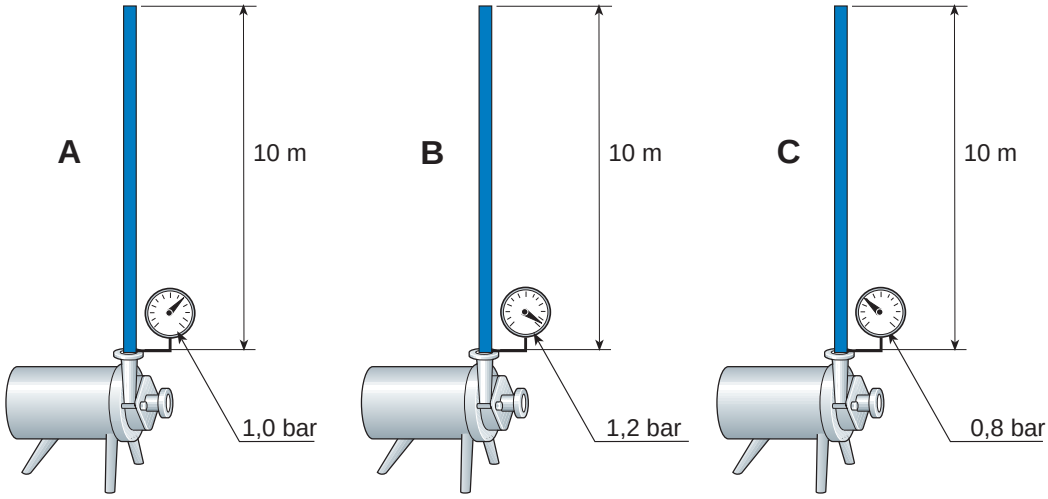
Note:
In the pump flow charts, the head is always in metres liquid column and the power consumption for water with density 1,0. This means that for pumping liquids of higher density, the power in the curve must be multiplied by the density.

Head and pressure

Density

The head in metres liquid column is independent of the density of the liquid being pumped. However, the density is of great importance to the discharge pressure and for the power consumption.

If the pump and the viscosity of the liquid are the same in the different cases, the liquid column will be lifted to the same height (10 metres in the example), regardless of the density. The pump head in metres liquid column is the same. However, as the density – the mass of the liquid – varies, the pressure gauge readings will also vary (Figure 6.7.14).



A *Pumping water of relative density = 1,0*
10 m ***liquid*** *col*
10 m ***water*** *col = 1,0 bar*

B *Pumping sugar solution of relative density = 1,2*
10 m ***liquid*** *col = 12 m*
water *col = 1,2 bar*

C *Pumping alcohol of relative density 0,8*
10 m ***liquid*** *col = 8 m*
water *col = 0,8 bar*

Fig. 6.7.14 *Comparison of liquid and water columns for products with different densities.*

The pump pressure in metres water column is consequently obtained if the pressure in metres liquid column is multiplied by the relative density.

The pump must do more work with the heavier liquid than with the lighter. The power required changes proportionally to the *density*. If, in example A, the figure requires 1 kW, then example B will require 1,2 kW and example C only 0,8 kW.

Viscosity

Liquids of higher viscosity create higher resistance to flow than liquids of lower viscosity. When liquids of higher viscosity are pumped, the flow rate and head are reduced and power demand increases because of increased flow resistance in the impeller and pump casing.

Centrifugal pumps can handle liquids of relatively high viscosities, but are not recommended for viscosities much above 500 cP, because the power demand rises sharply above that level.

Liquid-ring pumps

Liquid-ring pumps (Figures 6.7.15 and 6.7.16) are self-priming if the casings are at least half-filled with liquid. They can then handle liquids with a high gas or air content.

The pump consists of an impeller with straight radial vanes (4) rotating in a casing, an inlet, an outlet and a drive motor. From the inlet (1), the liquid is led between the vanes and accelerated out towards the pump casing, where it forms a *liquid ring* with essentially the same speed of rotation as the impeller.

There is a channel in the wall of the casing. It is shallow at (2) and becomes progressively deeper and wider as it approaches (3) and then gradually becomes shallow again to point (6). As the liquid is transported by the vanes, the channel is also filled, increasing the volume available for the liquid between the vanes. This results in a vacuum in the centre, which causes more liquid to be drawn into the space from the suction line.

The deep channel (3) has been passed, the volume between the vanes is reduced as the channel becomes shallower. This gradually forces the liquid towards the centre and increases the pressure and liquid is discharged through port (7) to pump outlet (5).

Air in the suction line will be pumped in the same way as the liquid.

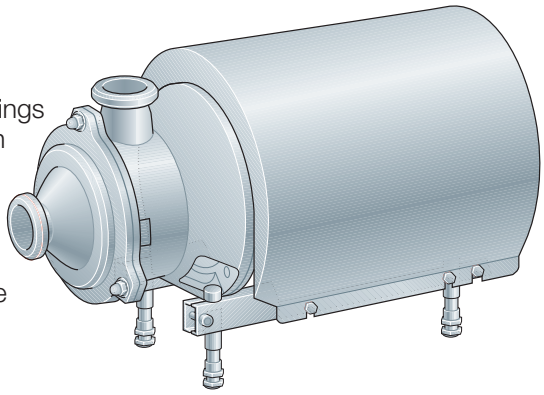


Fig. 6.7.15 *Liquid-ring pump.*

Applications

Liquid-ring pumps for the dairy industry are used where the product contains large quantities of air or gas, and where centrifugal pumps therefore cannot be used. The clearances between impeller and casing are small, and this type of pump is therefore not suitable for handling abrasive products.

A common application is as a CIP return pump for cleaning solution after a tank, as the CIP solution contains normally large amounts of air.

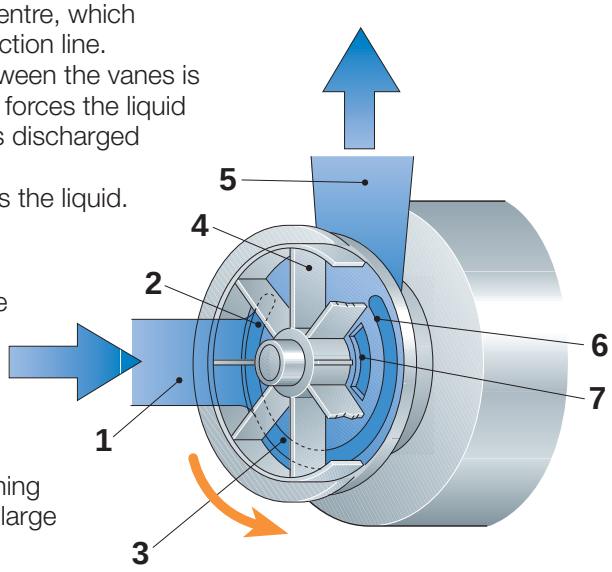


Fig. 6.7.16 *Working principle of a self-priming liquid-ring pump.*

1 *Suction line*
2 *Shallow channel*
3 *Deep channel*
4 *Radial vanes*
5 *Pump outlet*
6 *Shallow channel*
7 *Discharge port*

Positive displacement pumps

Pumping principle

This group of pumps works on the positive displacement principle. They are divided into two main categories: rotary pumps and reciprocating pumps. Each category includes several types.

The principle of a positive displacement pump is that for each revolution or each reciprocating movement, a definite net amount of liquid is pumped, regardless of manometric head, H.

However, at lower viscosities there may be some *slip* (internal leakage) as the pressure increases. This will reduce the flow per revolution or stroke. The slip is reduced with increased viscosity.

Throttling the outlet of a positive displacement pump will increase the pressure dramatically. It is therefore important that:

1 No valve after the pump can be closed
2 The pump is fitted with a pressure-relief valve, built into the pump or as a by-pass valve.

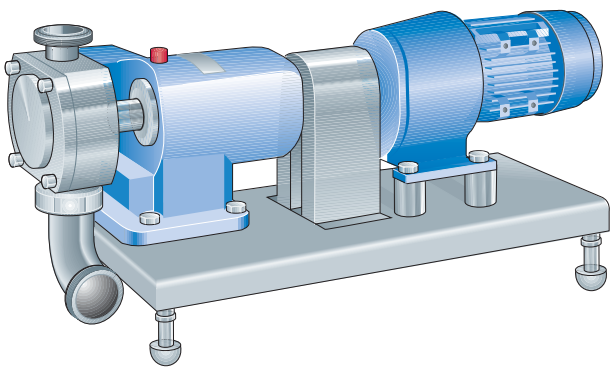


Fig. 6.7.17 *Positive displacement pump of the lobe-rotor type with geared motor assembled on a frame.*

Flow control

The flow of a positive displacement pump is normally controlled by regulating the speed. Adjustment of the stroke of a reciprocating pump is another possibility.

Pipe dimensions and lengths

Great care must be taken in dimensioning the pipework when high-viscosity products are pumped. The pumps must then be placed close to the

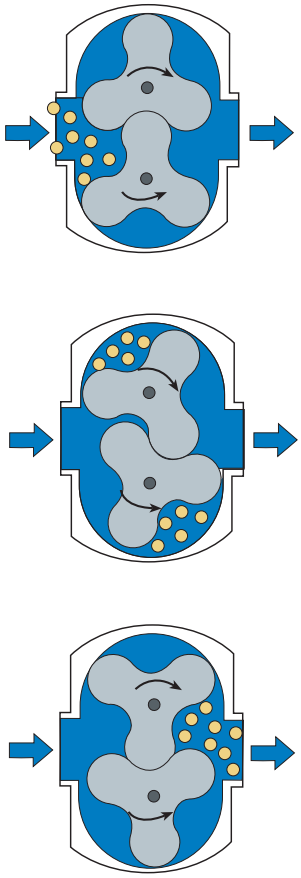


Fig. 6.7.18 *Lobe-rotor pump principle.*

feeding product tank and the pipe dimensions must be large. Otherwise the pressure drop will be so high that the pump will cavitate.

The same applies to the outlet side. The pressure will be very high if the pipes are long and narrow.

Lobe-rotor pumps

The lobe-rotor pump (Figure 6.7.17) has two rotors, usually with 2 – 4 lobes each. A vacuum is created at the inlet when the rotors rotate. This vacuum draws the liquid into the pump. It is then moved along the periphery of the pump casing to the outlet. There, the volume is reduced and the liquid forced out through the outlet. The course of events is illustrated in Figure 6.7.18.

The rotors are independently driven by a timing gear at the back of the pump. The rotors do not touch each other or the pump casing, but the clearances between all parts in the pump are very narrow.

Applications

This type of pump has 100 % volumetric efficiency (no slip) when the viscosity exceeds approximately 300 cP. Because of the sanitary design and the gentle treatment of the product, this type of pump is widely used for pumping cream with a high fat content, cultured milk products, curd/whey mixtures, etc.

Eccentric-screw pumps

This pump is tighter than the lobe rotor pump for lower viscosity products. It is not considered quite as hygienic as the lobe-rotor pump, but handles the pumped product gently. The range of application is the same as that of the lobe-rotor pump.

The eccentric-screw pump (Figure 6.7.19) cannot be run dry, even for a few seconds, without being damaged.

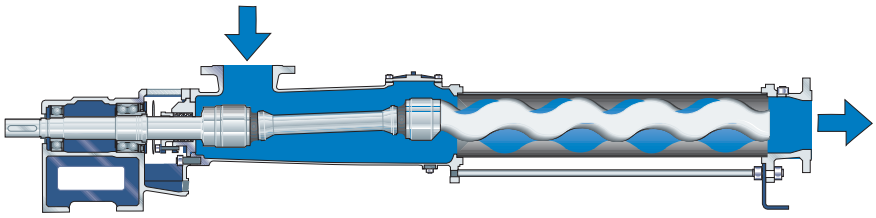


Fig. 6.7.19 *The eccentric-screw pump.*

Piston pumps

A piston pump normally has 1, 2, 3 or 5 pistons, Figure 6.7.20. A rotating crankshaft drives the pistons backwards and forwards via a piston rod. Check valves on both the suction- and pressure side regulate the flow in the right direction.

A 5-piston pump gives a less pulsating flow than a 3-piston one.

Piston pumps are normally used when high pressure and low energy consumption are required. The high-pressure homogeniser is an example of a piston pump followed by a homogenising device.

Volumetric efficiency is also close to 100 % at low viscosity and varying

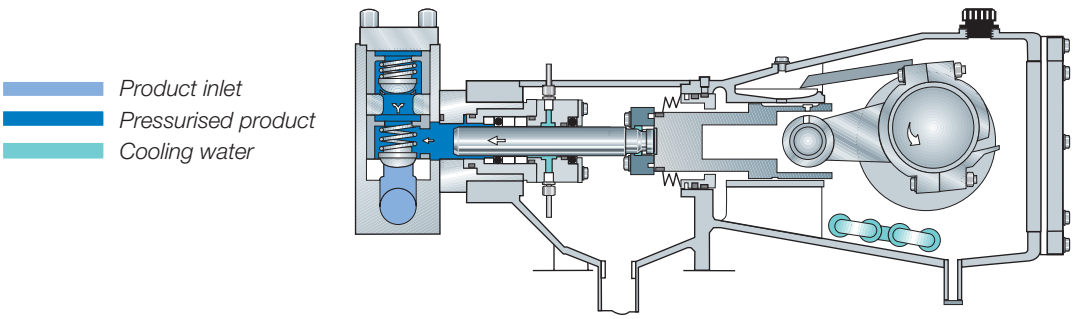


Fig. 6.7.20 *Piston pump.*

back pressure. A piston pump can therefore be used as an accurate metering pump. The capacity is proportional to the crankshaft speed.

For metering purposes, a special type of piston pump can be used. The capacity of each piston is adjusted via its stroke length. This type of pump is used when several different components are mixed in given proportions. Each piston handles one component.

Diaphragm pumps

Air-powered diaphragm pumps, one of which is illustrated in Figure 6.7.21, are used for gentle treatment of the product. There are pulsations in the outlet pressure and the capacity will change with changing product pressures, as the air pressure is constant. These pumps are therefore mainly used to transport products and not used very often within the processes themselves.

Mechanically powered diaphragm pumps are often used as metering pumps.

Working principle

Diaphragm pumps are double-acting positive displacement pumps with two alternating pump chambers. The compressed air required for driving the unit is admitted through a control valve to the rear of each diaphragm in turn. This displaces the medium from alternate pump chambers.

The diaphragm has the additional function of separating the pumped product from the compressed air. Since the same pressure prevails in both the compressed air and pumping chambers during each stroke, the diaphragms themselves are not subjected to pressure differences. This is one reason for the long life of the diaphragms.

A vacuum is created by the retraction of the diaphragm, and the pumped product flows into the chamber. The volume in the opposite chamber is simultaneously reduced, and the product is discharged through the outlet check valve.

The two diaphragms are connected with a common piston rod, and suction therefore always occurs in one chamber while product is discharged from the other. The compressed air serves a dual purpose during each phase: the actual discharge process and the intake of further medium to be conveyed.

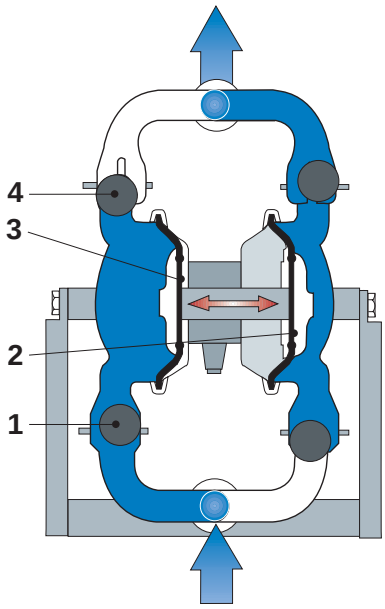


Fig. 6.7.21 *The diaphragm pump.*
1 *Open ball valve during sucking*
2 *Sucking diaphragm*
3 *Pumping diaphragm*
4 *Closed ball valve*

Peristaltic pumps (hose pumps)

This type of pump (Figure 6.7.22) can be used for transportation as well as for relatively accurate metering of products.

The rotor rotates in the lubricant-filled pump housing and compresses the hose with the rollers. The suction and discharge sides are hermetically sealed from each other.

During rotation, the medium (liquid or gas) inside the hose is transported to the lower outlet connection. This creates a vacuum on the suction side, and the product is drawn into the pump. The pump is *self-priming* and is therefore suitable for emptying barrels with juice concentrates and anhydrous milk fat (AMF).

The volume between the rollers is equal to half the volume transported per rotation. This amount is constantly pumped to the outlet connection during rotation, while the same amount is drawn in on the suction side.

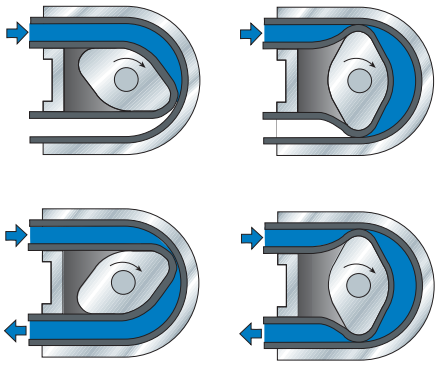
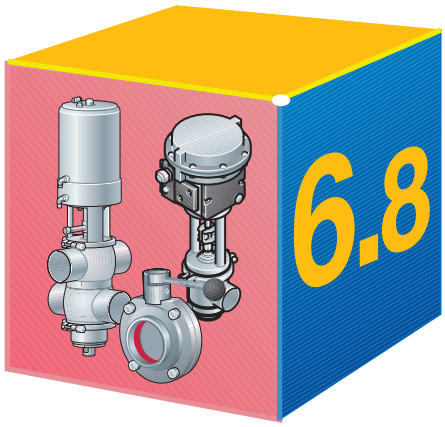


Fig. 6.7.22 *Pumping sequence of a peristaltic pump.*

Pipes, valves and fittings



The pipe system

The product flows between the components of the plant in the pipe system.

A dairy also has conduit systems for other media such as water, steam, cleaning solutions, coolant and compressed air. A waste-water system to the drain is also necessary. All these systems are basically built up in the same way. The difference is in the materials used, the design of the components and the sizes of the pipes.

All components in contact with the product are made of stainless steel. Various materials are used in the other systems, *e.g.* cast iron, steel, copper and aluminium. Plastic is used for water and air lines, and ceramic for drainage and sewage pipes.

The following section deals only with the product line and its components. The pipe systems for service media are described in the section dealing with utility installations.

The following types of fittings are included in the product pipe system:

- Straight pipes, bends, tees, reducers and unions
- Special fittings such as sight glasses, instrument bends, etc.
- Valves for stopping and directing the flow
- Valves for pressure and flow control
- Pipe supports

For hygiene reasons, all product-wetted parts of dairy equipment are made of stainless steel. Two main grades are used, AISI 304 and AISI 316. The latter grade is often called acidproof steel. Corresponding (not exactly equivalent) specifications for European steel grades are:

USA	AISI 304	AISI 316	AISI 316L
Europe	EN 1.4301	EN 1.4401	EN 1.4404

Connections

Permanent joints are welded (Figure 6.8.1). Where disconnection is required, the pipe connection is in the form of a threaded union with a male end and a retained nut with a joint ring in between, or a clamped union with a joint ring (Figure 6.8.2).

The union permits disconnection without disturbing other pipework. This type of joint is therefore used to connect process equipment, instruments, etc. that need to be removed for cleaning, repair or replacement.

Different countries have different union standards. These can be SMS (Swedish Dairy Standard) also used internationally, DIN (German), BS (British), IDF/ISO* and ISO clamps (widely used in the USA).

Bends, tees and similar fittings are available for welding, and with welded

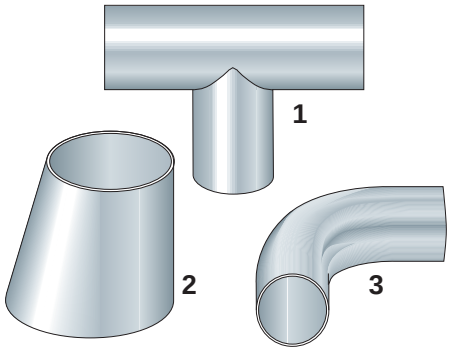


Fig. 6.8.1 *Some examples of fittings for permanent welding.*
1 *Tees*
2 *Reducers*
3 *Bends*

*) *IDF = International Dairy Federation*
ISO = International Standardisation Organisation

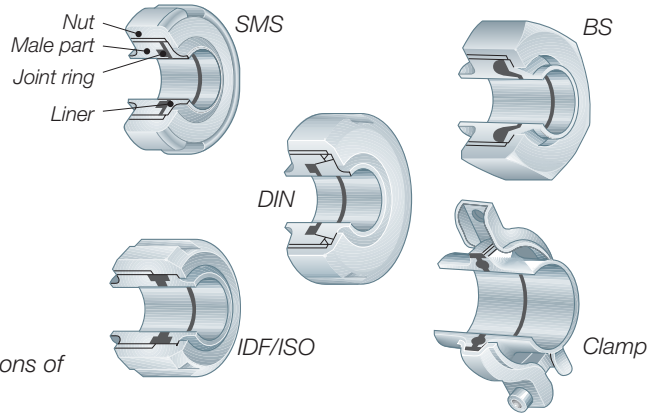


Fig. 6.8.2 *Dairy unions of different standards.*

unions. In the latter case, the fitting can be ordered with nut or male ends or with clamp fittings.

All unions must be tightened firmly to prevent liquid from leaking out or air from being sucked into the system and causing problems in downstream parts of the process.

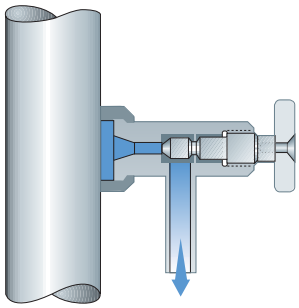


Fig. 6.8.3 *Sampling cock.*

Special pipe fittings

Sight glasses are fitted in the line where a visual check of the product is required.

Bends with instrument connections are used for fitting instruments like thermometers and gauges. The sensor should be directed against the flow to make readings as accurate as possible. The connection boss can also be used for a sampling cock. Instrument connections can also be provided with welding special bosses directly onto the pipe during installation.

Sampling devices

Sampling devices need to be installed at strategic points in the plant to collect product samples for analysis. For quality control, such as determining the fat content of milk and the pH value of cultured products, the samples can be collected from a sampling cock (Figure 6.8.3).

For hygienic quality tests, the sampling method must preclude any risk of contamination from outside the pipe. A sampling plug can therefore be used. This plug, shown in Figure 6.8.4, has a rubber bung at the bottom. The plug is first removed and all parts that could contaminate the sample are sterilised (typically a wad moistened in a chlorine solution just before sampling), after which the needle of a hypodermic syringe is inserted through the bung into the product, and a sample is withdrawn.

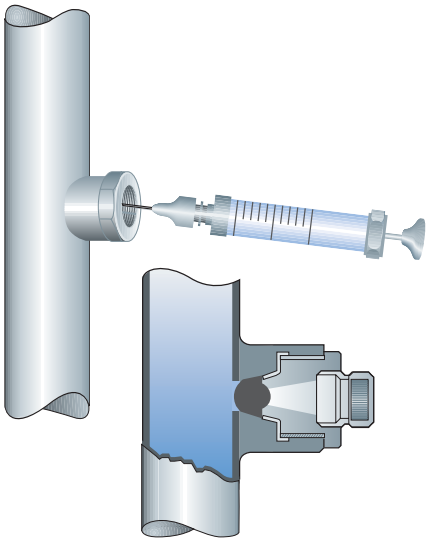


Fig. 6.8.4 *Sampling cock for bacteriological analysis.*

The aseptic sampling valve (Figure 6.8.5) consists of three parts, a valve body, a valve head and a membrane. The rubber membrane is placed on the stem of the valve head and works as a stretchable plug. The aseptic sampling valve is designed for sterilisation before and after each sampling.

The manual valve is opened by rotating a handle or by activating a lever. The stem and the membrane are then retracted, allowing liquid to pass.

Using the reverse procedure the built-in spring closes the valve and keeps the channel between the hose pieces open for sterilisation.

Samples of aseptic products – heat treated at such a high temperature that they are sterile – are always collected through an aseptic sampling valve to avoid reinfection.

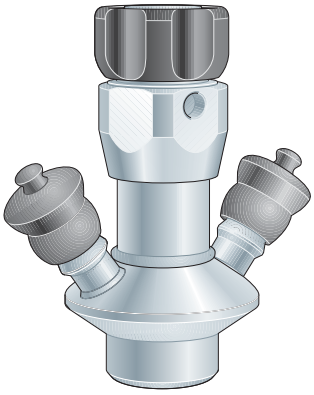


Fig. 6.8.5 *Plug for aseptic sampling.*

Valves

Mixproof valve systems

There are many junctions in a piping system where product normally flows from one line to the other, but which must sometimes be closed off so that two different media can flow through the two lines without being mixed.

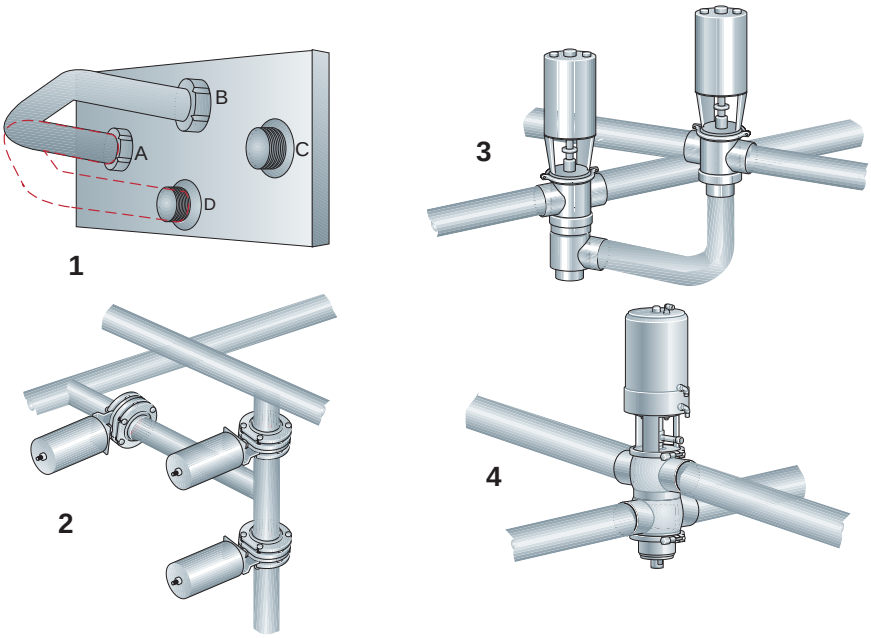


Fig. 6.8.6 *Sanitary mixproof valve systems.*
1 Swing bend for manual change between different lines.
2 Three shut-off valves can perform the same function.
3 One shut-off valve and one change-over valve can do the same job.
4 One mixproof valve is enough for securing and switching the flow.

When the lines are isolated from each other, any leakage must go to drain without any possibility of one medium being mixed with the other.

This is a common problem faced when engineering dairy plants. Dairy products and cleaning solutions flow in separate lines, and have to be kept separate. Figure 6.8.6 shows four different solutions to the same task.

Shut-off and change-over valves

There are many places in a piping system where it must be possible to stop the flow or divert it to another line. These functions are performed by valves.

Seat valves, manually or pneumatically controlled, or butterfly valves, are used for this purpose.

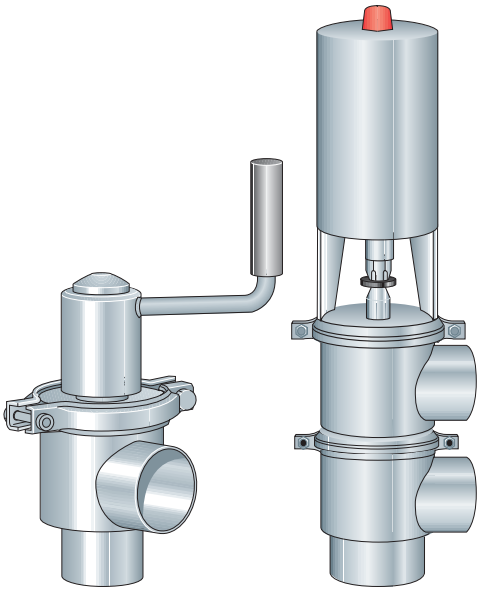


Fig. 6.8.7 *Manual shut-off seat valve and pneumatically operated change-over seat valve. The operating mechanism is interchangeable between shut-off and change-over seat valves.*

Seat valves

The valve body has a seat for the closing plug at the end of the stem. The plug is lifted from and lowered onto the seat by the stem, which is moved by a crank or a pneumatic actuator (Figure 6.8.7).

The seat valve is also available in a change-over version. This valve has three to five ports. When the plug is lowered, the liquid flows from inlet 2 to outlet 1, and when the plug is lifted to the upper seat, the flow is directed through outlet 3, according to the drawings to the right in Figure 6.8.8.

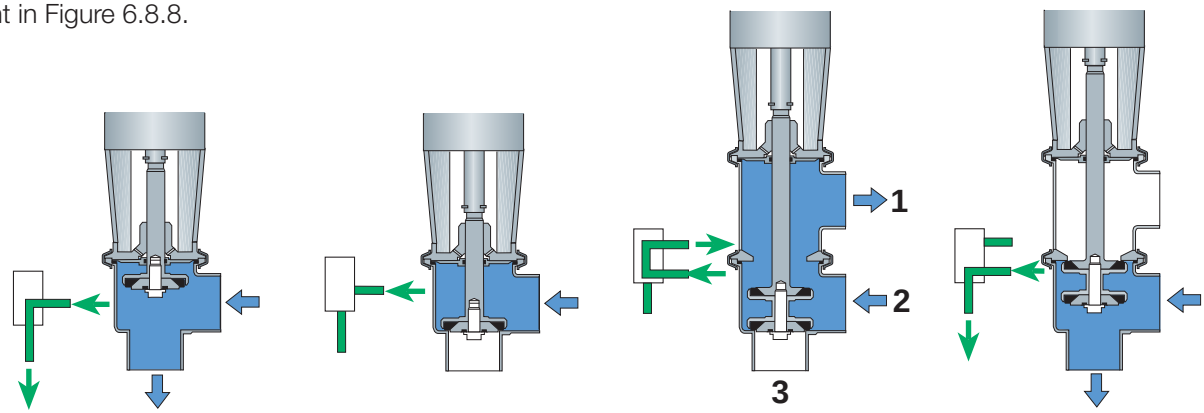


Fig. 6.8.8 *Shut-off and change-over valves with the plug in different positions and the corresponding flow chart symbols.*

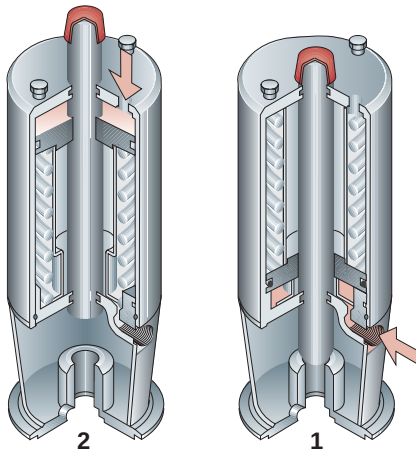


Fig. 6.8.9 *Examples of pneumatically operated actuators.*
1 Valve opened by spring. Closed with compressed air.
2 Valve closed by spring. Opened with compressed air.

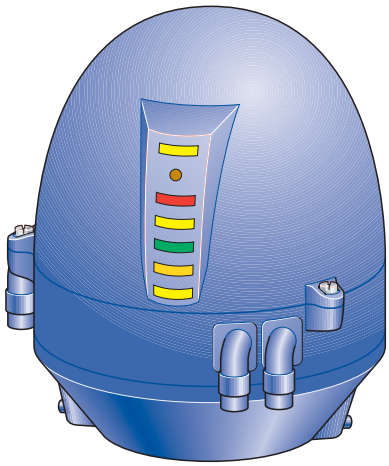


Fig. 6.8.10 *The valve plug position indicator and control unit is fitted on top of the actuator.*

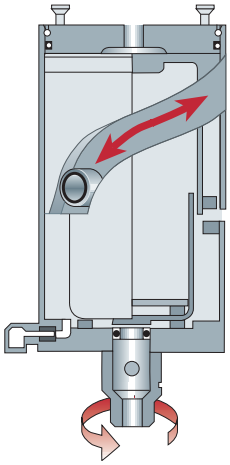


Fig. 6.8.12 *Principle of the air driven actuator for butterfly valves.*

This type of valve can have up to five ports. The number is determined by the process requirements.

There is also another type of seat valve, where the valve plug closes against the flow to eliminate pressure chocks in the product lines. This type of valve can be either in change-over or shut-off version.

Various remote-controlled actuator alternatives are available. For example, the valve can be opened by compressed air and closed with a spring, or vice versa. It can also be both opened and closed by compressed air (Figure 6.8.9).

Actuators for an intermediate plug position and for two-stage opening and closing are also available.

The valve control unit (Figure 6.8.10) is fitted on the top of the valve actuator. The top unit includes indication unit, activation stem, sensor system and solenoid valves to control and supervise all kinds of pneumatic processing valves. It receives signals from a PLC to control the valve and it sends feedback signals to the PLC to indicate when the valve is in a certain position.

The top unit can easily be set by remote control and indicate seat lift of mixproof valves and it includes a maintenance program to indicate when plug seals of a single seat is worn out.

The modern top units can be used for digital as well as bus communication systems. More basic top units can be used only in digital systems for simple control and indication of open/closed valve positions.

A solenoid valve is fitted in the top unit. An electric signal triggers the solenoid valve and allows compressed air to enter the actuator. The valve then opens or closes as required. On the way, the compressed air passes through a filter to free it from oil and other foreign matter that might affect proper operation of the valve. The air supply is cut off when the solenoid is de-energized and the air in the product valve is then evacuated through an exhaust port in the solenoid valve.

Butterfly valves

The butterfly valve (Figure 6.8.11) is a shut-off valve. Two valves must be used to obtain a change-over function.

Butterfly valves are often used for sensitive products, such as yoghurt and other cultured milk products, as the restriction through the valve is very small, resulting in very low pressure drop and no turbulence. It is also good for high viscosities and, being a straight-through valve, it can be fitted in straight pipes.

The valve usually consists of two identical halves with a seal ring clamped between them. A streamlined disc is fitted in the centre of the valve. It is usually supported by bushes to prevent the stem from seizing against the valve bodies.

With the disc in the open position, the valve offers very low flow resistance. In the closed position, the disc seals against the seal ring.

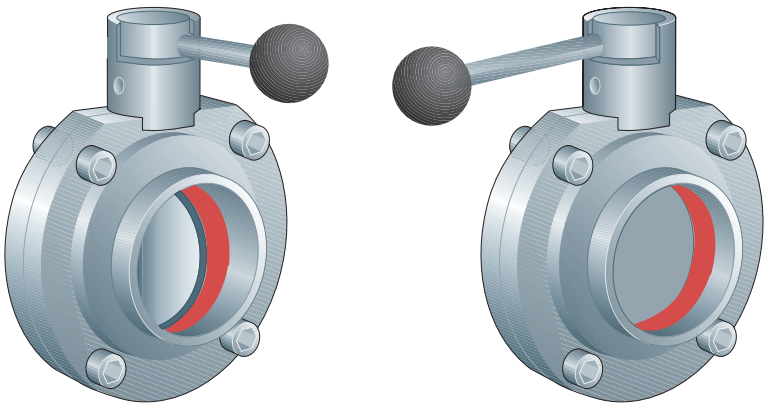


Fig. 6.8.11 *Manually controlled butterfly valve in open position (left) and in closed position (right).*

Manual control

The butterfly valve is fitted with a handle, usually for two positions – open and closed.

This type of valve is not really suitable as a control valve, but can be used for coarse control with a special handle for infinite positions.

Automatic control

An air actuator (Figure 6.8.12) is used for automatic control of the butterfly valve. The function can be:

- Spring closing/air opening (Normally closed, NC)
- Air closing/spring opening (Normally open, NO)
- Air opening and closing (A/A)

The disc is easy to turn until it touches the seal ring. Then it needs more power to compress the rubber. A normal, spring powered actuator is strongest in the beginning, when less power is required, and weaker at the end, when more power is required. It is therefore an advantage to use actuators which are designed so that they provide the correct power at the right time.

Another type of the butterfly valve is the "sandwich" valve, shown in Figure 6.8.13. It is the same type of butterfly valve as described above, but it is fitted between two flanges welded to the line. Its function is the same as an ordinary butterfly valve. During operation, it is clamped between the flanges with screws. For servicing, the screws are loosened. The valve part can then be pulled out for easy servicing.

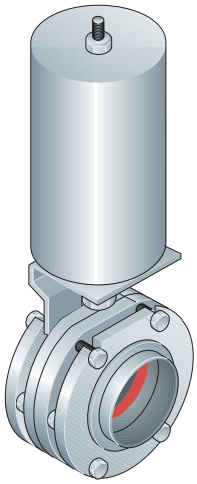


Fig. 6.8.13 *Pneumatically operated butterfly "sandwich" valve design for simplified maintenance.*

Mixproof valves

Mixproof valves (Figure 6.8.15) can be either double- or single-seated, but when discussing mixproof valves, it is generally the double-seat type (Figure 6.8.14) that is referred to.

A double-seated valve has two independant plug seals separating two liquids, forming a leakage chamber between them under atmospheric pressure during every working condition. In case of rare accidental leaking of product, this will flow into the leakage chamber and be discharged through the leakage detection pipe.

When the valve is open, the leakage chamber is closed. The product can then flow from one line to the other.

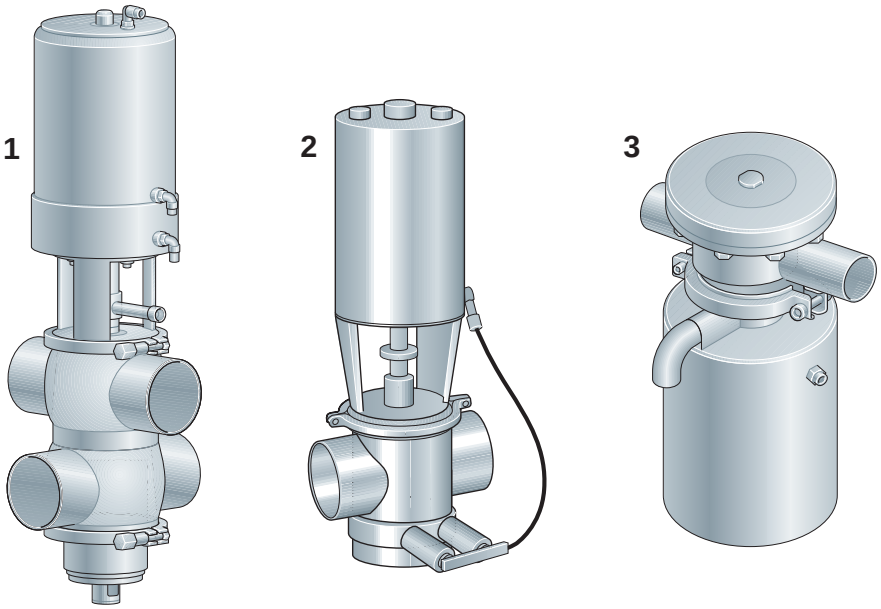


Fig. 6.8.15 *Three types of mixproof valves.*
1 *Double-seat valve with seat-lift cleaning*
2 *Single-seat valve with external cleaning and leakage indication*
3 *Tank outlet valve*

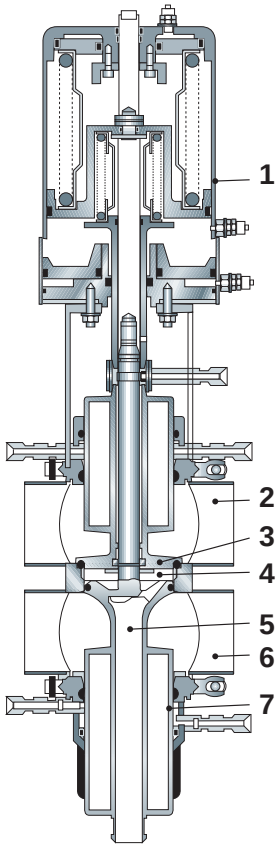


Fig. 6.8.14 *Double-seat mixproof valve with balanced plug and built-in seat lift*
1 *Actuator*
2 *Upper port*
3 *Upper plug*
4 *Leakage chamber*
5 *Leakage detection pipe*
6 *Lower port*
7 *Lower plug with balancer*

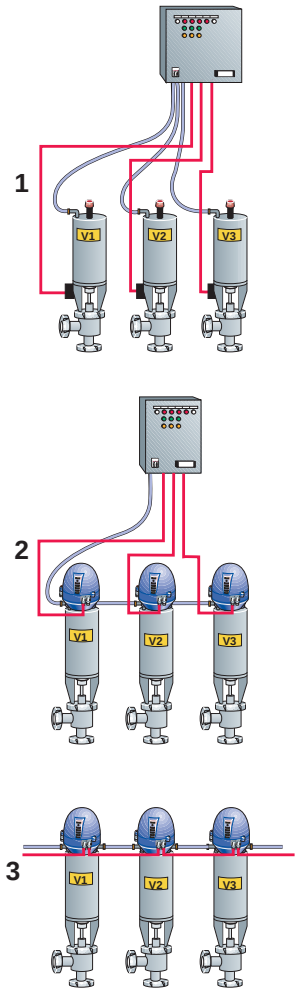


Fig. 6.8.16 *Valve position indication systems.*
1 *Indication only*
2 *Indication with top unit*
3 *Indication and control system*

During cleaning one (upper or lower) of the plugs lift so that seat and plug are cleaned. The cleaning liquid is discharged through the leakage chamber. External cleaning of upper and lower plugs and leakage chamber, as well as aseptic-like operation are also possible.

The valve can be cleaned and water hammer protected to any level according to the needs in the specific process. There is virtually no spillage of product when operating the valve.

It is also possible to have a double-seated tank outlet valve. This is designed for mixproof tank outlet operation when cleaning of the line right up to the bottom of the tank is required.

The independent seat lift of the lower plug provides easy cleaning without the need of external cleaning. The lower plug is insensitive to high pressure and water hammer in the line.

The tank outlet valve is compact and the valve body can be turned in any angle to fit the piping.

Position indication and control

Position indication only

A valve can be fitted with various types of position indication (Figure 6.8.16), depending on the control system of the plant. Different types of switches are microswitches, inductive proximity switches or Hall elements. The switches are used for feedback signals to the control system.

When only switches are fitted to the valves, it is necessary to have one solenoid valve for each valve in a solenoid-valve cabinet. A solenoid valve supplies compressed air to the product valve when it receives a signal and releases the air pressure when the signal disappears.

This system (1) requires one electric cable and one air hose for each valve.

The combined unit (2) is a basic top unit, which is fitted on the top of the valve actuator. It includes activation stem, sensor system and solenoid valves. One air hose can supply many valves but one electric cable per valve is still required.

The ultimate control

This is done with a top unit shown in Figure 6.8.10, which is specially designed for computer control. The top unit includes indication unit, activation stem, sensor system and solenoid valves.

This top unit can be used for digital and bus communication systems, allowing only one air hose and one electrical cable to control and communicate with a large number of valves. The top unit can be programmed centrally and the installation costs are low.

The unit includes many functions, such as remote setting, control and indication of seat lift on mixproof valves, maintenance program for single seat valves, control and indication on position of valve plug, etc.

Check and control valves

Check valves

A check valve (Figure 6.8.17) is fitted when it is necessary to prevent the product from flowing in the wrong direction. The valve is kept open by the liquid flow in the correct direction. If the flow stops, the valve plug is forced against its seat by the spring. The valve then closes against reversal of the flow.

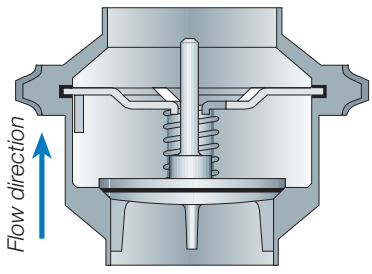


Fig. 6.8.17 *Check valve*

Control valves

Shut-off and change-over valves have distinct positions, open or closed. In

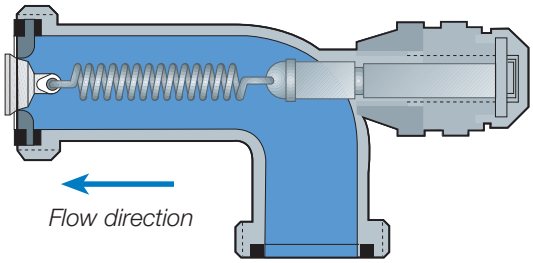


Fig. 6.8.18 *Pressure relief valve.*

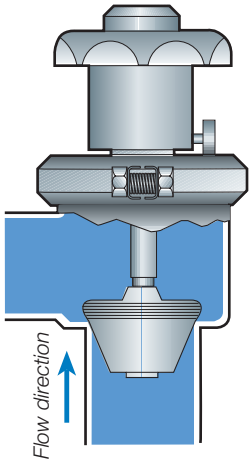


Fig. 6.8.19 *Manual control valve with variable-flow plug.*

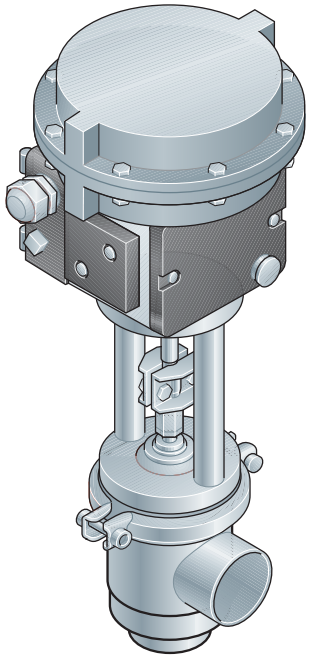


Fig. 6.8.20 *Pneumatic control valve with variable-flow plug.*

the regulating valve, the passage can be changed gradually. The control valve is used for accurate control of flows and pressures at various points in the system.

A **pressure relief valve** (Figure 6.8.18) maintains the pressure in the system. If the pressure is low, the spring holds the plug against the seat. When the pressure has reached a certain value, the force on the plug overcomes the spring force and the valve opens. The opening pressure can be set to the required level by adjusting the spring tension.

Manual control valve with variable-flow plug (Figure 6.8.19).This valve has a stem with a specially shaped plug. When the regulating handle is turned, the plug moves up or down, varying the passage and thereby the flow rate or the pressure. A scale on the valve indicates the setting.

The **pneumatic control valve with variable-flow plug** (Figure 6.8.20) works similarly to the previously described valve. The plug-and-seat arrangement is similar to that of the manual valve. The flow is gradually throttled when the plug is lowered towards the seat.

This type of valve is used for automatic control of pressures, flows and levels in processes. A transmitter is fitted in the process line and continuously transmits the measured value to a controller. This controller then adjusts the setting of the valve so that the pre-set value is maintained.

A valve often used is the **constant-pressure valve** (Figure 6.8.21). Compressed air is supplied through a reducing valve to the space above a diaphragm. The air pressure is adjusted by the reducing valve until the product pressure gauge shows the required pressure. The pre-set pressure is then maintained regardless of changes in the operating conditions. Figure 6.8.22 describes the function of the constant-pressure valve.

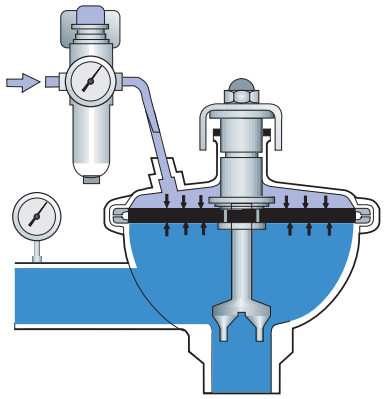


Fig. 6.8.21 *Constant-pressure valve.*

The valve reacts rapidly to changes in the product pressure. A reduced

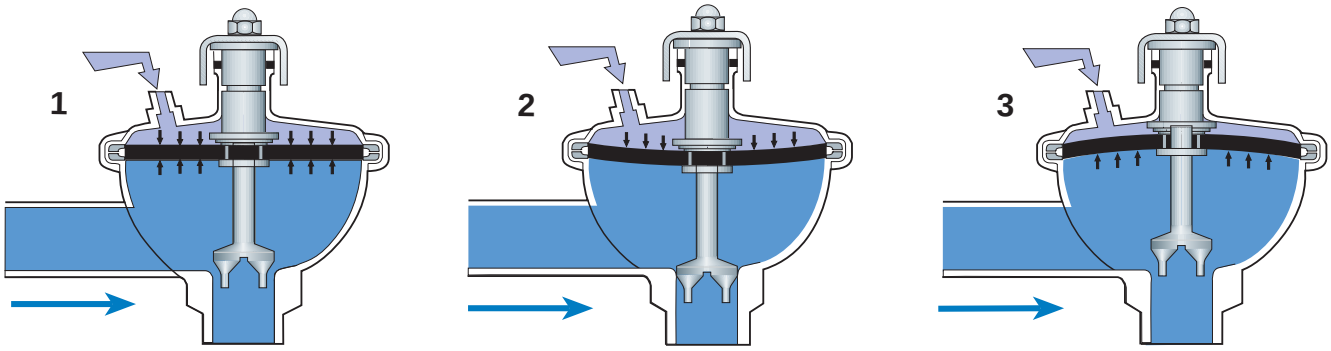


Fig. 6.8.22 *Function of the constant-pressure valve when regulating the pressure before the valve.*
1 *Equilibrium air/product.*
2 *Product pressure **drops**, the valve closes and the product pressure increases to the preset value.*
3 *Product pressure **increases**, the valve opens, and the product pressure drops to the preset value.*

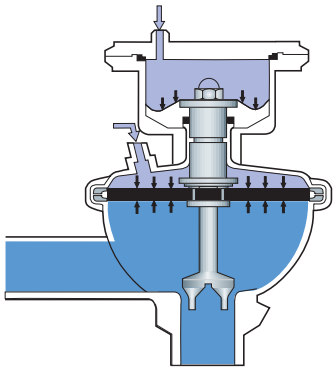


Fig. 6.8.23 *Constant-pressure modulating valve with a booster for control of products with a higher pressure than the available air pressure.*

product pressure results in a greater force on the diaphragm from the air pressure, which remains constant. The valve plug then moves downwards with the diaphragm, the flow is reduced and the product pressure increased to the pre-set value.

An increased product pressure results in a force on the diaphragm that is greater than the downward force from the compressed air. The valve plug then moves upwards, increasing the passage for the product. The flow will then increase until the product pressure has dropped to the pre-set value. This valve is available in two versions for constant pressure before or after the valve.

The valve cannot control the product pressure if the available air pressure is lower than the required product pressure. In such cases, a booster can be fitted to the top of the valve. In this way, the valve can be used for product pressures up to about twice the available air pressure.

Valves for constant inlet pressure are often used after separators and pasteurisers. Those for constant outlet pressure are used before filling machines.

Valve systems

There must always be a free drain opening between product and CIP flows and between different products.

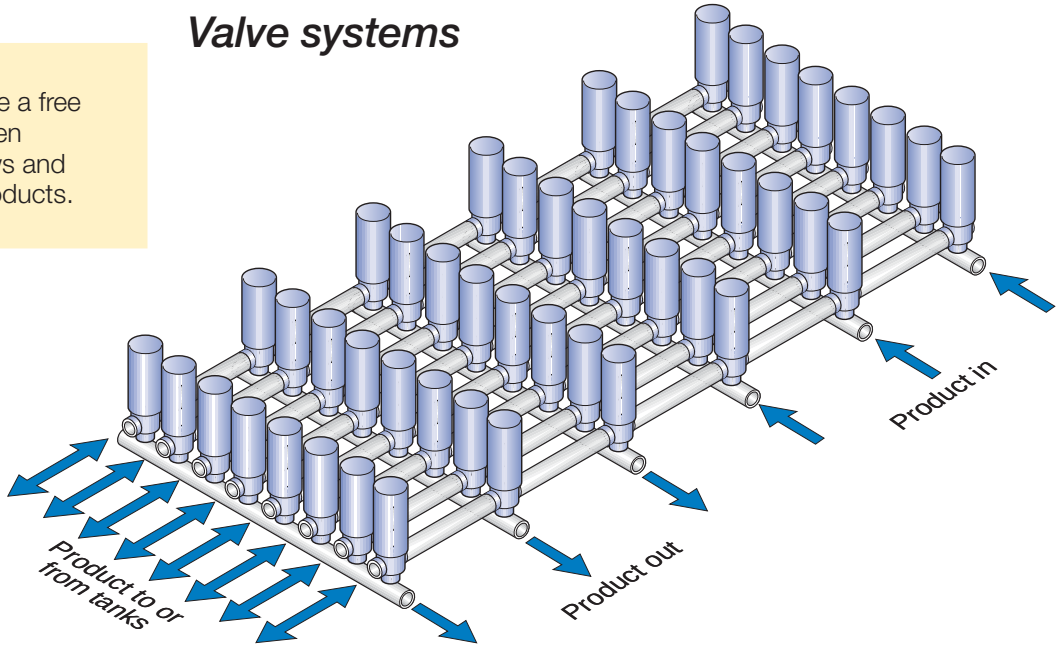


Fig. 6.8.24 *Valve arrangement in a tank garden for independent routing of products and cleaning solutions to and from the tanks.*

Valves are arranged in clusters to minimise dead ends and make it possible to distribute the product between different parts or blocks within the dairy. Valves are also used to isolate individual lines so that one line can be safely cleaned while the product is flowing in others.

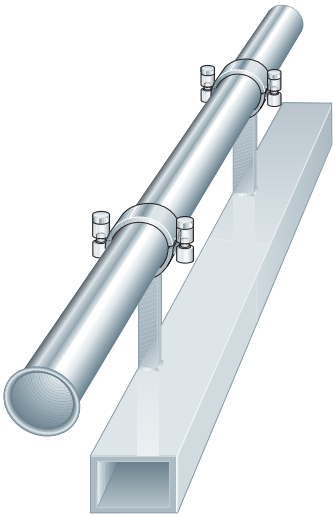


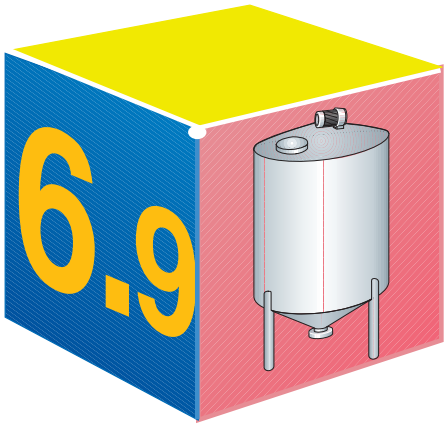
Fig. 6.8.25 *Examples of standard pipe supports.*

Pipe supports

Pipes usually run about 2 – 3 metres above the dairy floor. All components must be easily accessible for inspection and maintenance. The lines should slope slightly (1:200 – 1:1000) to be self-draining. There should be no pockets at any point along the line where the product or cleaning fluid can collect.

Pipes must be firmly supported. On the other hand the pipes should not be so restrained that movement is prevented. The pipes will expand considerably, when the product temperatures are high and during cleaning. The resulting increase in length and torsional forces in bends and equipment must be absorbed. This, plus the fact that the various components make the pipe system very heavy, place great demands on accuracy and on the experience of the system designer.

Tanks



Tanks in a dairy factory are used for a number of purposes. The sizes range from 150 000 litres for the silo tanks in the reception department down to approximately 100 litres for the smallest tanks.

Tanks can generally be divided into two main categories according to function:

- Storage tanks
- Process tanks

Storage tanks

Silo tanks

Silo tanks for milk reception belong to the storage category and have been described in Chapter 5, Collection and reception of milk. They vary in size from 25 000 to about 150 000 litres and the wetted surfaces are made of stainless steel. They are often placed outdoors to save on building costs.

In these cases, the tanks are insulated. They have a double shell with a minimum of 70 mm mineral-wool insulation in between. The outer shell can be of stainless steel, but for economic reasons, it is usually made of mild steel and coated with anti-corrosion paint.

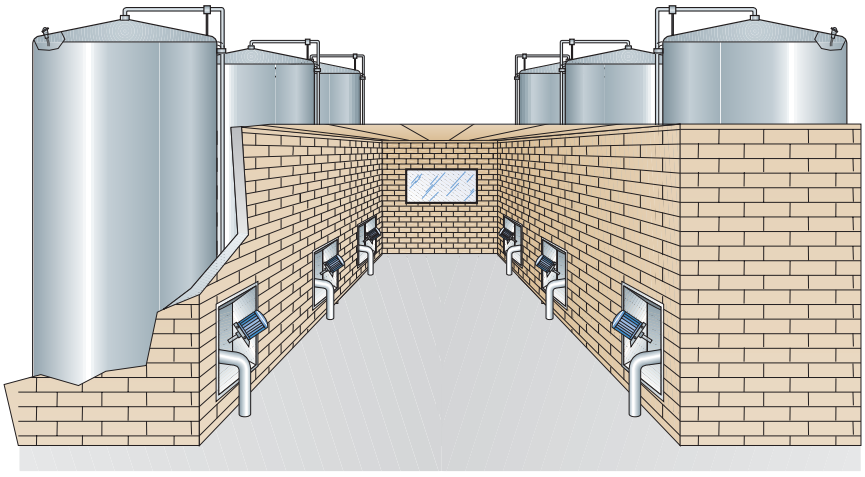


Fig. 6.9.1 *Layout of outdoor silo tanks with their manholes in alcoves in the walls of a covered control station.*

To make complete drainage easy, the bottom of the tank slopes downwards with an inclination of about 6 % towards the outlet. This is a statutory requirement in some countries.

Silo tanks are fitted with various types of agitators and monitoring and control equipment.

The number and size of the silo tanks are determined by such factors as the milk intake per day, the number of days per working week, the number

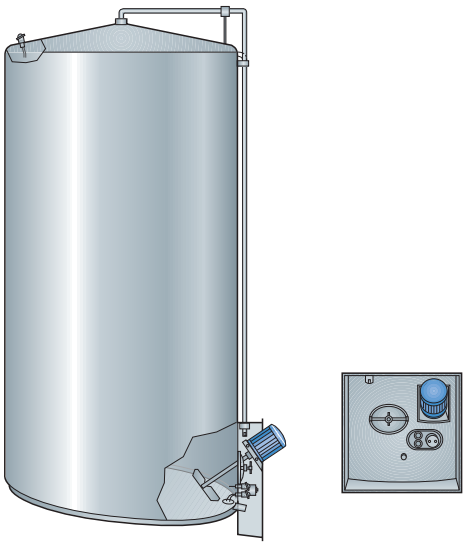


Fig. 6.9.2 *Silo tank alcove with manhole and motor for propeller agitator.*

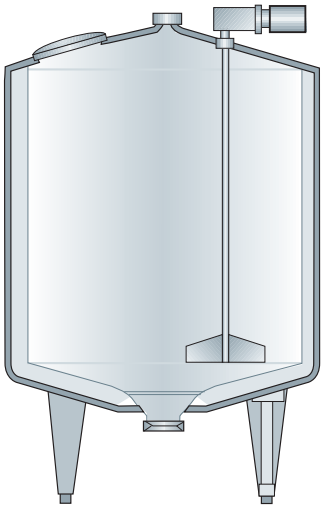


Fig. 6.9.3 *A typical storage tank has a capacity of 1 000 litres up to about 50 000 litres.*

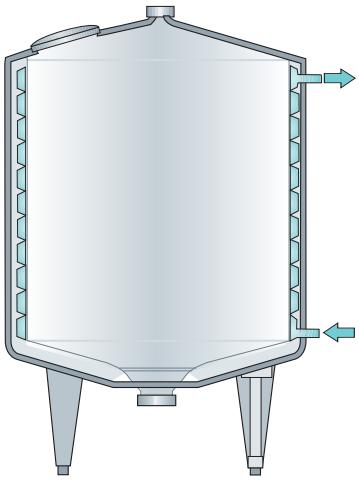


Fig. 6.9.4 *Mixing tank with welded-on heating/cooling channels.*

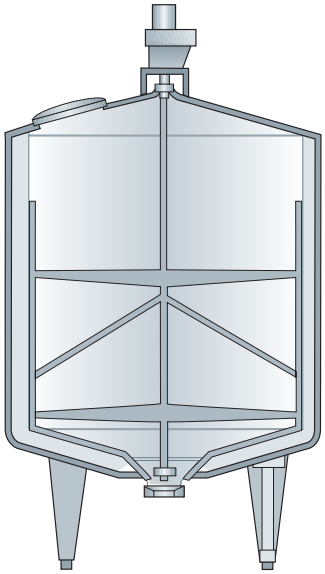


Fig. 6.9.5 *An insulated process tank with scraper agitator for viscous products.*

of hours per working day (one, two or three shifts), the number of different products to be manufactured, and the quantities involved.

Intermediate storage tanks

These tanks are used to store a product for a short time before it continues along the line. They are used for buffer storage, to level out variations in flow. After heat treatment and cooling, the milk is pumped to a buffer tank, and from there to filling. If filling is interrupted, the processed milk is buffered in the tank, until operation can be resumed. Similarly, milk from this tank can be used during a temporary processing stoppage.

In storage tanks, (Figure 6.9.3), with a capacity of 1 000 to 50 000 litres the inner shell is made of stainless steel. The tank is insulated to maintain a constant product temperature. In this case, the outer shell is also of stainless steel, and there is a layer of mineral wool between the shells.

The storage tank has an agitator and can be fitted with various components and systems for cleaning and for control of level and temperature. This equipment is basically the same as previously described for silo tanks.

A good general assumption is that the process requires a buffer capacity corresponding to a maximum of 1,5 hours normal operation, *i.e.* 1,5 x 20 000 = 30 000 litres.

Mixing tanks

As the name implies, these tanks, (Figure 6.9.4), are used for mixing different products and for the admixture of ingredients to the product. The tanks may be of the insulated type or have a single stainless steel shell. Equipment for temperature control may also be fitted. Insulated tanks, with mineral wool between the inner and outer shells, have a jacket outside the inner shell through which a heating/cooling medium is pumped. The jacket consists of welded-on channels.

Agitators for mixing tanks are designed to suit the specific application.

Process tanks

In these tanks, Figure 6.9.5, the product is treated for the purpose of changing its properties. They are widely used in dairies, *e.g.* ripening tanks for butter cream and for cultured products such as yoghurt, crystallisation tanks for whipping cream, and tanks for preparing starter cultures.

There are many different types of process tanks. The application determines the design. Common features are some form of agitator and temperature control. They have stainless steel shells, with or without insulation. Monitoring and control equipment may also be fitted.

Balance tank

There are a number of problems associated with the transport of the product through the line:

- The product handled must be free from air or other gases if a centrifugal pump is to function properly.
- To avoid cavitation, the pressure at all points in the pump inlet must be higher than the vapour pressure of the liquid.
- A valve must be actuated to redirect the untreated liquid, should the temperature of a heat-treated product drop below the required value.
- The pressure on the suction side of the pump must be kept constant to ensure a uniform flow in the line.

These problems, as well as some others dealt with here, are often resolved by fitting a balance tank in the line on the suction side of the pump. The balance tank keeps the product at a constant level above the pump inlet. In other words, the head on the suction side is kept constant.

The tank in Figure 6.8.6 contains a float connected by a lever to an

eccentrically-pivoted roller that operates the inlet valve on the tank. As the float moves downwards or upwards with the liquid level, the valve is opened and closed respectively.

If the pump draws more from the tank than flows in at the inlet, the level drops and the float with it. The valve opens and lets in more liquid. In this way, the liquid in the tank is kept at a constant level.

The inlet is located at the bottom of the tank so that the liquid enters below the surface. Consequently, there is no splashing and, above all, no aeration. Any air already present in the product on entry will rise in the tank. Some deaeration takes place. This has a favourable effect on the operation of the pump, and the product is treated more gently.

The balance tank is often included in a recirculating system where liquid is returned for recycling, *e.g.* as a result of insufficient heat treatment. In this case, a temperature indicator actuates a flow diversion valve, which directs the product back to the balance tank. This causes a quick increase in the liquid level and an equally quick movement of the float mechanism to close the inlet valve. The product then circulates until the fault has been repaired or the plant is shut down for adjustment. A similar procedure is employed for circulating cleaning solution when the line is cleaned.

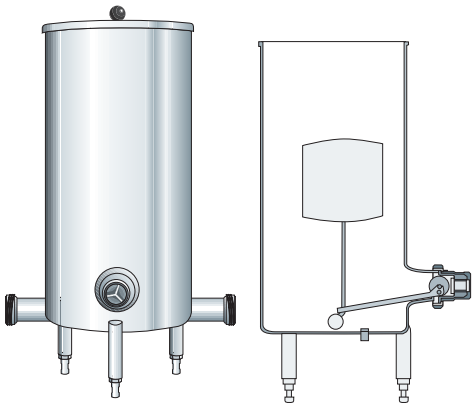


Fig. 6.9.6 *Balance tank for constant inlet pressure to the pump.*

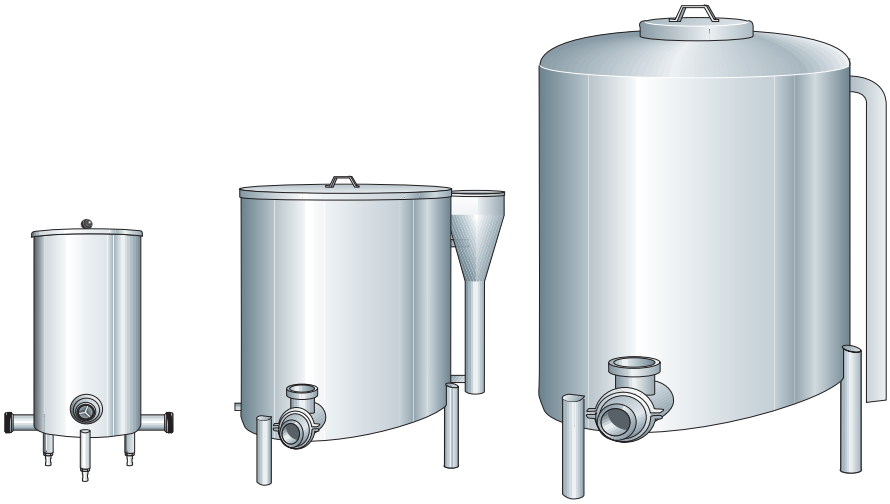


Fig. 6.9.7 *Balance tanks are available in different sizes.*

Automation

Getting the most out of a plant

The nature of dairy operations has changed over the past few decades. Small, local dairies with manual operations have become outdated and been replaced by larger units with factory-style production.

This trend has caused many and far-reaching consequences. Processes in small dairies were supervised and controlled by a few skilled people, who carried out most operations manually and also cleaned the equipment by hand at the end of each run. As dairies expanded, both the number and size of the machines grew, as did the number of manual operations required. Cleaning, in particular, was a laborious business – every machine that had been in contact with the product had to be disassembled and cleaned by hand at least once a day.

Cleaning-In-Place (CIP), introduced in the mid-1950s, is used at most of today's dairies. CIP means that equipment no longer needs to be disassembled for cleaning. Machines are designed to be cleaned with detergent solutions, which are circulated through the production lines according to a set cleaning program.

Extensive mechanisation of dairy operations gradually became a reality, with the result that more and more of the heavy manual labour was taken over by machines. Mechanisation, together with the rapid expansion of production capacity, also led to a substantial increase in the number of operations that had to be executed. More valves had to be operated, more motors had to be started and stopped. The timing of individual operations also became critical. Operating a valve too soon or too late, for example, could lead to product losses. Every malfunction in the process, and every operator error, could have serious economic and qualitative consequences. Automation was the solution to handle these problems.

Process control

Automation is a fast-moving field. Only a few decades ago, process control systems were based on electro-mechanical relays, wired together in a logical pattern. They were replaced by hardwired electronic control systems, which were faster and more reliable, as they contained no moving parts.

The next improvement was programmable control systems with the logic expressed in data bits stored in an electronic memory, not in the physical arrangement of the wiring. This not only made it easier to modify the program whenever necessary, but also reduced the cost of the hardware.

In modern control systems, the growing capability and reduced cost of computers and microprocessors has been utilised to distribute control functions to local units. This gives the system as a whole more flexibility and a very high potential. The new processors can be used to control a single machine, or build up a total control and management system to make an entire plant more productive.

Totally integrated plant control

Nowadays, the next step in the evolution of automated processes is taken towards the totally integrated plant control system.

A plant consists of more than one process area, *e.i.* reception, cheese and liquid milk production. Each area has a its own configuration of one or several Process Controllers and they will often have a User Interface for operators, handling product transfer from one process area to the other.

It is essential to keep track of production and economy in a plant. The Process Controllers contain a substantial amount of information and data from the process at all times, day and night, week and month. Knowing what is happening is a key to be able to run the plant more efficiently and economically.

The Process Controllers themselves provide all the basic data for the Manufacturing Execution System (MES), where the data can be further processed and stored in a database. This is preferably handled by a separate computer.

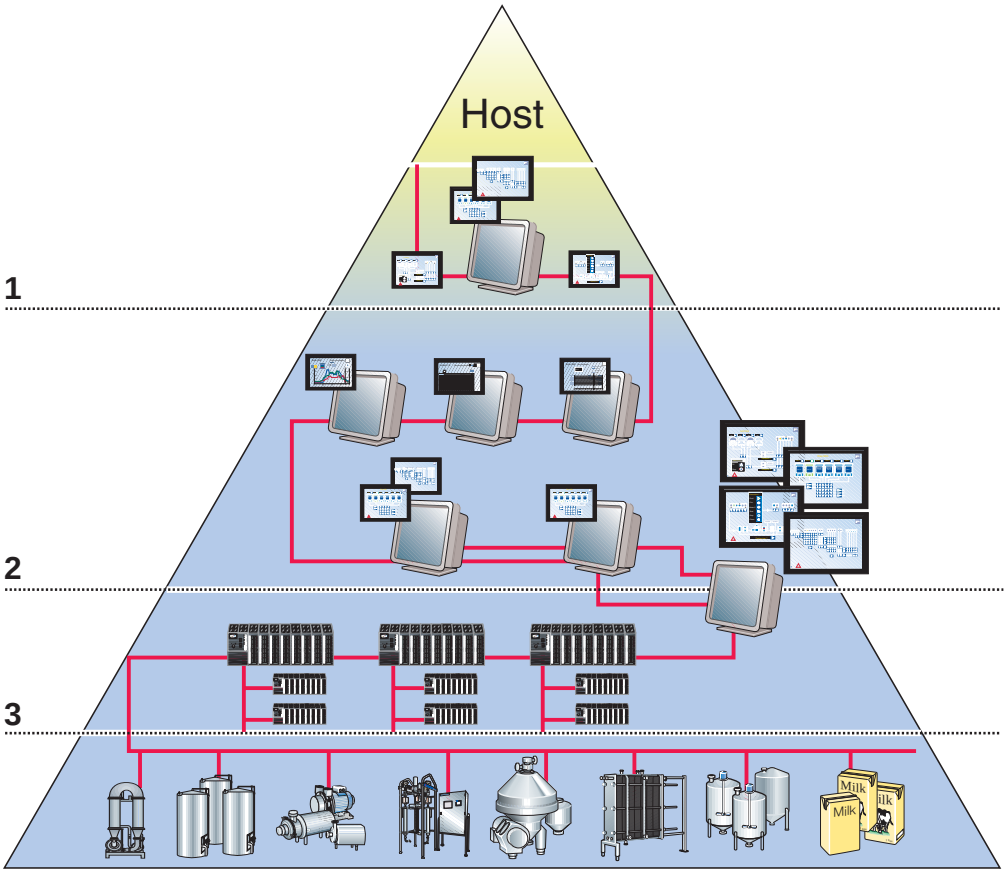


Fig. 6.10.1 *Schematic control system layout for a complete process line.*
1 *Business planning and logistics*
2 *Manufacturing operations and control*
3 *Production control*

A modern MES system is dedicated to handle large volumes of data. It computes and processes the data to produce various types of reports, to analyse production economy, etc. and to assist in planning and making preventive maintenance forecasts.

Why do we need automation?

Several aspects must be considered when designing a dairy. Therefore, the final production solution of a plant is always a compromise between product-related, process-related and economic aspects, in which external demands on the plant must be satisfied. These external requirements relate to factors such as legislation, type and amount of product, product quality, hygiene, production availability, flexibility, labour and economy.

The product-related aspects include raw materials, product treatment and quality of the end product, while the process-related aspects include

selection of process equipment to satisfy external demands. Even if the processing units in a plant are chosen primarily to achieve the stated product quality, various compromises must be made, particularly if many different products are to be manufactured.

Such considerations apply, for example, to the cleaning requirements of the equipment and its suitability for connection to the proposed cleaning system. Compromises must also be made on other matters, such as the consumption of energy and service media, and the suitability of the equipment to be controlled. When selecting process equipment, it is important to remember that the process control solution should also be considered.

Correctly applied process control, in which a thorough knowledge of products, processes and process equipment guides the design, has many advantages. The most important are:

- Safety
- Product quality
- Reliability
- Production economy
- Flexible production
- Production control

Safety is secured by the control system through the continuous supervision of equipment and processes. A malfunctioning machine will be brought to a safe status if a serious fault occurs, and a process fault will stop the related process. This system ensures the prevention of unwanted mixing of products, overfilling of tanks and other faults, which might cause product losses and production disruptions.

The process is monitored in exactly the same way during each production run, which means that the finished product will always have the same high quality after fine-tuning of all processing variables for an optimum outcome.

Precise control of the process means that product losses and consumption of service media, cleaning solutions and energy are kept to a minimum. As a result, the production economy of a well-designed and adapted control system is very good.

Flexible production can be achieved by programming the control system with various production alternatives and production recipes. Changes in production can be implemented simply by altering a recipe, instead of modifying the actual program.

The control system can also provide relevant production data and information in the form of reports, statistics, analyses, etc. The data becomes a tool for more precise management decisions.

A plant design is always a compromise between:

1 Product
2 Process
3 Economy
4 External factors

The most important advantages of automation are:

- Production safety
- Product quality
- Reliability
- Production economy
- Flexible production
- Production control
- Tracability

Control levels

The following definitions have been adopted to describe the level of control in the system:

- Manual control
- Unit control and supervision
- Line control and supervision
- Production management

Manual control

All operations in the plant are carried out manually. Control modules are manually operated, but normally they are started or stopped from panels with push buttons, with no interlocking function. Some single valves, such as the diversion valve in a manual pasteuriser, may be automatically controlled, but the plant or line is still considered to be manual.

Unit control and supervision

Each process unit is operated from its specific operator panel. Each unit has a standardised way of communicating with other units and supervisory

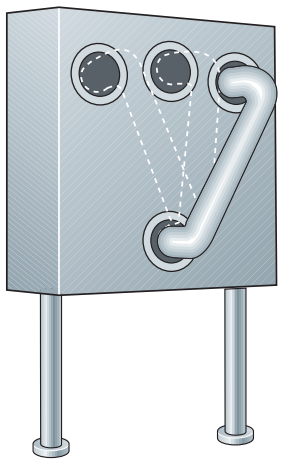


Fig 6.10.2 *Swing-bend is an example of a manual control system.*

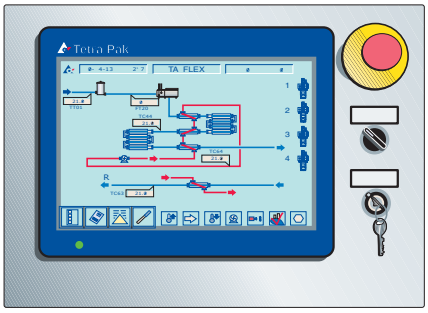


Fig 6.10.3 *Unit control and supervision system.*

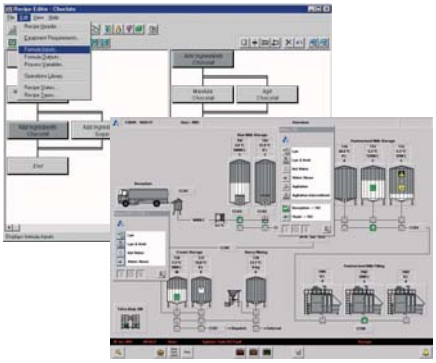


Fig 6.10.4 *Line control and supervision system.*

Fig 6.10.5 *Production management system.*

systems. The units either communicate with a limited number of I/O-signals or with a communication link. The complexity of the control systems is low, so the demands on the local service organisation are limited.

Line control and supervision

The operator supervises the plant or line from one or more User Interfaces. Process units, with their own specific operator panel, are normally supervised from central User Interfaces. Co-ordination of routings and operation of units is done from one or more plant PLCs.

Line control and supervision gives an excellent plant overview and facilitates increased plant functionality, *i.e.* operations can be carried out in a sequence and losses can be minimised by optimisation of the process sequences. Changes in the process will require modification in the control program, and therefore demands on the local service organisation are high.

Production management

Production and cleaning can be executed in jobs or batches, using recipes. The Production Manager can schedule batches from an operator station, which can be situated in an office. The operator of the process supervises the execution of scheduled batches from one or more operator stations. In a bigger plant, each operator station should encompass a dedicated production area.

Control of process units that have their own specific operator panels should be included in the execution of batches. One or more plant PLCs control the routings, and the plant server co-ordinates all activities in the plant. The history of the batches is stored in a database. The use of advanced technology means the control system is highly complex. Changes in the process will result in modifications of the plant models, recipes and programs, and therefore the demands on the local service organisation are high.

Operations can be carried out in sequences, and product losses can be minimised by sequence optimisation. The performance of the plant can be analysed, and the way a specific end product was produced can be traced back through production.

Requirements for a control system

Reliability, flexibility and economy are the most important requirements for a modern process control system.
This means that the control system should:

- Be reliable and easy to maintain
- Have a user interface that is logical, self-instructing and efficient
- Be based on off-the-shelf hardware and software
- Include software for diagnostic testing and modification
- Be easy to extend

Extending a control system

One of the most important requirements for a control system is the possibility to extend the system when required. It should be possible to build a system of any size, step by step, by adding standard components. A small process controller installed to control a reception line could be extended later with more controllers of the same brand that control milk treatment, filling, etc. At the same time, management routines could be added to existing controllers to feed data into management computers.

When extending a control system, it is very important that all control system components, from the remote sensor to the user interface, are easy to connect to each other in order to create a smooth functioning control system platform. Using products from a sole supplier will normally guarantee this.

How does the control system work?

Definitions

Automation = Process Control and Production Management.
Automation means that all actions needed to control a process with optimal efficiency are handled by a control system on the basis of instructions that have been programmed into it.

Process Control System = The system executing Process Control. It normally incorporates:

- **User Interfaces**, which are used by the process operator to communicate with the control system and the process.
- **Process Control**, normally a PLC (Programmable Logic Controller), which executes actual control of the process.
- **I/O-system** interfaces with control modules and transmitters in the process.

Management Execution System (MES) = The system executing Production Management.

- It can also form a link to other company systems such as Enterprise Resource Planning (ERP) systems.

Fig 6.10.6 *Process Control is normally executed by a PLC (Programmable Logic Controller).*

Logic

Logic is a fundamental concept in Process Control. It denotes the decision-making mechanism, making it possible to perform a given task according to a given model. The human mind is programmed by education and experience to perform a task in a certain way.

Figure 6.10.7 shows in a manual system, how an operator uses logic to solve a control problem, which involves supplying a process line with milk from a battery of tanks. He receives information from the process, *e.g.* that tank T1 will soon be empty, tank T2 is currently being cleaned, tank T3 is full of product, etc. This information is processed logically by the operator. The figure illustrates his train of thought – the questions and decisions he has to formulate. Finally, he implements his decisions by pushing the correct buttons on his panel to actuate the right valves, pumps and other control modules.

The operator has no great difficulty in solving this particular control problem. Even so, the potential for errors is always present. Detergent and milk could be mixed by mistake. The process line may run out of milk, resulting in burning-on at the heat transfer surfaces. Milk in the tanks may be wasted when the tank is cleaned. The risk of such errors increases if the operator is responsible for several similar sections of the process at the same time. He may be rushed and under stress, which heightens the risk of him making a mistake.

At first glance it is easy to assume that the operator is constantly faced with choices between many alternative solutions to control problems. A closer look reveals that this is not the case. After many hours of operation the dairy has verified the control sequences, which results in optimum product quality, safety and economy. In other words, the operator has acquired a more or less permanent control logic. He selects tanks according to established routines, uses a stopwatch to time milk drainage from a tank, so that he knows exactly when to switch to a full tank in order to minimise product losses, and so on. Each process can be analysed in this way and it is then possible, on the basis of the analysis, to determine the control logic that produces optimum results.

The control logic is stored in the form of a program in the specific process controller, which is normally a PLC.

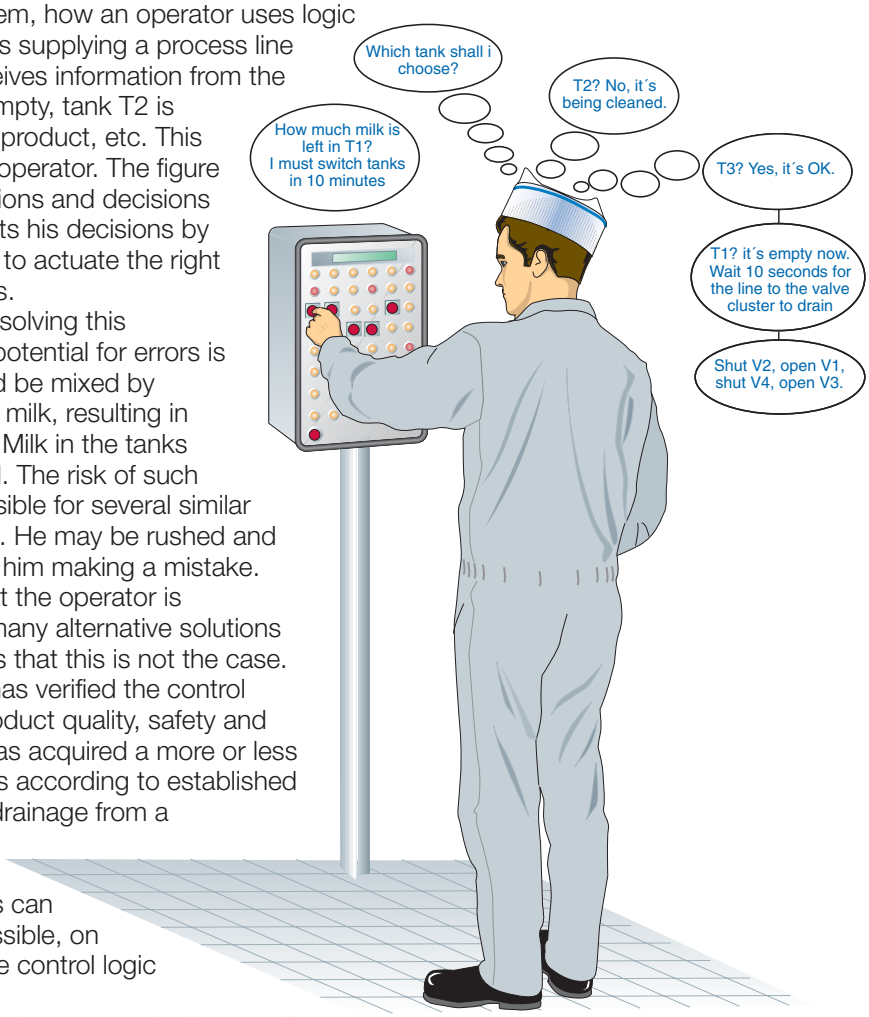


Fig 6.10.7 *In a manual process the operator uses his logic to solve the processing demands.*

Control system

All the transmitters and control modules in the process (4) are connected to the logic by the Input/Output (I/O) system (3). In this way, all the necessary information regarding temperatures, flows, pressures, etc. is transmitted to the logic of the control system. After processing of I/O-signals and operator commands, the logic sets the correct output signals to actuate the control modules involved in the process. This is done in a certain order to comply with the logical conditions that apply to the process. The control modules send back feedback signals confirming that the commands have been carried out. These feedback signals are used by the logic as conditions, permitting the next step in the sequence to be actuated. The principal layout of a control system is shown in Figure 6.10.8.

If the output signal and the feedback signal do not match, an alarm signal is generated, trying to bring the related process to a safe state. This assumes, of course, that the fault in question can be predicted. As a process becomes more complicated, and demands on operational security and economy become stricter, the required control program (logic) has to be extended accordingly.

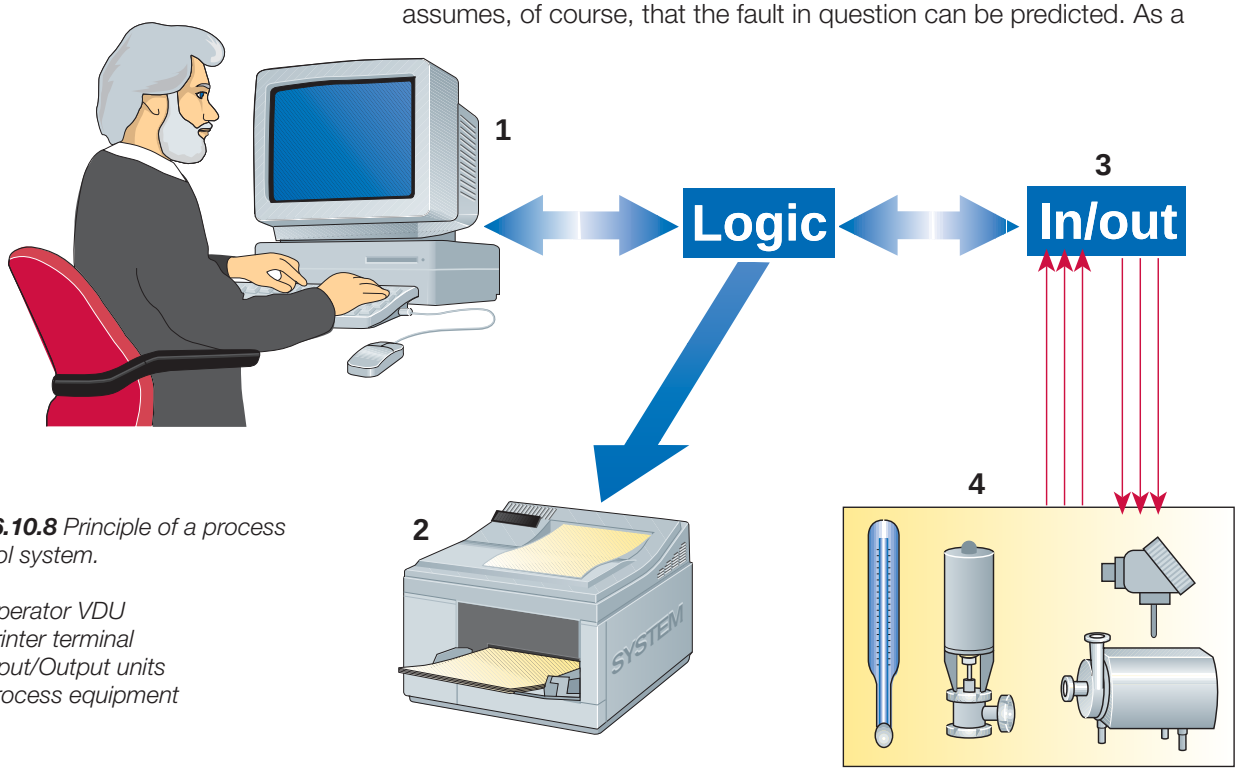


Fig. 6.10.8 *Principle of a process control system.*

1 Operator VDU
2 Printer terminal
3 Input/Output units
4 Process equipment

All user interfaces (1) are connected to the logic as well as local operator panels.

Distributed intelligence

Efficient process control requires first-class electronic solutions in the process. The operation of the entire automatic process control system will be jeopardised if transmitters and sensors do not work properly.

The valve control system shown in Figure 6.10.9 is an example of distributed intelligence. Running a dairy of any size involves keeping track of hundreds or thousands of valves and operating them in different combinations and sequences. PLCs are dedicated systems to solve these control tasks in the shortest possible time. To do this, the PLC needs a channel for instant communication with all the valves. This makes the installation expensive, but new valve control systems have been developed to provide an economical solution.

A modern system consists of a number of valve tops (1), one for each valve. The valve tops are connected to a common fieldbus cable and a common compressed-air line. The fieldbus cable is connected to a gateway communicating with the control system (2) and the power supply serving

the valve tops. Several fieldbuses can be connected to the process controller to control the required number of valves.

Another important advantage of the system is that the valve top unit reports the valve status back to the control system. The modem scans the status of all valves continuously and instantly informs the process controller if a malfunction arises. This facilitates fault tracing and maintenance, especially since it is possible to disconnect individual valve units without disrupting the operation of other parts of the control system.

The fieldbus concept is also starting to be applied for transmitters and instrumentation as a whole – distributed temperature control and flow-metering are just two examples.

For the producer, the advantage is not only a significant reduction in installation and commissioning costs, but also the increased amount of useful information, which makes the total investment in a control system lower than for a traditional system.

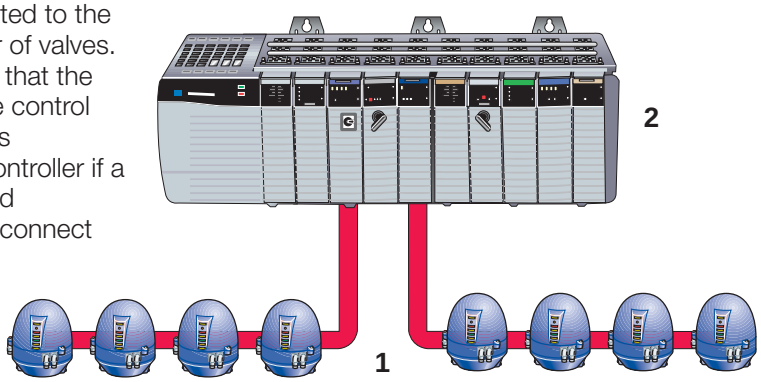


Fig. 6.10.9 *Valve control system.*

1 *Valve control units*
2 *Control system (PLC)*

Batch control

Production in liquid food plants is becoming more complex as new and more complicated recipes are introduced. Strict recipe procedures must be followed to manage production and guarantee product quality.

The increased number of products demanded by producers means shorter production runs. In order to stay competitive in this situation, the efficient planning and running of production is a necessity.

The manufacture of 50 tons of strawberry yoghurt, for example, is called a batch. Instead of only executing conventional process operations, such as transfers to and from process units, the batch control system takes total control of production, from milk reception until the yoghurt cups are stored for distribution. The major benefit of batch control is that the system helps with all the necessary actions.

Recipe management

Using recipe management, a producer will have full control when introducing new products. If no new process equipment is needed, there is no need to call in external assistance to reprogram the control system. All procedures are edited on site using easy-to-understand tools.

All previous recipes are automatically stored and ready to use whenever needed in the future. Any existing recipe can be easily modified on line and stored as a new version or a completely new recipe.

Flexibility is maximised, as all recipes are scalable.

Control of production

The batch control system gives comprehensive on-line information about what is happening in production: production figures and totals to date, data on products scheduled for runs later in the day, and current problems related to production and lines. All this information can be displayed on any user interface connected to the network.

How does the data management system work?

Work Tracking

Logging production data

Everything that occurs in the control system can be logged automatically in a database and tagged with a specific identity. This means it is possible to automatically compare parameters between production runs by producing

a report, which will probably reveal any quality problem that has occurred in a specific period. In this way, it is possible to solve problems concerning inconsistent quality or difficulties in running a particular product.

In addition, it is possible to automatically produce a report defining all target and actual values during production – all events and any errors that occurred during a particular production run. Laboratory data can be added and connected directly to the tagged output.

Tracking production

The producer must define the target level for tracking production. There are systems and methods available to provide the required level. Alternatives are:

1 Full traceability – production runs are separated with flush/CIP.
2 Limited traceability – filling and emptying of tanks or process lines cannot be done simultaneously.
3 No traceability – filling and emptying is done simultaneously.

The full traceability level provides all the data for any type of report, but this also imposes restrictions on how the plant can be run. The lowest level will give a more flexible plant, but with minimal or no traceability.

Analysis

The customer requirement trends regarding plant engineering have been more and more focused on lower production costs and minimising losses, rather than process components and simple transfer functions. Often the requirements set out in the contract propose “minimising losses” or “reducing losses to 1 %”, etc. There are hardly any proven tactics or methods to deal with such demands, unless a certain methodology is used when designing and commissioning the plant. There are many questions that need to be resolved. How do you:

- Estimate theoretical product losses?
- Design the plant process and automation to minimise, measure and confirm product losses?
- Commission while keeping the product loss paragraph in mind?
- Ensure that product loss reports during normal plant operation are meaningful and lead to correct actions?

For day-to-day production, a report can be produced based on the optimal running scenarios decided during plant dimensioning, optimisation or at later stages. The optimal running scenario for the given production day could also be sourced from other programs. There could be several optimal scenarios in the plant, (generated during optimisation or later), depending on time of the year, the day, etc. The manager or planner selects the correct optimal scenario for the day.

The report shows unit by unit whether the plant is operating according to the optimal dimensioning and production planning.

Certain figures are shown for each unit. These figures represent specific set values (taken from the optimal scenario) compared with the actual figures. The figures/unit could be:

Lines, pasteurisers, filling machines

- Ratio of production hours/idle hours
- Ratio of start/emptying/production run hours
- Ratio of circulation (or, for lines or machines: transfer selected, but pump idle) time/production time
- Amount and type of cleaning

Tanks

- Ratio of product in tank period/24 hr
- Amount and type of cleaning

The figures for optimal and actual running are compared. If the figures differ by more than a certain value, they are highlighted. The reason could be operator error, less than optimal planning or that the plant is not dimensioned for that type of production. The deviation could also be caused by equipment faults (temporary problems). The findings and causes can be scrutinised later by the planning manager.

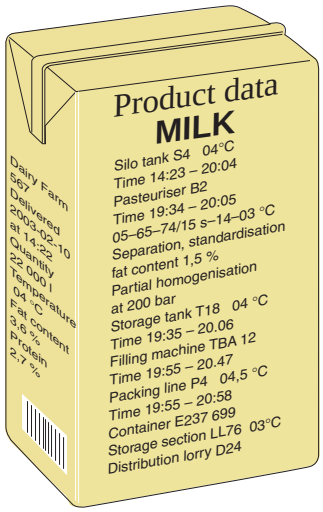


Fig. 6.10.10 *The whole dairy process can be traced.*

Planning and scheduling

Development of planning and scheduling systems within the industry has only just begun. The basic idea is to integrate the whole information structure of the plant or the entire company.

There are already tools available to produce an analysis of customer orders, available production resources and raw materials, and turn this into the optimal production schedule for a specific period.

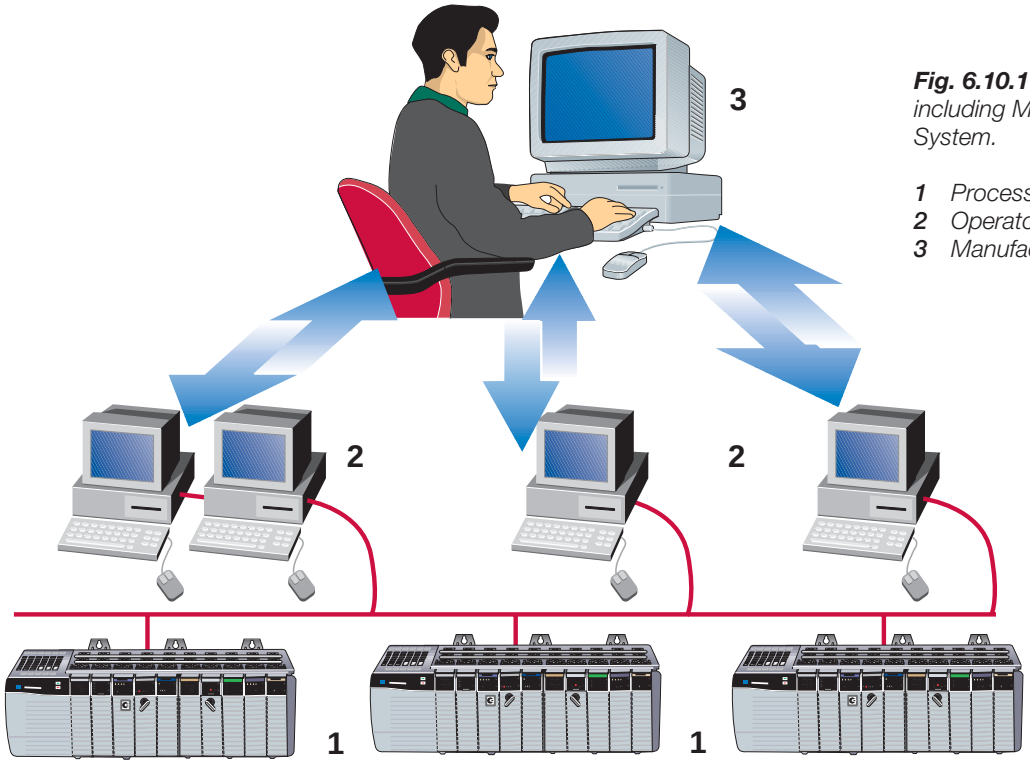
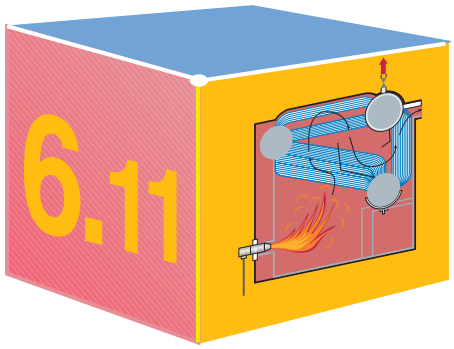


Fig. 6.10.11 *Totally integrated system including Management Information System.*

1 *Process controllers*
2 *Operator VDU*
3 *Manufacturing Execution System*

Service systems



Prerequisites for dairy processing

A number of service installations must be supplied for dairy operations. Among these are water, heat in the form of steam and hot water, refrigeration, compressed air and electricity.

Water supply equipment

Water in nature moves in a continuous cycle (Figure 6.11.1). Heated by the sun, it evaporates from the surface of the oceans, seas and lakes. The water is suspended in the air and carried by the wind over land where it cools, condenses and falls as rain, hail or snow. Some of it, the surface water, runs from the ground directly to lakes and rivers and returns to the sea. The remainder soaks through the top layers of the soil and becomes ground water.

Water is a solvent for many substances, so pure water does not exist in nature. Gases such as sulphur dioxide dissolve in water while it is still in the air, causing the 'acid rain' which is such a great problem in industrialised countries. Water also begins to dissolve various substances as soon as it reaches the ground. Surface water picks up organic matter, insecticides, chemicals from industrial effluents, etc. from the topsoil, as well as bacteria and other micro-organisms.

As the water filters through the various layers of soil, much of the organic matter is removed, together with a proportion of the organisms and chemicals. At the same time, a number of naturally occurring salts are added, so that ground water is often fairly rich in salts of various kinds. These are present as ions, *e.g.* of sodium, potassium, magnesium, calcium, chloride, carbonate, nitrate and sulphate.

Ground water is therefore the least polluted supply, but the composition varies from place to place according to local waste-water discharge, soil conditions and many other factors. Dissolved and suspended substances in the water supply can cause problems in dairies. The incoming water must therefore be treated so that harmful substances can be reduced in concentration, neutralised, or removed altogether.

Most countries have strict legislation regarding the content of micro-organisms and toxic compounds in water. Analytical procedures, methods of sampling and the intervals between sampling are precisely specified. The diseases that can be transmitted by water are chiefly intestinal, so testing for pathogenic types of bacteria often concentrates on *E. coli.* Faecal pollution is indicated if *E. coli* are present in significant quantities.

The dairy industry consumes large quantities of water for various

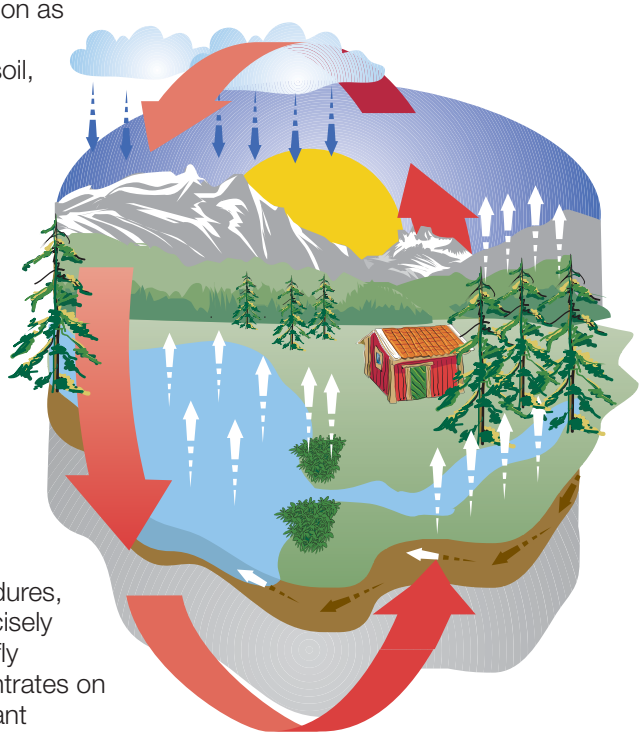


Fig. 6.11.1 *The water cycle in nature.*

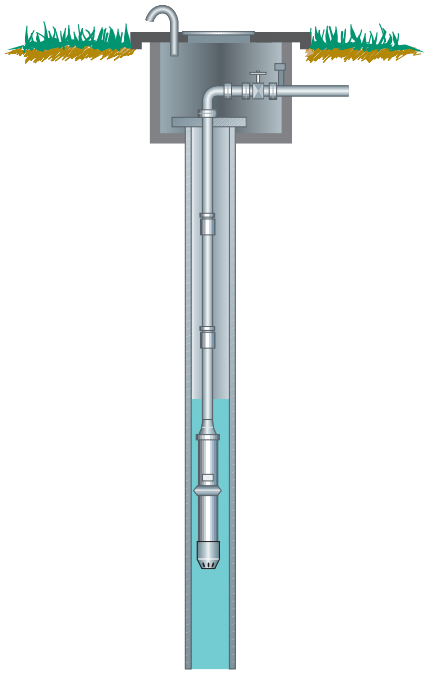


Fig. 6.11.2 *Pipe well with submersible pump.*

purposes, such as pre-treatment of dairy products, rinsing of equipment, cooling and cleaning. The quantity used varies from dairy to dairy according to cleaning methods, etc. and whether water is consumed in production, *e.g.* for recombining milk from powder or juice production.

The dairy water supply often comes from the municipal waterworks. This water is taken from a river or a lake and is then treated so that it meets the requirements for drinking water. The water authority delivers the water to the dairy at the pressure and in the quantity required. The intake is measured and recorded. The price paid by the dairy is then calculated per unit of volume and includes an additional levy for municipal waste-water treatment.

Many dairies have their own wells. A simple well shaft is dug where the ground water is close to the surface. A long tube is driven into the ground if the water is deeper down as Figure 6.11.2. The water is brought up by means of a pump, often submersible, and stored in a reservoir – usually at ground level but sometimes at a higher level (a water tower). From here, it is delivered by pumping or gravity to the various points of consumption in the dairy.

Water treatment

Water has many applications in a dairy and the quality requirements vary with the application. With present-day techniques of filtration, softening, ion exchange, sterilisation, total desalination and reverse osmosis, it is possible to obtain water of a very high quality, but the cost is also high. It is therefore important that the quality demands for different applications are carefully defined, so that the water can be treated accordingly.

Water used in the manufacture of dairy products must be of the highest

Table 6.11.1
Specifications for water

	Drinking water	Water for dairy products
Coliform bacteria, cfu*/100 ml	<1	0
Gelatine bacteria/ml	<100	0
Sediment, mg/l	None	None
Turbidity	None	None
Smell	None	None
Taste	None	None
Colour strength	<20	<10
Dry matter, mg/l	<500	<500
Permanganate consumption, mg/l	<20	<10
Ammonium, mg/l	<0,5	–
Calcium + magnesium, mg/l	<100	<100
Total hardness as $CaCO_3$, mg/l	–	<100
Iron, mg/l	<0,2	<0,1
Manganese, mg/l	–	<0,05
Copper, mg/l	0	0
Aluminium, mg/l	<0,1	<0,1
Zinc, mg/l	0	0
Bicarbonate, mg/l	–	<80
Chloride, mg/l	<100	–
Nitrate, mg/l	<30	–
Nitrite, mg/l	<0,02	–
Fluoride, mg/l	1	1
Chlorine surplus, mg/l	–	0
Algae, protozoa, etc,	None	None
Toxic matter	None	None
pH	7 – 8,5	7 – 8,5

** colony forming units*

quality, exceeding the requirements for acceptable drinking water. It should consequently be completely clear, free from smell, colour and taste, soft and virtually sterile. Softening (reducing the calcium and magnesium content) and dechlorination (removal of chlorine disinfectant by filtration through active carbon) are therefore necessary. Table 6.11.1 shows the requirements for drinking water and for water used in dairy processes.

Water that flows through narrow pipes, should be softened to prevent clogging. All water used for steam generation and feed water for boilers should also be softened to prevent scale from forming on the heating surfaces. Boiler scale is undesirable in terms of both safety and economy.

Piping system design

Water is distributed from the intake to wherever it is needed in the dairy. The water flows through a piping system similar to that used for the product. Stainless steel is used for pipes with a diameter of 2,5 " (65 mm) or larger, galvanised steel is used for smaller pipes. The system includes shut-off valves, pressure gauges and routing valves. Strainers and sometimes pressure-reducing valves are incorporated to maintain the required pressure in the system.

Many dairy applications make special demands on the water supply. Large quantities of water are often needed over a relatively short period at a sustained high pressure. Short but intensive periods of consumption may occur at several outlet points simultaneously. The system and the pressure must therefore be dimensioned to suit these instantaneous load conditions.

For example, a dairy might increase its output without increasing the water supply capacity to match. If this happens, and several instantaneous loads occur simultaneously, the supply pressure will drop to a dangerously low level for the proper functioning of certain equipment. A pressure tank can be used to prevent this. The pressure tank acts as an accumulator. A typical volume of a water tank is 1 – 3 m^3. Water is held in the tank at a pressure determined by an air cushion. On demand, the pressure tank supplies the equipment with the required amount of water at the required pressure. When the instantaneous demand has been met, the tank accumulates more water in preparation for the next withdrawal. Figure 6.11.3 shows this type of pressure tank. During periods of zero demand, the tank is filled with water to the pre-set pressure. The pressure switch (4) shuts off the power supply to the pump (6). As soon as water is drawn from the tank, the resulting drop in pressure is sensed by the pressure switch which, via a contactor, starts the pump and water is pumped into the tank. When the withdrawal operation is over, the water level rises in the tank until the pre-set pressure is reached again. The pressure switch then stops the pump and the pressure tank is ready to meet the next instantaneous demand.

The same function, as described above, can be achieved by using frequency controlled pumps and a small pressure tank.

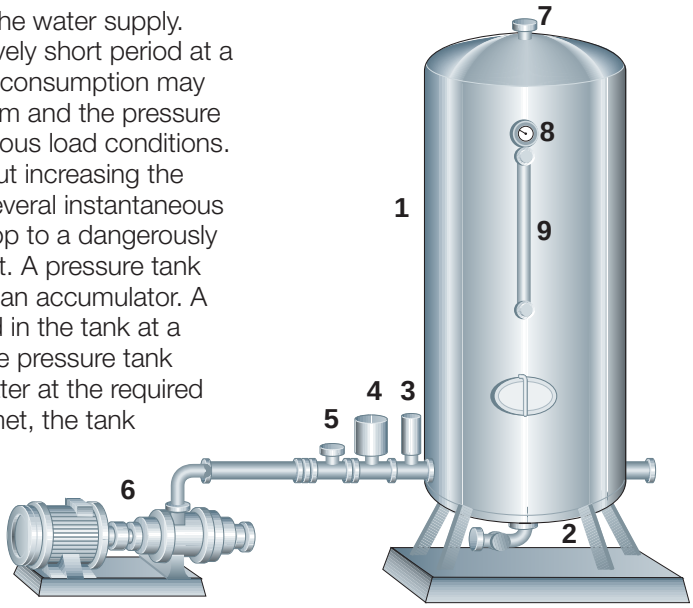


Fig. 6.11.3 *Water pressure tank*
1 *Tank*
2 *Drain valve*
3 *Safety valve. Opens at 600 kPa*
4 *Pressure switch*
5 *Check valve*
6 *Liquid-ring pump*
7 *Vent valve*
8 *Pressure gauge*
9 *Level glass*

Heat production

The operation of a dairy requires large quantities of thermal energy to heat various products, detergent solutions, etc. Heat is usually transferred to the product in heat exchangers by a thermal conductor known as the heating medium. This medium is generated in a heating plant and is distributed through a piping system to the various points of consumption (*e.g.* the heat exchanger in the hot water unit of a pasteuriser). Here, heat is transferred to the product to be heated. The heating medium then flows back to the heating plant, where it is re-heated before returning to the points of consumption. This circuit operates continuously.

Steam at a temperature of 140 – 150 °C is frequently used as a heating medium. Systems using hot water have been installed in dairies which have been built in recent years. Most equipment requires a water temperature

around 100 °C for heating. UHT plants however, require steam of higher temperature. The pressure in the system must be above atmospheric pressure so that the water cannot boil. The installation cost of a hot-water system is slightly lower than that of a steam system. The system is also easier to regulate and the operation is simpler. The disadvantage is that heat transfer in a hot-water system is lower than in a steam system.

If UHT treatment is included in the process, hot water system shall not be considered, since the process requires a temperature that can only be met with steam systems.

Steam production

Generation of the heating medium takes place in steam boilers which are sometimes located in the heating plant. The boiler is usually fuelled with oil, coal or gas. Thermal energy is released by the burning fuel and absorbed by the heating medium. The efficiency of the boiler is in the range of 80 – 92 %, and heat losses in the piping system often amount to about 15 %.

Consequently, only between 65 and 77 % of the total thermal energy of the fuel can be utilised in production. From the point of view of operating costs, it is most important that the efficiency of the boiler does not drop below the minimum level, and for this reason, boiler efficiency is very closely checked in the dairy.

The steam temperature in the steam system described below must be between 140 and 150 °C. In the case of saturated steam, this is equivalent to a gauge pressure of 270 – 385 kPa (2,7 – 3,8 bar). The boilers operate at a considerably higher pressure, as a rule 900 – 1 100 kPa (9 – 11 bar), so that smaller piping dimensions can be used to compensate for heat and pressure losses in the system.

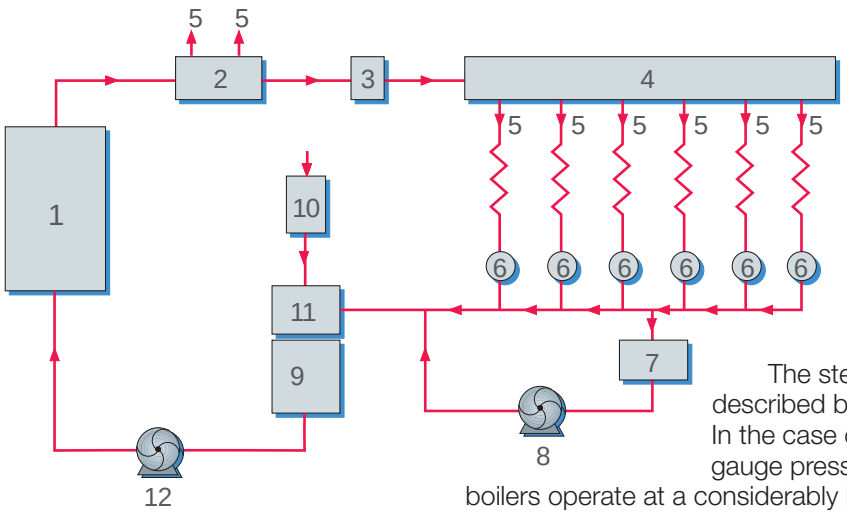


Fig. 6.11.4 *Steam production and distribution system*

1 *Boiler*
2 *Steam distribution vessel for high-pressure steam*
3 *Pressure-reducing valve*
4 *Distribution vessel for low-pressure steam*
5 *Points of consumption*
6 *Steam traps*
7 *Condensate tank*
8 *Condensate pump*
9 *Feed-water tank*
10 *Water softening filters*
11 *Feed water degassing unit*
12 *Feed water pump*

Figure 6.11.4 is a simplified diagram of the steam system and the distribution network. The water used for generation of steam is referred to as feed water. Makeup water often contains calcium salts, which make the water hard. Treatment of feed water is often necessary, as it contains oxygen and carbon dioxide.

If this is not done, the salts will be deposited in the system and form scale in the boiler, resulting in drastically reduced efficiency. Oxygen can cause severe corrosion in the water and steam parts. Water-softening filters (10) are therefore included in the system. They remove the calcium and magnesium salts, and a de-gassing apparatus (11) removes the gases in the feed water. Impurities in the form of sludge are removed by blowing down the boiler. Chemical conditioning of boiler water and treatment of boiler feed water are necessary to keep the steam system in good operating condition.

A feed water pump keeps the water in the boiler at a constant level. The water in the boiler is heated by the burning fuel and converted to steam. It takes a great deal of heat, about 2 260 kJ (540 kcal) at atmospheric pressure, to convert one kilogram of water to steam. This heat, which is referred to as vaporisation heat, will subsequently be released as the steam condenses on the heat transfer surfaces at the points of consumption (5).

The condensed steam, condensate, is collected in steam traps (6) and a condensate tank (7) and pumped back to the boiler by a condensate pump.

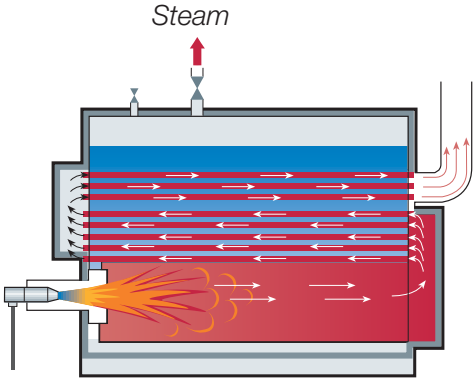


Fig. 6.11.5 *Principle of the fire tube boiler*

Steam boilers

Two main types of boilers are used for the generation of steam: the fire tube boiler (which is the most common type in dairies) and the water tube boiler. The choice is influenced by the required steam pressure and steam power, *i.e.* the quantity of steam utilised at a given time. Boilers for low pressures and small power outputs are often tubular boilers in which the flue gases

pass inside the tubes. Boilers for high pressures and large steam power outputs are mostly water-tube boilers, in which the water is circulated inside the tubes.

Figure 6.11.5 shows the principle of the fire tube boiler. The hot flue gases are blown by a fan through the tubes. Heat from the flue gases is conducted through the walls of the tubes to the water surrounding the outside of the tubes. The water is heated to boiling point and the steam is collected in the steam dome for distribution to the system.

When the pressure inside the steam dome reaches the required (pre-set) level, the steam valve can be opened and the steam flows to the points of consumption. The burner is started and stopped automatically, keeping the steam pressure at the required level. Feed water is added so that the correct water level is maintained in the boiler. The safety valve opens if the highest permitted pressure in the steam dome is exceeded.

Water-tube boilers (Figure 6.11.6) are available in a wide range of models. The principle is that the feed water passes through tubes which are externally heated by the flue gases. Steam generation takes place in the tubes, which are inclined so that the steam can rise to the steam dome. The steam passes into the two upper domes via the superheater before being fed into the distribution system. The steam is heated by the flue gases for a second time in the superheater *i.e.* the steam is superheated, and becomes dryer as a result.

The lower dome also collects sediment sludge, the impurities which were present in the feed water. The sludge is removed from this dome by bottom-blowing the boiler. In other types of boilers, the sludge collects in the bottom of the boiler.

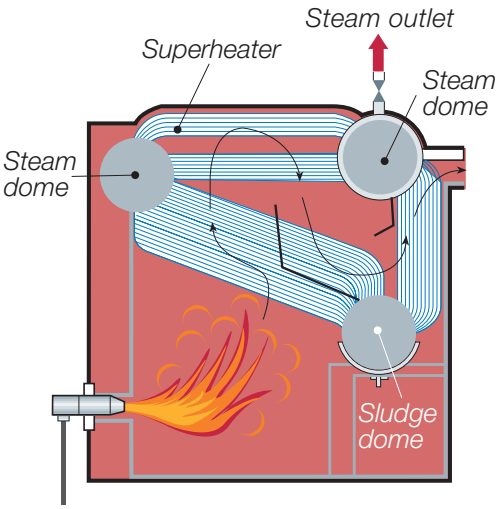


Fig. 6.11.6 *Principle of the water-tube boiler including three steam domes.*

Collecting the condensate

The steam which passes through the piping system is cooled by the surrounding air and consequently starts to condense. It is possible to reduce this condensation by insulating the pipes, but condensation can never be completely avoided. The pipes must therefore be installed with a slight slope towards the condensate collection points, which are located in various parts of the piping system.

Steam traps are installed at these points. They permit the condensate to pass (and preferably also air), but not steam. The condensate is collected in the same way at the various steam consumption points and is returned to a collecting tank in the heating plant by condensate pumps and a piping system. Condensate can be returned to the feed water tank by steam pressure without using a condensate tank or condensate pump. This system is very often used.

Other equipment

The firing equipment of industrial steam boilers consists of a burner, (often an oil-fired burner of the atomiser type), in which the oil is dispersed as a fine mist. This mist is ignited by high-voltage electrodes and the resulting flue gases are blown through the boiler by a fan. Safety equipment is also included to eliminate the risk of accidents and damage. Modern steam generating boilers are fitted with automatic control devices which permit operation without the need for constant supervision.

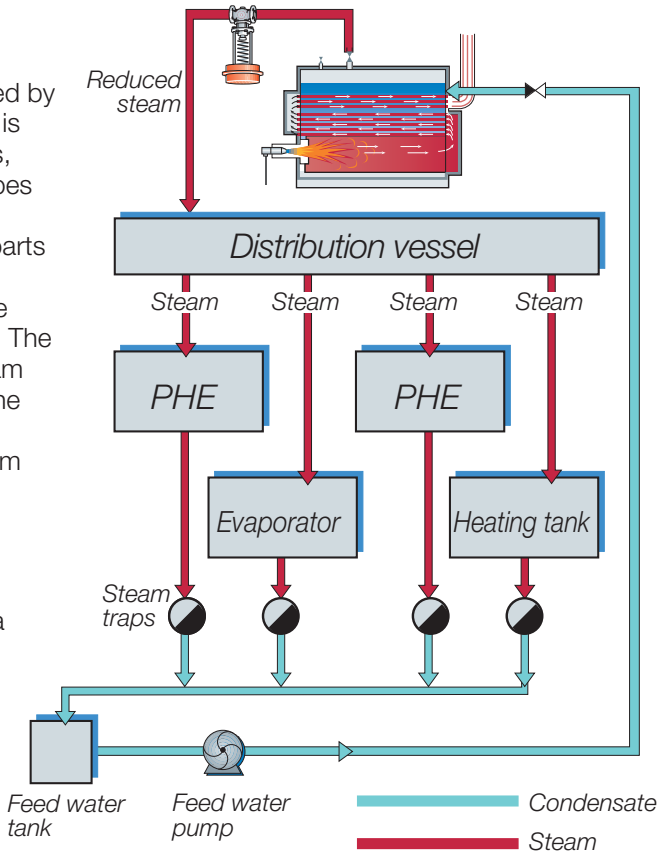


Fig. 6.11.7 *System for steam distribution and condensate collection.*

The steam piping system

A system for steam distribution and condensate collection is schematically shown in Figure 6.11.7. The steam passes through the main valve on the steam dome of the boiler to the distribution vessel via a pressure reduction valve. From here, the steam continues to the various points of consumption. A pressure-reducing valve is often fitted before the consumption point, for fine adjustment of the steam pressure.

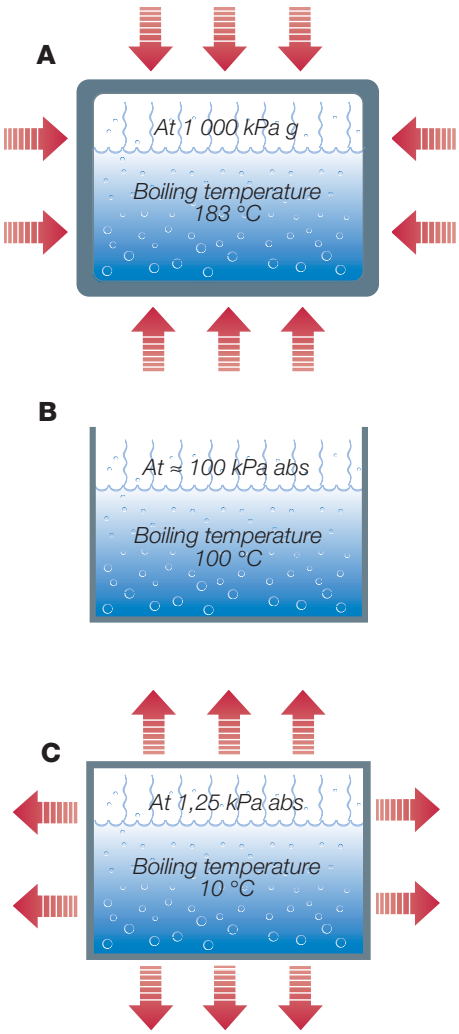


Fig. 6.11.8 *Reduction of pressure causes water to boil at lower temperatures. (g = gauge)*

The steam piping system is exposed to extensive variations in temperature. This results in considerable thermal expansion of the pipes. The pipes must therefore be installed to permit axial movement.

The location of the condensate trap and the design of the pipe system must be done with care to avoid collection of water in the pipes. If a plug of water is formed, it will move through the pipe at high velocity, minimum at the same velocity as the steam, which is approximately 25 – 30 m/s. This is called a water hammer, and it can cause great damage to both pipes and valves.

Refrigeration

Many stages in the process require that the product is heated to a certain temperature. Any increase in temperature will naturally result in increased activity by any micro-organisms which may be present in the product, as well as speeding up the chemical reactions which are controlled by enzymes. Activity of this kind must be avoided as much as possible, so it is important for the product temperature to be reduced quickly as soon as a particular stage of production has been completed. The need for refrigeration in dairies is consequently very great, and the operating costs of the refrigeration plant represent a significant item in the budget of any dairy.

The principle of refrigeration

The refrigeration effect is based on the fact that heat is absorbed when a liquid is converted into vapour.

This phenomenon, vaporisation heat, has already been mentioned in the description of the steam boiler. The internal pressure of the steam boiler is higher than atmospheric pressure and the water therefore boils at a higher temperature; water at a gauge pressure of 1 000 kPa (10 bar) boils at 183 °C. See Figure 6.11.8 (A).

Conversely, water boils at a lower temperature if the pressure is reduced. Water at atmospheric pressure boils at 100 °C. See Figure 6.11.8 (B). If the pressure is reduced to below atmospheric pressure, a vacuum is created and the water boils at a temperature below 100 °C. Water can be made to boil at about 80 °C by connecting a vacuum pump to a vessel containing water and reducing the absolute pressure to 50 kPa (0,5 bar). Water will boil at 10 °C if the pressure is reduced to 1.25 kPa (0,0125 bar), as shown in Figure 6.11.8 (C).

If this vessel is placed in an insulated room in which the air temperature is 20 °C, heat from the air will be transferred to the water in the vessel. The water will then be converted to steam. If the steam formed in this way is continuously extracted so that the pressure inside the container does not exceed 1,25 kPa, the air in the room will be cooled by transfer of heat to the water in the vessel; the water acts as a *refrigerant*.

1,25 kPa is very low, and it would therefore be extremely expensive to use water as a refrigerant. There are other liquids which boil at the same temperature under considerably higher pressures. Such a liquid has a higher vapour pressure than water. One example is ether; if a drop of ether falls on the skin, it feels cold. This is because heat from the skin is transferred to the liquid ether as it boils and is converted to vapour. Ether boils at a temperature below 37 °C at atmospheric pressure. If the pressure at the surface of the liquid is reduced by a vacuum pump, such liquids can be made to boil at temperatures well below 0 °C.

Ammonia is a common refrigerant. It boils at atmospheric pressure at a temperature of about –33 °C. If the pressure is reduced to 50 kPa (0,5 bar), ammonia boils at –45 °C. Freon R22 is another common refrigerant which, unlike ammonia, is non-toxic and odourless and which will neither burn nor explode. As a refrigerant, it has approximately the same vapour pressure as ammonia at various temperatures.

The use of refrigerants such as R12 and R22 is now restricted in most countries because they deplete the stratospheric ozone layer. These re-

frigerants are basically chlorinated fluorocarbons (CFCs). It is the chlorine that breaks down ozone. In addition, CFCs contribute to the greenhouse effect. In choosing refrigerant systems, it is desirable to replace CFC refrigerants with environmentally acceptable alternatives wherever possible.

How refrigeration works

A refrigeration system is a closed circuit in which the refrigerant cycles between gaseous and liquid form by undergoing alternate pressure reduction (expansion) and pressure increase (compression).

The principal components of the system are:

- Evaporator
- Compressor
- Condenser
- Expansion valve

Figure 6.11.9 shows how the system operates. The refrigerant is under low pressure in the evaporator, where it absorbs heat from the surrounding space. This causes part of the refrigerant to vaporise continuously. The vapour is continuously extracted from the evaporator by the compressor, which thus keeps the pressure of the refrigerant and its vaporisation temperature at a constant level.

The vaporised refrigerant is compressed to a higher pressure in the compressor. The hot refrigerant gas is then forced from the compressor to the condenser for cooling. Compression causes both the vaporisation temperature and the condensation temperature of the refrigerant vapour to rise. Where ammonia is used, the operating vaporisation temperature is often about –20 °C, which corresponds to a vaporisation pressure of 200 kPa (2 bar) absolute.

The pressure of the boiled-off gas is boosted to about 1 000 kPa (10 bar) in the compressor. This corresponds to a vaporisation temperature of +25 °C. The ammonia gas then condenses, *i.e.* it changes from a vapour to a liquid. This is done in the condenser by cooling the gas with water or air. The heat absorbed by the ammonia in the evaporator is released in the condenser.

The condensed liquid ammonia must then be returned from the condenser to the evaporator. The liquid passes through the expansion valve in order for the pressure to be reduced. This also reduces the temperature of the liquid. The expansion valve is set to give an exact reduction in pressure (so that the liquid assumes the same pressure as in the evaporator). A small proportion of the liquid vaporises in the expansion valve when the pressure is reduced. The vaporisation heat which this requires is obtained from the liquid, which is consequently cooled.

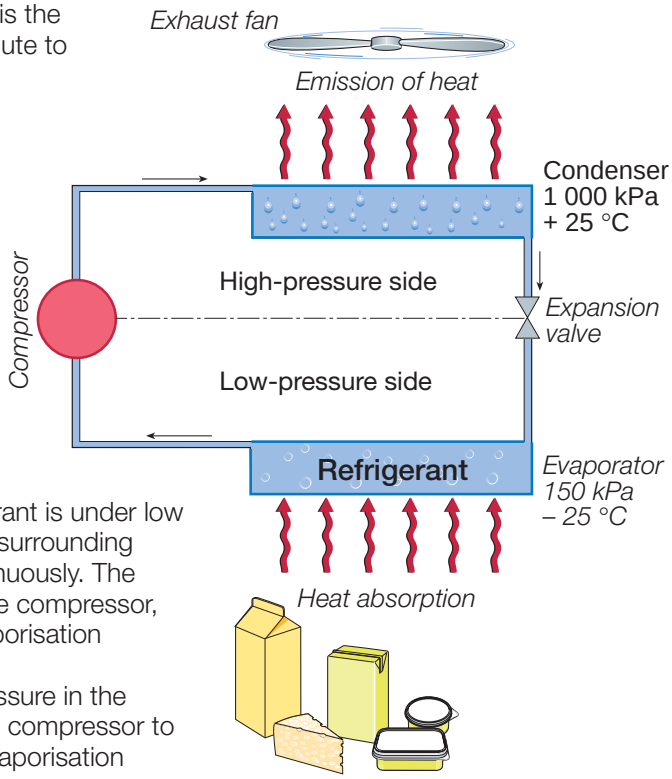


Fig. 6.11.9 *Schematic representation of a refrigeration system with ammonia refrigerant.*

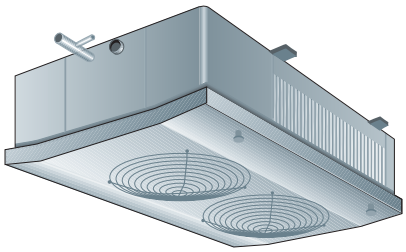


Fig. 6.11.10 *A small air cooler*

The evaporator

The evaporator is the part of the refrigeration plant in which the evaporation of the refrigerant takes place. The design of the evaporator is determined by the selection of refrigerant. There are three main types of evaporators used in dairies:

- Air-circulation evaporators
- Shell-and-tube and plate type evaporators
- Coil evaporators for ice accumulation

In air-circulation evaporators (Figure 6.11.10), air is chilled by being passed through a battery of tubes equipped with fins to maximise their heat-transfer area. The refrigerant circulating in the tubes absorbs heat from the air and is vaporised. Air-circulation evaporators are used for refrigeration of storage areas and for cooling the air in air-conditioning plants.

Shell-and-tube and plate type evaporators are widely used in dairies, where their function is to extract heat from the circulating coolants that cool products in process heat exchangers. Such coolants include ice water, brine (salt water) and alcohols such as ethanol and glycol, which have freezing points below 0 °C.

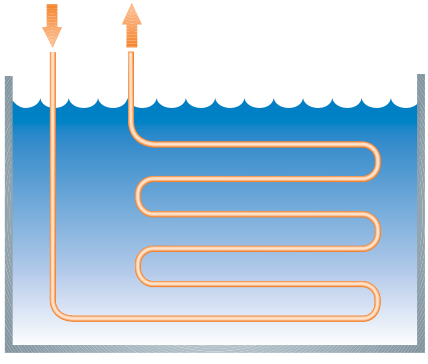


Fig. 6.11.11 *Ice water tank with evaporator coils.*

The coil evaporator (Figure 6.11.11), for ice accumulation, is designed to be placed in a water vessel to produce ice-water. During the night, water freezes in a layer on the evaporator tubes, inside which the refrigerant is circulated. This makes it possible to use cheap electric energy for running the cooling plant. The ice melts during the day, permitting a great deal of refrigerating capacity to be removed from this 'ice bank' in the form of ice water.

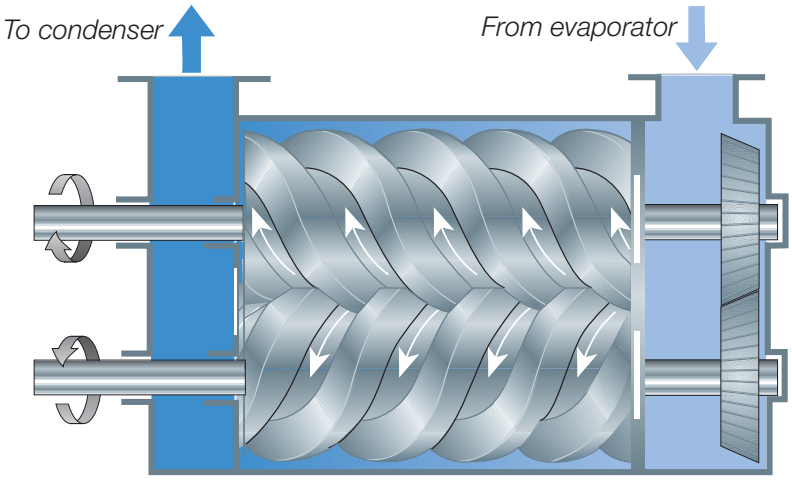


Fig. 6.11.12 *Design principle of the screw compressor.*

The compressor

The refrigerant vapour is compressed to a high pressure in the compressor. This increases the temperature of the vapour. The work carried out by the compressor is transferred to the gas in the form of heat. This means that the gas leaving the compressor contains a greater quantity of heat than was absorbed in the evaporator. All this heat must therefore be removed by cooling in the condenser.

The most commonly used refrigerating compressor is the piston compressor. The gas is drawn into cylinders and compressed by pistons in the cylinders. The machines can be equipped with a varying number of cylinders. They are available for refrigerating capacities between 0,1 and 400 kW.

The screw compressor (Figure 6.11.12), is also very common nowadays, especially for higher capacities. The principal components are two helical rotors installed in a common housing. As the rotors turn, gas is drawn into the gaps between the teeth (see also under Positive displacement pump in Chapter 6.7) and is trapped in the clearances. The volume between the teeth is progressively reduced as the captive gas is conveyed along the length of the rotors, so the gas is gradually compressed and the pressure increases. The compressed vapour continues to the condenser. Oil is sprayed on the meshing faces in most screw compressors in order to reduce leakage between the gaps in the rotors. In this way it is possible to obtain high efficiency even at low speeds. The oil is removed from the vapour in an oil trap before the condenser.

Screw compressors are used in large installations. One of the greatest advantages of the screw compressor is that the capacity can be varied down to 10 % of full power without excessive electric power losses.

The condenser

The heat absorbed in the evaporator and the heat transmitted to the vapour in the compressor are removed by cooling in the condenser. Condensers are divided into three types:

- Air-cooled condensers
- Liquid-cooled condensers
- Evaporation condensers

The selection of the condenser is determined by external factors such as

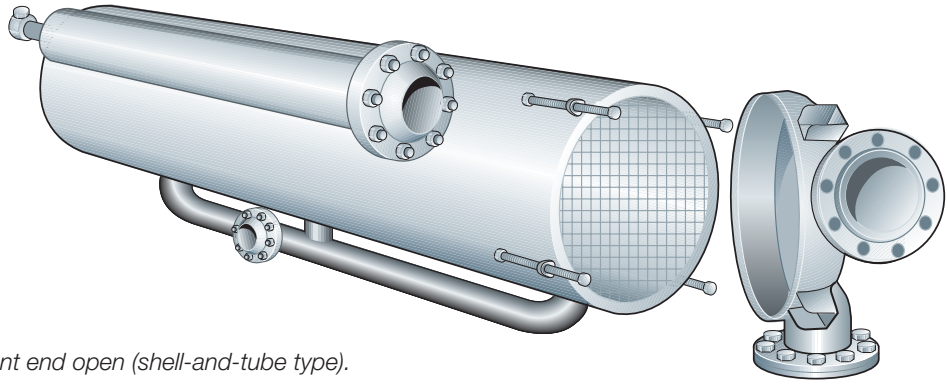


Fig. 6.11.13 *Tube condenser with front end open (shell-and-tube type).*

water supply, the price of water and the operating time of the plant.

Air-cooled condensers have, until now, mostly been used in small refrigeration plants, but are becoming more common in large plants. The reason for this is the rapidly increasing cost of water and, occasionally, the uncertainty of the water supply. In the air-cooled condenser, the refrigerant passes through a cooling coil with fin elements, around which the cooling air circulates. As it is cooled, the refrigerant condenses in the coil and then flows to the throttling valve.

The water-cooled condenser is the most economical type where a cheap supply of water is available. The most common type is the tube condenser (Figure 6.11.13). It operates by circulating cooling water inside the tubes. This condenses the refrigerant on the external tube surfaces.

The water-cooled condenser (Figure 6.11.14) is often combined with a cooling tower. The cooling water is cooled by air in the cooling tower and is then pumped to the condenser, where it absorbs the condensation heat from the refrigerant. From there, it is pumped back to the cooling tower for the air-cooling to be repeated.

The evaporation condenser is a combination of an air-cooled condenser and a cooling tower. This type is used when there is a shortage of cooling water or where the cost of cooling water is too high.

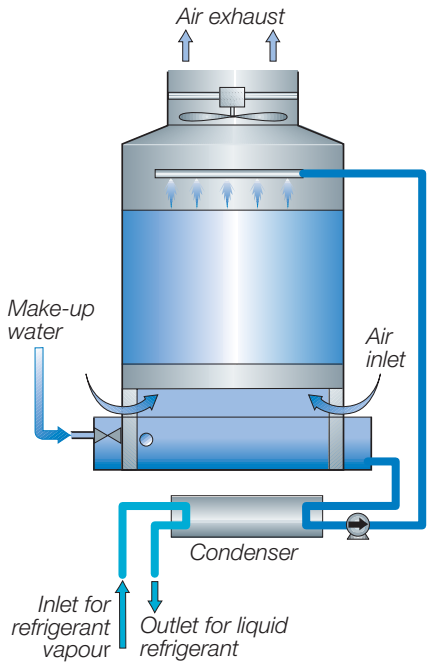


Fig. 6.11.14 *Combined tube condenser and cooling tower circuit.*

Other equipment

The installation described has been greatly simplified to illustrate how the refrigeration plant works. Many other components are required in order for the plant to function, *e.g.* refrigerant tanks, filters, oil traps, safety valves, shut-off valves, level, pressure and temperature gauges and other forms of safety equipment in order to permit safe operation of the plant. The plant can also be equipped with automatic control devices to eliminate the need for constant supervision and to provide more economical operation.

Cooling systems in dairies

Ice water is the most common form of cooling water used in dairies. Water is cooled in an ice water tank where ice is formed on evaporator coils.

Glycol system is used when low temperatures are required that cannot be achieved with water as cooling media. A typical solution contains 30 % of glycol and 70 % of water. This solution has a freezing point of about –13 °C. Glycol used in food industry shall be propylene glycol and if there is any possibility that it can come in contact with product all additives shall be non-toxic. These additives are added as corrosion protection and to stabilise the glycol.

Cooling towers are used to get cooling water that is close to the wet bulb temperature. The process has a low energy demand and can be a cheap way to get low grade cooling water.

Chillers are used when there is an even demand for cooling water during the whole day and there is no use to accumulate energy in the form of ice in an ice water tank.

Pipe systems for cooling water

If pipes that are not rustproof are used, they must be rust protected by painting. Insulation shall stand moisture and shall include a vapour barrier to avoid condensation inside the insulation.

Production of compressed air

The dairy industry has an extensive requirement for advanced instruments and equipment for automatic control, monitoring and regulation of the various production processes. Pneumatically-controlled automatic systems have proved reliable in the damp atmosphere of the dairy and are frequently used. Reliability requires compressed air free from impurities, which makes demands on the design of the compressed-air system. Compressed air also has other applications:

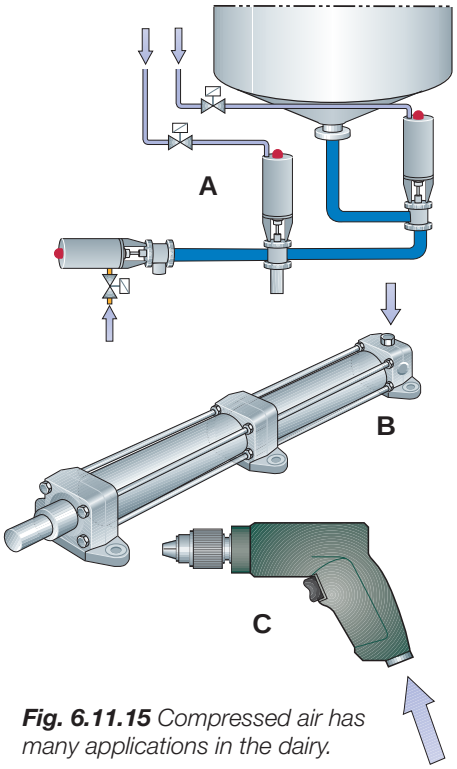


Fig. 6.11.15 *Compressed air has many applications in the dairy.*

A *Air for actuating valves*
B *Air for powering cylinders*
C *Air for pneumatic tools*

- Powering the actuators in some machines, such as filling machines
- Emptying product from pipes
- Agitation in storage tanks
- Pneumatic tools in the workshop

Demands on compressed air

The various applications for compressed air in the dairy make different demands concerning air pressure, dryness, purity and quantity. Based on the requirements for purity, compressed air is divided into three quality classes:

- Compressed air which comes into direct contact with the product. This class should be clean, oil-free, dry, odourless and practically sterile. Relatively small quantities of this A-quality air are used. The supply pressure is often between 200 and 300 kPa (2 – 3 bar).
- Compressed air which does not come into contact with the product, but which must be clean, dry and preferably oil-free, as it will be used for the control of instruments and as the source of power to actuate pneumatic components and valves, etc. This compressed air is supplied at a pressure of between 500 and 600 kPa (5 – 6 bar).
- Compressed air which should be free from solid particles and as dry as possible, as it will be used for pneumatic tools, etc. Supply pressure approximately 600 kPa (6 bar).

Untreated air from the atmosphere always contains impurities. These are found in untreated compressed air, together with impurities from the compressor. There may be particles produced from wear and from oil particles. Atmospheric air also contains water vapour, which must be removed if the compressed air is to meet the necessary standard of quality.

The largest quantities of compressed air are used for pneumatic machines in the dairy and in the workshop. This air must be supplied at a pressure of approx. 600 kPa (6 bar), for which a compressor plant producing an operating pressure of 700 kPa (7 bar) is required to compensate for the pressure drop in the distribution system. Only a small quantity of compressed air is needed at pressures lower than those required for the control of instruments and as a source of power. It would therefore be uneconomical to use separate compressors for this air, as it would also require a separate system of air conduits. Consequently, compressed air for all applications is taken from the central compressor plant and then receives individual treatment to meet the several requirements of its applications.

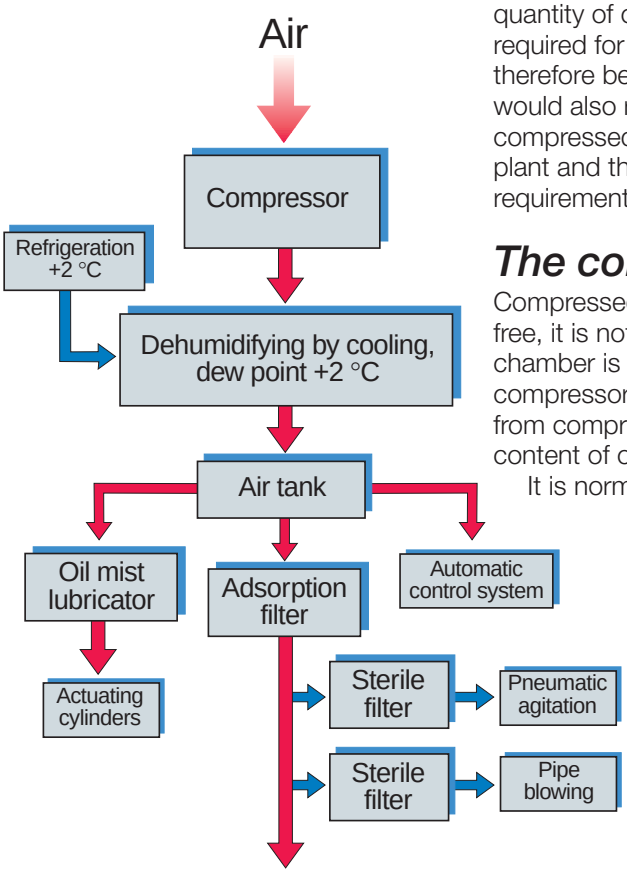


Fig. 6.11.16 *Compressed-air installation*

The compressed-air installation

Compressed air is produced in an air compressor. When air must be oil-free, it is not possible to use compressors in which the compression chamber is lubricated with oil to increase compression efficiency. Oil-free compressors must be used. It is practically impossible to remove all the oil from compressed air, but it is nevertheless possible to get a remaining oil content of only 0,01 ppm.

It is normal to use two identical compressors to meet the overall compressed-air requirement of the dairy. The types of compressors used include oil-lubricated compressors, screw compressors with oil-free compression chambers, special piston compressors with non-lubricated cylinders and a means of preventing oil from the crankcase from entering the compression chamber, and finally turbocompressors.

Figure 6.11.16 shows an example of an installation. Air is supplied from the compressor to a dehumidifier, where the water vapour in the air is removed by cooling and precipitation. The dried air then continues to an air receiver. The compressed air is taken from this tank and used to control instruments, operate valves and power actuating cylinders, etc.

Compressed air of the highest quality, which comes into direct contact with the product when used for pneumatic agitation of tanks and for emptying product from pipes, undergoes further drying in adsorption filters and is then sterilised in special filters before being used.

Air drying

Air always contains some water vapour. The greatest amount of water vapour (in g/m^3) that air can hold varies with the temperature.

Air containing the maximum possible amount of vapour is said to be *saturated*. At 30 °C, saturated air contains 30,1 g water per cubic metre. If the temperature drops to 20 °C, the saturation vapour content is only 17,1 g/m^3. This means that 30,1 – 17,1 = 13,0 g/m^3 will precipitate (condense) as free water. The temperature at which water vapour begins to condense is called the *dew point*.

Air in the atmosphere, at a temperature of 20°C, contains a maximum of 17,1 g/m^3 of water. The degree of dryness of air containing only 6,8 g/m^3 of water may be described as its "relative humidity", (RH), *i.e.* the ratio between the actual water content and the maximum possible water content.

The relative humidity of the air in this case will be:

$$\frac{6{,}8 \times 100}{17{,}1} = 40\%$$

The dew point of this air is 5 °C. The vapour will condense to form free water if it is cooled to below 5 °C.

If the air in the atmosphere, which is at a pressure of 100 kPa (1 bar), is compressed to half its volume, with no change in temperature, the pressure will increase to 200 kPa (2 bar). A cubic metre of air at this higher pressure will then contain 2 x 6,8 = 13,6 g water/m^3. The dew point of the air will also have been increased from 5 to 16 °C as a result of being compressed.

If the air is now compressed again to half its volume, the pressure will increase to 400 kPa (4 bar). A cubic metre of this compressed air contains 2 x 13,6 = 27,2 g water/m^3. However, air at 20 °C can only contain 17,1 g/m^3 of water, regardless of the pressure. The surplus of 27,2 – 17,1 = 10,1 g/m^3 will therefore condense in the form of free water.

Conversely, it is possible to reduce the dew point of the air if it is allowed to expand to a reduced pressure (greater volume).

Air which has been compressed in a compressor, Figure 6.11.16, contains a great deal of water. It is also hot – about 140 – 150 °C – and must therefore be cooled. For this purpose, it passes through an aftercooler, where most of the water is precipitated by cooling with water or air. The compressed air then continues to a cooler-drier, where further cooling takes place until a dew point of about 2°C is reached. The dried air will now have a pressure of 700 kPa (7 bar), a temperature of 2 °C and a water content of 5,6 g/m^3.

The requirement for a dairy is that the dew point should be at least 10 °C below the lowest ambient temperature to which the compressed air lines are exposed.

A dew point of 2 °C is considered satisfactory in most cases. If the air system passes through areas with temperatures below 0 °C, the air will have to be dried to an even lower dew point in order to avoid condensation of water inside the air lines, which would cause problems. Adsorption driers should be used in such cases. The humidity in the air is adsorbed by a drying agent such as silica gel.

Sterile air is obtained by filtering the compressed air in sterile filters. The filter element of these filters consists of chemically pure cotton or polyester or polypropylene. Micro-organisms are killed as the air is heated in the compressor. Reinfection can occur in the pipes, and the sterile filters are therefore fitted immediately before the equipment where the air is used. The filters are normally adapted for steam sterilisation.

Pipe system

The most rational solution is to have a single compressor plant and a single distribution network for the compressed air. It is of the greatest importance in a modern, highly automated dairy that instruments and control systems can always be supplied with compressed air at the correct pressure and in the correct quantity. In some cases, the design may involve installation of regulators which supply compressed air to the control system, so that the air supply to less sensitive points can be shut off if there is a tendency for the pressure in the supply line to drop.

Electric power

Dairies normally purchase their electric power from local distributors. In most cases it is supplied at high voltage, between 3 000 and 30 000 V, but dairies with a power demand of up to approximately 300 kW may also take low-voltage supplies of 200 – 440 V.

The principal components of the electrical system are:

- High voltage switchgear
- Power transformers
- Low voltage switchgear
- Generating set
- Motor control centres (MCC)

High voltage switchgear

The high voltage switchgear is the main panel for high voltage distribution.

The switchgear consists of a number of cubicles with a central busbar system to which various types of switches are connected. One or more cubicles are used for the incoming supply from the distributor. Each supply/cubicle has a switch for isolation. After the incoming cubicles, there is a cubicle with equipment for metering the electric energy used. After the metering cubicle come cubicles for outgoing supply, one per transformer/supply. A normal dairy has between one and four transformers. Each transformer is protected by a switch (circuit breaker or load disconnector and fuse) that cuts off the power in case of fault or overload.

If the dairy has very large motors, for instance 300 kW and above, it may be worthwhile to supply them with high voltage from separate cubicles in the switchgear.

Power transformer

The power transformer receives power from cables connecting it to the high voltage switchgear. The power transformer converts high voltage to low

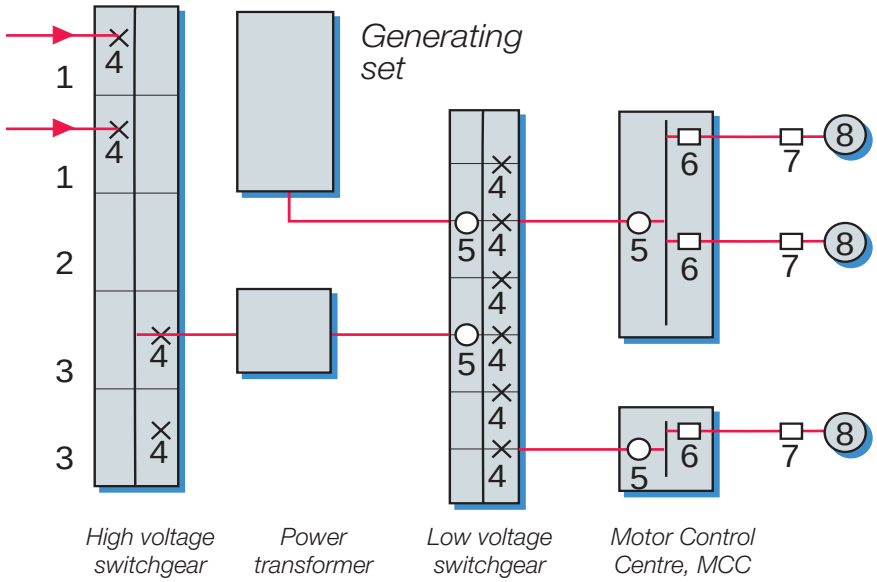


Fig. 6.11.17 *Example of a power distribution system for a dairy plant.*

1 *Cubicle for incoming supply*
2 *Cubicle for metering equipment*
3 *Cubicle for transformer supply*
4 *Circuit breaker*
5 *Main switch*
6 *Motor starter*
7 *Isolating switch*
8 *Consumption point (motor)*

voltage, normally between 200 and 440 V. The size of the transformer depends on the power demand. The normal capacity range is 400 – 2 000 kVA.

There are two main types of transformer:

- Oil-insulated for indoor and outdoor installation
- Dry-insulated for indoor installation

Oil-insulated transformers are less expensive, but require a separate, fireproof room because of the inflammable oil. The room should have a sump under the transformer, where leaking oil can be collected.

Dry-insulated transformers do not contain inflammable oil and can therefore be installed in connection with the load. Transformers are subject to losses of approximately 1 kW per 100 kVA. This lost energy is given off as heat, which must be removed by ventilation.

Low voltage switchgear

The low voltage switchgear receives power from cables or bars connecting it to the power transformer. The low voltage switchgear is the main panel for low voltage distribution; it contains equipment for switching, controlling and protection of outgoing supplies.

The size of the power transformer determines how big the main switch and busbar system of the switchgear must be.

The switchgear contains:

- One incoming unit with a main switch for isolation of the switchgear plus instruments for control of voltage, current, etc.
- Several outgoing units to large power consumers such as Motor Control Centres, (MCC), homogenisers, etc. Each supply has a circuit breaker or load breaker and a fuse for the protection of cables and apparatus.
- One unit with power factor correction equipment (not always).

Generating set

A generating set can be used for local production of electric power. The generating set may run continuously or be used as a standby if the local distribution system is out. The generator is usually diesel-powered, has its own integrated control panels, and delivers a low voltage supply. Several generating sets can run in parallel if needed.

Motor control centre, MCC

The MCCs receive power from cables connecting them to the low voltage switchgear. The MCCs control, protect and distribute power to the final consumption points in the plant.

An MCC contains one incoming unit with main switch for isolation and outgoing units for supply to machines and motors. The most common types of supplies are:

- One or three-phase circuit breakers (or fuses)
- Motor starters for direct on-line start
- Motor starters for star-delta start
- Two-speed starters
- Variable speed drives (via frequency converters)

Normally, a number of connection points are supplied from an MCC. Some machines have an enclosed MCC/Control Panel with all the necessary equipment.

The MCC controls, protects and distributes power to final consumption points in the plant.

An MCCs can be controlled:

- Manually by push-buttons on the front,
- Manually by push-button panels located in process areas,
- By electronic control systems inside the MCC or in a central control room.

Individual machines and motors receive power from cables connecting them to the MCCs. The cables are normally installed on cable trays or in pipes. An isolating switch (safety switch) is installed close to each motor for use during servicing.

All material used must have a suitable protection (IP = International Protection classification) against contact with solid objects and ingress of

water, depending on the room (surroundings) in which is installed. International standards are available as a help for this classification. Normally, IP 54 is required within process and packaging areas.

Design of electrical installations

When designing above electrical installations one has to follow domestic laws, regulations and standards. Today most national standards, etc. comply with international standards. Some of these standards are mandatory, which means that one must follow them. Some standards are only recommendations.

IP 54 is required within process and packaging areas.

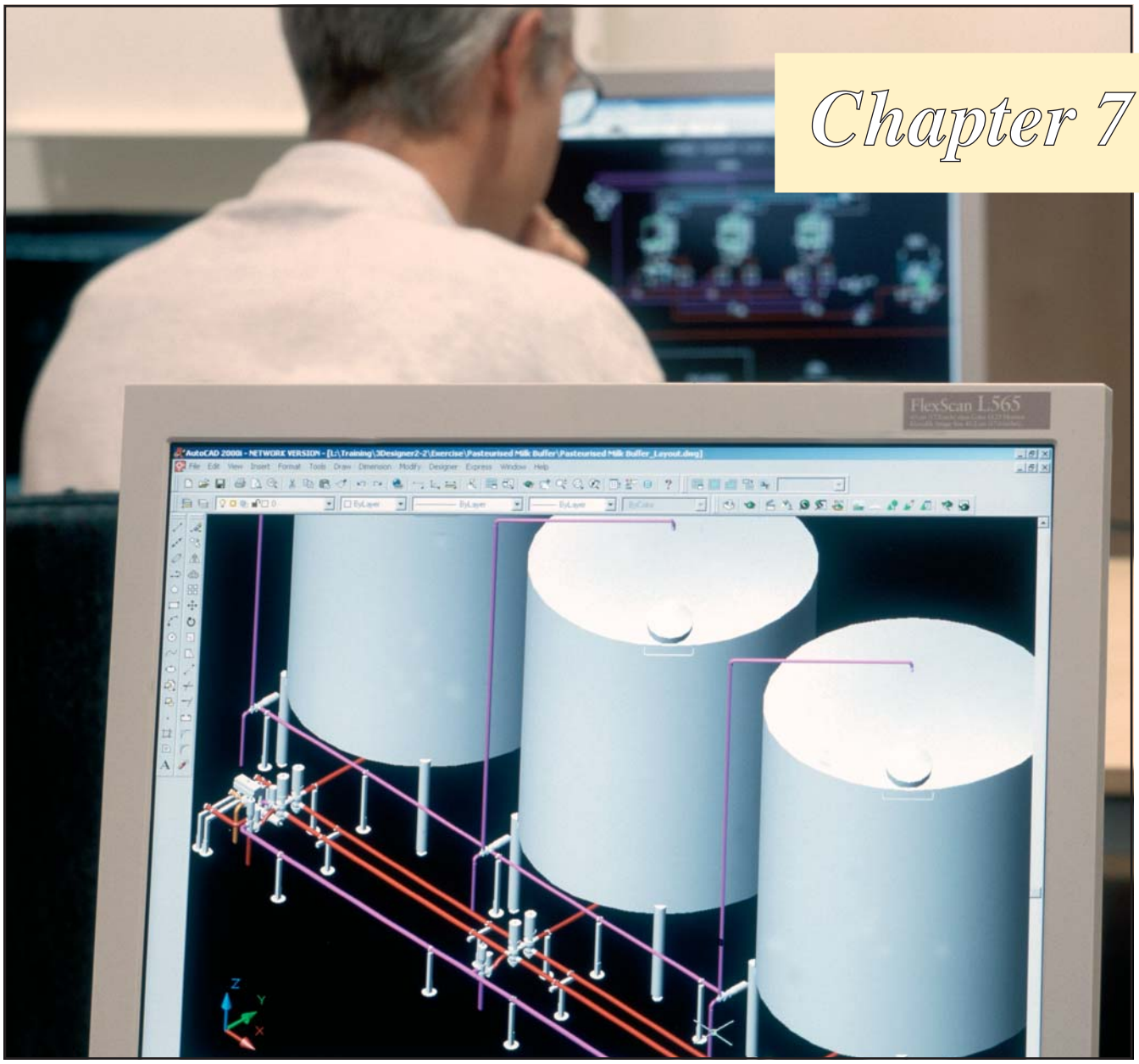
The organisation handling international electrical standards is IEC, International Electrotechnical Commission. IEC was founded in 1906 and has taught electricians to speak one common language and to design similar to each other. In Europe there is also the European organisation, CENELEC, European Commite for Electrotechnical Standardisation.

Within the EU countries there are also some EU directives one has to follow, such as the Machinery Directive, Low Voltage Directive and the Electro Magnetic Compability Directive. Manufacturers following these directives can put the CE-mark on their equipment.

Electrical plants are also designed with respect to different earthing/ wiring systems. The following systems are defined in the standards:
TN system, a system having one or more points of the source of energy directly earthed, the exposed conductive parts of the installation being connected to that point by protective conductors.
TN-C system, a system in which neutral and protective functions are combined in a single conductor throughout the system (Also called a 4 core system).
TN-S system, a system having separate neutral and protective conductors throughout the system (Also called a 5 core system).
TT system, a system having one point of the source of energy directly earthed, the exposed conductive parts of the installation being connected to earth, electrodes electrically independent of the earth electrodes of the source.
IT system, a system having no direct connection between live parts and earth, the exposed conductive parts of the electrical installation being earthed.

The most common system is a combination of two of the above systems, the TN-C-S system, which is a combination of the TN-C and TN-S systems. In this case, it is normally a TN-C system up to the Motor Control Centres and a TN-S system inside the MCC, as well as after them, out to the process, filling and packaging plant.

Today the electrical systems have become more complex with high demands on safety and precision. The use of noise generating devices, such as frequency converters, has increased the general noise level on the electrical supply. Modern control systems are also more complex and of course one has to install both electrical system and control system in a correct and co-ordinated way. Here, correct earthing/grounding and cable installations are especially important.



Chapter 7

Designing a process line

In the dairy, raw milk passes through several stages of treatment in various types of processing equipment before reaching the consumer in the form of a finished, refined product. Production usually takes place continuously in a closed process, where the main components are connected by a system of pipes. The type of treatment involved and the design of the process depend on the end product.

The process described in this chapter is general milk pasteurisation. This process is the basic operation in market milk processing, and also constitutes an important pre-treatment stage in a chain of dairy processes such as cheesemaking and cultured milk production. The aim is to present some of the considerations which the plant designer has to face when planning a whole milk pasteurisation plant.

Process design considerations

There are many aspects to be considered when a process line is designed. They can vary and be extremely complex, which places considerable demands on those responsible for the preliminary planning. Project engineering always involves a compromise between different requirements such as:

- Product-related – concerning the raw material, its treatment and the quality of the end product
- Process-related – concerning plant capacity, selection of components and their compatibility, degree of process control, availability of heating and cooling media, cleaning of process equipment, etc.
- Economic – that the total cost of production to meat the stipulated quality standards is as low as possible
- Legal – legislation stipulating process parameters as well as choice of components and system solutions

The process illustrated in Figure 7.1 deals with heat treatment – pasteurisation – of whole milk, *e.g.* market milk for sale to consumers.

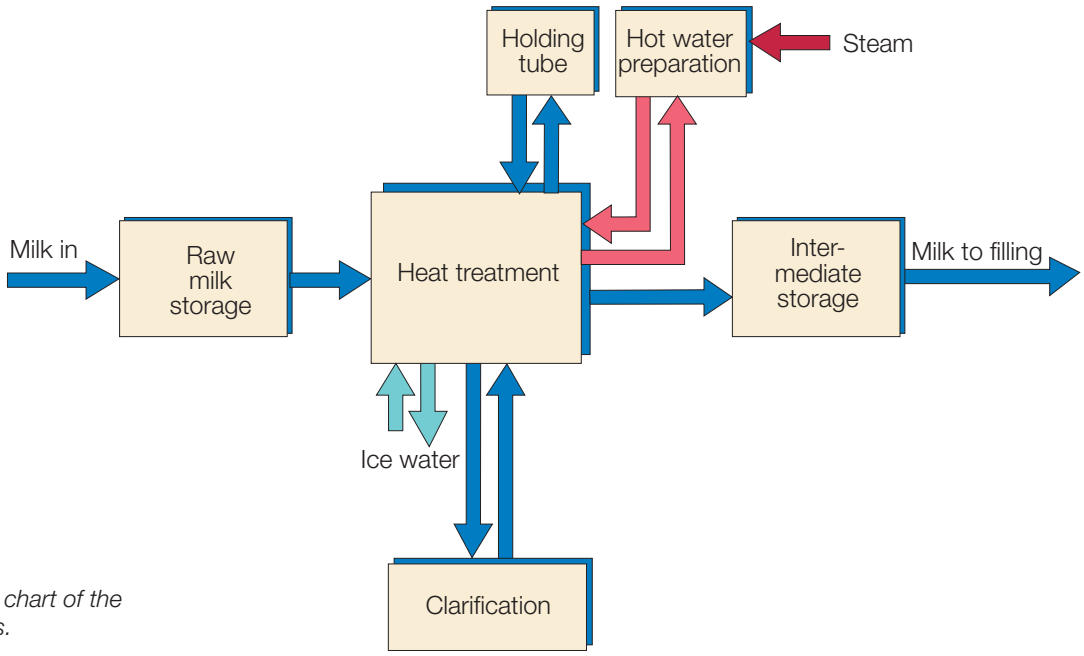


Fig. 7.1 *Generalised block chart of the milk pasteurisation process.*

Some legal requirements

In most countries where milk is processed into various products, certain requirements are determined by law to protect consumers against infection by pathogenic micro-organisms. The wording and recommendations may vary, but the combination below covers the most commonly stated requirements:

- **Heat treatment**

The milk must be heat treated in such a way that all pathogenic micro-organisms are killed. A minimum temperature/holding time of 72°C for 15 seconds must be achieved.

- **Recording**

The heating temperature must be automatically recorded and the transcript saved for a prescribed period of time.

- **Clarification prior to heat treatment**

As milk often contains solid matter such as dirt particles, leucocytes (white blood corpuscles) and somatic cells (of udder tissue), it must be clarified. Since pasteurisation is less likely to be effective if bacteria are hidden in lumps and particles in the milk, clarification must take place upstream of

heating. Milk can be clarified in a filter or, more effectively, in a centrifugal clarifier.

- **Preventing reinfection**

Heat exchangers are calculated so that a higher pressure should be maintained in the pasteurised milk flow compared to the unpasteurised milk and service media. If a leakage should occur in the heat exchanger, pasteurised milk must flow into the unpasteurised milk or cooling medium, and not in the opposite direction. In order to safeguard that, a booster pump to create a pressure differential is often required and in certain countries it is mandatory.

In the event of temperature drop in the pasteurised product due to a temporary shortage of heating medium, the plant must be provided with a flow diversion valve to divert the insufficiently heated milk back to the balance tank.

According to regulations set by the European Communities, the heat treatment equipment must be approved or authorised by the competent authority and at least fitted with:

- Automatic temperature control
- Recording thermometer
- Automatic safety device preventing insufficient heating
- Adequate safety system preventing the mixture of pasteurised or sterilised milk with incompletely heated milk
- Automatic recording device for the safety system referred to in the preceding intent.

Equipment required

The following equipment is required for a remote controlled process:

- Silo tanks for storing the raw milk.
- Plate heat exchanger for heating and cooling, a holding tube and a hot water unit.
- Centrifugal clarifier (as only whole milk is to be treated, a centrifugal separator is not needed in this example).
- Intermediate storage tank for temporary storage of processed milk.
- Pipes and fittings for connecting main components and pneumatically operated vaves for controlling and distributing the product flow and cleaning fluids.
- Pumps for transportation of milk through the entire milk treatment plant.
- Control equipment for control of capacity, pasteurisation temperature and valve positions.
- Various service systems:
  - Water supply
  - Steam production
  - Refrigeration for coolant
  - Compressed air for pneumatically operated units
  - Electric power
  - Drain and waste water.

Most of the various service systems are described in Chapter 6.11.
Service media requirements are calculated after the plant design is agreed upon. Thus, the temperature programme for pasteurisation must be known, as well as the specifications for all other areas where heating and cooling are needed (cold storage, cleaning systems, etc.), before the number and power of electrically operated machines, number of pneumatically operated units, working hours of the plant, etc. can be determined. Such calculations are not presented in this book.

Legal requirements for:

- Heat treatment
- Recording
- Clarification prior to heat treatment
- Preventing reinfection

Choice of equipment

Silo tanks

The number and size of silo tanks are determined by the raw milk delivery schedules and volume of each delivery. In order to operate the plant continuously without stoppages due to lack of raw material, a suffient supply of raw milk must be available.

Preferably, the milk should have been stored for at least one hour before being processed, as natural degassing of the milk takes place during that period of time. Short periods of agitation are acceptable, but agitation is not really needed until about 5 – 10 minutes before the silo is to be emptied, to equalise the overall quality. This avoids interference with the natural degassing process.

Heat exchanger

The main aim of pasteurising milk is to destroy pathogenic micro-organisms. To achieve this, the milk is normally heated to not less than 72 °C for at least 15 seconds and then cooled rapidly. These parameters are stipulated by law in many countries. The plate heat exchanger is most common for market milk pasteurisation purposes. Tubular heat exchangers can be used when long running times are essential. Scraped-surface heat exchangers are used for viscous products.

When the relevant parameters are known, the size (dimensioning) of the heat exchanger can be calculated. In the present example, the parameters are:

- Plant capacity, l/h 20 000
- Temperature programme, °C 4 – 72 – 4
- Regenerative effect, % 90 – 94
- Temperature of the heating medium, °C 74 – 75
- Temperature of the coolant, °C +2

The demand for service media (steam, water and ice water) is also calculated, as this substantially influences the choice of valves for steam regulation and ice water feed.

In plate heat exchangers, the connection plates between the sections are provided with inlets and outlets for product and service media. The inlet and outlet connections can be oriented either vertically or horizontally. The ends of the plate heat exchanger (frame and pressure plate) can likewise be fitted with inlets and outlets.

When long running time is essential the tubular heat exchanger is an alternative to the plate heat exchanger.

Dimensioning data for the heat exchanger are given in Chapter 6.1.

Hot water heating systems

Hot water or saturated steam at atmospheric pressure can be used as the heating medium in pasteurisers. Hot steam, however, is not used because of the high differential temperature. The most commonly used heating medium is therefore hot water typically about 2 – 3 °C higher than the required temperature of the product.

Steam is delivered from the steam boiler at a pressure of 600 – 700 kPa (6 – 7 bar). This steam is used to heat water, which in turn heats the product to pasteurisation temperature.

The water heater in Figure 7.2 is a closed system consisting of a specially designed, compact and simple cassette-type of plate heat exchanger (3) equipped with a steam regulating valve (2) and a steam trap (4).

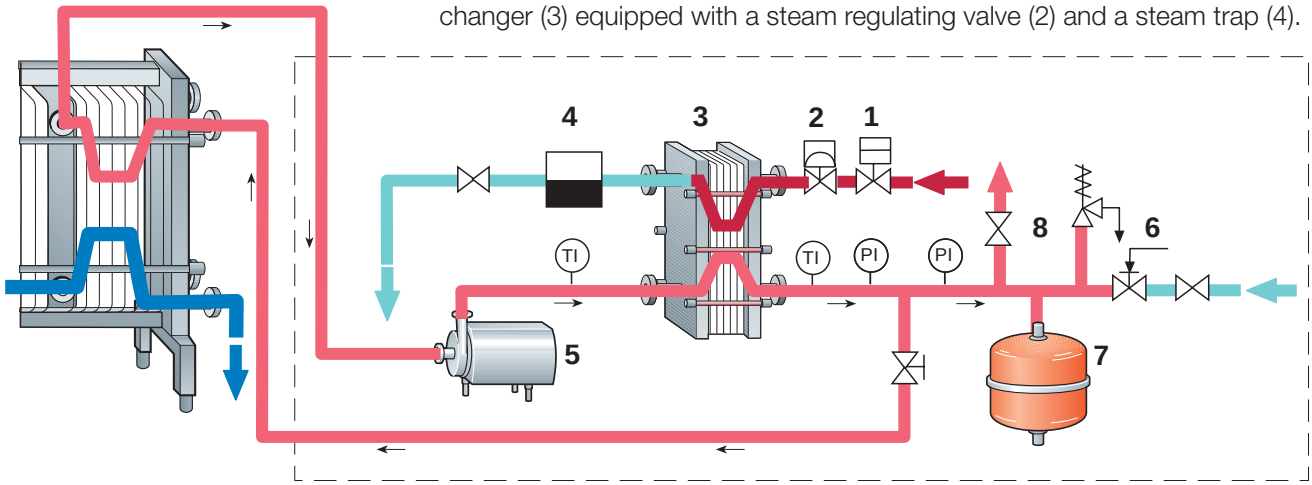


Fig. 7.2 *Principle of the hot water system connected to a pasteuriser.*

1 *Steam shut-off valve*
2 *Steam regulating valve*
3 *Heat exchanger*
4 *Steam trap*
5 *Centrifugal pump*
6 *Water regulating valve*
7 *Expansion vessel*
8 *Safety and ventilation valves*
TI *Temperature indicator*
PI *Pressure indicator*

Product
Steam
Heating medium
Water, incl. condensate

The service water is circulated by the centrifugal pump (5) via the heater (3) and the heating section of the pasteuriser.

The function of the expansion vessel (7) is to compensate for the increase in the volume of the water that takes place when it is heated. The system also includes pressure and temperature indicators as well as safety and ventilation valves (8).

Temperature control

A constant pasteurisation temperature is maintained by a temperature controller acting on the steam regulating valve (2) in Figure 7.2. Any tendency for the product temperature to drop is immediately detected by a sensor in the product line before the holding tube. The sensor then changes the signal to the controller, which opens the steam-regulating valve to supply more steam to the water. This increases the temperature of the circulating water and stops the temperature drop in the product.

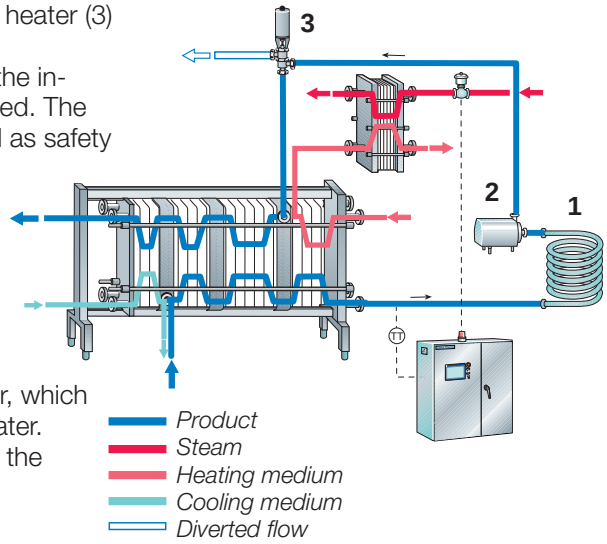


Fig. 7.3 *Automatic temperature control loop.*

TT *Temperature transmitter*
1 *Holding tube*
2 *Booster pump*
3 *Diversion valve*

Holding

The length and size of the externally located holding tube are calculated according to the known holding time and hourly capacity of the plant and the pipe dimension, typically the same as for the pipes feeding the pasteurisation plant. Dimensioning data for the holding tube are given in Chapter 6.1. Typically, the holding tube is covered by a stainless steel hood to prevent people from being burnt when touching it and from radiation as well.

Pasteurisation control

It is essential that the milk has been properly pasteurised before it leaves the plate heat exchanger. If the temperature drops below 72 °C, the unpasteurised milk must be kept apart from the already pasteurised product. To accomplish this, a temperature transmitter and flow diversion valve are fitted in the pipe downstream of the holding tube. The valve, 3 in Figure 7.3, returns unpasteurised milk to the balance tank if the temperature transmitter detects that the milk passing it has not been sufficently heated.

Pasteuriser cooling system

As already noted, the product is cooled mainly by regenerative heat exchange. The maximum practical efficiency of regeneration is about 94 – 95 %, which means that the lowest temperature obtained by regenerative cooling is about 8 – 9 °C. Chilling the milk to 4 °C for storage therefore requires a cooling medium with a temperature of about 2 °C. Ice water can only be used if the final temperature is above 3 – 4 °C. For lower temperatures, it is necessary to use brine or alcohol solutions, to avoid the risk of freezing cooling media.

The coolant is circulated from the dairy refrigeration plant to the point of use, as shown in Figure 7.4. The flow of coolant to the pasteuriser cooling section is controlled to maintain a constant product outlet temperature. This is done by a regulating circuit consisting of a temperature transmitter in the outgoing product line, a temperature controller in the control panel and a regulating valve in the coolant supply line. The position of the regulating valve is altered by the controller in response to signals from the transmitter.

The signal from the transmitter is directly proportional to the temperature of the product leaving the pasteuriser. This signal is often connected to a temperature recorder in the control panel and recorded on a graph, together with the pasteurisation temperature and the position of the flow-diversion valve.

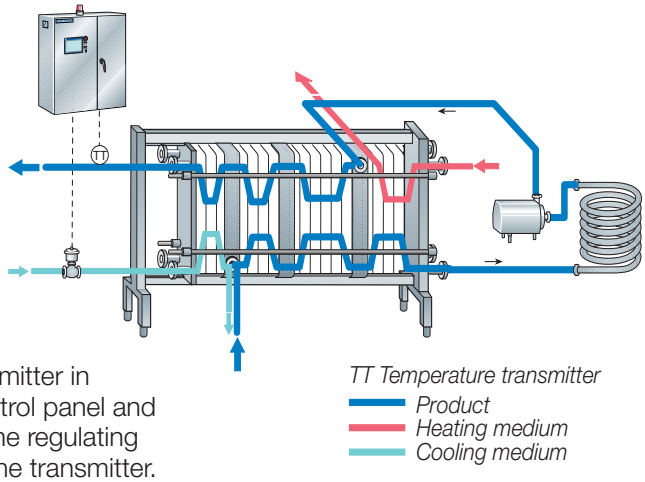


Fig. 7.4 *Cooling system for pasteuriser.*

Booster pump to prevent reinfection

Care must be taken to avoid any risk of contamination of the pasteurised product by unpasteurised product or cooling medium. If any leakage should occur in the pasteuriser, *it must be in the direction from pasteurised product to unpasteurised product or cooling medium.*

This means that the pasteurised product must be under higher pressure than the medium on the other side of the heat exchanger plates. In Figure 7.3, a booster pump (2) is therefore installed in the product line, either after the holding section or before the heating section. The latter position minimises the operating temperature of the pump and prolongs its life. The pump increases the pressure and maintains a positive differential pressure on the pasteurised product side, throughout the regenerative and cooling sections of the pasteuriser.

Installation of a booster pump is specified in the legal requirements for pasteurisation in some countries.

The complete pasteuriser

A modern milk pasteuriser, complete with equipment for operation, supervision and control of the process, is made using matching components, forming a sophisticated process unit, as in Figure 7.5.

Balance tank

The float-controlled inlet valve regulates the flow of milk and maintains a constant level in the balance tank. If the supply of milk is interrupted, the level will begin to drop.

As the pasteuriser must be full at all times during operation to prevent the product from burning on to the plates, the balance tank is often fitted with a low-level electrode which transmits a signal as soon as the level reaches the minimum point. This signal actuates the flow diversion valve, which returns the product to the balance tank.

The milk is replaced by water and the pasteuriser shuts down when circulation has continued for a certain time.

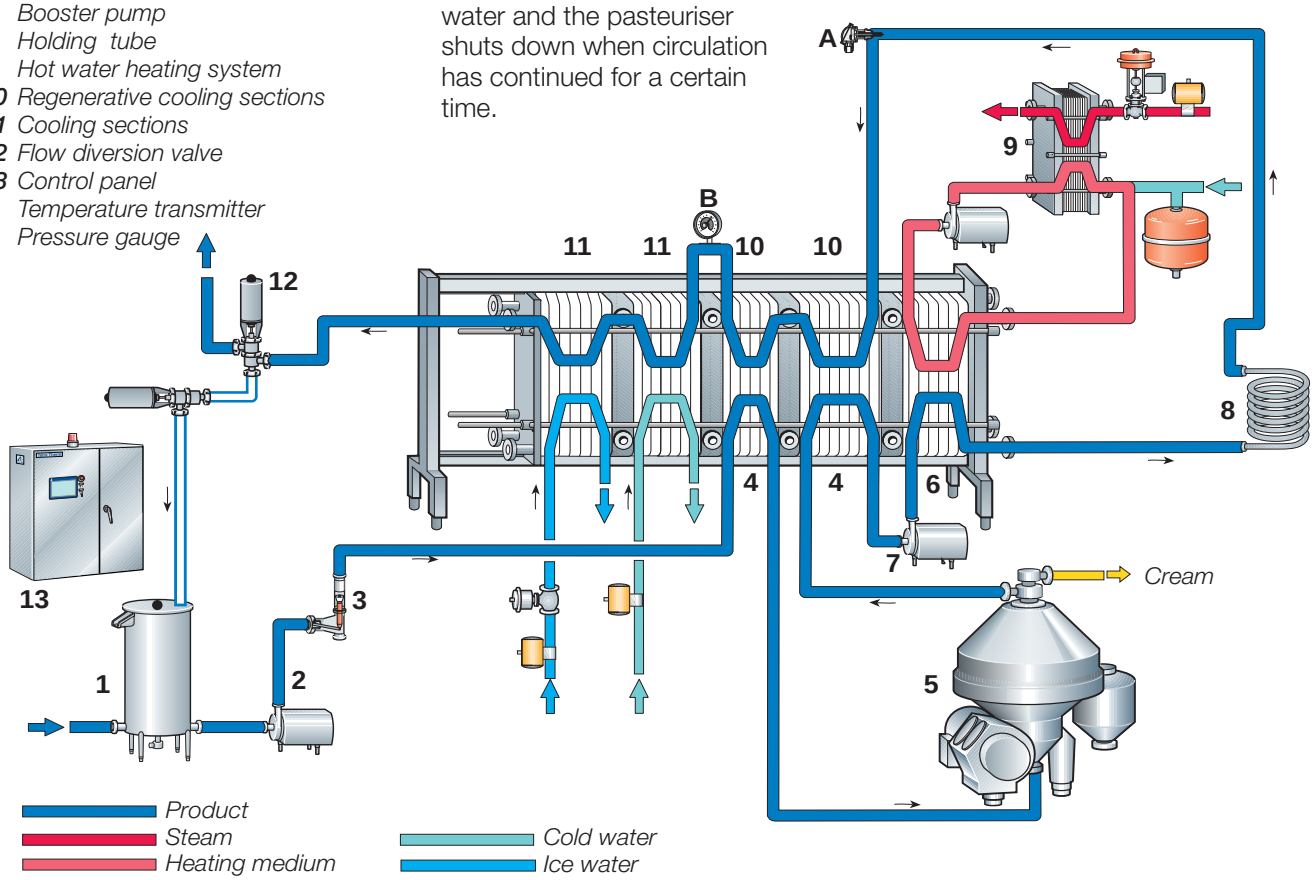


Fig. 7.5 *The complete pasteuriser plant consists of:*

1 *Balance tank*
2 *Feed pump*
3 *Flow controller*
4 *Regenerative preheating sections*
5 *Centrifugal clarifier*
6 *Heating section*
7 *Booster pump*
8 *Holding tube*
9 *Hot water heating system*
10 *Regenerative cooling sections*
11 *Cooling sections*
12 *Flow diversion valve*
13 *Control panel*
A *Temperature transmitter*
B *Pressure gauge*

Feed pump

The feed pump supplies the pasteuriser with milk from the balance tank, which provides a constant head.

Flow controller

The flow controller maintains the flow through the pasteuriser at the correct value. This guarantees stable temperature control and a constant length of the holding time for the required pasteurisation effect. Often the flow controller is located after the first regenerative section.

Regenerative pre-heating

The cold untreated milk is pumped through the first section in the pasteuriser, the pre-heating section. Here, it is regeneratively heated with pasteurised milk, which is cooled at the same time.

If the milk is to be treated at a temperature between the inlet and outlet temperatures of the regenerative section, for example clarification at 55 °C, the regenerative section is divided into two sections. The first section is dimensioned so that the milk leaves at the required temperature of 55 °C. After being clarified, the milk returns to the pasteuriser, which completes the regenerative pre-heating in the second section.

The regenerative energy-saving effect in a milk pasteuriser is typically between 90 and 94 %.

Pasteurisation

Final heating to pasteurisation temperature with hot water, normally of a temperature 2 – 3 °C higher than the pasteurisation temperature (Δ_t = 2 – 3 °C), takes place in the heating section. The hot milk continues to an external tubular holding cell. After the holding cell, the temperature of the milk is checked by a sensor in the line. It transmits a continuous signal to the temperature controller in the control panel. The same signal is also transmitted to a recording instrument which records the pasteurisation temperature.

Flow diversion

A sensor after the holding cell transmits a signal to the temperature monitor. As soon as this signal falls below a pre-set value, corresponding to a specified minimum temperature, the monitor switches the flow-diversion valve to divert the flow. In many plants, the position of the flow-diversion valve is recorded together with the pasteurisation temperature.

For the location of the flow diversion valve, various solutions are available to satisfy local regulations and recommendations. Below are three alternatives which are commonly utilised:

1 The flow diversion valve is situated just after the holding cell. Where a booster pump is installed, the valve is located before the pump. If the temperature drops under pre-set level, the valve diverts the flow to the balance tank and the pump stops. The flow in the regenerative and cooling sections thus comes to a standstill (even when no booster pump is integrated).

   After a short while, without temperature increase, the heat exchanger is emptied, cleaned and sanitised. When satisfactory heating is possible, the plant is restarted.

2 The flow diversion valve is located after the cooling section of the plant. Following a drop of temperature, the flow is diverted to the balance tank and the plant is emptied of product, cleaned and sanitised. The plant is then ready for restart when the temperature conditions are acceptable again.

3 The flow diversion valve is located between the holding cell and the booster pump. If the temperature drops, the valve diverts the flow. The booster pump is not stopped, but other valves around the heat exchanger will automatically be positioned so that the milk in the regenerative and cooling sections will be circulated to maintain the right pressure in the plant. This also preserves a proper temperature balance.

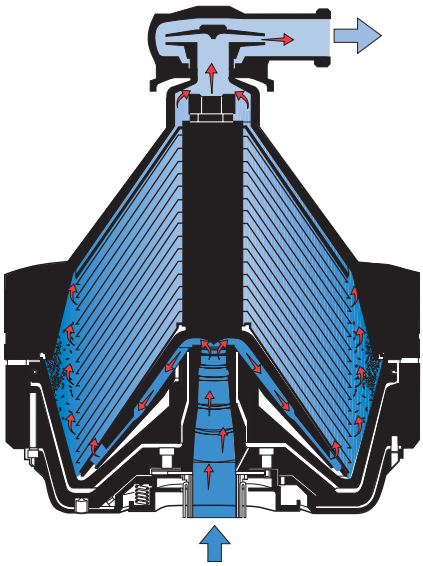


Fig. 7.6 *Bowl of a centrifugal clarifier.*

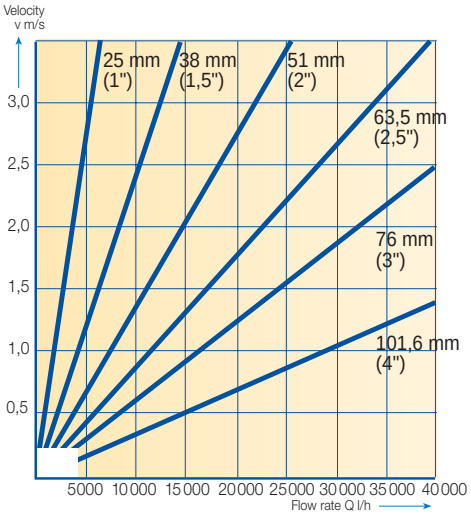
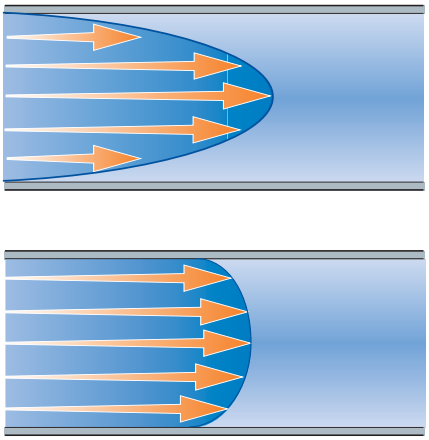


Fig. 7.7 *Product velocity and flow rate graph.*

Laminar flow



Turbulent flow

Fig. 7.8 *Velocity profile diagrams for laminar and turbulent flows.*

When the heating conditions are acceptable, the process can be resumed without intermediate cleaning.

Cooling

After the holding section, the milk is returned to the regenerative section(s) for cooling. Here the pasteurised milk transferes its heat to the cold incoming milk. The outgoing pasteurised milk is then chilled with cold water, ice-water, a glycol solution or some other refrigerant, depending on the required temperature. The temperature of the chilled milk is normally recorded, together with the pasteurisation temperature and the position of the flow diversion valve. The graph consequently shows three curves.

Centrifugal clarifier

As the milk in the present example is not going to be separated into skim milk and cream, a centrifugal clarifier is shown in Figure 7.6.

Some dairies specify centrifugal clarification of cold (<6 °C) raw milk immediately after arrival at the dairy, especially when the milk is going to be stored until the next day. However, clarification at about 55 °C is much more efficient, because the viscosity of the milk is lower at that temperature.

The milk feeding the clarifier is therefore taken from the first regenerative heating section at 55 °C.

Design of piping system

In the example in this chapter, 20 000 litres of milk per hour have to pass through pipes, fittings and process equipment during production. The product velocity through the pipes is determined by the size of the passage, *i.e.* the inside diameter of the pipe. The larger the diameter, the lower the product velocity.

For a flow rate of 20 000 litres per hour, the product velocity in a 76 mm (3") pipe will be 1,25 m/s. The velocity will be 2,75 m/s if a 51 mm (2") pipe is selected.

Higher velocities result in greater friction in the liquid itself and between the liquid and the pipe wall. Consequently, there is more mechanical treatment of the product. For each product, there is an upper velocity limit that should not be exceeded if quality demands are to be met. For milk, this velocity is about 1,8 m/s.

It might then seem reasonable to choose a larger pipe size than the minimum required by velocity considerations. But larger pipes mean larger components and greatly increased costs. The diameter nearest the limit is therefore chosen. In our case, this is 2,5" (63,5 mm), which corresponds to a velocity of 1,75 m/s, as shown in Figure 7.7.

Laminar and turbulent flows

Laminar flow is a type of flow in which the particles maintain a continuous, steady motion along parallel paths. This type of flow occurs, for example, in straight, round pipes or between parallel walls at low velocities.

On the other hand, in turbulent flow the particles have an irregular motion and intermix intensively with each other.

The length of a line represents the mean velocity of the particles at various points in the section through the passage, as illustrated in Figure 7.8. In laminar flow, the velocity is greatest at the centre of the passage. Due to the friction between the layers, the velocity slows progressively towards the walls, where it is zero.

In turbulent flow, the layers intermix and therefore the velocity of the liquid is roughly the same in the central part of the passage, but drops rapidly towards the walls. On the walls, a very thin laminar layer of the liquid has zero instantaneous velocity.

To obtain laminar flow in a round pipe, the diameter must be small, the velocity low and the viscosity of the liquid high.

Flow resistance

Every component in the line offers resistance to the flow when a liquid is forced through a pipe system. In straight pipes, the resistance is due to friction between the liquid and the walls. In bends, additional friction occurs from the liquid having to change direction. In the same way, friction, changes of direction and changes of section result in resistance in fittings, valves and process equipment. The magnitude of this resistance is relative to the velocity of the liquid in the system.

The resistance of each component in the line can be obtained from the resistance coefficient given by the manufacturer. The total resistance of the line can then be calculated by multiplying the sum of the coefficients by the square of the flow velocity and dividing the result by 2 g (g = the acceleration due to gravity = 9,81 m/s^2).

Example: The product velocity in a pipe system is 1,75 m/s (pipe diameter 2,5" and flow rate 20 000 litres/hour). The sum of the resistance coefficients amounts to 190. The flow resistance will be:

$$\frac{1{,}75 \times 1{,}75 \times 190}{2 \times 9{,}81} = 29{,}7 \text{ metres liquid column or head}$$

Flow resistance is expressed in terms of the liquid column, or head, needed to compensate for the loss of pressure due to the resistance. This way of reckoning dates back to the original application of pumping, which was to lift water from a low level to a higher level, *e.g.* from a mine shaft to ground level. The performance of the pump was judged by the height to which it could lift the water. In our case, the total resistance in the pipe system is equivalent to the work done by a pump lifting a liquid 30 metres vertically.

This also means that a column of water 30 metres high would exert enough pressure to overcome the flow resistance, as illustrated in Figure 7.9.

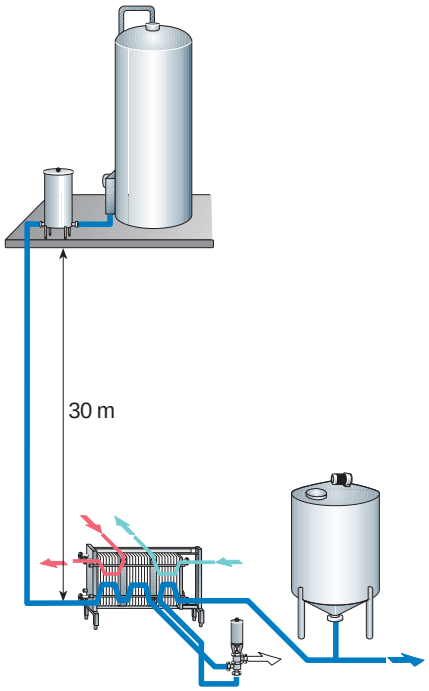


Fig. 7.9 *Process line illustrating the example with a 30-metre head between tank and process.*

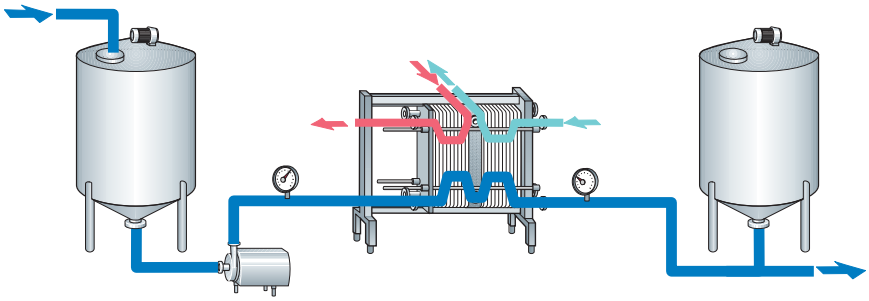


Fig. 7.10 *Pressure drop can be shown by pressure gauges in the process line.*

Pressure drop

The flow resistance of a liquid in a component results in a loss of pressure. If the pressure is measured with a pressure gauge (Figure 7.10) before and after the component, the pressure will be lower on the discharge side. The component, for instance a shut-off valve, causes a pressure drop in the line. This pressure drop (measured in terms of head) is equivalent to the resistance in the component. The magnitude depends on the velocity, *i.e.* the flow rate and the size of the pipes.

The pressure drop of a component is often stated as the loss of head in metres for different flow rates instead of the resistance coefficient. The graph in Figure 7.11 covers flow rates from 5 000 litres/hour for the smallest pipe diameter, 1,5" (38 mm), to 200 000 litres/hour for the largest, 4" (101,6 mm) shut-off valve.

For a flow rate of 20 000 litres/hour and a pipe size of 2,5" (63,5 mm), a velocity of 1,75 m/s, the graph indicates a pressure drop, or loss of head, of 0,4 metre over the fully open valve.

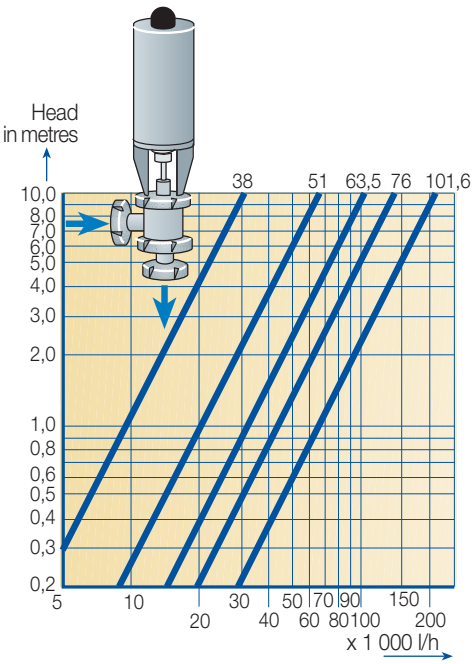


Fig. 7.11 *Pressure-drop graph for a shut-off valve.*

The pressure drop over each of the components in the line for a given flow rate can be determined in the same way. These values, added together, then give the total pressure drop for the system.

Every component in the line should be dimensioned to cause the lowest possible pressure drop. A pressure drop involves an increase in flow velocity, either in the form of turbulence or by local acceleration through passages. Higher velocities result in increased friction at the surfaces of the pipe and other equipment and greater forces in bends, etc. This increases the mechanical treatment of the product.

In the case of milk, this may lead to breakage of the fat globules, exposing the released fat to attack by lipase enzymes. Eventually, the resulting high content of free fatty acids adversely affects the flavour of the milk. This problem is aggravated if air is present during the mechanical treatment of the product. This can occur if air is sucked in through leaking unions. For other products, such as yoghurt, the treatment of the product must be particularly gentle. The greatest care must be taken in the selection of components as well as in the dimensioning and design of the process line.

The size of the pipes in a system must be such that the velocity of the liquid does not exceed the critical value for the product (1,8 m/s for milk, lower for some other dairy products). The number of valves in the line should be kept to a minimum and the pressure drop across them should be as low as possible. They should also be placed so that unnecessary changes of direction are avoided.

Process control equipment

To ensure trouble-free operation of the process and achieve the desired product quality, it is necessary to control quantities such as liquid levels, flows, temperatures, pressures, concentrations and pH values at certain pre-determined levels. The equipment for measuring and controlling these parameters is called instrumentation, which includes various types of sensors, transmitters, actuators and control equipment.

A *sensor* is an element, which measures an actual quantity. A *transmitter* converts the signal from the sensor to a standardised signal. This value is also known as the measured value. Sometimes sensors and transmitters are combined in one measuring device, also called transmitter, for example a pressure transmitter. Design and functionality vary according to requirements. Examples of measuring devices are temperature, level, pressure and conductivity transmitters.

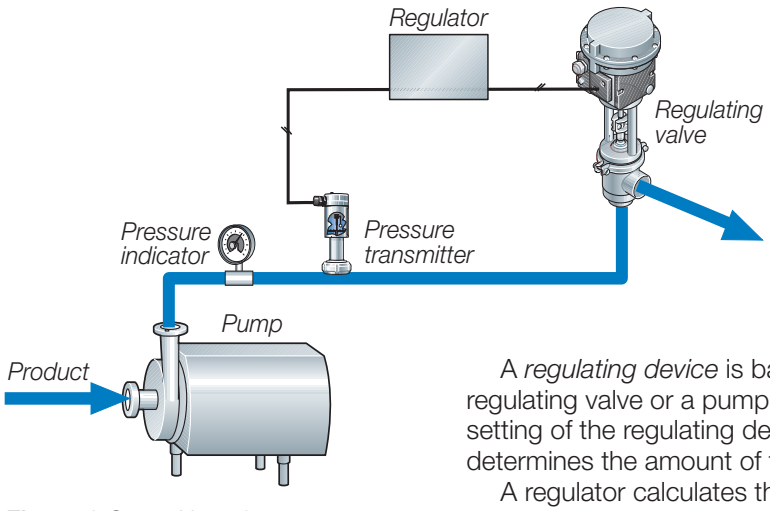


Fig. 7.12 *Control loop for pressure control, consisting of a transmitter, a regulator and a regulating valve.*

A *regulating device* is basically an adjusting mechanism, such as a regulating valve or a pump with variable speed, fitted in a process line. The setting of the regulating device, valve plug position or motor speed, determines the amount of the regulated quantity.

A regulator calculates the difference between the measured value and the set value and, based on that difference, adjusts the signal to the regulating device. The regulator setting is correct if the two values are the same. If the measured value changes, the signal from the transmitter changes accordingly. Now, the measured value does not equal the set value and the regulator adjusts the signal to the regulating device. As a result, the position of the regulating device is adjusted (valve position or speed) to match. The transmitter immediately senses the change in quantity and transmits this information to the regulator. This cycle of comparison and correction, the *control loop*, is repeated until the set and measured values match. A control loop is illustrated in Figure 7.12.

Transmitters

Transmitters in control systems vary considerably in design and function.

Some transmitters react directly to changes in the measured value. In the pressure transmitter, Figure 7.13, the pressure of the product on a membrane is transferred to the sensor and a transmitter, which gives an electrical signal, directly proportional to the product pressure.

Most transmitters, however, operate indirectly. They measure the changes in a physical quantity, which has a constant relation to the quantity to be controlled. This type of transmitter has been shown previously in connection with the transport of liquid through the line, where a required flow rate is maintained by controlling the pressure of the product at the pump outlet.

The above-mentioned pressure transmitter can also be used to measure the level in a tank. Installed in the bottom of a tank, it senses the static pressure of the liquid column above the diaphragm. This pressure is proportional to the height of the liquid. A signal is transmitted to an instrument, which indicates the level.

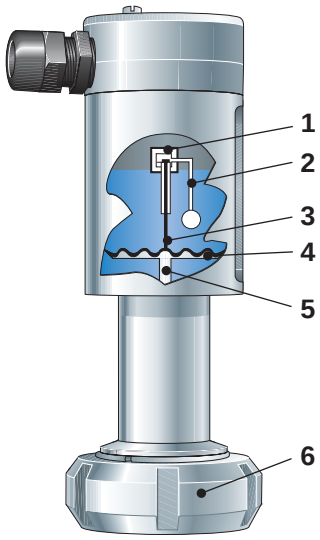


Fig. 7.13 *Pressure transmitter*

1 *Sensor*
2 *Reference pressure*
3 *Capillary pipe*
4 *Membrane*
5 *Process pressure*
6 *Nut*

Table 7.1
Variations in resistance with temperature according to a given characteristic

Resistance Ω	Temperature °C
100,00	0
103,90	10
107,79	20
111,67	30
115,54	40
119,40	50
123,24	60
130,89	80
138,50	100

Many types of transmitters utilise the fact that the electrical resistance of metals varies with temperature in a characteristic manner. One such transmitter is the common temperature transmitter, Figure 7.14. A wire of platinum is mounted in a protective tube, which is inserted in the line so that it is heated by the liquid. Table 7.1 shows the resistance values of a platinum wire at various temperatures.

The resistance can be measured by connecting the metal wire to an electrical circuit. Any change in the resistance will correspond to a given change in temperature, and the temperature of the product can therefore be determined.

The transmitters described above are those most often used in dairies. There are, however, many other types available on the market.

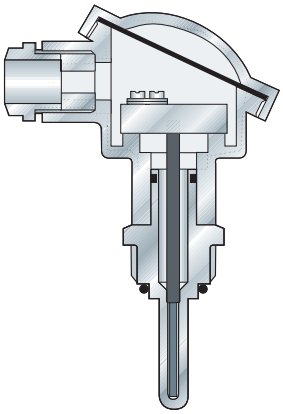


Fig. 7.14 *Resistance type temperature transmitter*

Regulators

The regulator in Figure 7.15 is the brain of the temperature control system and the controller is available in many different forms. According to a previous definition, a regulator is a device that continuously compares the measured value with a reference or pre-set (set-point) value. Any differential causes the regulator to transmit a corrective signal to the regulating unit, which then adjusts its setting accordingly. The corrective process continues until the measured value and the setpoint value coincide again.

The regulator may be a local electronic regulator or built into the control system as a software regulator. On electronic controllers there is a knob for setting the required set point, which is indicated by an indicator on a scale. The measured value, the output from the transmitter, can be read on the scale at all times. There is also a scale showing the output signal to the regulating device.

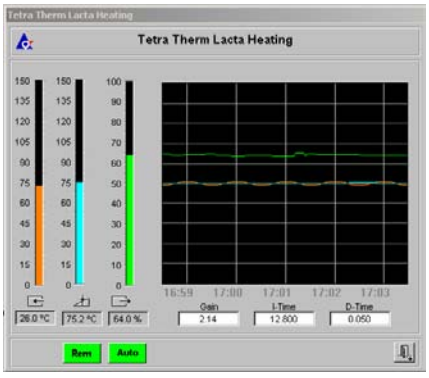


Fig. 7.15 *Regulator*

Nowadays, most regulators are based on software in the control system. The regulator is displayed on the User Interface (operator station) as a graphical representation of the electronic regulator, with process value, set point and output signal. These parameters are sometimes also displayed as trend curves, which can assist the operator when working with the regulating system.

Some regulators have a switch function, which can be used to produce a signal at a given maximum or minimum value. This signal can be used to perform a change in the process. An example is to re-circulate the flow of a pasteuriser if the temperature at the outlet of the heat exchanger holding section should drop below 72 ºC. The switch is set to operate at this temperature and as soon as the temperature drops under this value it will close the solenoid valve controlling the air supply to the flow diversion valve, thereby forcing the pasteuriser to re-circulate the product.

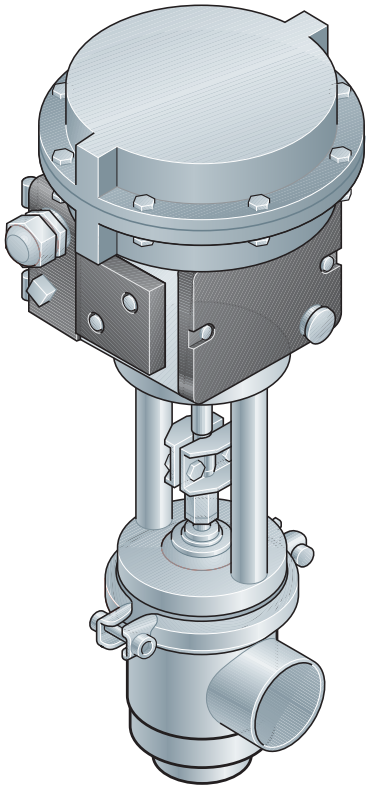


Fig. 7.16 *Regulating valve.*

The regulating device

A pneumatic regulating valve, shown in Figure 7.16, is built around a body with a seat for the plug, which is attached to the lower end of the regulating stem. The stem is operated between the open and closed positions by differencing pressure between the upper and lower sides of the piston. When the pressure is higher on the lower side, the piston moves upwards, lifting the plug from its seat. A higher pressure on top of the piston closes the valve.

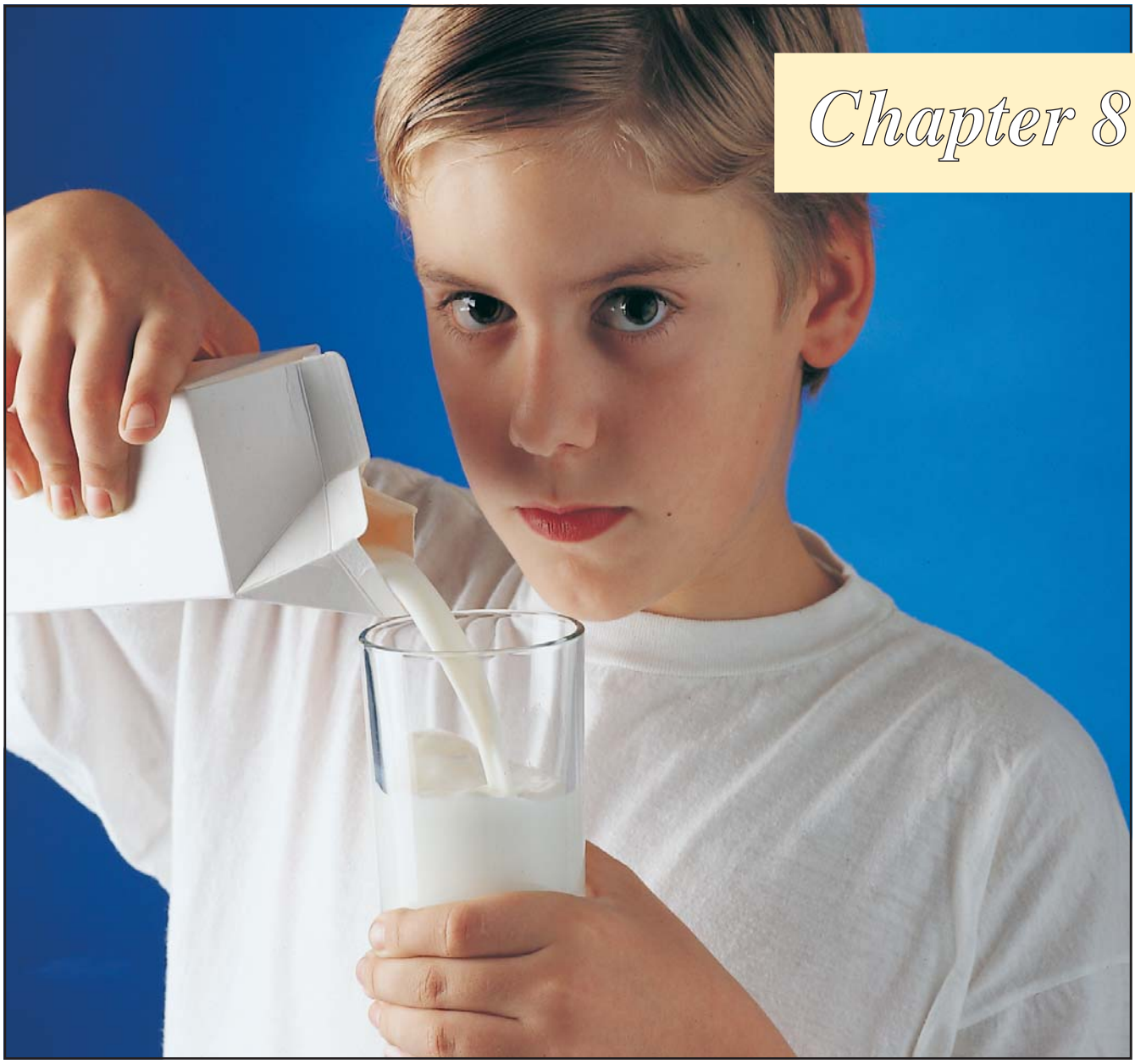
Actuation is essentially as follows: a pneumatic signal from a controller is supplied to a proportioning device, a positioner, at the top of the valve. The positioner ensures that the position of the plug, in relation to the seat, always is proportional to the regulating signal. When the signal corresponds to the pre-set value, the positioner balances the pressures on either side of the piston so that the position of the plug remains constant. In this balanced condition the pressure drop over the valve is exactly that required, and the measured value, registered by the transmitter coincides with the pre-set value.

Should the product pressure drop, the transmitter reduces its signal to the regulator. As the measured value now no longer coincides with the pre-set value, the regulator reacts by increasing its signal to the valve actuator. The positioner then increases the pressure on the upper side of the piston, moving the plug towards the seat. The resulting increase in the valve flow resistance increases the product pressure and the reverse cycle of operations is initiated, retarding the downward movement of the piston.

When the pressure in the line has regained the pre-set value, the positioner again holds the valve piston in balance.

Automatic temperature control

The automatic temperature control system normally has a resistance-type temperature transmitter fitted in the product line. The regulator is a regulator included in the program of the process controller. The set point is automatically set to the correct value, depending on the status of the program. The regulating device is a regulating valve in the steam line.



Chapter 8

Pasteurised milk products

Pasteurised milk products are liquid products made from milk and cream intended to be used directly by consumers. This group of products includes whole milk, skim milk, standardised milk, and various types of cream.

Cultured products are also included in this category, but as these are made with special bacteria cultures, they are dealt with separately under Chapter 11, "Cultured milk products".

All the building blocks described in Chapter 6 are, in principle, used in the processing of pasteurised milk products.

In most countries, clarification, pasteurisation and chilling are compulsory stages in the processing of consumer milk products. In many countries, the fat is routinely homogenised, while in others homogenisation is omitted because a good "cream-line" is regarded as evidence of quality. De-aeration is practised in certain cases when the milk has a high air content, and also when highly volatile off-flavour substances are present in the product. This may occur, for example, if cattle feed contains plants of the onion family.

Processing of market milk products requires first-class raw material and correctly designed process lines if end products of the highest quality are to be attained. Gentle handling must be ensured so that the valuable constituents are not adversely affected.

To ensure milk quality, there are microbiological standards for intra-community trade in milk within Europe, set by the Council of the European Union (EU) to safeguard human and animal health. These standards are shown in Table 8.1.

Table 8.1
EU standards for maximal bacteria count in milk

Product	Plate count (CFU/ml)
Raw milk	100 000
Raw milk stored in silo (6 °C) at the dairy for more than 36 hours	300 000
Pasteurised milk after incubation for 5 days at 6 °C	50 000
UHT and sterilised milk after incubation for 15 days at 30 °C	10/0,1 ml

CFU = Colony Forming Units

Another measure of raw milk quality is the amount of *somatic cells* that can be tolerated in raw milk. Somatic cell count is used as a criterion for ascertaining abnormal milk. Raw milk intended for intra-community trade must not contain more than 400 000 somatic cells per ml according to the EU directive.

Processing of pasteurised market milk

Depending on legislation and regulations, the design of process lines for pasteurised market milk varies a great deal from country to country and even from dairy to dairy. For instance, fat standardisation (if applied) may be pre-standardisation, post-standardisation or direct standardisation. Homogenisation may be total or partial, etc.

The simplest process is just to pasteurise the whole milk. Here, the process line consists of a pasteuriser, a buffer tank and a filling machine. The process becomes more complicated if it has to produce several types of market milk products, *i.e.* whole milk, skim milk and standardised milk of various fat contents, as well as cream of various fat contents.

The following assumptions apply to the plant described below:

- Raw milk
  - Fat content 3,8 %
  - Temperature +4 °C

- Standardised milk
  - Fat content 3,0 %
  - Temperature +4 °C
- Standardised cream
  - Fat content 40 %
  - Temperature +5 °C
- Plant capacity
  - 20 000 l per hour
  - 7 hours per day

Figure 8.1 shows a typical process flow in a market milk line. The milk enters the plant via balance tank (1) and is pumped to plate heat exchanger (16), where it is pre-heated before it continues to separator (5), which produces skim milk and cream.

The standardisation of market milk takes place in an in-line system of the type already described in Chapter 6.2. The fat content of the cream from the separator is set to the required level and is then maintained at that level, regardless of moderate variations in the fat content and in the flow rate of the incoming milk. The fat content of the cream is usually set at 35 to 40 %

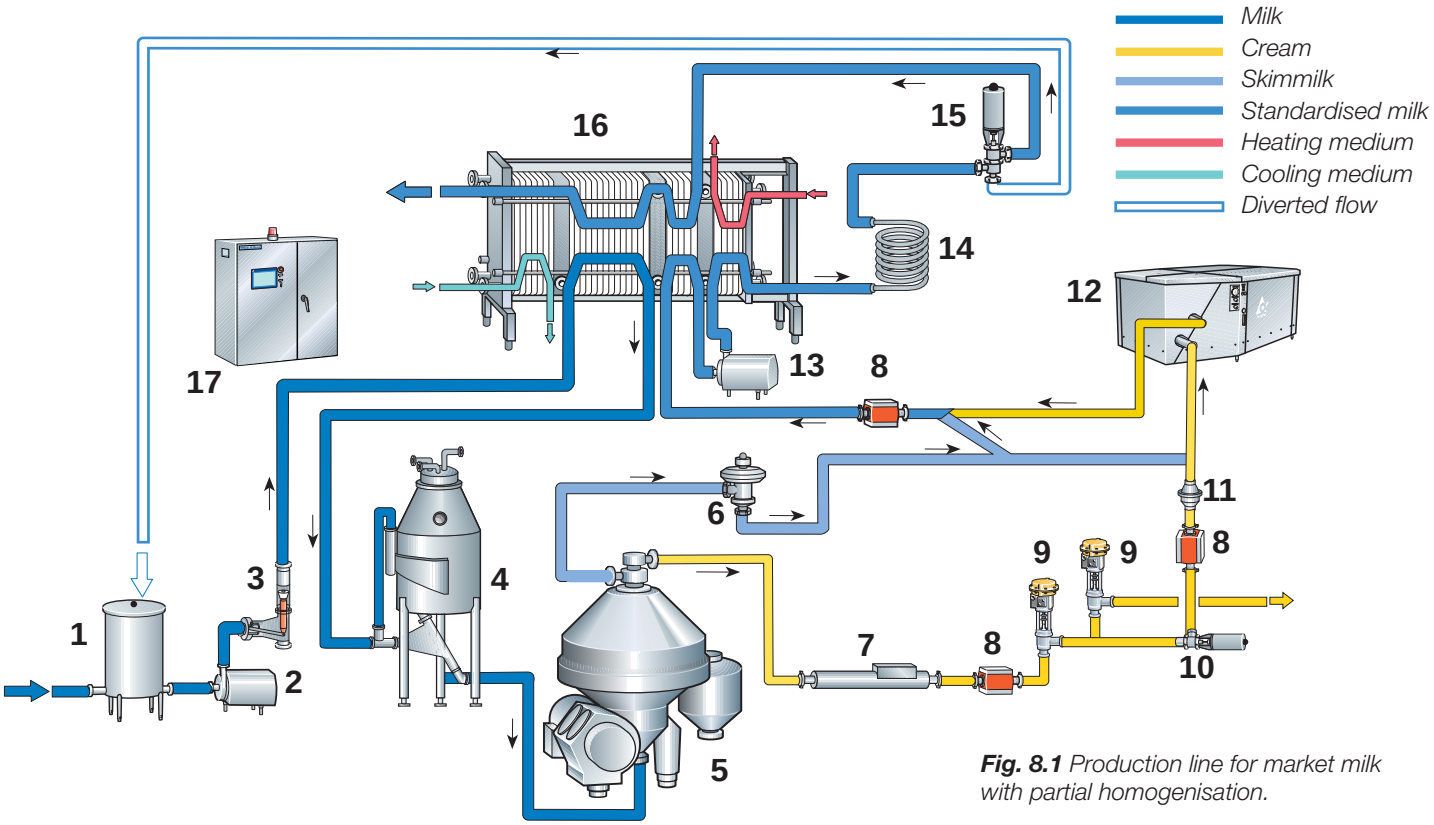


Fig. 8.1 *Production line for market milk with partial homogenisation.*

1 *Balance tank*
2 *Product feed pump*
3 *Flow controller*
4 *Deaerator*
5 *Separator*
6 *Constant pressure valve*
7 *Density transmitter*
8 *Flow transmitter*
9 *Regulating valve*
10 *Shut-off valve*
11 *Check valve*
12 *Homogeniser*
13 *Booster pump*
14 *Holding tube*
15 *Flow diversion valve*
16 *Plate heat exchanger*
17 *Process control*

for whipping cream, but can be set at other levels, *e.g.* for production of butter or other types of cream. Once set, the fat content of the cream is kept constant by the control system, consisting of density transmitter (7), flow transmitter (8), regulating valves (9) and the control system for the standardisation system.

In this example, partial homogenisation is used, *i.e.* only the cream is treated. The reason for choosing this system is that it can manage with a smaller homogeniser (12) and thus consume less power, while still maintaining a good homogenisation effect.

The working principle of the system, also described in Chapter 6.3, will be: After passage of the standardisation device, the flow of cream is divided into two streams. One, with the adequate hourly volume to give the market milk the required final fat content, is routed to the homogeniser and the other, the surplus cream, is passed to the cream treatment plant. As the fat content of the cream to be homogenised should be a maximum of 18 %, the ordinary cream of, say 40 %, must be "diluted" with skim milk prior to

homogenisation. The capacity of the homogeniser is carefully calculated and fixed at a certain flow rate.

In a partial homogenisation arrangement, the homogeniser is also connected with the skim milk line so that it always has enough product for proper operation. In that way, the relatively low flow of cream is compensated with skim milk up to the rated capacity. Following homogenisation, the 18 % cream is eventually mixed in-line with the surplus volume of skim milk to achieve 3 % before pasteurisation. The milk, now with standardised fat content, is pumped to the heating section of the milk heat exchanger where it is pasteurised. The necessary holding time is provided by a separate holding tube (14). The pasteurisation temperature is recorded continuously.

A booster pump (13) which increases the pressure of the product to a level at which the pasteurised product cannot be contaminated by untreated milk or by the cooling medium if a leak should occur in the plate heat exchanger.

If the pasteurisation temperature should drop, this is sensed by a temperature transmitter. A signal activates the flow diversion valve (15) and the milk flows back to the balance tank. See also Chapter 7.

After pasteurisation, the milk continues to a cooling section in the heat exchanger, where it is regeneratively cooled by the incoming untreated milk, and then to the cooling section where it is cooled with ice-water. The cold milk is then pumped to the filling machines.

Standardisation

The purpose of standardisation is to give the milk a defined, guaranteed fat content.

The purpose of standardisation is to give the milk a defined, guaranteed fat content. The level varies considerably from one country to another. Common values are 1,5 % for low-fat milk and 3 % for regular-grade milk, but fat contents as low as 0,1 and 0,5 % also occur. The fat is a very important economic factor. Consequently, the standardisation of milk and cream must be carried out with great accuracy.

Some options applicable to continuous fat standardisation are discussed in Chapter 6.2.

Pasteurisation

Along with correct cooling, pasteurisation is one of the most important processes in the treatment of milk. If carried out correctly, these processes will supply milk with longer shelf life.

Temperature and pasteurisation time are very important factors which must be specified precisely in relation to the quality of the milk and its shelf-life requirements, etc. The pasteurisation temperature for homogenised, HTST pasteurised, regular-grade milk is usually 72 – 75 °C for 15 – 20 seconds.

The pasteurisation process may vary from one country to another, according to national legislation. A common requirement in all countries is that the heat treatment must guarantee the destruction of unwanted micro-organisms and of all pathogenic bacteria, without the product being damaged.

Homogenisation

Homogenisation has already been discussed in Chapter 6.3. The purpose of homogenisation is to disintegrate or finely distribute the fat globules in the milk, in order to reduce creaming. Homogenisation may be total or partial. Partial homogenisation is a more economical solution, because a smaller homogeniser can be used.

Determining homogenisation efficiency

Homogenisation must always be sufficiently efficient to prevent creaming.

The result can be checked by determining the homogenisation index, which can be found in the manner decscribed in the following example:

A sample of milk is stored in a graduated measuring glass for 48 hours

at a temperature of 4 – 6 °C. The top layer (1/10 of the volume) is siphoned off, the remaining volume (9/10) is thoroughly mixed, and the fat content of each fraction is then determined. The difference in fat content between the top and bottom layers, expressed as a percentage of the top layer, is referred to as the homogenisation index.

An example: If the fat content is 3,15 % in the top layer and 2,9 % in the bottom layer, the homogenisation index will be (3,15 – 2,9) x 100: 3,15 = 7,9. The index for homogenised milk should be in the range of 1 to 10.

Quality maintenance of pasteurised milk

Due to its composition, milk is highly susceptible to bacterial and chemical (copper, iron, etc.) contamination as well as to the effects of exposure to light, particularly when it is homogenised.

It is therefore most important to provide good cleaning (CIP) facilities for the plant and to use detergents, sanitisers and water of high quality.

Once packed, the product must be protected from light – both daylight and artificial light. Light has a detrimental effect on many nutrients, and it can also affect the taste.

Sunlight flavour originates from the protein in milk. Exposure to light degrades the amino acid methionine to methional. Ascorbic acid (Vitamin C) and riboflavin (Vitamin B_2) play a significant part in the process, and oxygen must also be present. Methional has a characteristic taste; some people compare it to cardboard, others to emery. This flavour does not occur in

Table 8.2

Losses of taste and vitamins at an exposure of 1 500 Lux

Carton				Bottle		
Taste	**Vitamin C**	**Vitamin B_2**	**Hours**	**Taste**	**Vitamin C**	**Vitamin B_2**
	– 1 %		**2**		– 10 %	– 10 %
	– 1,5 %		**3**	little	– 15 %	– 15 %
	– 2 %		**4**	evident	– 20 %	– 18 %
	– 2,5 %		**5**	strong	– 25 %	– 20 %
	– 2,8 %		**6**	strong	– 28 %	– 25 %
	– 3 %		**8**	strong	– 30 %	– 30 %
no loss	– 3,8 %	no loss	**12**	strong	– 38 %	– 35 %

Measured by the Dairy Science Institute at the Justus Liebig University in Giessen, Germany, in 1988.

sterilised milk, which is always homogenised, probably because Vitamin C is degraded by heat and the S – H components of the whey proteins undergo chemical changes.

Table 8.2 shows the influence of light on pasteurised milk in a transparent glass bottle and in a carton. The first vitamin losses take place when the milk in the transparent glass bottle has been exposed to 1 500 Lux – an average lighting value – for only two hours. In the opaque carton, there is only a minor loss.

After four hours' exposure, a change of flavour is already evident in bottled milk, but not in the cartoned product.

Shelf life of pasteurised milk

The shelf life of pasteurised milk is always dependent on the quality of the raw milk. Naturally, it is also most important that production conditions are

technically and hygienically optimised, and that the plant is properly managed.

When produced from raw milk of sufficiently high quality and under good technical and hygienic conditions, ordinary pasteurised milk should have a shelf life of 8 – 10 days at 5 – 7 °C in an unopened package.

The shelf life can however be drastically shortened if the raw milk is contaminated with micro-organisms such as species of Pseudomonas that form heat-resistant enzyme systems (lipases and proteases), and/or with heat-resistant bacilli such as *Bacillus cereus* and *Bacillus subtilis* which survive pasteurisation in the spore state.

To improve the bacteriological status of pasteurised milk and thereby safeguard or even prolong its shelf life, the pasteurisation plant can be supplemented with a bactofugation or a microfiltration plant.

The bactofugation process is based on centrifugal separation of micro-organisms; although the reduction effect of two-stage centrifugation on bacteria spores is up to >99 % (see Chapter 14, *Cheese*), this is not considered good enough for pasteurised market milk if extended shelf life at up to 7 °C is required.

Reduction effects of up to 99,5 – 99,99 % on bacteria and spores can be achieved with microfilter membranes of pore sizes of 1,4 µm or less. A general flowchart for milk treatment including microfiltration is illustrated in Figure 8.2.

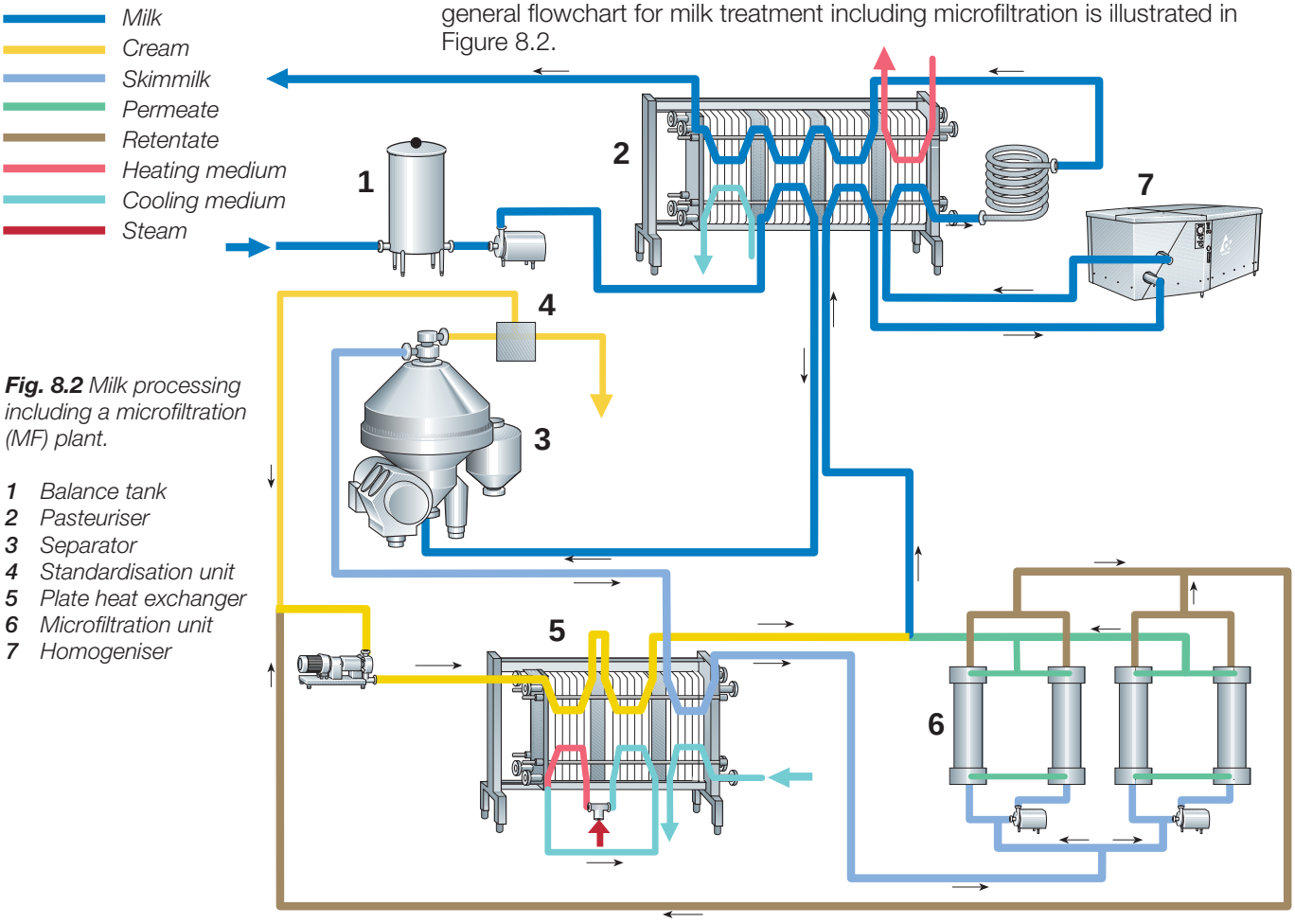


Fig. 8.2 *Milk processing including a microfiltration (MF) plant.*

1 *Balance tank*
2 *Pasteuriser*
3 *Separator*
4 *Standardisation unit*
5 *Plate heat exchanger*
6 *Microfiltration unit*
7 *Homogeniser*

Since the small pore sizes needed for effective retention of bacteria and spores also trap milk fat globules, the MF module is fed with skim milk. In addition to the MF unit, the plant contains a high temperature treatment unit for the mixture of the cream phase and bacteria concentrate (retentate), which after heat treatment is remixed with the permeate, the processed skim milk phase.

The cream and retentate phase are sterilised at about 130 °C for a couple of seconds. After re-mixing with the microfiltered skim milk phase, the product is homogenised and finally pasteurised at 72 °C for 15 – 20 seconds and cooled to +4 °C.

The plant shown in Figure 8.2 can handle up to 10 000 litres of raw milk per hour. After separation, the skim milk is routed to the MF module. Part of the cream, typically of 40 % fat content, is remixed with the skim milk to produce fat-standardised pasteurised market milk, while the surplus cream is separately processed. The proportions of remixed and surplus cream depend on the specified fat content of the market milk.

About 5 % of the feed leaves the MF module as retentate, the bacteria-rich phase. The total solids content of the retentate averages 9 – 10 %, of which some 3,9 % is protein (including protein from the micro-organisms) and some 0,25 % fat.

In the plant shown here the whole milk flow is homogenised, but partial homogenisation is also possible.

Milk treated in this way will keep its fresh flavour and white colour. Moreover, if strictly hygienic conditions are maintained in the plant, from reception of the raw milk up to and including the packaging and filling system, the foundation of a long shelf life is laid. If the milk is kept at a temperature of not more than 7 °C during the whole chain from the dairy via the retailer to the consumer, it is possible to attain a shelf life of up to 40 – 45 days in an unopened package.

The shelf life of pasteurised milk is basically and always dependent on the quality of the raw milk.

ESL milk

The term “Extended Shelf Life”, ESL, is frequently applied in Canada and the USA to fresh liquid products of good keeping quality at +7 °C and below. The expression *ESL* and the idea behind it have now also spread to Europe and other continents.

There is no single definition of ESL, as it is a concept involving many factors. What it means, in essence, is the ability to extend the shelf life of a product beyond its traditional life by reducing the major sources of reinfection and maintaining the quality of the product all the way to the consumer.

A typical temperature/time program is 125 – 130 °C for 2 – 4 seconds. This type of heat treatment is also called *ultrapasteurisation*.

Production of cream

Cream for sale to consumers is produced with different fat contents. Cream of lower fat content, 10 – 18 %, is often referred to as half cream or coffee cream; it is increasingly used for desserts and in cooking. Cream with a higher fat content, typically 35 – 40 %, is usually considerably thicker. It can be whipped into a thick froth and is therefore referred to as “whipping cream”. Whipping cream is used whipped or unwhipped as a dessert, for cooking, etc.

Whipping cream

In addition to tasting good and keeping well, whipping cream must also have good “whippability”, *i.e.* it must be easy to whip and produce a fine cream froth with a good increase in volume (overrun). The froth must be firm and stable, and must not be susceptible to syneresis. Good whippability depends on the cream having a sufficiently high fat content. Whipping cream with 40 % fat is usually easy to whip, but the whippability decreases as the fat content drops to 30 % and below. However, it is possible to produce good whipping cream with a low fat content (about 25 %) by adding substances which improve whippability, *e.g.* powder with a high lecithin content made from sweet buttermilk.

Unintentional air inclusion must be avoided in the manufacture of the cream. Air pickup leads to formation of froth and destabilisation. If cream is subjected to excessive mechanical treatment, especially just after it has left the cooling section, the fat-globule membranes will be damaged, resulting

in fat amalgamation and formation of clusters. Creamlining takes place when roughly treated cream is stored in the pack. The layer of cream will be dense and sticky. This “homogenisation effect” greatly impairs the whipping characteristics of the cream.

Air is intentionally beaten into cream when it is whipped. This produces a froth full of small air bubbles. The fat globules in the cream collect on the walls of these air bubbles. Mechanical treatment destroys the membranes of many fat globules, and a certain amount of liquid fat is liberated. This fat makes the globules stick together.

The fat globules must contain the correct proportions of liquid and crystallised fat in order to obtain a firm froth. Warm cream contains liquid fat, which makes whipping impossible. Cream for whipping must therefore be stored at a low temperature (4 – 6 °C) over a relatively long period of time to obtain proper crystallisation of the fat. This storage period is called *ripening time*. Cream is usually ripened in jacketed process tanks with scraper agitators. Heat is released during crystallisation. However, cooling and agitation should not start until about two hours after the process tank has been filled. The reason is that during this period of fat crystallisation the fat globules can easily be split, releasing free fat and causing lump (cluster) formation. At cooling the agitation must be gentle. See also Figure 8.4, concerning the progress of crystallisation of 40 % cream. Slightly lower final temperatures can be used in the summer, when the milk fat is usually softer than during the winter.

The whipping method

The best whipping result is obtained when the temperature of the cream is below 6 °C. The whipping bowl and instrument should also be correctly proportioned in relation to one another so that whipping is completed as quickly as possible. Otherwise the temperature may rise appreciably during whipping, resulting in an inferior froth (butter may be formed in the worst case).

Whipping time and increase of the volume *i.e.* overrun, are two criteria that should be measured to check whipping properties. An adequate whipping bowl (holding one litre) and instrument (preferably an electric beater) are required for this test. A suitable volume of cream (say 200 ml) is cooled to +6 °C ±1 °C and then poured into the bowl.

The height of the cream is measured before whipping starts. The beater is stopped when the froth has reached acceptable firmness (which means that it will not start to run when the bowl is inverted).

Whipping time is measured with a stopwatch, which is started and stopped simultaneously with the beater.

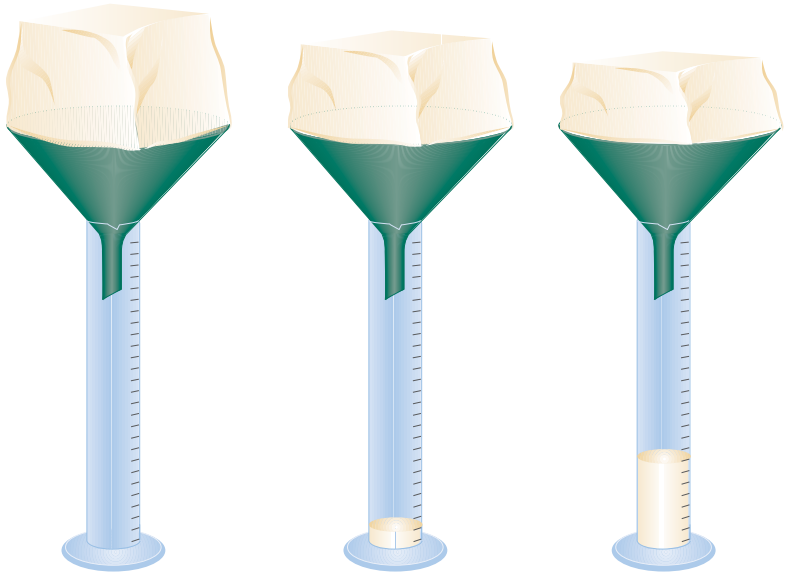


Fig. 8.3 *Test of leakage of whipped cream after 2 hours at 18–20 °C and 75 % R.H.*

The height of the whipped cream is measured to establish the overrun. If, for instance, the height was 5 cm initially and is 10,5 cm after whipping, the overrun will be (10,5 – 5) x 100 / 5 = 110 %. With 40 % cream, the whipping time should be about two minutes and the overrun between 100 and 130 %.

The quality of the froth is measured by the leakage of liquid after two hours at 18 – 20 °C and 75 % R.H.

Directly after whipping and measurement of overrun, all the whipped cream is placed on a plain metal net. The froth is formed, as shown in Figure 8.3, and the net is placed over a funnel of adequate size, which in turn is placed over a graduated measuring glass. The amount of liquid that has accumulated in the glass is read off after two hours' storage at the above-mentioned temperature and humidity. The judgement criteria are:

0-1 ml	Very good
1-4 ml	Good
> 4 ml	Poor

The whipping-cream production line

The Scania method

The process stages in the manufacture of whipping cream include heating of the whole milk to separation temperature (62 – 64 °C) separation and standardisation of the cream fat content to the required value, and pasteurisation and chilling of the cream in a heat exchanger before it continues to a process tank for ripening.

Treatment of cream with a high fat content involves several problems which must be carefully considered when the process line is designed. The most serious problem is how to avoid shearing and turbulence during crystallisation of the fat. The fat in the globules is in liquid form at higher temperatures, and fat globules seem to be unaffected by treatment at temperatures above 40 °C.

The fat starts to crystallise as soon as cooling begins in the process line. This is a fairly slow process; some crystallisation still continues after four or five hours. Crystallised fat has a lower specific volume than liquid fat, so tension forces are generated in the fat globules during crystallisation. This makes the fat globules very sensitive to rough treatment at 10 – 40 °C.

The progress of crystallisation of 40% cream cooled to 8 °C is illustrated in Figure 8.4. The cream must not be agitated while the processing tank is being filled. Agitation and cooling start about two hours after the tank has been filled.

Crystallisation releases heat of fusion, causing the temperature to rise by 2 – 3 °C. Final cooling in the processing tank is absolutely essential. The cream is normally cooled to 6 °C, or even lower. The fat globules seem to be less sensitive to rough treatment at these temperatures, but they are still more sensitive than at temperatures above 40 °C.

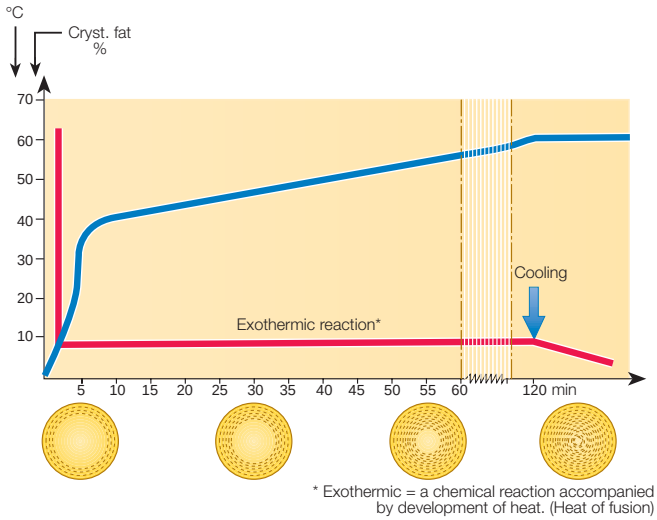


Fig. 8.4 *The crystallisation process for 40 % cream at 8 °C.*

The biggest problem in processing whipping cream is the formation of clusters, which reduce the emulsion stability of the cream. Clusters occur when fat globules with partly crystallised fat and weak membranes are subjected to rough mechanical treatment. Reduced emulsion stability of cream is responsible for product defects in whipping cream, such as cream plugs in containers, reduced whippability and lipolysis.

Figure 8.5 shows a process in which great care has been taken to eliminate rough treatment of the whipping cream. This method, developed in collaboration with some Swedish dairy co-operatives, is called the *Scania method*. The standardised cream may have come from a dedicated cream production line, or may be surplus cream from a market milk production line of the type shown in Figure 8.1. In either case, the separation temperature should be 62 – 64 °C, to guarantee the highest possible cream quality (*i.e.* the lowest amount of free fat).

The standardised cream is fed from above to a holding tank (1) at separation temperature. The optimum holding time in the tank is 15 – 30 minutes before pasteurisation starts. The flow rate at pasteurisation should be very close to the average rate of infeed to the holding tank. This makes it possible to collect small flows of surplus cream in the holding tank over a period of time, ensuring minimum mechanical agitation of the cream.

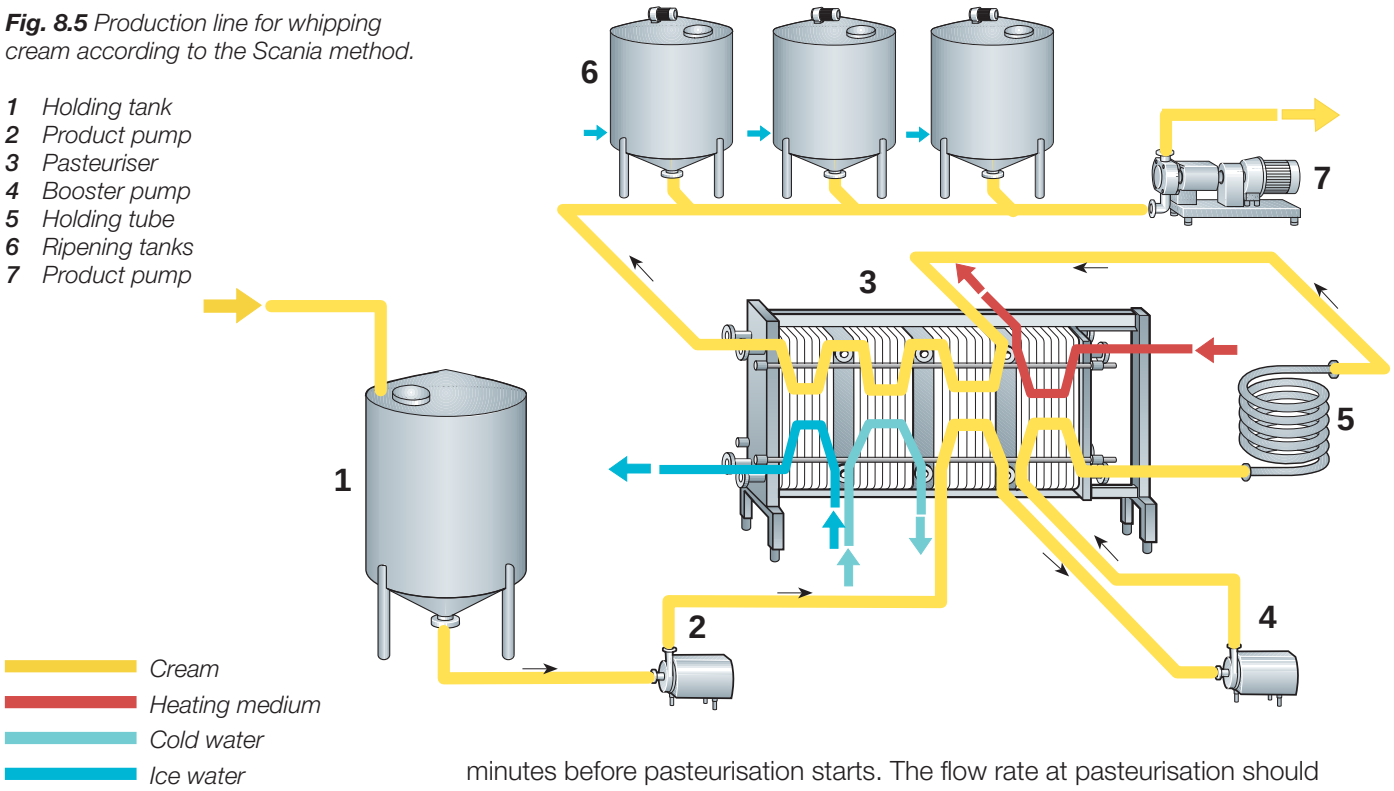


Fig. 8.5 *Production line for whipping cream according to the Scania method.*

1 *Holding tank*
2 *Product pump*
3 *Pasteuriser*
4 *Booster pump*
5 *Holding tube*
6 *Ripening tanks*
7 *Product pump*

The holding tank has no agitator, and about 50 % of the air content in the cream is naturally eliminated there. Volatile off-flavours are removed at the same time, and the risk of fouling in the pasteuriser is reduced. Holding the cream at about 63 °C in the tank inactivates most lipase enzymes and stops hydrolysis of free fat. The maximum holding time, including filling and emptying, should be about four hours. For longer production runs, two holding tanks should be installed and used alternately, with intermediate cleaning of one tank while the other is in use.

From the holding tank, the cream is pumped to a regenerative heating section in the heat exchanger (3). The booster pump (4) then pumps the cream through the heating section and holding tube (5). Since pumping takes place at a high temperature (over 60 °C), at which the cream is less sensitive to mechanical treatment, both product pump (2) and booster pump (4) can be centrifugal pumps.

After pasteurisation, typically above 80 – 95 °C for up to 10 seconds, the cream is pumped to the cooling sections in the heat exchanger where it is concurrently cooled to 8 °C in the deep cooling section before continuing to

the ripening tanks (6). Cooling in the heat exchanger to an average temperature of 8 °C seems to be optimum for cream with a fat content of 35 – 40 %. At higher fat contents, higher cooling temperatures must be used to prevent the cream from clogging the cooling section due to rapidly increasing viscosity. This produces a sharp rise in the pressure drop over the cooling section, which in turn causes damage to the fat globules and possibly even leakage of butteroil from that section. The process must then be stopped and the system flushed out, cleaned and restarted.

Because of the instability of the freshly chilled fat globules, shearing and turbulence should be avoided (no pump and adequately dimensioned piping) during transportation from the cooling section of the heat exchanger to the processing tank for final cooling and fat crystallisation. The pressure for this transport must therefore be provided by the booster pump.

After ripening, the cream is pumped to the packaging machines. The temperature is now low, and most of the milk fat is crystallised, which means that the cream is now less sensitive to mechanical treatment. A frequency-controlled centrifugal pump can be used at low pressure drops, up to 1,2 bar, provided that a pressure transmitter is also integrated into the system. Lobe rotor pumps running a maximum of 250 – 300 rpm are recommended at pressure drops from 1,2 – 2,5 up to 3 bar.

Half- or coffee cream

Cream containing 10 – 18 % fat is known as *half-* or *coffee cream*.

Figure 8.6 shows a process line for half-cream. Untreated milk from the storage tanks is heated regeneratively in the heat exchanger to separation temperature, 62 – 64 °C. The milk then flows to the separator for separation to skim milk and cream with the required fat content, usually 35 – 40 %.

The treatment of the cream is the same as described for whipping cream, with the exception that the half-cream is mixed with skim milk to obtain the required fat content. The cream is homogenised.

The mixing of cream and skim milk is done with a metering pump which injects the skim milk into the cream line. The cream temperature is then adjusted to homogenising temperature.

After homogenisation the cream is returned to the heat exchanger, where it is pasteurised at 85 – 90 °C for 15 – 20 seconds, before being cooled to about 5 °C and packed.

Two principal requirements must be met in production of cream:

- The cream should be viscous, to convey a more appetising impression.
- The cream should have good coffee stability. It must not flocculate when poured into hot coffee.

Cream with a low fat content has a relatively low viscosity and is not of the

Fig. 8.6 *Production line for half- and coffee cream*

1 *Fat standardisation tank*
2 *Product pump*
3 *Plate heat exchanger*
4 *Homogeniser*
5 *Holding tube*

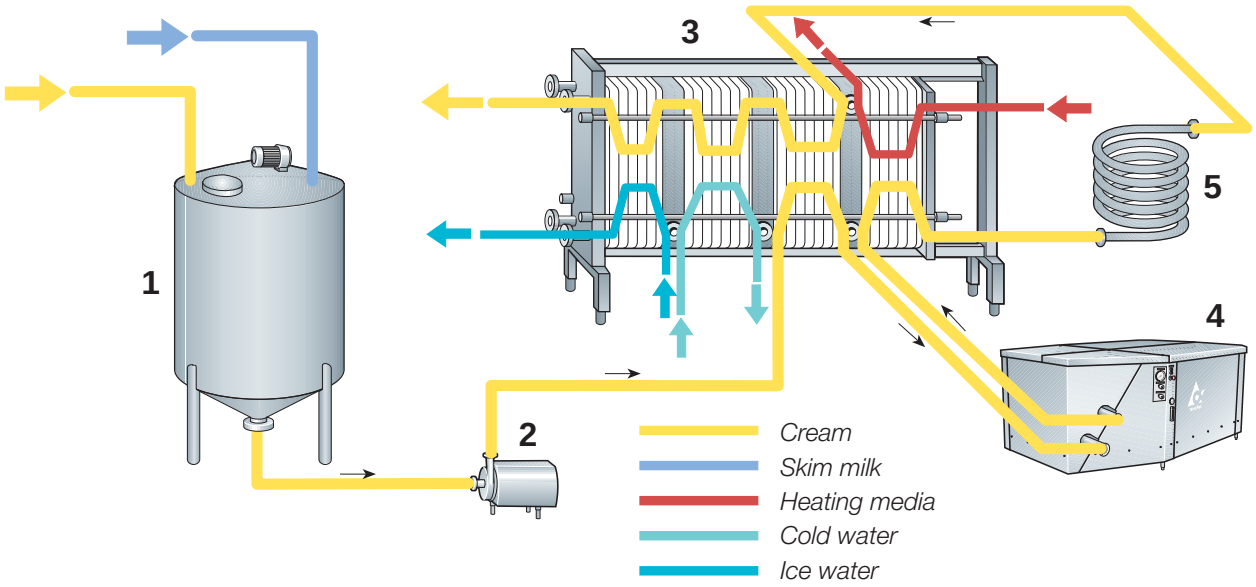


Table 8.3
Viscosity test; increasing homogenising pressure at 57 °C

Homogenising pressure MPa	Cream viscosity seconds
10	18
15	28
20	45

consistency normally wanted by customers. It is necessary to select the correct temperature and pressure for homogenisation to give the cream the correct viscosity.

The viscosity of cream increases with increasing homogenising pressure and is reduced by a temperature increase. The cream viscosity in Table 8.3 can be obtained by keeping the homogenising temperature constant at about 57 °C and homogenising the cream at three different pressures: 10; 15 and 20 MPa (100; 150 and 200 bar). The viscosity is measured with a SMR viscosity meter, described in Chapter 11, *Cultured milk products*. The longer the time (in seconds) for the cream to flow through the meter, the higher the viscosity. Cream which has been homogenised at 20 MPa has the highest viscosity.

Table 8.4 shows the viscosity if the homogenising temperature is varied at a constant homogenising pressure of 15 MPa.

The viscosity of cream decreases with increasing homogenising temperature, which should consequently be as low as possible. However, the fat must be liquid to achieve the homogenising effect. This means that the homogenising temperature should not be below 35 °C.

The coffee stability of cream can be affected considerably by the homogenising conditions: temperature, pressure and position of the homogeniser (upstream or downstream of the heat exchanger).

Table 8.4
Viscosity test; effect of homogenising temperature at 15 MPa

Homogenising temp. °C	Viscosity seconds
35	49
50	35
65	10

The coffee stability of cream can be improved to a certain extent by adding sodium bicarbonate (maximum 0,02 %), if legally permitted. Coffee stability is a certain kind of thermal stability and is a complicated issue, involving several factors:

- The temperature of the coffee; the hotter the coffee, the more easily the cream will flocculate.
- The type of coffee and the manner in which it is prepared; the more acid the coffee, the more easily the cream will flocculate.
- The hardness of the water used to make the coffee; cream will flocculate more readily in hard water than in soft water, as calcium salts increase the ability of the proteins to coagulate.

Packaging

The principal and fundamental functions of packaging are to:

- Enable efficient food distribution
- Maintain product hygiene
- Protect nutrients and flavour
- Reduce food spoilage and waste
- Increase food availability
- Convey product information

Glass bottles for milk were introduced back at the beginning of the 20th century. As a package, glass has some disadvantages. It is heavy and fragile, and must be cleaned before re-use, which causes some problems for dairies. Since 1960, other packages have entered the milk market, mainly paperboard packages but also plastic bottles and plastic pouches.

A package should protect the product and preserve its food value and vitamins on the way to the consumer. Liquid foods tend to be perishable, so a clean, non-tainting package is absolutely essential. The package should also protect the product from mechanical shock, light and oxygen. Milk is a sensitive product; exposure to daylight or artificial light destroys some essential vitamins and has a deleterious effect on the taste (sunlight flavour, see Table 8.2).

Other products, such as flavoured milk, contain flavouring matter or vitamins that are oxygen-sensitive. The package must therefore exclude oxygen.

A milk carton usually consists of paperboard and plastic (polyethylene). Paperboard comes from wood, which is a renewable resource. The paperboard gives stiffness to the packages as well as making them resistant to mechanical stress. The paperboard also serves to some extent as a light barrier.

A thin layer of food-grade polyethylene on either side of the paperboard makes the cartons leakproof. On the outside, the plastic also protects the cartons from condensation when chilled products are taken out of storage.

Because of its purity, this polyethylene produces minimal environmental impact when incinerated or deposited in landfills.

For products with a long non-refrigerated shelf life and very sensitive products, a thin layer of aluminium foil is sandwiched between layers of polyethylene plastic. This gives almost complete protection of the product against light and atmospheric oxygen.

All packages end up as waste. The growing volume of household waste could become an environmental problem in our society. Ways of tackling this problem can be summarised in principle under five headings :

- **Reduction.** Reducing the input of raw materials and choosing materials that are not environmentally harmful helps to conserve natural resources.
- **Recycling.** Packages can be collected after use and used again. However, it should be remembered that even a refilled package ultimately ends up as waste.
- **Recovery of materials.** Packages can be collected and the materials used to manufacture new products, but it is important that the new products meet a real need.
- **Recovery of energy.** All packages incorporate energy, which can be extracted when the waste is incinerated. The potential yield depends on the type of packaging material.
- **Landfill.** Waste can be deposited as landfill and the area can ultimately be landscaped for recreational or other purposes.

Paperboard packages have a very low weight, and their main component comes from a source that is renewable. Compared to most other packages, the amount of waste generated is small. A one-litre Tetra Brik pack weighs 27 g and generates only that amount of waste.

Paperboard packages are highly suitable for energy recovery. Wood and oil (the raw material for the plastic) are conventional sources of energy, and it can be said that we simply borrow these raw materials for packages

Functions of packaging:
- Enable efficient food distribution
- Maintain product hygiene
- Protect nutrients and flavour
- Reduce food spoilage and waste
- Increase food availability
- Convey product information

before using them as fuel. The incineration of two tons of packaging material yields as much energy as one ton of oil.

Waste as landfill is the least efficient form of waste managament. However, if Tetra Pak packages are deposited in this way, there are no toxic substances in them which could contaminate ground water.

Chapter 9

Long-life milk

Heat treatment in the production of long-life products is often called "sterilisation". This means that the product is exposed to such powerful heat treatment that all relevant micro-organisms and most of the heat-resistant enzymes are inactivated. Such products have excellent keeping qualities and can be stored for long periods of time at ambient temperatures. Many dairies can therefore distribute these products over long distances and thereby find new markets.

There are many advantages for the producer, retailer and consumer if a product does not require refrigeration and can be stored for long periods without spoiling. The producer can, for example, reach geographically wider markets, simplify production planning by reducing product changes and

losses, make deliveries easier by using fewer and cheaper distribution vehicles, and eliminate return of unsold products. Handling becomes easier for the retailer, as expensive refrigerated display space is not necessary and stock planning is simplified.

Finally, the consumer gains in convenience as he can make fewer trips to the shops, there will be less congestion in the home refrigerator and he will have emergency reserves available for unexpected guests. This includes expensive products such as cream, desserts and sauces.

Raw material quality

The milk is unsuitable for UHT treatment if it:
- Is sour
- Has the wrong salt balance
- Contains too much serum proteins – typical of colostrum

Milk exposed to high heat treatment must be of *very good quality*. It is particularly important that the proteins in the raw milk do not cause thermal instability. The heat stability of the proteins can be quickly determined by an *alcohol test*. When samples of the milk are mixed with equal volumes of an ethyl alcohol solution, the proteins may become unstable and the milk flocculates. The higher the concentration of ethyl alcohol solution that can be added without getting flocculation, the better the heat stability of the milk. Production and shelf life problems can usually be avoided if the milk remains stable (does not precipitate) even after addition of alcohol solutions with a 75 % alcohol concentration.

The alcohol test is typically used to reject all milk that is unsuitable for UHT treatment because it:
- Is sour, due to a high bacterial count of acid-producing micro-organisms
- Has the wrong salt balance
- Contains a high level of serum proteins – typical of colostrum

Raw milk of bad quality has an adverse effect on both processability and final product quality. Sour milk has poor thermal stability and causes not only processing problems, *e.g.* burning-on on the heating surfaces resulting in short running times, but also difficulties with cleaning, as well as sedimentation of proteins at the bottom of the packages during storage.

Milk stored for a long time at low temperature may contain high numbers of *psychrotrophic bacteria*, which can produce *heat-resistant enzymes* that are difficult to completely inactivate by heat treatment. During storage they can cause organoleptic changes such as rancidity, bitterness or even gelation (age-thickening or sweet curdling).

The bacteriological quality of the milk must be high. This applies not only to the total bacterial count, but also, and more importantly, to the count of spore-forming bacteria that influence the rate of insterility.

Sterilising efficiency

When micro-organisms and/or bacterial spores are subjected to heat treatment or any other kind of sterilising/disinfectant procedure, not all micro-organisms are killed at once. Instead, a certain proportion is destroyed in a given period of time while the remainder survives. If the surviving micro-organisms are once more subjected to the same treatment for the same length of time, an equal proportion of them will be killed, and so on. In other words, a given exposure to sterilising or disinfectant agents always kills the same *proportion* of micro-organisms present.

Logarithmic reduction of spores

$$K \times t = \log N/N_t$$

where
- N = number of micro-organisms (spores) originally present,
- N_t = number of micro-organisms (spores) present after a given time of treatment (t), and
- K = a constant
- t = time of treatment

The lethal effect of sterilisation on micro-organisms can thus be expressed mathematically as the logarithmic function to the left.

This formula results in a straight line when drawn as a semi-logarithmic graph with the duration of treatment plotted on the linear axis and the number of survivors on the logarithmic axis.

A logarithmic function can approach zero, but never reach it! To put it another way, sterility defined as the absence of living bacterial spores in an unlimited volume of product is impossible to achieve. Rather than applying demands that are impossible and cannot be determined under practical

conditions, we should look for a more workable and realistic concept. *"Sterilising effect"* or *"sterilising efficiency"* is such a concept. These terms state the number of decimal reductions in counts of bacterial spores achieved by a sterilisation process.

Each time a sterilisation process is performed, it can be characterised by a certain sterilising effect. In any heat sterilisation process, the sterilising effect is determined by the time/temperature condition applied. The higher the temperature and the longer the holding time, the more efficient the process, *i.e.* the greater the sterilising effect.

The sterilising effect is expressed by the number of decimal reductions achieved in the process. For example, a sterilising effect of 9 indicates that out of 10^9 bacterial spores fed into the process, only 1 (10^0) will survive.

An exponential function can never reach zero!

$$\log 10^9 - \log 10^0 = 9 - 0 = 9$$

The higher the temperature and the longer the holding time, the more efficient the process, *i.e.* the greater the sterilising effect.

The efficiency of the sterilisation process is mainly determined by two factors:

- The temperature and the length of time it is applied
- The heat resistance of the micro-organisms

Other factors such as product composition, viscosity, uniformity and pH will also affect sterilising efficiency. Equipment for in-flow sterilisation (UHT treatment) usually has a sterilising effect of around 9 – 10 on bacterial spores growing at ambient temperature.

Spores of *Bacillus subtilis* or *Bacillus stearothermophilus* are generally used as test organisms to determine the sterilising effect of UHT equipment, since these strains – especially *B. stearothermophilus* – form fairly heat-resistant spores. *Clostridium botulinum* has been traditionally used for calculation of the effect of in-container sterilisation.

The sterilisation process must be designed in such a way that there is only a negligible risk that a product will be spoiled before the consumer uses it, or that it contains surviving and growing pathogenic micro-organisms. *Clostridium botulinum* has always been considered as the most significant micro-organism in public health terms. Sterilisation processes were designed with destruction of this micro-organism's spores in mind. However, in heat-treated milk and milk products, the probability of survival and growth of *Clostridium botulinum* spores is very low indeed.

The lethal effect on bacterial spores starts at a temperature around 115 °C and increases very rapidly with rising temperature. Bacteria can be divided into two groups:

1 Those existing as vegetative cells only (easy to kill by heat or other means),
2 Those existing in a vegetative state and as spores as well, *i.e.* spore-forming bacteria. While these bacteria are easily killed as long as they are in the vegetative state, their spores are difficult to eliminate.

Products to be sterilised usually contain a mixed flora of both vegetative cells and bacterial spores, as shown in Figure 9.1. Unfortunately, the correlation between the two is not very good. High spore counts may be found in products with low total counts, and *vice versa*, so total count determination cannot serve as a reliable basis for enumeration of spores in food products.

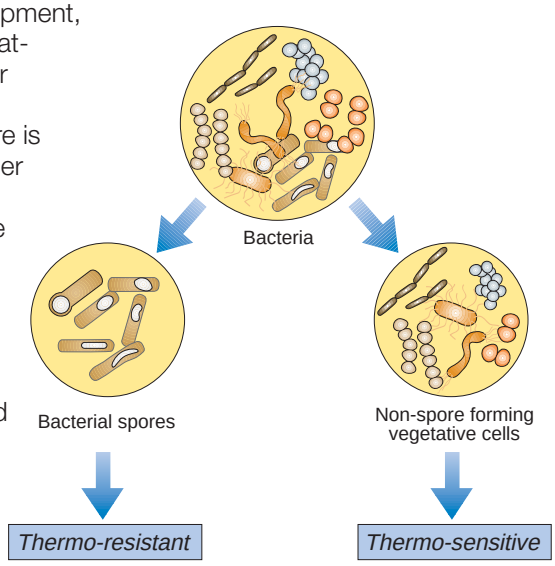


Fig. 9.1 *Thermal impact on bacteria in different states.*

Q_{10} value

As mentioned above, the sterilising effect of a heat sterilisation process increases rapidly with increasing temperature. This, of course, also applies to chemical reactions occurring as a consequence of heat treatment. The Q_{10} value has been introduced as an expression of this increase in speed of a reaction. It states how many times the speed of a reaction increases if the temperature of the system is raised by 10 °C.

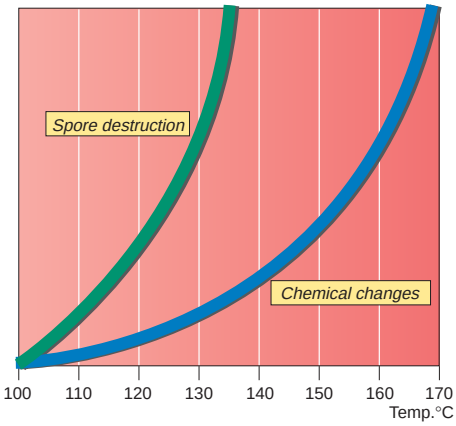


Fig. 9.2 *Curves representing the speed of changes in chemical properties and of spore destruction with increasing temperature.*

The Q_{10} value for flavour changes – and for most chemical reactions – is around 2 to 3, *i.e.* if the temperature of a system is raised by 10 °C, the speed of chemical reactions doubles or triples. Q_{10} values can also be determined for the killing of bacterial spores. The values found range between 8 and 30. The variation is so wide because different kinds of bacterial spores react differently to temperature increases. The changes in chemical properties and spore destruction by the influence of increased temperature are shown in Figure 9.2.

From this graph we can also see that in the range of UHT temperatures, the bacteriological killing effect increases considerably with temperature, whereas the chemical changes remain mild. This clearly illustrates the advantages of UHT treatment against in-container sterilisation operating at low temperature for a long time. Using ultra high temperatures with short holding times can provide a high sterilisation effect while causing only minimal chemical changes in the treated product. In-container sterilisation operating at low temperature for a long time leads to more extensive changes in product quality. See Figures 9.5 and 9.6.

F_0 value

In this context it should also be mentioned that the connection between time and temperature of sterilisation is also expressed as a F_0 value according to the following logarithmic function:

$$F_0 = \frac{t}{60} \times 10^{\frac{T-121,1°C}{z}}$$

where:

t = sterilisation time in seconds at temperature T in °C
T = sterilisation temperature in °C
z = a value expressing the increase in temperature to obtain the same lethal effect in 1/10 of the time. The value varies with the origin of the spores (10 – 10,8 °C) and can generally be set as 10 °C.

To obtain commercially sterile milk from good quality raw milk in practice, UHT plants are designed to achieve a minimum F_0 value of 5 – 6. According to legislation in some countries, a minimal F_0 value of 3 is required.

F_0 = 1 after the product is heated at 121,1 °C for *one minute*.

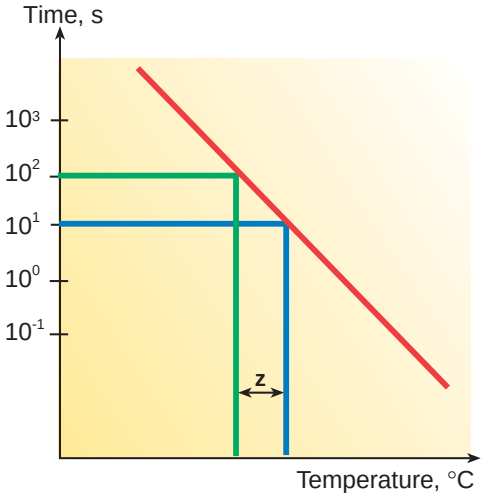


Fig. 9.3 *The z value expresses the increase in temperature to obtain the same lethal effect in 1/10 of the time.*

B* and C* values

The effective working range of UHT treatments is also defined in some countries by reference to two other parameters:

Bacteriological effect: B* (known as B star)
Chemical effect: C* (known as C star)

These values are based on experiments performed by Horak (1980) with natural milk incubated at 55 °C to enumerate thermophilic micro-organisms. The results were presented in the form of straight lines relating log of time with temperature for a constant sterilising effect. These data were extrapolated to give the line that would correspondent to 9 decimal reductions of this natural thermophilic spore population.

B* is based on the assumption that commercial sterility is achieved at 135 °C for 10,1 sec. with a corresponding z value of 10,5 °C. This reference process is given a B* value of 1,0.

Similarly, the C* value of 1 is based on the conditions for 3 % destruction of thiamine. This is equivalent to 135 °C for 30,5 seconds with a z value of 31,4 °C.

A UHT process operates satisfactorily with regard to the keeping quality of the product when the following conditions are fulfilled:

$$B^* > 1$$
$$C^* < 1$$

A commercially sterile product is free from micro-organisms which grow under the prevailing conditions.

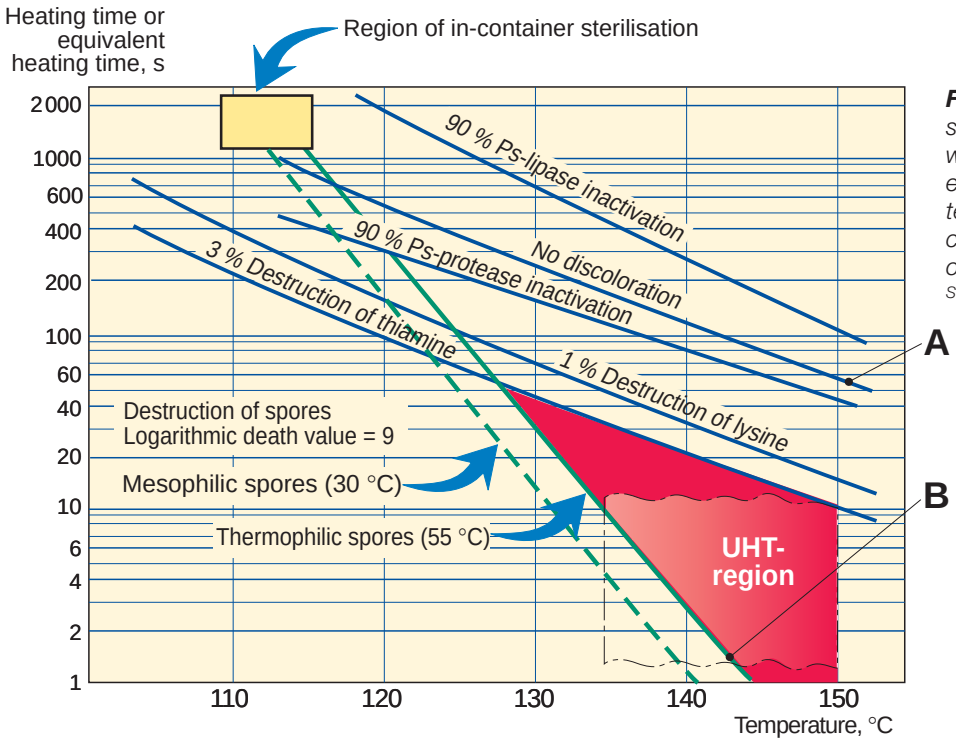


Fig. 9.4 *Limiting lines for destruction of spores and effects on milk. The values within brackets (30 °C and 55 °C) express the optimal growth temperatures of the vital types of corresponding spore forming micro-organisms.*
Source: Kessler

"The fastest particle"

In some countries (especially the United States), particular attention is paid to the residence time in a holding cell or tube, with special reference to the holding time for the "fastest particle". Depending on the flow pattern of the liquid (turbulent or laminar flow), the efficiency coefficient for milk is in the interval of 0,5 – 0,90. This involves applying a correction factor in calculations of holding times. In special cases in the USA, it is reckoned that the fastest particle passes a holding cell twice as fast as the average particle, *i.e.* the efficiency coefficient (η) is 0,5. In all relevant cases in industrial installations, the equipment is designed for maintaining turbulent flow, and an efficiency factor of 0,85 – 0,90 is utilised.

Commercial sterility

You will also encounter the expression "commercial sterility", which is frequently used for UHT-treated products. A commercially sterile product is defined as one which is free from micro-organisms that grow under the prevailing conditions.

According to the WHO/FAO and ECC, the commercial sterility of low-acid food is defined as follows:

Codex Alimentarius Commission (WHO/FAO)

The condition achieved by application of heat, sufficient, alone or in combination with other appropriate treatments, to render the food under normal non-refrigerated conditions at which the food is likely to be held during distribution and storage.

European Council Directive 92/46/ECC

In random sampling checks, UHT milk must meet the following standards after incubation at 30 °C for 15 days:

Plate count (30 °C)	≤10 (per 0,1 ml)
Organoleptic check	normal

Other UHT milk regulations

The Food Milk and Dairy Hygiene Regulation (1995) for UHT milk states: UHT milk shall be obtained by applying heat to a continuous flow of milk entailing the application of high temperature for a short time (not less than 135 °C for not less than 1 second), so that all residual micro-organisms and their spores are destroyed, but the chemical, physical and organoleptic changes to the milk are minimal. *(M.Lewis; N.Heppell: Continuous Thermal Processing of Foods (2000)*

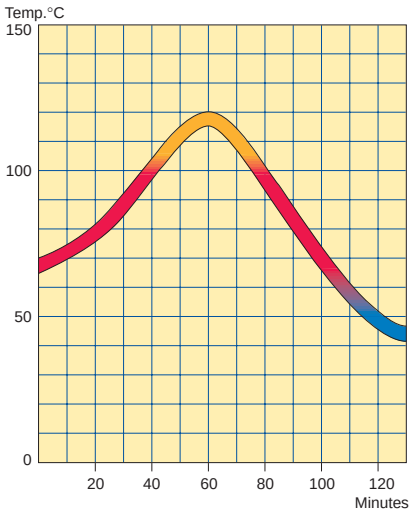


Fig. 9.5 *Temperature curve for in-container sterilisation.*

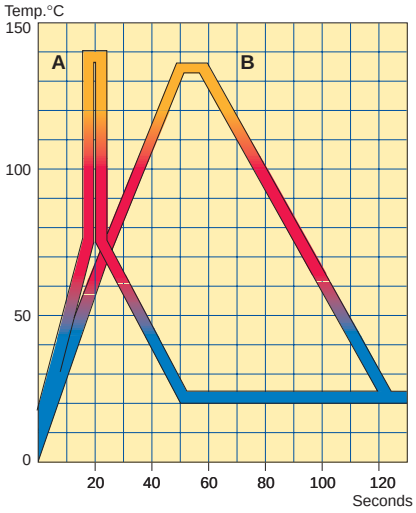


Fig. 9.6 *Temperature curves for direct, **A**, and indirect, **B**, UHT treatment.*

Council Directive 92/46/ECC (1992):
UHT milk must have been obtained by applying to the raw milk a continuous flow of heat entailing the application of high temperature for a short time (not less than +135 °C for not less than a second) – the aim being to destroy all residual spoilage micro-organisms and their spores – so that the chemical, physical and organoleptic changes are minimal.

Chemical and bacteriological changes at high heat treatment

When milk is kept at a high temperature for a long time, certain chemical reaction products are formed, which results in discoloration (browning). It also acquires a cooked and caramel flavour, and there is occasionally a great deal of sediment. These defects are largely avoided by heat treatment at a higher temperature for a shorter time. It is important that the optimum time/temperature combination is chosen to enable satisfactory spore destruction while keeping heat damage to the milk to a minimum.

Figure 9.4 shows the relationship between the sterilising effect and browning reaction. The **A** line represents the lower limit of time/temperature combinations that cause the milk to turn brown. Line **B** is the lower limit of combinations for complete sterilisation (destruction of thermophilic spores). The regions for in-container sterilisation and UHT treatment are also marked in the figure.

The figure shows that while the two methods have the same sterilising effect, there is a great difference in the chemical effects; the browning reaction and destruction of vitamins and amino-acids. At lower temperature loads the difference is much smaller. This is the reason why UHT milk tastes better and has a higher nutritive value than in-container sterilised milk.

Taste is a very subjective factor, but it is quite clear that the taste of UHT-treated milk has improved over the years. Many people find it impossible to tell the difference between good UHT milk and pasteurised milk.

As was mentioned in chapter 2, it appears that it is possible to differentiate pasteurised, UHT and sterilised milk by their lactulose content. The higher the temperature load has been, the higher the lactulose content.

Ever since UHT-treated milk was introduced on the market, the quality and primarily the taste and odour have been discussed. Initially, UHT-milk was almost as white as ordinary pasteurised milk, but the product had a cooked taste and odour. There have been a lot of efforts to obtain a flavour closer to that of ordinary pasteurised milk, and these efforts continue.

In this context it is important to mention that the temperature at which the milk is organoleptically tested has a big influence on the result. At refrigeration temperature, some 5 – 7 °C, the UHT flavour will be suppressed. Therefore, when, for instance, a comparison is made between the influence of various methods of UHT treatment, the organoleptic evaluation should be carried out at 20 °C after the samples have been stored at 20 °C for various periods, say 2, 4 and 6 weeks.

Tests carried out in this way show that significant differences exist between direct and indirect methods, the latter exposing the milk to a higher temperature load. However, in principle there is no pronounced difference between the two direct methods (steam injection and steam infusion).

Shelf life

Another term used in connection with UHT treatment to characterise the quality of the treatment is the shelf life of the product. This is defined as the period during which a product can be stored without the quality falling below a certain acceptable, minimum level. The concept is subjective – shelf life can be very long if the standards set for product quality are low.

The physical and chemical limiting factors of shelf life are incipient gelling, increase in viscosity, sedimentation and cream lining. The organoleptic limiting factors are deterioration of taste, smell or colour.

Nutritional aspects

When studying any type of food process, it is important to consider the nutritional aspects. Extensive research has been carried out on the effect of heat treatment on milk.

The heat effect of UHT treatment on the constituents of milk can be summarised as follows:

Certain conclusions regarding changes in nutritional value can be drawn from these chemical changes. There are no changes in the nutritional value of fat, lactose and mineral salts, but there are marginal changes in the nutritional value of proteins and vitamins.

The major protein in milk, casein, is not affected by heat treatment. Denaturation of whey proteins does not mean that the nutritional value (in terms of biological value, digestibility and availability of lysine) is lower in UHT milk than in raw milk. Although sterilised milk has a lower biological value (0,85), the nutritional value reported for UHT milk (0,90) does not differ significantly from that of raw milk (0,91).

Constituents heat effects

Fat	No changes
Lactose	Marginal changes
Proteins	Partial denaturation of whey proteins
Mineral salts	Partial precipitation
Vitamins	Marginal losses

The small loss of the essential amino-acid lysine causes the marginal changes. However, it has been shown that about 0,4 – 0,8 % of the lysine is lost, and this figure is the same for pasteurised milk. The corresponding value for in-container sterilised milk is 6 – 10 %.

Some of the vitamins in milk are considered to be more or less thermostable in regard to pasteurisation or UHT treatment. Among these are the fat-soluble vitamins A, D and E and some of the water-soluble group B vitamins. However, degradation of vitamin A can be much higher if the product is fortified. Other vitamins are less stable in response to heat, *e.g.* B_9 (folic acid) and B_{12} (cobulamin). The time/temperature curve in Figure 9.6 shows that thiamine losses are less than 3 % in UHT-treated milk, but considerably higher in in-container sterilised milk (approximately 20 – 50 %). The same relationship regarding destruction of vitamins can be found in all other heat-sensitive vitamins in UHT and in-container sterilised milk, for example B_6, B_{12}, folic acid and vitamin C. Losses of vitamin B_2 and vitamin C in in-container sterilised milk may be as high as 100 %.

Some of the vitamins, *e.g.* folic acid and vitamin C, are oxidation-sensitive, and their losses occur mainly during storage due to a high oxygen content in the milk or in the package. However, milk is not a good source of vitamin C and folic acid, as the content is far below the recommended daily intake.

Generally speaking, losses of vitamins are considerably higher when food is prepared in the home than in UHT treatment and pasteurisation of milk. The general conclusion should therefore be that UHT milk and pasteurised milk are of about the same quality, while in-container sterilised milk is of inferior quality in terms of nutritional value.

There are no changes in the nutritional value of fat, lactose and mineral salts, but there are marginal changes in the nutritional value of the proteins and vitamins.

Production of long-life milk

Two methods are used for the production of long-life milk for ambient storage:

A In-container sterilisation

B Ultra High Temperature (UHT) treatment followed by aseptic packaging in packages protecting the product against light and atmospheric oxygen

In-container sterilisation

Two processes are used for sterilisation in bottles or cans.

- Batch processing in autoclaves, Figure 9.7
- Continuous processing systems such as:
  - Vertical hydrostatic towers, Figure 9.8
  - Horizontal sterilisers, Figure 9.9

Batch processing

The batch system can be operated by three methods:

1 In stacks of crates in a static pressure vessel, autoclave, Figure 9.7
2 In a cage that can be rotated in a static autoclave
3 In a rotary autoclave.

The rotary methods have an advantage over the static method due to the quicker uptake of heat from the heating medium and the greater uniformity of treatment with respect to bacterial kill and colour of finished product.

In autoclave sterilisation the milk is usually pre-heated to about 80 °C and then transferred to clean, heated bottles. The bottles are capped, placed in a steam chamber and sterilised, normally at 110 – 125 °C for 3 – 40 minutes. The batch is then cooled and the autoclave filled with a new batch. The principle is the same for cans.

Batch sterilisation in autoclaves is a technique that is used more often for canned solid foods than for liquid products. The fact that sterilisation takes place after bottling or canning eliminates the need for aseptic handling, but on the other hand, heat resistant packaging materials must be used.

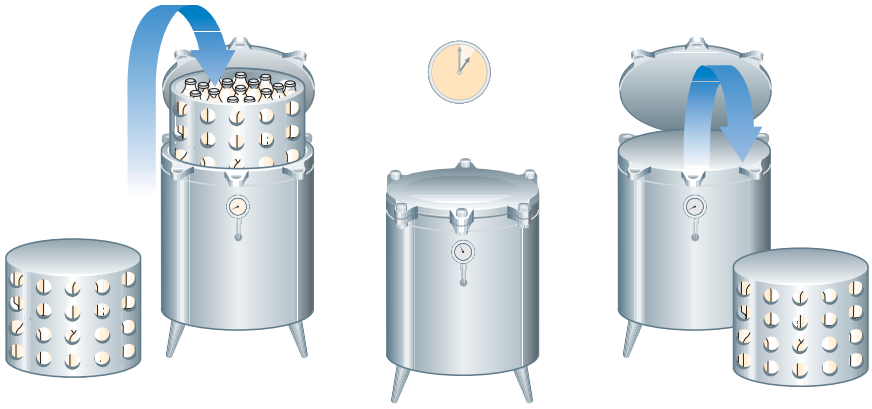


Fig 9.7 *Batch processing in a static pressure vessel (autoclave).*

Continuous processing

Continuous systems are normally preferred when more than 10 000 units per day are to be produced. For continuity of operation, the design of machines for continuous production depends on the use of a pressure lock system through which the filled containers pass from low pressure/low temperature conditions into a relatively high pressure/high temperature zone. After this, they are subjected to steadily decreasing temperature/pressure conditions and are eventually cooled with chilled or cold water.

There are two main types of machine on the market for continuous sterilisation, differing basically in the type of pressure lock system used.

1 The hydrostatic vertical bottle steriliser
2 The horizontal rotary valve-sealed steriliser

Hydrostatic vertical steriliser

This type of steriliser, often referred to as the tower steriliser, Figure 9.8, basically consists of a central chamber maintained at sterilising temperature by steam under pressure, counterbalanced on the inlet and discharge sides by columns of water giving an equivalent pressure. The water on the inlet side is heated and the water on the outlet side cooled, each at a

temperature adjusted to give maximum heat uptake/abstraction compatible with avoidance of breakage of the glass by thermal shock.

In the hydrostatic tower the milk containers are slowly conveyed through successive heating and cooling zones. These zones are dimensioned to correspond to the required temperatures and holding times in the various treatment stages.

In many cases the milk is pre-treated in a pre-sterilising plant similar to a UHT plant. The milk is heated to 135 °C or higher for a few seconds and then cooled to 30 – 70 °C (depending on the material of the bottle – as a rule plastic bottles require the lower temperature), and transferred to clean, heated bottles before it is treated in the hydrostatic tower. Pre-sterilisation can take place in an indirect or direct plant. The main reason for pre-sterilisation is either just to decrease the number of spores that will be finally removed by the second sterilisation in the container, or achieve in principle the same sterility level in the pre-sterilisation step as in the UHT plant. Thus the second sterilisation will remove only the micro-organisms that entered the product due to the non-aseptic filling process (F_0 = 1 – 2). Both pre-sterilisations are applied in order to lower the heat load in the heating tower and thereby reduce the unwanted chemical and organoleptic changes and get closer to the quality obtained by the UHT process followed by aseptic filling.

The time cycle of a hydrostatic steriliser is approx. one hour, including 3 – 30 minutes for passage through the sterilising section at 115 – 125 °C.

The hydrostatic steriliser is suitable for heat-treatment of 2 000 x 0,5 l to 16 000 x 1 l units per hour. Bottles made of glass or plastic can be used.

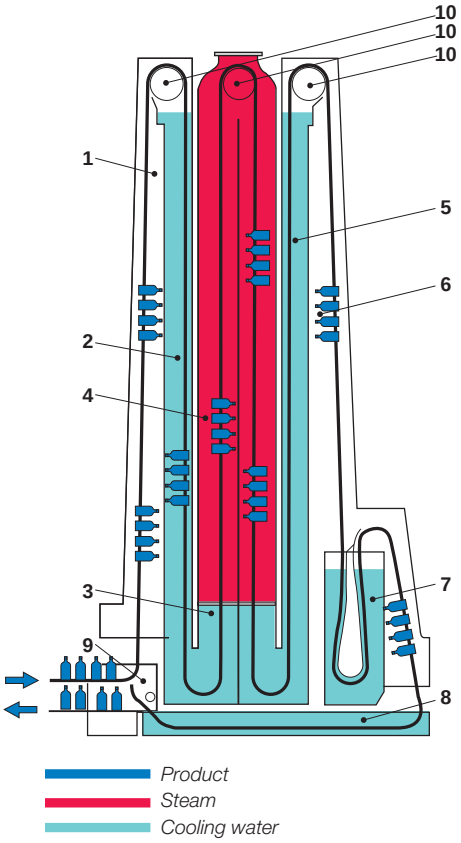


Fig. 9.8 *Hydrostatic vertical continuous bottle steriliser*

1 1st heating stage
2 Water seal and 2nd heating stage
3 3rd heating stage
4 Sterilisation section
5 1st cooling stage
6 2nd cooling stage
7 3rd cooling stage
8 4th cooling stage
9 Final cooling stage
10 Upper shafts and wheels, individually driven

Horizontal steriliser

The rotary valve-sealed steriliser, Figure 9.9, is a comparatively low-built machine with a mechanically driven valve rotor, through which the filled containers are passed into a relatively high pressure/high temperature zone, where they are subjected to sterilising temperatures of the order of 132 – 140 °C for 10 – 12 minutes. With an overall cycle time of 30 – 35 minutes, a capacity of 12 000 units per hour can be achieved.

The rotary valve-sealed steriliser can be used for sterilisation of plastic bottles and glass bottles, as well as flexible containers made of plastic film and plastic laminates.

Another system that ought to be mentioned in this context is the horizontal continuous rotating autoclave for *evaporated milk* in cans. The steriliser design comprises three cylindrical vessels, each containing a helical strip attached to a roller inside the vessel. A number of channels are formed so that the cans are forwarded along the roller during processing and simultaneously rotated. This type of steriliser is also equipped with a double detector system – one at the exit of the pre-heater and the other at the end of the pressure cooler – making it possible to detect non-sterile cans.

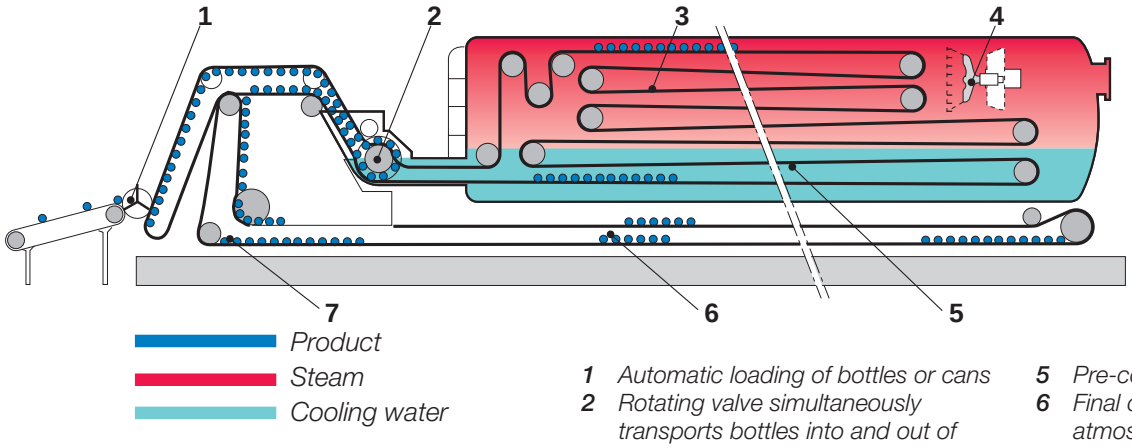


Fig. 9.9 *Horizontal steriliser with rotary valve seal and positive pressurisation (steam/air mixture) facility.*

1 Automatic loading of bottles or cans
2 Rotating valve simultaneously transports bottles into and out of pressure chamber
3 Sterilisation area
4 Ventilation fan
5 Pre-cooling area
6 Final cooling at atmospheric pressure
7 Unloading from conveyor chain

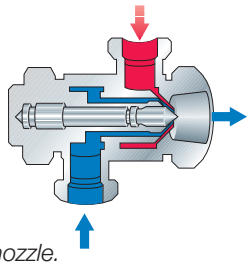


Fig. 9.10 *Steam injection nozzle.*

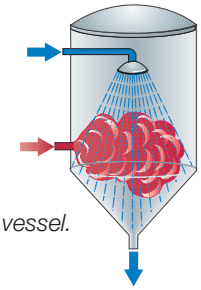


Fig. 9.11 *Steam infusion vessel.*

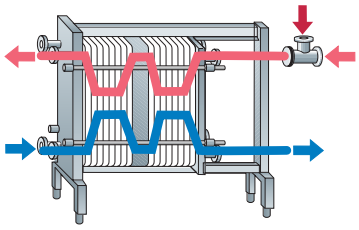


Fig. 9.12 *Plate heat exchanger for heating and cooling.*

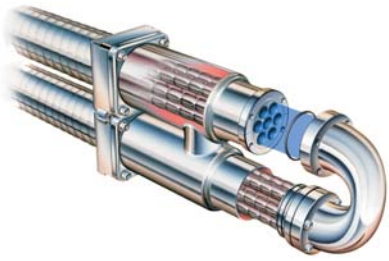


Fig. 9.13 *Tubular heat exchanger for heating and cooling.*

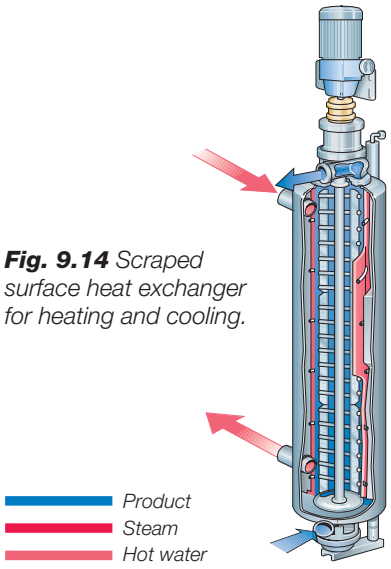


Fig. 9.14 *Scraped surface heat exchanger for heating and cooling.*

UHT treatment

In a modern UHT plant, the milk is pumped through a closed system. On the way it is pre-heated, high-heat treated, homogenised, cooled and packed aseptically. Low-acid liquid products (pH above 4,5 – for milk more than pH 6,5) are usually treated at 135 – 150 °C for a few seconds, by either indirect heating, direct steam injection or infusion. High-acid products (pH below 4,5) such as juice are normally heated at 90 – 95 °C for 15 – 30 seconds. All parts of the system downstream of the actual high-temperature heating section are of aseptic design to eliminate the risk of re-infection.

Compared to traditional sterilisation in hydrostatic towers, UHT treatment of milk saves time, labour, energy and space. UHT is a high-speed process and has much less effect on the colour and flavour of the milk. However, regular consumers of autoclave-sterilised milk are accustomed to its "cooked" or caramel flavour and may find the UHT-treated product "tasteless".

The UHT processes

UHT is a technique for preserving liquid food products by exposing them to brief, intensive heating. This treatment destroys the micro-organisms in the product.

This applies only as long as the product remains under aseptic conditions, so it is necessary to prevent re-infection by packaging the product in previously sterilised packaging materials under aseptic conditions after heat treatment. Any intermediate storage between treatment and packaging must take place under aseptic conditions. This is why UHT processing is also called *aseptic processing*.

Development of UHT

Experiments on sterilisation of milk in bottles had been carried out by Louis Pasteur, but it was not until around 1960, when both aseptic processing and aseptic filling technologies became commercially available, as the modern development of UHT processing started. UHT-treated milk and other UHT-treated liquid food products are now accepted worldwide, but it has not always been like that.

The first UHT plants operated on the principle of *direct steam injection*. Compared with the in-container sterilisation plants, the new UHT plants soon gained a reputation for producing an excellent flavour. The first *indirect plants* were introduced on the market some ten years later.

Research and development have been intense since UHT was first introduced. Modern plants deliver a superior product with the colour and nutritional values practically unchanged.

UHT plants

UHT treatment is a continuous process, and its application is therefore limited to products that can be pumped. UHT treatment can be applied to a wide range of dairy and food products. The list shown is not exhaustive. Many other liquid food products are likely to be of great interest to dairies in the future.

UHT plants are often flexibly designed to enable processing of a wide range of products in the same plant. Both low-acid products (pH > 4,5) and high-acid products (pH < 4,5) can be treated in a UHT plant. However, only low-acid products require UHT treatment to make them commercially sterile. Spores cannot develop in high-acid products such as juice, and heat treatment is therefore intended only to kill yeast and moulds. Normal high-temperature pasteurisation (90 – 95 °C for 15 – 30 seconds) is sufficient to make high-acid products commercially sterile.

UHT plants are fully automatic and have four operating modes: *plant pre-sterilisation, production, AIC* (Aseptic Intermediate Cleaning) and *CIP* (Cleaning In Place). Safety aspects must be a prime consideration in the design of a UHT plant. The risk of supplying an unsterilised product to the

aseptic filling machine must be eliminated. Interlocks in the control programming must provide security against operator errors and tampering with the process. It should, for example, be impossible to start production if the plant is not properly pre-sterilised.

All sequences involved in starting, running and cleaning the plant are initiated from a control panel, which contains all the necessary equipment for control, monitoring and recording of the process.

Common UHT products

- Fresh and recombined liquid milk
- Concentrated milk
- Dairy creams
- Flavoured milk drinks
- Fermented milk products (yoghurt, buttermilk, etc.)
- Whey-based drinks
- Ice cream mix
- Desserts (custards and puddings)
- Protein drinks
- Soy drinks
- Baby foods
- Fruit and vegetable juices
- Beverages such as tea and coffee
- Toppings and creams based on vegetable fat
- Soups
- Sauces
- Purées
- Dressings
- Nutritional solutions

Various UHT systems

There are two main types of UHT systems on the market.

In the direct systems the product comes in direct contact with the heating medium, followed by flash cooling in a vacuum vessel and eventually further indirect cooling to packaging temperature.

The direct systems are divided into:

- Steam injection systems (steam injected into product), Figure 9.10
- Steam infusion systems (product introduced into a steam-filled vessel), Figure 9.11

It is also possible to combine direct heating and indirect cooling without subsequent flash cooling.

In the indirect systems the heat is transferred from the heating media to the product through a partition (plate or tubular wall). The indirect systems can be based on:

- Plate heat exchangers, Figure 9.12
- Tubular heat exchangers, Figure 9.13
- Scraped surface heat exchangers, Figure 9.14

Furthermore, it is possible to combine the heat exchangers in the indirect systems according to product and process requirements.

General UHT operating phases

These operating phases are common to all UHT systems and are therefore not described under each system.

Pre-sterilisation

Before start of production the plant must be pre-sterilised in order to avoid re-infection of the treated product. The pre-sterilisation involves:

- Hot water sterilisation at the same temperature as the product shall undergo. Minimum time for the hot water sterilisation is 30 minutes from the moment the relevant temperature has been reached in the whole aseptic part of the plant.
- Cooling the plant to conditions required for production.

Production

The production phases vary according to the different processes and are described below.

Aseptic intermediate cleaning

The full CIP cycle takes 70 to 90 minutes and is normally carried out immediately after production. Aseptic Intermediate Cleaning (AIC) is a useful tool in cases where a plant is used for very long production runs. A 30 minute AIC can be carried out whenever it is necessary to remove fouling in the production line without losing aseptic conditions. The plant does not have to be resterilised after AIC. This method saves downtime and permits longer production runs.

CIP

The CIP cycle for direct or indirect UHT plants may comprise sequences for pre-rinsing, caustic cleaning, hot-water rinsing, acid cleaning and final rinsing, all automatically controlled according to a pre-set time/temperature program. The CIP program must be optimised for different operating conditions in different plants.

Direct UHT plants

UHT processing means commercial sterility to ensure food safety and long shelf life at ambient temperature. It entails heating the product to a specific temperature for a specific length of time. The higher the temperature, the shorter the time required to destroy micro-organisms. The more rapidly the product can be heated and then subsequently cooled down again, the less impact the process has on the chemical changes in the product , such as changes in taste, colour and even to some extent, nutritional value.

The most effective way of achieving rapid heating is to mix high temperature steam directly with the product, followed by flash cooling in a vacuum vessel. This is called a direct system.

Flash cooling is an operation, which as well as cooling, also involves deaeration and deodorisation of the treated product. In addition, deaeration secures higher homogenisation efficiency and the deaeration will also positively influence the storage stability of the processed product in terms of preventing oxidation during storage.

The rapid heating and cooling explains why direct systems deliver superior product quality and are often chosen to manufacture heat - sensitive products, such as premium quality market milk, enriched milk, cream, formulated dairy products, soy milk and soft ice mix, as well as dairy desserts and baby food.

Processing of starch-based products in a direct system has a positive effect on texture and smoothness, thus enhancing the mouthfeel.

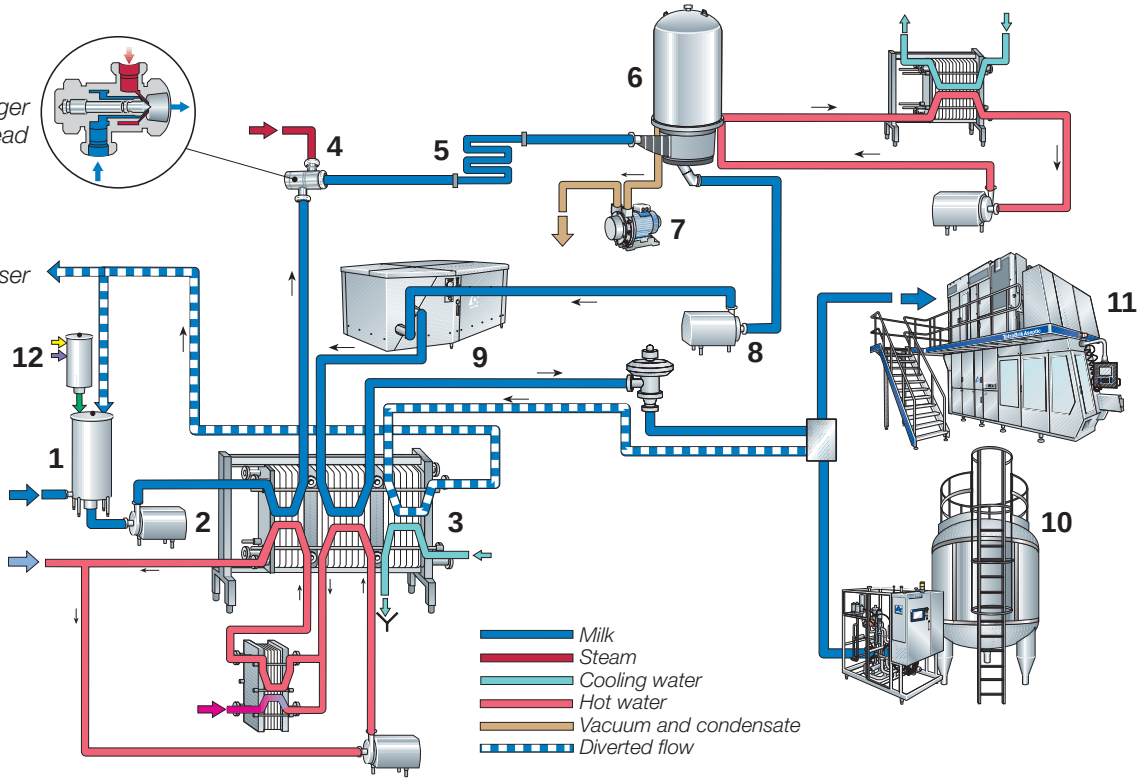
Direct UHT plant based on steam injection and plate heat exchanger

In the flowchart in Figure 9.15, the product at about 4 °C is supplied from the balance tank (1) and forwarded by the feed pump (2) to the pre-heating section of the plate heat exchanger (3). After pre-heating to approximately 80 °C, the product then continues to the ring nozzle steam injector (4). The steam injected into the product instantly raises the product temperature to about 140 – 150 °C (the pressure prevents the product from boiling). The product is held at UHT temperature in the holding tube (5) for a few seconds before it is flash cooled.

Flash cooling takes place in the condenser-equipped vacuum vessel (6) in which partial vacuum is maintained by a pump (7). The vacuum is

Fig. 9.15 *UHT process with heating by direct steam injection combined with plate heat exchanger.*

1 *Balance tank milk*
2 *Feed pump*
3 *Plate heat exchanger*
4 *Steam injection head*
5 *Holding tube*
6 *Vacuum vessel*
7 *Vacuum pump*
8 *Centrifugal pump*
9 *Aseptic homogeniser*
10 *Aseptic tank*
11 *Aseptic filling*
12 *CIP*



controlled so the amount of vapour flashed off from the product equals the amount of steam previously injected. A centrifugal pump (8) feeds the UHT-treated product to the aseptic two-stage homogeniser (9).

After homogenisation, the product is cooled to approximately 20 °C in the plate heat exchanger (3) and then continues directly to an aseptic filling machine or to an aseptic tank for intermediate storage before being packed.

The energy efficiency is optimised by heat regeneration in the water circuit. The water used for cooling after the homogeniser is utilised for pre-heating.

If the temperature drops during production, the product is diverted into a reject tank and the plant is flushed by water. The plant must be cleaned and sterilised before restart.

Plants with capacities of 2 000 – 30 000 l/h are available.

Direct UHT plant based on steam injection and tubular heat exchanger

As an alternative to the above design, the plate heat exchanger in Figure 9.15 (3) can be exchanged for tubular heat exchangers, as shown in Figure 9.16, when products of low or medium viscosity are to be treated.

Following pre-sterilisation of the plant and cooling down to some 25 °C, the milk at about 4 °C is routed into a tubular heat exchanger (3) for pre-heating to approx. 80 °C.

Steam injection (4) instantly raises the temperature to 140 – 150 °C. The milk is held at this temperature for a few seconds (5) before being cooled down. The injected steam is flashed off as vapour in a vacuum vessel (6), whereupon the temperature of the milk drops to 80 °C.

After aseptic homogenisation (9), the milk is cooled (10) to packaging temperature, approximately 25 °C, and routed into an aseptic tank (11) for intermediate storage before being aseptically packaged (12).

The heating and cooling media circulate in a closed water loop, which transports heat energy between the heat exchanger sections in the process.

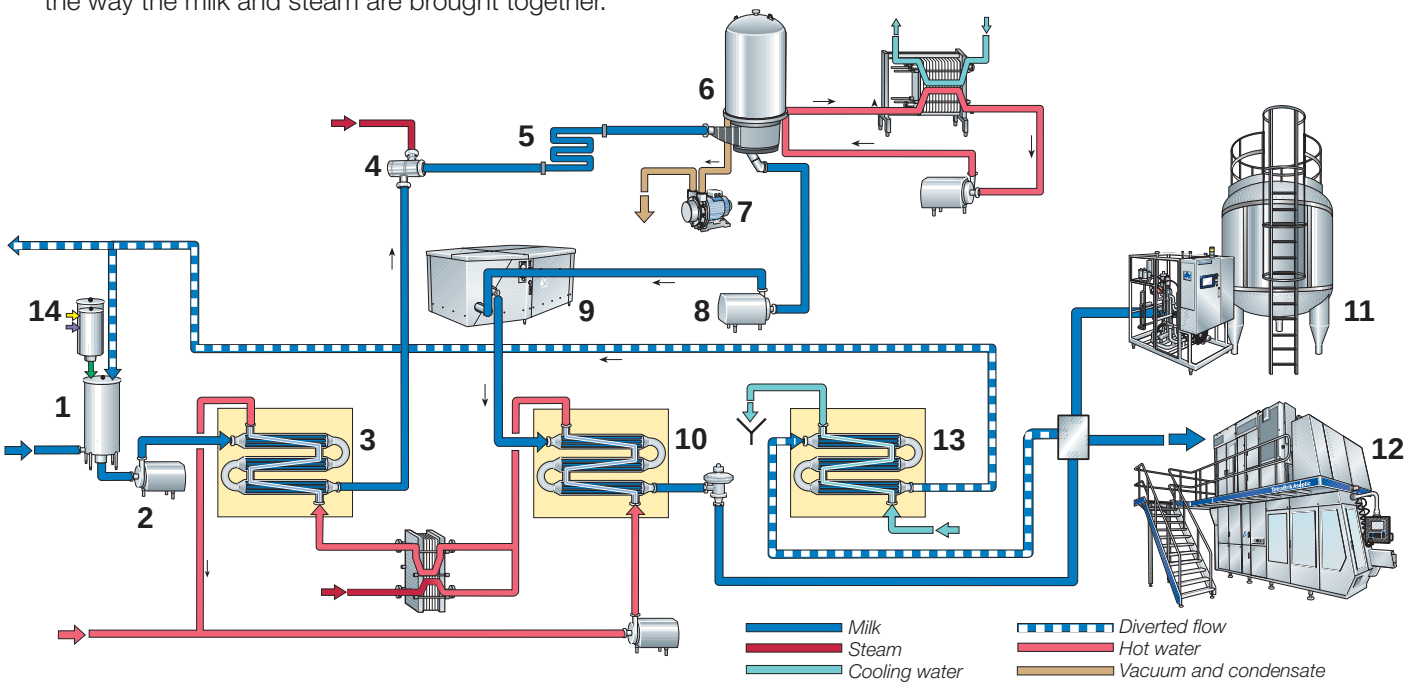
If the temperature drops during production, the product is diverted into a reject tank and the plant is flushed by water. The plant must be cleaned and sterilised before restart.

Direct UHT plant based on steam infusion

The main difference between this system and the steam injection system is the way the milk and steam are brought together.

Fig. 9.16 *UHT process with heating by direct steam injection combined with tubular heat exchanger.*

1 *Balance tank*
2 *Feed pump*
3 *Tubular heat exchanger, preheater*
4 *Steam injection head*
5 *Holding tube*
6 *Vacuum vessel*
7 *Vacuum pump*
8 *Centrifugal pump*
9 *Aseptic homogeniser*
10 *Tubular heat exchanger, cooler*
11 *Aseptic tank*
12 *Aseptic filling*
13 *Tubular heat exchanger, diverted flow cooler*
14 *CIP*



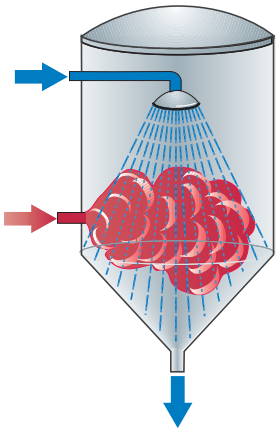


Fig. 9.17 *Vessel in which the product is heated by steam infusion.*

The basic principle of steam infusion is to heat a product by passing it through an atmosphere of steam, as shown in Figure 9.17. The product-spreading system may vary, but the resulting milk droplet size must be uniform, so that the rate of heat transfer does not vary. If the droplet size varies, the infuser will depart from the theoretical model upon which the design is based.

Otherwise, the process is similar to the steam injection system.

Indirect UHT plants

In many cases, products must not only be attractive and healthy to eat and drink, but also economical to manufacture, store and distribute. The most cost-effective method of UHT processing is indirect heating – a heating method in which the processed product never comes into direct contact with the heating medium. There is always a wall in between. This technique applies to all types of heat exchangers.

Indirect UHT plants are a suitable choice for processing of milk, flavoured milk products, cream, dairy desserts, yogurt drinks and other non-dairy applications, such as juices, nectars and tea.

Indirect UHT plant based on plate heat exchangers

UHT plants of the indirect heating type are built for capacities up to 30 000 l/h. A typical flowchart is shown in Figure 9.18.

The product at about 4 °C is pumped from the storage tank to the balance tank (1) of the UHT plant and from there by the feed pump (2) to the regenerative section of the plate heat exchanger (3). In this section the product is heated to about 75 °C by UHT-treated product, which is cooled at the same time. The pre-heated product is then homogenised (4) at a pressure of 18 – 25 MPa (180 – 250 bar). Homogenisation before UHT treatment is possible in indirect UHT plants, which means that non-aseptic homogenisers can be used. However, an aseptic downstream homogeniser might improve the texture and physical stability of certain products that have a high content of protein, dry matter or fat.

Double homogenisation, using one homogeniser upstream and one downstream, can be used to obtain premium quality and long shelf life stability for some products. This process solution is appropriate for products such as coffee cream and evaporated concentrated milk.

The pre-heated, homogenised product continues to the heating section of the plate heat exchanger, where it is heated to about 137 °C. Heating is

1 *Balance tank*
2 *Feed pump*
3 *Plate heat exchanger*
4 *Non-aseptic homogeniser*
5 *Holding tube*
6 *Aseptic tank*
7 *Aseptic filling*
8 *CIP*

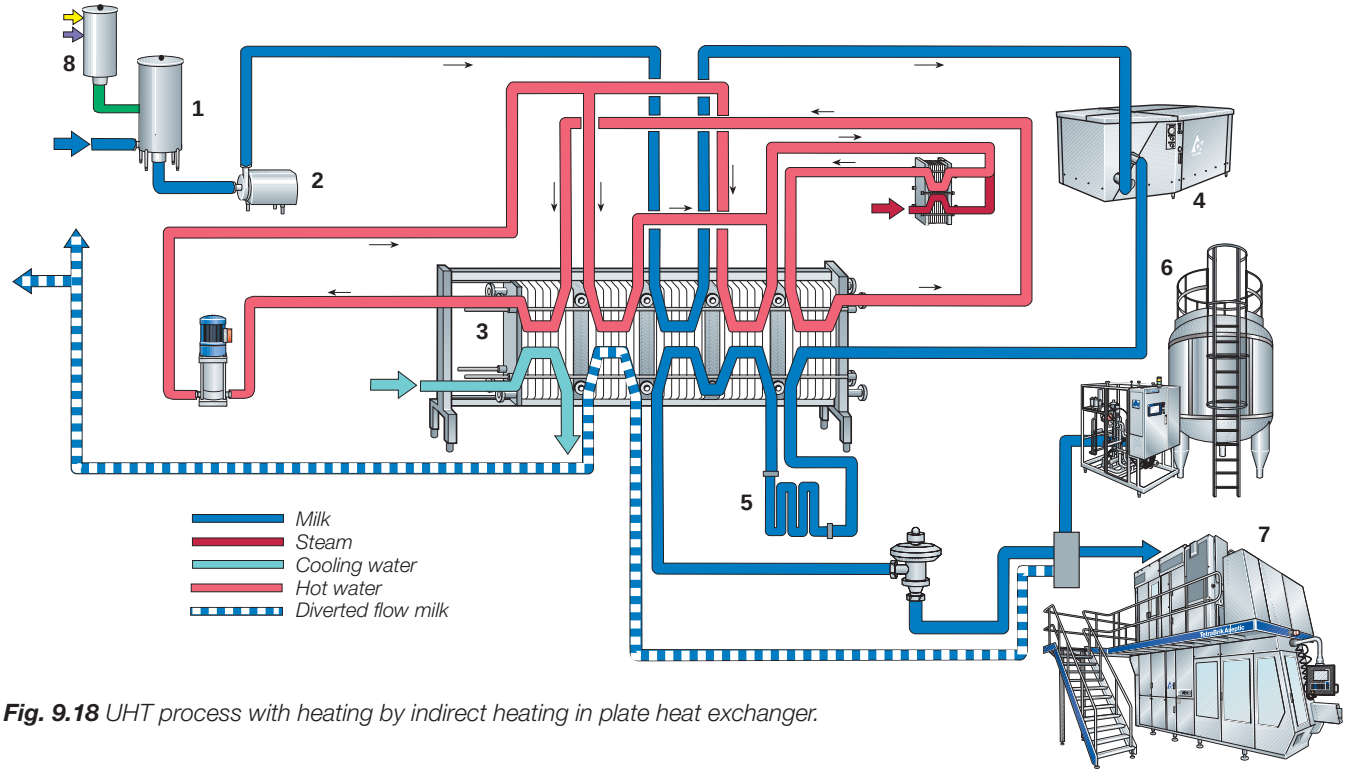


Fig. 9.18 *UHT process with heating by indirect heating in plate heat exchanger.*

performed by hot water in a closed water curcuit. After heating, the product passes through the holding tube (5), dimensioned for about 4 seconds.

Finally, cooling is performed regeneratively in two sequences: first against the cold end of the hot water circuit, and then against the cold incoming product. The product that leaves the regenerative cooler continues directly to aseptic packaging or to an aseptic tank for intermediate storage.

If the temperature drops during production, the product is diverted into a reject tank and the plant is flushed by water. The plant must be cleaned and sterilised before restart.

Split heating

In many cases, indirect UHT plants are designed for a variable capacity between 50 and 100 % of the nominal and are directly connected to a line of aseptic packaging machines. To avoid over-processing of the product if one of the packaging machines stops, the heating section can be divided and split into subsections.

The split heating system is illustrated in Figure 9.19. In the event of a sudden 50 % reduction of the flow compared with nominal, a valve (C) is activated so that the heating medium by-passes outside the first heating section (A). The temperature of the product will thus be kept at the pre-heating temperature (75 °C) until the product reaches the second (final) heating section (B) where heating to the relevant UHT temperature takes place.

The time/temperature curves in Figure 9.20 show the difference in the heat load on the product at nominal and half capacity. The dotted line on the graph represents the temperature development in a system without split heating facilities running at 50 % of nominal capacity.

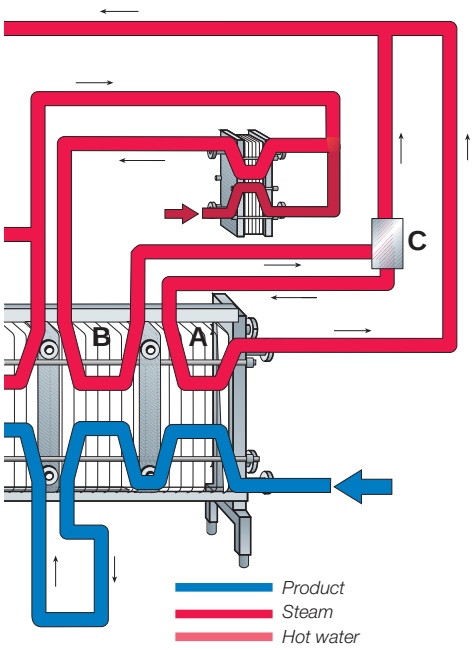


Fig. 9.19 *Split heating system in a plate heat exchanger.*
A *First heating section*
B *Final heating section*
C *Change-over valve*

Indirect UHT plant based on tubular heat exchangers

A tubular system is chosen for UHT treatment of products with low or medium viscosity that may or may not contain particles or fibres. The term medium viscosity is a diffuse concept, as the viscosity of a product can vary depending on raw material, additives and mechanical treatment.

Soups, tomato products, fruit and vegetable products, certain puddings and desserts are examples of medium-viscosity products well suited to treatment in a tubular concept. Tubular systems are also frequently utilised when longer processing times are required for ordinary market milk products.

The running time of indirect systems can be prolonged even further by installation of a stabilising holding tube, which stabilises milk proteins and thus minimises fouling in the heat exchangers and the ordinary holding tube.

The processing principle, shown in Figure 9.21, does not differ very much from the UHT plant with plate heat exchanger described above. Plants with capacities from 1 000 up to 30 000 l/h can be built.

The tubular heat exchanger comprises of a number of tubes assembled into modules that can be connected in series and/or in parallel to offer a complete optimised system for any heating or cooling duty. This system can also be provided with a split heating arrangement.

If the temperature drops during production, the product is diverted into a reject tank and the plant is flushed by water. The plant must be cleaned and sterilised before restart.

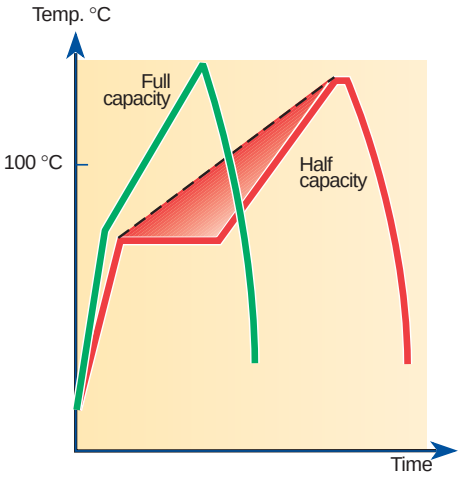


Fig. 9.20 *Effect on heat load with split heater. The broken line represents the temperature development in a system without split heating facilities.*

Note: *Operating at 50 % of the nominal capacity, the holding time will be doubled in order to compensate that the UHT temperature is lowered.*

Indirect UHT plant based on scraped surface heat exchangers

Scraped surface heat exchangers are the most suitable type for treatment of high-viscosity food products with or without particles.

A scraped surface system is based on a number of relevant heat exchangers and a typical flowchart for this process is shown in Figure 9.22. Specific hourly capacities or temperature programs cannot be stated owing to the wide variation in the physical characteristics of individual products.

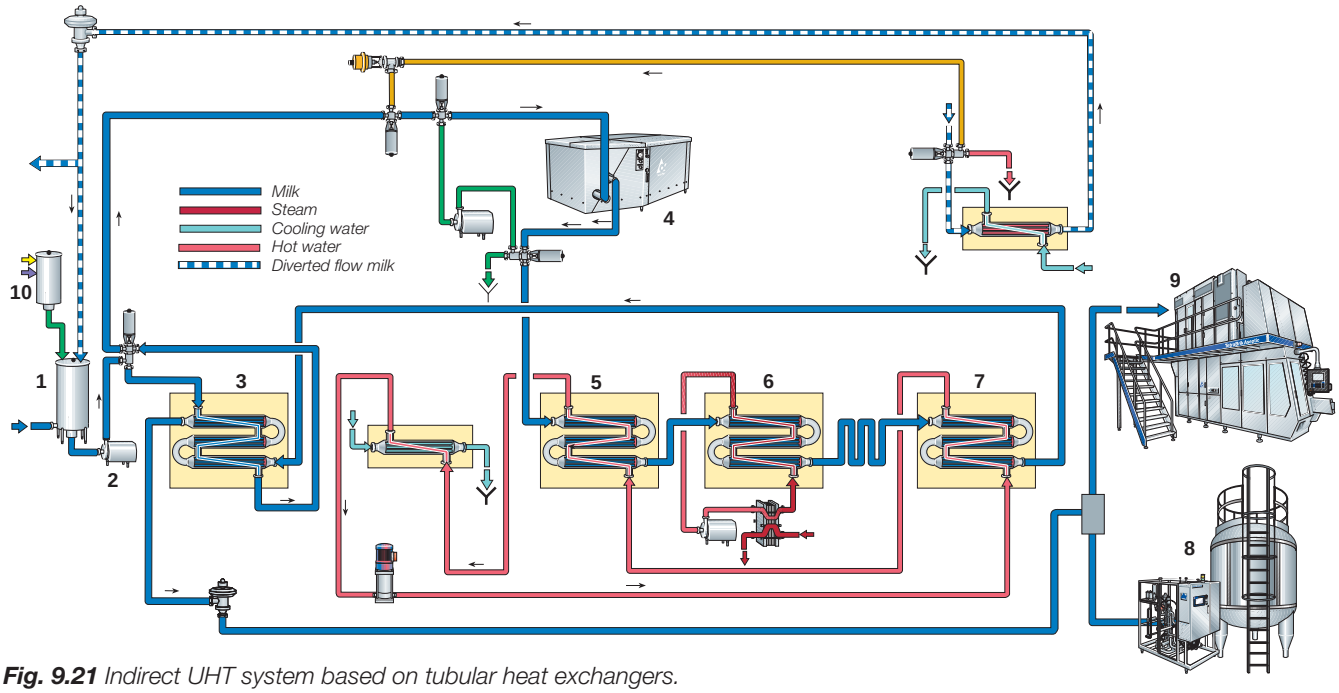


Fig. 9.21 *Indirect UHT system based on tubular heat exchangers.*

1 *Balance tank*
2 *Feed pump*
3 *Tubular heat exchanger, regenerative preheater and cooler*
4 *Non-aseptic homogeniser*
5 *Tubular heat exchanger, heater*
6 *Tubular heat exchanger, final heater*
7 *Tubular heat exchanger, cooler*
8 *Aseptic tank*
9 *Aseptic filling*
10 *CIP*

The product is pumped from a tank (1) by a feed pump (2) to the first scraped surface heat exchanger (3). Additional heating stages (4) can be utilised to bring the product up to the desired temperature. Monitors located at different stages of the process check that these temperatures have been attained.

The holding tube (5) maintains the product at the required temperature for a predetermined period of time. The product is cooled with water (6 and 7) and chilled water (8) until it reaches packaging temperature.

Finally, the cooled product is pumped to an aseptic buffer tank (10), which provides a buffer volume between the continuous process line and the packaging system.

Failure to meet the pre-set values automatically opens a return valve to direct the product to a reclaim tank.

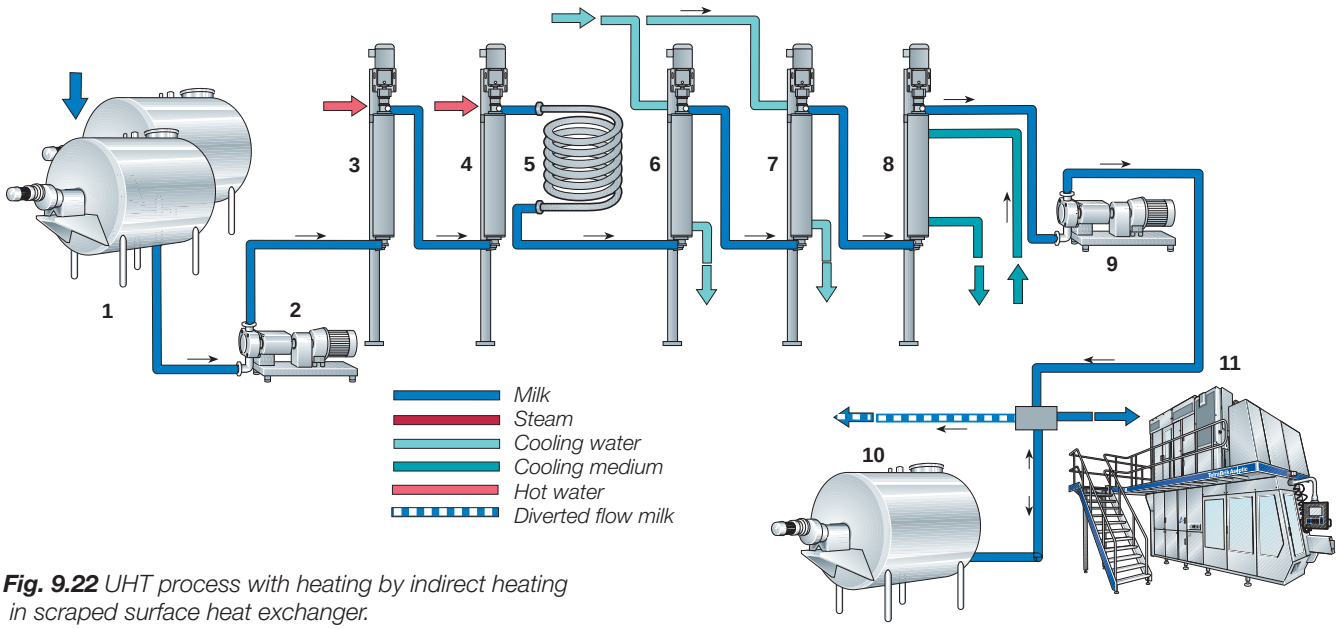


Fig. 9.22 *UHT process with heating by indirect heating in scraped surface heat exchanger.*

1 *Product tank*
2 *Positive feed pump*
3 *Scraped surface heat exchanger, heater*
4 *Scraped surface heat exchanger, heater*
5 *Holding tube*
6 *Scraped surface heat exchanger, cooler*
7 *Scraped surface heat exchanger, cooler*
8 *Scraped surface heat exchanger, cooler*
9 *Positive pump*
10 *Aseptic tank*
11 *Aseptic filling*

Aseptic storage

The aseptic tank, in Figure 9.23, is used for intermediate storage of UHT-treated dairy products. Product flow and service media connections are placed in its valve and control module. An aseptic tank can be used in many ways in UHT lines, depending on plant design and the capacities of the various units in the process and packaging lines. Two examples are shown in Figures 9.24 and 9.25.

- If one of the packaging machines unexpectedly stops, the aseptic tank takes care of the surplus product during the stoppage.
- Simultaneous packaging of two products. The aseptic tank is first filled with one product, sufficient to last for a full shift of packaging. Then the UHT plant is switched over to another product, which is packed directly in the line of packaging machines.

One or more aseptic tanks included in the production line thus offer flexibility in production planning.

Direct packaging from a UHT plant requires recirculation of a minimum extra volume of 300 litres per hour to maintain a constant pressure to the filling machines. Products that are sensitive to reprocessing cannot tolerate this and the required overcapacity must then be fed from an aseptic tank. One of the major advantages of an aseptic tank is that the product is only processed once, and in optimal conditions. This will always secure consistent, and best, product quality.

The optimum arrangement of UHT plants, aseptic tanks and aseptic packaging machines must thus be decided for each individual process.

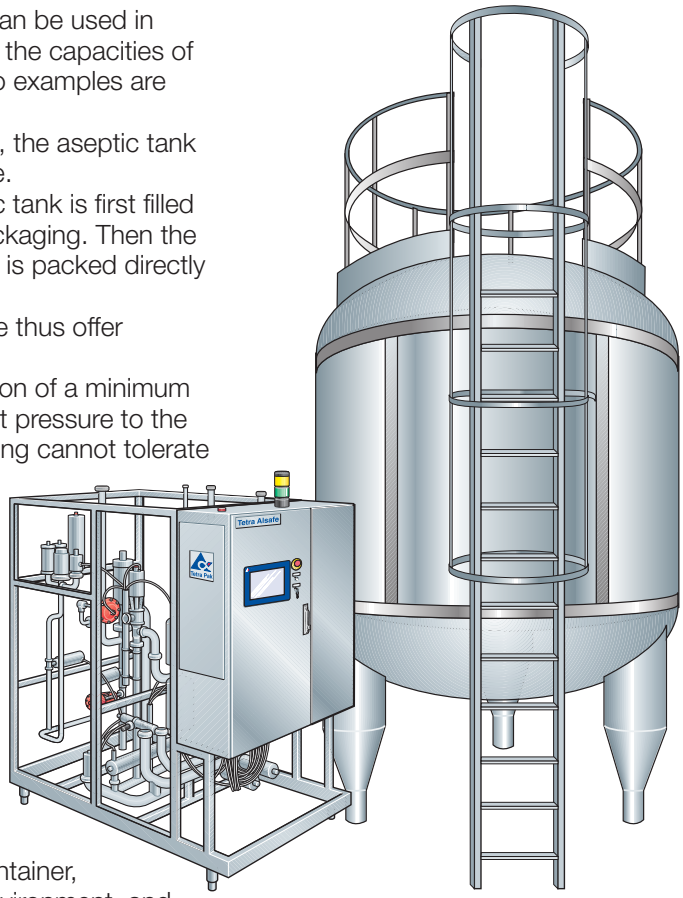


Fig. 9.23 *Aseptic tank with valve and control module.*

Aseptic packaging

Aseptic packaging has been defined as a procedure consisting of sterilisation of the packaging material or container, filling with a commercially sterile product in an aseptic environment, and producing containers that are tight enough to prevent recontamination, *i.e.* that are hermetically sealed, Figure 9.26.

For products with a long non-refrigerated shelf life, the package must also give almost complete protection against light and atmospheric oxygen. A milk carton for long-life milk must therefore be of high-quality carton board sandwiched between layers of polyethylene plastic.

The term “aseptic” implies the absence or exclusion of any unwanted organisms from the product, package or other specific areas. “Hermetic” is a term used to indicate suitable mechanical properties to exclude the entry of bacteria into the package or, more strictly, to prevent the passage of micro-organisms and gas or vapour into or from the container.

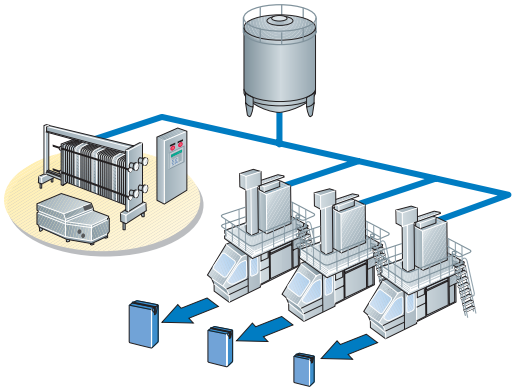


Fig. 9.24 *Aseptic tank used as a buffer for packaging of one product.*

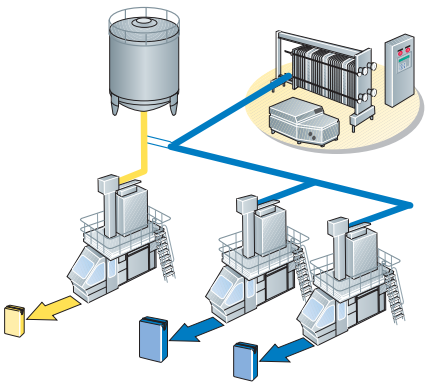


Fig. 9.25 *Aseptic tank used as an intermediate storage tank for one product while a second is processed and packed.*

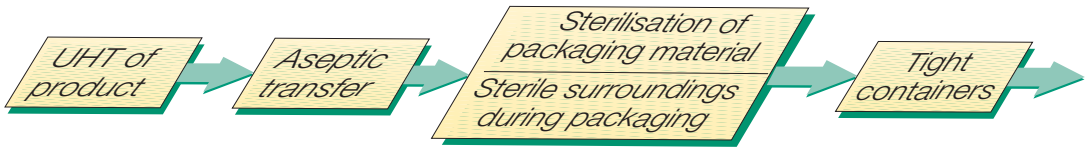


Fig. 9.26 *Packaging under aseptic conditions.*

UHT pilot plants

Special pilot plants are available for testing small quantities of new, interesting products. In these plants it is possible to study the effects of varying technological parameters related to the UHT process, such as temperature programs, holding times, heating method (direct or indirect) and deaeration or no deaeration, as well as homogenising pressures and temperatures. Many technological parameters are related to the product such as recipes, ingredients, pre-treatment, etc.

These product parameters are just as important as the process parameters, and successful development of a new UHT product requires that all of them are studied together. At the same time, the pilot plant can be used to study heat-related properties of the product such as stability, sensitivity, and heat resistance of spores.

Many laboratories in the food and dairy industry have installed UHT pilot plants for product development. Such plants are also found in schools, universities and other scientific institutions that are interested in food and dairy technology. Some manufacturers of UHT plants also have pilot plants for research and trials with customers' products.

The complete UHT plant can consist of one module for indirect heating in plate heat exchangers and additional modules for direct heating, tubular heating and homogenisation. The flow chart in Figure 9.27 illustrates a pilot

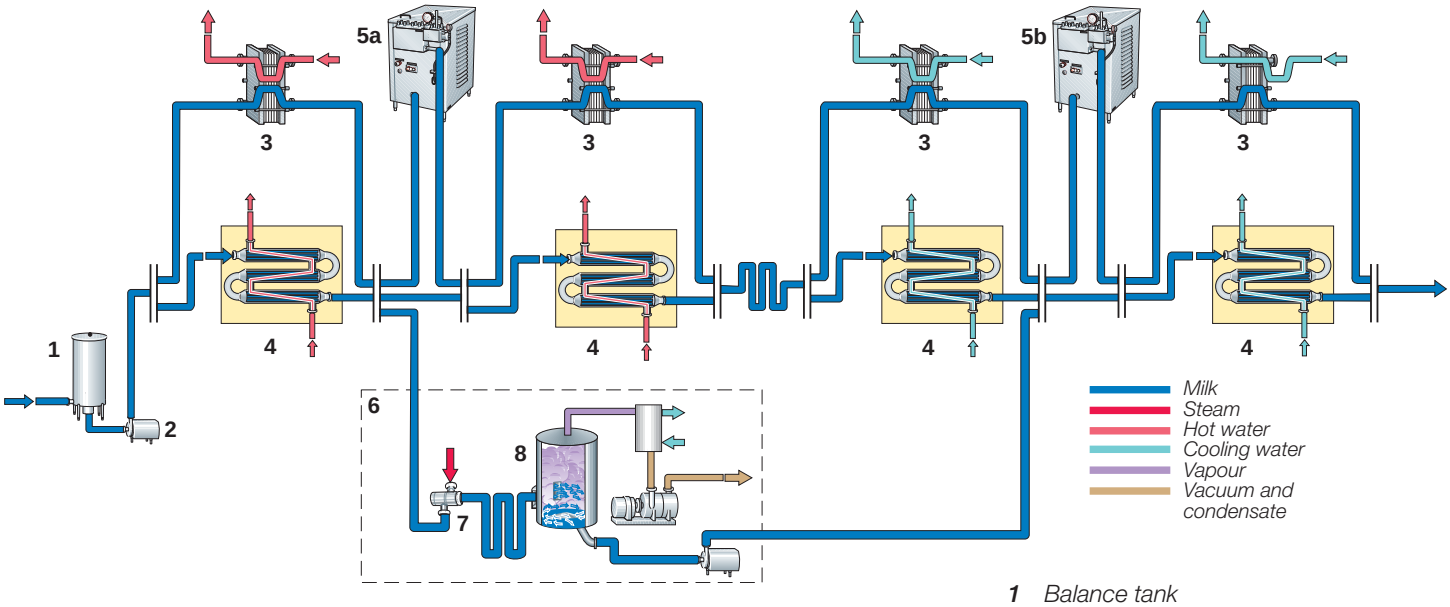


Fig. 9.27 *Process flow chart for UHT pilot plant including indirect heating in plate heat exchangers or tubular heat exchangers and direct heating module (within broken line) as well as aseptic and non-aseptic homogenisation alternatives.*

1 *Balance tank*
2 *Feed pump*
3 *Plate heat exchanger*
4 *Tubular heat exchanger*
5 *Homogeniser*
6 *Direct heating module*
7 *Steam injector*
8 *Vacuum vessel*

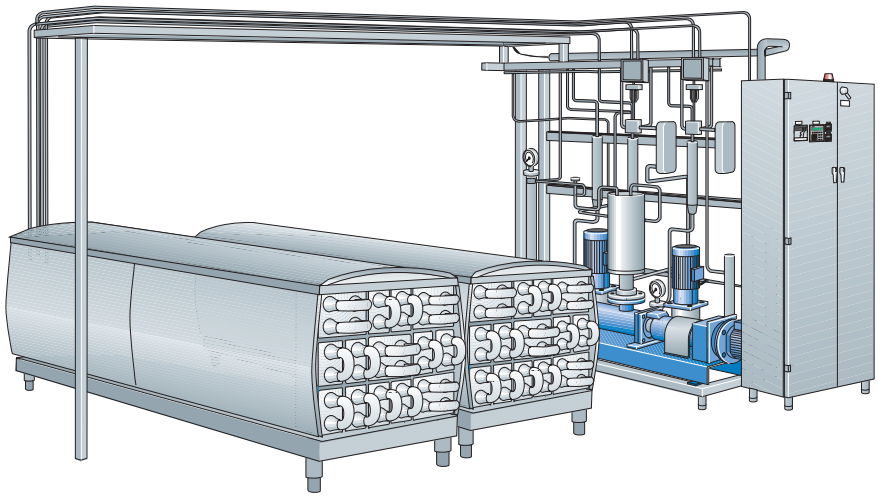


Fig. 9.28 *UHT pilot plant based on tubular heat exchangers.*

plant for indirect heating in plate heat exchangers, or alternatively in a tubular heat exchanger and additional modules for direct heating and homogenisation of the product, either upstream (non-aseptic, 5a) or downstream (aseptic, 5b).

Chapter 10

Cultures and starter manufacture

Bacteria cultures, known as 'starters', are used in the manufacture of yoghurt, kefir and other cultured milk products as well as in buttermaking and cheesemaking. The starter is added to the product and allowed to grow there under controlled conditions. In the course of the resulting fermentation, the bacteria produce substances which give the cultured product its characteristic properties such as acidity (pH), flavour, aroma and consistency. The drop in pH, which takes place when the bacteria ferment lactose to lactic acid, has a preservative effect on the product, while at the same time the nutritional value and digestibility are improved.

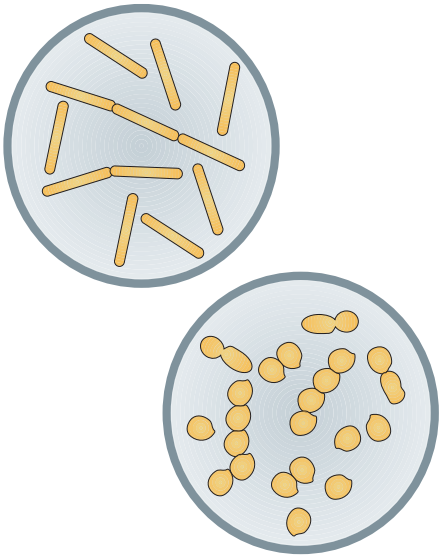


Fig. 10.1 *Bacteria in yoghurt: Lactobacillus bulgaricus and Streptococcus thermophilus, below.*

Cultured dairy products and cheeses have different characteristics, and different starter cultures are therefore used in their manufacture. Starter cultures can be classified according to their preferred growth temperatures:

- **Mesophilic bacteria** – optimal growth temperatures of 20 to 30 °C
- **Thermophilic bacteria** – optimal growth temperatures of 40 to 45 °C

The cultures may be of:

- **Single-strain** type; containing only one strain of bacteria
- **Multiple-strain** type; a mixture of several strains, each with its own specific effect

Mesophilic bacteria cultures can be further divided into O and LD cultures. Table 10.1, reproduced from the *Technology of Cheesemaking by Barry A Law*, lists the new names of various cultures.

Some *Streptococcus diacetylactis* bacteria are such powerful acidifiers that they can be used alone as acidifying cultures, but they are used primarily together with *Str. cremoris/lactis*. However, it is *not* possible to use a pure *Leuc. citrovorum* culture, because growth of *Leuc. citrovorum* in milk is conditional upon the availability of nutrients produced by *Str. lactis* or *Str. cremoris. Leuc. citrovorum* grows very slowly in milk in the absence of acid-producing bacteria, and cannot produce aromatic substances in such conditions.

Bacterial characteristics such as optimum growth temperature and salt tolerance are very important in the composition of a culture. The purpose of

Table 10.1

Speces of lactic acid bacteria (LAB) in various culture types and typical product applications

Culture types	Species names	Product application
Mesophilic		
O type*	*Lactococcus lactis* subsp. *lactis*	Cheddar cheese
	Lc. lactis subsp. *cremoris*	Feta cheese
		Cottage cheese
LD type**	*Lc. lactis* subsp. *lactis*	Gouda cheese
	Lc. lactis subsp. *cremoris*	Tilsiter cheese
	Lc. lactis subsp. *lactis biovar. diacetylactis*	Soft cheeses with mould
	Leuconostoc mesenteroides subsp. *cremoris*	
Thermophilic		
Streptococcus type	*Streptococcus thermophilus*	Mozzarella cheese
		Stabilised Brie
		Swiss-type cheese
Yoghurt type	*S. thermophilus*	Mozzarella cheese
	Lactobacillus delbrueckii subsp. *bulgaricus*	Pizza cheese
Lactobacillus type	*Lb. helveticus*	Swiss-type cheese
	Lb. delbruecklii subsp. *lactis*	Grana cheese
Mixed types		
RST type	*Lc. lactis* subsp. *lactis*	Cheddar cheese
	Lc. lactis subsp. *cremoris*	
	S. thermophilus	
FRC types	*Lc. lactis* subsp. *lactis*	Feta cheese
	Lc. lactis subsp. *cremoris*	White brine cheeses
	S. thermophilus	
	Lb. delbrueckii subsp. *bulgaricus*	

* O cultures contain only acid-producing strains of bacteria
** LD cultures contain citrate-fermenting bacteria

From Technology of Cheesemaking by Barry A. Law

the component strains is to produce the desired result in *symbiosis*, not to compete with each other. Their characteristics must therefore be complementary in this respect. Table 4.1 in Chapter 4: Micro-organisms lists essential data for some important culture bacteria.

Dairies normally buy ready-mixed starters – commercial cultures – from special laboratories. These laboratories put a lot of effort into research and development to compose special cultures for a given product, *e.g.* butter, cheese and a large number of cultured milk products. Thus, the dairies can obtain cultures with selected properties for specific product characteristics such as texture, flavour and viscosity.

The dairies can buy the commercial cultures in various forms:

- **Deep-frozen, super concentrated** cultures in readily soluble form, for direct inoculation of the product
- **Freeze-dried, super concentrated** cultures in powder form, for direct inoculation of the product
- **Deep-frozen, concentrated** cultures for propagation of bulk starter
- **Freeze-dried, concentrated** cultures in powder form, for propagation of bulk starter
- **Liquid**, for propagation of mother culture (nowadays fairly rare)

The super concentrated cultures are known as DVS (Direct Vat Set) or DVI (Direct Vat Inoculation).

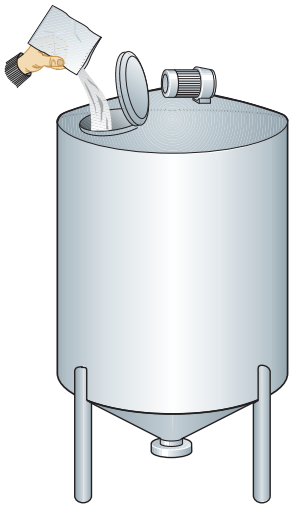


Fig. 10.2 *Bulk starter manufactured from freeze-dried or frozen commercial cultures.*

Stages of propagation

In recent years, concentrated cultures have generally been used for direct manufacture of a bulk starter, (see Figure 10.2), as well as for direct use in production. However, future handling of cultures will most probably be based on specially designed super concentrated cultures that can be used directly in production, without any further propagation at the dairy.

There are, however, some dairies that still propagate their own bulk starters in successive stages via a mother culture, as shown in Figure 10.3.

The process may involve two or more stages. Cultures in various stages of propagation are known by the following names:

- **Commercial culture**, master culture – the original culture that the dairy buys from the laboratory
- **Mother culture** – the culture prepared from master culture at the dairy. The mother culture is prepared daily and is, as the name indicates, the origin of all cultures made at the dairy
- **Intermediate culture** – an intermediate step in the manufacture of large volumes of bulk starter
- **Bulk starter** – the starter used in production

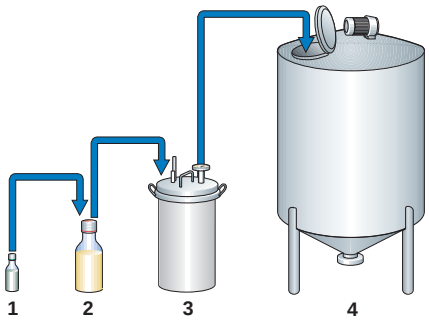


Fig. 10.3 *Steps in the manufacture of starters.*
1 *Commercial culture*
2 *Mother culture*
3 *Intermediate culture*
4 *Bulk starter*

Process technology

Starter manufacture is one of the most important and also one of the most difficult processes in the dairy. Production failures can result in heavy financial loss, as modern dairies process large quantities of milk.

Very careful attention must therefore be paid to the manufacturing technology and choice of process equipment. Starter production demands the very highest standard of hygiene. The risk of airborne infection by yeasts, mould fungi and bacteriophages must be reduced to an absolute minimum. Dairies that still propagate their own bulk starters should prepare their mother culture in a separate room supplied with filtered air at a pressure slightly above normal atmospheric pressure. The cleaning system for the equipment must also be carefully designed to prevent detergent and other CIP residues from coming into contact with the cultures and spoiling them.

Manufacture of intermediate culture and bulk starter can take place close to the point of production, or in the same room, where the mother culture is prepared.

The use of DVS cultures will reduce the risks for reinfection, as less

manual operations are required. This implies of course that the addition of the super concentrated culture can be done in a hygienic way.

Stages in the process

The process, presented in Figure 10.4, is essentially the same for production of mother culture, intermediate culture and bulk starter. It comprises the following stages:

- Heat treatment of the medium
- Cooling to inoculation temperature
- Inoculation
- Incubation
- Cooling of the finished culture
- Storage of the culture

Skim milk is the medium most frequently used for starter production, but reconstituted skim milk with 9 – 12 % dry matter (DM), made from top-grade skim milk powder, is another alternative.

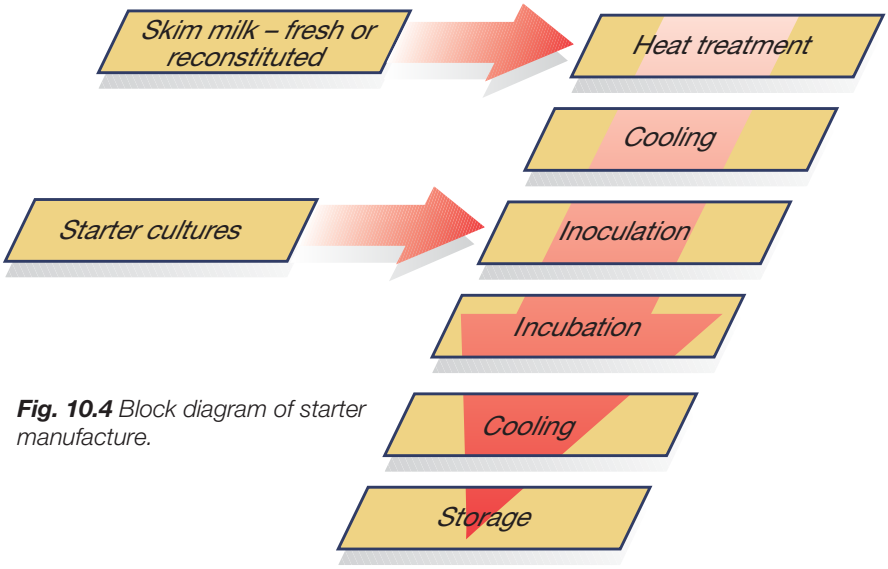


Fig. 10.4 *Block diagram of starter manufacture.*

The basic reason for using fresh or reconstituted skim milk is that anomalies in the flavour of the culture are much more readily apparent. Fresh milk from selected farmers is also used in some dairies.

A medium with constant composition, such as reconstituted antibiotic-free skim milk, is more reliable than ordinary skim milk.

The medium can also be modified by addition of growth factors such as Mn^{2+} (Manganese), *e.g.* 0,2 mg $MnSO_4$ per litre of culture, which is supposed to promote growth of *Leuc. mesenteroides* subsp. *cremoris.* Phage-inhibiting media (PIM) offer an alternative for production of single-strain or multi-strain starters. These media contain phosphates, citrates or other chelating agents which make Ca^{2+} (Calcium) insoluble. The reason for doing this is that most phages require Ca^{2+} for proliferation. Removing Ca^{2+} from the medium protects the lactic acid bacteria from being infected and thus avoids failure of starter activity. Skim milk powders with PIM are available in certain markets. Phage robust cultures are also available today.

Heat treatment of the medium

The first step in starter manufacture is heat treatment of the medium. It is heated to 90 – 95 °C and held at that temperature for 30 to 45 minutes. This heat treatment improves the properties of the medium through

- Destruction of bacteriophages
- Elimination of inhibitory substances
- Some decomposition of protein
- Expulsion of dissolved oxygen
- Destruction of original living micro-organisms

Cooling to inoculation temperature

After heat treatment, the medium is cooled to inoculation temperature, which differs according to the type of bacteria culture used. It is important that the temperatures recommended by the producer of the commercial culture, or empirically determined optimum temperatures, are maintained.

In propagation of multi-strain cultures, even small deviations from the proper incubation temperature may favour growth of one strain at the expense of the other(s), resulting in failure to obtain the desired typical characteristics of the end product. Figure 10.6 demonstrates what happens when typical yoghurt bacteria are incubated at a progressive temperature range.

Typical inoculation temperature ranges are 20 – 30 °C for mesophilic types of bacteria and 42 – 45 °C for thermophilic types.

Inoculation

For inoculation, a determined quantity of bacteria culture is transferred to the heat-treated medium after the temperature has been adjusted to the correct level. To prevent any deviations in the culture, it is most important that the starter dosage, the propagation temperature and the time are kept constant throughout all stages — mother culture, intermediate culture and bulk starter.

The amount of starter used can also affect the relative proportions of different bacteria which produce lactic acid and aroma substances. Variations in the amount of starter can consequently cause variations in the product. Each manufacturer must therefore determine which practical conditions suit his particular production process best. Figure 10.5 illustrates how the amount of starter used for inoculation affects the acidifying process in a culture. The curves represent dosages of 0,5 % and 2,5 % respectively. The inoculation temperature is 21 °C in both cases.

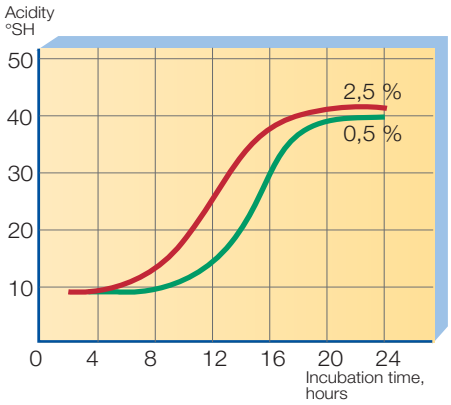


Fig. 10.5 *Acid development curves for inoculation with 0,5 % and 2,5 % of a mesophilic culture, incubating at 21 °C.*

Incubation

As soon as inoculation has taken place and the starter has been mixed into the medium, the bacteria begin to multiply – incubation begins. The incubation time is determined by the types of bacteria in the culture, the inoculation dosage, etc., and can vary from 3 to 20 hours. It is most important that the temperature is carefully controlled and that no contaminants are allowed to come into contact with the culture.

During incubation, the bacteria multiply rapidly and ferment lactose to lactic acid. A culture containing aroma-producing bacteria will also produce aromatic substances such as diacetyl, acetic and propionic acids, ketones and aldehydes of various kinds, alcohols, esters and fatty acids, as well as carbon dioxide.

The importance of a correct incubation temperature is illustrated in the graph in Figure 10.6, which refers to a yoghurt culture. The culture contains two strains of bacteria, *Str. thermophilus* and *Lb. bulgaricus*, which coexist in symbiosis and together produce the desired characteristics of the yoghurt, such as pH, flavour, aroma and consistency. Most yoghurt has a ratio of cocci to bacilli between 1:1 and 2:1. The bacilli must never be allowed to gain the upper hand, as the flavour will then be too acidic.

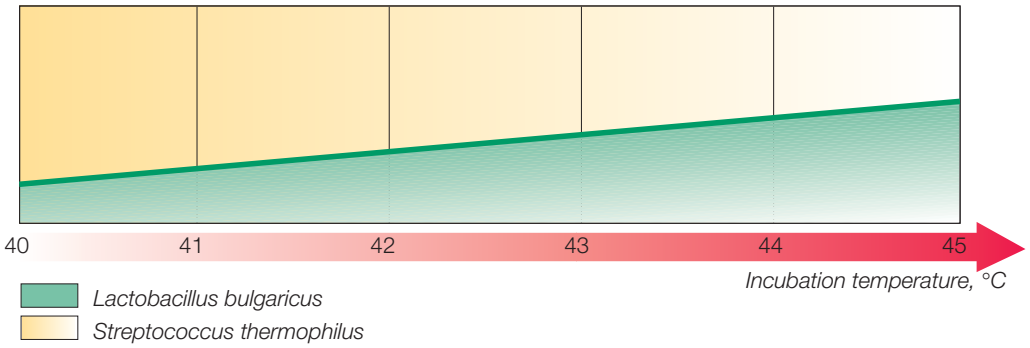


Fig. 10.6 *Effect of incubation temperature on relative counts of cocci and bacilli at constant dosage and incubation time.*

An example of growth of *Str. thermophilus and Lb.bulgarius* with resulting aroma formation is demonstrated in Figure 10.7.

In this context, it may be mentioned that acetaldehyde is recognised (Pette and Lolkema, 1950 c; Schultz and Hingst, 1954) as the principal flavour component in the flavour of yoghurt. A principal role in acetaldehyde production is attributed to *Lb. bulgaricus*, although various strains of this species show considerable differences. In the associated growth of *Str. thermophilus* and *Lb. bulgaricus*, the rate of acetaldehyde production is considerably increased compared to the single *Lb. bulgaricus* species (Bottazzi *& al*., 1973). Thus, the symbiotic relationships between these species favourably influence production of acetaldehyde in the manufacture of yoghurt. During production of yoghurt, formation of acetaldehyde does not become evident until a certain level of acidification, pH 5,0, has been reached. It attains a maximum at pH 4,2 and stabilises at pH 4,0 (A.Y. Tamime & R.K. Robinson, Yoghurt - science and technology).

The optimum aroma and flavour of yoghurt are usually obtained with an acetaldehyde content ranging between 10 and 25 ppm and a pH value of between 4,4 and 4,0.

One of the factors affecting the ratio of cocci to bacilli is the incubation temperature. At 40 °C, the ratio is about 4:1, while at 45 °C it is about 1:2 (see Figure 10.6). The optimum temperature for inoculation (and incubation) in yoghurt manufacture is thus 43 °C, to achieve a cocci-to-bacilli ratio of 1:1, with a rate of inoculum of 2,5 – 3 % and an incubation time of 2,5 – 3 hours.

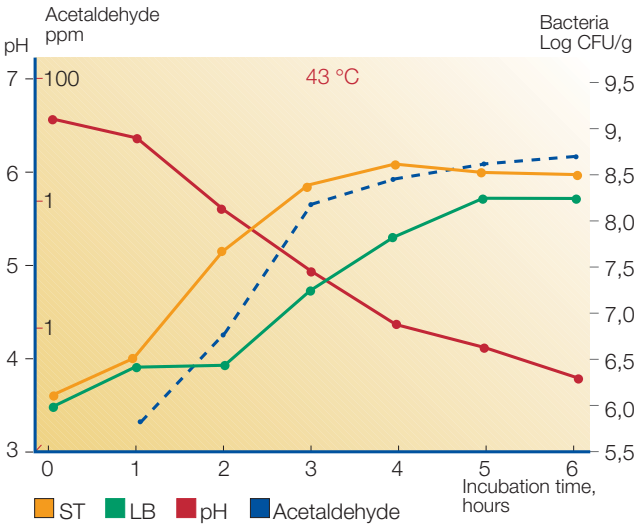


Fig. 10.7 *Growth of Str. thermophilus and Lb. bulgaricus with resulting aroma development, at 2,5 % inoculation.*
The curves are derived from information received from Chr. Hansen A/S.

During the incubation period, it is essential that the person responsible for production regularly checks acidity development and otherwise follows the routines found to give optimal results.

Careful handling of all starter cultures is a very important aspect of the processing of cultured milk products; this task should therefore always be given to skilled personnel.

Cooling the culture

Cooling is started at an empirically determined acidity to stop bacterial growth and thus to preserve the activity of the culture at a high level. Figure 10.8 demonstrates the course of events for an ordinary lactic-acid-forming culture inoculated with 1 % mother culture at 20 °C.

Cooling to 10 – 12 °C is often practised when the culture is going to be used within the next six hours. If the culture needs to be stored for an extended period, (more than six hours), it is advisable to cool it to about 5 °C.

In large-scale production, or production during more than one shift, it is more convenient to prepare starters at regular intervals of, say, four hours. This means that active cultures are available at all times, making it easier to follow the prescribed processing schedule and to assure consistently high quality in the end products.

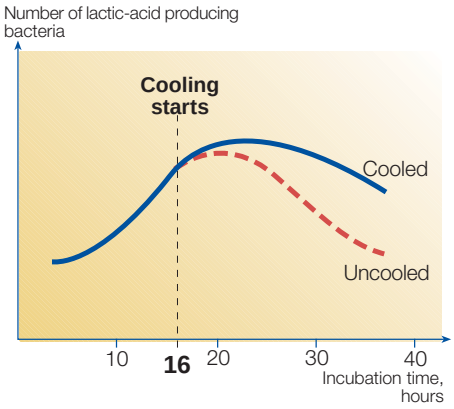


Fig. 10.8 *Growth of lactic-acid producing bacteria with and without cooling at the end of incubation.*

Preservation of starters

A great deal of research work has been done to find the best way to treat starters in order to preserve their activity during storage. One method is freezing. The lower the temperature, the better the cultures keep. Freezing with liquid nitrogen to –160 °C and storage below –45 °C preserves cultures very well.

Modern forms of starter cultures – concentrated, deep-frozen or freeze-dried (lyophilised) – can be stored for a considerable time provided that the manufacturers' recommendations are followed.

Table 10.2 shows the recommendations issued by Chr. Hansen A/S of Hørsholm, Denmark.

It should be noted that deep-frozen cultures require lower storage temperature than lyophilised cultures. Moreover, the former are supplied in

Table 10.2
Storage conditions and shelf lives of some concentrated cultures. (Chr. Hansen A/S, Denmark)

Type of culture	Storage	Shelf life, months
1 Freeze-dried DVS	Freezer below –18 °C	>24
2 Deep-frozen DVS	Freezer below –45 °C	>12
3 Freeze-dried REDI-SET	Freezer below –18 °C	>24
4 Deep-frozen REDI-SET	Freezer below –45 °C	>12

1 Freeze-dried, super concentrated culture (for direct inoculation of product)
2 Deep-frozen, super concentrated culture (for direct inoculation of product)
3 Freeze-dried, concentrated culture (for preparation of bulk starter)
4 Deep-fozen, concentrated culture (for preparation of bulk starter)

insulated polystyrene boxes packed with dry ice, and time in transit should not exceed 72 hours. The latter, on the other hand, can be transported at temperatures up to some 20 °C for up to 10 days without shortening the stated shelf life, provided that they are stored at the recommended temperature after arrival at the buyer's premises.

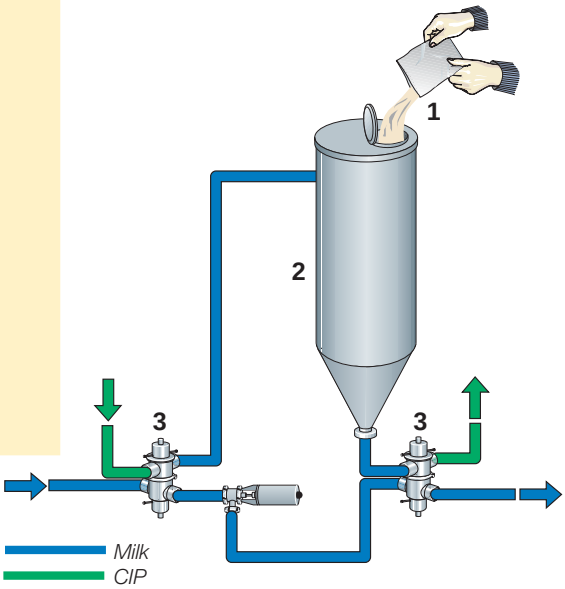


Fig. 10.9 *In-line incubation with freeze dried culture.*

1 *Culture bag*
2 *Mixing container*
3 *Mix-proof valves*

Inoculation of super concentrated cultures

Deep-frozen or freeze dried super concentrated culture should be Inoculated to the fermentation tanks or cheese vat in a hygienic way. There are some different methods for this type of inoculation.

In-line inoculation

The super concentrated culture can be inoculated direct in the milk stream prior to the incubation tank. A by-pass line including a small container is connected to the milk pipe illustrated in Figure 10.9. The container is loaded with freeze dried or deep frozen culture enough for inoculation of one incubation tank. When the operator decides to inoculate the tank during milk filling, he activates the valves for the by-pass line and the milk will bring in the culture to the tank.

After inoculation of the tank the by-pass line and container are cleaned and sterilsed. The container can then be loaded with culture again for inoculation of the second incubation tank. The small container can be built into a sterile air cabinet in order to minimize the reinfection risk.

Another solution for hygienic inoculation of culture is shown in Figure 10.10. Above the small container an inoculation box is connected. This box is fitted with sight glass on top, armholes equipped with rubber gloves and spraying and drain device for disinfectants. In the box each type of culture packages can be disinfected and opened under hygienic conditions. For opening the operator is working with *e.g.* a pair of scissors. Every handling in the box can be done via the two armholes with the gloves.

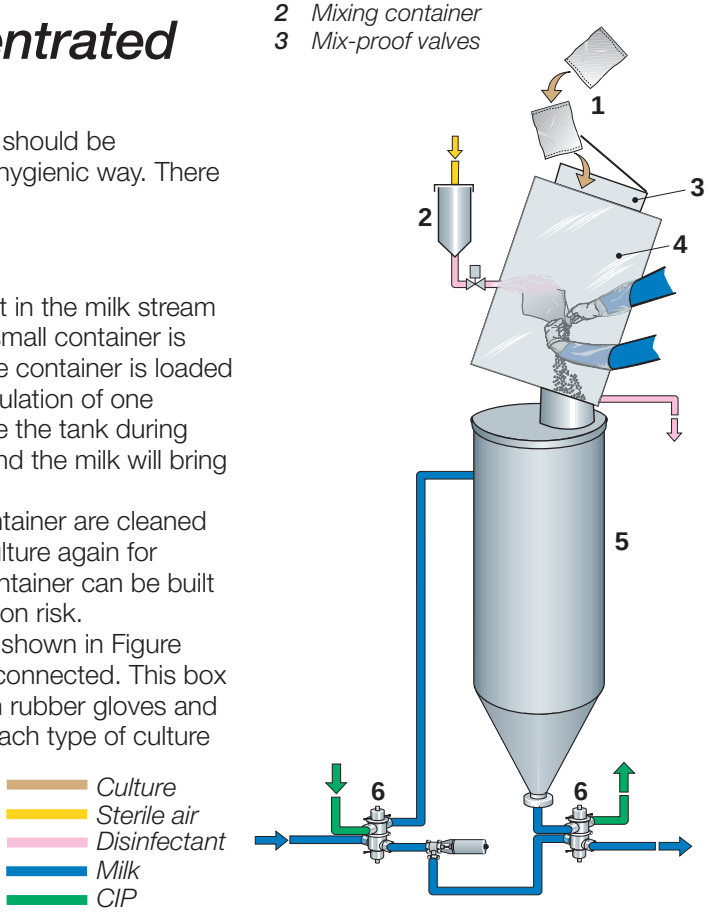


Fig. 10.10 *In-line incubation with freeze dried culture.*

1 *Culture bags*
2 *Disinfectant container*
3 *Sight glass*
4 *Inoculation box*
5 *Mixing container*
6 *Mix-proof valves*

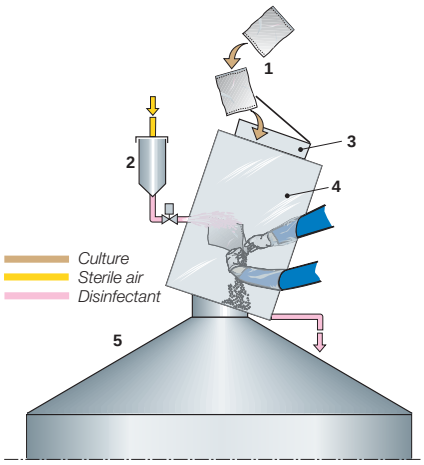


Fig. 10.11 *Hygienic inoculation with freeze dried culture.*

1 *Culture bags*
2 *Disinfectant container*
3 *Sight glass*
4 *Inoculation box*
5 *Incubation tank*

Tank inoculation

The inoculation box shown in Figure 10.11 can also be connected direct on the fermentation tank. The inoculation of the culture is done in the same way as described above for in-line inoculation.

Automatic Inoculation System (AISY)

In dairies or cheese factories, having a lot of tanks to be inoculated, a special inoculation system, AISY, has been developed by the culture company Chr. Hansen and Tetra Pak. The AISY system combines the advantages of the DVS cultures and an automatic inoculation system. The system is shown in Figure 10.12. DVS cultures are transferred into a buffer tank and diluted in cold water. After a few minutes of stirring, the diluted culture can be inoculated in-line to the milk stream or automatically pumped to fermentation tanks or cheese vats for inoculation of the milk.

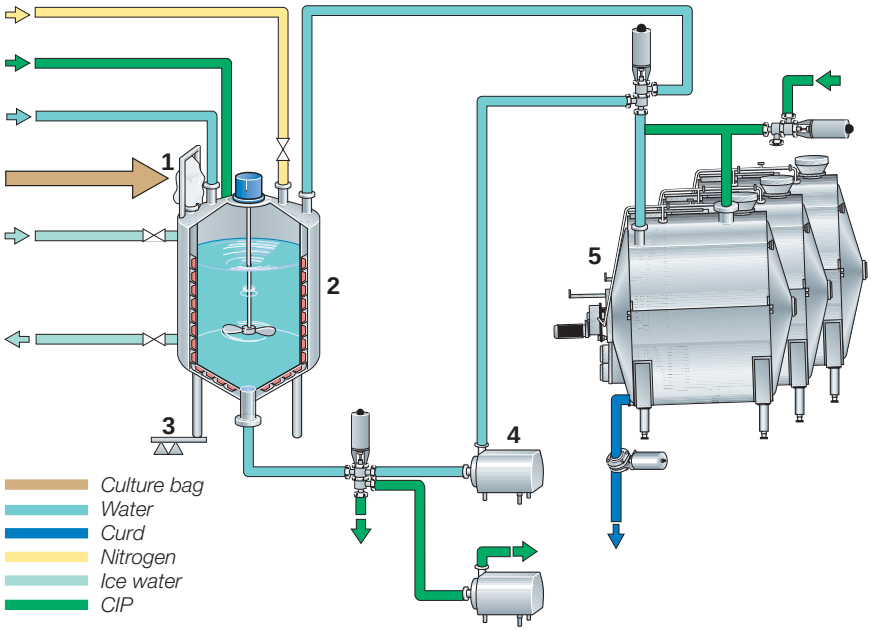


Fig. 10.12 *The inoculation system AISY, applied to cheesemaking tanks.*

1 *Culture bag*
2 *Mixing tank*
3 *Weighing cell*
4 *Feed pump*
5 *Cheesemaking tank*

Chapter 11

Cultured milk products

Milk products prepared by lactic acid fermentation (e.g. yoghurt) or a combination of this and yeast fermentation (e.g. Kefir) are called fermented or cultured milks. The term cultured will be used in this chapter.

Cultured milk is the collective name for products such as yoghurt, ymer, kefir, cultured buttermilk, filmjölk (Scandinavian sour milk), cultured cream and koumiss (a product based on mares' milk). The generic name of cultured milk is derived from the fact that the milk for the product is inoculated with a starter culture which converts part of the lactose to lactic acid. Carbon dioxide, acetic acid, diacetyl, acetaldehyde and several other

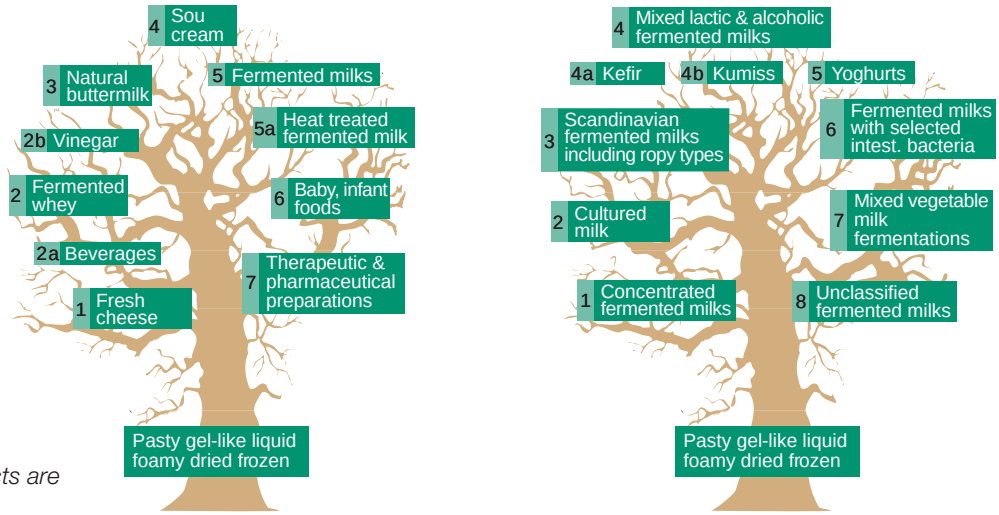


Fig. 11.1 *The cultured milk products are like branches on family trees.*

substances are formed in the conversion process, and these give the products their characteristic fresh taste and aroma. The micro-organisms used in the production of kefir and koumiss also produce ethyl alcohol.

Cultured milk originates from the Near East and subsequently became popular in Eastern and Central Europe. The first example of cultured milk was presumably produced accidentally by nomads. This milk turned sour and coagulated under the influence of certain micro-organisms. As luck would have it, the bacteria were of the harmless, acidifying type and were not toxin-producing organisms.

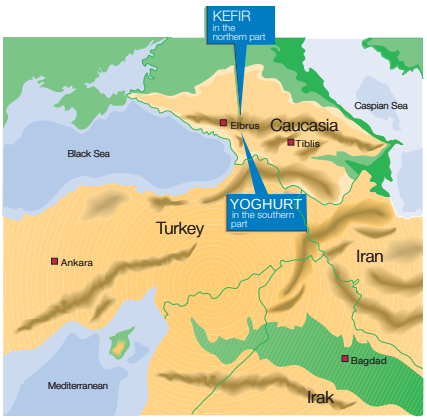


Fig. 11.2 *Mount Elbrus in the Caucasus mountain range is the birthplace of Kefir and Yoghurt.*

A legend

The legend tells that yoghurt and kefir were born on the slopes of Mount Elbrus in the Caucasus range by a miracle of Nature. Micro-organisms of various kinds happened to land in a pitcher of milk at the same time and at the right temperature, and found that they could live in symbiosis.

On the southern slope of Mount Elbrus, micro-organisms preferring relatively high temperatures, 40 – 45 °C, came together in a milk pitcher that probably belonged to a Turkish nomad, and the result was what the Turks called “Yogurut”. Some sources say that this name was introduced in the 8th Century and that it was changed in the 11th Century to its present form, *yoghurt.*

It is further claimed, however much truth there may be in the story, that yoghurt acts as a “preservative” against human ageing; that if you happen to meet a Cossack galloping along bareback in some Caucasian valley, he is likely to be 130 to 140 years old!

Kefir, the legend goes on to relate, was created on the northern slope by a mixture of micro-organisms that are not so fond of heat. They thrive best at 25 – 28 °C. The name kefir may be derived from the Turkish language. The first syllable of the name, *kef*, is Turkish and means pleasurable, which was probably the shepherd’s first comment on the flavour.

Kefir contains several different types of micro-organisms, among which yeast is most famous as it is capable of forming alcohol. The maximum alcohol content of kefir is about 0,8 %

General requirements for cultured milk production

The conversion of lactose into lactic acid has a preservative effect on milk. The low pH of cultured milk inhibits the growth of putrefactive bacteria and other detrimental organisms, thereby prolonging the shelf life of the product. On the other hand, acidified milk is a very favourable environment for yeasts

and moulds, which cause off-flavours if allowed to infect the products.

The digestive systems of some people lack the lactase enzyme. As a result, lactose is not broken down in the digestive process into simpler types of sugars. These people can consume only very small volumes of ordinary milk. They can, however, consume cultured milk, in which the lactose is already partly broken down by the bacterial enzymes.

In the production of cultured milk, the best possible growth conditions must be created for the starter culture. These are achieved by heat treatment of the milk to destroy any competing micro-organisms. In addition, the milk must be held at the optimum temperature for the relevant starter culture. When the best possible flavour and aroma have been achieved, the cultured milk must be cooled quickly, to stop the fermentation process. If the fermentation time is too long or too short, the flavour will be impaired and the consistency wrong.

In addition to flavour and aroma, correct appearance and consistency are important features. These are determined by the choice of pre-processing parameters. Adequate heat treatment and homogenisation of the milk, sometimes combined with methods to increase the MSNF content, as for milk intended for yoghurt, are essential " foundation-stones" for the construction of the coagulum during the incubation period.

Some of the most important cultured milk products are described below. The production technique for other cultured products has many similarities; the pre-treatment of the milk, for example, is almost the same. The process descriptions for other products therefore concentrate primarily on the production stages which differ from those in yoghurt production.

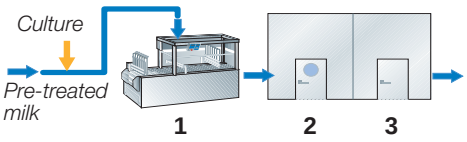


Fig. 11.3 *Set yoghurt.*
1 Cup filler
2 Incubation room
3 Rapid cooling room

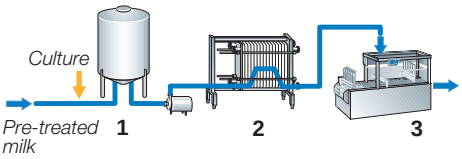


Fig. 11.4 *Stirred yoghurt.*
1 Incubation tank
2 Cooler
3 Cup filler

Yoghurt

Yoghurt is the best known of all cultured-milk products, and the most popular worldwide. Consumption of yoghurt is highest in countries around the Mediterranean, in Asia and in Central Europe.

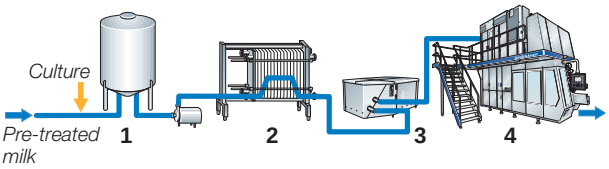


Fig. 11.5 *Drinking yoghurt.*
1 Incubation tank
2 Cooler
3 Homogeniser
4 Filling machine

The consistency, flavour and aroma vary from one district to another. In some areas, yoghurt is produced in the form of a highly viscous liquid, whereas in other countries it is in the form of a softer gel. Yoghurt is also produced in frozen form as a dessert, or as a drink. The flavour and aroma of yoghurt differ from those of other acidified products, and the volatile aromatic substances include small quantities of acetic acid and acetaldehyde.

Yoghurt is typically classified as follows:

- **Set type;** incubated and cooled in the package, Figure 11.3
- **Stirred type;** incubated in tanks and cooled before packing, Figure 11.4
- **Drinking type;** similar to stirred type, but the coagulum is broken down to a liquid before being packed, Figure 11.5
- **Frozen type;** incubated in tanks and frozen like ice cream, Figure 11.6
- **Concentrated;** incubated in tanks, concentrated and cooled before being packed. This type is sometimes called *strained yoghurt*, sometimes *labneh or labaneh,* Figure 11.7

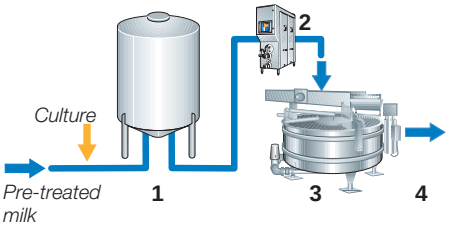


Fig. 11.6 *Frozen yoghurt.*
1 Incubation tank
2 Contiuous freezer
3 Ice cream bar freezer
4 To hardening tunnel

Flavoured yoghurt

Yoghurt with various flavouring and aroma additives is very popular, although the trend back towards natural yoghurt is clearly discernible in some markets. Common additives are fruit and berries in syrup, processed or as a purée. The proportion of fruit is usually about 15 %, of which about 50 % is sugar.

The fruit is mixed with the yoghurt before or in conjunction with packing; it can also be placed in the bottom of the pack, before the latter is filled with yoghurt. Alternatively, the fruit can be separately packed in a twin cup integrated with the basic cup.

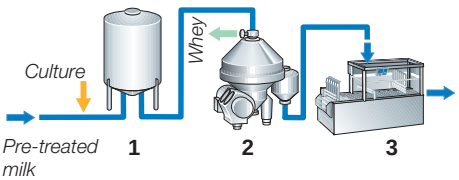


Fig. 11.7 *Concentrated yoghurt.*
1 Incubation tank
2 Separator
3 Cup filler

Sometimes yoghurt is also flavoured with vanilla, honey, coffee essences, etc. Colouring and sugar in the form of sucrose, glucose or aspartame (a sugar-free diet sweetener) are often added together, with the flavouring.

When necessary stabilisers may also be added to modify the consistency.

The additives increase the DM (Dry Matter) content of the finished yoghurt; a typical composition for fruit yoghurt is:

• Fat	0,5	–	3,0	%
• Lactose	3,0	–	4,5	%
• Milk solids non fat (MSNF)	11,0	–	13,0	%
• Stabiliser (if used)	0,3	–	0,5	%
• Fruit	12,0	–	18,0	%

Factors affecting the quality of yoghurt

Milk for yoghurt production must:
- Have a low bacteria count
- Not contain enzymes and chemical substances which may slow down the development of the yoghurt culture
- Not contain antibiotics and bacteriophages

Numerous factors must be carefully controlled during the manufacturing process in order to produce a high-quality yoghurt with the required flavour, aroma, viscosity, consistency, appearance, freedom from whey separation and long shelf life:

- Choice of milk
- Milk standardisation
- Milk additives
- Deaeration
- Homogenisation
- Heat treatment
- Choice of culture
- Culture preparation
- Plant design

Pre-treatment of the milk thus includes a number of measures which are all very important to the quality of the end product. The mechanical treatment to which yoghurt is subjected during production also affects its quality.

Choice of milk

Milk intended for yoghurt production must be of the highest bacteriological quality. It must have a low content of bacteria and substances which may impede the development of the yoghurt culture. The milk must not contain antibiotics, bacteriophages, residues of CIP solution or sterilising agents. The dairy should therefore obtain the milk for yoghurt production from selected, approved producers. The milk must be very carefully analysed at the dairy.

Milk standardisation

The fat and dry solids contents of the milk are normally standardised according to the FAO/WHO code and principles described below.

Fat

Yoghurt may have a fat content of 0 to 10 %. A fat content of 0,5 – 3,5 % is, however, the most typical. Yoghurt can be classified in the following groups according to the FAO/WHO code and principles:

• Yoghurt	Min. milk fat		3	%
• Partially skimmed yoghurt	Max. milk fat	<	3	%
	Min. milk fat	>	0,5	%
• Skimmed yoghurt	Max. milk fat		0,5	%

Dry matter (DM) content

According to the FAO/WHO code and principles the minimum MSNF is

8,2 %. An increase in the total DM content, particularly the proportion of casein and whey proteins, will result in a firmer yoghurt coagulum, and the tendency to whey separation will then be reduced.

The most common ways to standardise the DM content are:

- Evaporation (10 – 20 % of the milk volume is normally evaporated)
- Addition of skim milk- or protein powder, usually 1 – 3 %
- Addition of milk concentrate
- Addition of UF retentate from skim milk

Milk additives

Sugar or sweeteners and stabilisers may be used as additives in yoghurt production.

Sugar or sweetener

The disaccharide sucrose, or a monosaccharide such as glucose, can be added alone, or in conjunction with fruit addition. To satisfy dieters, among whom diabetics are an important category, sweeteners should be used. A sweetener has no nutritive value, but tastes very sweet, even in very small doses. Sweeteners cannot be used as preservatives for sweetened condensed milk.

The fruit in question usually contains about 50 % sugar or a corresponding amount of sweetener, so the required sweetness can normally be supplied by adding 12 to 18 % fruit.

It should be noted that adding too much sugar (more than 10 %) to the milk before the inoculation/incubation period has an adverse effect on fermentation conditions, because it changes the osmotic pressure of the milk.

Stabilisers

Hydrophilic colloids can bind water. They increase the viscosity and help to prevent whey separation in yoghurt. The type of stabiliser and the rate at which it should be added must be determined experimentally by each manufacturer. The product may acquire a rubbery, hard consistency if the wrong stabiliser, or an excess of stabiliser, is used.

Correctly produced, natural yoghurt requires no addition of stabilisers, as a firm, fine gel with a high viscosity will occur naturally. Stabilisers can be used in fruit yoghurts and must be used in pasteurised and whipped yoghurt. Stabilisers (0,1 – 0,5 %) such as gelatin, pectin, starch and agar-agar are the most commonly used substances.

Table 11.1

Influence of homogenisation and heat treatment on the viscosity of a cultured milk (Swedish filmjölk).

Pressure at 60 °C	Viscosity = flow-off time in seconds at 20 °C	
MPa	Ordinary past. milk (72 °C/20 sec)	Highly heated milk (95 °C/5 min)
0	5,7	15,0
2,5	5,6	14,6
5,0	7,1	15,8
7,5	8,0	19,0
10,0	8,9	22,1
15,0	10,4	28,7
20,0	11,2	30,2
30,0	13,8	32,7

By courtesy of the Swedish Dairies Association (SMR), dept. C-lab., Malmö/Lund, Sweden.

Deaeration

The air content of the milk used to make cultured milk products should be as low as possible. However, some admixture of air is unavoidable if the MSNF content is increased by addition of milk powder. If this is done, the milk should be deaerated as part of the subsequent processing.

When the MSNF content is increased by evaporation, deaeration is a part of that process.

The advantages gained through deaeration are:

- Improved working conditions for the homogeniser
- Less risk of fouling during heat treatment
- Improved stability and viscosity of the yoghurt
- Removal of volatile off-flavours (deodorisation)
- Shortened fermentation time

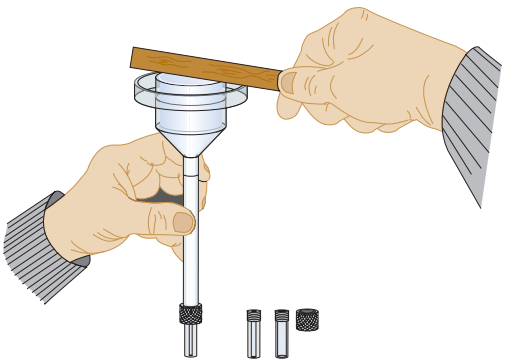


Fig 11.8 *The SMR viscosimeter.*

Homogenisation

The main motives for homogenising milk intended for cultured milk production are to prevent creaming during the incubation period and to assure uniform distribution of the milk fat.

Homogenisation also improves the stability and consistency of cultured milks, even those with low fat contents.

Homogenisation with subsequent heating at high temperature, usually 90 – 95 °C for about five minutes, has a very good influence on the viscosity.

Table 11.1 illustrates the dual influence on the viscosity of a cultured milk (Swedish filmjölk; 3 % fat and about 8,7 % MSNF) when it is pre-treated at various homogenisation pressures and heating temperatures. The homogenisation temperature is 60 °C in all cases.

The viscosity is measured with a simple viscosimeter (SMR viscosimeter) at 20 °C, and the result is given in seconds for 100 ml of product to pass a nozzle of a certain diameter. Figure 11.8 shows a viscosimeter provided with exchangeable nozzles, each of a diameter of 2 – 6 mm.

The viscosity of full-stream homogenised milk runs parallel to the homogenisation pressure, regardless of whether it has been subjected to ordinary heat treatment or not. The table also shows that high-temperature heat treatment makes the product more viscous.

As a general recommendation, the milk should be homogenised at 20 – 25 MPa and 65 – 70 °C to obtain optimum physical properties in the product. Homogenisation is frequently utilised even in production of low-fat cultured milks.

The question of single- or double-stage homogenisation is sometimes discussed. Generally speaking, this is a matter of the design of the homogenisation system and of the homogeniser head in particular.

Heat treatment

The milk is heat treated before being inoculated with the starter in order to:

- Improve the properties of the milk as a substrate for the bacteria culture
- Ensure that the coagulum of the finished yoghurt will be firm
- Reduce the risk of whey separation in the end product

Optimum results are achieved by heat treatment at 90 – 95 °C and a holding time of about five minutes. That temperature/time combination denatures about 70 – 80 % of the whey proteins (99 % of the β-lactoglobulin). In particular, the β-lactoglobulin, which is the principal whey protein, interacts with the κ-casein, thereby helping to give the yoghurt a stable body.

UHT treatment and sterilisation of milk intended for culturing do not, however, have the same favourable influence on viscosity, for reasons not yet fully understood.

Choice of culture

Culture laboratories now use advanced techniques to produce customised yoghurt cultures to satisfy specific flavour and viscosity requirements. Some

examples of end-product properties that can be achieved are:

- High viscosity with low acetaldehyde content and a fairly high final pH
- Low viscosity and medium acetaldehyde content, suitable for drinking yoghurt, etc.

Culture preparation

The handling of the starter for production of yoghurt (and all other cultured milks) demands maximum precision and hygiene. The basic methods of traditional culture preparation and new trends are discussed in Chapter 10, *Cultures and starter manufacture*.

However, it should once again be emphasised that concentrated, frozen and freeze-dried cultures are now available on the market and are being more and more widely used. This saves the need to invest in a separate culture room – a saving which must be offset against subscription costs and the cost of providing adequate storage facilities for the cultures. The greatest advantage, however, is that direct inoculation of milk with a concentrated culture minimises the risk of contamination, as the intermediate stages of propagation are excluded.

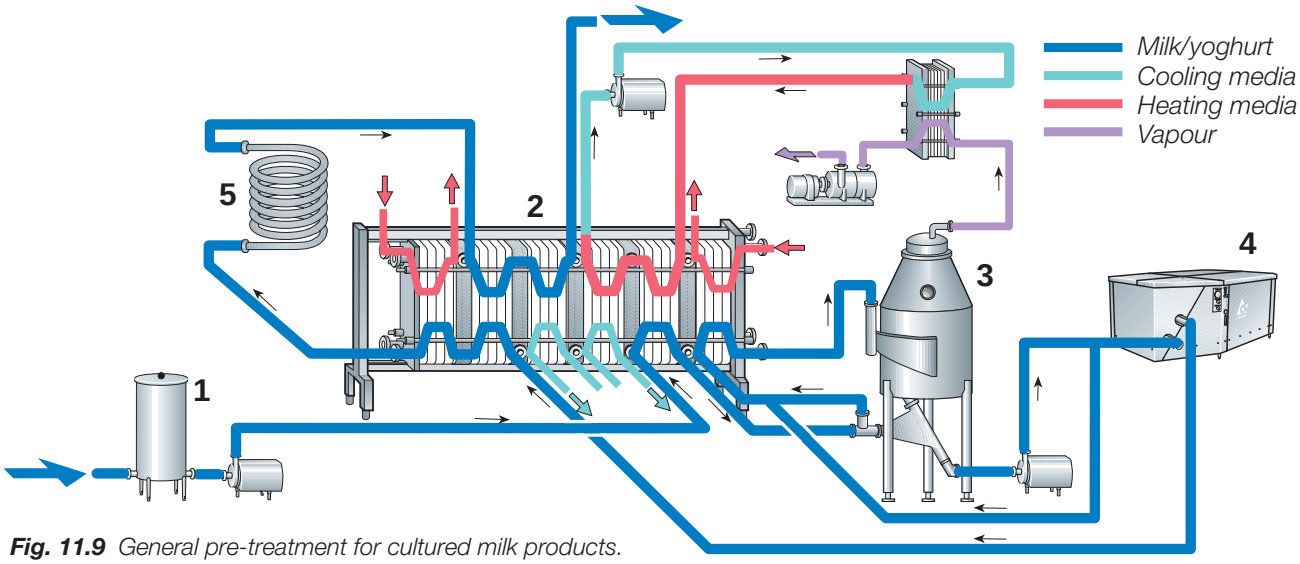


Fig. 11.9 *General pre-treatment for cultured milk products.*

1 *Balance tank*
2 *Plate heat exchanger*
3 *Evaporator*
4 *Homogeniser*
5 *Holding tube*

Plant design

The coagulum formed during fermentation is sensitive to mechanical treatment. This makes the selection and dimensioning of pipes, valves, pumps, coolers, etc. very important as well as the plant lay-out.

Production lines

The pre-treatment of the milk is the same, regardless of whether set or stirred yoghurt is to be produced. It includes standardisation of the fat and DM contents, heat treatment and homogenisation.

Figure 11.9 shows an example of the design of a process line for yoghurt production. The milk storage tanks, from which the milk is pumped to the process line, are not shown in the figure. It is assumed that the milk has been standardised to the required fat content before entering the line. In the example, standardisation of the DM content takes place in an evaporator in the process line. If recombined milk is used, or if the DM content is adjusted by addition of milk powder, the equipment used is similar to that described in Chapter 18, *Recombined milk*. The milk, increased in DM by milk powder addition, should preferably be deaerated to reduce the risk of whey separation in the final yoghurt.

Any additives, such as stabilisers, vitamins, etc., can be metered into the milk before the heat treatment. From the balance tank (1), the milk is pumped to the heat exchanger (2), where it is pre-heated regeneratively to about 70 °C and then heated to 90 °C in the second section.

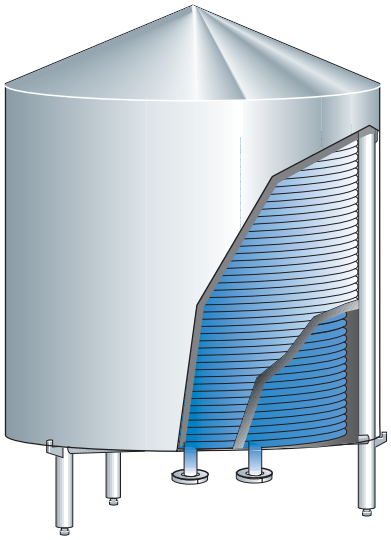


Fig. 11.10 *Tubular holding section.*

Evaporation

From the heat exchanger, the hot milk flows to a vacuum vessel (3), where 10 – 20 % of the water in the milk is evaporated. The proportion depends on the required DM content of the milk. If 10 – 20 % of the milk is evaporated, the total DM content will be increased by about 1,5 – 3,0 %. The degree of evaporation is controlled by the temperature of the milk at the inlet to the vacuum vessel, the circulation rate through the vessel and the vacuum in the vessel. Some of the water evaporated from the product is used to pre-heat the incoming milk. This improves the thermal economy of the plant.

A certain amount of milk must be recirculated through the vacuum vessel in order to obtain the desired degree of evaporation. Each passage evaporates 3 – 4 % water, so to obtain 15 % evaporation, the recirculated flow must be four to five times the capacity of the pasteuriser. The milk temperature drops from 90 °C to about 70 °C during evaporation.

The evaporation equipment described is designed for capacities up to about 8 000 l/h. Larger evaporators of the falling-film type are used for higher capacities – up to 30 000 l/h.

Evaporation of 10 – 20 % of the milk volume increases the DM content in the milk by 1,5 – 3,0 %.

Homogenisation

After evaporation the milk continues to homogeniser (4) and is homogenised at a pressure of approx. 20 – 25 MPa (200 – 250 bar).

Pasteurisation

The homogenised milk flows back through the regenerative section to the pasteurisation section of heat exchanger (2) and is reheated to 90 – 95 °C. The milk then flows to a holding section dimensioned for a holding time of five minutes.

Other time/temperature programs can be used. The tubular holding section shown in Figure 11.10 offers a holding efficiency of 90 – 95 %, which is appreciably higher than when one holding tank is integrated in a continuously operated plant.

Cooling the milk

After pasteurisation, the milk is cooled, first in the regenerative section and then with water, to the desired inoculation temperature (typically 40 – 45 °C). Alternatively, if set yoghurt is to be produced, and the pre-treatment capacity does not match the packing capacity, the milk is cooled to a temperature below 10 °C (preferably 5 °C).

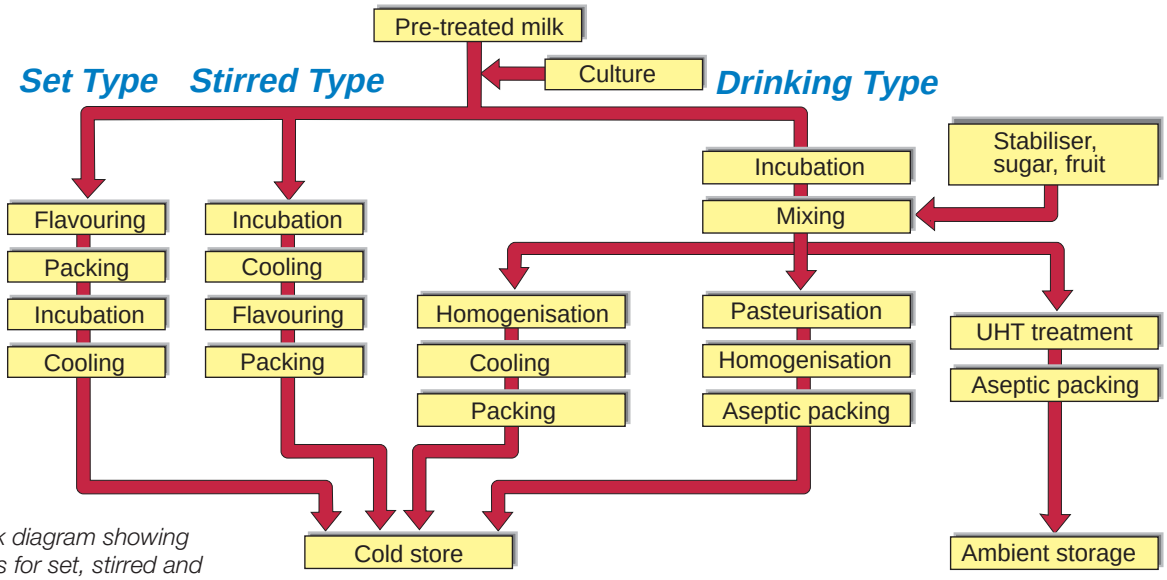


Fig. 11.11 *Block diagram showing production steps for set, stirred and drinking yoghurt.*

Design of the yoghurt plant

When the yoghurt milk has been pre-treated and cooled to inoculation temperature, the procedure for further treatment depends on whether set, stirred, drink, frozen or concentrated yoghurt is to be produced. The block diagrams in Figures 11.11 – 11.13 show the various production stages for each process.

The quality of the yoghurt in terms of texture and flavour depends on the design of the plant, the treatment of the milk and the treatment of the product. Modern plants are designed to satisfy demands for high production, continuous treatment and high quality. The level of automation varies, and complete CIP systems are normally integrated into the plants.

The level of automation is usually high in large-scale production. Excessive mechanical treatment of the product must be avoided, as it may cause product defects such as thin consistency and whey separation. The total amount of treatment to which the product is subjected must be taken into consideration when the plant is designed. The choice of suitable equipment and the matching and optimisation of the plant are consequently a question of achieving a suitable balance between cost and quality.

In modern plants, stirred and set types of yoghurt are often produced concurrently. In the production of set yoghurt, the product flow is continuously controlled from the point where the milk is accepted in the pre-treatment section to the packaging of the product. In the production of stirred yoghurt, the pre-treatment of the milk is continuous up to the point at which it is pumped into the incubation tanks, to which the bulk starter is added. The continuity is interrupted by the time-consuming incubation, which must be free from any physical disturbance.

Stirred yoghurt

A typical plant for continuous production of a relatively large volume of stirred yoghurt is shown in Figure 11.14.

The pre-treated milk, cooled to incubation temperature, is pumped to the incubation tanks (7) in succession. Simultaneously, a pre-set volume of bulk starter (6) or a DVS culture is dosed into the milk stream. After a tank

Frozen yoghurt

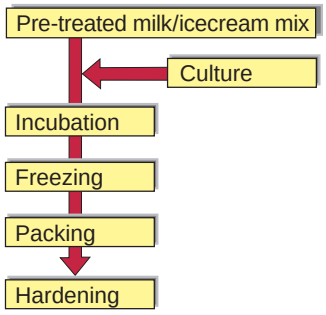


Fig. 11.12 *Block diagram showing production steps for frozen yoghurt.*

Concentrated yoghurt

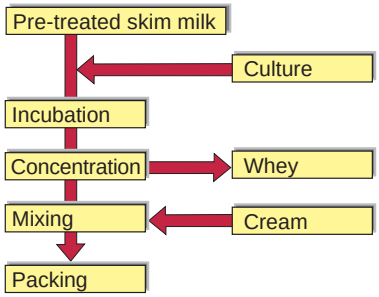


Fig. 11.13 *Block diagram showing production steps for concentrated yoghurt.*

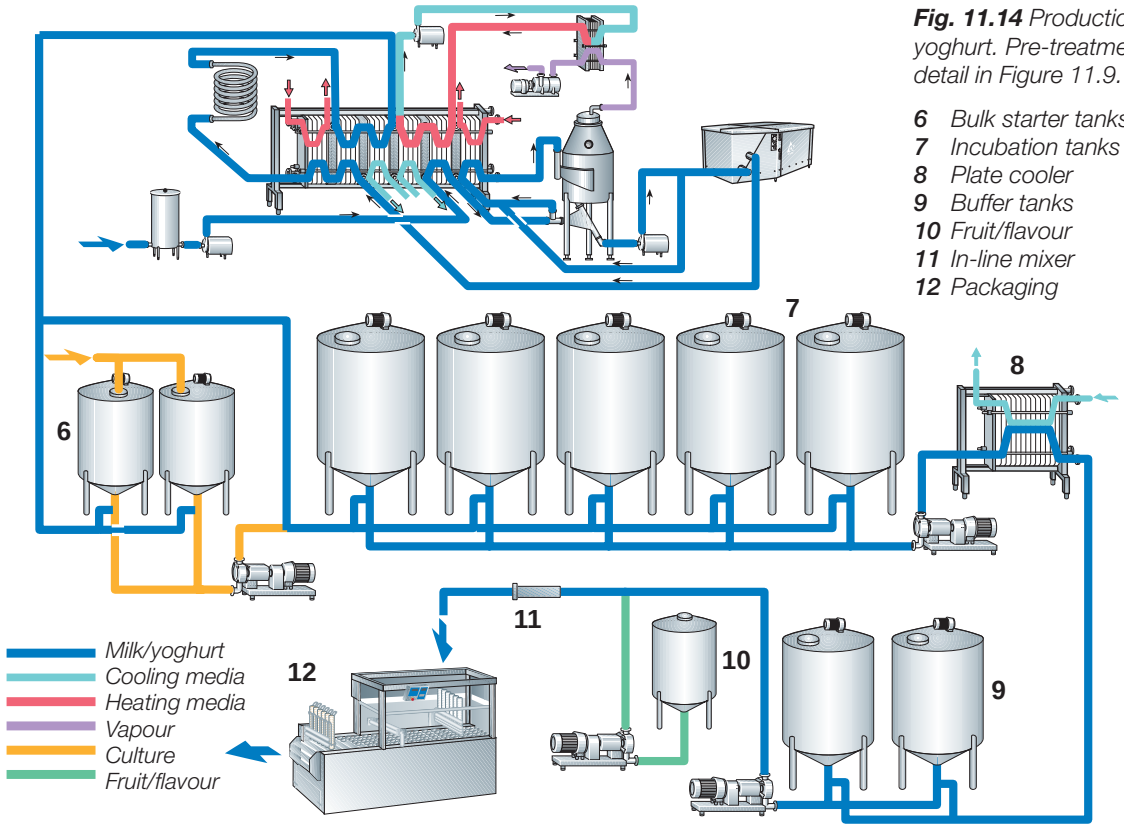


Fig. 11.14 *Production line for stirred yoghurt. Pre-treatment is shown in detail in Figure 11.9.*

6 *Bulk starter tanks*
7 *Incubation tanks*
8 *Plate cooler*
9 *Buffer tanks*
10 *Fruit/flavour*
11 *In-line mixer*
12 *Packaging*

has been filled, agitation commences and continues for a short time to assure uniform distribution of the starter culture.

The incubation tanks are insulated, to ensure that the temperature remains constant during the incubation period. The tanks can be fitted with pH meters to check the development of acidity.

In typical production of stirred yoghurt the incubation period is 3 to 3,5 hours at 42 – 43 °C, when the ordinary type of bulk starter (2,5 – 3 % inoculum) is utilised and 4 to 5 hours when e.g. a freeze-dried DVS culture (about 0,02 % Inoculum) is used. The relative short incubation time indicates that the multiplication (generation) period is fast. For typical yoghurt bacteria, the generation period is some 20 – 30 minutes. To attain optimum quality conditions, cooling to 15 – 22 °C (from 42 – 43 °C) should be accomplished within 30 minutes after the ideal pH-value has been reached, to stop further developement of bacteria.

Cooling the coagulum

In the final stage of incubation, when the required pH (normally about 4,2 – 4,5) has been reached, the yoghurt must be cooled to 15 – 22 °C. This temporarily stops any further increase in acidity. At the same time, the coagulum must be subjected to gentle mechanical treatment, so that the final product will have the correct consistency. In some cases a strainer or a structurising valve is built into the line, prior to the cooler, in order to optimize the yoghurt structure and appearance.

Cooling takes place in a plate heat exchanger (8) with special platage. This ensures gentle mechanical treatment of the product. The capacities of pump and cooler are often dimensioned to empty a tank in 20 – 30 minutes in order to maintain a uniform product quality. If cultures with other fermentation curves are utilised, which may have an influence on the incubation time, the cooling time should be adapted in view of that. You have *e.g.* yoghurt cultures having a flat fermentation curve at about pH 4,4 giving a mild taste to the yoghurt. For such yoghurt a longer cooling time can be accepted.

The cooled yoghurt is pumped to buffer tanks (9) before being routed to the filling machine(s) (12).

Flavouring

After cooling to 15 – 22 °C, the yoghurt is ready for packing. Fruit and various flavourings can be added (10) to the yoghurt when it is transferred from the buffer tanks to the filling machines. This is done continuously with a variable-speed metering pump, which feeds the ingredients into the yoghurt in the fruit-blending unit shown in Figure 11.15. The blending unit is static and hygienically designed to guarantee that the fruit is thoroughly mixed into the yoghurt. The fruit metering pump and the yoghurt feed pump operate synchronously.

The fruit additives can be:

- Sweet; normally 50 – 55 % ordinary sugar content
- Natural; unsweetened

The fruit should be as homogeneous as possible. A thickener in the form of pectin can be added. The proportion of pectin is hardly ever higher than 0,5 %, which corresponds to 0,05 – 0,005 % of pectin in the end product.

Proper heat treatment is an extremely important stage in the pre-treatment of fruit additives. Scraped-surface heat exchangers, or tanks with scraper units, can be used for adequate pasteurisation of whole berries or fruit with solid particles. The temperature program should be such that all vegetative micro-organisms are inactivated without impairing the taste and texture of the fruit. Continuous production, with rapid heating and cooling, is therefore important with regard to product quality and economic aspects.

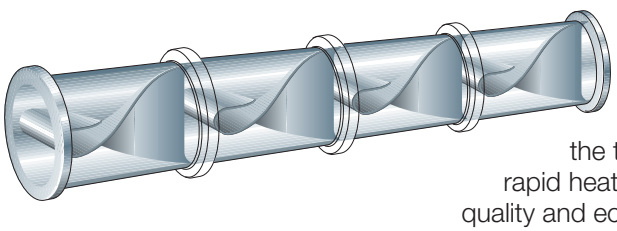


Fig. 11.15 *In-line fruit mixer built into the pipe.*

Following the heat treatment, it is important that the fruit is packed in sterilised containers under aseptic conditions. Deterioration of cultured milk products is too often caused by reinfection from inadequately treated fruit.

Packing

Various types of filling machines are used to pack yoghurt. The sizes of the packages vary from one market to another. In general, the total packing capacity should match the capacity of the pasteurisation plant, so as to obtain optimal running conditions for the plant as a whole.

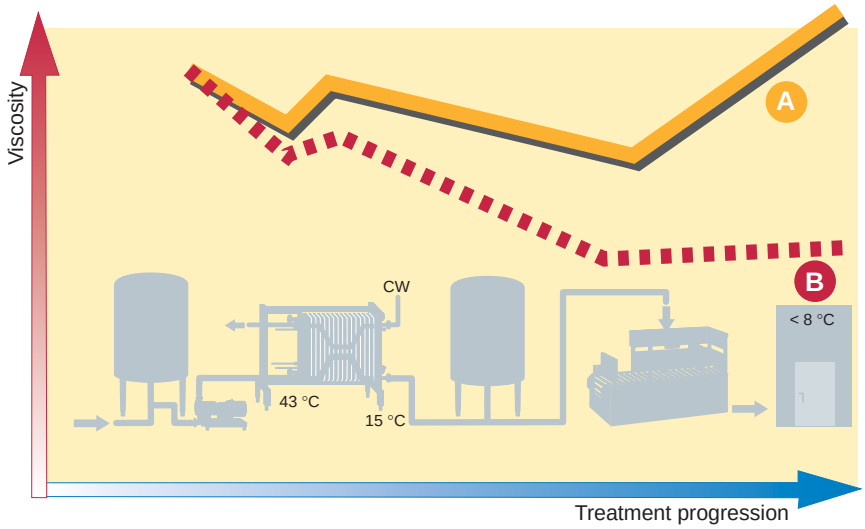


Fig.11.16 *Viscosity development of stirred yoghurt during cooling, packing and cold storage.*
A *Optimum plant design* ***B*** *Badly designed plant*

Plant design

As mentioned, the plant design is one important factor affecting the quality of the yoghurt and, of course, all other cultured products.
Figure 11.16 shows curves for the development of viscosity in stirred yoghurt from the moment it leaves the incubation tank, via packing and up to about 24 hours in cold storage.

Curve A represents the ideal situation, when all operations that influence the structure and viscosity are optimised.

It is inevitable that the product will become less viscous while being treated, since yoghurt belongs to the class of products with thixotropic flow behaviour. However, if all parameters and equipment are fully optimised, the viscosity will be almost fully regenerated, and the likelihood of syneresis occuring will be minimised.

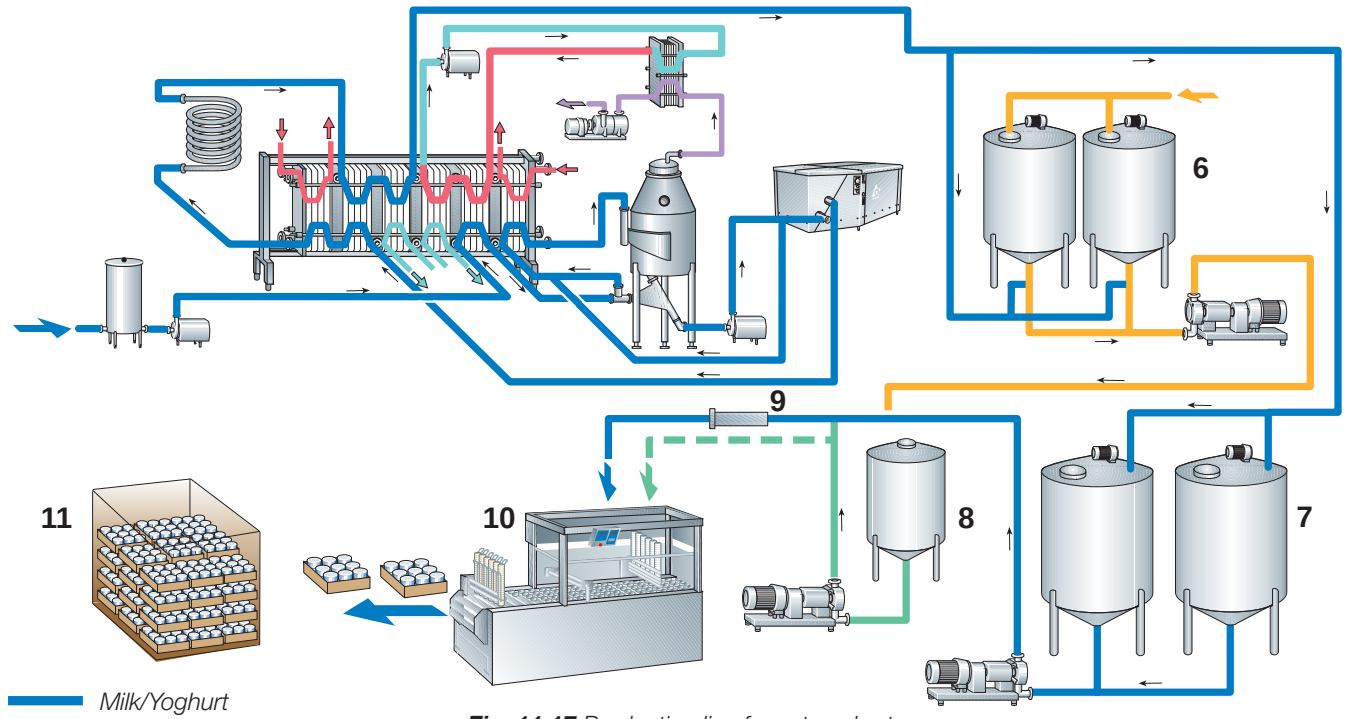
Curve B shows the result when the product has been maltreated en route from the incubation tank up to packaging and cold storage. If the yoghurt coagulum has been treated too hard, the viscosity will be too low, resulting in a liquid product with high risk for whey separation.

Set yoghurt

In order to reduce installation costs, it is possible to use the same plant for production of both stirred and set yoghurt. The pre-treatment of the milk intended for either product is identical up to cooling down to incubation temperature. Figure 11.17 shows how this kind of production can be arranged. The starter is metered into the stream of milk as it is pumped from an intermediate storage tank to the filling machine.

Flavouring/Packaging

Flavouring can be continuously metered into the milk stream prior to the filling machine. If fruit or additives with particles should be added these have to be dosed into the packages or cups first before they are filled with inoculated milk. It is, however, important to remember that additives with low pH have a negative influence on fermentation.



Milk/Yoghurt
Cooling media
Heating media
Vapour
Culture
Fruit/flavour
Optional fruit line

Pre-treatment is shown in detail in Figure 11.9

6 *Bulk starter tanks*
7 *Buffer tanks*
8 *Flavour/fruit tank*
9 *Mixer*
10 *Packaging*
11 *Incubation*

Fig. 11.17 *Production line for set yoghurt.*

An alternative production system

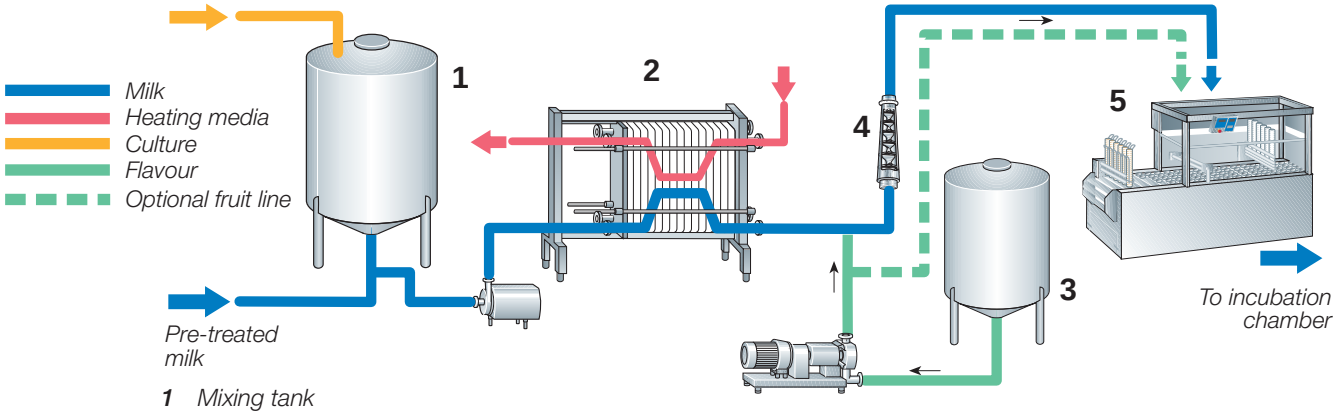
Another and more frequently used system for production of *set yoghurt* is illustrated in Figure 11.18. This system offers flexibility in production planning, because it is not necessary to match pre-treatment capacity to packing capacity.

The milk, pre-treated in the same way as for stirred yoghurt, is cooled to a temperature of less than 10 °C, preferably to 5 °C, and pumped into one, two or more tanks (1). Following inoculation and thorough stirring, the milk is ready to be heated in-line (2) to incubation temperature, before being packed (4) in containers.

Bulk starter culture can also be added in-line, prior to heating to incubation temperature.

Flavouring/Packing

The previously described flavouring (3) and packing process is also applicable to the alternative system.



Milk
Heating media
Culture
Flavour
Optional fruit line

Pre-treated milk

1 *Mixing tank*
2 *Plate heat exchanger*
3 *Flavour/fruit tank*
4 *Static mixer*
5 *Packaging*

Fig. 11.18 *Final steps in set yoghurt production; this system gives greater flexibility in production planning.*

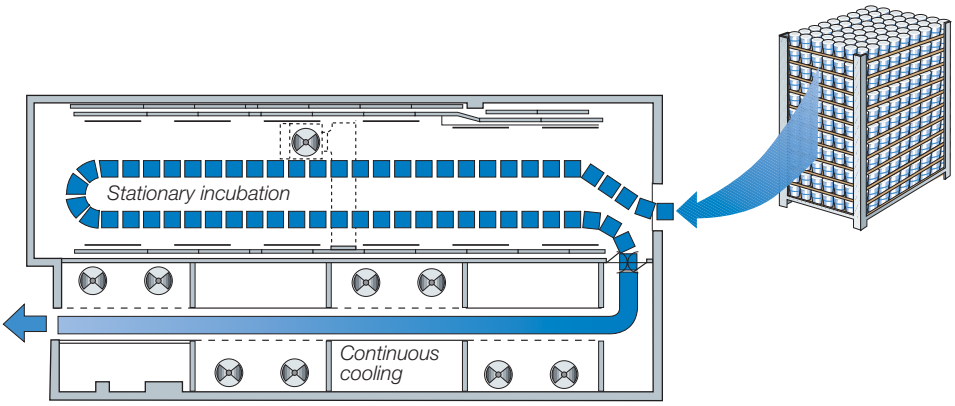


Fig. 11.19 *Combined incubation room and cooling tunnel.*

Incubation and cooling

Following packaging the packages, after crating and palletising, are trucked into either of two systems for incubation and subsequent cooling, viz.:

- Combined incubation/cooling chamber, when the pallets are stationary through both incubation and cooling, before being trucked to the final chilling store.
- An incubation room able to accommodate a large number of filled pallets. After adequate incubation, the pallets are trucked to a conveyor passing through the cooling sections enclosed in a tunnel. This system offers continuous cooling and is illustrated in Figure 11.19.

Incubation

The filled packages/containers are placed in crates of open design, and at a certain distance from each other, so that the circulating warm/cold air for the incubation and cooling room or chamber can reach every individual container. The crates are normally stacked on pallets, which are then trucked into the incubation room. This ensures uniform quality, provided that the temperature is accurately controlled.

Cooling

When the empirically determined optimum pH (typically 4.5) is reached, it is time to start cooling. The normal target temperature is 18 – 20 °C; it is important to stop further growth quickly, which means that a temperature of about 35 °C should be reached within 30 minutes, and 18 – 20 °C after another 30 – 40 minutes.

Final cooling, normally down to 5 °C, takes place in the cool store, where the products are held to await distribution.

Cooling efficiency depends on the size of the individual package, the design and material of the packages, the depth of the crate stack, the spacing between individual packages in each crate, and the design of the crates.

At a depth of one metre, for example, the free cross section of the stack for air-flow must be not less than 25 % of the total area. A smaller, free cross-section will require higher airflows, which also means higher energy consumption.

The pallets (crates) are stationary during incubation. They are placed in the incubation room/chamber in such a way as to facilitate first in/first out handling. In a typical incubation period of 3 – 3,5 hours, it is very important that the product is not exposed to any mechanical disturbance during the last 2 – 2,5 hours, when it is most sensitive to the risk of whey separation.

The cooling capacity should be adequate to achieve the above-mentioned temperature program. As a guide, the total cooling time is about 65 – 70 minutes for small packages (0,175 – 0,2 kg sizes) and about 80 – 90 minutes for large packages (0,5 kg size).

Eventually, regardless of the type of incubation/cooling chamber, the set yoghurt is cooled to about 5 °C in the chill store.

A *Homogenised and cooled*
Shelf life: 2 – 3 weeks, refrigerated
B *Homogenised, pasteurised, aseptically packed*
Shelf life: 1 – 2 months, refrigerated
C *Homogenised, UHT treated, aseptically packed*
Shelf life: several months at room temperature

1 *Mixing tank*
2 *Homogeniser*
3 *Plate heat exchanger*
4 *Buffer tank*
5 *Aseptic filling*
6 *UHT treatment*
7 *Filling*

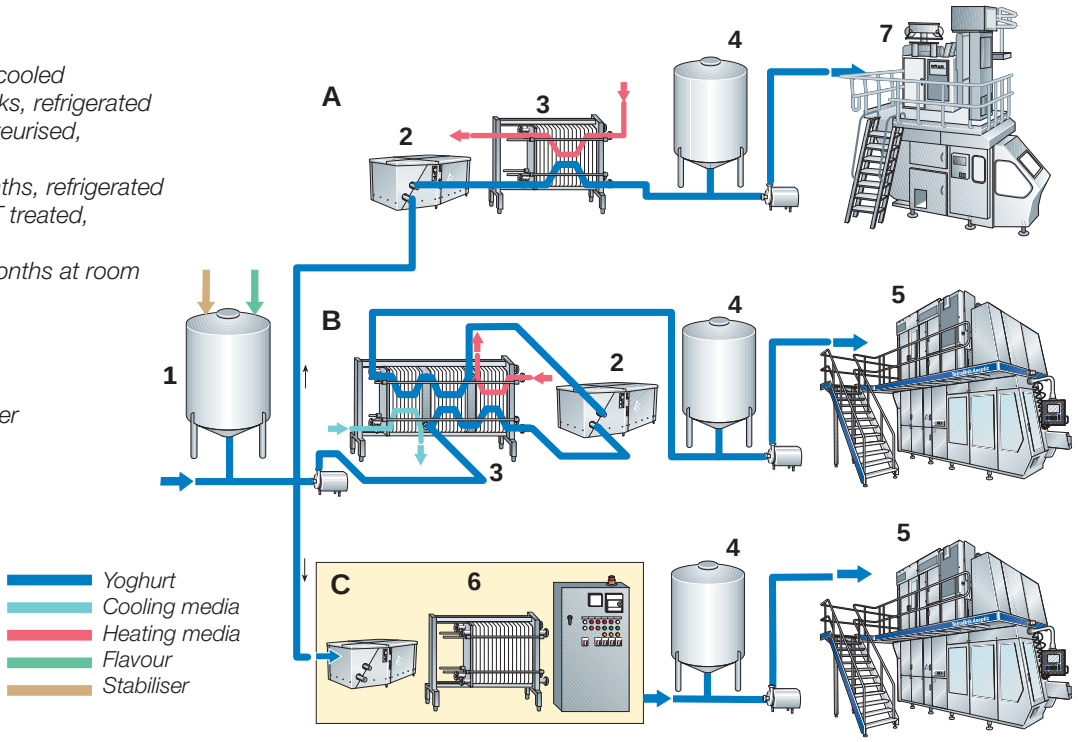


Fig. 11.20 *Process alternatives for drinking yoghurt.*

Drinking yoghurt

A low-viscosity drinkable yoghurt, normally with a low fat content, is popular in many countries. The composition can be the same as for stirred yoghurt but can also be reduced in DM by *e.g.* dilution with water.

The yoghurt intended for production of drinking yoghurt is produced in the ordinary way with fermentation in tanks. In order to get a stable drinking yoghurt without sedimentation, a stabiliser (commonly pectin) should be added to the product before cooling. The yoghurt with added pectin is homogenised prior to cooling to get optimal stabilising effect.

Long-life yoghurt

Shelf life of a fermented milk product is dependent on a number of visible and organoleptical factors like whey separation, changes in viscosity, structure, colour, acidity and aroma. It is of course also dependent on bacteriological defects.

Because of the tendency towards larger and more centralised production units, the markets are becoming geographically larger and transport distances longer. In some cases, the sales district may be so large that only one delivery per week is economically justifiable. This, in turn, necessitates methods which extend the shelf life of the product beyond normal. In some countries, it is difficult to maintain the integrity of the cooling chain. Therefore, there is a demand for a sterilised yoghurt that can be stored at room temperature.

The shelf life of cultured milk products can be extended in two ways:

- Production and packing under aseptic conditions
- Heat treatment of the finished product, either immediately before packing or in the package.

It should be noted that if the micro-organisms in the yoghurt are killed by heating, the product is then, according to the definition in many countries, not allowed to be called yoghurt.

Production under aseptic conditions

In aseptic production, measures are taken to prevent the yoghurt from being infected by yeast and moulds. These micro-organisms would destroy the product, as they can survive and multiply in an acid environment and can cause off-flavours and whey separation. The prime measure is thorough

cleaning and sterilisation of all surfaces in contact with the product. The special feature of aseptic production is, however, that it takes place under aseptic conditions; using aseptic tanks which are permanently pressurised with sterile air, remote-controlled aseptic valves, aseptic metering devices for fruit and aseptic filling machines. Infection by airborne micro-organisms can then be prevented. This extends the shelf life of the product significantly.

Clean Room production conditions

Hygenic conditions must be maintained in all food industries, not only in the equipment coming in direct contact with the product, but also in the premises where production takes place.

A system based on filtration of the air through absolute filters, as shown in Figure 11.21, can be installed to clean the air in processing rooms, tanks, etc. to a high standard of purity. In this system one main filter and a fan are serving four tanks. An alternative is that each tank is equipped with its own filter. An absolute filter is capable of trapping particles larger than 0,3 microns and will capture most micro-organisms, as the average diameters of cocci, bacilli and fungi (yeasts and moulds) are 0,9; 0,25 – 10 and 3 – 15 microns respectively.

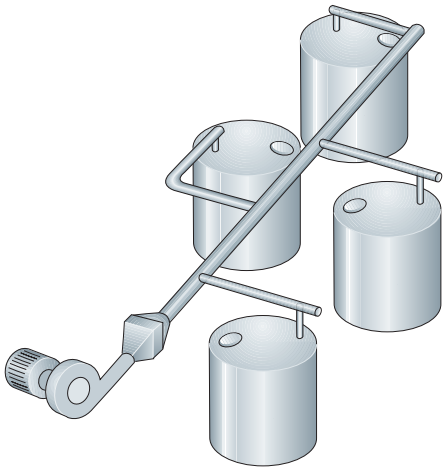


Fig. 11.21 *An air filtration system for the "Clean Room" concept.*

Each system or tank to be supplied with air is equipped with an extra pipe for the air and a safety system to prevent the tank from imploding as a result of the vacuum created by the drop in temperature after cleaning.

Air velocity is approx. 0,5 m/s and the tank is positively pressurised to approx. 5 – 10 m water gauge, corresponding to about 0,05 – 0,1 bar.

The filter is normally placed in the process room, with the result that all contaminant particles in the ambient air will eventually be filtered out, thereby creating Clean Room conditions.

Similar systems are used in bacteriological laboratories, hospital operating theatres and pharmaceutical factories.

The "clean room" conditions will improve the production safety and minimise the risk for re-infection. However, the most critical areas for re-infection are at fruit addition and packaging. It is therefore of high importance that contamination can be excluded during these operations and that a high hygienic filling machine is used.

Production and packing under aseptic or high hygiene conditions are important prerequisites to improve shelf life and production safety of a yoghurt for cold distrubution.

Heat treatment of yoghurt

Heat treatment of yoghurt is another method to prolong its shelf life. Dependent on temperature used the product can be stored chilled or ambient. The heat treatment temperature is dependent on a number of factors as: milk quality, milk pre-treatment, pH of yoghurt, fruit quality, particle size, stabiliser type and microbiological requirements of the final product.

All types of yoghurt (stirred, set, drinking and concentrated) can be prolonged in shelf life by heating.

Heat treatment of yoghurt prolongs its shelf life by:

- Inactivating the starter bacteria and their enzymes
- Inactivating contaminants such as yeasts and moulds

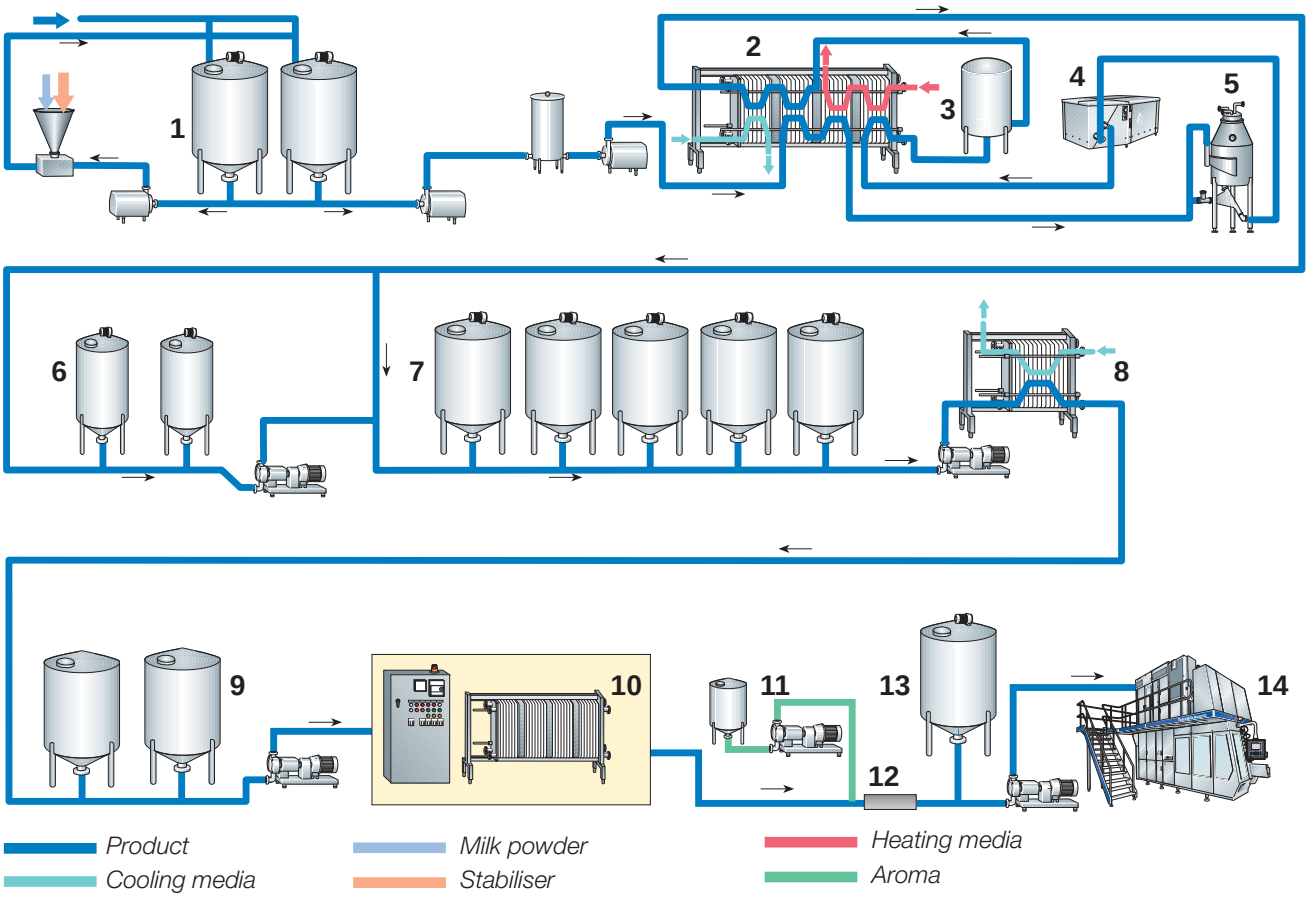
Long-life stirred yoghurt

In production of stirred yoghurt, the coagulum from the incubation tanks can be heat-treated at 60 – 70 °C for a few seconds. This heat-treatment will minimise post-acidification giving the yoghurt a shelf life in cold store of 1 – 2 months if packed under high hygenic conditions.

If the aim is to produce a yoghurt for ambient storage the heating temperature should be in the range of 75 – 110 °C for a few seconds and dependent on factors as milk quality, milk treatment, pH of yoghurt etc.

Different processing solutions can be used.

- Yoghurt and fruit mixed. Heat-treated and cooled together.



1 *Mixing tanks*
2 *Pasteuriser*
3 *Holding tube*
4 *Homogeniser*
5 *Dearator*
6 *Culture preparation*
7 *Incubation tanks*
8 *Plate cooler*
9 *Buffer tanks*
10 *UHT treatment*
11 *Aseptic fruit addition*
12 *Static mixer*
13 *Aseptic buffer tank*
14 *Aseptic packaging*

Fig. 11.22 *Long-life stirred yoghurt production.*

- Yoghurt and fruit heat-treated and cooled separately prior to mixing.
- Yoghurt heat-treated and cooled. Fruit heat-treated and mixed warm to the cold yoghurt.

The product should, in all cases, be packed in an aseptic filling machine to prevent reinfection, as in Figure 11.22.

Viscosity reduction and whey separation are associated with heating of fermented milk. These problems can however be avoided by using stabilisers. The stabilisers will re-build the reological properties of the product.

Long-life set yoghurt

Set yoghurt can be heat-treated at *e.g.* 60 – 70 °C for 30 minutes in the packages, in special pasteurising chambers. The time is of course dependent on the size and shape of the package. Also for set type a stabiliser should be used.

Long-life drinking yoghurt

Drinking yoghurt may have the same composition as ordinary milk. It is however popular in many countries to dilute the product with water. In certain regions drinking yoghurt can be a mixture of 30 % yoghurt and 70 % water.

Pectin is a common stabiliser used to avoid sedimentation and whey separation as well as to improve the viscosity and the mouth feel of the product after heating. The pectin is preferably added as a water solution to the yoghurt prior to the final heat treatment. In order to get the optimal stabilising effect of the pectin, mechanical treatment *e.g.* homogenisation, should take place. Other additives to the drinking yoghurt are sugar and fruit concentrate or aroma.

Heating to a temperature of about 75 °C and above kills all the virulent micro-organisms in the yoghurt.

In many countries yoghurt is defined as a product in which the microbiological flora is kept alive right up to the instant of consumption. This means that heat treatment of the end product is prohibited. In some countries the use of stabilisers is forbidden by law or is only permitted to a limited extent.

A process line for heat treatment of yoghurt can also be used for production of pudding and desserts.

Frozen yoghurt

Frozen yoghurt can be manufactured in two ways. Either, the yoghurt is mixed with an ice cream mix or an ice cream mix is fermented, before further processing.

In the latter alternative a conventional line for production of stirred type yoghurt can be used. About 4 – 6 % starter is dosed into the pipeline as the mix is pumped to the incubation tanks. The incubation time of the yoghurt mix is appreciably longer than for normal yoghurt production. This is because the yoghurt mix contains much more carbohydrates than normal yoghurt. An incubation time of 7 – 8 hours is required at a saccharose content of 10 – 12 % to attain the characteristic acidity of yoghurt, which occurs at pH 4,5. For both alternatives further processing will be identical with the conventional production of ice cream. (See Chapter 19. *Ice cream*.)

Frozen yoghurt can be divided into soft-served and hard-frozen types. The mix intended for soft-served yoghurt differs somewhat from that of the hard-frozen type. Typical recipes are:

Ingredients, %	Soft-served	Hard-frozen
Fat	4	6
Sugar	11 – 14	12 – 15
MSNF	10 – 11	12
Stabiliser, emulsifier	0,85	0,85
Water	71	66

Concentrated yoghurt

In concentrated yoghurt the DM of the product is increased after fermentation. Whey is drained off from the coagulum.The concentration of the yoghurt is done either by a nozzle separator or by ultrafiltration.

The manufacturing principles are identical with the manufacturing of quarg, see Chapter 14. The only difference is the type of cultures used. Concentrated yoghurt is known under names such as 'strained-type' yoghurt and Labneh.

Kefir

Kefir is one of the oldest cultured milk products. It originates from the Caucasus region. The raw material is milk from goats, sheep or cows. Kefir is produced in many countries, although the largest quantity – an annual total of about five litres per capita – is consumed in Russia.

Kefir should be viscous and homogenous, and have a shiny surface. The taste should be fresh and acid, with a slight flavour of yeast. The pH of the product is usually 4,3 – 4,4.

A special culture, known as Kefir grain, is used for the production of Kefir. The grains consist of proteins, polysaccharides and a mixture of several types of micro-organisms, such as yeasts and aroma and lactic-acid forming bacteria. The yeasts represent about 5 – 10 % of the total microflora.

The Kefir grains are yellowish in colour and about the size of a cauliflower florette, *i.e.* about 15 to 20 mm in diameter. The shape of the grains is

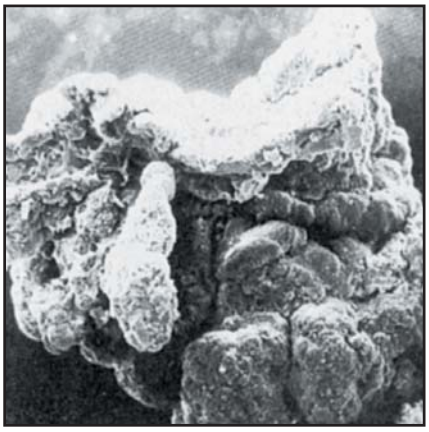


Fig. 11.23 *Kefir grain.*

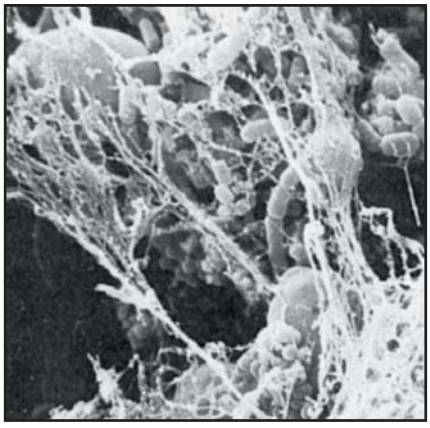


Fig. 11.24 *The micro-organisms in cultured products often live in symbiosis with each other.*

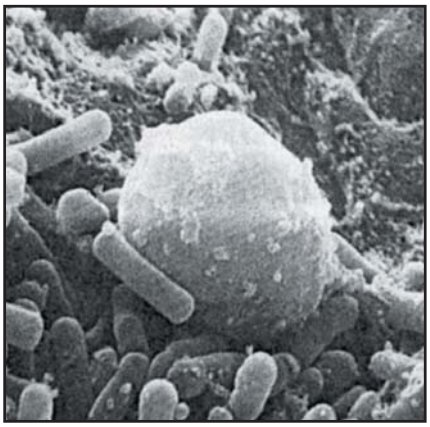


Fig. 11.25 *Yeast and lactic acid at the surface of a kefir grain, seen through an electron photomicroscope.*

irregular, as seen in Figure 11.23. They are insoluble in water and in most solvents. When steeped in milk, the grains swell and become white. During the fermentation process, the lactic-acid bacteria produce lactic acid, whereas the lactose-fermenting yeast cells produce alcohol and carbon dioxide. Some breakdown of protein also takes place in the yeast metabolism, from which Kefir derives its special yeast aroma. The contents of lactic acid, alcohol and carbon dioxide are controlled by the incubation temperature during production.

A The yoghurt bacteria *Lactobacillus bulgaricus* (rod shaped) and *Streptococcus thermophilus* (spherical) live together.

B Yeast and lactic acid bacteria at the surface of a kefir grain. The "ball" in the centre is a yeast fungus and the rods are different kinds of bacteria.

C The centre of a kefir grain. Yeast and bacteria are united by a network consisting mainly of proteins and polysaccharides.

Depending on local conditions and requirements, the equipment and process variables may differ significantly from one manufacturer to another.

Raw materials

As with other cultured milk products, the quality of the raw material is of major importance. It must not contain any antibiotics or other bactericidal agents. The raw material for kefir manufacture can be milk from goats, sheep or cows.

Production of starter culture

Kefir culture is normally produced from milk of various fat contents, but skim milk and reconstituted skim milk, too, have lately been utilised for better control of the microbial composition of the kefir grains.

As in propagation of starter cultures for other cultured milk products, the milk substrate must be thoroughly heat-treated to inactivate bacteriophages.

Production takes place in two stages. The basic reason for this is that kefir grains are bulky and awkward to handle, whereas relatively small volumes of mother culture are easier to control. Figure 11.26 shows the various process stages.

In the first stage, the pre-treated substrate is inoculated with active kefir grains. Incubation takes place at about 23 °C, and the proportion of grains is about 5 % (1 part grains to 20 parts substrate) or 3,5 % (1 part grains to 30 parts milk). The incubation time is about 20 hours; as the grains tend to sink to the bottom, intermittent stirring for about 10 – 15 minutes every 2 – 5 hours is recommended. When the desired pH value (say 4,5) has been reached, the culture is stirred before the grains are strained off from the mother culture, now also called filtrate. The strainer has holes with a diameter of 3 – 4 mm.

The grains are washed in the strainer with boiled and cooled water (sometimes skim milk). They can then be reused to incubate a new batch of mother culture. The microbial population grows by about 10 % per week during incubation, so the grains must be weighed and the surplus removed, before the batch is reused.

In the second stage, the filtrate can be

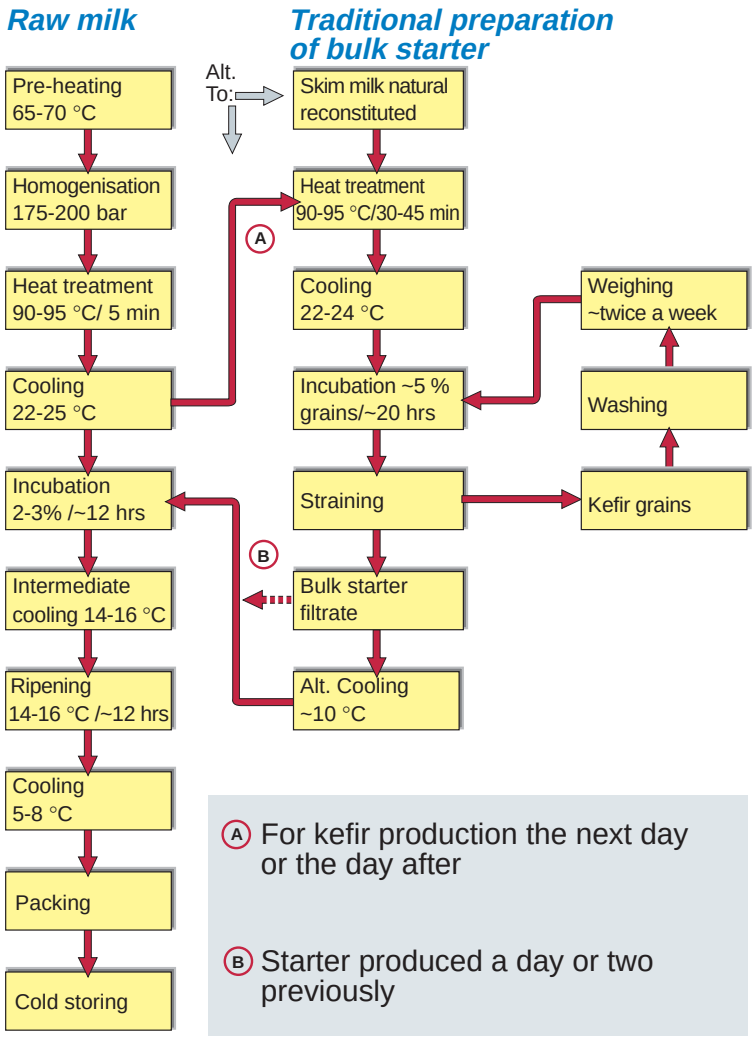


Fig. 11.26 *Typical block diagram of the various process stages in kefir production.*

cooled to about 10 °C if it has to be stored for a few hours before being used. Alternatively, if large quantities of kefir are going to be produced, the filtrate can be immediately inoculated into the pre-treated milk intended as the substrate for the bulk starter. The dosage is 3 – 5 % of the volume of the substrate. After incubation at 23 °C for about 20 hours, the bulk starter is ready for inoculation into the kefir milk.

Production of kefir

The process stages are much the same as for most cultured milk products. The following combination is typical for traditional production of kefir:

- Fat standardisation (not always practised)
- Homogenisation
- Pasteurisation and cooling to incubation temperature
- Inoculation with starter culture (here also called 'filtrate')
- Incubation in two stages (this, together with the specific culture, is characteristic of kefir)
- Cooling
- Packing

Fat standardisation

The fat content of kefir is reported to vary between 0,5 % and 6 %. The raw milk is often used with its original fat content. However, fat contents of 2,5 to 3,5 % are frequently specified.

Homogenisation

Following fat standardisation, if any, the milk is homogenised at about 65 – 70 °C and 17,5 – 20 MPa (175 – 200 bar).

Heat treatment

The heat treatment program is the same as for yoghurt and most cultured milks: 90 – 95 °C for five minutes.

Inoculation

Following heat treatment, the milk is cooled to inoculation temperature, usually about 23 °C, after which 2 – 3 % starter is added.

Incubation

The incubation period is normally divided into two stages, acidulation and ripening.

The acidulation stage

The acidulation stage lasts until a pH value of 4,5 is reached or, expressed as acidity, until 85 – 100 °Th (35 – 40 °SH) has developed. This takes about 12 hours. The coagulum is then stirred and pre-cooled while still in the tank. At a temperature of 14 – 16 °C, cooling is stopped and agitation discontinued.

The ripening stage

The typical slightly yeasty flavour starts to develop during the following 12 – 14 hours. Final cooling commences when the acidity has reached 110 – 120 °Th (pH about 4,4).

Cooling

The product is cooled rapidly to 5 – 8 °C in a heat exchanger. This stops any further reduction in pH. It is of vital importance that the product is treated gently when cooled and during subsequent packing. Mechanical agitation in pumps, pipes and filling machines must therefore be minimised. Air entrainment must also be avoided, as air increases the risk of syneresis in the product.

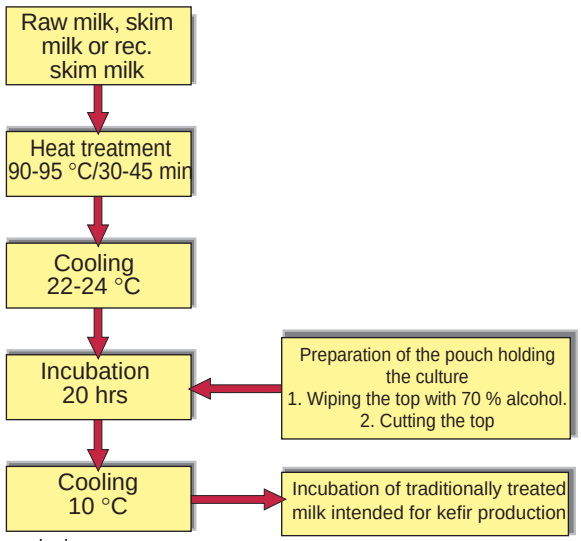


Fig. 11.27 *Bulk starter preparation for kefir with a freeze-dried culture.*

Alternative kefir production

As previously mentioned, the traditional method of preparing bulk starter for kefir manufacture is laborious. This, in combination with the complexity of the microflora, sometimes leads to unacceptable variations in product quality.

To overcome these problems, freeze-dried concentrated kefir culture that is handled in the same way as similar forms of other cultures, have been developed at culture laboratories.

After thorough examination of kefir grains obtained from various sources, strains of bacteria and yeasts were isolated and tested for various growth characteristics, lactic acid production, aroma formation, etc. The composition of the freeze-dried culture was then chosen to obtain a balance of micro-organisms in the bulk starter and product comparable to that of traditional kefir manufactured with grains in a mother culture.

Concentrated freeze-dried kefir cultures for direct use in the milk intended for the end product are now commercially available. The block chart in Figure 11.27 illustrates the processing stages.

Compared to traditional bulk starter production, the technique based on freeze-dried culture reduces the number of process stages, and with it the risk of reinfecting the culture.

Cultured cream is bright, has a uniform structure and is relatively viscous. The taste should be mild and slightly acidic.

Cultured cream

Cultured cream has been used for years in some countries. It forms the basis of many dishes in the same manner as yoghurt. Cultured cream can have a fat content of 10 – 12 % or 20 – 30 %. The starter culture contains *Lc. lactis subsp. lactis* and *Lc. lactis subsp. cremoris* (O cultures) whereas *Lc. lactis subsp. lactis biovar. diacetylactis* and *Leuc. mesenteorides subsp. cremoris* (LD and L cultures) bacteria are used for the aroma.

Cultured cream is bright, has a uniform structure and is relatively viscous. The taste should be mild and slightly acidic. Cultured cream, like other cultured products, has a limited shelf life. Strict hygiene is important to ensure product quality.

Yeast and moulds can develop in packages which are not air-tight. These micro-organisms occur mainly on the surface of the cultured cream. In the event of extended storage, the lactic-acid bacteria enzymes, which break down b-lactoglobulin, become active and the cultured cream goes bitter. The cultured cream also loses its flavour because carbon dioxide and other aromatic substances diffuse through the packaging.

Long-life cultured cream can also be produced by heat treatment of the product prior to the packing. Stabilisers are added as for other heat-treated fermented dairy products.

Production

The process line for production of cultured cream includes equipment for standardisation of the fat content, homogenisation and heat treatment of the cream, and also inoculation and packing.

Homogenisation

The cream is homogenised. For cream with 10 – 12 % fat the homogenisation pressure is normally 15 – 20 MPa (150 – 200 bar) at 60 – 70 °C. Up to a certain point, an increase in homogenisation temperature improves the consistency.

For cream with 20 – 30 % fat, the homogenisation pressure should be lower, 10 – 12 MPa (100 – 120 bar), as there is not enough protein (casein) to form membranes on the enlarged total fat surface.

Heat treatment

The homogenised cream is normally heat treated for five minutes at 90 °C.

Other time/temperature combinations can be used if the homogenisation technique is carefully matched to the heat treatment.

Inoculation and packing

The pre-treated cream is cooled to an inoculation temperature of 18 – 21 °C. 0,01 % DVS culture or 1 – 2 % of bulk starter culture is added.

Inoculation can take place in a tank or in the packages. The fermentation time is 18 – 20 hours. When fermentation is completed, the cultured cream is cooled quickly, to prevent any further pH reduction. The viscosity of the fermented cream may be very high, and it may therefore be difficult to pack. In spite of precautions, the mechanical treatment to which the cultured cream is subjected during stirring, pumping and packing also causes a slight deterioration in the consistency of the product – it will become thinner.

The cream is sometimes inoculated, packaged and fermented in the packages to avoid mechanical treatment. This is especially the case when a high fat cream is produced.

After inoculation of the cream and subsequent packing, the product is stored at 20 °C until the acidity of the fat-free phase is about 85 °Th, which takes about 16 – 18 hours. The packages are then carefully transferred to the chilled store, where they are kept for at least 24 hours at a temperature of about 6 °C before distribution.

Cultured cream is often used in cooking.

Long-life cultured cream

The shelf life of the cultured cream can be prolonged by heat treatment. Stabilisers are added either in the cream before fermentation or in the fermented cream before final heat treatment. The viscosity of the ready product is dependent on the choice of stabiliser as well on the design of the plant.

Buttermilk

Buttermilk is a by-product of butter production from sweet or fermented cream.

The fat content is about 0,5 %, and it contains a lot of membrane material including lecithin. The shelf life is short, as the taste of the buttermilk changes fairly quickly because of oxidation of the membrane material content. Whey separation is common in buttermilk from the manufacture of butter, based on fermented cream, and product defects are therefore difficult to prevent.

Fermented buttermilk

Fermented buttermilk is manufactured on many markets in order to overcome problems such as off-flavours and short shelf life. The raw material can be sweet buttermilk from the manufacture of butter based on sweet cream, skim milk or low-fat milk.

In all cases the raw material is heat treated at 90 – 95 °C for about 5 minutes before being cooled to inoculation temperature. Ordinary lactic-acid bacteria are most commonly used. In some cases, when the raw material is skim milk or low fat milk, grains of butter are also added to the product to make it look more like buttermilk. Buttermilk may also be flavoured with *e.g.* fruit concentrate.

Fig. 11.28 *Examples of milk products utilising new bacteria combinations to achieve positive effects on the intestine function are BRA and Onaka.*

Trends in cultured milk products

The latest years there has been increased focus on Functional Foods. Within this category certain types of lactic acid bacteria plays a large role.

For a number of years it has been known, at least in the northern part of Sweden, that a certain type of cultured milk called *Långfil* has been used to heal wounds and treat vaginal fungus infections. However, studies of lactic

acid bacteria and their importance to health can be traced back to the beginning of the twentieth century. Elie Metchnikoff, professor at the Pasteur Institute in Paris, France, knew that many people in his Russian home district consumed a great deal of yoghurt and lived for a long time. (Professor Metchnikoff was awarded a Nobel Prize in Medicine in 1908, but that was for the discovery of phagocytosis, *i.e.* the phenomenon that white blood corpuscles, leucocytes, eat bacteria that have invaded the body.)

Metchnikoff argued that lactobacilli ingested by consumption of yoghurt pass through the stomach and destroy putrefactive bacteria in the colon. By doing so they inhibit the production of "poisonous" waste products that cause chronic morbid alterations in the system, especially arteriosclerosis.

L. acidophilus and *Bifido*-bacteria are important members of the human intestinal flora.

This theory of Metchnikoff's was plausible, but it has also been criticised on the grounds that lactobacilli cannot survive the low pH, approximately 2, that prevails in the stomach. However that may be, the following fragments of information reflect the situation in the final decade of the twentieth century.

Interest in the deliberate use of lactic acid bacteria as a health-giving constituent of certain foods and forage products has snowballed in the past few years. The greatest enthusiasts claim that living lactic acid bacteria will be the 21st century's answer to the 20th century's penicillin and sulfa drugs.

The expression "functional food" is applied to foods with near-medicinal properties that promote health. "Food for special health use" is another term for the same thing.

Lactic acid bacteria have been used since time immemorial to ferment foods. The special strains of bacteria normally used in production of yoghurt, as well as other types such as *Lactobacillus acidophilus, L. reuteri,* Bifido-bacteria and certain species of *Lactococcus lactis*, are among those that have been found of interest for production of functional foods.

What properties must a lactic acid bacterium have to be able to function in the intestine? The following four characteristics that are of primary importance:

- Ability to colonise and survive
- Adhesive capacity
- Ability to aggregate
- Antagonistic effects

L. acidophilus and Bifido-bacteria are important members of the human intestinal flora. The former normally predominates in the small intestine and the latter in the large intestine.

Production of these important bacteria is reduced in some people as a result of medication, stress or old age. In many people, reduced production of intestinal bacteria can cause symptoms such as swelling, indigestion and pronounced illness.

Consumption of live *L. acidophilus* and Bifido-bacteria in milk products is an ideal way to restore the balance of the intestinal flora. Apart from the possible prevention and relief of diarrhoea, literature indicates that *L. acidophilus* and Bifido-bacteria may help to:

- Reduce the cholesterol level in the blood
- Relieve lactose malabsorption (lactose intolerance)
- Strengthen the immune system
- Reduce the risk of stomach cancer.

(Nutrish cultures, Chr. Hansen's Laboratories, Hørsholm, Denmark)

These micro-organisms can be utilised alone or in combination with other cultures, *e.g.* thermophilic, yoghurt or mesophilic cultures. A product called BRA milk, for example, was introduced on the Swedish market. The name has a double meaning: "BRA" is the Swedish word for good, and also the initials of Bifido, Reuteri and Acidophilus bacteria. This product is available in sweet and sour versions.

Thus, lactic acid bacteria may have a great potential for promoting the health of both human beings and animals. The claimed effects, however, are by no means fully documented. It is therefore important that sufficient resources are invested in this field in the near future, both to find new interesting health effects of lactic acid bacteria and to compile scientific documentation.

Chapter 12

Butter and dairy spreads

The International Dairy Federation (IDF) has introduced a standard concerning butters and spreads: IDF Standard 166:1993, "Guidelines for Fat Spreads". These guidelines are intended to provide a broad framework permitting the development of more specific group or individual standards, according to the requirements of individual countries.

Definitions

Fat spread: A fat spread is a food in the form of an emulsion (mainly of the water-in-oil type), comprising principally an aqueous phase and edible fats and oils.

Edible fats and oils: Foodstuffs mainly composed of triglycerides of fatty acids. They are of vegetable, animal, milk or marine origin.

Tables 12.1 and 12.2 below are taken from this IDF standard.

Table 12.1

Essential composition of milk fat and margarine products

Milk fat products	Mixed fat products	Margarine products
Milk fat 100 % of total fat	Milk fat min. 15 %, max. 80 % of total fat	Milk fat max. 3 % of total fat

Note. Restricted zone(s) may be imposed, with respect to the fat content and to the proportion of milk fat to other types of fat, in accordance with national or other relevant legislation.

The principal raw materials should be water and/or milk products, edible fats and/or oils, or mixtures of these. Concerning the fat content, the IDF standard states that fat spreads shall be classified into three groups, according to the origin of the fat. The maximum fat content shall be 95 %.

The name of the food shall be as specified in national legislation. The products, however, shall comply with the general requirements in Table 12.2, which are designed to be applied consistently to products in all three groups.

Table 12.2

Names of milk fat and margarine products

Fat content %	Milk fat products	Mixed fat products	Margarine products
80 – 95	Butter*	Blend	Margarine*
> 62 – < 80	Dairy spread	Blended spread	Fat spread
60 – 62	3/4 fat or reduced fat butter	3/4 fat or reduced fat blend	3/4 fat or reduced fat margarine
> 41 – < 60	Reduced fat dairy spread	Reduced fat blended spread	Reduced fat spread
39 – 41	1/2 or low fat butter	1/2 or low fat blend	1/2 or low fat margarine or Minarine*
< 39	Low fat dairy spread	Low fat blended spread	Low fat spread

** The following FAO/WHO individual standards currently apply to products in international trade and indicate the designations permitted:*
A1 – Standard for Butter and Whey Butter
(A16 – Standard for Low Fat Dairy Spreads – draft)
Codex Standard 32–1981 for Margarine
Codex Standard 13–1981 for Minarine

Table 12.3
Examples of fat products (Sweden)

Product/ Composition	Butter	Margarine	Dairy Spread Bregott (Margarine)	Low fat Dairy spread Lätt & Lagom (Minarine)	M-cocos	Lard
Basic material	Cultured cream	Veg. oils and fats	Cultured cream and vegetable oil	AMF* + vegetable oil + conc. of butter milk pref.	Coconut oil	Lard
Fat, %	80	80	80	40	100	100
Moisture, %	16 – 18**	≈18	17 – 18**	48	0	0
Salt, %	0 – 2	1,5 – 2,0	1,4 – 2,0	1,2	0	0
Protein, %	0,7	0,2 – 0,4	0,6	7,5	0	0
Specific energy, kJ/100 g	3 140	3 100 – 3 150	3 140	1 710	3 900	3 900
Vitamins, I.U./100 g	A 2 500 D 55	A 3 000 D 300	A 3 000 D 300	A 3 000 D 300	0 0	0 0
Keeping quality at 6–7 °C	2 – 3 months	3 months	2 – 3 months	1,5 months	6 – 12 months	6 months
Usage	Table Cooking	Table Cooking	Table Cooking	Table	Cooking Confectionery	Frying Baking

** AMF = Anhydrous Milk Fat* *** Varies with salt content*
Table from Livsmedelsbranschens Utbildningsorgan, Brevskolan, Sweden

Table 12.3, which lists the names, approved designations and compositions of some commercial fat products in Sweden, can serve as an example.

For many years, there were just a few recognised types of cooking fat, viz. butter, margarine, lard and coconut oil.

Butter and margarine are the two products that most interest is focused on. Both products are used for spreading on bread as well as for cooking and baking. Both of them share the disadvantage that when traditionally produced, they do not spread easily at ordinary refrigeration temperature (+5 °C). This led to the development during the 1960s and 1970s of a variety of more readily spreadable proprietary products including low-fat (40 %) blends, also called *minarines*, and later reduced-fat (60 %) products called *mellarines*.

Butter

Butter is usually divided into two main categories:

- Sweet cream butter
- Cultured or sour cream butter made from bacteriologically soured cream

Butter can also be classified according to salt content: unsalted, salted and extra salted.

Until well into the 19th century, butter was still made from cream that had been allowed to sour naturally. The cream was then skimmed from the top of the milk and poured into a wooden tub. Butter was made by hand in churns. The natural souring process is very sensitive, and infection by foreign micro-organisms often spoiled the result.

As knowledge of cooling increased, it became possible to skim the cream before it had gone sour, and make butter from the sweet cream. Buttermaking methods gradually improved, and so did the product quality

and economic yield. It was eventually found that sweet cream could be soured by the addition of naturally soured milk or acid buttermilk. It then became possible to make ripened cream butter under more controlled conditions.

The invention of the separator (1878) meant that cream could be skimmed from milk quickly and efficiently. It was also the start of large-scale buttermaking. Contributions to the quality of the product and buttermaking economics were also made by the introduction of pasteurisation in the 1880s, the use of pure bacteria cultures in the 1890s and the introduction of the buttermaking machine at the turn of the century.

Today's commercial buttermaking is a product of knowledge and experience gained over the years about such matters as hygiene, bacterial acidification and temperature treatment, as well as the rapid technical development that has resulted in the advanced machines now used.

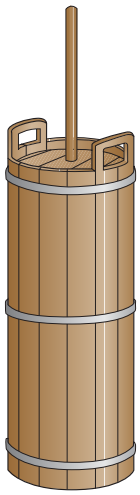


Fig. 12.1 *Traditional hand churn, formerly used for domestic buttermaking.*

Sweet and cultured (sour) cream butter

Variations in the composition of butter are due to differences in production.

As can be seen from Table 12.3, butter contains 80 % fat and 16 – 18 % moisture, basically depending on whether it is salted or not. Butter also naturally contains the Vitamins A and D.

The colour of butter varies with the content of carotenoids, which make up from 11 to 50 % of the total vitamin A activity of milk. As the carotenoid content of milk normally fluctuates between winter and summer, butter produced in the winter period has a brighter colour. In this context it might be mentioned that butter made of cream from buffalo milk is white, as buffalo milk does not contain carotenoids. Butter should also be dense and taste fresh. The water content should be dispersed in fine droplets so that the butter looks dry. The consistency should be smooth, so that the butter is easy to spread and melts readily in the mouth.

Sour cream butter should smell of diacetyl, while sweet butter should taste of cream – a faint cooked flavour is acceptable in the case of sweet butter.

Butter made from sour cream has certain advantages over the sweet cream variety. The aroma is richer, the butter yield higher, and there is less risk of reinfection after temperature treatment, as the bacteria culture suppresses undesirable micro-organisms.

However, sour cream butter has its drawbacks. This point is mentioned in the next sentence. Buttermilk from sour cream butter has a far lower pH than buttermilk from sweet cream butter, which sometimes makes it harder to dispose of than sweet buttermilk. Another disadvantage of cultured cream butter is that it is more sensitive to oxidation defects, which give it a metallic taste. This tendency is accentuated if the slightest trace of copper or other heavy metals is present, and this reduces the chemical keeping properties of the butter considerably.

Buttermaking

Butter was originally made on the farm for household use. In those days, a manually operated butter churn, Figure 12.1, was used. Following churning and discharge of buttermilk, the butter grains were collected in a shallow trough and manually worked until acceptable dryness and structure were achieved.

Butter can be produced in churns in a batch process or in a continuous process with modern buttermaking machines.

Large-scale butter manufacturing processes generally involve quite a number of stages. Figure 12.2 schematically shows both batch production in a churn and continuous production in a buttermaking machine. Churns are still used, but are rapidly being replaced by continuous buttermaking machines.

The cream can be supplied by a liquid milk dairy (surplus cream) or separated from whole milk at the creamery. In the former case, the cream should have been pasteurised by the supplier. Storage and delivery to the

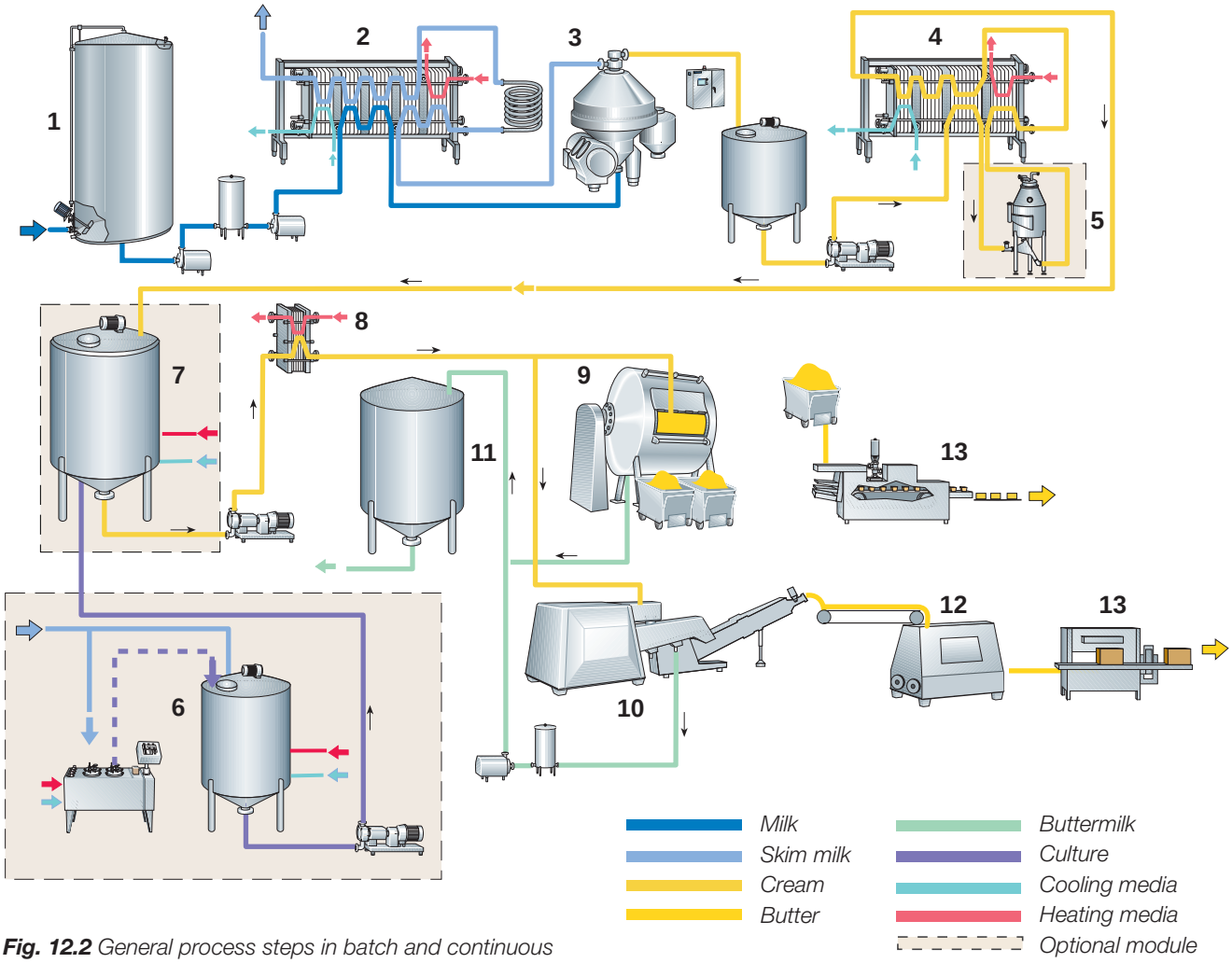


Fig. 12.2 *General process steps in batch and continuous production of cultured butter.*

1 *Milk reception*
2 *Preheating and pasteurisation of skim milk*
3 *Fat separation*
4 *Cream pasteurisation*
5 *Vacuum deaeration, when used*
6 *Culture preparation, when used*
7 *Cream ripening and souring, when used*
8 *Temperature treatment*
9 *Churning/working, batch*
10 *Churning/working, continuous*
11 *Buttermilk collection*
12 *Butter silo with screw conveyor*
13 *Packaging machines*

creamery should be undertaken in such a way that reinfection, aeration or foaming do not take place. After reception procedures, weighing-in and analysis, the cream is stored in tanks.

If the cream is produced at the creamery, the whole milk is pre-heated to 63 °C in the pasteuriser before being separated. The warm cream is routed into an intermediate storage tank before being pumped to the cream pasteurisation plant. For gentle treatment of the cream, please see the description of the *Scania method* in Chapter 8.

The skim milk from the separator is pasteurised and cooled before being pumped to storage. When cultured butter is to be produced, part of the skim milk should be utilised for starter preparation.

From the intermediate storage tank(s) the cream continues to pasteurisation at a temperature of 95 °C or higher. The high temperature is needed to destroy enzymes and micro-organisms that would impair the keeping quality of the butter.

The destruction of unwanted micro-organisms is also beneficial in the case of sour cream butter, as this creates perfect growth conditions for the bacteria culture. The heat treatment releases strongly antioxygenic sulphhydryl compounds, which further reduce the risk of oxidation.

Vacuum deaeration can also be included in the line if the cream has an undesirable flavour or aroma, *e.g.* onion taste. Any flavouring will be bound in the fat and transmitted to the butter, unless removed. Vacuum treatment before pasteurisation involves pre-heating the cream to the required temperature and then subjecting it to flash cooling to free any entrapped gas and volatile substances. After this, the cream is returned to the pasteuriser for further treatment – heating, holding and cooling – before proceeding to the ripening tank.

Vacuum deaeration is recommended when the cream has a very strong flavour or aroma defect, *e.g.* onion taste. Vacuum treatment may have an unfavourable effect on the yield and the butter consistency.

In the ripening tank, of a recommended maximum volume of 30 000 litres, the cream is subjected to a temperature programme which will give the fat the required crystalline structure, when it solidifies during cooling. The programme is selected to match factors such as the composition of the butterfat, expressed, for example, in terms of iodine value, which is a measure of the unsaturated fat content. The treatment can also be modified to produce butter with good consistency despite a low iodine value, *e.g.* when the unsaturated proportion of the fat is low.

Ripening usually takes 12 – 15 hours. Where possible, the acid-producing bacteria culture is added before the temperature treatment. The quantity of culture added depends on the treatment programme selected with reference to the iodine value, (Table 12.4).

From the ripening tank, the cream is pumped to the continuous buttermaker or the churn; sometimes a passage through a plate heat exchanger is desirable, to bring it to the required temperature. In the churning process, the cream is agitated violently to break down the fat globules, causing the fat to coalesce into butter grains. The fat content of the remaining liquid, *i.e.* buttermilk, decreases.

The cream is split into two fractions: butter grains and buttermilk. In traditional churning, the machine is stopped when the grains have reached a certain size, and then the buttermilk is drained off. Buttermilk drainage is continuous in continuous buttermaking machines.

After drainage, the butter is worked to a continuous fat phase containing a finely dispersed water phase. It used to be common practice to wash the butter with water after churning, to remove any residual buttermilk and milk solids, but this is rarely done nowadays. If the butter is to be salted, salt is spread over the surface in batch production, or added in slurry form during the working stage in continuous buttermaking.

After salting, the butter must be worked further to ensure uniform distribution of the salt. The working of the butter also affects the characteristics by which the product is judged – aroma, taste, keeping quality, appearance and colour. The finished butter is discharged into the packaging unit and then to cold storage.

The raw material

The cream must be of good bacteriological quality, without taste or aroma defects. The iodine value is the deciding factor in the selection of manufacturing parameters. Unless corrected, fat with a high iodine value (high unsaturated fat content) will produce greasy butter. Butter of acceptable consistency can be obtained from both hard fat (iodine value down to 28) and soft fat (iodine value up to 42), by varying the ripening treatment to suit the iodine value.

Cream containing antibiotics or disinfectants is unsuitable for the manufacture of acidified butter. If harmful micro-organisms have been given the chance to develop, the cream cannot be used, even if they can be rendered inactive by heat treatment. Therefore, strict hygiene is essential in all stages of the production process.

A problem in countries with a refrigerated distribution chain for raw milk is that cold storage causes changes in the micro-organic composition. Where lactic-acid bacteria once dominated, there are now bacteria strains that have a high resistance to cold – the *psychrotrophic bacteria*. These are normally destroyed during pasteurisation and therefore have no effect on the quality of the butter. Some psychrotrophic bacteria strains, however, produce lipolytic enzymes which can break down the fat. These enzymes can withstand temperatures above 100 °C. Consequently, it is vital that development of psychrotrophic bacteria is prevented. One solution is to chill the raw material to 2 – 4 °C immediately on arrival at the dairy and store it at that temperature until it is pasteurised or, even better, to thermise the milk at 63 – 65 °C for 15 seconds and cool it to 2 – 4 °C. Pasteurisation should take place as soon as possible, and definitely not later than 24 hours after arrival.

Cream containing antibiotics or disinfectants is unsuitable for cultured butter manufacture.

Pasteurisation

Cream is pasteurised at a high temperature, usually 95 °C or higher, normally without any holding time. The heat treatment should be sufficient to result in a negative peroxidase test.

This vigorous treatment kills not only pathogenic bacteria but also other bacteria and enzymes that could affect keeping quality. The heat treatment should not be so intense that there will be defects, such as a cooked flavour.

Vacuum deaeration

If necessary, any undesirable flavouring substances of a volatile nature can be removed by vacuum treatment. The cream is first heated to 78 °C and then pumped to a vacuum chamber where the pressure corresponds to a boiling temperature of 62 °C. The reduced pressure causes volatile flavouring and aromatic matter to escape in the form of gas when the cream is flash-cooled. After this treatment, the cream is returned to the heat exchanger for pasteurisation and cooling, and then continues to the ripening tank.

Onion off-flavour is a very common defect during the summer, when various onion plants grow in the fields. Sorting of the cream is sometimes necessary to avoid strong flavours.

Heat treatment should be strong enough to result in a negative peroxidase test, but not so intense as to cause defects such as cooked flavour

Bacterial souring

Culture preparation

Bacteria cultures for the manufacture of cultured or sour cream butter are produced as described in Chapter 10, *"Cultures and starter manufacture"*. The addition of acid-producing bacteria gives the butter a strong aroma and it also improves the fat yield.

Starter cultures are of the LD or L type, which means that they contain the aroma-producing bacteria *Str. diacetylactis (Cit+ Lactococci)* and *Leuc. citrovorum (Leuconostoc mesenteroides ssp. cremoris)*, or only the latter type.

In LD cultures, the proportion of *Str. diacetiylactis* can vary between 0,6 and 13 %, while the *Leuc. citrovorum* content varies from 0,3 to 5,9 % of the total bacteria count. The proportional relationship between the aroma producers is governed by prevalent growth conditions.

Lactic acid, diacetyl and acetic acid are the most important of the aroma substances produced by bacteria. Production of the most important of the aromatics in butter, diacetyl, depends on the availability of oxygen.

The cultures must be active so that bacteria growth and acid production are rapid. A high bacteria count is then obtained *i.e.* about 1 x 10^9 bacteria/ml of mature culture. A 1 % inoculum dosage and a growth temperature of 20 °C should produce an acidity of 12 °SH after seven hours and 18 – 20 °SH after 10 hours. The culture must be balanced. It is important that acid and aroma production and the subsequent reduction of diacetyl have the correct proportional relationship.

Skim milk is mostly used as a substrate, or growth medium, for starter cultures, as it is easier to detect taste defects in skim milk cultures. The milk should be pasteurised at 90 – 95°C for 15 – 30 minutes. The development of the acid- and aroma-forming process in an LD culture is shown in Figure 12.3.

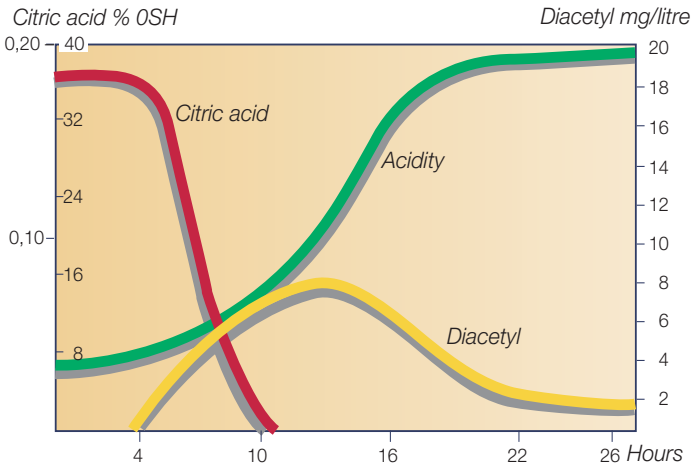


Fig. 12.3. *Acid and aroma development in skim milk at 20 °C and an LD culture dosage of 1 %.*

Slow acid production is characteristic of the first stage of growth. During this phase, citric acid fermentation and diacetyl yield are relatively

+ *Abbreviation for citrate, which is metabolised to flavour and aroma compounds.*
ssp = species of (New names for starters – see also Table 10.1 in Chapter 10)

insignificant. Acid production accelerates rapidly in the next phase, as fermentation of citric acid forms diacetyl. Most of the diacetyl is reduced by the aroma-imparting bacteria.

When acid production has slowed down, reduction of diacetyl decreases and the content more or less stabilises. The culture enters the ripening phase when the acidification phase ends. Characteristics of this phase include a very gradual increase in acidity and a reduction of diacetyl to tasteless matter by the aroma bacteria.

Souring of the cream

The souring of the cream, and the temperature treatment which gives the fat the necessary crystalline structure for optimum butter consistency, take place simultaneously in the ripening tanks. These are usually triple-shell insulated tanks of stainless steel, with heating and cooling media circulating between the shells. They are fitted with reversible scraper agitators for efficient stirring, even when the cream has coagulated. Both heating and cooling are very gradual, and this smooth temperature characteristic is advantageous from a consistency point of view.

The amount of bulk starter culture added to the cream varies from 1 to 7 %, basically depending on the incubation temperature.

The bulk starter should be well mixed before being pumped to the ripening tank. The starter is often pumped in before the cream. Some manufacturers, however, prefer to add the starter in the cream pipeline. Either way, the bulk starter must be carefully mixed into the cream.

The cream needs temperature treatment if the butter is to have the required consistency. The treatment programme depends on the iodine value of the cream. The acidification temperature will also be determined by this programme, as ripening takes place at the same time. It is possible to modify the consistency-related temperature programme so that it is adapted to the starter culture.

The amount of bulk starter to be added to the cream must be decided on the basis of the temperature programme for the process, as shown in Table 12.4. It must be proportioned to suit the acidifying and ripening temperatures as well as the duration of the various phases. Bulk starter dosage can vary from 1 to 7 % of the amount of cream. The lower percentage applies to the temperature of 21 °C at which cream with hard fat (low iodine value) is temporarily held; the higher percentage to cream with soft fat which is held at a temperature of 15 – 16 °C. The souring process should be completed when the temperature treatment is finished and the cream proceeds to churning. The acidity of the non-fat part of the cream should then be about 36 °SH.

Temperature treatment

Before churning, the cream is subjected to a programme of temperature treatment, which will control the crystallisation of the fat, so that the butter will have the desired consistency. The consistency of the butter is one of its most important quality characteristics, both directly and indirectly, as it affects the other characteristics – mainly taste and aroma. Consistency is a complicated concept involving properties such as hardness, viscosity, plasticity and spreadability.

The fatty acids in milk fat were described in Chapter 2, *The chemistry of milk*. The relative amounts of fatty acids with high melting points determine whether the fat will be hard or soft. Soft fat has a high content of low-melting fatty acids, and at room temperature this fat has a large continuous phase of liquid fat, *i.e.* the ratio of liquid to solid fat is high. On the other hand, in a hard fat, the ratio of liquid to solid fat is low.

In buttermaking, if the cream is always subjected to the same temperature treatment, it will be the chemical composition of the milk fat that determines the consistency of the butter. Soft milk fat will result in soft and greasy butter, whereas butter from hard milk fat will be hard and stiff. The consistency of the butter can be optimised if the temperature treatment is modified to suit the iodine value of the fat. The temperature treatment regulates the amount of solid fat to a certain extent – this is the major factor that determines the consistency of the butter.

Butterfat crystallisation

The fat in the fat globules is in liquid form after pasteurisation. When the cream is cooled to below 40 °C, the fat starts to crystallise. If the cooling is gradual, the different fats will crystallise at different temperatures, depending on their melting points. This would be an advantage, as this type of cooling would result in a minimum of solid fat – a soft butter could then be made from cream containing hard milk fat with low iodine values. The course of crystallisation in 40 % cream is discussed in Chapter 8 under the heading *Production of cream*.

Crystal formation is very slow during gradual cooling, and the crystallisation process takes several days. This would be dangerous from a bacteriological point of view, as the fat would be kept at temperatures sensitive to bacterial attack. It would also be impractical for economic reasons.

A method of speeding up the crystallisation process is quick cooling of the cream to a low temperature, where the formation of crystals is very rapid. The drawback of this method is that triglycerides with low melting points are "trapped" in the same crystals and mixed crystals are formed. A great proportion of the fat would be crystallised if no measures were taken. The ratio of liquid to solid fat would be low and the butter made from this cream would be hard.

Quick cooling of the cream to a low temperature speeds up the crystallisation process.

This can be avoided if the cream is heated carefully to a higher temperature to melt the low-melting triglycerides out of the crystals. The melted fat is then recrystallised at a slightly lower temperature, resulting in a higher proportion of "pure" crystals and a lower proportion of mixed crystals. A higher liquid-to-solids ratio and a softer fat will consequently be obtained.

It is obvious that the amount of mixed crystals, and thereby the ratio of liquid to solid fat, can be determined to a certain degree by selecting the heating temperature at which the fat crystals are melted after cooling and crystallisation and also the recrystallisation temperature. The temperatures are selected according to the hardness (iodine value) of the fat.

Several methods are now available for measuring the ratio of liquid to solid fat in a sample. The NMR pulse spectrometer test is a very fast and accurate method. This technique is based on the fact that protons (hydrogen nuclei) in fat have different magnetic properties according to whether the fat is in the liquid or solid state.

Table 12.4 gives examples of programmes for different iodine values. The first temperature is the value to which the cream is cooled after pasteurisation, the second the heating/souring value and the third the ripening value.

Treatment of hard fat

For optimum consistency when the iodine value is low, i.e. the butterfat is hard, the amount of mixed crystals must be minimised and the amount of "pure" fat maximised to increase the ratio of liquid to solid fat in the cream. The liquid-fat phase in the fat globules will then be maximised and much of it can be pressed out during churning and working, resulting in butter with a relatively large continuous phase of liquid fat and with a minimised solid phase.

The treatment necessary to achieve this result comprises:

- Rapid cooling to about 8 °C and storage for about two hours at that temperature
- Gentle heating to 20 – 21 °C and storage at that temperature for at least two hours. Water at a maximum of 27 °C is used for heating.
- Cooling to about 16 °C and then to churning temperature

Cooling to about 8 °C starts the formation of mixed crystals that bind fat from the liquid continuous phase.

When cream is heated gently to 20 – 21 °C, the bulk of the mixed crystals melt, leaving only pure crystals of fat with a high melting point. During the storage period at 20 – 21 °C, the melted fat crystals begin to recrystallise, now forming pure crystals.

Table 12.4.
Principal temperature programmes adjusted to the iodine value and recommended volumes of culture, when used.

Iodine value	Temperature programme, °C	Approx. % of starter in cream
< 28	8 – 21 – 20	1
28 – 29	8 – 21 – 16	2 – 3
30 – 31	8 – 20 – 13	5
32 – 24	6 – 19 – 12	5
35 – 37	6 – 17 – 11	6
38 – 39	6 – 15 – 10	7
> 40	20 – 8 – 11	5

After one or two hours the higher-melting fat has started to recrystallise. When the temperature is reduced to about 16 °C, the melted fat continues to crystallise and form pure crystals. During the holding period at 16 °C, all fat with a melting point of 16 °C or higher will crystallise. The treatment has caused the high-melting fat to form pure crystals and thereby reduced the amount of mixed crystals. This increases the ratio of liquid to solid fat, and the butter made from the cream will consequently be softer.

Treatment of medium-hard fat

With an increase in the iodine value, the gentle heating is stopped at a lower temperature. A greater amount of mixed crystals will form, absorbing more liquid fat than is the case in the hard-fat programme. For iodine values up to 39, the heating temperature can be as low as 15 °C.

The souring time is extended at the lower temperatures.

Treatment of very soft fat

The “summer method” of treatment is used when the iodine value is higher than 39 – 40. After pasteurisation, the cream is cooled to 20 °C and soured for about five hours at that temperature. It is cooled when the acidity is about 22 °SH. The cream is cooled to about 8 °C if the iodine value is around 39 – 40, and to 6 °C if it is 41 or higher. It is generally believed that souring temperatures below 20 °C will result in soft butter. The same applies to higher cooling temperatures after souring.

Churning

Batch production

The cream is churned after temperature treatment and after souring, where applicable. Butter is traditionally made in cylindrical, conical, cubical or tetrahedral churns with adjustable speed. Axial strips and dashers are fitted inside the churn. The shape, setting and size of the dashers in relation to the speed of the churn are factors that have an important effect on the end product. Modern churns have a speed range that permits selection of the most suitable working speed for any set of butter parameters.

The size of churns has increased greatly in recent years. Churns of 8 000 to 12 000 litres capacity or more are used in large central creameries.

Before transfer to the churn, the cream is stirred and the temperature adjusted. The churn is usually filled to 40 – 50 %, to allow space for foaming.

Butter formation

The fat globules in cream contain both crystallised fat and liquid fat (butter oil). The fat crystals have become structured, to some extent, so that they form a shell, (although a weak one), closest to the membrane of the fat globule.

A foam of large protein bubbles forms when the cream is agitated. Being surface active, the membranes of the fat globules are drawn towards the air/water interface and the fat globules are concentrated in the foam.

When agitation continues, the bubbles become smaller as the protein gives off water, making the foam more compact and thereby applying pressure on the fat globules. This causes a certain proportion of the liqu id fat to be pressed out of the fat globules and causes some of the membranes to disintegrate.

The liquid fat, which also contains fat crystals, spreads out in a thin layer on the surface of the bubbles and on the fat globules. As the bubbles become increasingly dense, more liquid fat is pressed out and the foam is soon so unstable that it collapses. The fat globules coagulate into grains of butter. At first, these are invisible to the naked eye, but they grow progressively larger as working continues.

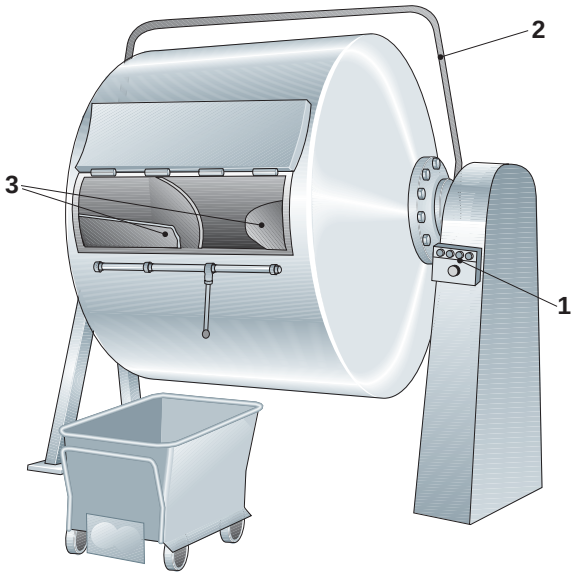


Fig. 12.4 *Butter churn for batch production.*

1 *Control panel*
2 *Emergency stop*
3 *Angled baffles*

Churning recovery

Churning recovery (yield) is a measure of how much of the fat in the cream has been converted to butter. It is expressed in terms of the fat remaining in the buttermilk as a percentage of the total fat in the cream. For example, a churning recovery of 0,50 means that 0,5 % of the cream fat has remained in the buttermilk and that 99,5 % has been turned into butter. Churning yield is considered acceptable if the value is less than 0,70.

The curve in Figure 12.5 shows how churning recovery can vary over the year. The fat content of buttermilk is highest during the summer.

Working

Working takes place when the buttermilk has been drained off. The butter grains are pressed and squeezed to remove the moisture between them. The fat globules are subjected to a high pressure, and liquid fat and fat crystals are forced out. In the resulting mass of fat (eventually the continuous phase), the moisture becomes finely dispersed by the working process, which is continued until the required moisture content is obtained. The finished butter should be dry, *i.e.* the water phase must be very finely dispersed. No water droplets should be visible to the naked eye.

The moisture content should be checked regularly during working, and adjusted so that it complies with the requirements for the finished butter.

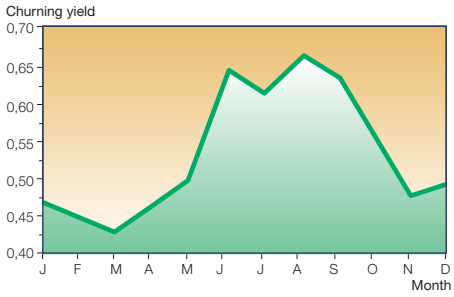


Fig. 12.5 *How churning yield can vary during the year (Sweden).*

Vacuum working

Working at reduced air pressure is a method that is frequently used. The result is a butter that contains less air and it is therefore somewhat harder than normal. In vacuum-worked butter, the air amounts to about 1 % by volume as compared with 5 – 7 % for normal butter.

Continuous production

Methods of continuous buttermaking were introduced at the end of the 19th century, but their application was very restricted. Work was resumed in the 1940s and resulted in three different processes, all based on the traditional methods: churning, centrifugation and concentration or emulsifying. One of the processes, based on conventional churning, was the Fritz method. This now predominates in Western Europe. In machines based on this method, butter is made in more or less the same way as by traditional methods. The butter is basically the same, except that it is somewhat matt and denser as a result of uniform and fine water dispersion.

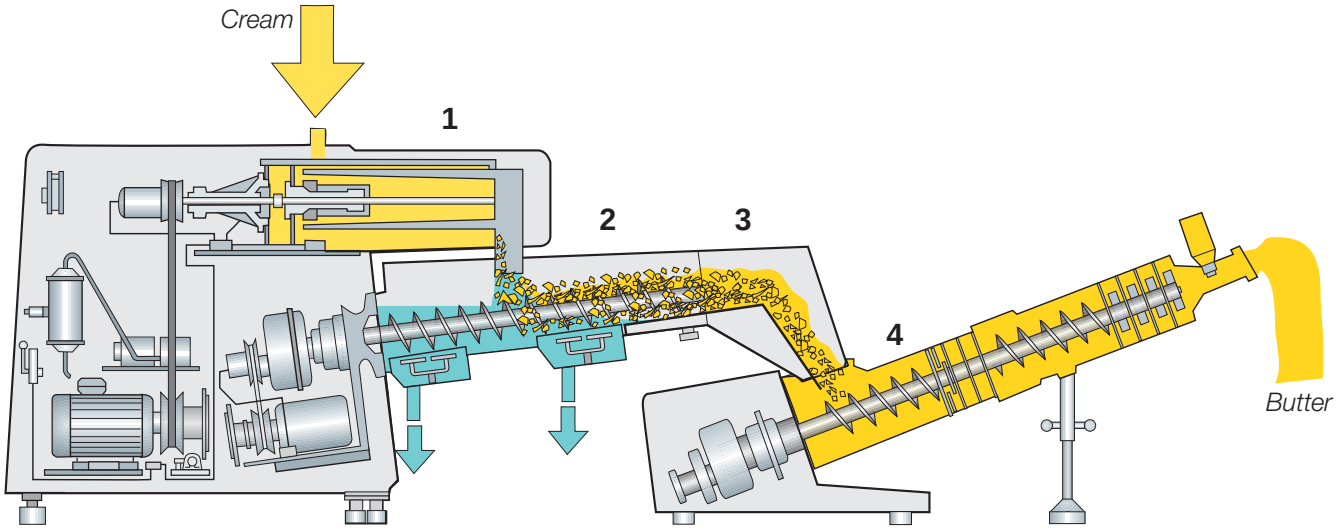


Fig. 12.6 *A continuous buttermaking machine.*
1 *Churning cylinder*
2 *Separation section*
3 *Squeeze-drying section*
4 *Second working section*

The manufacturing process

The cream is prepared in the same way as for conventional churning before being continuously fed from the ripening tanks to the buttermaker.

A sectional view of a buttermaker is shown in Figures 12.6 and 12.7. The cream is first fed into a double-cooled churning cylinder (1) fitted with beaters that are driven by a variable-speed motor.

Rapid conversion takes place in the cylinder and, when finished, the butter grains and buttermilk pass on to a separation section (2), also called the first working section, where the butter is separated from the buttermilk. The first washing of the butter grains takes place en route with recirculated chilled buttermilk. The separation section is equipped with a screw that initiates the working of the butter, while conveying it to the next stage.

As it leaves the separation section, the butter passes through a conical channel and a perforated plate, the squeeze-drying section (3), where any remaining buttermilk is removed. The butter grains then proceed to the second working section (4). Each working section has its own motor, so that they can operate at different speeds for optimum results. Normally, the first screw rotates at twice the speed of the screw in the second section.

Following the last working stage, salt may be added by a high-pressure injector in the injection chamber (5).

The next section, the vacuum working section (6), is connected to a vacuum pump. In this section, it is possible to reduce the air content of the butter to the same level as for conventionally churned butter.

The final working stage (7) is made up of four small sections, each of which is separated from the adjacent one by a perforated plate. Perforations of different sizes and working impellers of different shapes are used to optimise treatment of the butter. In the first of these small sections, there is also an injector for final adjustment of the moisture content. Once regulated, the moisture content of the butter deviates less than ~ 0,1 %, provided the characteristics of the cream remain the same.

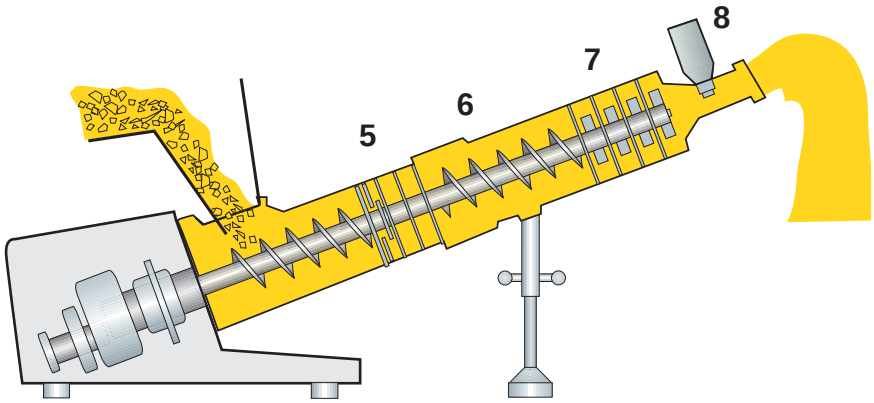


Fig. 12.7 *The vacuum working section.*
5 *Injection section*
6 *Vacuum working section*
7 *Final working stage*
8 *Moisture control unit*

Transmitters (8) for moisture content, salt content, density and temperature can be fitted in the outlet from the machine. The signals from the instruments can be used for automatic control of these parameters.

The finished butter is discharged from the end nozzle as a continuous ribbon into the butter silo, for further transport to the packing machines.

Continuous buttermaking machines are available for production capacities of 200 – 5 000 kg/h butter from sour cream and 200 – 10 000 kg/h butter from sweet cream.

New trends and possibilities for yellow fat products

Since the turn of the century, the pattern of edible fat consumption has shifted from butter to margarine. During the 1980s there was also a clear trend towards reduced fat and low-fat products.

These changes in consumer habits can be explained by the increasing use of prepared foods and heightened health-consciousness.

As was mentioned in the introduction to this chapter, some new yellow fat products appeared on the market back in the 1970s. The general advantage claimed for them was that they were easier to spread at refrigerator temperature, while some were also specifically developed to satisfy the increasing demand for products of lower fat content without sacrificing the taste of butter. Two examples from Sweden, where they are now firmly established on the market, are *Bregott* and *Lätt & Lagom*.

There is a clear trend towards reduced fat and low-fat products.

Bregott

Bregott is a spread of 80% fat content, of which 70 – 80% consists of milk fat and 20 – 30% of liquid vegetable oil, such as soybean or rapeseed oil. The manufacturing technique is the same as for butter.

As Bregott contains vegetable oil, it is classed as a margarine. Bregott can also be used for cooking.

Lätt & Lagom

Lätt & Lagom is legally defined in Sweden as a “soft” margarine (the IDF standard suggests this designation – or low fat blend), which means that the fat content must be between 39 and 41 grams per 100 grams of product. This type of spread is also called a *minarine.*

The product is intended solely as a spread. It should not be used for cooking or baking, and definitely not for frying, on account of its high protein content. The manufacturing process is essentially the same as for margarine.

Butter oil – or strictly speaking anhydrous milk fat (AMF) – and soybean or rapeseed oil are mixed in proportions determined by the requirements of good spreadability at refrigerator temperature. Following the mixing, an appropriate amount of the water phase, also containing protein harvested from ordinary cultured buttermilk, is added. The whole mixture is pasteurised in a plate heat exchanger and finally chilled, while being worked in special scraped-surface coolers and pin rotors.

The presence of AMF and buttermilk protein gives the product a butter-like aroma.

There are many similar products around the world. Their common features are reduced fat content, vitamin enrichment and often the presence of vegetable oils, which are a source of polyunsaturated fatty acids. Using modern technologies, it is possible to obtain products with the required physical and dietetic properties.

Process line for spreadable mix

This process is a combination of two known process steps: cream concentration, and crystallisation combined with phase inversion.

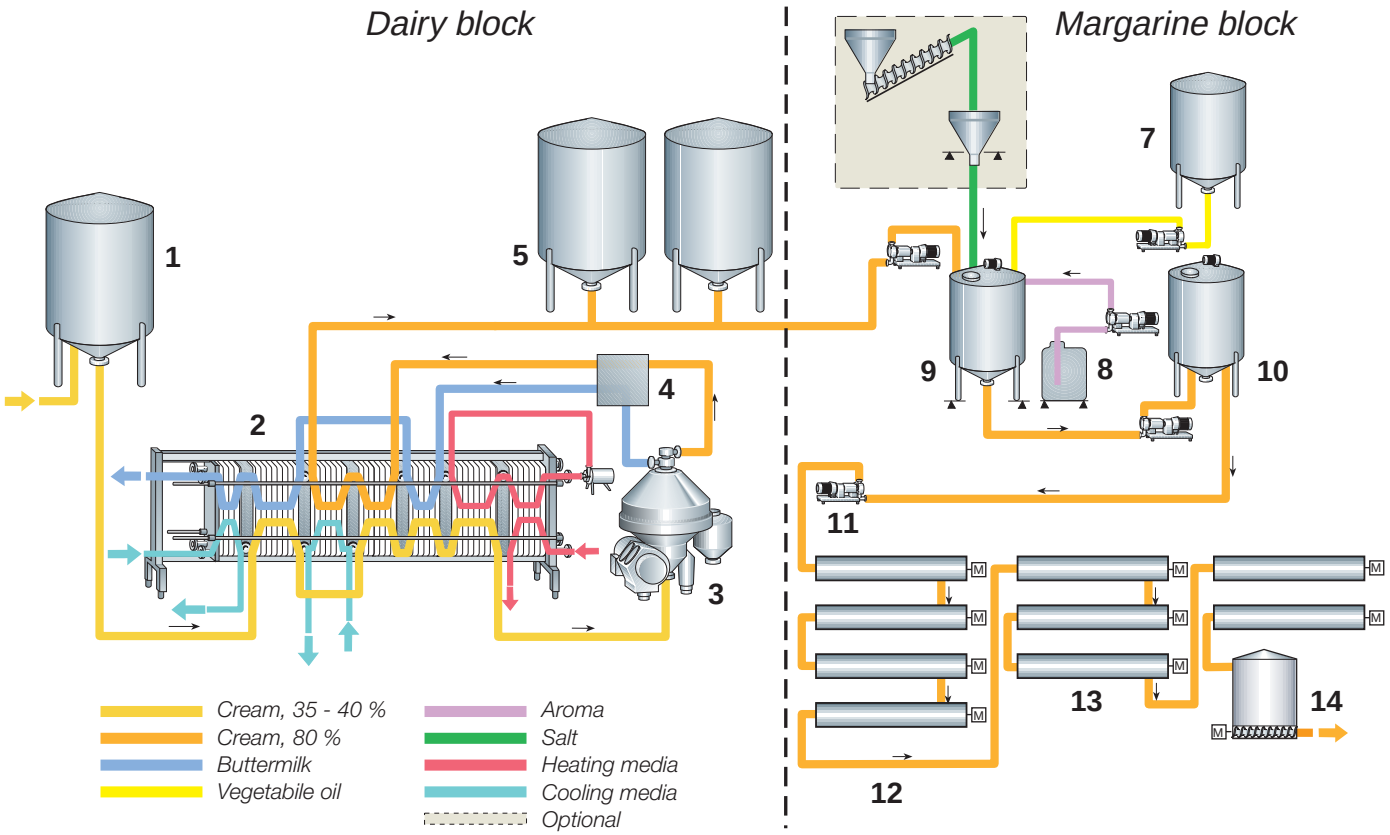


Fig. 12.8 *Process line for the production of butter and dairy spreads.*

Dairy block
1 *Cream tank*
2 *Plate heat exchanger*
3 *Centrifugal cream concentrator*
4 *Cream standardisation*
5 *Pre-crystallisation tanks*

Margarine block
6 *Salt dosage, optional*
7 *Vegetable oil tanks*
8 *Aroma dosage*
9 *Mixing*
10 *Buffer tank*
11 *High pressure pump*
12 *Scraped-surface cooler*
13 *Pin rotors*
14 *Silo with screw conveyor in the bottom*

The cream is usually concentrated to 75 – 82 % fat content in a hermetic separator, where the heavy phase is skim milk, here also called buttermilk, which contains *less fat* than the buttermilk from traditional butter processes. In most cases, skim milk has a higher by-product value than buttermilk.

For production of spreads of 40 to 60 % fat content the concentrated cream of approximately 75 – 80 % fat is diluted with water before processing, which results in a lower content of proteins and lactose. When cream of the same fat content as that of the final product is processed, the higher content of proteins and lactose impairs the flavour of the spread.

A further advantage of using concentrated cream as a base for low-fat products is that no extra emulsifier is required, as the natural emulsifiers in the milk are available in the cream.

The process line

The process line is built around two blocks:

1 A typical “dairy block“ with cream concentration, pasteurisation and cooling
2 A typical “margarine block” with preparation of the mix and phase inversion accompanied by working and cooling

The process line is illustrated in Figure 12.8.

Dairy block (to the left of the dotted line in Figure 12.8.)
The process starts with pasteurised cream of 35 to 40 % fat content. As the cream may come from another creamery or a local cream storage tank, its temperature must be adjusted to 60 – 70 °C before it enters the cream concentrator, a hermetic centrifugal machine. The degree of concentration, *i.e.* the cream fat content, is automatically controlled by the continuous standardisation device described in Chapter 6.2. Fat contents of up to 82 % can be attained, (on special request even up to 84 %, but then at the expense of a high fat content – more than 10 % – in the skim phase). Following fat standardisation, the cream is cooled to 18 – 20 °C, before being routed to a holding/pre-crystallisation tank.

Margarine block (to the right of the dotted line in Figure 12.8)
This part of the process line starts with a batching station where the product mix is prepared. Various ingredients are mixed together, according to the recipe for the product in question. Thus, concentrated cream is mixed with appropriate volumes of vegetable oil, salt and water phase, in that order. After thorough mixing, the mixture is pumped into a buffer tank (10). A new batch can then be prepared.

The process is continuous from the buffer tank, from which the product mix is taken to the high pressure pump (11). It is then fed into the scraped-surface coolers (12), where phase inversion takes place. Before final cooling, the spread is held and worked by pin rotors (13). Leaving the final cooling stage, the product enters the storage silo (14), from where it is pumped into the filling machine, often a tub-filling machine.

The whole process is controlled from a process computer and a recipe computer.

Packaging

There are basically three ways of transporting butter or dairy spreads from the machine to packaging:

1 The product is discharged into a silo with a screw conveyor at the bottom. The conveyor feeds the product to the packaging machine.
2 The product is pumped direct to the packaging machine
3 Transfer by means of trolleys filled with product. The trolleys are often fitted with screw conveyors. A combination of these methods is also possible.

Butter can be packed in bulk packs of more than 5 kg and in packets from 10 g to 5 kg. Various types of machines are used, depending on the type of packaging. The machines are usually fully automatic, and both portioning and packaging machines can often be reset for different sizes, for example 250 g and 500 g or 10 g and 15 g.

The wrapping material must be greaseproof and impervious to light, flavouring and aromatic substances. It should also be impermeable to moisture, otherwise the surface of the butter will dry out and the outer layers become more yellow than the rest of the butter.

Butter is usually wrapped in aluminium foil. Parchment paper, once the most common wrapping material, is still used but has now been largely replaced by aluminium foil, which is much less permeable.

After wrapping, the pat or bar packets continue to a cartoning machine for packing in cardboard boxes, which are subsequently loaded on pallets and transported to the cold store.

Figure 12.2 shows the transport of butter from churning equipment to packaging machines. Dairy blends and spreads are mostly packed in tubs holding 250 to 600 g.

Cold storage

For the sake of consistency and appearance, butter, dairy blends and spreads should be placed in cold storage after packing and kept at +5 °C.

Alternative buttermaking methods

There have been many attempts to develop new methods for manufacturing butter with no undesirable properties. One of these methods, the NIZO method (Dutch), uses sweet cream as a raw material. One of the NIZO method's advantages is that it is easier to utilise sweet buttermilk.

In this process, sweet butter grains are mixed after churning with a highly aromatic starter and a concentrated starter permeate, which is basically a solution of lactic acid.

The highly aromatic starter is prepared using skim milk, which has an

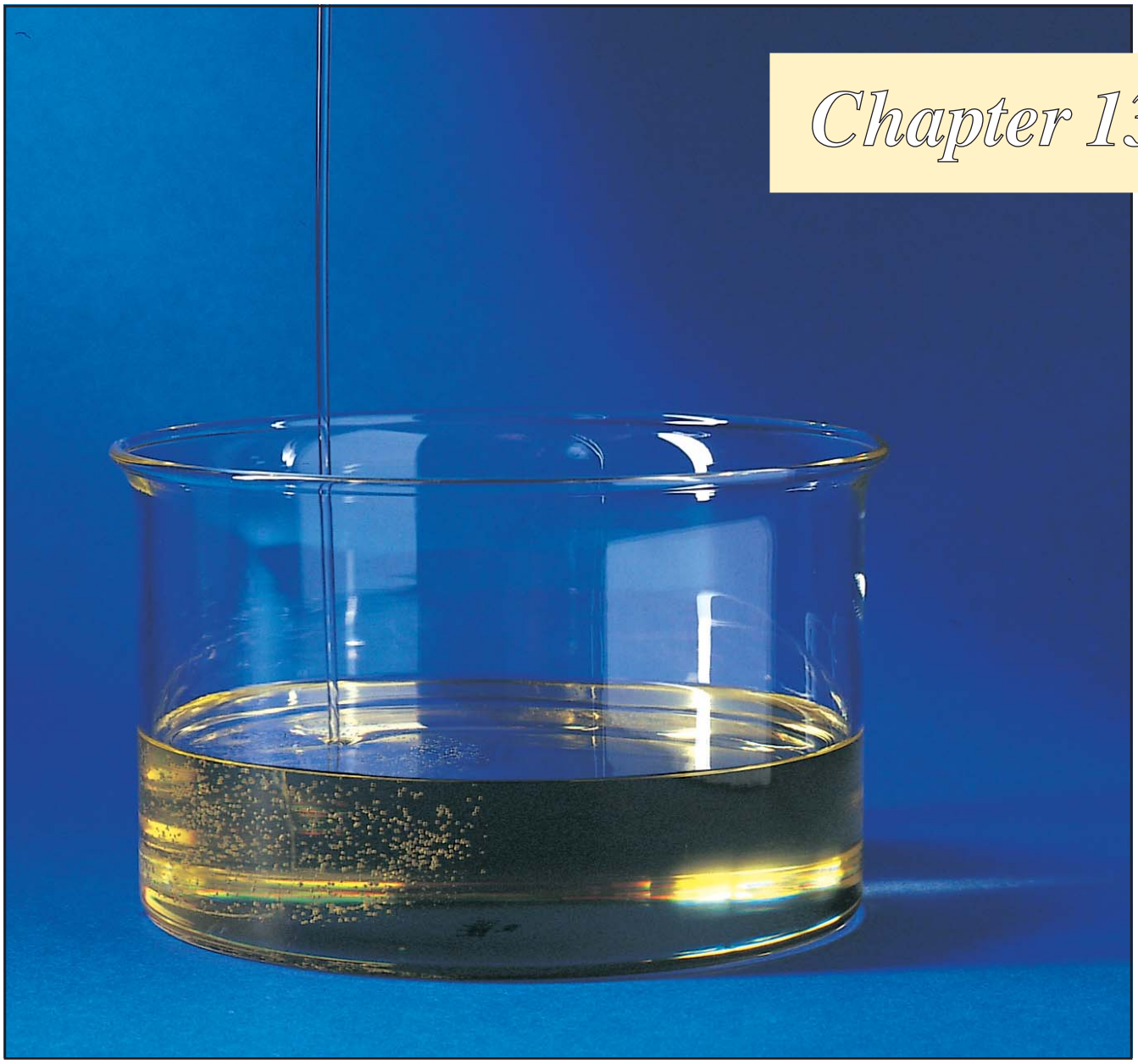
increased DM content – *e.g.* raised by evaporation or addition of SMP. To prepare the starter permeate, a partially delactosed whey is soured by *Lactobacillus helveticus*. After fermentation, the liquid is ultrafiltered and the permeate is further concentrated by evaporation to achieve a lactic acid concentration of approximately 16 %.

The highly aromatic starter is then mixed with the starter permeate, and the mixture is aerated to stimulate formation of diacetyl. For the final process of buttermaking, two types of culture are used to prepare two starter types.

Starter 1 (highly aromatic) is mixed with the permeate and aerated.
Starter 2 is incubated in the traditional way. Both starters interact with the butter grains during the buttermaking process.

In this way, it is possible to obtain aromatic butter, which is also very stable regarding auto-oxidation.

It is very likely that several similar methods will be adopted in the future if current tests fulfil their promise. However, there are still some obstacles. The methods cannot be used in countries where the addition of foreign substances (lactic acid) to dairy products is prohibited.



Chapter 13

Anhydrous Milk Fat (AMF) and Butteroil

Anhydrous milk fat and butteroil are products consisting of more or less pure milk fat. Although they are modern industrial products, they have ancient traditional roots in some cultures. Ghee, a milk fat product with more protein and a more pronounced flavour than AMF, has been known in India and Arab countries for centuries.

Anhydrous milk fat products are manufactured in three distinct qualities specified by FIL-IDF International Standard 68A:1977:

- Anhydrous Milk Fat must contain at least 99,8 % milk fat and be made from fresh cream or butter. No additives are allowed, *e.g.* for neutralisation of free fatty acids.
- Anhydrous Butteroil must contain at least 99,8 % milk fat, but can be made from cream or butter of different ages. Use of alkali to neutralise free fatty acids is permitted.
- Butteroil must contain 99,3 % milkfat. Raw material and processing specifications are the same as for Anhydrous Butteroil.

In this chapter, the expression “AMF” will be used for all products described in FIL-IDF International Standard 68A:1977.

AMF characteristics

Butter has been the traditional form of storage for milk fat, but in some cases AMF is more preferable, because it requires less storage space.

Butter is regarded as a fresh product, although it can usually be stored at +4 °C for up to six weeks. If it is stored for a longer period of time, say up to 10 – 12 months, a storage temperature of at least –25 °C is mandatory.

AMF is typically packed in 200-litre drums nitrogen (N_2) headspace, and can be stored for several months at +4 °C. AMF is liquid at temperatures above 36 °C and solid below 16 – 17 °C.

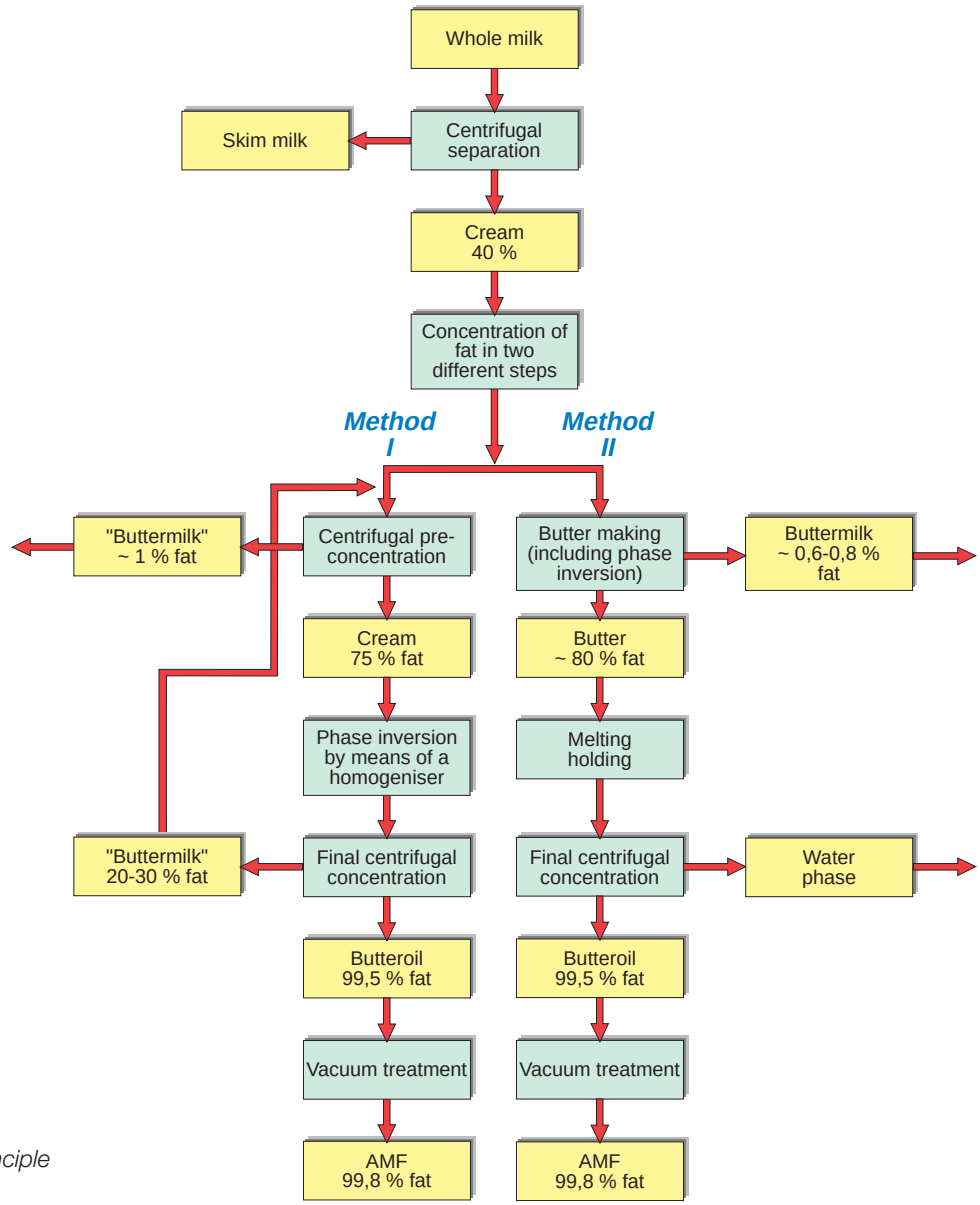


Fig. 13.1 *Block chart showing principle of AMF production.*

AMF is convenient to use in liquid form because it is easy to mix with, and meter into other products. Thus, AMF is used for recombination of various dairy products, but it is also used in the chocolate and ice cream manufacturing industries.

Demand for butter is decreasing, partly due to the increased use of AMF. One field of application where the use of AMF will increase is in “blends “ of different fat contents and with mixtures of butter and vegetable oils, to make products with different functional properties.

Customised fat products for various applications can be obtained by fractionation of AMF.

Production of AMF

Principles of production

Production of AMF principally takes place according to two methods; continuous flow direct from cream (milk), and from reworked butter. The block chart in Figure 13.1 visualises the two methods.

The quality of the AMF is a result of the quality of the raw material and there should therefore be no difference whatever method is chosen. If, for any reason, the respective qualities of cream and butter should be considered not good enough, there are some means of improving quality by polishing (washing) the oil or even neutralising it, before the final evaporation step is passed. These operations are discussed below under *AMF Refining*.

Manufacture of AMF from cream

A production line for manufacture of AMF from cream is outlined in Figure 13.2.

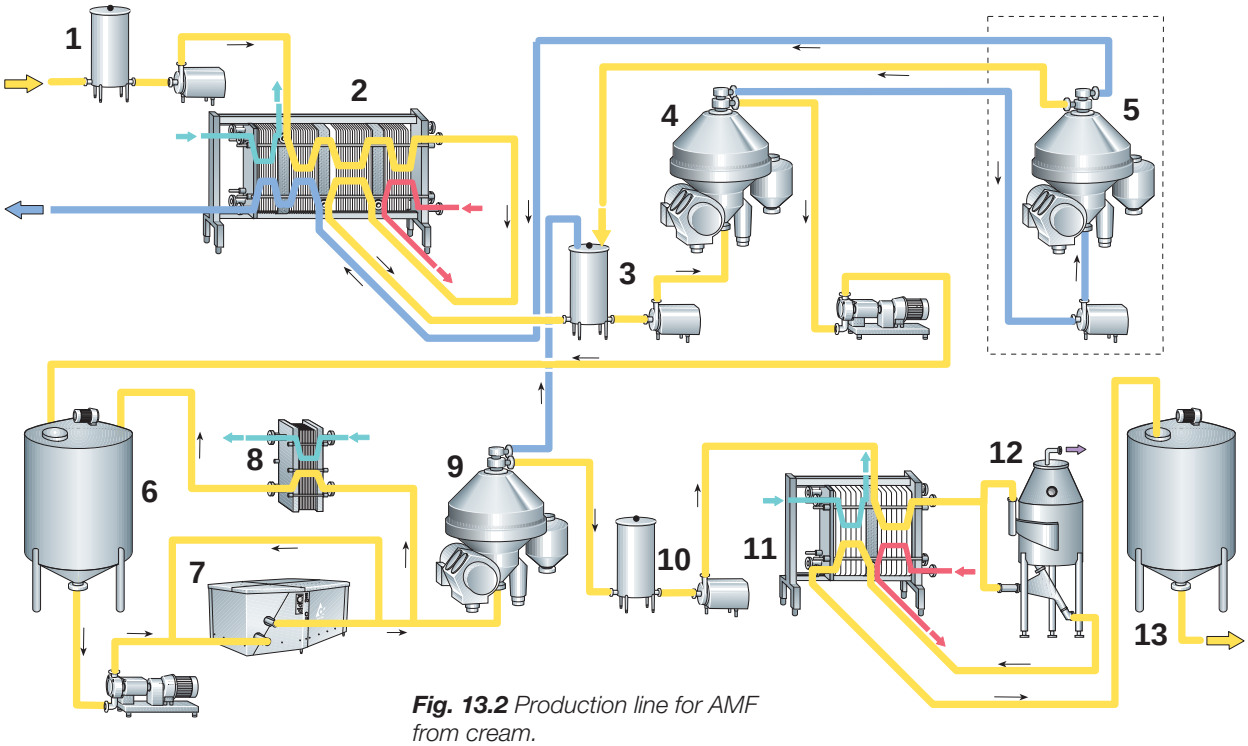


Fig. 13.2 *Production line for AMF from cream.*

1 *Balance tank*
2 *Plate heat exchanger for heating or pasteurisation*
3 *Balance tank*
4 *Pre-concentrator*
5 *Separator (optional) for "buttermilk" from the pre-concentrator (4)*
6 *Buffer tank*
7 *Homogeniser for phase inversion*
8 *Plate heat exchanger for cooling*
9 *Final concentrator*
10 *Balance tank*
11 *Plate heat exchanger for heating/cooling*
12 *Vacuum chamber*
13 *Storage tank*

Pasteurised or non-pasteurised cream of 35 – 40 % fat content enters the AMF plant via the balance tank (1) and is routed via the plate heat exchanger (2) for temperature adjustment or pasteurisation to the centrifuge (4) for pre-concentration of the fat to about 75 %. The temperature at pre-concentration and downstream to the plate heat exchanger (11) is maintained at approx. 60 °C. The “light” phase is collected in a buffer tank (6) to await further processing while the “heavy“ phase, typically called buttermilk, can be passed through a separator (5) for recovery of fat which will then be mixed with incoming cream (3). The skimmed buttermilk goes back to the plate heat exchanger (2) for heat recovery and then to a storage tank.

After intermediate storage in tank (6), the cream concentrate is fed to a homogeniser (7) for phase inversion (disruption of the fat globules to release the fat), after which it is passed through the final concentrator (9). In this concentrator the product is separated into a light phase with 99,5 % fat and a heavy phase, with a substantial amount of fat, which is returned to the process via balance tank (3).

As the homogeniser operates at a slightly higher capacity than the final concentrator, the surplus product not caught by the concentrator is recirculated to the buffer tank (6). Part of the mechanical energy used in the homogenisation process is converted into heat; to avoid disturbing the temperature cycle of the plant, this surplus heat is removed in the cooler (8).

Finally, the oil consisting of some 99,5 % fat is pre-heated to 95 – 98 °C in a plate heat exchanger (11) and routed into a vacuum chamber (12) to obtain a moisture content not exceeding 0,1 %, after which the oil is cooled (11) to approx. 40 °C, the typical packing temperature.

The key components of an AMF plant operating on cream are thus separators for concentration of fat and homogenisers for phase inversion.

Manufacture of AMF from butter

AMF is often produced from butter, especially from butter that is not expected to be used within a reasonable period of time. There may be some difficulty in achieving a completely bright oil after the final concentration step when freshly produced butter is the starting material; the oil tends to be impaired by slight cloudiness. This phenomenon does not occur with butter that has been stored for two weeks or more.

The reason for this phenomenon is not fully understood, but it is known that it takes some time (weeks) after churning before the “body” of the butter is fully developed. It has also been noted that when samples of butter are heated, the emulsion of fresh butter seems to be more difficult to split than that of aged butter and that it does not look so bright either.

Sweet cream, non-salted butter is normally used as the raw material, but cultured cream, salted butter may also be used.

Figure 13.3 shows a standard plant for production of AMF from butter. The plant is fed with butter from boxes (25 kg) which have been stored for some period of time. The raw material may also be frozen butter stored at – 25 °C.

After having been stripped of the boxes, the butter is melted by indirect heating in equipment of various kinds. Before the final concentration starts, the temperature of the melted butter should have reached 60 °C.

As a rule, melting by direct heating (steam injection) leads, to formation of a new type of emulsion with small air bubbles forming a dipersed phase, which is very difficult to separate. In the subsequent concentration, this phase is concentrated together with the oil and causes cloudiness.

After melting and heating, the hot product is pumped to a holding tank (2) where it may be held for up to 30 min, primarily to ensure complete melting, but also to allow the protein to aggregate.

From the holding tank, the product is pumped to the final concentrator (3), after which the light phase, containing 99,5% fat, proceeds to a plate heat exchanger (5) for heating to 90 – 95°C. From there is proceeds to a

vacuum vessel (6), and finally back to the plate heat exchanger (5) for cooling to the packing temperature of approx. 40°C.

The heavy phase can be pumped into a tank for buttermilk or into a waste-collecting tank, depending on whether it is “pure”, or contaminated with a neutraliser.

If the butter comes direct from a continuous buttermaker, the same risk of obtaining a cloudy oil arises as in the aforementioned case of fresh butter. However, with a final concentrator of hermetic design, it is possible to regulate the level inside the machine to obtain a bright oil phase of 99,5 % fat at a slightly lower volume, and a heavy phase of relatively high fat

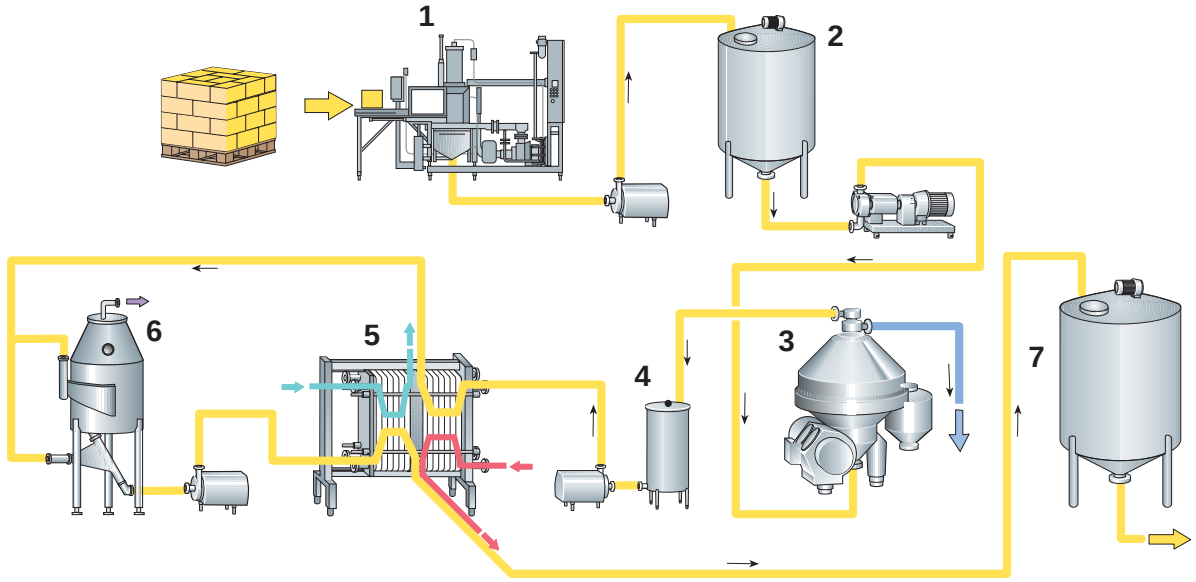


Fig. 13.3 *Production line for AMF from butter.*

1 *Melter and heater for butter*
2 *Holding tank*
3 *Concentrator*
4 *Balance tank*
5 *Plate heat exchanger for heating/ cooling*
6 *Vacuum chamber*
7 *Storage tank*

content (about 7 %) at a slightly higher volume. The heavy phase should then be reseparated and the cream obtained should be recycled, by mixing it with the cream fed to the continuous buttermaker.

AMF refining

AMF can be refined for various purposes. Examples of refining processes are:

- Polishing
- Neutralisation
- Fractionation
- Decholesterolisation

Polishing

Polishing involves washing of the oil with water to obtain a clear, shiny (bright) product. In this step, 20 – 30 % water is added to the oil coming from the final concentrator. The water temperature should be the same as the oil temperature. After a short hold, the water is separated out again, taking water-soluble substances (mainly protein) with it.

Neutralisation

Neutralisation is performed to reduce the level of free fatty acids (FFA) present in the oil. High levels of FFA give rise to off-flavours in the oil and the products in which it is used.

Alkali (NaOH) at a concentration of 8 – 10 % is added to oil in an amount corresponding to the level of FFA. After a hold of around 10 seconds, water is added in the same proportion as for polishing, and the saponified FFA is

separated out together with the water phase. It is important that the oil and alkali are well mixed, but this must be done gently to avoid re-emulsification of the fat.

The arrangement of a neutralisation step is shown in Figure 13.4. The alkali solution in tank (1), at 8 – 10 % concentration and a temperature equal to that of the oil leaving the final concentrator, is dosed (2) into the oil stream. After thorough mixing (3), the flow passes a holding section (4) for 10 seconds, after which hot water is dosed into the stream (5) in an amount of some 30 % of the flow en route to a second concentrator (6), via a mixing unit (7).

Fractionation

Fractionation is a process where the oil is separated into high-melting and low-melting fats. These fractions have different properties and can be used in various products.

There are several methods of fractionating fat, but the most commonly used is one in which no additives are used. The process can be briefly described as follows:

The AMF, often polished to obtain the highest possible degree of purity in the "raw oil", is melted and then cooled slowly to a calculated temperature at which the specified fraction crystallises out while fractions with lower melting points remain liquid. The crystals are harvested with special filters. The filtrate is then cooled to a lower temperature at which other fractions crystallise and are harvested, and so on.

Decholesterolisation

Decholesterolisation is a process in which cholesterol is removed from the AMF.

A frequently used method is to mix the oil with a modified starch, beta-cyclodextrine (BCD). The BCD molecule surrounds the cholesterol and forms a precipitate, which can be separated out by centrifugation.

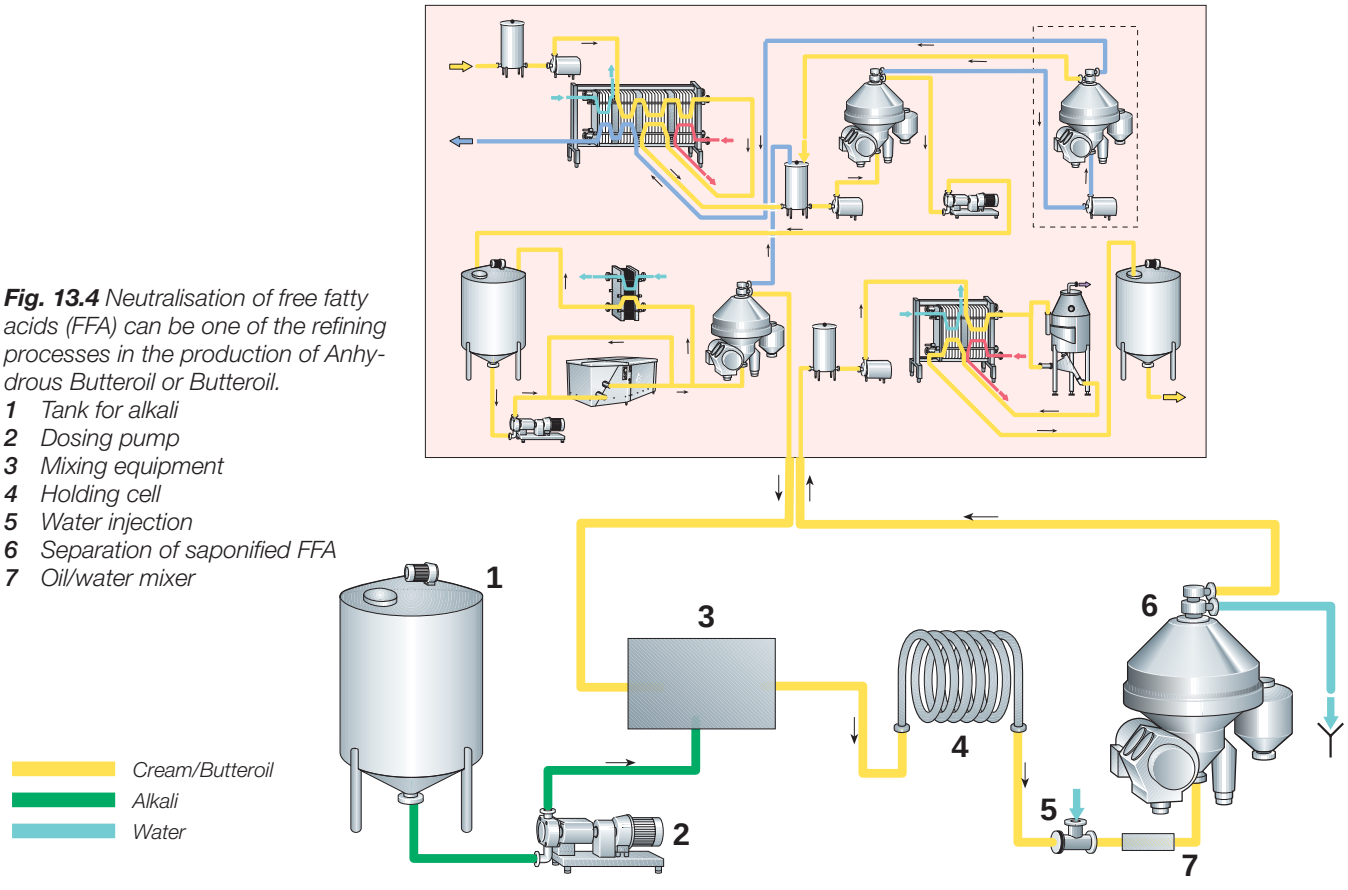


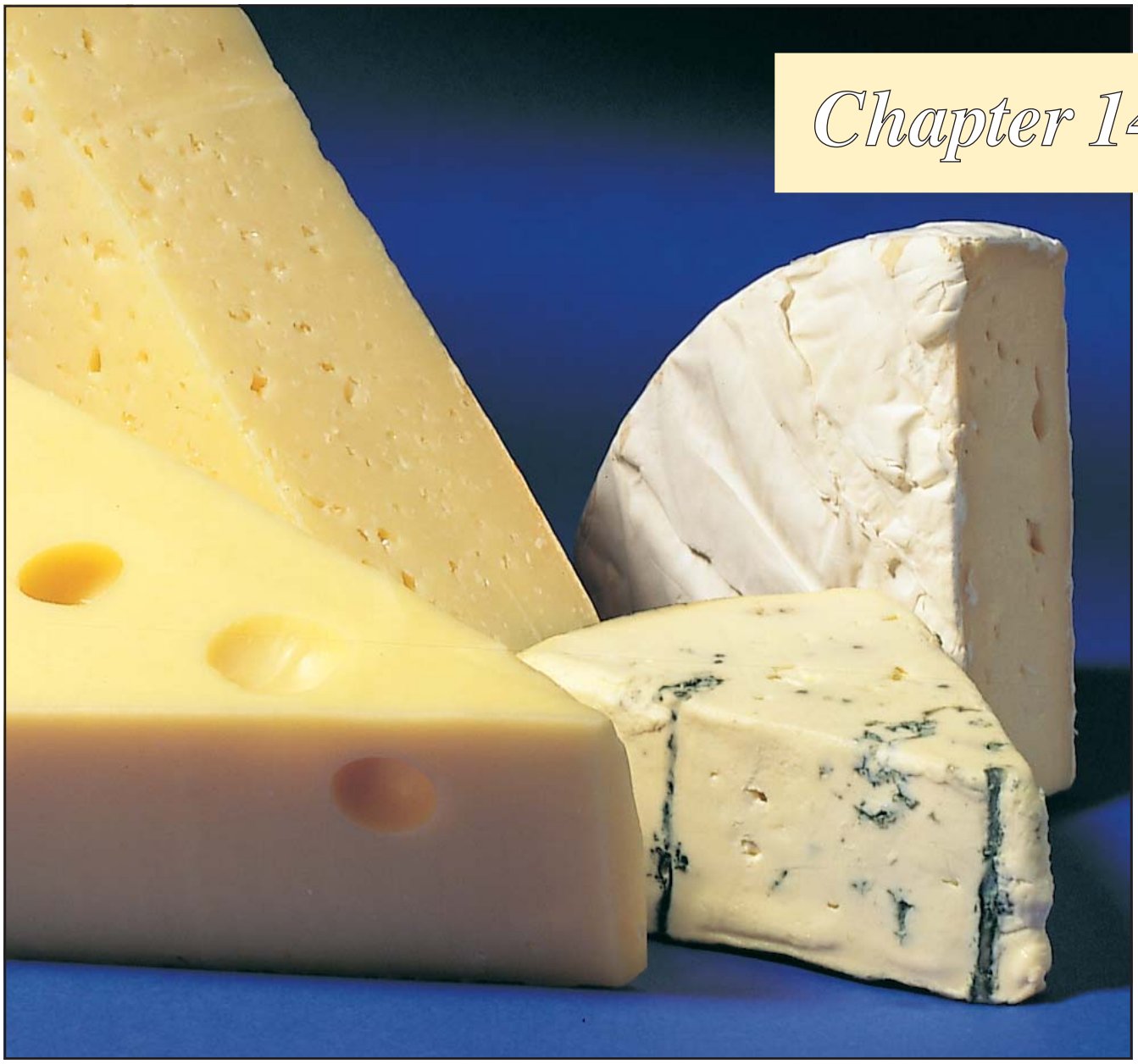
Fig. 13.4 *Neutralisation of free fatty acids (FFA) can be one of the refining processes in the production of Anhydrous Butteroil or Butteroil.*

1 *Tank for alkali*
2 *Dosing pump*
3 *Mixing equipment*
4 *Holding cell*
5 *Water injection*
6 *Separation of saponified FFA*
7 *Oil/water mixer*

Packaging

AMF is filled in containers of various sizes. For households and restaurants, containers of 1 kg to 19,5 kg are available and for industrial uses drums of at least 185 kg are used.

Normally an inert gas, nitrogen (N_2), is first injected in the container. As the N_2 gas is heavier than air, it sinks to the bottom. When filling the AMF – which is heavier than N_2 – the AMF will sit underneath and the N_2 gas will create an “air-tight lid”, preventing the AMF from air-induced oxidation.



Chapter 14

Cheese

Tradition and basic knowledge

- *Cheese has been made in most cultures since ancient times.*
- *Cheese is a milk concentrate, the basic solids of which consist mainly of protein (actually casein) and fat. The residual liquid is called whey.*
- *As a rule of thumb, the casein and fat in the milk are concentrated approximately 10 times in production of hard and some semi-hard types of cheese.*
- *No strict definition of the concept of cheese is possible, as so many variants exist.*

- The moisture content of the cheese serves to distinguish various categories, such as hard (low-moisture), semi-hard and soft cheeses. A generally accepted classification of cheese is given in FAO/WHO Standard No. A 6.
- Each category is distinguished by a number of characteristics, such as structure (texture, body), flavour and appearance, which result from the type of milk, the choice of bacteria and the manufacturing technique employed.
- Processed cheese is a heat-treated product based on different types of cheese of varying age according to FAO/WHO Standard No. A 8 (b).
- Whey cheese is a type of cheese predominantly produced in Norway and Sweden and is defined according to FAO/WHO Standard No. A 7 as follows:

  Whey cheeses are products obtained by the concentration of whey and the moulding of concentrated whey, with or without the addition of milk and milk fat.
- Cream cheese is a soft unripened cheese briefly described in the FAO/WHO Standard C 31 as "possessing a mild creamy or acid flavour and aroma typical of a milk product cultured with lactic acid and aroma-producing bacteria. It spreads and mixes readily with other foods".

Terminology for classification of cheese

(Source: Codex Alimentarius, FAO/WHO, Standard A6)
Cheese is the fresh or ripened solid or semi-solid product in which the whey protein/casein ratio does not exceed that of milk, obtained:

A By coagulating (wholly or partly) the following raw materials: milk, skimmed milk, partly skimmed milk, cream, whey cream, or buttermilk, through the action of rennet or other suitable coagulating agents, and by partially draining the whey resulting from such coagulation;

or

B By processing techniques involving coagulation of milk and/or materials obtained from milk that give an end product which has similar physical, chemical and organoleptic characteristics as the product systemised under Classification of cheese.

In 1974 some Russians found a cheese in the permafrost of the Siberian tundra. It was at least 2 000 years old and was said to be an unrivalled delicacy.

Definitions

1.1 Cured or ripened cheese is cheese that is not ready for consumption shortly after manufacture, but which must be held for such time, at such temperature, and under such other conditions as will result in the necessary biochemical and physical changes characterising the cheese.

1.2 Mould-cured or mould-ripened cheese is a cured cheese in which the curing has been accomplished primarily by the development of characteristic mould growth throughout the interior and/or on the surface of the cheese.

1.3 Uncured, unripened or fresh cheese is cheese that is ready for consumption shortly after manufacture.

Classification of cheese

The classification shown in Table 14.1 applies to all cheeses covered by this standard. However, this classification shall not preclude the designation of more specific requirements in individual cheese standards.

Table 14.1
Classification of cheese

Term I		Term II	Term III
If the MFFB* is, %	**The 1st phrase in the designation shall be**	**If the FDS** is, %**	**The 2nd phrase in the designation shall be**	**Designation according to principal curing characteristics**
< 41	Extra hard	> 60	High fat	1. Cured or ripened
49 – 56	Hard	45 – 60	Full fat	a. mainly surface
54 – 63	Semi-hard	25 – 45	Medium fat	b. mainly interior
61 – 69	Semi-soft	10 – 25	Low fat	2. Mould cured or ripened
> 67	Soft	< 10	Skim	a. mainly surface
				b. mainly interior
				3. Uncured or unripened***

* MFFB equals percentage moisture on fat-free basis, *i.e.*

$$\frac{\text{Weight of moisture in the cheese}}{\text{Total weight of cheese – weight of fat in cheese}} \times 100$$

** FDS equals percentage fat on dry basis, *i.e.*

$$\frac{\text{Fat content of the cheese}}{\text{Total weight of cheese – weight of moisture in cheese}} \times 100$$

*** Milk intended for this type of cheese to be pasteurised.

Examples:

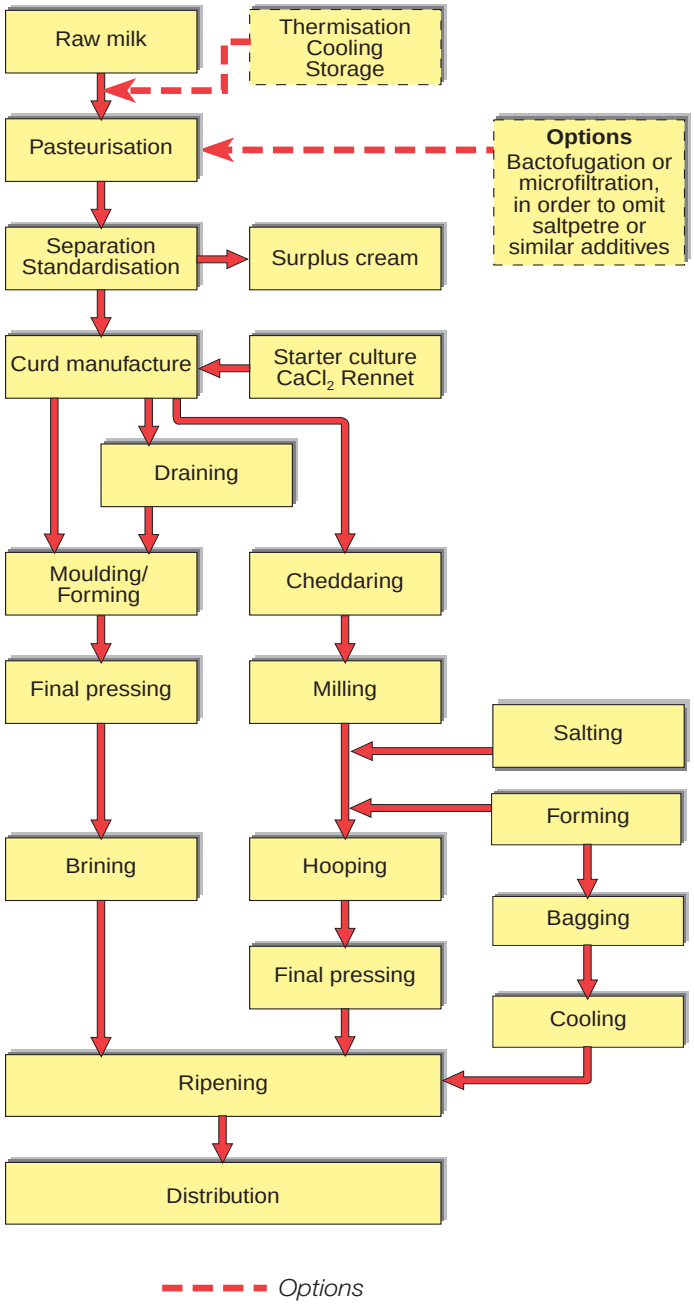
Type	Origin	FDB	MFFB	Term 1
Parmesan	I	35+	≈ 40 %	Extra hard
Grana	I	35+	≈ 41 %	Extra hard
Emmenthal	CH	45+	≈ 52 %	Hard
Gruyère	F	45+	≈ 52,5 %	Hard
Cheddar	UK	50+	≈ 55 %	Hard/Semi-hard
Gouda	NL	45+	≈ 57 %	Semi-hard
Tilsiter	D	45+	≈ 57 %	Semi-hard
Havarti	DK	45+	≈ 59 %	Semi-hard
Blue cheese	DK, F, S etc.	50+	≈ 61 %	Semi-hard/Semi-soft
Brie	F	45+	≈ 68 %	Semi-soft
Cottage cheese	USA	>10	< 69 %	Soft

Cheese production – general procedures for hard and semi-hard cheese

Cheesemaking involves a number of main stages that are common to most types of cheese. There are also other modes of treatment that are specific to certain varieties. The main stages for production of hard and semi-hard cheese are illustrated schematically on the block chart in Figure 14.1.

The cheese milk is pre-treated, possibly pre-ripened after addition of a bacteria culture appropriate to the type of cheese, and mixed with rennet. The enzyme activity of the rennet causes the milk to coagulate into a solid gel known as coagulum. This is cut with special cutting tools into small cubes of the desired size – primarily to facilitate expulsion of whey.

During the rest of the curdmaking process, the bacteria grow and



Cheese milk

Fat standardisation

- Fat relative to SNF (Casein) = F/SNF (Casein)

Pasteurisation

- 70-72 °C/15-20 s (not always employed)
- Cooling to renneting temperature about 30 °C

Options

Mechanical reduction of bacteria

- Bactofugation
- Microfiltration

From milk to cheese

In the cheese vat

- Conditioning of cheese milk
  - Additives:
    - Calcium chloride
    - Saltpetre, if permitted by law
    - Starter bacteria, appropriate to type of cheese
    - Rennet as coagulant

Coagulum

- Cutting into grains (curd)
- Removing part of the whey
- Adding water
- Heating, scalding, directly or indirectly, depending on type of cheese
- Collection of curd for pre-pressing and/or final moulding/pressing, and if required
- Brine salting or for cheddar cheese
- Cheddaring followed by milling, salting, hooping, and pressing
- Formed, pressed, and salted cheese to ripening room storage for required time

Fig. 14.1 *Process flow in production of hard and semi-hard cheese.*

multiply and form lactic acid from the lactose. The curd grains are subjected to mechanical treatment with stirring tools, while at the same time the curd is heated, according to a pre-set program. The combined effect of these three actions – growth of bacteria, mechanical treatment and heat treatment – results in syneresis, *i.e.* expulsion of whey from the curd grains. The finished curd is placed in cheese moulds, mostly made of plastic, which determine the shape and size of the finished cheese.

The cheese is pressed, either by its own weight or more commonly by applying pressure to the moulds. Treatment during curdmaking, pressing, brining and storage conditions determines the characteristics of the cheese.

The process flow chart in Figure 14.1 also shows salting and storage. Finally, the cheese is coated, wrapped or packed.

Milk treatment prior to cheesemaking

The suitability of milk as a raw material for cheese production depends largely on conditions at the dairy farm. Quite apart from the general demand

for strict hygienic conditions, *milk from sick cows or animals undergoing treatment with antibiotics must not be used for cheesemaking, or any other milk product.*

Feeding animals on badly prepared silage can adversely affect the quality of several varieties of cheese.

Milk from sick cows or animals undergoing treatment with antibiotics must not be used for cheesemaking, or any other milk product.

Milk collection

With the traditional method of milk reception, i.e. morning delivery of milk in churns to the dairy in the course of a few hours of all milk needed for the day's production, the milk was treated almost immediately after being weighed in. The fat content was then standardised in conjunction with separation and pasteurisation and, after regenerative cooling to renneting temperature, the milk was pumped to the cheesemaking tanks.

The practice of collecting milk from farms at intervals of two or three days is widespread. This means that particularly stringent requirements must be met regarding the way the milk is treated by the producers. Especially a quick cooling of the collected milk to 4 °C is essential.These requirements also extend to the tanker driver, who collects the milk on the farmhouses. He must have the authority to refuse to accept milk that is even slightly affected and/or impaired by off-flavours. Bovine mastitis is a common disease that causes the cow pain as well as drastically affecting the composition and the quality of the milk; farmers must discard such milk, or at least not send it to the dairy.

Heat treatment and mechanical reduction of bacteria

Thermisation

Thermisation
Moderate heat treatment at 65 °C for 15 s which is often given to cheese milk.

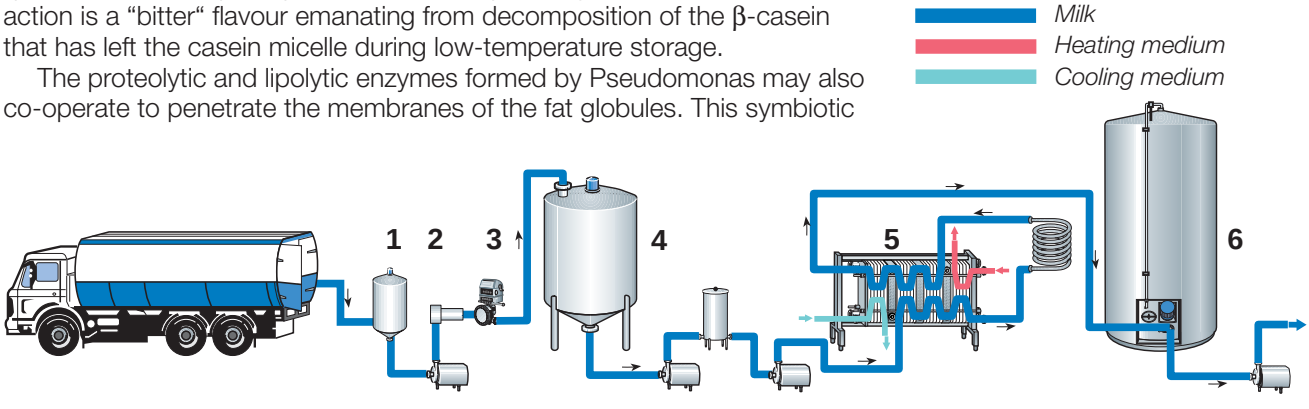
When collection of milk on alternate days was introduced, cheese producers who had to use such milk noticed that the quality of the cheese frequently deteriorated. This tendency was particularly noticeable when the milk had to be stored a further day after reception, even when it was chilled to 4 °C in conjunction with transfer from road tanker to storage tank. Even longer storage times may be expected when working weeks are limited to six or even five days.

During cold storage, the milk protein and milk salts change character, which tends to impair cheesemaking properties. It has been shown that about 25 % of the calcium precipitates as phosphate after 24 hours storage at +5 °C. This reduction, however, is temporary. When the milk is pasteurised, the calcium redissolves and the coagulating properties of the milk are almost completely restored. β-casein also leaves the complex casein micelle system during cold storage, which further contributes to reducing the cheesemaking properties. However, this reduction too is almost completely restored by pasteurisation.

Another and equally important phenomenon is that the microflora introduced into the milk by recontamination – especially *Pseudomonas spp* – will adapt to the low temperature at which their enzymes, proteinases and lipases, will decompose protein and fat respectively. The result of such action is a "bitter" flavour emanating from decomposition of the β-casein that has left the casein micelle during low-temperature storage.

The proteolytic and lipolytic enzymes formed by Pseudomonas may also co-operate to penetrate the membranes of the fat globules. This symbiotic

Fig. 14.2 *Reception arrangements for cheese milk.*
1 *Air eliminator*
2 *Filter*
3 *Milk meter*
4 *Intermediate storage tank*
5 *Thermisation and cooling or cooling only*
6 *Silo tank*



co-operation leads to liberation of fatty acids, especially the lower ones, by lipase action, giving the milk a rancid flavour.

So, if milk that is already at least 24 – 48 hours old cannot be processed within about 12 hours after arrival at the dairy, it is advisable to chill it to about +4 °C or, preferably, thermise it.

Thermisation means moderate heat treatment, 65 °C for 15 seconds, followed by cooling to +4 °C, after which the milk is still phosphatase positive. This technique was basically introduced for the purpose of arresting growth of psychrotrophic flora when milk was stored for a further 12 – 48 hours after arrival at the dairy. As mentioned in Chapter 1, the "critical age" of raw milk kept at +4 °C normally falls between 48 and 72 hours after milking. Figure 14.2 shows the arrangement of a milk reception station.

Pasteurisation

Before the actual cheesemaking begins, the milk usually undergoes pre-treatment designed to create optimum conditions for production.

Milk intended for cheese that requires more than one month of ripening needs not necessarily be pasteurised, but usually is. National legislation often stipulates if the milk has to be pasteurised or not.

From Table 14.1, you can see that milk intended for unripened cheese (fresh cheese) must be pasteurised. This implies that cheese milk for types needing a ripening period of at least one month need not be pasteurised.

On the other hand, whey used for fodder must be pasteurised, to prevent it from spreading bovine diseases. However, if the cheese milk is pasteurised, it is not necessary to pasteurise the whey separately.

Milk intended for original Emmenthal, Parmesan and Grana, some extra hard types of cheese, must not be heated to more than 40 °C, to avoid affecting flavour, aroma and whey expulsion. Milk intended for these types of cheese normally comes from selected dairy farms with frequent veterinary inspection of the herds.

Regular HTST pasteurisation at 72 – 73 °C for 15 – 20 seconds is most commonly applied.

Although cheese made from unpasteurised milk is considered to have a better flavour and aroma, most producers (except makers of the extra hard types) pasteurise the milk, because its quality is seldom so dependable that they are willing to take the risk of not pasteurising it. Pasteurisation equalises the bacterial composition of the milk from one day to the next, eliminating disturbances in an automatic or time-controlled process.

Pasteurisation must be sufficient to kill bacteria capable of affecting the quality of the cheese, e.g. Coliforms, which can cause early "blowing" and a disagreeable taste. It must also kill most of the natural pathogenic bacteria.

Regular HTST pasteurisation at 72 – 73 °C for 15 – 20 seconds is therefore most commonly applied. (Phosphatase negativ).

However, spore-forming micro-organisms in the spore state survive pasteurisation and can cause serious problems during the ripening process. One example is Clostridium tyrobutyricum, which forms butyric acid and large volumes of hydrogen gas by fermenting lactic acid. The butyric acid has an unsavoury taste, and the gas destroys the texture of the cheese completely.

More intense heat treatment would reduce this particular risk, but would also seriously impair the general cheesemaking properties of the milk, as it increases the level of denaturated whey proteins. This is unacceptable in terms of both quality and legal requirements. Other means of reducing thermo-tolerant bacteria are therefore used.

Traditionally, certain chemicals have been added to cheese milk prior to production to prevent "blowing" and development of the unpleasant flavour caused by heat-resistant, spore-forming bacteria (principally Clostridium tyrobutyricum). The most commonly used chemical is sodium nitrate ($NaNO_3$), but in the production of Emmenthal cheese, hydrogen peroxide (H_2O_2) is also used. However, as the use of chemicals has been widely criticised, mechanical means of reducing the number of unwanted micro-organisms have been adopted, particularly in countries where the use of chemical inhibitors is banned. These inhibitors can also effect some off the added bacteria in the starter culture.

Mechanical reduction of bacteria

Bactofugation

As discussed in Chapter 6.2, bactofugation is a process in which a specially designed hermetic centrifuge, the Bactofuge®, is used to separate bacteria, and especially the spores formed by specific bacteria strains, from milk.

Bactofugation has proved to be an efficient way of reducing the number of spores in milk, since their density is higher than that of milk. Bactofugation normally separates the milk into a fraction that is more or less free from bacteria, and a concentrate (bactofugate), which contains both spores and bacteria in general and amounts to up to 3 % of the feed to the Bactofuge. Bactofugation of milk is mostly a part of milk pre-treatment.

In applications where quality milk for cheese and powder production is the objective, the Bactofuge is installed in series with the centifugal separator, either downstream or upstream of it.

The same temperature is often chosen for bactofugation as for separation, typically 55 – 60 °C.

There are two types of Bactofuge:

- Two-phase Bactofuge
- One-phase Bactofuge

The two-phase Bactofuge has two outlets at the top:

– one for continuous discharge of the heavy phase (bactofugate) via a special top disc, and
– one for the bacteria-reduced phase

The one-phase Bactofuge has one outlet at the top of the bowl, for bacteria-reduced milk. The bactofugate is collected in the sludge space of the bowl and discharged at pre-set intervals through ports in the bowl body.

These two types make it possible to choose various combinations of equipment to optimise the bacteriological status of milk used for both cheesemaking and other purposes.

It should be mentioned at this point that whey, if intended for production of whey protein concentrate as an ingredient in infant formulae, should be bactofuged after recovery of fines and fat.

Process alternatives

There are about ten possible ways to configure a bactofugation plant; three examples are given here:

Two-phase Bactofuge with continuous discharge of bactofugate

This concept, shown in Figure 14.3, works under airtight conditions and produces a continuous flow of air-free bacteria concentrate (bactofugate) as the heavy phase. This phase, comprising up to 3 % of the feed flow (adjusted by an external pump with variable speed control) is often sterilised and remixed with the main flow.

The steriliser can be of different types; plate heat exchanger, tubular or infusion heater. Typical heat treatment is 120 °C for one minute, which is sufficient to inactivate spores from Clostridia micro-organisms. After cooling, the bactofugate can be remixed with the bactofugated milk before it is pasteurised at 72 °C for 15 seconds followed by regenerative cooling to the renneting temperature.

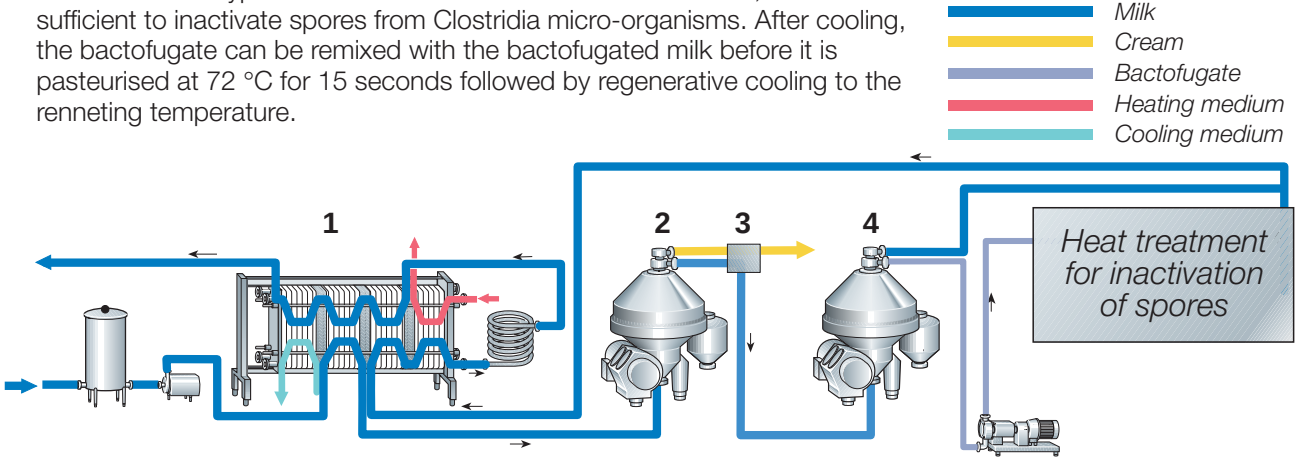


Fig.14.3 *Bactofugation with continuous discharge, sterilisation and remix of the bactofugate.*
1 *Pasteuriser*
2 *Centrifugal separator*
3 *Automatic standardisation system*
4 *Two-phase Bactofuge*

The Bactofuge with continuous discharge of bactofugate is used in applications where:

- Remixing of sterilised bactofugate is possible
- There is an alternative use for the bactofugate in a product where the heat treatment is strong enough to inactivate the micro-organisms

At nominal capacity a Bactoguge reduce approximately 98 % of spores from *Cl. Tyributyricum* and 95 % of the aerobic forming spores.

One-phase Bactofuge with intermittent discharge of bactofugate

To achieve the same reduction effect as mentioned above, nominal capacities are likewise recommended. The bactofugate from a one-phase Bactofuge is discharged intermittently through ports in the bowl body at pre-set intervals of 15 – 20 minutes, which means that the bactofugate will be rather concentrated and thus also low in volume, 0,15 – 0,2 % of the feed. When the bactofugate is to be re-introduced into the cheese milk, it must be sterilised. This is illustrated in Figure 14.4, which also shows that before being pumped to the steriliser, the concentrate is diluted with bactofuged milk (about 1,8 % of the feed) to obtain a sufficient volume for proper sterilisation. Starting and stopping of the discharge pump (5) is linked to the operation mode of the discharge system of the Bactofuge.

Where legislation does not permit re-use of the bactofugate, it can be discharged to the drain or collected in a tank.

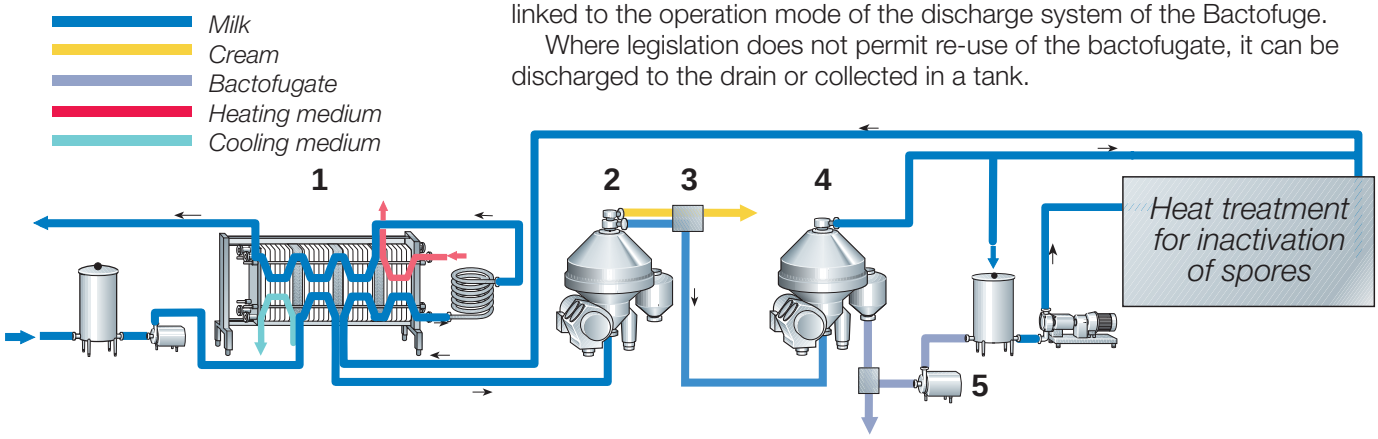


Fig.14.4 *Bactofugation with intermittent discharge of the bactofugate and steriliser.*
1 *Pasteuriser*
2 *Centrifugal separator*
3 *Automatic standardisation system*
4 *One-phase Bactofuge*
5 *Discharge pump*

Double bactofugation with two one-phase Bactofuges in series

Bactofuging milk once is not always sufficient, particularly with high spore loads in the milk. With double bactofugation, reduction of *Clostridia* spores reaches more than 99 %. Figure 14.5 illustrates a plant with two one-phase Bactofuges in series serving one sterilising unit.

The bactofugate treatment procedure mentioned above applies here too.

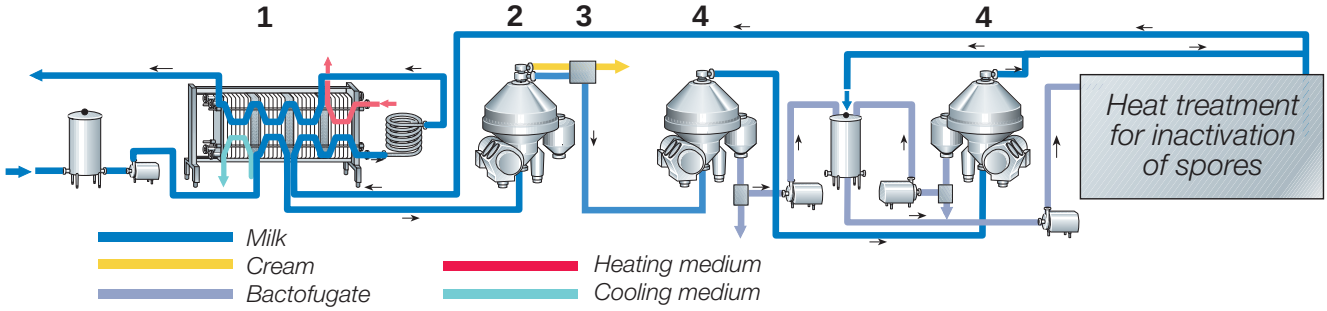
Double bactofugation is sufficient (in most cases) to produce cheese without addition of bacteria-inhibiting chemicals. However, for safety reasons, during periods when very high loads of spore-formers are expected, small amounts of chemicals (2,5 – 5,0 g per 100 l of milk) may be used, if legally allowed.

Fig.14.5 *Double bactofugation with steriliser.*
1 *Pasteuriser*
2 *Centrifugal separator*
3 *Automatic standardisation system*
4 *One-phase Bactofuge*

Microfiltration

It has been known for a long time that a membrane filter with a pore size of approximatly 0,2 micron can filter bacteria from a water solution.

In microfiltration of milk, the problem is that most of the fat globules and



some of the proteins are as large as, or larger than, the bacteria. This results in the filter fouling very quickly when membranes of such a small pore size are chosen. It is thus the skim milk phase that passes through the filter, while the cream needed for standardisation of the fat content is sterilised, typically together with the bacteria concentrate obtained by simultaneous microfiltration. The principle of microfiltration is discussed in Chapter 6.4, Membrane filters.

In practice, membranes with a pore size of 1,4 micron are chosen to lower the concentration of protein. In addition, the protein forms a dynamic membrane that contributes to the retention of micro-organisms.

The microfiltration concept includes an indirect sterilisation unit for combined sterilisation of an adequate volume of cream for fat standardisation and of retentate from the filtration unit.

Figure 14.6 shows a milk treatment plant with microfiltration. The microfiltration plant is provided with two loops working in parallel. Each loop can handle up to 5 000 l/h of skim milk, which means that this plant has a throughput capacity of approximately 10 000 l/h. Capacity can thus be increased by adding loops.

The raw milk entering the plant is pre-heated to a suitable separation temperature, typically about 60 – 63 °C, at which it is separated into skim milk and cream. A pre-set amount of cream, enough to obtain the desired fat content in the cheese milk, is routed by a standardisation device to the sterilisation plant.

In the meantime, the skim milk is piped to a separate cooling section in the sterilising plant to be cooled to 50 °C, the normal microfiltration temperature, before entering the filtration plant.

The flow of milk is divided into two equal flows, each of which enters a loop where it is fractionated into a bacteria-rich concentrate (retentate), comprising about 5 % of the flow, and a bacteria-reduced phase (permeate).

The retentates from both loops are then united and mixed with the cream intended for standardisation before entering the steriliser. Following sterilisation at 120 – 130 °C for a few seconds, the mixture is cooled to about 70 °C before being remixed with the permeate. Subsequently, the total flow is pasteurised at 70 – 72 °C for about 15 seconds and cooled to renneting temperature, typically 30 °C.

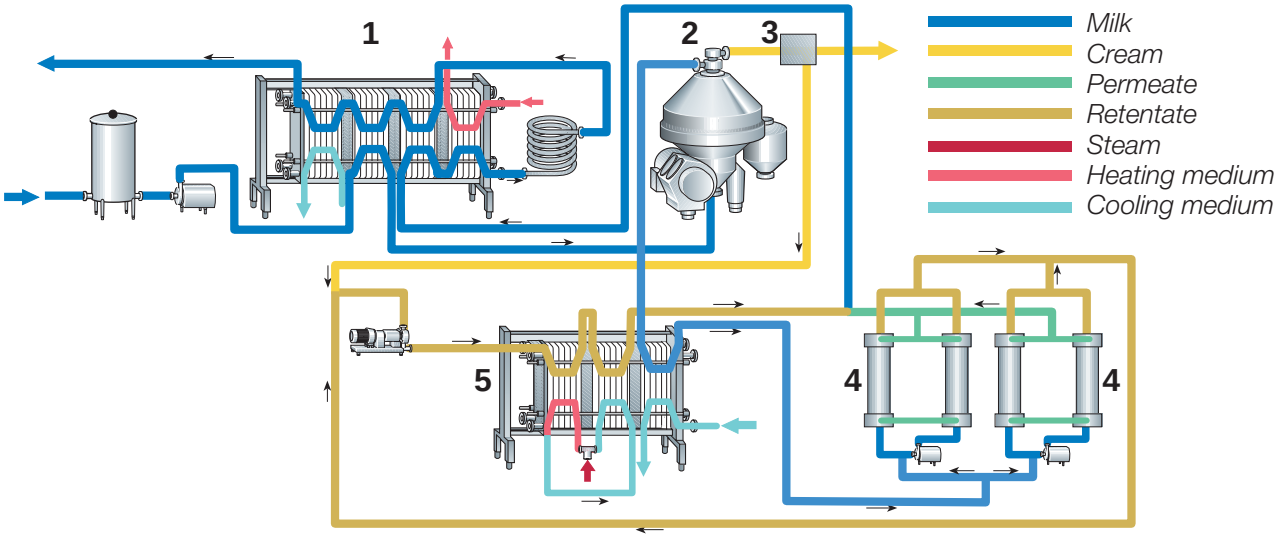
Due to its high bacteria-reducing efficiency, microfiltration allows production of hard and semi-hard cheese without requiring chemicals to inhibit growth of Clostridia spores.

Standardisation

Types of cheese are often classified according to fat on dry solids, FDS. The fat content of the cheese milk must therefore be adjusted accordingly. The

Fig.14.6 *Milk treatment including double-loop microfilter and sterilisation of bacteria concentrate, together with the cream needed for fat standardistion of the cheese milk.*

1 *Pasteuriser*
2 *Centrifugal separator*
3 *Automatic standardisation system*
4 *Double-loop microfiltration plant*
5 *Sterilisation plant*



protein content of the cheese milk can in some cases also be standardised. For this reason, the protein and fat contents of the raw milk should be measured throughout the year and the ratio between them standardised to the required value. Figure 14.7 shows an example of how the fat and protein content of milk can vary during one year (the figures are a five-year average).

The final fat, protein and dry solids ratios are important factors in the yield and quality of the cheese.

Fat standardisation

Standardisation of fat can be accomplished either by in-line remixing after the separator (see Chapter 6.2, Automatic in-line standardisation systems), or, for example, by mixing whole milk and skim milk in tanks followed by pasteurisation. The fat content must finally be adjusted to the protein content, in order to achieve the desired fat in dry solids ratio.

Protein standardisation

The protein level of the milk can be adjusted by membrane filtration techniques or by adding skim milk powder. The protein content can be levelled up to a constant value corresponding to the maximum level of the year.

When the protein content is increased by ultrafiltration, the level of total dry solids in the milk increases. This affects the cheesemaking process, and ultimately the quality of the cheese. It is also possible to standardise the casein fraction, not just the total protein content.

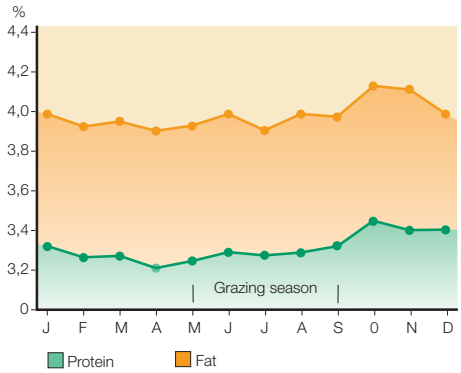


Fig. 14.7 *Example of seasonal variations in milk protein and fat content. Average figures for five years.*

Additives in cheese milk

The essential additives in the cheesemaking process are the starter culture and the rennet. Under certain conditions it may also be necessary to supply other components such as calcium chloride ($CaCl_2$) and saltpetre (KNO_3 or $NaNO_3$). An enzyme, *Lysozyme,* has also been introduced as a substitute for saltpetre to inhibit *Clostridia* organisms.

Starter

The starter culture is a very important factor in cheesemaking; it performs several duties.

Two principal types of culture are used in cheesemaking:

- *Mesophilic* cultures with a temperature optimum between 25 and 40 °C
- *Thermophilic* cultures, which develop at up to 50 °C

The most frequently used cultures are *mixed strain cultures*, containing two or more strains of bacteria, which can support each other in their functioning. Mixed strain cultures often consist of either a cocktail of mesophilic bacteria or thermophilic bacteria, or sometimes a combination of both. These cultures not only produce lactic acid, but also have the ability to form gas (CO_2) and aroma components. Carbon dioxide is essential for creating the holes in round-eyed cheeses and supports the openness of granular types of cheese. Gouda, Manchego and Tilsiter are based on mesophilic cultures, and Emmenthal and Gruyère on thermophilic cultures.

Single-strain cultures are mainly used where the object is to develop acid and contribute to protein degradation, *e.g.* in Cheddar and related types of cheese.

Three characteristic abilities of starter cultures are of primary importance in cheesemaking:

1. Produce lactic acid
2. Break down the protein and, when applicable
3. Produce carbon dioxide (CO_2)

The main task of the culture is to develop acid in the curd.

When milk coagulates, bacteria cells are concentrated in the coagulum. Forming of acid lowers the pH, which is important in assisting syneresis (contraction of the coagulum accompanied by expelling of whey). Furthermore, salts of calcium and phosphorus are released, which influence

The main task of the culture is to develop acid in the curd.

the consistency of the cheese and help to increase the firmness of the curd.

Another important function performed by the acid-producing bacteria is to suppress surviving bacteria from pasteurisation or recontamination bacteria, which either need lactose or cannot tolerate lactic acid.

Production of lactic acid stops when all the lactose in the cheese (except in soft cheeses) has been fermented. Lactic acid fermentation is normally a relatively fast process. For some types of cheese, such as Cheddar, it must be completed before the cheese is pressed, and for other types within a week.

If the starter also contains CO_2-forming bacteria, acidification of the curd is accompanied by production of carbon dioxide through the action of citric acid fermenting bacteria. Hetero fermentative bacteria in a mixed strain starter culture have the ability to develop CO_2 and are essential for production of cheese with a texture of round holes/eyes or irregularly shaped eyes. The evolved gas is initially dissolved in the moisture phase of the cheese; when the solution becomes saturated, the gas is released and creates the eyes.

The ripening process in hard and certain semi-hard cheeses is a combined proteolytic effect in which the original enzymes of the milk and those of the bacteria in the culture, together with rennet enzyme, cause the break down of the protein into peptides and amino acids.

Disturbances in cultures

Disturbances in the form of slow acidification or failure to produce lactic acid can sometimes occur.

One of the most common causes is the presence of *antibiotics* used to cure udder diseases.

Another possible source is the presence of *bacteriophages,* thermo-tolerant viruses found in the air and soil.

The detrimental action of both phenomena is discussed in Chapter 10, Cultures and starter manufacture.

A third cause of disturbance is *detergents and sterilising agents* used in the dairy. Carelessness, especially in the use of sanitisers, is a frequent cause of culture disturbances.

Disturbances in the form of slow acidification or failure to produce lactic acid can depend on:

- Antibiotics
- Bacteriophages
- Detergent residues

Calcium chloride ($CaCl_2$)

A low concentration of Ca ions in the cheese milk causes a soft coagulum. This results in heavy losses of fines (casein) and fat, as well as poor syneresis during cheesemaking.

Between 5 – 20 g of calcium chloride per 100 kg of milk is normally enough to achieve a constant coagulation time and result in sufficient firmness of the coagulum. By adding more $CaCl_2$ the amount of rennet used can be reduced, as the $CaCl_2$ supports the action of rennet. However, excessive addition of calcium chloride may make the coagulum so hard that it is difficult to cut.

For production of *low-fat* cheese, and if legally permitted, *disodium phosphate* (Na_2PO_4), usually 10 – 20 g/kg, can sometimes be added to the milk before addition of calcium chloride. This increases the elasticity of the coagulum due to formation of colloidal calcium phosphate, $Ca_3(PO_4)_2$, which will have almost the same effect as the milk fat globules entrapped in the curd.

Carbon dioxide (CO_2)

Addition of CO_2 is a method of improving the quality of cheese milk, as the carbon dioxide acts as an inhibitor. Carbon dioxide occurs naturally in milk, but most of it is lost in the course of processing. Adding carbon dioxide by artificial means lowers the pH of the milk. This will then result in shorter coagulation time and a reduction of the amount of rennet.

Saltpetre ($NaNO_3$ or KNO_3)

As previously mentioned, fermentation problems may be experienced if the cheese milk contains spores of butyric-acid bacteria (*Clostridia)* and/or

Coliform bacteria. Saltpetre (sodium or potassium nitrate) can be used to counteract these bacteria, but the dosage must be accurately determined with reference to the composition of the milk, the process for the type of cheese, etc., as too much saltpetre will also inhibit growth of the starter. Overdosage of saltpetre may affect the ripening of the cheese or even stop the ripening process.

Saltpetre in high doses may discolour the cheese, causing reddish streaks and an impure taste. If there is no mechanical method used to reduce spores (bactofugation or microfiltration), it is normal to add around 15 – 20 g of sodium nitrate per 100 l of milk to inhibit their growth. However, with single bactofugation and a high load of spores in milk, 2,5 – 5,0 g per 100 l of milk will prevent the remaining spores from growing. The maximum permitted dosage is about 30 g of saltpetre per 100 kg of milk.

For semi-hard cheese types, the sodium nitrate can be added after whey suction and before water addition. The advantage is that the saltpetre amount can be lowered and the nitrate level in the total whey is reduced.

In recent times, usage of saltpetre has been questioned from a medical point of view, and in some countries it is also forbidden.

If the milk is treated in a Bactofuge or a microfiltration plant, the saltpetre requirement can be radically reduced or even eliminated. This is an important advantage, as an increasing number of countries are prohibiting the use of saltpetre. For Emmenthal cheese, saltpetre may not be used, as it reduces the forming of round holes.

Colouring agents

The colour of cheese is to a great extent determined by the colour of the milk fat, and undergoes seasonal variations. Colours such as *carotene* and *orleana*, an anatto dye, are used to correct these seasonal variations in countries where colouring is permitted.

Green chlorophyll (contrast dye) is also used, for example in blue veined and Feta cheeses, to obtain a “pale” colour as a contrast to the blue mould.

Rennet

Except for fresh cheese types such as cottage cheese and quarg, in which the milk is clotted mainly by lactic acid, all cheese manufacture depends upon formation of curd by the action of rennet or similar enzymes.

Coagulation of casein is the fundamental process in cheesemaking. It is generally done with rennet, but other proteolytic enzymes can be used, as well as acidification of the casein to the iso-electric point (pH 4,6 – 4,7).

The active principle in rennet is an enzyme called chymosine, and coagulation takes place shortly after the rennet is added to the milk. The renneting process operates in several stages; it is customary to distinguish these as follows:

- Transformation of casein to paracasein under the influence of rennet
- Precipitation of paracasein in the presence of calcium ions

The whole process is governed by the temperature, acidity, and calcium content of the milk, as well as other factors. The optimum temperature for rennet is in the region of 40 °C, but lower temperatures are normally used in practice, principally to enable control of the coagulum’s hardness.

Rennet is extracted from the stomachs of young calves and marketed in the form of a solution with a strength of 1:10 000 to 1:15 000, which means that one part of rennet can coagulate 10 000 – 15 000 parts of milk in 40 minutes at 35 °C. Bovine and porcine rennet are also used, often in combination with calf rennet (50:50, 30:70, etc.). Rennet in powder form is normally 10 times as strong as liquid rennet.

Substitutes for animal rennet

The search for substitutes for animal rennet was carried out primarily in India and Israel, on account of vegetarians’ refusal to accept cheese made with animal rennet. In the Muslim world, the use of porcine rennet is out of the question, which is a further important reason to find adequate

substitutes. Interest in substitute products has grown more widespread in recent years due to a shortage of animal rennet of good quality.

There are two main types of substitute coagulants:

- Coagulating enzymes from plants
- Coagulating enzymes from micro-organisms

Investigations have shown that coagulation ability is generally good with preparations made from plant enzymes. A disadvantage is that the cheese very often develops a bitter taste during storage.

Various types of bacteria and moulds have been investigated, and the coagulation enzymes produced are known under various trade names.

DNA technology has been utilised in recent times, and a DNA rennet with characteristics identical to those of calf rennet is now being thoroughly tested with a view to securing approval.

Other enzymatic systems

Several research institutions are working to isolate enzymatic systems that can be used to accelerate the ageing of cheese. The technique is not yet fully developed, and is therefore not commonly used.

Cheesemaking modes

Cheese of various types is produced in several stages according to principles that have been worked out by years of experimentation. Each type of cheese has its specific production formula, often with a local touch.

Some basic processing alternatives are described below.

Curd production

Milk treatment

As discussed above, the milk intended for most types of cheese is preferably pasteurised just before being pumped into the cheese tank. Milk intended for traditional Swiss Emmenthal cheese or Parmesan cheese is an exception to this rule.

Milk intended for cheese is not normally homogenised, unless it is recombined. The basic reason is that homogenisation causes a substantial increase in water-binding ability, making it very difficult to produce semi-hard and hard types of cheese. The losses of fat and dry solids in the whey will also increase.

However, in the special case of Blue and Feta cheeses made from cows' milk, the fat is homogenised in the form of 15 – 20 % cream. This is done to make the product whiter and, more importantly, to make the milk fat more accessible to the lipolytic activity by which free fatty acids are formed; these are important ingredients in the flavour of these two types of cheese.

General composition of milk intended for Gouda

Fat, %	3,4
Protein, %	3,3
Lactose, %	4,7
Total solids, %	12,5

Filling

In all cheesemaking, air pickup should be avoided when the milk is fed into the cheesemaking tank, because this would affect the quality of the coagulum and be likely to cause losses of fat and casein in the whey.

The milk is therefore preferably fed to the tank via a combined bottom inlet/outlet pipe or a foam repressing top inlet.

Starter addition

The starter is normally added to the milk at renneting temperature, while the cheese tank is being filled. There are two reasons for early in-line dosage of starter:

1. To achieve good and uniform distribution of the bacteria
2. To give the bacteria time to become "acclimatised" to the "new" medium

Avoid air pick-up during filling of the cheese vat or tanks.

The time needed from inoculation to start of growth, also called the pre-ripening time, is about 30 to 60 minutes, special in case of adding deep-frozen starter.

The quantity of starter needed varies with the type of cheese. Further information about various starters can be found in Chapter 10, Cultures and starter manufacture.

Additives and renneting

If necessary, calcium chloride and saltpetre are added before the rennet. Anhydrous calcium chloride salt can be used in dosages of up to 20 g/100 kg of milk. Saltpetre dosage must not exceed 30 g/100 kg of milk. In some countries, dosages are limited or prohibited by law.

The rennet dosage is up to 30 ml of liquid rennet of a strength of 1:10 000 to 1:15 000 per 100 kg of milk. To facilitate distribution, the rennet may be diluted with at least double the amount of water. After rennet dosage, the milk is stirred carefully for not more than 5 minutes. It is important that the milk comes to a standstill within another 5 – 8 minutes in order to avoid disturbing the coagulation process and causing loss of casein in the whey.

To further facilitate rennet distribution, automatic dosage systems are available to dilute the rennet with an adequate amount of water and sprinkle it over the surface of the milk through separate nozzles.

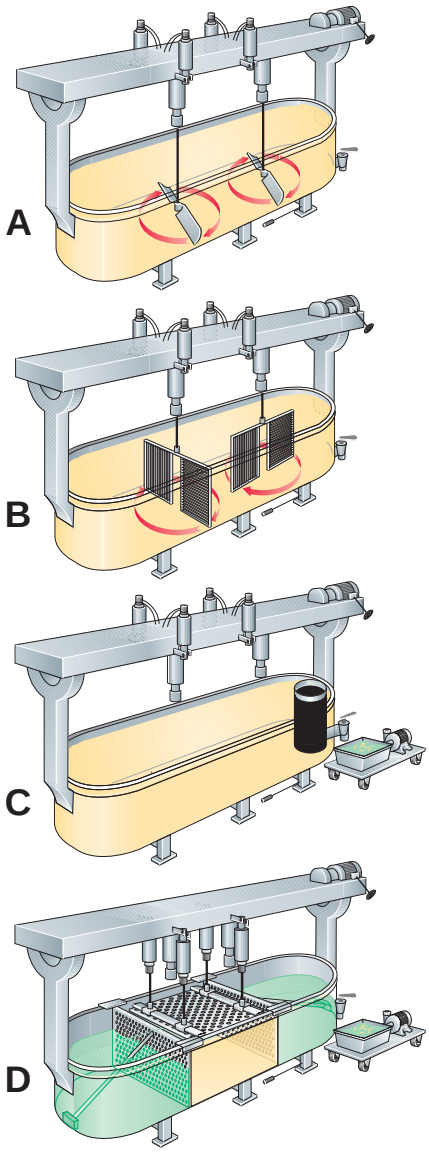


Fig. 14.8 *The main cheese production modes are shown in a traditional semi-manual cheese vat.*
A *Stirring*
B *Cutting*
C *Whey drainage*
D *Pressing*

Cutting the coagulum

The renneting or coagulation time is typically about 30 minutes. Before the coagulum is cut, a simple test is normally carried out to establish its whey-eliminating quality. Typically, a knife is stuck into the clotted milk surface and then drawn slowly upwards until proper breaking occurs. The curd may be considered ready for cutting as soon as a glass-like splitting flaw can be observed. Equipment for measurement of the progress of the coagulation is on the market. The principle is the changing in light shattering and reflection. Based on experiences, the cutting point of the set can be started on a fixed output of the measurement.

Cutting gently breaks the curd up into grains with a size of 3 – 15 mm, depending on the type of cheese. The finer the cut, the lower the moisture content in the resulting cheese.

The cutting tools can be designed in different ways. In a modern, enclosed, horizontal cheesemaking tank, Figure 14.9, stirring and cutting are done with tools welded to a horizontal shaft powered by a drive unit with a frequency converter. The dual-purpose tools cut or stir depending on the direction of rotation; the coagulum is cut by razor-sharp radial stainless steel knives. Stirring blades mounted on the tip-ends of the tools, in combination with the rounded backside of the knives, give gentle and effective mixing of the curd.

In addition, the cheese tank can be provided with an automatically operated whey strainer, nozzles for proper distribution of coagulant (rennet) and spray nozzles to be connected to a cleaning-in-place (CIP) system.

Pre-stirring

Immediately after cutting, the curd grains are very sensitive to mechanical treatment, therefore the stirring has to be gentle. It must, however, be fast enough to keep the grains suspended in the whey. Sedimentation of curd in the bottom of the tank causes formation of lumps. This puts strain on the stirring mechanism, which must be very strong. The curd of low-fat cheese has a strong tendency to sink to the bottom of the tank, which means that the stirring must be more intense than for curd with a high-fat content.

Lumps may influence the texture of the cheese, as well as causing loss of casein in the whey.

The mechanical treatment of the curd and the continued production of lactic acid by bacteria help to expel whey from the grains.

First drainage of whey

For semi-hard types of cheese, such as Gouda and Edam, it is desirable to rid the grains of relatively large quantities of whey, so that heat can be supplied by direct addition of hot water to the mixture of curd and whey, which also lowers the lactose content.

Discharge of whey make also space for the added water. Some producers also drain off whey to reduce the energy consumption needed for indirect heating of the curd. For each individual type of cheese, it is important that the same amount of whey, normally 30 % of the batch volume, is drained off every time.

Figure 14.9 shows the whey drainage system in an enclosed, fully mechanised cheese tank. A longitudinal slotted tubular strainer is suspended from a stainless steel cable connected to an outside hoist drive.

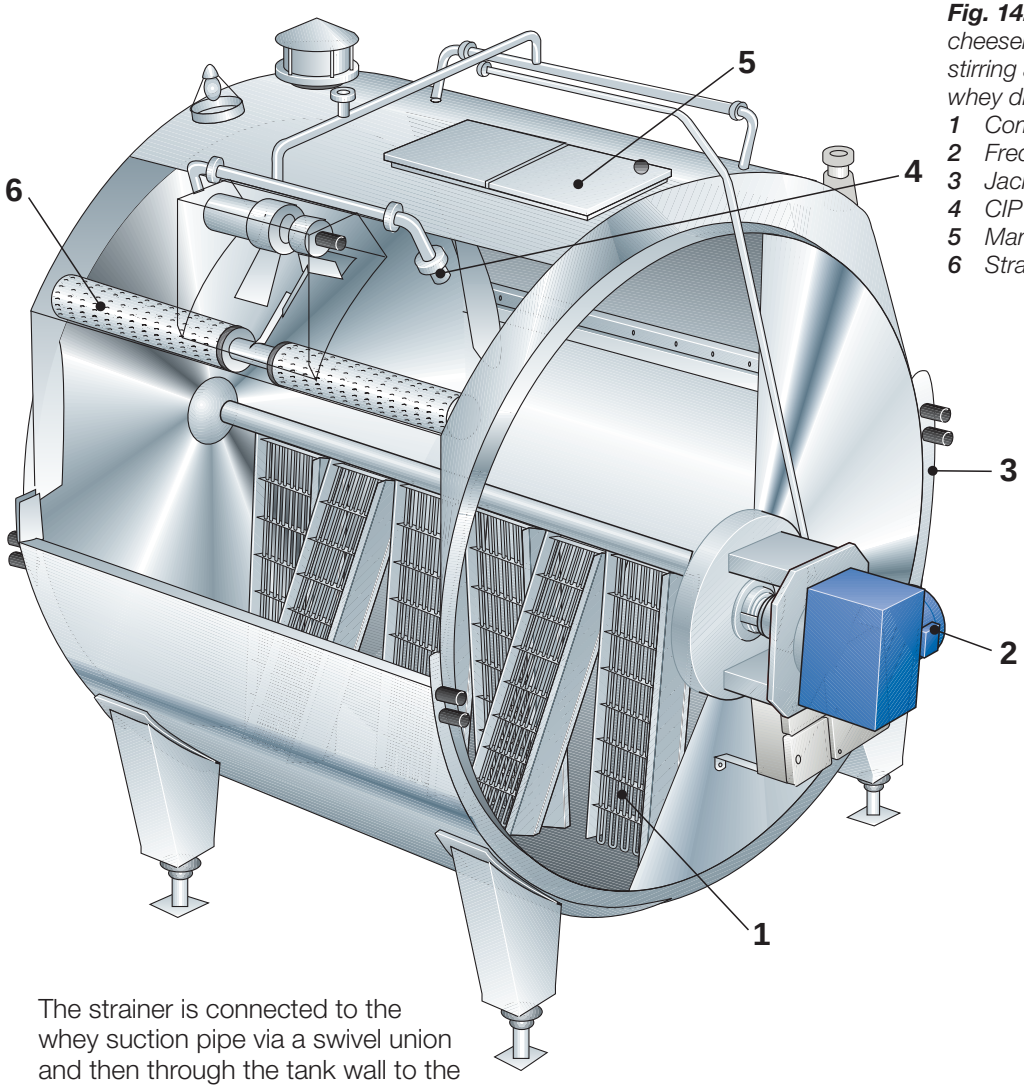


Fig. 14.9 *Horizontal enclosed cheesemaking tank with combined stirring and cutting tools and hoisted whey drainage system.*

1 *Combined cutting and stirring tools*
2 *Frequency-controlled motor drive*
3 *Jacket for heating*
4 *CIP nozzle*
5 *Manhole cover*
6 *Strainer for whey drainage*

The strainer is connected to the whey suction pipe via a swivel union and then through the tank wall to the external suction connection. A level electrode attached to the strainer controls the hoist motor, keeping the strainer just below the liquid level throughout the whey drainage period. A signal to start is given automatically. A predetermined quantity of whey can be drawn off, which is controlled via a pulse indicator from the hoist motor. Safety switches indicate the upper and lower positions of the strainer.

The whey should always be drawn off at a high capacity, say within 5 – 6 minutes, as stirring is normally stopped while drainage is in progress and lumps may be formed in the meantime. Drainage of whey therefore takes place at intervals, normally during the second part of the pre-stirring period and after heating.

A less sophisticated manner to get rid of the whey is the “hole in the wall” solution. This means that holes are positioned on the tank end walls at

fixed levels. This is a cheap way of draining the whey, but has some disadvantages. Whey can only be discharged to fixed levels and the losses of fines in the whey are higher compared to a hoisted whey strainer.

Heating/cooking/scalding

Heat treatment is required during cheesemaking to regulate the size and acidification of the curd. The growth of acid-producing bacteria is limited by heat, which is thus used to regulate production of lactic acid. Apart from the bacteriological effect, the heat also promotes contraction of the curd accompanied by expulsion of whey (syneresis).

Depending on the type of cheese, heating can be done in the following ways:

- By steam in the tank jacket only
- By steam in the jacket in combination with addition of hot water to the curd/whey mixture
- By hot water addition to the curd/whey mixture only

The time and temperature program for heating is determined by the method of heating and the type of cheese. Heating to temperatures above 40 °C, sometimes also called cooking, normally takes place in two stages. At 37 – 38 °C, the activity of the mesophilic lactic acid bacteria is retarded, and heating is interrupted to check the acidity, after which heating continues to the desired final temperature. Above 44 °C, the mesophilic bacteria are totally deactivated, and they are killed if held at 52 °C between 10 and 20 minutes.

Cheddar cheese is cooked by steam in the jacket. The heating slope is normally 0,2 – 0,5 °C/min.

Heating beyond 44 °C is typically called scalding. Some types of cheese, such as Emmenthal, Gruyère, Parmesan and Grana, are scalded at temperatures as high as 50 – 56 °C. Only the most heat-resistant lactic-acid-producing bacteria survive this treatment. One that does so is Propionibacterium freudenreichii ssp. shermanii, which is very important to the formation of the character of Emmenthal cheese.

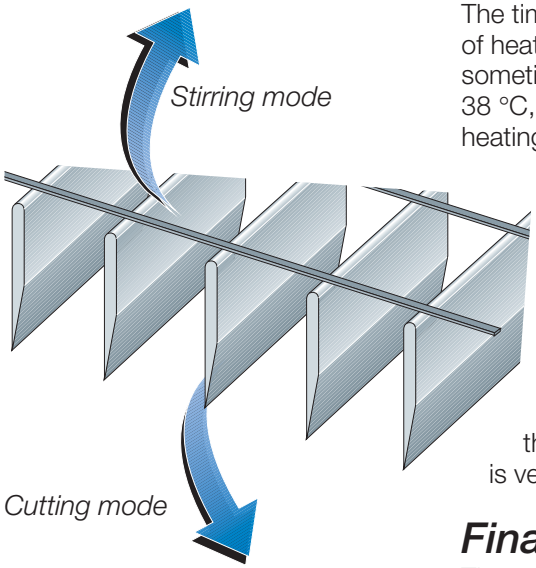


Fig. 14.10 *Cross-section of the combined cutting and stirring tool blade with sharp cutting edge and blunt stirring edge.*

Final stirring

The sensitivity of the curd grains decreases as heating and stirring proceed. More whey is exuded from the grains during the final stirring period, primarily due to the continuous development of lactic acid, as well as the mechanical effect of stirring.

The duration of final stirring depends on the desired acidity and moisture content of the cheese.

Second drainage of whey

In many cheesemaking recipes, a second removal of whey is recommended, as it reduces the required drainage capacity of downstream equipment. This whey can be used for pre-filling of strainer vats. This amount of whey from the first removal can be reduced in order to obtain a better whey quality with less fines.

Final removal of whey and principles of curd handling

Drainage principles

As soon as the required acidity and firmness of the curd have been attained – and checked by the producer – most of the residual whey has to be removed from the curd. The already discharged whey is used for pre-fill of the pre-press vat or the drainage column. When continuous drainage equipment is utilised, the whey can be used to achieve the right curd/whey ratio.

The whey, when in the curd/whey mixture, is present in three forms:

- Whey between the curd particles – free whey
- Whey incorporated in the curd grains
- Whey bound to protein

The free whey is easily drainable by increasing the compactness of the curd block by pressing.

The whey inside the grains is more difficult to evacuate. However, by increasing the acidity and applying pressure on the grains, this whey is released and behaves as free whey.

The whey bound to protein is not drainable under normal cheesemaking procedures.

It is vital to the drainage process that the discharge of whey is gentle and does not exert excessive force on the curd. During whey drainage, the curd grains deform and partly fuse together due to the static pressure in the column or the pre-press vat.

Depending on how the curd grains are treated after whey separation, four different types of cheese are obtained.

- If the grains are filled in moulds and subsequently pressed, the result is a cheese with an open or granular structure, *i.e.* Tilsiter
- Collecting the grains in a layer for an acidification period results in a cheese with a closed texture, *i.e.* Cheddar, Mozzarella
- When the curd grains are washed with water and cooled, and then mixed with cream or dressing, the final product will be a type of Cottage cheese
- When the curd is kept under the surface of the whey during the combined draining and pre-pressing sequence, the result will be a round-eyed type of cheese, *i.e.* Emmenthal, Gouda

Related properties, essential for cheese quality, are to be controlled via the following parameters of the curd before production continues:

- Moisture content
- Temperature
- Fat content
- Acidity
- Curd grain size and size distribution
- Curd strength and deformability

Cheese with granular texture

The curd/whey mixture is pumped across a static screen, a vibrating strainer or a rotating strainer, Figure 14.14.The grains are separated from the whey and discharged directly into the pre-pressing vat or column. The resulting cheese acquires a texture with irregular holes or eyes, also called a granular texture, Figure 14.11.

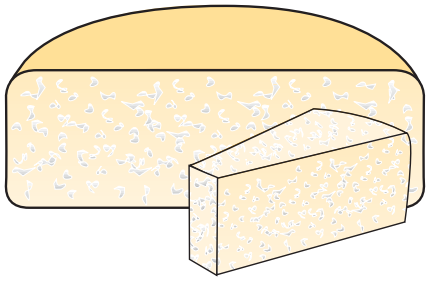


Fig. 14.11 *Cheese with granular texture.*

As the curd grains are exposed to air before being collected and pressed, they do not fuse completely; a large number of tiny air pockets remain in the interior of the cheese. The carbon dioxide formed and released during the ripening period fills and gradually enlarges these pockets.

Round-eyed cheese

Gas-producing bacteria (*Sc. cremoris/lactis, L. cremoris* and *Sc. diacetylactis*) are used in production of round-eyed cheese, Figure 14.12. The *Propionic* bacteria is responsible for the big eyes in Emmenthal cheese.

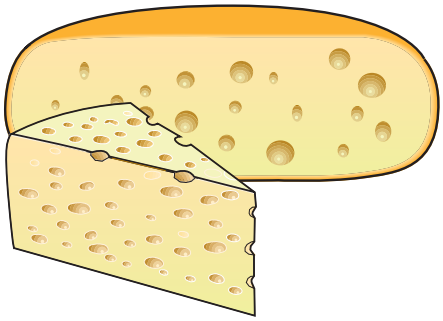


Fig. 14.12 *Cheese with round eyes.*

Studies of the formation of round holes/eyes have shown that when curd grains are collected below the surface of the whey, the curd contains microscopic cavities. Starter bacteria accumulate in these tiny whey-filled cavities. The gas formed when they start growing initially dissolves in the liquid, but as bacterial growth continues, local supersaturation occurs, which results in the formation of small holes. Later, after gas production has stopped due to lack of substrate, (*e.g.* citric acid), diffusion becomes the most important process. This enlarges some of the holes, which are already relatively large, while the smallest holes disappear. Enlargement of bigger holes at the expense of the smaller ones is a consequence of the laws of

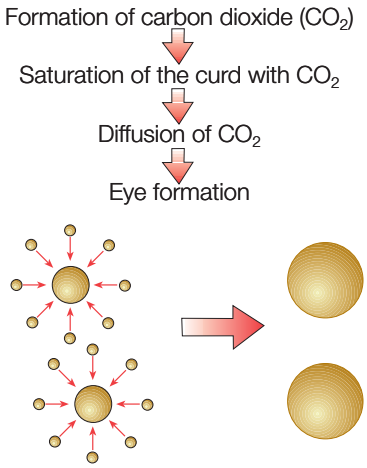


Fig 14.13 *Development of gas in cheese and eye formation.*
(By courtesy of dr. H. Burling, R&D dept. SMR, Lund, Sweden.)

surface tension, which state that it takes less gas pressure to enlarge a large hole than a small one. The course of events is illustrated in Figure 14.13. At the same time, some CO_2 escapes from the cheese.

Two systems can be applied for draining the whey under its surface. The horizontal in a pre-pressing vat or vertical in a perforated drainage column.

The choice of system depends on:

- Type of cheese to be produced
- Batch or continuous production
- Plant production capacity
- Flexibility regarding cheese types and dimensions
- Addition of herbs, spices, etc. in the cheese
- Level of automation
- Level of investment

Drainage equipment

As part of the cheese production line, there are generally two methods of draining the whey from the curd; separating the whey from the curd grains by a strainer, or settling the curd in the whey before it is decanted. The first method creates a granular curd, while the second produces a round-eyed type of cheese.

Strainers

A rotating strainer consists of a slightly inclined perforated rotating cylinder. The curd/whey mixture is fed into the centre of the cylinder and the whey is drained through the perforation. The dry curd grains are continuously discharged into a drainage column or pre-pressing vat.

Static and vibrating strainers consist of a perforated plate or a wedge-wire screen on which the curd/whey mixture is introduced at the top. The screen is placed under a certain angle to facilitate the curd to decend. The screen can have a vibrating function in order to avoid clogging and increase drainage capacity.

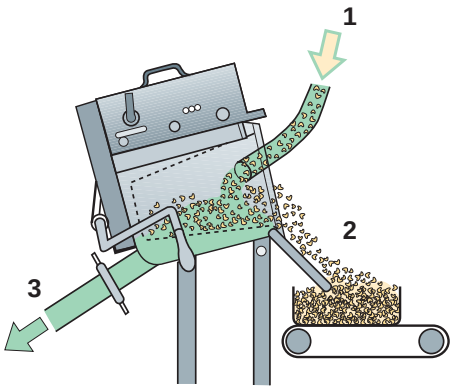


Fig. 14.14 *Curd and whey are separated in a rotating strainer.*
1 *Curd/whey mixture*
2 *Drained curd*
3 *Whey outlet*

Pre-pressing vats

The whey is drained off in the batch-operated pre-pressing vat, and the curd is pre-pressed before being portioned and moulded.

Pre-pressing vats are available for different batch sizes from 10 000 up to 20 000 l. The inside height of the vat is about 500 mm.

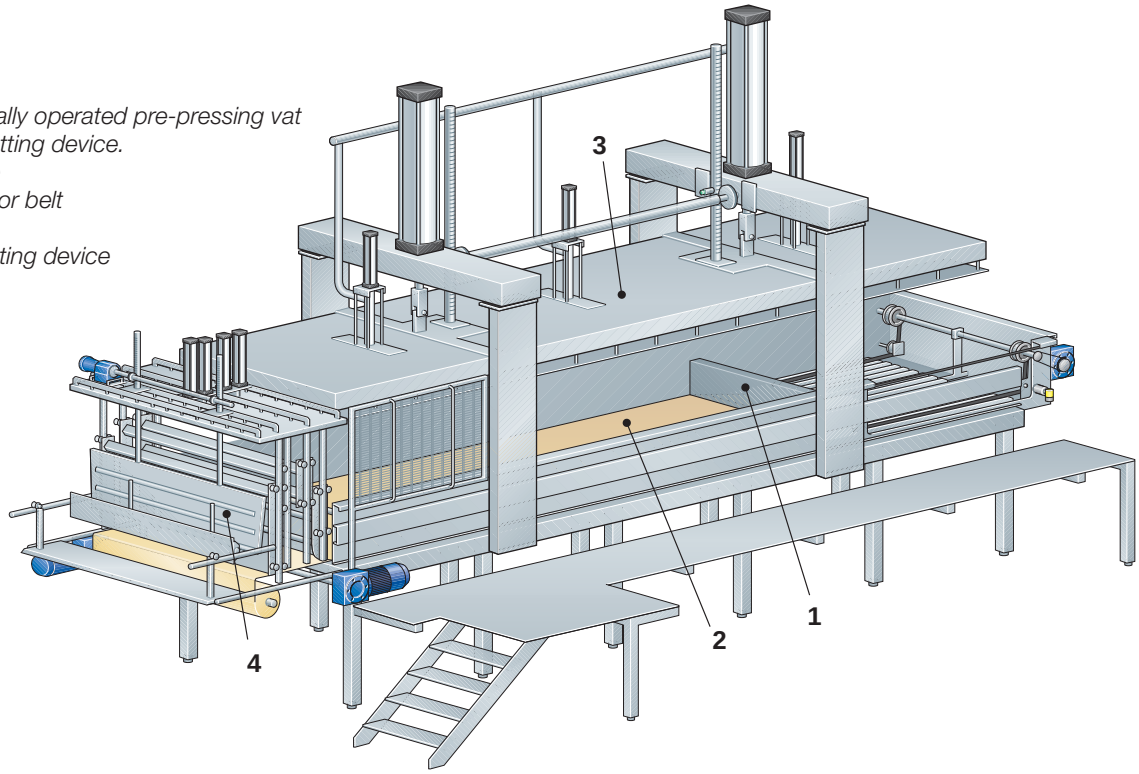


Fig. 14.15 *Mechanically operated pre-pressing vat with unloading and cutting device.*
1 *Movable end plate*
2 *Perforated conveyor belt*
3 *Pressing plates*
4 *Unloading and cutting device*

The pre-pressing vat consists of a stainless steel, rectangular open vat with double walls. In the front part of the vat is a door, which can be closed when the vat is filled. The end walls are covered with perforated screens for whey drainage. Their positions are not fixed and can be set depending on the type of cheese, curd amount, curd layer thickness, etc.

The bottom of the vat is covered by a plastic, woven belt that can move forwards or backwards. Whey is drained through the belt, which supports the curd layer. The plastic belt also transports the curd bed out of the vat after drainage.

Whey from the cheesemaking tank is pumped to the pre-pressing vat to prevent incorporation of air into the curd and warm up the cold stainless steel vat.

The curd/whey mixture is then automatically spread into a uniform layer by a movable distributor, which runs on the sidewall of the vat. In the case of granular cheese production, the curd is distributed in the same way, but the whey is first strained off and collected in a tank.

Curd/whey can also be filled through different pipe outlets above the vat. The operator then has to manually rake the curd to a uniform layer before pre-pressing is applied.

An overall, pneumatically-operated, pressing plate hangs in a frame over the curd bed and covers the whole layer. The pressing plate is perforated for whey drainage. Maximum pressure on the curd is around 50 g/cm^2.

After the pressing is completed, the discharge end of the vat is opened and the plastic belt moves the complete curd block a pre-set distance. A guillotine knife cuts off a slab of curd. This slab is transported sideways and another guillotine knife cuts off a pre-set length, so that it fits in the mould for final pressing. These operations continue until the vat is empty. Alternatively, fixed vertical ribbon knives can be mounted at the end for longitudinal cutting of the curd bed. Mould filling can be manual or mechanised.

A modern pre-press vat is normally designed and equipped for CIP cleaning.

Continuous drainage system

The continuous drainage, forming and mould-filling machine offers an advanced drainage system. The Tetra Tebel Casomatic single-column version is shown in Figure 14.16. There is also a multi-column version available in which a changeable insert is placed. This insert contains one to sixteen drainage columns.

Two buffer tanks are also required in the automatic and continuous system. One buffertank is filled up and the other is emptying. To start with a filled buffertank ensures a better whey/curd ratio during the whole batch. There is a better batch separation when using two tanks and the stirring action in the buffertank can be used as a part of the final stirring in the curdmaking process.

The capacity per single column is 1 000 – 1 300 kg/h depending on cheese type. Several columns are usually placed in a row and work in sequence filling moulds on a common conveyor.

In the multi-column version, the capacity depends on cheese type, cheese size and number of drainage tubes in the insert. For semi-hard, round-eyed cheese, the capacity can be 1 000 – 2 500 kg/h.

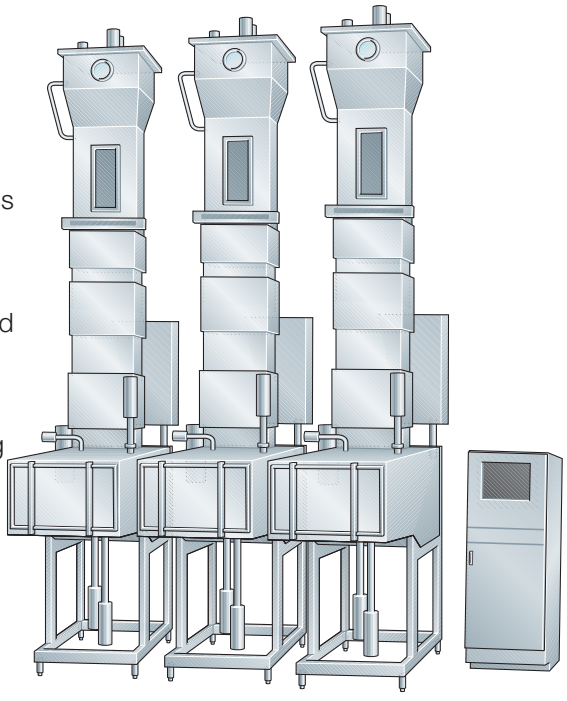


Fig. 14.16 *Continuous drainage columns are of a modular design and the number can be adapted to the plant capacity.*

Buffer tanks

The buffer tank is a vertical stainless steel tank with a conical bottom. The vertical tank wall is equipped with a cooling jacket. Inside the tank, a stirrer is situated in the lower conical part. The stirrer speed is adjustable in correlation with the filling height of the tank, as the intensity of stirring is critical for the curd/whey ratio.

The buffer tank in the drainage system is intended to:

- Create a uniform feed of curd/whey mixture
- Be a link between batch curd production and continuous drainage

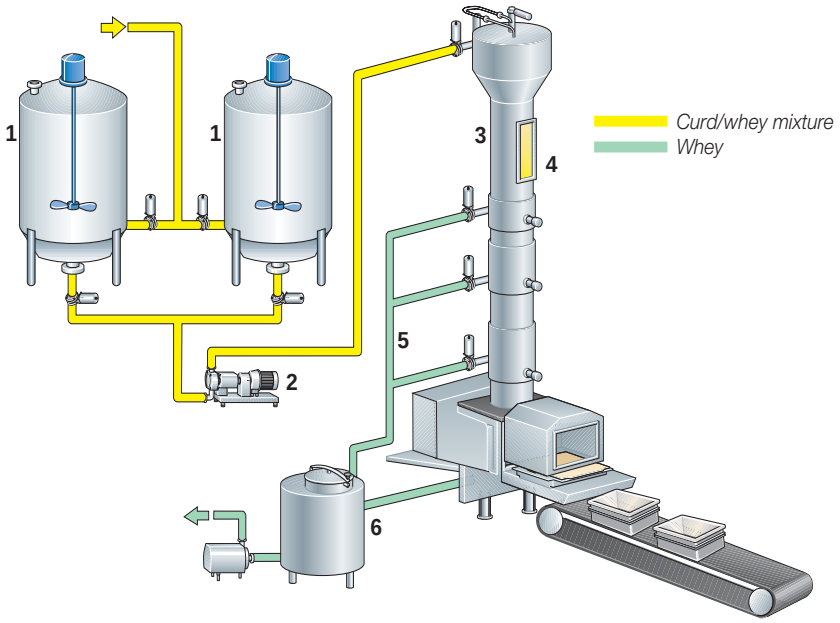


Fig. 14.17 *Whey drainage system.*
1 Buffer tank for curd/whey mixture
2 Positive feed pump
3 Drainage column
4 Sight glass
5 Whey drainage lines
6 Whey collecting tank

- Cool the curd/whey mixture for moisture adjustment
- Deaerate the curd/whey mixture
- Extend the stirring period and release the cheesemaking tank for a new batch
- Mix the curd with other ingredients, *i.e.* herbs, spices

The curd/whey mixture, normally in a ratio of 1:3,5 – 5,0, is pumped from the buffer tank to the drainage columns by a frequency-controlled positive displacement pump.

Single-column system

In the single-column system, the curd/whey mixture enters the column under the whey level. A hopper located on top of each column assure a more or less constant whey level during production. The column is filled up with curd, but the whey level is always above the level of curd to avoid incorporation of air in the curd.

The drainage columns can be round or rectangular-shaped to suit the cheese to be produced. The cheese size depends on the type of cheese, the drainability of the whey and the capacity.

A strainer can be placed on the top of the column if granular types of cheese are to be produced. The hopper on top of the column contains two level control systems (whey and curd) and a pressure indicator. An overflow gauge assures that the level in the column is always constant.

The whey is drained off in three perforated sections at different levels of the column. For draining, the driving force is the pressure difference between the curd/whey mixture inside the column and the whey on the outside. The pressure difference is set as a recipe parameter in the processing control computer software. Each of the three perforated sections has its own specific pressure difference, controlled by remote regulating valves. As the curd column becomes more compact, the more the pressure difference can increase. The resulting effect is that when the curd column descends, a greater pressure difference is allowed and more whey can be drained.

The moisture accuracy at the bottom of the curd column will be high and, as the dosing height is pre-set, the final cheese weight is accurate.

The column of curd rests on a horizontal knife. At pre-set intervals, the curd column is cut in uniform blocks and placed in moulds. The operating sequence is:

- A slide cassette is positioned under the column and a support dosing plate is pushed up through the slide cassette until it is just underneath the knife
- The knife opens and the curd column rests on the dosing plate. This descends to the pre-set height for the cheese block

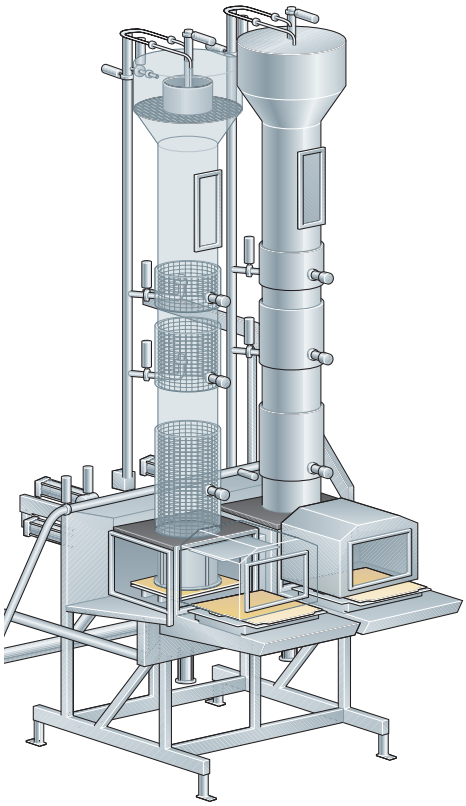


Fig. 14.18 *Whey is drained through the perforated sections on the column.*

- The knife cuts off the curd column and the bottom of the column closes
- The dosing plate descends to its bottom position
- The slide cassette with the curd block is pushed forward to a horizontal sluice
- The sluice gate opens and the curd block falls into a mould
- The slide cassette is positioned back under the column, the sluice gate locks, and the dosing plate is again pushed up and ready for the next dosing and mould-filling sequence

Multi-column system

The Tetra Tebel Casomatic multi-column system is a vertical unit that provides higher production flexibility in terms of cheese sizes and shapes. The inner drainage insert can be replaced by other inserts containing inner drainage tubes of various configurations and dimensions. The drainage insert can consist of one single tube, round or rectangular, *i.e.* one Euroblock 295 x 495 mm, or 16 small tubes, *i.e.* for baby Gouda.

The drainage inserts are hoisted and placed on a platform adjacent to the column when changed. Two or more columns are normally placed beside each other using the same mould conveyor for delivering cheeses. The moulds used must all have the same outer measurements. When inserts with several drainage tubes are used, multi-moulds with the same configuration as the insert tube must be used.

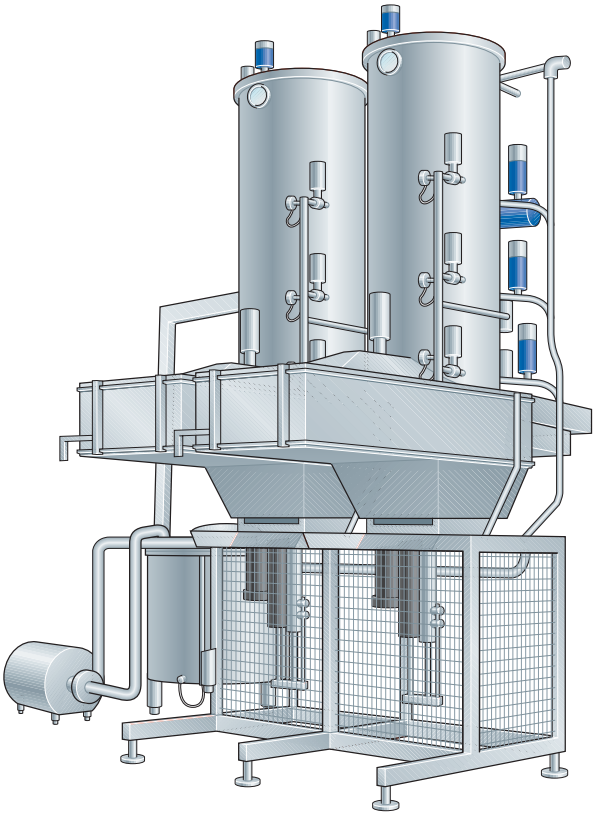


Fig. 14.20 *Continuous whey drainage system in multi-column design and with two columns.*

The curd/whey mixture is pumped from the buffer tanks to the top of the multi-column. The inlet is tangential and a rotating distributor ensures uniform filling of each drainage tube. The whey level is always above the curd level when producing round-eyed cheeses.

When granular cheese is to be produced, a de-wheying strainer is placed on top of the column.

The discharge of whey through three perforated sections is equal to that of the single-column system.

Both versions of the continuous drainage and mould-filling systems are designed and equipped for CIP cleaning.

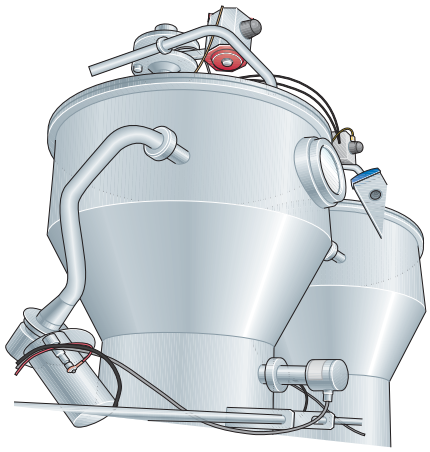


Fig. 14.19 *The top of the column contains level controls for both curd and whey.*

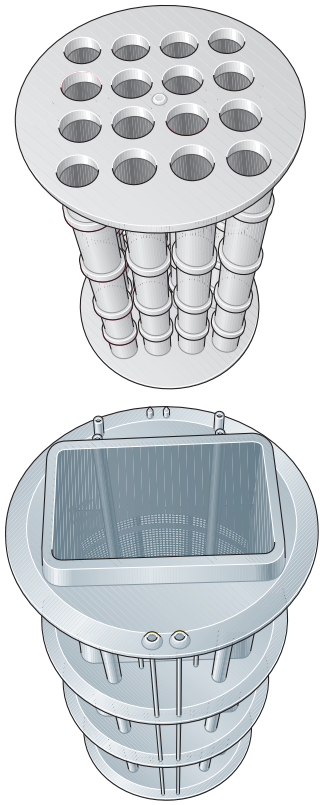


Fig. 14.21 *Each column is equipped with an exchangable insert giving the cheeses their desired chape and size.*

Cheese moulds

The curd blocks leaving the drainage equipment are placed in a mould for final pressing. The shape of the mould should correspond with the shape of the final cheese.

After the curd block is placed in the mould, a lid is placed on top of the curd block. The lid must fit the mould opening exactly in order to minimise uneven rims. The filled mould is conveyed to the pressing section of the plant.

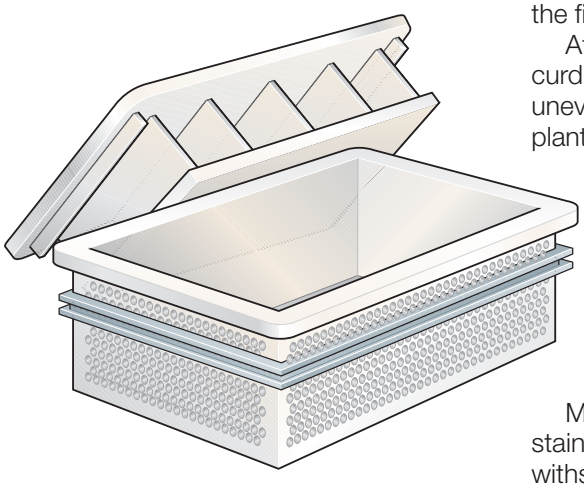


Fig. 14.22 *A cheese mould made of plastic.*

The moulds are used to:

- Get rid of most of the remaining whey in the curd block
- Form a stable rind on the cheese surface
- Achieve the correct, uniform shape of the cheese

The mould and lid are either micro-perforated or the inside is fitted with a net. The net can be free-hanging or incorporated in the mould. On micro-perforated moulds, grooves on the inside contribute to good rind forming and drainage.

Most of the cheese moulds are made from plastic, but in some plants stainless steel moulds are still in use. Their design must be very rigid to withstand the applied pressure, conveying and mechanised handling. Each mould and lid is in use several times during a production run. They must also withstand common cleaning detergents as they pass a cleaning station in their production loop.

Closed texture cheese

Closed texture types of cheese, of which Cheddar is a typical example, are normally made with starter cultures containing bacteria that do not produce gas – typically single-strain, lactic-acid-producing bacteria like *S. cremonis* and *S. lactis*.

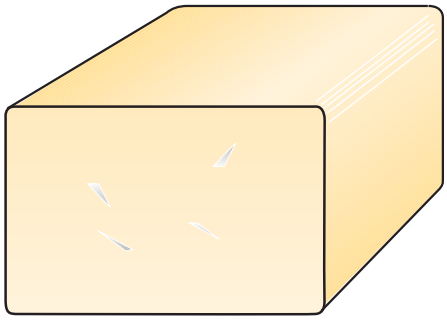


Fig. 14.23 *Closed texture cheese with typical mechanical holes.*

The specific processing technique may, however, result in formation of cavities called mechanical holes, as shown in Figure 14.23. While the holes in granular and round-eyed cheeses have a characteristically shiny appearance, mechanical holes have rough inner surfaces.

When the pH of the curd mass has reached about 6,0 – 6,1 (about two hours after renneting), the whey is drained off, and the curd is subjected to a special form of treatment called cheddaring.

After all whey has been discharged, the curd is left for continued acidification and matting. During this period, typically 2 – 2,5 hours, the curd is formed into blocks, which are turned upside down and stacked. When the pH of the cheddared curd has reached 5,20 – 5,25, the blocks are milled into “chips”, which are dry-salted before being hooped (moulds for Cheddar cheese are called hoops).

Mechanised cheddaring machine

A highly advanced, mechanised cheddaring machine, the Tetra Tebel Alfomatic, is also available, and the principle is shown in Figure 14.24. These machines have capacities ranging from one to eight tonnes of cheese per hour. The most common version of the machine is equipped with four conveyors, individually driven at pre-set and adjustable speeds, and mounted above each other in a stainless steel frame. The curd/whey mixture is uniformly distributed on a special drainage screen, where most of the whey is removed. The curd then falls on to the first conveyor, which is perforated and has stirrers for further whey drainage. Guide rails control the width of the curd mat on each conveyor.

The second conveyor allows the curd to begin matting and fusing. It is then transferred to a third conveyor, where the mat is inverted and cheddaring takes place.

At the end of the third conveyor, the curd is milled to chips of uniform size, which fall onto the fourth conveyor. In machines for stirred curd types (Colby cheese), additional stirrers can be added on conveyors 2 and 3 to facilitate constant agitation, preventing fusing of the curd granules. In this case, the chip mill is also bypassed.

The last conveyor is the mellowing conveyor. Salt is added to the curd at

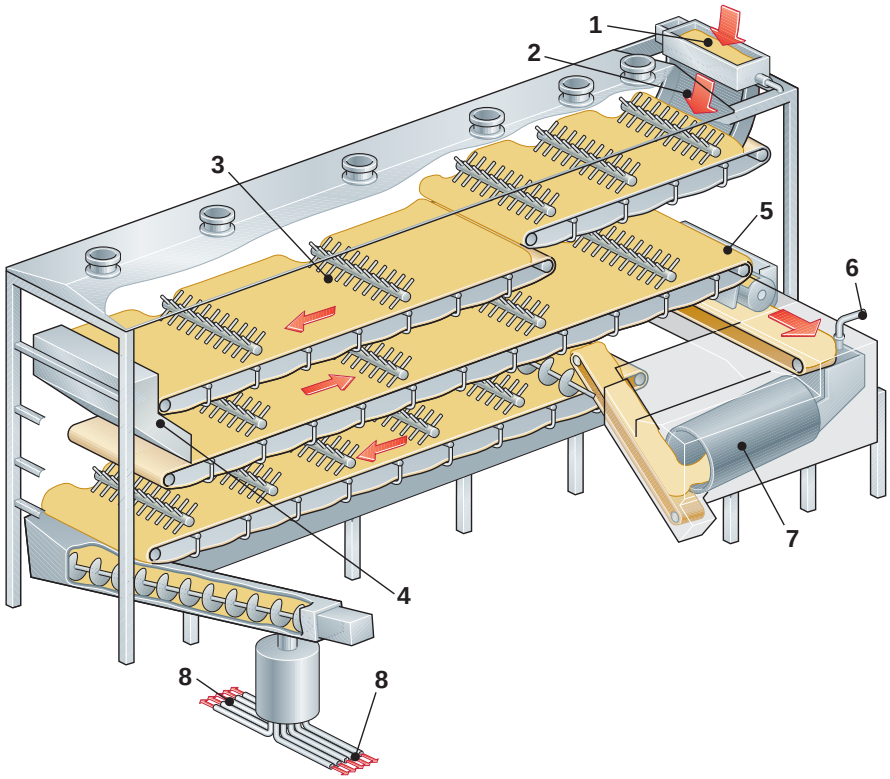


Fig. 14.24 *Continuous system for dewheying, cheddaring, milling and salting of curd for cheddar cheese.*
1 *Feed of curd/whey mixture*
2 *Strainer*
3 *Curd stirrer*
4 *Turning the curd upside down*
5 *Chip mill*
6 *Salt feed*
7 *Salt distribution drum*
8 *Chips drawn to blockformer by vacuum*

the beginning and left on, so that it can diffuse into the curd. The curd is stirred during its mellowing time to prevent it from fusing, and to promote even absorption of the salt.

An alternative system for salt application is the salt mixing drum system as shown in Figure 14.24. After the chip mill, the curd is weighed and salt is added accordingly (on a weight-for-weight basis). The salt and curd enter a flighted mixing drum, which provides efficient mixing. The salted curd will then enter the last conveyor for its mellowing period.

The first conveyor can also be equipped with a wash-water system for production of the aforementioned Colby cheese.

A machine with two or three conveyors suffices for production of cheeses of the Pasta Filata family (Mozzarella, Kashkaval, Pizza cheese, etc.), in which cheddaring is a part of the processing technique, but the milled chips are not normally salted before cooking and stretching.

The machine, regardless of the number of conveyors, is equipped with spray nozzles for connection to a CIP system to ensure thorough cleaning and sanitation. A cladding of detachable stainless steel panels further contributes to hygiene.

Final treatment of curd

As previously mentioned, the curd can be treated in various ways after most of the free whey has been removed. It can be:

1. Transferred directly to moulds (granular cheeses)
2. Pre-pressed into a block and cut into pieces of suitable size for placing in moulds (round-eyed cheeses)
3. Sent to cheddaring, the last phase of which includes milling into chips, which can be dry-salted and either hooped or shaped under vacuum, if intended for Pasta Filata types of cheese, transferred unsalted to a cooking-stretching machine

Pressing

After having been moulded or hooped, the curd is subjected to final pressing. There are five aims to:

- Assist final whey expulsion
- Provide texture

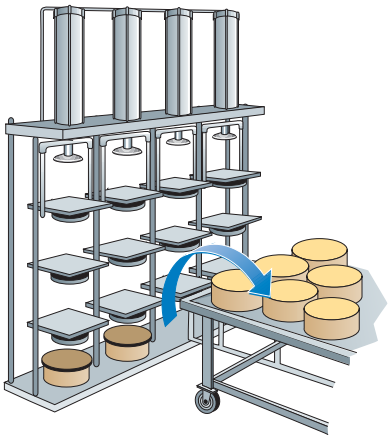


Fig. 14.25 *Traditional, manual, vertical pressing unit with pneumatically operated pressing plates.*

- Reach desired acidification
- Shape the cheese
- Provide a rind on cheeses with long ripening periods

The rate of pressing and pressure applied are adapted to each particular type of cheese. Pressing should be gradual at first, because initial high pressure compresses the surface layer and can lock moisture into pockets in the body of the cheese.

The pressure applied to the cheese should be calculated per unit area and not per cheese, as individual cheeses may vary in size, *e.g.* 300 g/cm^2. The pressure used depends on:

- Cheese dimensions
- Curd temperature
- Fat content
- Acidity level
- Type of mould
- Amount of residual whey in the cheese
- Available time for pressing

Most cheese presses are single presses, except for cheddar, in which case moulds are stacked. The pressure, hydraulic or pneumatic, is supplied to a pressing cylinder – one for each mould. The cheeses can be pressed per batch or per row in cases where a conveyor press is used.

The trend is to go for closed presses. The advantages are a better control over the ambient temperature and a total CIP cleanable press.

Trolley table press

Trolley table pressing systems are frequently used in manually operated cheese production plants. They comprise:

- Trolley table
- Moulds to be loaded manually on the table
- Tunnel press with as many pressing cylinders as the number of moulds loaded on the table

Tunnel press

Tunnel presses are recommended in cases where highly mechanised systems for pressing of cheese are required. Arriving on a conveyor system, the filled moulds are automatically fed into a tunnel press in rows of three, four or five by a pneumatic pushing device. The rows of moulds in the press are transported by push bars and slide across a stainless steel floor.

When the press has been filled, all air cylinders (one per mould) are connected to a common air supply line.

The pressure and intervals between increases of pressure, as well as the total pressing time, are automatically controlled from a separate panel. An Autofeed tunnel press system is designed for simultaneous loading and unloading, which allows optimum utilisation of the press.

Conveyor press

A conveyor press, Figure 14.26, is recommended in cases where the time between moulding and final pressing needs to be minimised. Both conveyor and tunnel presses are normally equipped with CIP systems.

The difference between a tunnel press and a conveyor press is mainly,

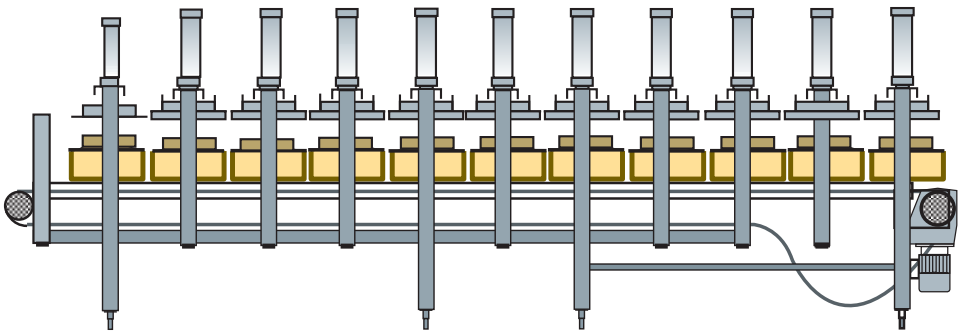


Fig. 14.26 *Conveyor press.*

that in a tunnel press the pressing starts, when the whole batch is collected in the press. The conveyor press starts as soon as possible after a row is filled. One batch does not need to be pressed in the same conveyor press.

The blockformer system

Producing well-formed uniform blocks has long been a critical problem for Cheddar cheese producers. The Tetra Tebel Blockformer, utilising a basically simple system of vacuum treatment and gravity feed, solves this problem. The milled and salted chips are drawn by vacuum to the top of a tower, as illustrated in Figure 14.27. The tower is filled, and the curd begins to fuse into a continuous columnar mass.

Vacuum is applied to the column throughout the program to deliver a uniform product, free from whey and air, at the base of the machine. Regular blocks of identical size, typically weighing about 18 – 20 kg, are automatically guillotined, ejected, and bagged ready for conveying to the vacuum sealing unit, which is integral with the production line. No subsequent pressing is needed.

Different tower types are available, each offering a different capacity. A standard blockformer tower has a height of some 8 metres. An extended blockformer, with an actual column height of around 7,5 metres, has a capacity of 1 000 kg/h.

A Twinvac blockformer has a capacity of 1 600 kg/h. This blockformer's column has a height of around 9 metres. The high capacity can be obtained as a result of a split in the vacuum applied to the curd column and the vacuum used for curd transport from the cheddaring machine. A more efficient and longer vacuum will be applied to the curd column, thus increasing the blockformer's capacity. Two vacuum units are required for the Twinvac blockformer.

CIP manifolds at the top of the towers assure good cleaning and sanitising results.

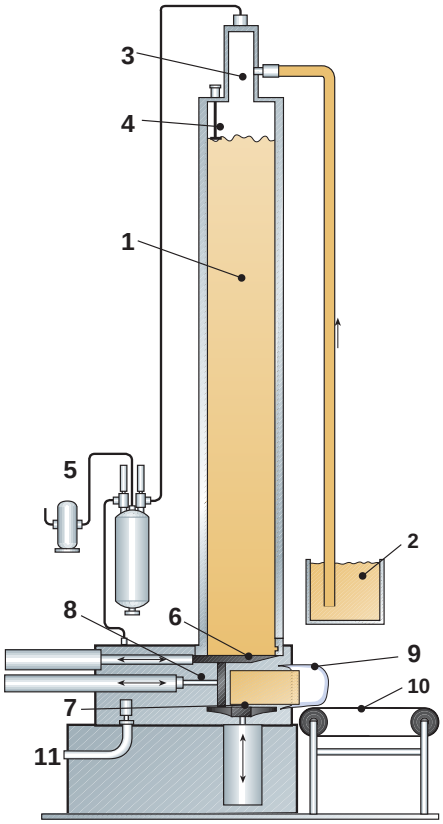


Fig. 14.27 *Blockformer system for Cheddar-type cheese.*
1 *Column*
2 *Curd feed*
3 *Cyclone*
4 *Level sensor*
5 *Vacuum unit*
6 *Combined bottom plate and guillotin*
7 *Elevator platform*
8 *Ejector*
9 *Barrier bag*
10 *Conveyor to vacuum sealing*
11 *Whey drainage*

Cooking and stretching of Pasta Filata types of cheese

Pasta Filata (plastic curd) cheese is characterised by an "elastic" string curd obtained by cooking and stretching cheddared curd. The "spun curd" cheeses – *Provolone, Mozzarella,* and *Caciocavallo* – originate from southern Italy. Nowadays, Pasta Filata cheese is produced not only in Italy, but also in several other countries. The Kashkaval cheese produced in several Eastern European countries is also a type of Pasta Filata cheese. The terms "low-moisture Mozzarella" and "pizza cheese" may be used to describe Pasta Filata cheese products designed to meet the requirements of pizza manufacturers.

After cheddaring and milling, at an acidity of approx. 0,7 – 0,8 % lactic acid in the whey (31 – 35,5 °SH), the chips are conveyed or shovelled into a steel mixing bowl or container, or into a sanitary dough-mixing machine filled with hot water at 65 – 70 °C, and the pieces are processed until they are smooth, elastic, and free from lumps. The mixing water is normally saved and separated with the whey to conserve fat.

Stretching and mixing must be thorough. "Marbling" in the finished product may be associated with incomplete mixing, water temperature that's too low, low-acidity curd, or a combination of these defects.

Continuous cooking and stretching machines are used in large-scale production. Figure 14.28 shows a Cooker-Stretcher. The speed of the counter-rotating augers is variable, so that an optimal working mode can be achieved. The temperature and level of cooking water are continuously controlled. The cheddared curd is continuously transferred into the hopper or cyclone of the machine, depending on the method of feeding – screw conveyor or blowing.

In production of Kashkaval cheese, the cooker may contain brine with 5 – 6 % salt instead of water. Warm brine, however, is very corrosive, so the container, augers and all other equipment coming into contact with the brine must be made of highly-durable special material.

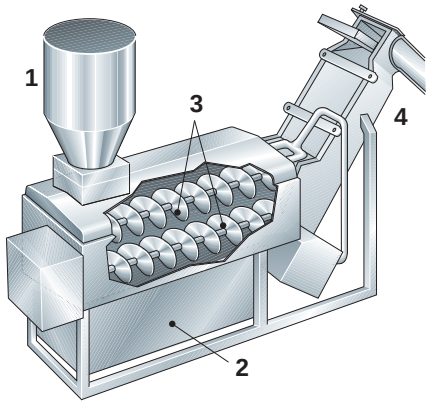


Fig. 14.28 *Continuously operating cooker-stretcher for Pasta Filata types of cheese.*
1 *Feed hopper*
2 *Container for temperature-controlled hot water*
3 *Two counter-rotating augers*
4 *Screw conveyor*

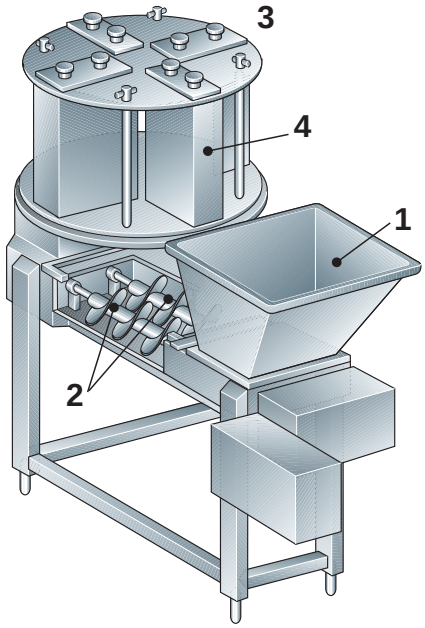


Fig. 14.29 *Moulding machine for pizza cheese*
1 *Hopper*
2 *Counter-rotating augers*
3 *Revolving and stationary moulds*
4 *Mould*

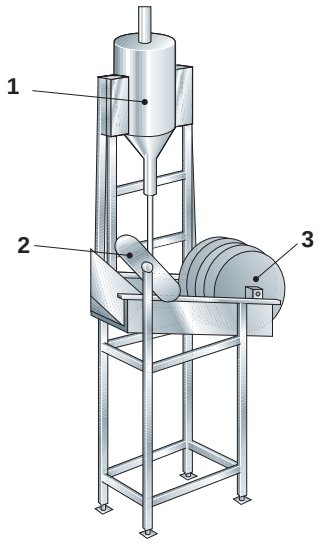


Fig. 14.30 *Dry salter for Pasta Filata.*
1 *Salt container*
2 *Level control for cheese mat*
3 *Grooving tool*

Moulding

As Pasta Filata cheese often occurs in various shapes – ball, pear, sausage, etc. – it is difficult to describe the process of moulding. However, automatic moulding machines are available for square or rectangular types, normally pizza cheese. Such a moulder typically comprises counter-rotating augers and a revolving mould-filling system, as illustrated in Figure 14.29.

The plastic curd enters the moulds at a temperature of 55 – 65 °C. To stabilise the shape of the cheese and facilitate emptying the moulds, the moulded cheese must be cooled. To shorten the cooling/hardening period, a hardening tunnel must be incorporated in a complete Pasta Filata line.

A production line for Pasta Filata types of cheese is illustrated in Figure 14.41.

Salting

In cheese, as in a great many foods, salt normally functions as a condiment. However, salt has other important effects, such as retarding starter activity and bacterial processes associated with cheese ripening. Application of salt to the curd causes more moisture to be expelled, both through an osmotic effect and a salting effect on the proteins. The osmotic pressure can be likened to the creation of suction on the surface of the curd, causing moisture to be drawn out.

With few exceptions, the salt content of cheese is 0,5 – 2,0 %. Blue cheese and white pickled cheese variants (Feta, Domiati, etc.), however, normally have a salt content of 3 – 7 %.

The exchange of calcium for sodium in paracaseinate that results from salting also has a favourable influence on the consistency of the cheese, which becomes smoother. In general, for semi-hard cheeses, the curd is exposed to salt at a pH of 5,3 – 5,6, *i.e.* approx. 5 – 6 hours after the addition of a vital starter, provided the milk does not contain bacteria-inhibiting substances.

Salting modes

Dry salting

Dry salting can be done either manually or mechanically. Salt is applied manually from a bucket or similar container containing an adequate (weighed) quantity that is spread as evenly as possible over the curd after all whey has been discharged. For complete distribution, the curd may be stirred for 5 – 10 minutes.

There are various ways to distribute salt over the curd mechanically. One is the same method as that used for salting of cheddar chips during the final stage of passage through a continuous cheddaring machine.

Another is a partial salting system used in production of Pasta Filata cheese (Mozzarella), illustrated in Figure 14.30. The dry salter is installed between the cooker-stretcher and moulder. With this arrangement, the normal brining time of eight hours can be reduced to some two hours, and less area is needed for brining.

Brine salting

Brine salting systems of various designs are available, from fairly simple to

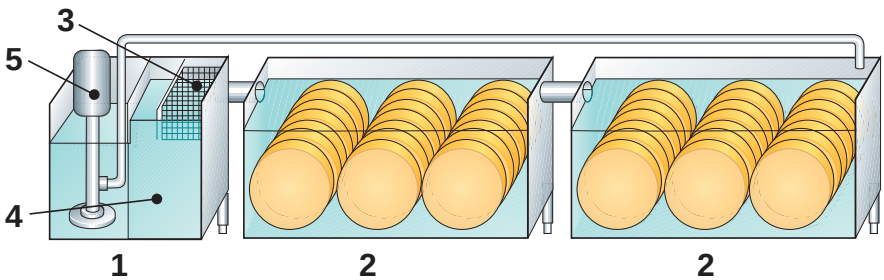


Fig. 14.31 *Brine bath system with containers and brine circulation equipment.*
1 *Salt dissolving container*
2 *Brining containers*
3 *Strainer*
4 *Dissolution of salt*
5 *Pump for circulation of brine*

technically very advanced. The most commonly used system remains the placing of the cheese in a container with brine. The containers should be placed in a cool room at about 12 – 14 °C. Figure 14.31 shows a practical, manually operated system.

A variety of systems based on shallow brining or containers for racks are available for large-scale production of brine-salted cheese.

Shallow or surface brining

In a shallow brining system, the cheese is floated into compartments, where brining in one layer takes place. To keep the surface wet, the cheese is dipped below the surface at intervals by a roller on the rim of each compartment. The dipping procedure can be programmed. Figure 14.33 shows the principle of a shallow brining system.

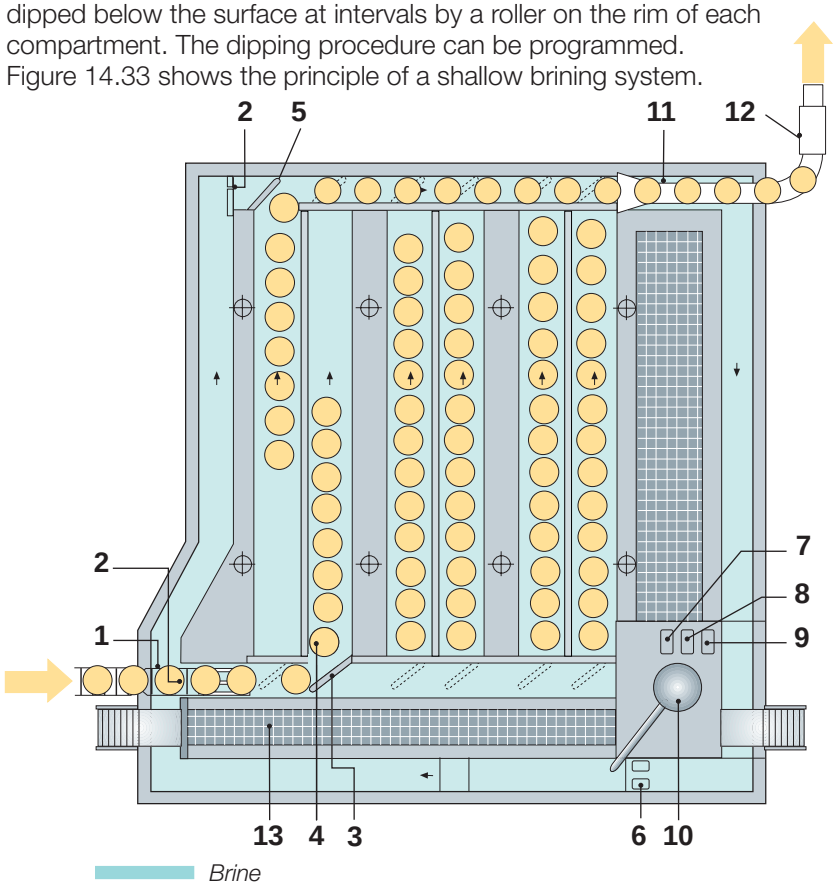


Fig. 14.32 *Surface brining system.*
1 Inlet conveyor with sliding plate
2 Regulating screen
3 Inlet door with regulating screen and guiding door
4 Surface brining department
5 Outlet door
6 Twin agitator with sieve
7 Brine level control with pump
8 Pump
9 Plate heat exchanger
10 Automatic salt dosing unit (including salt concentration measurement)
11 Discharge conveyor with gutter
12 Brine suction device
13 Service area

Deep brining

In a deep brining system, the cheeses float into hoisted cages. A cage consists of a number of perforated layers that are filled one by one with floating cheeses. Normally, the filling starts with the lowest layer. When one layer is filled, the cage descends one layer. The 2,5 – 3,0 m deep cages are mostly dimensioned for a batch covering a certain number of layers.

In general, deep brining is mostly used for longer brining times, due to the differences in brining time from the first to the last input. The system works on a first in-last out basis.

In the case of short brining times, there will be a difference in salt absorption. To achieve a more uniform brining time, the loaded cages can be emptied when half the time has elapsed and the cheeses are directed to an empty cage. The cheeses from the top layer of the first cage fill the bottom layer of the next cage.

Circulation of the brine through the filled cages is essential for refreshment of the brine around the cheeses. Turbines in the floating canals take care of both the transport of cheeses to and from the cages and the brine circulation.

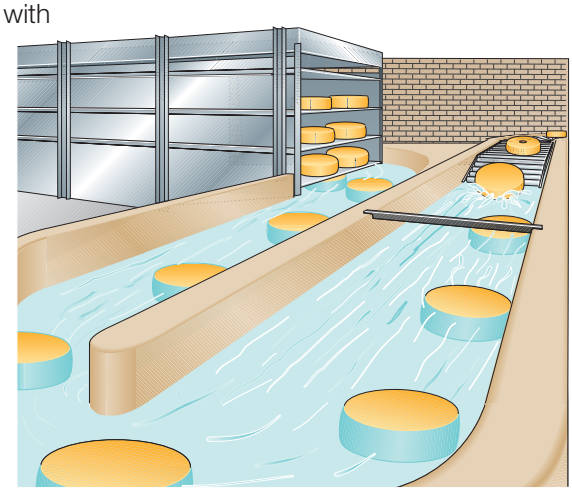


Fig. 14.33 *Deep brining system. The cage, 10 x 1,1 m with 10 layers, holds one shift's production.*

Rack brining system

Another deep brining system is based on racks. These racks are filled with

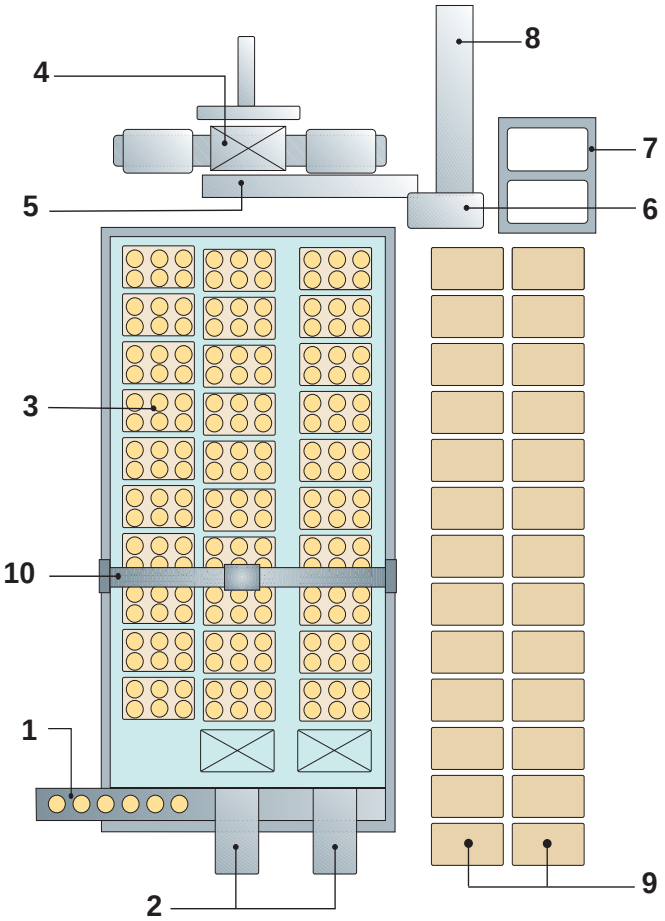


Fig. 14.34 *Rack brining system.*
1 *Feed conveyor*
2 *Mechanical loading station for brining racks*
3 *Brining racks*
4 *Mechanical unloading station for brining racks*
5 *Unloading conveyor*
6 *Lift*
7 *Rinsing bath*
8 *Belt conveyor*
9 *Space for empty racks and spare racks. Empty racks can also be stored in the brine. If the cheeses are packed/treated immediately after brining, this area is not needed.*
10 *Overhead travelling crane*

cheeses and the filled racks are placed in a brine bath. The size and loading of a rack predict the maximal variation in briningtime. All operations – filling the racks, placing them in the brine solution, hoisting the racks out of the brine and guiding them to an unloading station – can be completely automated. The principle of a rack brining system is shown in Figure 14.34.

Preparation of brine

The difference in osmotic pressure between brine and cheese causes some moisture with its dissolved components, whey proteins, lactic acid and minerals to be expelled from the cheese in exchange for sodium chloride. In the preparation of brine, it is important that this is taken into consideration. The brine has to be tested regularly for composition and temperature.

Salt is normally dissolved in the transport canal and HCl is injected into the stream. Besides dissolving salt to the desired concentration, the pH should be adjusted, *e.g.* with edible hydrochloric acid, to 4,6 – 4,8, but always lower then the final pH of the cheese. The hydrochloric acid must be free from heavy metals and arsenic. Lactic acid can of course be used, as can other "harmless" acids.

Calcium in the form of calcium chloride ($CaCl_2$) should also be added to give a calcium content of 0,1 – 0,2 %. Normally, the Ca content of the brine is kept on level by the exchange of Ca and Na.

Table 14.2 can serve as guide for preparation of brine. There is often a brine buffer from which the brine is pumped in case the brine bath is not completely filled up with cheeses. Brine flows back into the buffer when the cages are being filled.

Salt penetration in cheese

The following brief description, based on Report No. 22 from Statens Mejeriforsøg, Hillerød, Denmark, gives an idea of what happens when cheese is salted:

Cheese curd is criss-crossed by capillaries; approximately 10 000 capillaries per cm^2 have been found. There are several factors that can affect the permeability of the capillaries and the ability of the salt solution to flow through them, but not all such factors are affected by changes in technique. This applies, for example, to the fat content. As fat globules block the structure, salt penetration will take longer in a cheese with a high fat content than one with a low fat content.

The pH at the time of salting has considerable influence on the rate of

Table 14.2
Density versus salt concentration of brine at 15 °C

Density		Common salt brine	
kg/l	°Bé	kg salt in 100 l water	% salt in solution
1,10	13,2	15,7	13,6
1,12	15,6	19,3	16,2
1,14	17,8	23,1	18,8
1,16	20,0	26,9	21,2
1,17	21,1	29,0	22,4
1,18	22,1	31,1	23,7

salt absorption. More salt can be absorbed at low pH than at higher pH. However, at low pH,(*e.g.* <5,0), the consistency of the cheese is hard and brittle. At high pH, (*e.g.* >5,6), the consistency becomes elastic.

The importance of the pH of the cheese at the time of brining has been described by the research team at the Danish Hillerød institution:

Some parts of the calcium are more loosely bound to the casein, and at salting, the loosely bound calcium is exchanged for sodium by ion exchange. Depending on the quantity of loosely bound calcium, this determines the consistency of the cheese.

This loosely bound calcium is also sensitive to the presence of hydronium ions (H^+). The more H^+ ions, the more calcium (Ca^{++}) ions will leave the casein complex, and H^+ will take the place of calcium. At salting, H^+ is not exchanged for the Na^+ (sodium) of the salt. This means:

1 At high pH (6,0 – 5,8), there is more calcium in the casein. Consequently, more sodium will be bound to the casein complex, and the cheese will be softer; it may even lose its shape during ripening.
2 At pH 5,2 – 5,6 there may be enough Ca^{++} and H^+ ions in the casein complex to bind enough Na^+ to the casein. The resulting consistency will be good.
3 At low pH (< 5,2), too many H^+ ions may be included; as the Na^+ ions cannot be exchanged for the H^+ ions, the consistency will be hard and brittle.

Conclusion: it is important that cheese has a pH of about 5,4 before being brine salted.

Temperature also influences the rate of salt absorption and thus the loss of moisture. The higher the temperature, the higher the rate of absorption.

The higher the salt concentration of the brine, the more salt will be absorbed. At low salt concentrations, (*e.g.* <16 %), the casein swells and the surface will be smeary and slimy as a result of the casein being redissolved.

Salt concentrations of up to 18 – 23 % are often used at 10 – 14 °C. The duration of salting depends on:

- Salt content typical of the type of cheese
- Size of the cheese – the larger it is, the longer it takes
- Salt content and temperature of the brine

Brine treatment

In addition to readjusting the concentration of salt, the microbiological status of the brine must be kept under control, as various quality defects may arise. Certain salt-tolerant micro-organisms can decompose protein, giving a slimy surface; others can cause formation of pigments and discolour the surface. The risk of microbiological disturbances from the brine is greatest when weak brine solutions, <16 %, are used.

Pasteurisation is sometimes employed when the brine volume is limited.

- The brining system should then be so designed that pasteurised and unpasteurised brine are not mixed

Table 14.3

Salt content in different types of cheese

	% salt
Cottage cheese	0,25 – 1,0
Emmenthal	0,4 – 1,2
Gouda	1,5 – 2,2
Cheddar	1,75 – 1,95
Limburger	2,5 – 3,5
Feta	3,5 – 7,0
Gorgonzola	3,5 – 5,5
Other blue cheeses	3,5 – 7,0

- Brine is corrosive, so non-corroding heat exchanger materials such as titanium must be used; these materials, however, are expensive
- Pasteurisation upsets the salt balance of the brine and causes precipitation of calcium phosphate; some of this will stick to the plates and some will settle to the bottom of the brining container as sludge

Addition of chemicals is also employed. Sodium hypochlorite, sodium or potassium sorbate, or delvocide (pimaricine) are some of the chemicals used with variable results. The use of chemicals must of course comply with current legislation.

Other ways to reduce or stop microbiological activity are:

- Passing the brine through UV light, provided that the brine has been filtered, and will not be mixed with untreated brine after the treatment
- Microfiltration, which has become the most attractive method for brine purification

Table 14.3 lists the salt percentages in some types of cheese.

Ripening and storage of cheese

Ripening (curing)

After curdling, all cheese, apart from fresh cheese, goes through a whole series of processes of a microbiological, biochemical and physical nature. These changes affect the lactose, protein and fat, and constitute a ripening cycle that varies widely between hard, medium-soft and soft cheeses. Considerable differences occur even within these groups.

Lactose decomposition

The techniques that have been devised for making different kinds of cheese are always directed towards controlling and regulating the growth and activity of lactic acid bacteria. In this way, it is possible to simultaneously influence both the degree and the speed of fermentation of lactose. It has been stated previously that in the cheddaring process, the lactose is already fermented before the curd is hooped. As far as the other kinds of cheese are concerned, lactose fermentation ought to be controlled in such a way that most of the decomposition takes place during the pressing of the cheese and, at the latest, during the first week, or possibly the first two weeks, of storage.

Faulty fermentation can cause the cheese to burst.

The lactic acid produced is neutralised to a great extent in the cheese by the buffering components of milk, most of which have been included in the coagulum. Lactic acid is thus present in the form of lactates in the completed cheese. At a later stage, the lactates provide a suitable substrate for the propionic acid bacteria, which are important parts of the microbiological flora of Emmenthal, Gruyère and similar types of cheese. Besides propionic acid and acetic acid, a considerable amount of carbon dioxide is produced, which is the direct cause of the formation of the large round eyes in the above-mentioned types of cheese.

The lactates can also be broken down by butyric acid bacteria. If the conditions are otherwise favourable for this fermentation, hydrogen is evolved, in addition to certain volatile fatty acids and carbon dioxide. This faulty fermentation arises at a late stage, and the hydrogen can actually cause the cheese to burst.

The starter cultures normally used in the production of the majority of hard and medium-soft kinds of cheese not only cause the lactose to ferment, but also have the ability to attack the citric acid in the cheese simultaneously. This produces the carbon dioxide that contributes to formation of both round and granular eyes.

Fermentation of lactose is caused by the lactase enzyme present in lactic acid bacteria.

Protein decomposition

The ripening of cheese, especially hard cheese, is characterised first and

foremost by the decomposition of protein. The degree of protein decomposition affects the quality of the cheese to a very considerable extent, most of all its consistency and taste. The decomposition of protein is brought about by the enzyme systems of:

- Rennet
- Micro-organisms
- Plasmin, an enzyme that is part of the fibrinolytical system

The only effect of rennet is to break down the paracasein molecule into polypeptides. This first attack by the rennet, however, enables a considerably quicker decomposition of the casein through the action of bacterial enzymes than would be the case if these enzymes had to attack the casein molecule directly. In cheese with high cooking temperatures, scalded cheeses like Emmenthal and Parmesan, plasmin activity plays a role in this first attack.

In medium-soft cheeses like Tilsiter and Limburger, two ripening processes proceed parallel to each other, such as the normal ripening process of hard rennet cheese and the ripening process in the smear that is formed on the surface. In the latter process, protein decomposition proceeds further until ammonia is finally produced as a result of the strong proteolytic action of the smear bacteria.

Storage

The purpose of storage is to create the external conditions that are necessary to control the ripening cycle of the cheese as far as possible. For every type of cheese, a specific combination of temperature and relative humidity, air circulation and air velocity must be maintained in the different storage rooms during the various stages of ripening.

Storage conditions

Different types of cheese require different temperatures and relative humidities (RH) in the storage rooms.

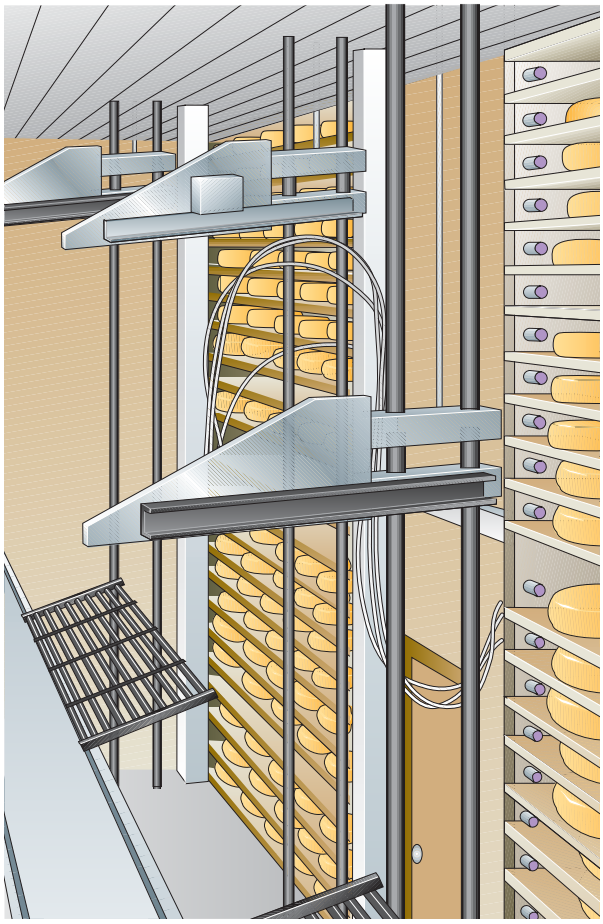


Fig. 14.35 *Mechanised cheese storage. Humidified air is blown through the plastic nozzles at each layer of cheese.*

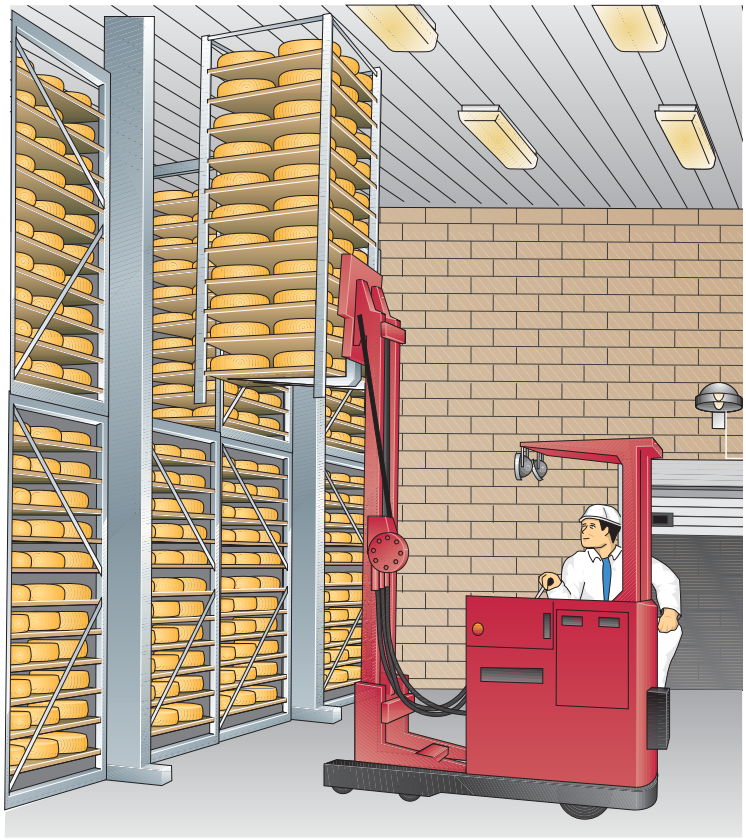


Fig. 14.36 *Cheese storage using pallets.*

The climatic conditions are of great importance to the rate of ripening, loss of weight, rind formation and development of the surface flora (in Tilsiter, Romadur and others) – in other words to the total nature or characteristics of the cheese.

Cheeses with rinds, most commonly hard and semi-hard types, can be provided with a plastic emulsion, paraffin or wax coating.

Rindless cheese is covered with a plastic film or packed in semi-permeable or shrinkable plastic bag, mostly under vacuum condition.

Covering the cheese has a dual purpose:

1 Prevent excessive water loss
2 Protect the surface from infection and dirt

The four examples below will give some idea of the variety of storage conditions for different kinds of cheese.

1 Cheeses of the *Cheddar* family are often ripened at low temperatures, 4 – 8 °C, and a RH lower than 80 %, as they are normally wrapped in a plastic film or bag and packed in cartons or wooden cases before being transported to the store. The ripening time may vary from a few months up to 8 – 10 months, to satisfy the preferences of various consumers.
2 Other types of cheese like *Emmenthal* may need to be stored in a "green" cheese room at 8 – 12 °C for some 3 – 4 weeks, followed by storage in a "fermenting" room at 22 – 25 °C for some 6 – 7 weeks. After that, the cheese is stored for several months in a ripening store at 8 – 12 °C. The relative humidity in all rooms is normally 85 – 90 %.
3 Smear-treated types of cheese – *Tilsiter, Havarti* and others – are typically stored in a fermenting room for around two weeks at 14 – 16 °C and a RH of about 90 %, during which time the surface is inoculated with a special cultured smear mixed with a salt solution. Once the desired layer of smear has developed, the cheese is normally transferred to the ripening room at a temperature of 10 – 12 °C and a RH of 90 % for a further 2 – 3 weeks. Eventually, after the smear is washed off and cheese is wrapped in aluminium foil, it is transferred to a cold store (6 – 10 °C and about 70 – 75 % RH), where it remains until distributed.
4 Other hard and semi-hard types of cheese, *Gouda* and similar, may first be stored for a couple of weeks in a "green" cheese room at 10 – 12 °C and a RH of some 75 %. After that, a ripening period of about 3 – 4 weeks may follow at 12 – 18 °C and 75 – 80 % RH. Finally, the cheese is transferred to a storage room at about 10 – 12 °C and a relative humidity of about 75 %, where the final characteristics are developed.

The values given for temperatures and relative humidities, RH, are approximate and vary for different sorts of cheese within the same group. The humidity figures are not relevant to film-wrapped or bag-ripened cheese.

Methods of air conditioning

A complete air conditioning system is normally required to maintain the necessary humidity and temperature conditions in a cheese ripening store, because humidity has to be removed from the cheese, which is difficult if the outside air has a high humidity. The incoming air must be dehumidified by refrigeration, which is followed by controlled rehumidification and heating to the required conditions.

It may also be difficult to distribute air humidity equally to all parts of the storeroom.

Distribution ducts for the air may be of some help, but they are difficult to keep free from mould contamination. The ducts must therefore be designed to allow cleaning and disinfection.

Storage layout and space requirements

The layout depends on the type of cheese. Installing permanent cheese racks in the store has been the conventional solution for both hard and semi-hard cheeses. The capacity of a store for cheeses weighing about 8 – 10 kg, with ten racks above each other is approximately 300 – 350 kg/m^2. Gangways between the racks are 0,6 m wide and the main corridor in the middle of the store is usually 1,5 – 1,8 m wide. Mounting the racks on wheels or hanging them from overhead rails eliminates the need for gangways between racks. They can be put close to each other and need only be moved when the cheese is handled. This system increases the capacity of the store by 30 – 40 %, but the cost of the store and building remains at the same level because of the higher cost of this type of rack.

Pallet racks or containers are a widely used system. Pallets or pallet containers can also be put on special wheeled pallets running on rails. This method also permits compact storage. Figure 14.35 shows a mechanised cheese store. A wooden shelf holding five cheeses is conveyed into the green cheese storage and then into a specially designed elevator – not shown in the picture – which lowers or lifts the shelf to a pre-set level and pushes it into storage. Figure 14.36 shows a ripening store based on pallets.

Cheese ripened in film is packed in cardboard boxes and piled on pallets for the later part of the storage period. This means that the cheese can be stored compactly. The pallets cannot be stacked on top of each other, but pallet racks can be used. However, the load per unit area must be taken into consideration if this method is adopted, as the weight will far exceed the normal load allowed in old buildings.

The load per unit area must be taken into consideration if the pallet rack method is adopted, as the weight will far exceed the normal load allowed in old buildings.

In comparison with permanent racks, the container system increases the storage capacity considerably.

There are companies that specialise in storage systems of various degrees of sophistication; anything from traditional racks up to and including computerised systems. They can also advise about optimum air conditioning for the various systems.

Processing lines for hard and semi-hard cheese

The following part of this chapter will only describe examples of processing lines for typical types of cheeses.

Hard types of cheese

Processing line for Emmenthal cheese

Milk intended for traditional Emmenthal cheese is normally not pasteurised, but the fat content is standardised. During periods when high loads of bacteria spores occur, the milk may also be treated in a bactofugation or microfiltration plant for mechanical reduction of spores, before which the milk should be heated to 50 – 63 °C. In large-scale, industrial Emmenthal production, the milk is normally standardised and pasteurised.

After pre-treatment, including addition of necessary ingredients, curd production can start. A preliminary flowchart for production of rindless Emmenthal cheese is illustrated in Figure 14.37.

Once the curd is satisfactorily acidified and firm enough, part of the whey is drained from the cheese tank and routed into the pre-press vat (2). When an adequate amount of whey has been transferred, the curd/whey mixture

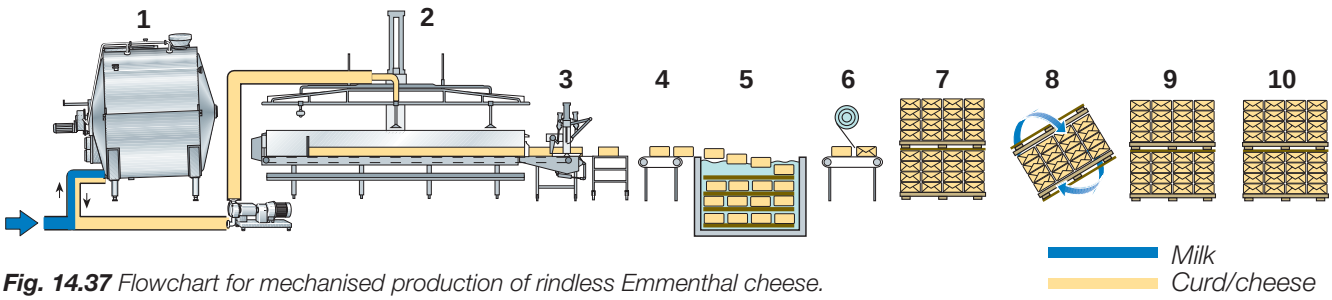


Fig. 14.37 *Flowchart for mechanised production of rindless Emmenthal cheese.*

1 *Cheesemaking tank*
2 *Press vat for total pressing of the curd*
3 *Unloading and cutting device*
4 *Conveyor*
5 *Brining*
6 *Wrapping in film and cartoning*
7 *Palletised cheeses in green cheese store*
8 *Turning the cheese*
9 *Fermenting store*
10 *Ripening store*

is pumped into the pre-press vat via distributors. Following the curd/whey transfer and levelling of the curd, the press lid is lowered. Surplus whey is simultaneously drained off.

Application of programmed pressures for pre-set times continues for 10 – 20 hours, depending on lactic acid development.

After pre-pressing, the cheese bed is cut into block of suitable size by being conveyed through the unloading device, which is provided with lengthwise and crosswise knives.

The blocks are positioned in pressing moulds.The cheeses are depending of their sizes pressed for 3 to 12 hours. When the cheeses have reached the desired pH the blocks are transferred to a brine bath and emerged in brine.

As Emmenthal cheeses are normally large, 30 kg up to more than 50 kg, the brining period will vary and may last for up to seven days.

Following brining, rindless cheese is typically wrapped in film under vacuum and packed in cartons or big containers before being transferred to the storerooms. Turning the cheese during storage is recommended, to obtain a better shape and more uniform eye formation. Palletised turning can be done with specially designed lifting trucks.

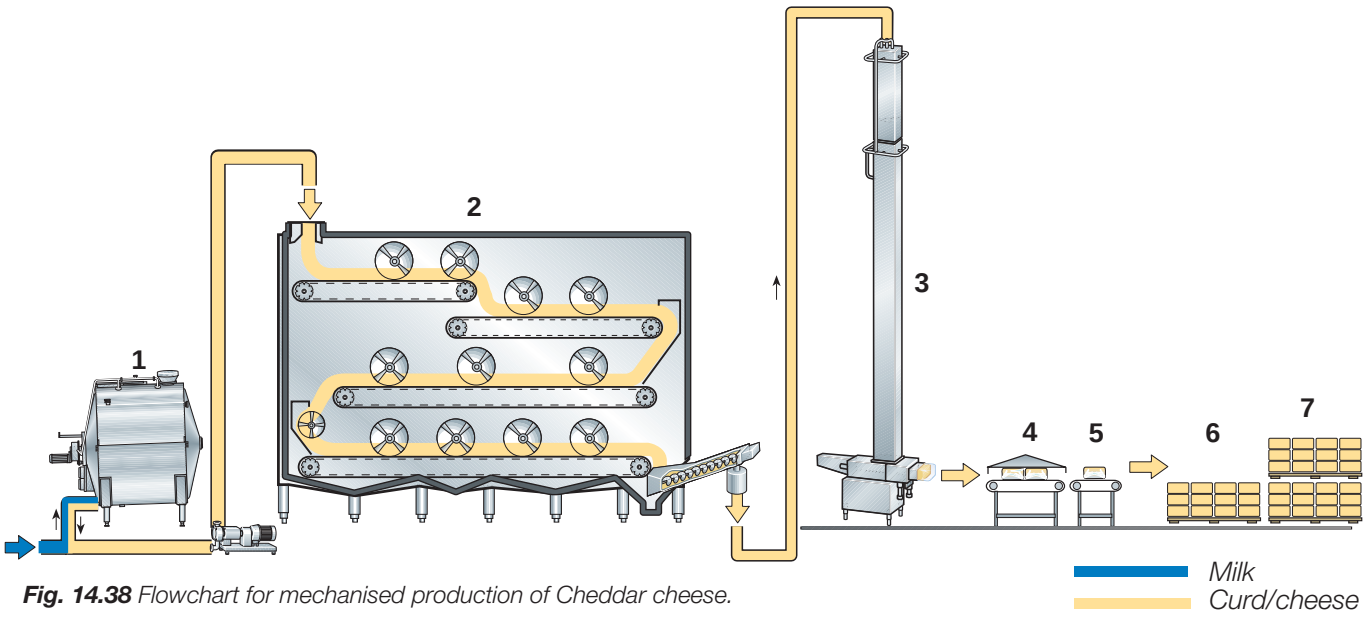


Fig. 14.38 *Flowchart for mechanised production of Cheddar cheese.*

1 *Cheesemaking tank*
2 *Cheddaring machine*
3 *Blockformer and bagger*
4 *Vacuum sealing*
5 *Weighing and carton packer*
6 *Rapid cooling store*
7 *Ripening store*

Processing line for Cheddar cheese

Cheddar cheese and similar types are the most widely produced in the world.

Cheddar cheese generally has a moisture on fat-free basis (MFFB) of 55 %, which means it can be classified as hard cheese, although it is on the verge of semi-hard types. The principle of a highly mechanised production line is shown in Figure 14.38.

The curd is normally manufactured from fat-standardised and pasteurised milk. At a pH of about 6,3, after some 2 to 2,5 hours of curd production, the curd-whey mixture is pumped from the cheese tank into the continuous cheddaring machine (2). Pre-drawing of whey is not normally practised.

To maintain a continuous feed, a calculated number of cheese tanks is scheduled for emptying in sequence at regular intervals, say every 20 minutes.

After a cheddaring period of about 2,5 hours including milling and dry salting of the chips at a curd pH of 5,3, the chips are transported by vacuum to a blockformer (3). An adequate number of blockformers must be available to maintain continuity.

The exit of each blockformer is manually provided with a plastic bag into which the cut-out block is pushed. Also an automatic bag loader can be intergraded in the line. The bagged block is then conveyed to a vacuum sealing machine (4). Following sealing, the cheese is weighed (5) en route to a packing machine (6), where it is covered by a carton, which is then conveyed to a rapid cooling store (7). The cheese is cooled down to a core temperature of approximately 15 °C in about 24 hours at a store temperature of 2 – 3 °C. Finally, the cheese is palletised and held from 4 to 12 months in the ripening store at a temperature of 5 – 10 °C.

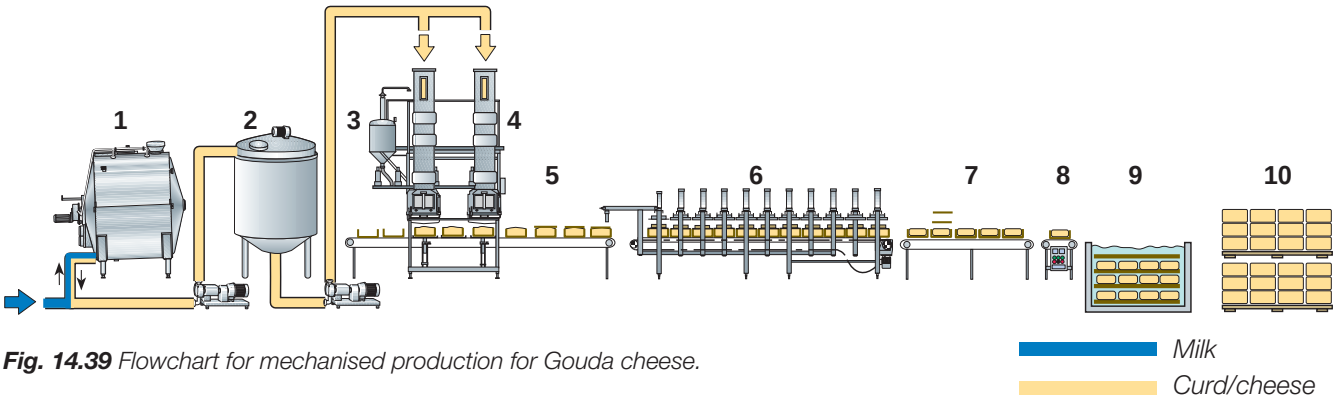


Fig. 14.39 *Flowchart for mechanised production for Gouda cheese.*

1 *Cheesemaking tank*
2 *Buffer tank*
3 *Whey collecting*
4 *Continuous drainage columns*
5 *Lidding*
6 *Conveyor press*
7 *De-lidding*
8 *Weighing*
9 *Brining*
10 *Ripening store*

Semi-hard types of cheese

Processing line for Gouda cheese

Gouda is probably the best-known representative of typical round-eyed cheeses. A Gouda processing line is illustrated in Figure 14.39.

Fat-standardised pasteurised milk is transformed into curd and whey in the usual manner in about two hours. Normally, part or sometimes all of the heating is done by direct addition of hot (50 – 60 °C) water in an amount equal to 10 – 20 % of the original volume of milk. To make this possible, some 30 – 40 % of whey must first be drained off.

After completion of curd production and further drainage of whey to a curd/whey ratio of 1:3,5 – 5,0, the contents of the cheese tank are emptied

into a buffer tank (2) provided with an agitator for proper distribution of the curd in the whey. The tank is also jacketed to enable the curd to be chilled to 1 – 2 °C with cold water and to control the moisture content in the batch.

The whey/curd mixture is pumped from the filled buffer tank into one or more drainage columns (4). At the very start, however, the column is first filled with whey, so that the subsequent curd will not be exposed to air when it enters the column.

For continuous operation, a suitable number of cheese tanks is operated in sequence and emptied at regular intervals of about 20 – 30 minutes.

Following pre-pressing, the cheese block is pushed out of the machine. Normally, the blocks are fed by gravity into clean moulds conveyed from the washing machine and stationed underneath the columns. A fully mechanised system also comprises:

- Mechanical lidding (5) of the moulds
- Transfer of moulds to conveyor or tunnel presses with pre-programmed pressures and pressing times (6)
- Filling and emptying of the presses
- Transport of moulds via a de-lidding station (7), a mould-turning device, a mould-emptying system and a weighing scale (8) to an advanced brining system (9).

The moulds and lids are separately conveyed to a combined mould and lid washing machine before being re-used.

After brining, the cheese is stored in a green cheese store for about 10 days at 10 – 12 °C, after which storage continues in a ripening store at 12 – 15 °C for some 2 – 12 months.

Processing line for Tilsiter cheese

Tilsiter has been chosen as a representative of granular textured cheese. The principle of a mechanised production line is similar to that for Gouda, but with a few exceptions, see Figure 14.40.

Milk pre-treatment and curd production are similar to those of Gouda cheese. The first basic difference is, that before the curd/whey mixture enters the column, the whey is separated from the curd. This is done in a strainer (4) located on top of the column.

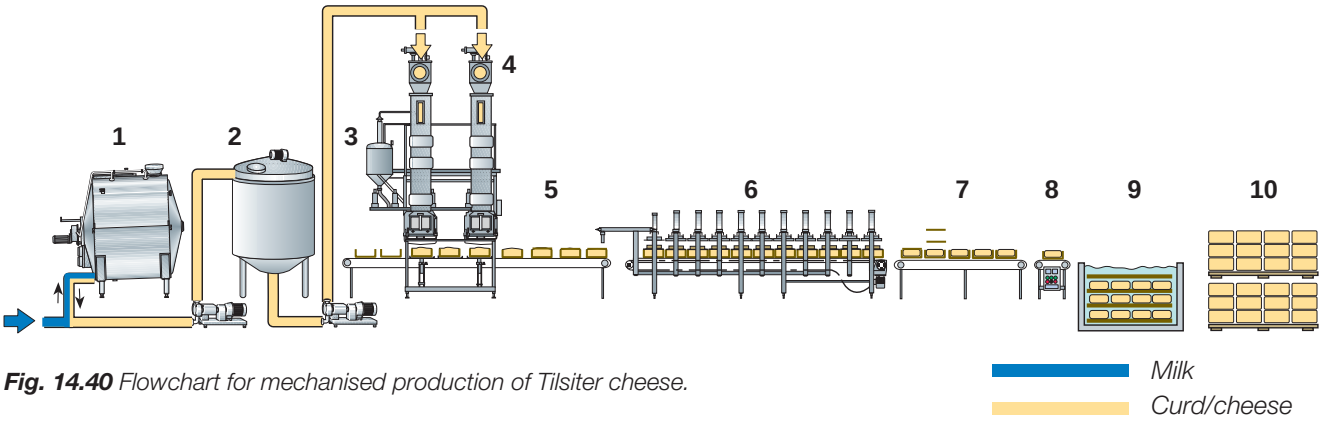


Fig. 14.40 *Flowchart for mechanised production of Tilsiter cheese.*

1 *Cheesemaking tank*
2 *Buffer tank*
3 *Whey collecting*
4 *Continuous drainage columns with strainer on top*
5 *Lidding*
6 *Conveyor press*
7 *De-lidding*
8 *Weighing*
9 *Brining*
10 *Ripening store*

After brining, however, Tilsiter cheese undergoes special treatment involving smearing of the surface with a bacteria culture in a 5 % salt solution to give it its specific flavour. Tilsiter cheese is therefore first stored in a fermenting room with a high relative humidity (90 – 95 %) and a temperature of about 14 – 16 °C. The smearing procedure is either manual or partly mechanised, and the smeared cheese is stored for about 10 – 12 days.

Following the period of surface treatment, the cheese is forwarded to

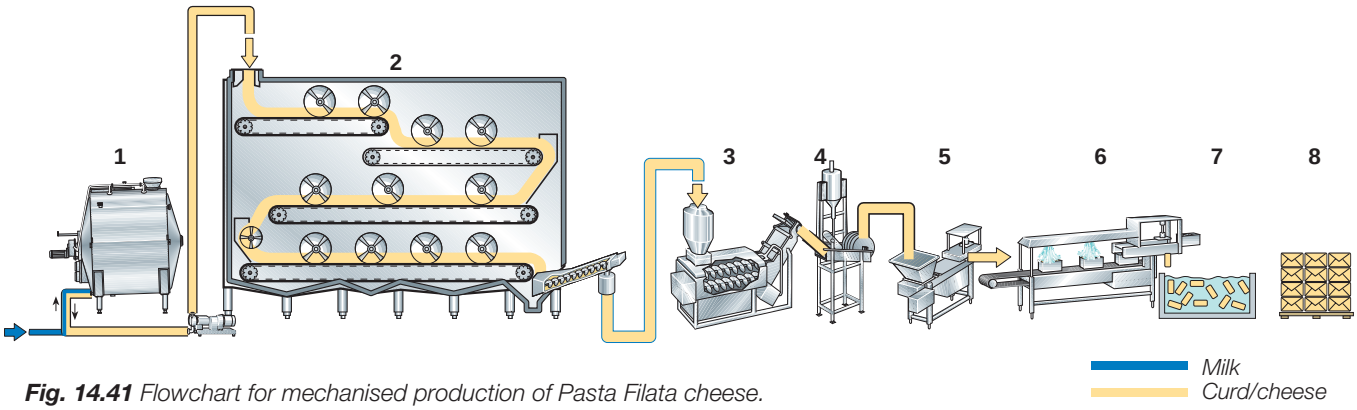


Fig. 14.41 *Flowchart for mechanised production of Pasta Filata cheese.*

1 *Cheesemaking tank*
2 *Cheddaring machine*
3 *Cooker/stretcher*
4 *Dry salting*
5 *Multi-moulding*
6 *Hardening tunnel*
7 *Brining*
8 *Store*

ripening storage at 10 – 12 °C, often after having passed a washing machine. The time in this store is around 2 – 3 weeks.

In conjunction with dispatch from the ripening store, the Tilsiter cheese may be washed and wrapped in aluminium foil before being transferred to a cold store at 6 – 10 °C.

Processing line for Pasta Filata cheese

"Formaggio a pasta filata" is the Italian name for types of cheese that in English are called Pasta Filata cheese, characterised by an "elastic" string curd, *e.g.* Mozzarella and Provolone. A production line is presented in Figure 14.41.

The typical Mozzarella cheese was originally, and still is, based on buffalo milk derived from the buffaloes bred in central Italy. Mozzarella is also produced from a mixture of buffalo and cow milk, but nowadays, most commonly from cow milk alone. Mozzarella is also called pizza cheese in some countries.

Production of Mozzarella typically involves:

- Curd production in the usual manner
- Cheddaring, including milling, but not salting
- Cooking and stretching to obtain the elastic, stringy character
- Forming, hardening and brining
- Packaging, *e.g.* in plastic bags. For consumer size packages it is packed together with some brine
- Short storage before dispatch

Fat-standardised pasteurised milk is converted to curd in the usual way. After that, the curd and whey are pumped to a mechanical cheddaring machine (2) of a somewhat simpler type than that used for Cheddar cheese production, where the curd is matted and milled into chips. The matting and milling process takes about 1,5 hours.

After cheddaring, the chips are transported into the receiver of a cooker-stretcher (4). The plasticised curd is then continuously extruded to the moulding machine (6), en route to which it may be dry-salted (5) to shorten the normal brining time of about eight hours to approximately two hours.

The curd is worked into the (multi-)mould, which is then conveyed through a hardening tunnel, where the cheese is cooled from 55 – 65 °C to 35 – 45 °C, by spraying chilled water over the moulds. At the end of the tunnel, the moulds pass a de-moulding device. The cheese falls into the gently flowing, cold (2 – 5 °C) brine bath and the empty moulds are returned to the filling machine.

The cheese may be bagged and packed in cartons, before being loaded on a pallet, which is then trucked to a store.

Semi-hard, semi-soft and soft types of cheese

Sometimes it is difficult to classify a type of cheese as distinctly semi-hard or semi-soft, or as semi-soft or soft, as some types occur in intermediate forms. The Tilsiter types are typical representatives of the former intermediate forms, as are Blue or Blue veined types of cheese, while Brie types may represent the latter.

The following brief descriptions refer to methods of production of:

- Blue (veined) cheese, representative of semi-hard and semi-soft types of cheese with inside mould formation by Penicillium roqueforti.
- Camembert cheese, representative of semi-soft/soft types of cheese with outside surface mould formation by Pencillium camemberti andPenicillium candidum.
- Cottage cheese and Quarg as representatives of soft fresh cheese.

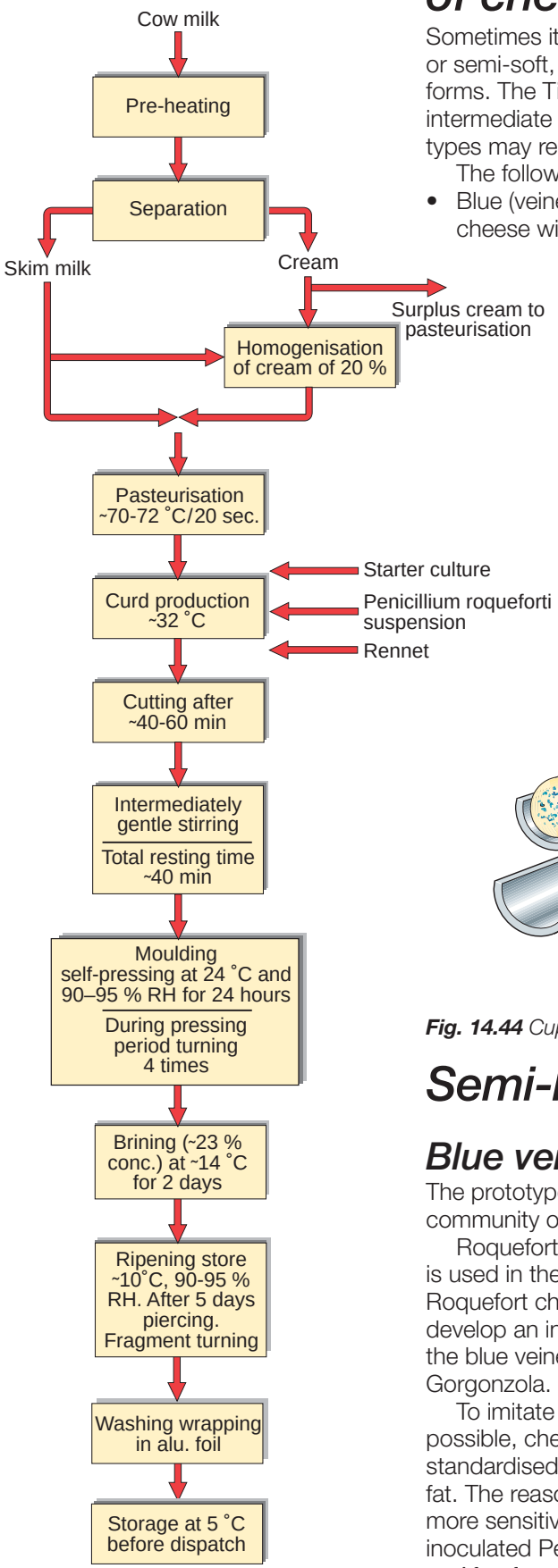


Fig. 14.42 *Principle of production of Blue cheese.*

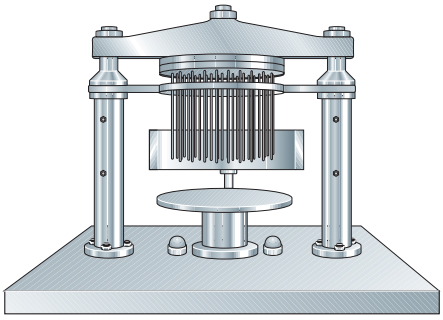


Fig. 14.43 *Pinching machine for piercing Blue cheese.*

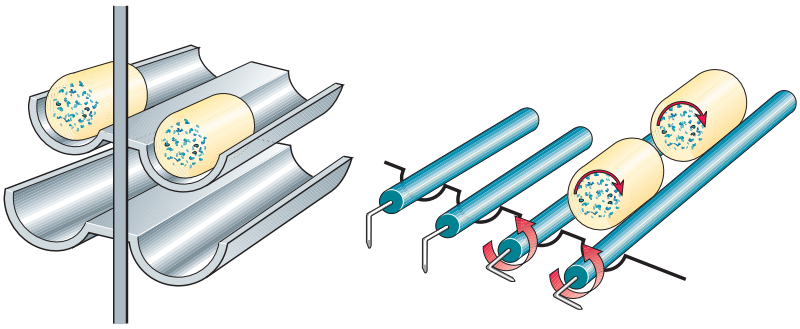


Fig. 14.44 *Cupped shelves and pivoted rods for storage of Blue cheese.*

Semi-hard and semi-soft cheese

Blue veined cheese

The prototype of blue veined cheese is Roquefort, which originates from the community of Roquefort in the Aveyron Departement in France.

Roquefort cheese is produced from sheep milk; if any other kind of milk is used in the production of a similar type of cheese, it must not be called Roquefort cheese. Blue veined cheese is the generic name for cheeses that develop an interior blue-green mould. Other well-known representatives of the blue veined group of cheeses are British Stilton, Danish Blue and Italian Gorgonzola.

To imitate the characteristic flavour of Roquefort cheese as closely as possible, cheese milk from cows should be partially homogenised, *i.e.* standardised by mixing skim milk with homogenised cream of about 20 % fat. The reason is that fat which has been exposed to homogenisation is more sensitive to the influence of the lipolytic enzymes emanating from the inoculated Penicillium roqueforti mould.

After fat standardisation, the milk is normally pasteurised at about 70 °C, cooled to 31 – 32 °C and fed to the cheese tank. After addition of an ordinary starter culture and a spore suspension of *P. roqueforti*, the milk is

gently, but thoroughly, agitated, to obtain good distribution of the micro-organisms before renneting.

The principle of blue cheese production is shown in the block chart in Figure 14.42. As this block chart is self-explanatory, only short comments are given here.

The cheese is pierced after about five days in the ripening store to facilitate admission of the oxygen needed for the growth of the mould. Piercing is done using a tool with needles about 2 mm in diameter and roughly equal in length to the height of the cheese. The number of needles depends on the diameter of the cylindrical cheese, which is often pierced alternately through the top and bottom, to avoid the risk of cracking. A piercing machine is shown in Figure 14.43.

During the ripening period of five to eight weeks at 9 – 12 °C and a RH of >90 %, the cheese rests on edge, normally on cupped shelves or on pivoted rods, as shown in Figure 14.44. The latter system facilitates turning of the cheese, which is done frequently to maintain the cylindrical shape.

After the pre-ripening period, the cheese is passed through a washing machine, to remove the smear that normally develops at the high RH in the store, as well as mould. After washing, the cheese is usually wrapped in aluminium foil or plastic film before being transferred to storage at about 5 °C, from which it is dispatched to a retail store after a couple of days.

Semi-soft/soft cheese

Camembert cheese

Camembert may serve as the characteristic type of cheese covered by white mould from Penicillium camemberti and Penicillium candidum. Brie is another representative.

The cheesemaking procedure is broadly the same as for Blue veined cheese.

The cheeses are, however, small and flat. Self-pressing in the moulds proceeds for about 15 – 20 hours, during which time the cheeses should be turned about four times. The cheese is then brined for 1,0 – 1,5 hours in saturated brine (about 25 % salt).

After salting, the cheeses are placed on stainless steel string racks, Figure 14.45, or trays. The racks are stacked as much as 15 – 20 high, and then trucked into a storeroom at 18 °C and 75 – 80 % RH, where they are dried for two days. Then the cheese is trucked to ripening storage at 12 – 13 °C and 90 % RH.

The cheeses are frequently turned during the ripening period. When the white mould is sufficiently developed, normally after 10 to 12 days, the cheese is packed in aluminium foil and often put in a box, before being transferred to a cold store, where it is held at 2 – 4 °C, pending distribution to retailers.

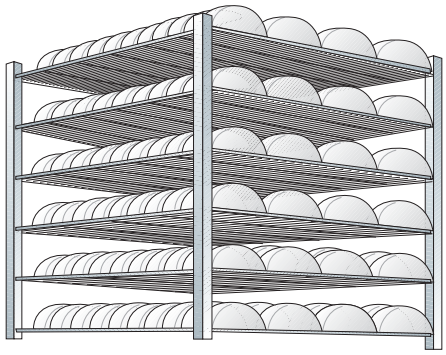


Fig. 14.45 *String racks for white mould cheese.*

Soft cheese

Cottage cheese

Cottage cheese is a creamed fresh curd, low in acidity due to the coagulation of the milk by reaching the iso-electrical point, pH about 4,7. The final curd is washed and covered with a dressing.

The producer of Cottage cheese can choose between three ways to make a product of identical character:

- Long-set method
- Medium-set method
- Short-set method

The basic differences between these methods are summarised in Table 14.4.

Table 14.4
Processing data for different modes of production of Cottage cheese

Process stage	Long-set	Medium-set	Short-set
Time before cutting	14 – 16 hours	8 hours	5 hours
Temp. of milk set	22,0°C	26,5°C	32,0°C
Starter addition	0,5%	3%	5%
Rennet (strength 1:10[4])	2 ppm	2 ppm	2 ppm

Irrespective of method, after cutting, the curd is left undisturbed for 15 – 35 minutes. At the cutting stage, the cheesemaker normally makes another choice, such as whether to produce small curd, medium-sized curd or large curd Cottage cheese, which is a matter of the fineness of the grains obtained at cutting.

Following the resting period and stirring, the curd is cooked – usually by indirect heating – for 1 – 3 hours, until a temperature of 47 to 56 °C is reached.

When the complete Cottage cheese production process takes place in the same tank, a certain volume of whey is drained off to make room for a corresponding volume of washing and cooling water.

When the same tank is used for the complete production, the curd is normally washed with three batches of water at temperatures of 30 °C, 16 °C and 4 °C respectively. Thorough washing dilutes the lactose and lactic acid, and further acid production and shrinkage are stopped by cooling the curd to about 4 – 5 °C. The total time for washing, including intermediate whey-water drainage periods, is about 3 hours.

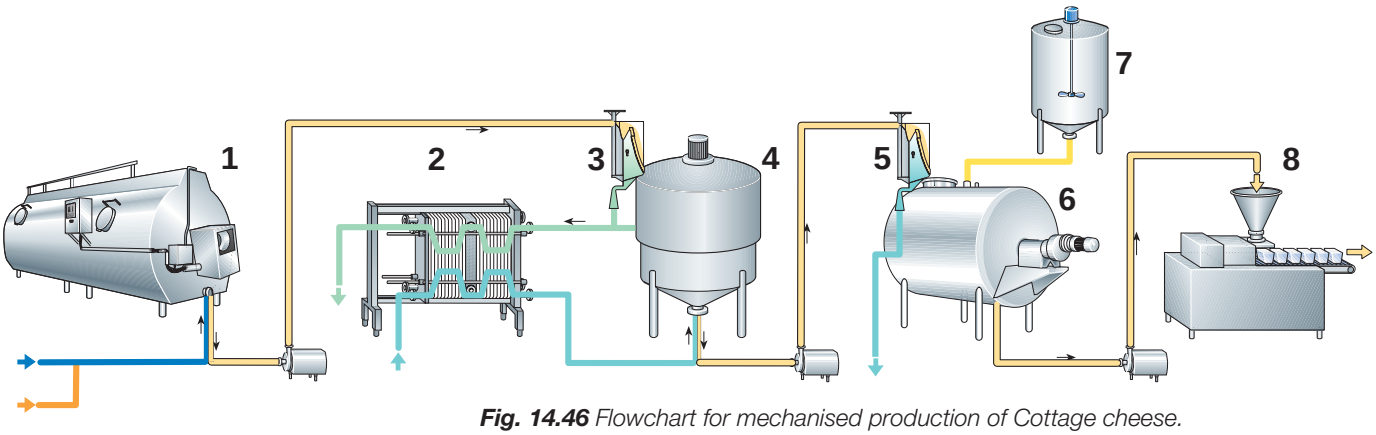


Fig. 14.46 *Flowchart for mechanised production of Cottage cheese.*

1 Cheese vat
2 Plate heat exchangerWhey strainer
3 Whey strainer
4 Cooling and washing tank
5 Water drainer
6 Creamer
7 Dressing tank
8 Filling machine

After all the water has been drained off, pasteurised (80 – 90 °C) cream at 4 °C containing a small amount of salt, known as dressing, is added and thoroughly worked in. Ordinary Cottage cheese contains approximately 79 % moisture, 16 % milk-solids-non-fat (MSNF), 4 % fat and 1 % salt.

Finally, the Cottage cheese is packed in containers and stored at 4 – 5 °C before being distributed to retail shops.

The description shows that Cottage cheese can be produced in a single tank. However, special washing and creaming systems have been developed to rationalise production, especially the washing of the curd and the dressing. The principle of a rationally functioning Cottage cheese production line is illustrated in Figure 14.46.

From the enclosed curd producing tank (1), which serves among other things to protect the milk from airborne infection during the long (16 – 20 hours) or relatively short (5 hours) coagulation period, the whey-curd mixture is pumped via a static whey strainer (3) to a cooling/washing (CW) tank (4).

While the whey is passed to a collection tank, the curd falls into the CW tank with a certain level of fresh water. Even before all the curd from the cheese tank has been transferred to the CW tank, fresh water is pumped in through the bottom inlet. At a certain level in the tank, there is an outlet for the surplus liquid, which passes an inner, perforated part so that the curd is retained. After some minutes, when the surplus liquid is more or less free from whey, the inflow of water is stopped and the water is circulated through a plate heat exchanger (2), where the temperature is gradually lowered to 3 – 4 °C. The whole cooling and washing procedure takes about 30 – 60 minutes, not including filling and emptying of the CW tank.

After washing and cooling, the curd is pumped via a drainer (5) to a creamer (6), designed for mixing the curd and cream dressing. Finally, the creamed Cottage cheese is packed in cups and stored in containers.

Quarg

Quarg is defined as “a sour skim milk curd cheese usually consumed unripened”.

Quarg is often mixed with cream, and sometimes also with fruit and seasonings. The standard of the product varies in different countries and the dry matter in non-fat Quarg may vary between 14 and 24 %.

When the Quarg separator was first introduced, the milk was pasteurised at approximately 73 °C, before fermentation and separation. This is referred to as the traditional method.

Nowadays, it is more common to use high-temperature, long-time pasteurisation of the skim milk, 85 – 95 °C for 5 – 15 minutes, and further heat treatment of the acidified milk before separation. The latter method is called thermisation, and temperatures 56 – 60 °C for up to three minutes are recommended. This, together with high-temperature pasteurisation of the skim milk, contributes to better yield.

A Quarg production line is illustrated in Figure 14.47.

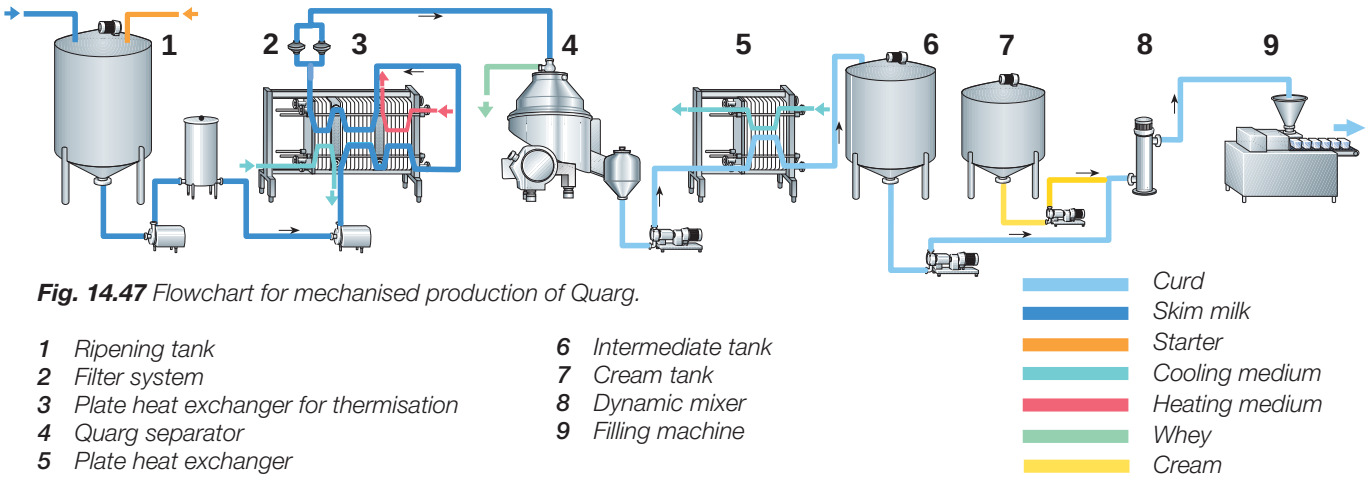


Fig. 14.47 *Flowchart for mechanised production of Quarg.*

1 *Ripening tank*
2 *Filter system*
3 *Plate heat exchanger for thermisation*
4 *Quarg separator*
5 *Plate heat exchanger*
6 *Intermediate tank*
7 *Cream tank*
8 *Dynamic mixer*
9 *Filling machine*

After pasteurisation and cooling to 25 – 28 °C, the milk is routed into a tank (1). A bacteria culture, typically containing *Streptococcus lactis/cremoris* bacteria, is also added, often together with a small amount of rennet, normally one-tenth of what is used in ordinary cheese production or about 2 ml liquid rennet per 100 kg milk. This is done to obtain a firmer coagulum.

A coagulum forms after about 16 hours at pH 4,5 – 4,7. After the coagulum has been stirred, Quarg production starts with thermisation (3) and cooling to 37 °C. The next step is centrifugal separation (4). The Quarg leaves the machine through nozzles at the periphery of the bowl and is

discharged into a cyclone from which it is forwarded by a positive displacement pump via a plate cooler (5) into a buffer tank (6). The whey is collected from the separator outlet.

The final cooling temperature depends on the total solids content and, in fact, on the protein content. At a dry matter content of 16 – 19 %, the cooling temperature is 8 – 10 °C. When the DM is 19 – 20 %, the Quarg should only be cooled to 11 – 12 °C.

Tubular coolers are also used, but they are uneconomical for small production volumes, because the losses of product expressed as a percentage of the feed are high, owing to the large hold-up volume of the tubular cooler.

The cooled product is normally collected in a buffer tank before being packed.

If the Quarg is creamed, an adequate volume of sweet or cultured cream is added to the flow and subsequently mixed in a dynamic mixing unit (8), before the product goes to the packaging machine (9).

Sometimes, there is a demand for a long-life Quarg product. The process includes heat treatment of the product to inactivate all micro-organisms. Suitable stabilisers must be added in the buffer tank and thoroughly distributed by agitation. They are needed to stabilise the protein system prior to the final heating, which is performed in a plate, tubular or scraped surface heat exchanger.

The Quarg processing line outlined here can also handle production of strained yoghurt or Labneh, as well as being a part of a cream cheese processing line.

Processed cheese

Processed cheese is made by further processing of finished cheese, usually a blend of hard rennet varieties with different aromas and degrees of maturity. There are two types of this cheese:

- Cheese blocks with a firm consistency, high acidity and relatively low moisture content
- Cheese spreads with a soft consistency, low acidity and high moisture content

Various flavourings can be added. Varieties with a smoked flavour can also be included under this heading.

Processed cheese usually contains 30 or 45 % fat, calculated by total solids, though varieties with lower or higher fat contents are also made. The composition in other respects depends entirely on the moisture content and the raw materials used in the manufacture.

Cheese for processing is of the same quality as cheese for direct consumption. Cheese with defects regarding surface, colour, texture, size and shape, as well as cheese with a limited shelf life, can also be used for processing, as can fermented cheese where the fermentation has been caused, for example, by coliform bacteria, provided that it is free from off-flavours. Butyric-acid fermented cheese can cause problems, as the bacteria may cause fermentation in the processed cheese.

High-quality processed cheese can only be produced from high-quality raw materials.

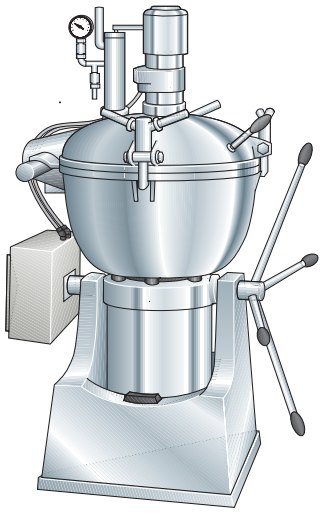


Fig. 14.48 *Cooker for processed cheese.*

Manufacture

The manufacturing process begins with scraping and washing the cheese, which is then ground. In large factories, the shredded cheese is melted continuously. In smaller plants, it is transferred to cookers (of which there are several types), one of which is shown in Figures 14.48 and 14.49.

Firstly, water, salt and emulsifier/stabiliser are mixed into the cheese. The mixture is heated to 70 – 95 °C, or even higher (depending on the type of processed cheese), in steam-jacketed cookers and by direct steam injection. This speeds up the cooking time of 4 – 5 minutes for block cheese and 10 – 15 minutes for spreads. It is kept constantly agitated

during heating, to avoid scorching. The process usually takes place under vacuum, which offers advantages from the point of view of heating and emulsification. The vacuum also removes undesirable odours and flavours, and makes it easier to regulate the moisture content. The capacity of a batch cooker is about 75 kg.

The pH of processed cheese should be 5,6 – 5,9 for spreads and 5,4 – 5,6 for sliced types. Variations in the pH of the raw material are adjusted by mixing cheese of different pH and adding emulsifiers/stabilisers to adjust the pH. The emulsifiers/stabilisers also bind calcium. This is necessary to stabilise the cheese, so that it will not release moisture or fat.

The processed cheese is then discharged from the cooker into a stainless steel container, which is transported to the packing station and emptied into the feed hoppers of the packing machines. These machines are usually fully automatic and can produce packages of different weights and shapes.

Normally, the cheese is hot-packed at cooking temperature.

The spreadable type of processed cheese should be cooled as rapidly as possible, and should therefore pass through a cooling tunnel after packing. Rapid cooling improves the spreading properties.

The cheese block on the other hand should be cooled slowly. After moulding, the cheese is left at ambient temperature.

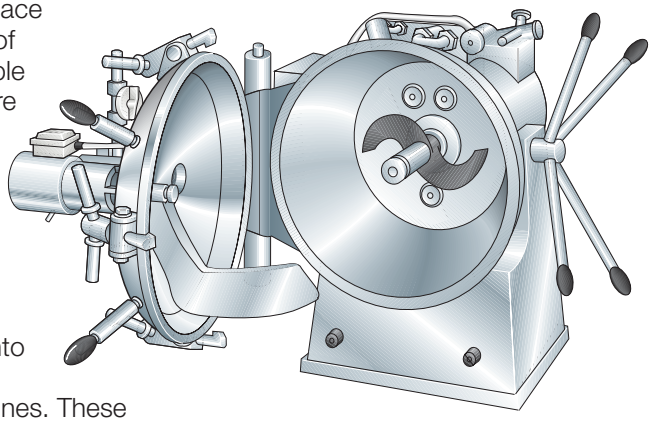
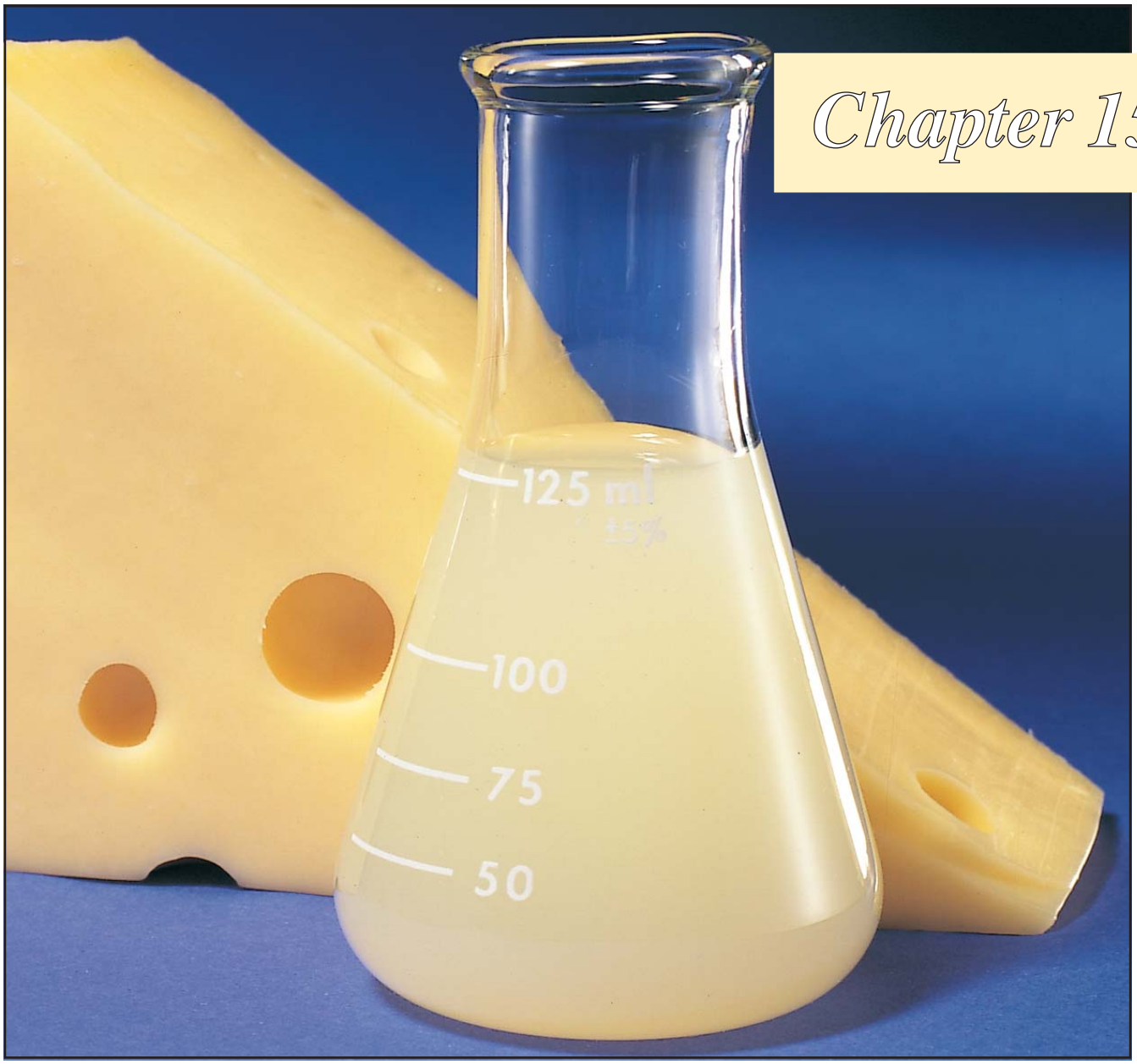


Fig. 14.49 *Cooker, open and tilted for emptying.*



Chapter 15

Whey processing

Whey, the liquid residue of cheese and casein production, is one of the biggest reservoirs of food protein still remaining largely outside human consumption channels. World whey output, at approximately 120 million tonnes in 1990, contains some 0,7 million tonnes of relatively high-value protein, equal to the protein contents of almost two million tonnes of soya beans. Yet, despite the chronic protein shortage in large parts of the world, a very considerable proportion of the total whey output is still wasted.

Whey comprises 80 – 90 % of the total volume of milk entering the process and contains about 50 % of the nutrients in the original milk: soluble protein, lactose, vitamins and minerals.

Whey as a by-product from the manufacture of hard, semi-hard or soft cheese and rennet casein is known as sweet whey and has a pH of 5,9 – 6,6. Manufacture of mineral-acid precipitated casein yields acid whey with a pH of 4,3 – 4,6. Table 15.1 shows approximate composition figures for whey from cheese and casein manufacture.

Whey is very often diluted with water. The figures above relate to undiluted whey. As to the composition of the NPN fraction, about 30 %

Table 15.1

Approximate composition of separated whey, %

Constituent	Cheese whey %	Casein whey %
Total solids	6,4	6,5
Water	93,6	93,5
Fat	0,05	0,04
True protein	0,55	0,55
NPN (non-protein nitrogen)	0,18	0,18
Lactose	4,8	4,9
Ash (minerals)	0,5	0,8
Calcium	0,043	0,12
Phosphorus	0,040	0,065
Sodium	0,050	0,050
Potassium	0,16	0,16
Chloride	0,11	0,11
Lactic acid	0,05	0,4

Table 15.2

Examples of utilisation of whey and whey products

Whey product	Whey	Whey concentrate or powder					Whey protein conc. or powder				Lactose	
	Liquid whey	Natural	Sweetened	Demineralised	Deproteinised	Delactosed	Demineralised	Delactosed	Demineralised and delactosed		Crude	Refined
Animal feed	•	•		•	•	•						
Human consumption												
Baby food				•			•	•	•			•
Diet food				•			•	•	•		•	•
Sausages				•			•					
Soups		•	•	•								
Bakery products	•	•		•			•					
Salad dressings		•		•								
Whey spread/cheese		•										
Cheese, natural processed		•		•								
Beverages	•								•			
Confectionery		•	•	•								•
Pharmaceutical products												•
Yeast products	•											
Industrial products											•	•

consists of urea. The rest is amino acids and peptides (gluco macro peptide from renneting action on casein). Table 15.2 lists some fields of application for whey and whey products.

Although whey contains valuable nutrients, it is only in recent years that new commercial processes have been developed for the manufacture of high-quality whey products.

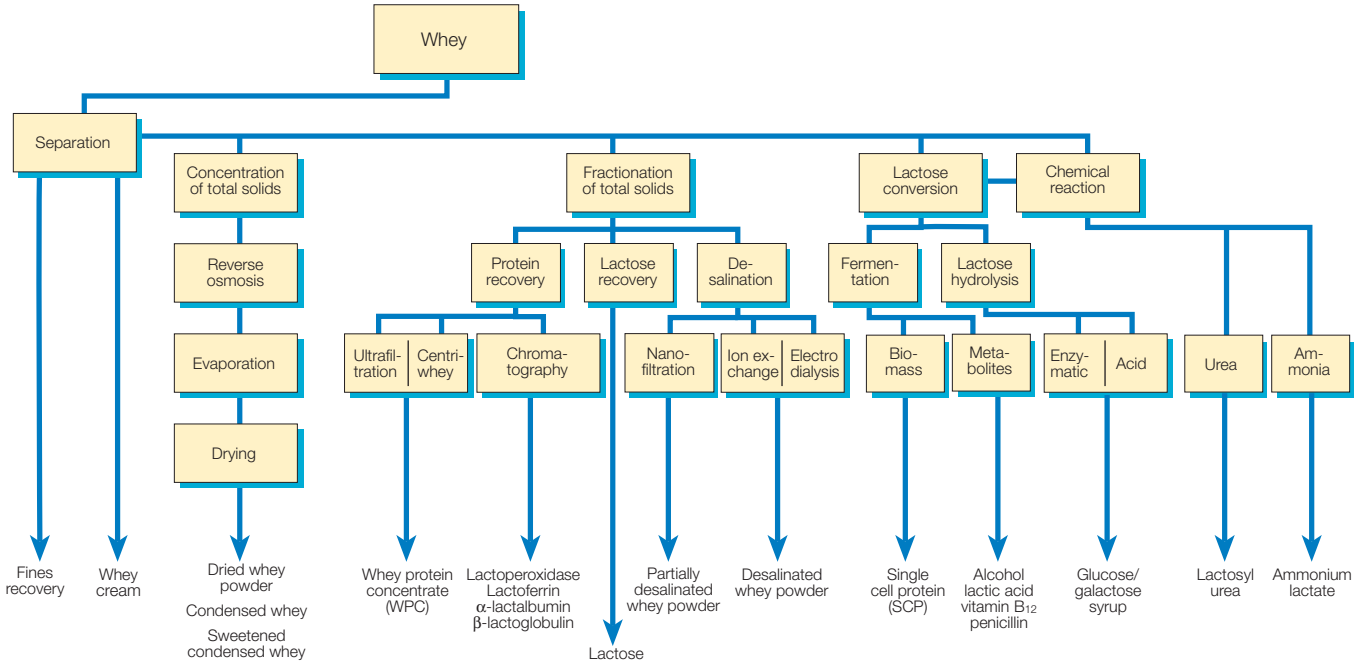


Fig. 15.1 *Whey processing alternatives.*

The block diagram in Figure 15.1 summarises various processes used in the treatment of whey and its end products. The first stage is filtering the curd particles left in the whey, followed by separation of fat and casein fines (Figure 15.2), partly to increase the economic yield and partly because these constituents interfere with subsequent treatment.

Production of whey powder, demineralised whey powder, lactose and delactosed whey powder predominates. However, a gradual shift is in progress towards new and interesting products that will transform the image of whey from an unwanted byproduct to an important raw material for the manufacture of quality products. Some of the products currently in use are described in this chapter.

Different whey processes

Whey must be processed as soon as possible after collection, as its temperature and composition promote the growth of bacteria. Otherwise, the whey should be quickly cooled down to about 5 °C, to temporarily stop bacterial growth.

If legally permitted, whey can be preserved by addition of sodium bisulphite, typically 0,4 % calculated as sulphur dioxide (SO_2), or hydrogen peroxide (H_2O_2), typically 0,2 % of a 30 % H_2O_2 solution.

Casein fines recovery and fat separation

Casein fines are always present in whey. They have an adverse effect on fat separation and should therefore be removed first. Various types of separation devices can be utilised, such as cyclones, centrifugal separators or vibrating/rotating screens, Figure 15.2.

Fat is recovered in centrifugal separators.

The collected fines are often pressed in the same way as cheese, after

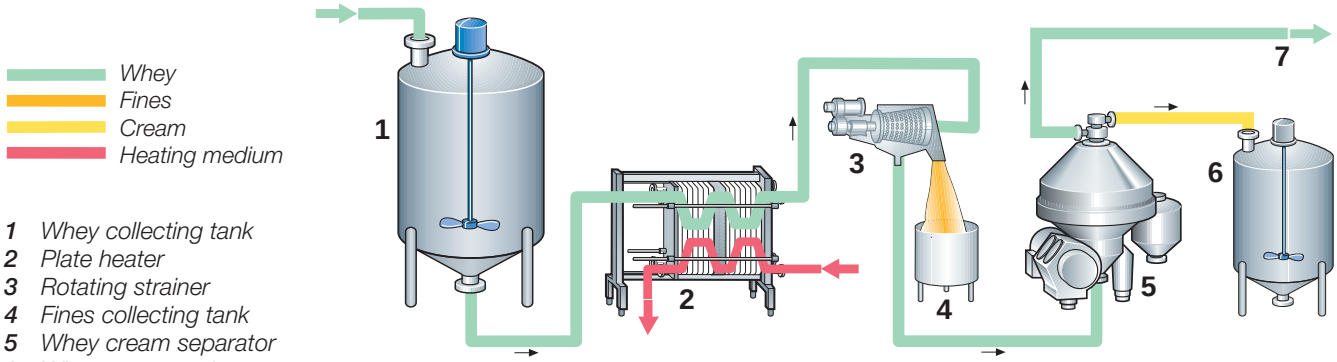


Fig. 15.2 *Fines and fat separation from whey.*

which they can be used in processed cheese manufacture and, after a period of ripening, also in cooking.

The whey cream, often with a fat content of 25 – 30 %, can partly be re-used in cheesemaking to standardise the cheese milk; this enables a corresponding quantity of fresh cream to be utilised for special cream products. For cheddar production, whey cream is generally not reused, due to the sensitivity of the starter for bacteriophages.

Cooling and pasteurisation

Whey which is to be stored before processing must either be chilled or pasteurised as soon as the fat and fines has been removed. For short-time storage (10 – 15 hours), cooling is usually sufficient to reduce bacterial activity. Longer periods of storage require pasteurisation of the whey.

Concentration of total solids

Concentration

Whey concentration traditionally takes place under vacuum in a *falling-film evaporator* with several stages to compensate for increasing energy costs. Mechanical and thermal vapour compression have been introduced in most evaporators to reduce evaporation costs still further.

RO (Reverse Osmosis) plants typically of spiral wound design are today often installed for pre-concentration to 18 – 20 % dry matter before transportation of the whey from the cheese plant. Furthermore, RO is today often used for pre-concentration to 12 – 14 % DM before evaporation.

After evaporation to 45 – 65 % total solids, the concentrate is cooled rapidly to about 30 °C in a plate heat exchanger and transferred to a triple-jacketed tank for further cooling to 15 – 20 °C, accompanied by constant stirring. This may continue for 6 – 8 hours to obtain the smallest possible crystals, which will give a non-hygroscopic product when spray dried.

Concentrated whey is a supersaturated lactose solution and, under certain conditions of temperature and concentration, the lactose can sometimes crystallise before the whey leaves the evaporator. At concentrations above a DM content of 65 %, the product can become so viscous that it no longer flows.

For more information on *RO* and *Evaporators,* see Chapter 6, Sections 6.4 and 6.5.

Drying

Basically, whey is dried in the same way as milk, *i.e.* in drum or spray dryers, see Chapter 17, Milk powder.

The use of *drum* dryers involves a problem: it is difficult to scrape the layer of dried whey from the drum surface. A filler, such as wheat or rye bran, is therefore mixed into the whey before drying, to make the dried product easier to scrape off.

Spray drying of whey, is at present, the most widely used method of

drying. Before being dried, the whey concentrate is usually treated as mentioned above to form small lactose crystals, as this results in a non-hygroscopic product which does not go lumpy when it absorbs moisture.

Acid whey from cottage cheese and casein production is difficult to dry due to its high lactic acid content. It agglomerates and forms lumps in the spray dryer. Drying can be facilitated by neutralisation and additives, such as skim milk and cereal products.

Fractionation of total solids

Protein recovery

Whey proteins were originally isolated through the use of various precipitation techniques, but nowadays membrane separation (fractionation) and chromatographic processes are used in addition to both precipitation and complexing techniques.

Fink and Kessler (1988) state that a maximum whey protein denaturation rate of 90 % is possible for all denaturable fractions. Proteose peptone, comprising some 10 % of the fraction, is considered undenaturable.

Native whey proteins, as constituents of whey powders, can easily be produced by careful drying of whey. Isolation of native whey proteins has therefore been developed. The native whey proteins obtained by membrane separation or ion exchange possess good functional properties, *i.e.* solubility, foaming, emulsion formation and gelling.

Protein recovery by UF

Native protein concentrates have a very good amino acid profile, with high proportions of available lysine and cysteine.

Whey protein concentrates (WPC) are powders made by drying the retentates from ultrafiltration of whey. They are described in terms of their protein content, (percentage protein in dry matter), ranging from 35 % to 85 %. To make a 35 % protein product, the liquid whey is concentrated about six-fold to an approximate total dry solids content of 9 %.

Example: 100 kg of whey yields approximately 17 kg of retentate and 83 kg of permeate at close to six-fold (5,88) concentration. Table 15.3 shows the compositions of the feed (whey) and the resulting retentate and permeate.

Table 15.3

Composition of whey and resulting retentate and permeate

Component	Weight in 100 kg Ordinary whey %	Weight in 16,7 kg Retentate %	Weight in 83,3 kg Permeate %
True protein	0,55	3,25	0,01
Lactose	4,80	5,34	4,69
Ash	0,55	0,76	0,51
NPN*	0,18	0,24	0,17
Fat	0,03	0,18	Traces
Total DM	6,11	9,77	5,38
TPK**		35,72	

* NPN = Non-protein nitrogen
** TPK = Total Protein Kjeldahl

Percentage protein in dry matter according to the values in Table 15.3: In concentration, most of the true protein, typically > 99 %, is retained, together with almost 100 % of the fat. The concentrations of lactose, NPN

and ash are generally the same in the retentate serum and permeate as in the original whey, but a slight retention of these components is reported. The overall retention figures, however, depend very much on:

- The type of membrane
- The flux
- The character of the feed (pre-diluted with water, pre-concentrated after demineralisation, etc.)

To obtain a more than 80 % protein concentrate, the liquid whey is first concentrated 20- to 30-fold by direct ultrafiltration to a solids content of approximatively 25 %; this is regarded as the maximum for economic operation. It is then necessary to diafilter the concentrate to remove more of the lactose and ash and raise the concentration of protein relative to the total dry matter. Diafiltration is a procedure in which water is added to the feed as filtration proceeds, in order to wash out low molecular components which will pass through the membranes, basically lactose and minerals.

Table 15.4 shows the compositions of some typical whey protein concentrate (WPC) powders.

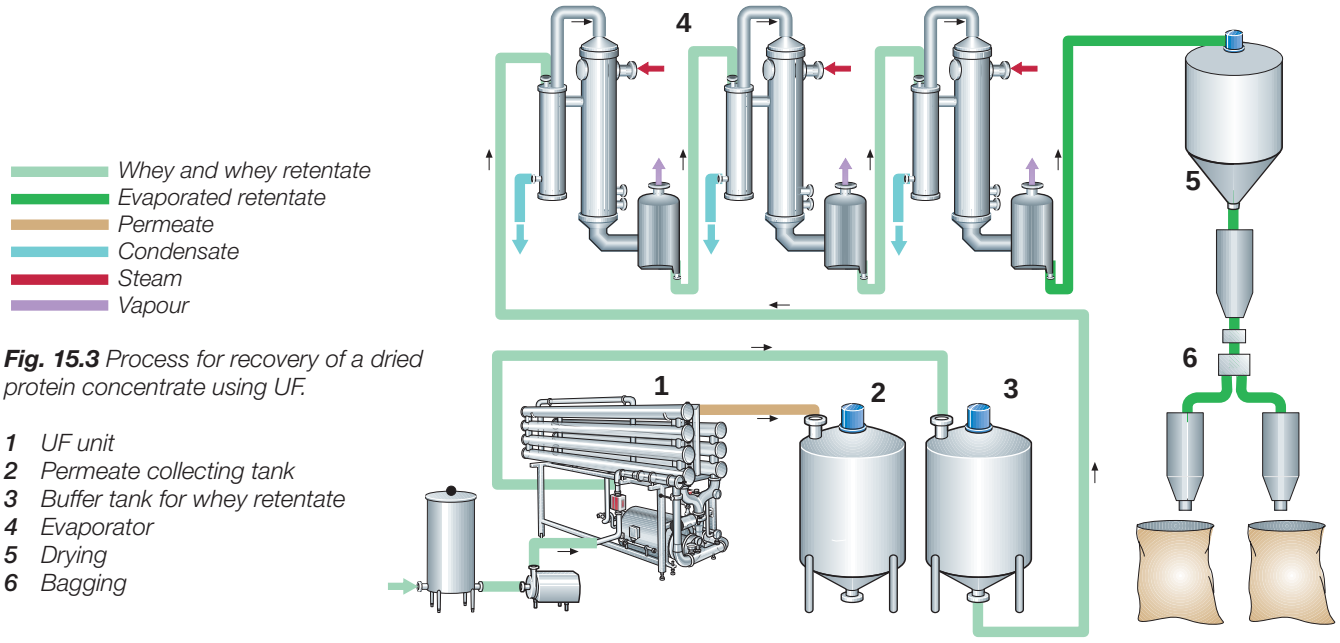


Fig. 15.3 *Process for recovery of a dried protein concentrate using UF.*

1 *UF unit*
2 *Permeate collecting tank*
3 *Buffer tank for whey retentate*
4 *Evaporator*
5 *Drying*
6 *Bagging*

Table 15.4

Composition in % of some whey protein concentrate powders

Product	1	2	3	4
Protein in dry matter	35	50	65	80
Moisture	4,6	4,3	4,2	4,0
Crude protein (Nx6,38)	36,2	52,1	63,0	81,0
True protein	29,7	40,9	59,4	75,0
Lactose	46,5	30,9	21,1	3,5
Fat	2,1	3,7	5,6	7,2
Ash	7,8	6,4	3,9	3,1
Lactic acid	2,8	2,6	2,2	1,2

Product specification:

1 Skim milk substitute, 35 % protein in dry matter
2 Protein supplement to other foods, 50 % protein in dry matter
3 Practical limit of protein by ultrafiltration alone, 65 % protein in dry matter
4 Product of ultrafiltration plus diafiltration, 80 % protein in dry matter

A process line for production of dried protein using UF is shown in Figure 15.3. About 95 % of the whey is collected as permeate, and protein concentrations as high as 80 – 85 % (calculated on the DM content) can be obtained in the dried product. For further details about UF, see Chapter 6.4, *Membrane filters.*

Defatting of whey protein concentrate (WP)

Defatted WP powder containing > 90 % protein dry matter is a very interesting option for some applications, *e.g.* as a replacement for egg white in whipped products such as meringues and as a valuable ingredient in various foods and fruit beverages.

Treatment of the whey retentate from a UF plant in a microfiltration (MF) plant can reduce the fat content of 90 % WP powder from 7,2 % to less than 0,4 %. Microfiltration also concentrates fat globule membranes and most of the bacteria in the MF retentate, which is collected and disposed of separately. The defatted MF permeate is routed to a second UF plant for further concentration; this stage also includes diafiltration.

As Figure 15.4 shows, the whey is pre-heated (1) and separated (2) to recover as much fat as possible, in the form of 25 – 30 % cream. This cream can be re-used for fat standardisation of cheese milk. The separation stage also removes fines. After this, the whey is pasteurised (1) and cooled to about 55 – 60 °C, before being transferred to an intermediate holding tank.

After a hold, the whey is pumped to the first UF plant (4), where it is concentrated about threefold. The retentate is pumped to the MF plant (5), while the permeate goes to a collecting tank, after regenerative cooling (1).

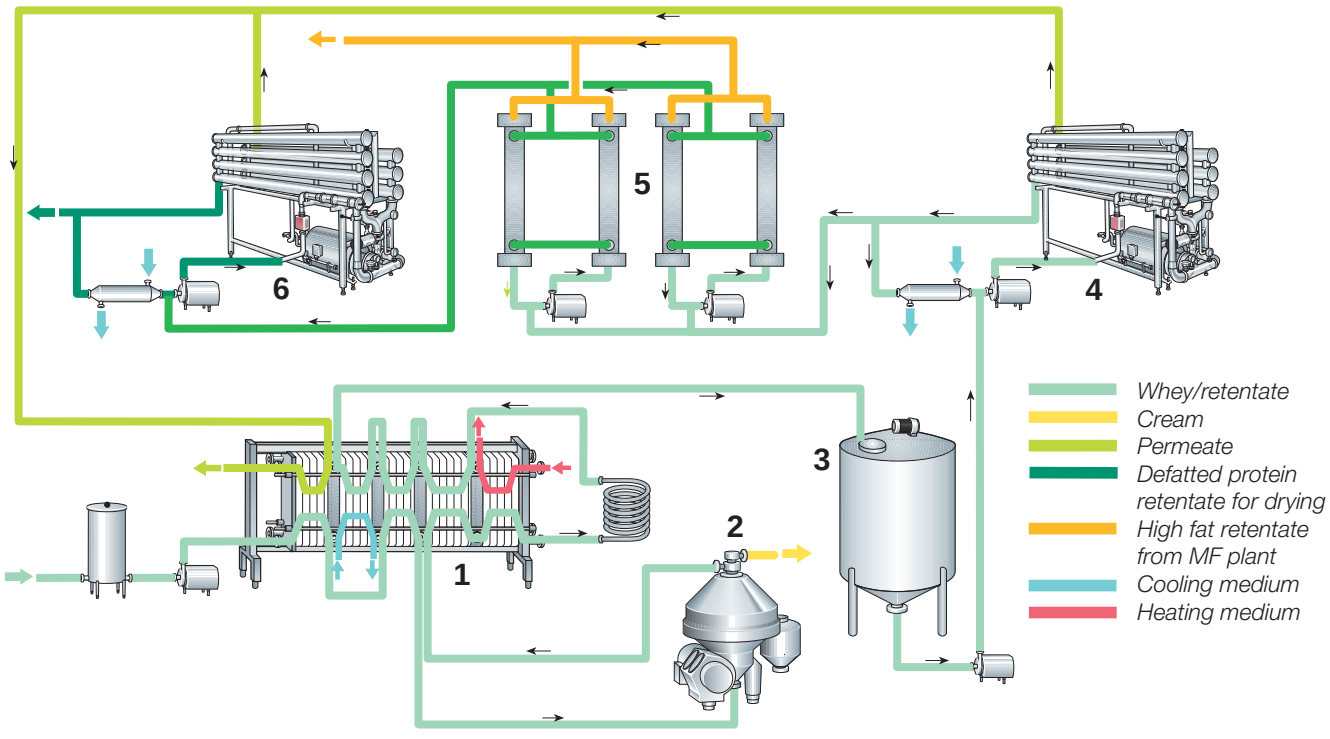
The retentate from MF treatment, which contains most of the fat and bacteria, is collected separately, and the defatted permeate is forwarded to further ultrafiltration with diafiltration (6). The resulting WPC (with about 20 – 25 % DM) is then spray-dried to reduce the moisture content to a maximum of 4 %, before bagging.

Recovery of denatured whey protein

In general, serum protein or whey proteins cannot be precipitated by rennet or acid. It is, however, possible to precipitate whey proteins with acid, if they are first denatured by heat. The process is divided into two stages:

Fig. 15.4 *Process for defatting of whey protein retentate.*

1 *Pasteuriser*
2 *Whey cream separator*
3 *Holding tank*
4 *First UF plant*
5 *MF plant*
6 *Second UF plant*



- Precipitation (denaturing) of the protein by a combination of heat treatment and pH adjustment
- Concentration of proteins by centrifugal separation

Denatured whey proteins can be mixed with cheese milk prior to renneting; they are then retained in the lattice structure formed by the casein molecules during coagulation. This discovery led to intensive efforts to find a method of precipitating and separating whey proteins, as well as a technique for optimising the yield

Adding denatured whey proteins to the cheese is not permitted by law in several countries, and also for certain types of cheese. Denatured proteins, either by adding or by pasteurisation at high temperatures, effect both yield and ripening of the cheese.

Figure 15.5 shows the Centri-Whey process line for manufacture of denatured whey proteins. After pH adjustment, the whey is pumped via an intermediate tank (1) to a plate heat exchanger (2) for regenerative heating.

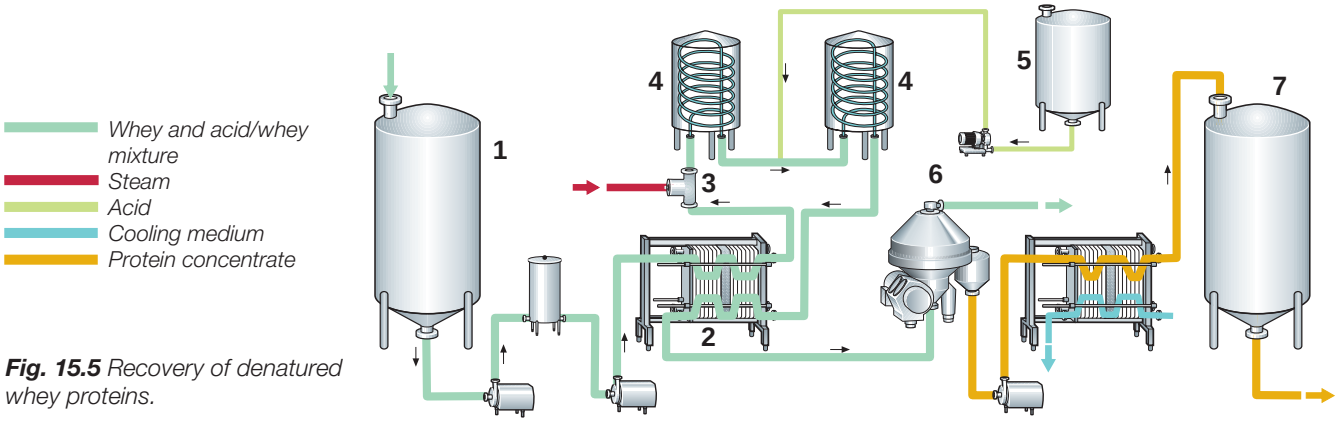


Fig. 15.5 *Recovery of denatured whey proteins.*

1 *Whey collecting tank*
2 *Plate heat exchanger*
3 *Steam injector*
4 *Holding tube*
5 *Acid tank*
6 *Clarifier*
7 *Collecting tank for denaturated whey protein*

The temperature of the whey is raised to 90 – 95 °C by direct steam injection (3), before it passes through a tubular holding section (4) with a holding time of 3 – 4 minutes. Acid is introduced during this stage, to lower the pH. The acid is either organic or inorganic (*e.g.* lactic acid or edible hydrochloric acid) as stipulated.

Those proteins that can be, and have been, modified by heat are precipitated within 60 seconds in a tubular holding section (4).

After regenerative cooling to about 40 °C, the precipitated proteins are separated from the liquid phase in a solids-ejecting clarifier (6). The clarifier discharges, at intervals of about 3 minutes, the accumulated protein in the form of a 12 – 15 % concentrate, of which about 8 – 10 % is protein. This method results in 90 – 95 % recovery of the coagulable proteins.

The addition of concentrated whey protein to cheese milk – principally in the manufacture of soft and semi-hard cheeses – causes only minor changes in the coagulating properties. The structure of the curd becomes finer and more uniform than with conventional methods. The processed whey proteins are more hydrophilic than casein. In the making of Camembert cheese, for example, an increase in yield of 12 % has been reported.

Chromatographic isolation of lactoperoxidase and lactoferrin

Generally speaking, use of natural bioactive agents is of great interest in products like infant formulas, health foods, skin creams and toothpaste. Examples of such components are the bioactive proteins lactoperoxidase (LP) and lactoferrin (LF), existing at low contents in whey; typically 20 mg/l of LP and 35 mg/l of LF. The Swedish Dairies Association (SMR) has developed a patented process based on chromatography for isolation of these proteins from cheese whey on an industrial scale.

The basic principle underlying the process is the fact that both LP and LF have isoelectric points in the alkaline pH area, (9,0 – 9,5), which means

that these proteins are positively charged at the normal pH of sweet whey, (6,2 – 6,6). The rest of the whey proteins *e.g.* β-lactoglobulin, α-lactalbumin and bovine serum albumin are negatively charged in the same pH range. A fundamentally suitable process for isolation of LP and LF is, therefore, to pass a specially designed cation-exchange resin for selective adsorption. The LP and LF molecules thus bind to the negatively charged functional group of the cation exchanger by charge interaction, leading to fixation of these molecules on the ion exchange resin, while the other whey proteins pass through because of their negative charge.

To make the process industrially viable, some basic criteria have to be satisfied. One of them is the need for a "particle-free" whey to maintain a high flow rate during the loading phase, because very large volumes of whey have to pass the ion exchange resin to achieve saturation. Cross-flow microfiltration (MF) with a pore size of 1,4 μm, operated under a uniform transmembrane pressure (UTP), has proved to be a successful technique for getting particle-free whey. Stable flux of 1 200 – 1 500 l/m^{2}h is easily sustained for 15 – 16 hours. This type of pre-treatment of the whey avoids build-up of increasing back pressure over the ion exchange column.

The ion exchange resin has a total capacity to adsorb 40 – 45 g of LP and LF per litre of resin, before breakthrough occurs. With a resin bed volume of 100 l, almost 100 000 l of whey can be treated per cycle.

With properly chosen conditions for elution of adsorbed bioactive proteins on the column, it is possible to obtain very pure fractions of LP and LF. Salt solutions of different strengths are used for this step. The proteins in the eluates occur in fairly concentrated form, of the order of 1 % by weight. The ion exchange step thus concentrates LP and LF by a factor of almost 500 compared to the original whey. Further processing of the eluates by UF and diafiltration yields very pure protein products, appr. 95 % purity. Finally, after sterile filtration in a cross-flow microfilter with 0,1 – 0,2 μm pores, the protein concentrates are spray dried. The overall process is illustrated in Figure 15.6.

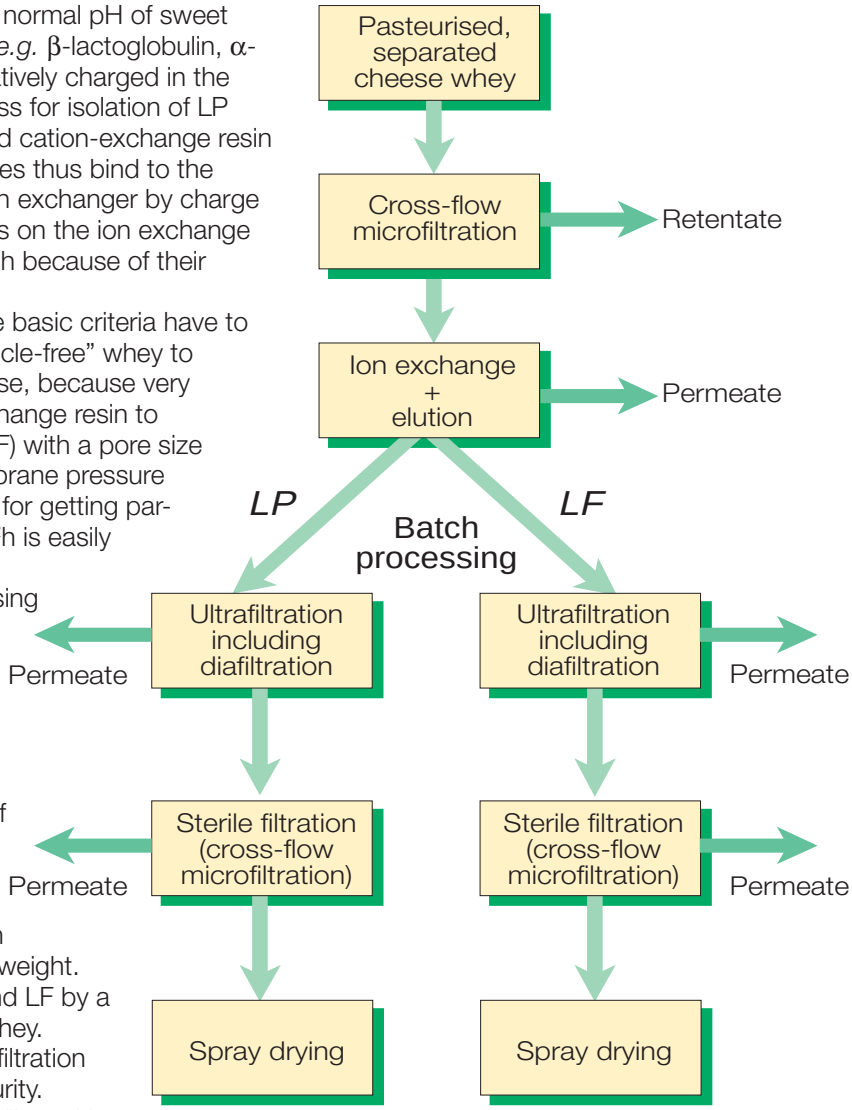


Fig. 15.6 *Block diagram for isolation of lactoperoxidase (LP) and lactoferrin (LF) from whey.*

Lactose recovery

Lactose is the main constituent of whey. There are two basic methods of recovery, depending on the raw material:

- Crystallisation of the lactose in untreated but concentrated whey
- Crystallisation of lactose in whey from which the protein has been removed by UF, or some other method, before concentration

Both methods produce a mother-lye, molasses, which can be dried and used as fodder. The feed value can be increased considerably if the molasses is desalinated and if high-quality proteins are added.

Crystallisation

The crystallisation cycle is determined by the following factors:

- Crystal surface available for growth
- Purity of the solution
- Degree of saturation
- Temperature
- Viscosity
- Agitation of the crystals in the solution

Several of these factors are mutually related to each other, for example degree of saturation and viscosity.

Figure 15.7 shows a production line for manufacture of lactose. The whey is first concentrated by evaporation to 60 – 62 % DM and then

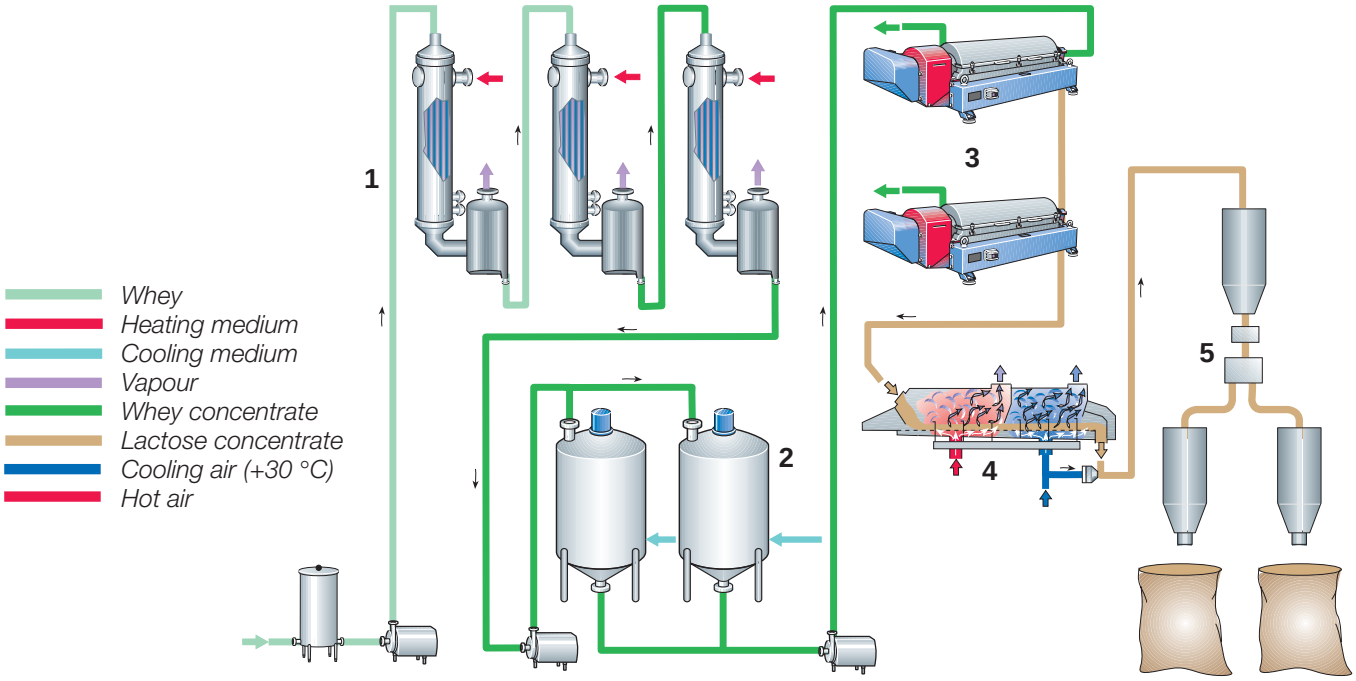


Fig. 15.7 *Process line for lactose manufacture.*

1 *Evaporator*
2 *Crystallisation tanks*
3 *Decanter centrifuges*
4 *Fluid-bed dryer*
5 *Packing*

transferred to crystallisation tanks (2), where seed crystals are added. Crystallisation takes place slowly, according to a predetermined time/temperature programme. The tanks have cooling jackets and equipment for control of the cooling temperature. They are also fitted with special agitators.

After crystallisation, the slurry proceeds to decanter centrifuges (3) for separation of the crystals, which are dried (4) to a powder. Following grinding (typically in a hammer mill) and sifting, the lactose is packed (5).

For efficient and simple separation of lactose crystals from the mother liquor, crystallisation must be arranged so that the crystals exceed 0,2 mm in size – the larger the better for separation.

The degree of crystallisation is determined in principle by the quantity of b-lactose converted to the desired α-lactose form, and the cooling of the concentrate must therefore be carefully controlled and optimised.

Lactose separation

Various types of centrifuges can be used for harvesting lactose crystals. One is the horizontal decanter centrifuge (Figure 15.8), which operates continuously and has a screw conveyor for unloading the lactose. Two machines are installed in series. The lactose from the first is reprocessed in the second for more efficient separation. During separation, impurities are washed from the lactose so that a high degree of purity is obtained. The residual moisture content of the lactose after the second separation stage is < 9 % and pure lactose accounts for about 99% of the dry solids.

Drying

The lactose is dried after separation to a residual moisture content of 0,1–0,5 %, depending on the future use of the product. The temperature during drying should not exceed 93 °C, as β-lactose is formed at higher temperatures. The drying time must also be taken into consideration. During quick drying, a thin layer of amorphous (shapeless, non-crystalline) lactose tends to form on the a-hydrate crystal, and this may later result in formation of lumps. Drying usually takes place in a fluidised bed drier. The temperature is maintained at 92 °C and the drying time is 15 – 20 minutes. The dried sugar is transported by air at a temperature of 30 °C, which also cools the sugar.

The crystals are normally ground to a powder immediately after drying and are then packed.

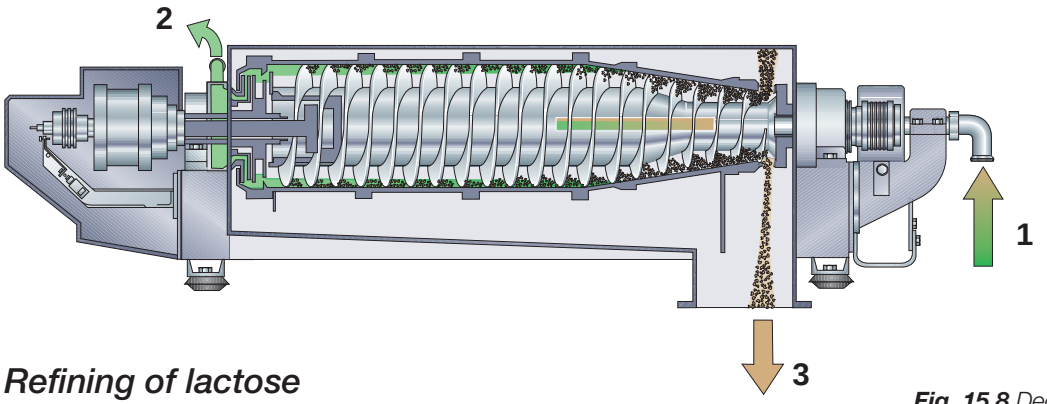


Fig. 15.8 *Decanter centrifuge.*

1 *Feed*
2 *Outlet for liquid phase*
3 *Outlet for solids phase*

Refining of lactose

A higher degree of purity is required for some applications, *e.g.* pharmaceutical manufacturing processes. Lactose for such use must therefore be further refined. During refining, the lactose is re-dissolved in hot water to a concentration of 50 %. Active carbon, phosphate and a filtration agent are added at the same time. After filtration, the lactose solution is transferred to a tank where crystallisation takes place.
The purified lactose is then separated, dried, ground and packed.

Demineralisation (Desalination)

As whey has a fairly high salt content, about 8 – 12 % calculated on dry weight, its usefulness as an ingredient in human foods is limited. By having the whey demineralised, various fields of application can, however, be found for whey which is partially (25 – 30 %) or highly (90 – 95 %) demineralised.

Partially demineralised whey concentrate can, for instance, be used in the manufacture of ice-cream and bakery products or even in quarg, whereas *highly* demineralised whey concentrate or powder can be utilised in formulas for infants and, of course, in a very wide group of other products.

Principles of demineralisation

Demineralisation involves removal of inorganic salts, together with some reduction in the content of organic ions, such as lactates and citrates.

The *partial* demineralisation is mainly based on utilisation of cross-flow membranes specially designed to “leak” particle species that have radii in the nanometer (10^{-9} m) range. This type of filtration is called nanofiltration (NF).

The *high* degree desalination is based on either of two techniques:

- Electrodialysis
- Ion exchange

Partial demineralisation by NF

By using a specially designed “leaky” RO membrane, small particles like certain monovalent ions, *e.g.* sodium, potassium, chloride and small organic molecules (like urea and lactic acid) can escape through the membrane, together with the aqueous permeate. This membrane process is known by various names such as ultraosmosis, “leaky” RO and nanofiltration (NF).

Because of their greater compactness, spiral-wound membranes are most often used in new installations. For further information about this type of membrane, see Chapter 6.4, Membrane filters.

Examples of permeation rates of normal sweet whey constituents during nanofiltration are given in Table 15.5.

As the table shows, reduction of the chloride content in sweet whey can be as high as 70 % and that of sodium and potassium 30 – 35 %. The reason for this difference in elimination of ions is the need of maintaining an electrochemical balance between negative and positive ions.

A critical aspect of nanofiltration in whey processing is that the leakage of lactose must be kept to a minimum (<0,1 %), to avoid problems with high BOD (biological oxygen demand) in the waste water (permeate). Installation

of NF equipment in whey processing can be considered in the following situations :

- As a low-cost alternative to diminish the salty taste of ordinary sweet whey powder
- As a preliminary step to more complete demineralisation of whey by electrodialysis and ion exchange
- For acid removal in hydrochloric and lactic acid casein whey; note that the permeation rate is low for lactate ions but high for free lactic acid molecules
- For salt reduction in salted whey (*e.g.* salt drippings in Cheddar cheese production)

Table 15.5

Permeation rates of normal sweet whey constituents during nanofiltration

Conditions		**Reduction**	**%**
Final DM	22%	Potassium	31
Concentration factor	4 x	Sodium	33
Temperature	21°C	Chloride	67
Pressure	2,5 MPa (25 bar)	Calcium	3
		Magnesium	4
		Magnesium	4
		Phosphorus	6
		Citrate	0
		Lactate	<3
		Ash	30
		NPN	27
		Lactose	1

High degree demineralisation

Electrodialysis

Electrodialysis is defined as the transport of ions through non-selective semi-permeable membranes under the driving force of a direct current (DC) and an applied potential. The membranes used have both anion and cation exchange functions, making the electrodialysis process capable of reducing the mineral content of a process liquid, *e.g.* seawater or whey.

Figure 15.9 is a schematic picture of an electrodialysis unit. It consists of a number of compartments separated by alternate cation and anion exchange membranes which are spaced about 1 mm or less apart. The end compartments contain electrodes. There can be as many as 200 cell pairs between each pair of electrodes.

The two electrodes at each end of the cell stack have separate rinse channels as shown in Figure 15.9, through which a separate acidified stream is circulated, to protect the electrodes from chemical attack.

For whey treatment, the whey feed and acidified brine pass through alternate cells in the stack, whose construction can be likened to that of a plate heat exchanger or plate sheet ultrafiltration module.

Operating principle

Alternate cells in the electrodialysis stack act as concentration and dilution cells respectively. Whey is circulated through the dilution cells, and a 5 % brine carrier solution through the concentration cells.

When direct current (DC) is applied across the cells, cations attempt to migrate to the cathode and anions to the anode, as shown in Figure 15.9. However, completely free migration is not possible, because the membranes act as barriers to ions of identical charge. Anions can pass

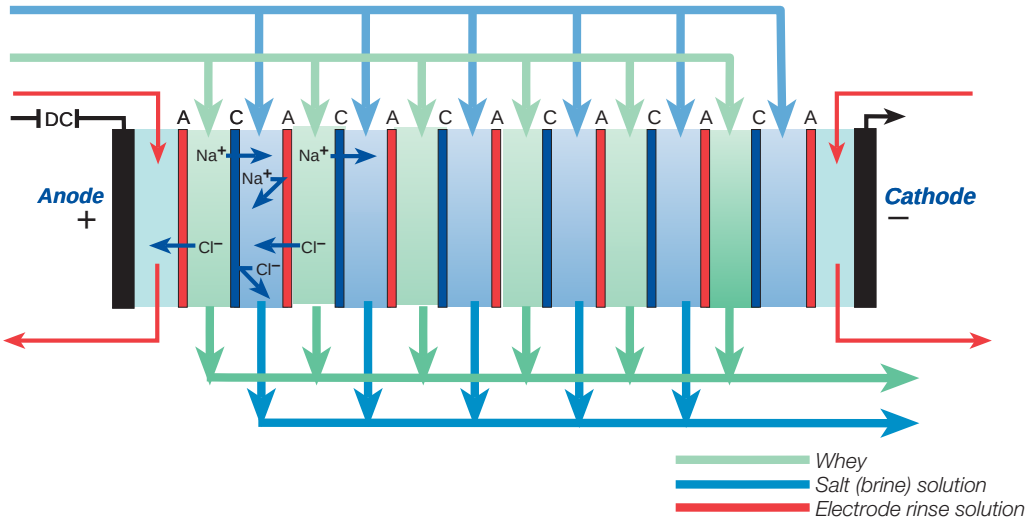


Fig. 15.9 *Cell packs for electrodialysis.*

A = *Anions* = *positively charged*
C = *Cations* = *negatively charged*
DC = *Direct Current*

through an anion membrane, but are stopped by a cation membrane. Conversely, cations can pass through a cation membrane but not an anion membrane. The net result is depletion of ions in the whey (dilution) cells. The whey is thus demineralised, to an extent determined by the ash content of the whey, residence time in the stack, current density and flow viscosity.

The electrodialysis plant can be run either continuously or in batches. A batch system, which is often used for demineralisation rates above 70 %, can consist of one membrane stack over which the process liquid, *e.g.* whey, is circulated until a certain ash level is reached. This is indicated by the conductivity of the process liquid. The holding time in a batch system can be as long as 5 – 6 hours for 90 % demineralisation at 30 – 40 °C. Pre-concentration of the whey to 20 – 30 % DM is desirable with regard to capacity utilisation and electric power consumption. The whey concentrate should be clarified before it enters the electrodialysis unit.

The high process temperature means that there is a risk of bacteriological growth taking place in the product. A bacteriostatic compound such as hydrogen peroxide is therefore often added to the whey, when allowed. The process liquid heats up during the process, so a cooling stage is needed to maintain the process temperature. In a continuous plant, consisting of five membrane stacks in series, the holding time can be reduced to 10 – 40 minutes. The maximum demineralisation rate of such a plant is often limited to about 60 – 70 %. In relation to capacity, the installed membrane area is much larger in a continuous plant than in a batch plant.

An electrodialysis plant can easily be automated and furnished with a programmed CIP system. The cleaning sequence normally includes water rinse, cleaning with an alkaline solution (max. pH 9), water rinse, cleaning with hydrochloric acid (pH 1) and a final water rinse. A typical cleaning programme takes 100 minutes.

Power supply and automation

Direct current is used in the electrodialysis plant, which should have facilities for regulating current in the range of 0 – 185 A and voltage in the range of 0 – 400 V. Flow rates, temperatures, conductivity, pH of process water and product, product inlet pressure, pressure difference between the stacks and current, as well as voltage over each membrane stack, are monitored and controlled during production.

Limiting factors in electrodialysis

A major limiting factor for using electrodialysis in dairy processing is the cost of replacing membranes, spacers and electrodes, which constitutes 35 – 40 % of the total running costs in the plant. Replacement is necessary due to fouling of the membranes, which in turn is caused by:

- Precipitation of calcium phosphate on the cation exchange membrane surfaces
- Deposition of protein on the anion exchange membrane surfaces

The first problem can be handled by proper flow design over the membrane surface and regular acid cleaning.

Protein deposits are the main factor in shortening the lifetime of the anion membranes. The background to this problem is as follows: at the normal pH of whey, the whey proteins can be regarded as large negative ions (anions) and move as such under the influence of the electrical field in the stack. These molecules, being too large to pass through the anion exchange membranes, are deposited as a thin protein layer on the faces of the anion exchange membranes in the whey compartments. Techniques such as polarity reversal can be used to dislodge these deposited materials from the membrane.

Although frequent high-pH cleaning removes most of the deposits, disassembly of the stack for manual cleaning is recommended at intervals of 2 – 4 weeks.

The processing cost of electrodialysis depends very much on the de-mineralisation rate. Increasing the capacity in steps from 50 % to 75 % to 90 % doubles the processing cost per step. This means that it is four times as expensive per kilo of product solids to demineralise to 90 % than to 50 %; the reason is that plant capacity is reduced at 90 % demineralisation.

Water treatment, electric power, chemicals and steam account for the operating costs of a demineralisation plant. Waste water treatment is a particularly heavy item. During production, lactose leaks through the membranes at a rate of 7 – 10 % at 90 % demineralisation. The phosphate removed from whey also accumulates in the waste stream. The cost of electric power amounts to 10 – 15 % of the processing cost, while the chemicals used in the process, mainly hydrochloric acid, account for less than 5 %. The cost of steam used for pre-heating the product and cooling costs for control of process temperature are 10 – 15 %, depending on the demineralisation level.

Electrodialysis is best for demineralisation levels below 70 %, where it is very competitive, compared to ion exchange.

Electrodialysis is best for demineralisation levels below 70 %, where it is very competitive compared to ion exchange.

Ion exchange

In contrast to electrodialysis, the process which removes ionisable solids from solutions on a continuous electro-chemical basis, an ion exchange process employs resin beads to adsorb minerals from solution, in exchange for other ionic species. The resins have a finite capacity for this, so that when they are completely saturated, the adsorbed minerals must be removed and the resins regenerated before reuse. Normally, the resins are used in fixed columns of suitable design.

Ion exchange resins are macromolecular porous plastic materials, formed into beads with diameters in the range of 0,3 to 1,2 mm for technical applications. Chemically, they act as insoluble acids or bases which, when converted into salts, remain insoluble. The main characteristic of ion exchange resins is their capacity to exchange the mobile ions they contain for ions of the same charge sign, contained in the solution to be treated. A simple example of this reaction is shown for sodium chloride removal, where R is the exchange group bound to the insoluble resin.

Cation exchange	$R – H + Na^+ = R – Na + H^+$	resin in H^+ form
Anion exchange	$R – OH + Cl^- = R – Cl + OH^-$	resin in OH^- form

The reaction above is deliberately written as an equilibrium, because the direction in which the reaction goes depends on the ion concentration in the liquid and in the solids phase of the resin. The equilibrium is characterised by a constant. On regeneration the reaction is reversed when the sodium-laden ion exchange resin is treated with, say, a 4 % hydrochloric acid solution. The high concentration of hydrogen ions in the acid drives the equilibrium to the left.

The equilibrium constant varies depending on ion species, which gives the selectivity of ion exchange processes. Generally speaking, multivalent ions have higher selectivity than monovalent ones and ions of the same valence are selected by size, large ions having higher selectivity. For cations typically found in dairy process streams, selectivity decreases in the order $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$.

Similarly, anion exchange selectively can be classified in the following way: $citrate^{3-} > HPO_4^{2-} > NO^{3-} > Cl^{-}$.

In practice, this means that the ion exchanger, after being exhausted by a liquid containing different ion species, will exist in different forms along the length of the column as described in Figure 15.10. This figure shows what happens in a column treating ordinary raw water in a cation exchanger loaded in the hydrogen ion form. The situation after regeneration with acid is also shown. It can be seen that the ions that remain longest in the cation-exchange column are Na ions. This can be understood from the selectivity order described above.

Going back to the picture of the exhausted cation-exchange column in the figure, the segregated distribution of ions means that Na ions leak first, followed by Mg^{2+} and Ca^{2+} ions. An initial ion leakage in the exhaustion phase may occur when the ion exchanger is not fully regenerated, but after a while the Na^{+} ions are eluted and replaced by H^{+} ions (see Figure 15.10). The status of the lower part of the ion exchanger determines the leakage of ions from the process liquid.

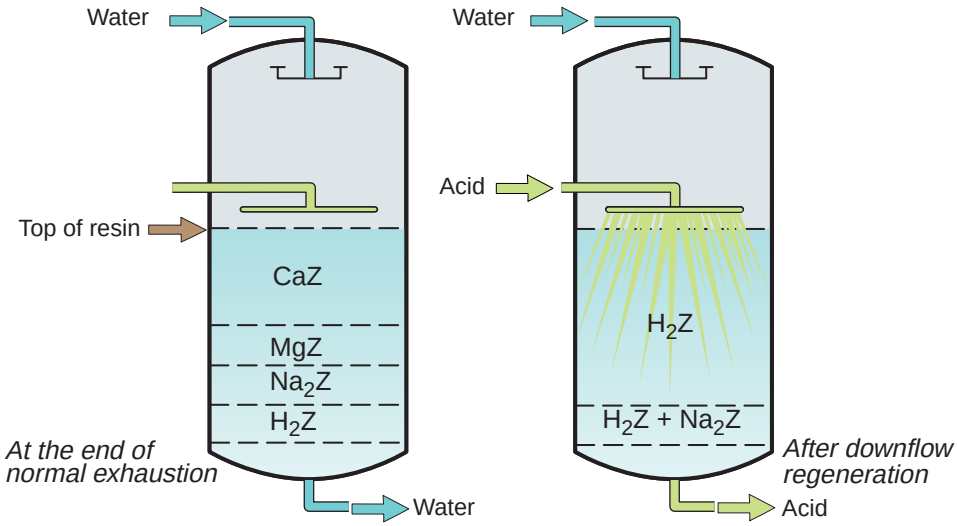


Fig. 15.10 *Cation exchanger resin bed before and after regeneration with acid.*

Ion exchange resin characteristics

Ion-exchange resins in industrial use today are based on polymeric plastic materials to build up the porous matrix structure. Common materials are polystyrene/divinyl benzene and polyacrylate. Functional groups are chemically bound to this matrix structure. Typical groups are:

- Sulphonic groups – SO_3^{-} H^{+} (strong acid cation exchanger)
- Carboxyl groups – COO^{-} H^{+} (weak acid cation exchanger)
- Quatenary amine N^{+} OH^{-} (strong base anion exchanger)
- Tertiary amines $-NH^{+}$ OH^{-} (weak base anion exchanger)

Both strong base and strong acid exchangers are fully ionised in the whole pH interval (0 – 14). Weak base and weak acid ion exchangers have

a restricted pH area in which they are active. Weak acid cation exchangers cannot normally be used in the low pH range (0 – 7), because the carboxyl groups are mainly present in their free acid form, as determined by their acid/base dissociation constant (often expressed as pK_a = –10 logarithm of the dissociation constant). At pH values higher than pK_a the carboxylic groups are in their salt form, and can consequently participate in ion exchange reactions. As a contrast, weak base anion exchange resins are only active in the low pH range, 0 – 7.

From the ease-of-regeneration point of view it is beneficial to use weak resins whenever possible. They can be regenerated with acid/base respectively with an excess of only 10 – 50 % of the theoretically needed amount. Strong resins require an acid/base excess of 300 – 400 % compared with the theoretical value for regeneration. For demineralisation according to the classical procedure, a strong acid cation exchanger regenerated in the hydrogen form is combined with a weak base anion exchanger working in the free base (hydroxyl) form. It is not possible to use a weak acid cation exchanger instead of a strong one, because of the very advantageous equilibrium for exchange of cations for the hydrogen bound to the hydroxylic groups.

Other important characteristics of ion exchangers, which are not further discussed, are:

- Ion exchange capacity
- Swelling properties
- Mechanical strength
- Fluidisation during backflushing of the bed
- Pressure drop
- Flow-velocity restrictions
- Water rinse requirements after regeneration

Ion exchange processes for demineralisation

Demineralisation by ion exchange has long been an established process for water treatment but has also been adopted during the past two decades for "de-ashing" of whey. Whey is not a uniform product as to composition. Whey from an acid casein/cheese curd has a pH of 4,3 – 4,6, while the pH of sweet whey is 6,3 – 6,6. The main difference between these two types of whey, apart from the acidifying medium, is the high level of calcium phosphate in the acid whey. It is good practice to use the cations as the base for calculating the salt load in whey because the anions, e.g. citrates and phosphates, are involved in proteolytic reactions. This complicates the calculation of specific ion contents. The figures for cation content are typical of sweet and acid whey respectively and are shown in Table 15.6.

Whey can consequently be characterised as a liquid with a high salt load which, as a consequence, results in short cycles when ion exchange is applied. This, in turn, results in high costs for regeneration chemicals, if they are not recovered.

Conventional ion exchange for demineralisation

A simple demineralisation plant using ion exchange is shown in Figure 15.11. The whey first enters the strong cation exchanger, loaded in H^+ form,

Table 15.6

Cation contents of sweet and acid whey

Ion	Sweet whey		Acid whey	
	%	meq/l	%	meq/l
Na	0,050	22,0	0,050	22,0
K	0,160	41,0	0,160	41,0
Ca	0,035	17,5	0,120	60,0
Mg	0,007	5,8	0,012	10,0
Total		86,3		133,0

and continues to anion exchange in a weak base anion-exchanger in its free base form. The ion exchange columns are rinsed and regenerated separately with dilute hydrochloric acid and sodium hydroxide (ammonia). Once a day, the columns are disinfected with a small amount of active chlorine solution.

The following net reactions take place during demineralisation (NaCl is used to illustrate the salts of whey and R represents the insoluble resin exchange site).

Cation exchange: $R - H + Na^+ + Cl^- \text{ —— } R - Na + H^+ + Cl^-$

Anion exchange: $R - OH + H^+ + Cl^- \text{ —— } R - Cl + H_2O$

The various flows in the ion exchange process include the following steps:

- Exhaustion 10 – 15 bed volumes of whey can be treated per regeneration. The bed volume is based on the bed volume of the cation exchanger.
- Regeneration
- Displacement of whey
- Backflushing
- Contact with regeneration solution
- Water rinse

The ion exchange columns are often made of rubber-lined mild steel, to avoid corrosion problems. The conical shape is used specially for the anion exchanger to allow for swelling of the bed, during transition from the free base form to the salt form.

Counter-current flow is often used for regeneration of the cation exchanger. Thus, when whey is treated in downward flow, regeneration takes place in upward flow. This system reduces consumption of regeneration chemicals by as much as 30—40 %, but at the expense of a more complicated design. The plant can easily be automated. Two or three parallel ion exchange systems are needed for a continuous flow of whey. A normal cycle time is six hours, four of which are used for regeneration.

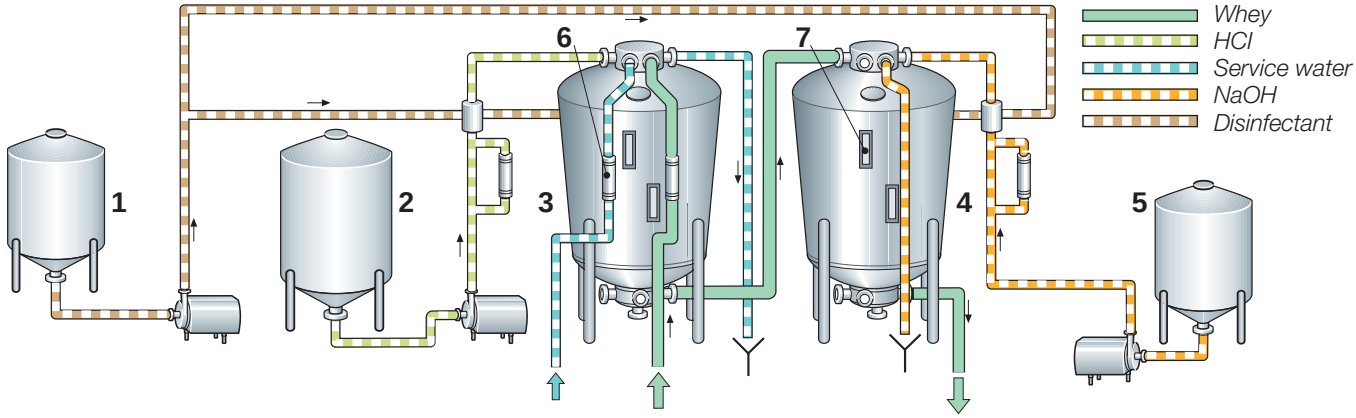


Fig. 15.11 *Plant for demineralisation of cheese whey by classical ion exchange.*

1 *Disinfection tank*
2 *HCl tank*
3 *Cation tank*
4 *Anion tank*
5 *NaOH tank*
6 *Flow meter*
7 *Sight glass*

The dotted lines are used in the regenerative and sanitation phases.

Process limitations

Whey is a liquid with a high salt load, which means short runs between regenerations. It also means a high consumption of regeneration chemicals and a high salt load in the waste from both ash removal and the required surplus of regeneration chemicals. Rinse-water consumption is also high, especially for washing out excess sodium hydroxide from the weak anion resin.

Losses of whey proteins occur on the columns due to denaturation/absorption. This is caused by great pH variation in the whey during the ion exchange process. Consumption of regeneration chemicals accounts for 60 – 70 % of the operating costs of the process.

The process is primarily designed for 90 % demineralisation, but any demineralisation rate can be chosen if a by-pass system is used.

An alternative ion exchange process

In order to reduce consumption of regeneration chemicals, and thus also create a better waste situation for a demineralisation plant, the R & D

department of the Swedish Dairies Association, SMR, has developed an alternative ion exchange process. In the unit operations of this process (Figure 15.12), the whey first enters the anion column containing a weak base resin regenerated in the bicarbonate form (HCO_3^-). During anion exchange the whey anions are exchanged for HCO_3^- ions. After this the whey enters the cation column, containing a weak acid cation exchange resin regenerated in the ammonium form (NH_4^+). During the passage of the whey through this column, the whey cations are exchanged for NH_4 ions. Thus, after the process, the whey salts are exchanged for ammonium bicarbonate ($NH_4\ HCO_3$). The reactions can be summarised in the following formulae, where NaCl is used to represent the whey salts and R represents the insoluble resin exchange site.

Anion exchange : $R - HCO_3 + Na^+ + Cl^- \text{ —— } R - Cl + Na^+ + HCO_3^-$

Cation exchange: $R - NH_4 + Na^+ + HCO_3^- \text{ —— } R - Na + NH_4^+ + HCO_3^-$

$NH_4\ HCO_3$ is a thermolytic salt which decomposes to NH_3, CO_2 and H_2O when heated. It is then volatilised during the subsequent evaporation of the whey, offering the possibility of recovering the NH_3 and CO_2 stripped off the whey, to make up a new regeneration solution ($NH_4\ HCO_3$). Part of the spent regeneration solution containing excess $NH_4\ HCO_3$ is collected for stripping in a distillation tower (about 100% excess $NH_4\ HCO_3$ is used).

Figure 15.13 shows the layout of a full-scale SMR process. The whey is first routed to the anion exchange column in HCO_3 form and then to the cation exchange column in NH_4 form. The ion exchange systems are paired, one working while the other is being regenerated. The cycle time is four hours.

After passing the ion exchange unit (1) the cooled whey is used for heat recovery in the absorption column and as cooling medium in the condenser (2) connected to the distillation tower (9). Then the whey enters the evaporator (3) and finally the demineralised whey concentrate is spray dried (10). The condensate from evaporator stage 2, which is especially rich in ammonia, is separated from the other condensate streams and continues to the absorption tower (4) where it forms the liquid base for the new regeneration solution. The condensates from evaporator stages 1 and 2 are used for cleaning the ion exchange resins. The ammonia is thus recovered, to a great extent. Most of the carbon dioxide stripped off during evaporation is recovered in gaseous form in the exhaust gases from the mechanical vacuum pump of the evaporator. This gas flows directly into the bottom of the absorption column, where it is completely absorbed together with other inlet streams, to form $NH_4\ HCO_3$. Recovery is not total, so the absorption tower is fitted with lines for injection of fresh 25 % NH_3 solution and CO_2.

The part of the regeneration solution which is rich in $NH_4\ HCO_3$ is collected in a tank (8), where the phosphate is precipitated by addition of $MgCl_2$ after a minor pH adjustment with NaOH. When the precipitate of magnesium ammonium phosphate ($MgNH_4PO_4$) has settled, the supernatant liquid is pumped to the top of the distillation tower (9) and at the same time pre-heated i-n a plate heat exchanger (not shown) using the bottom liquid as the heating medium. About 10 % of the liquid is stripped off as vapour, which in turn is condensed by the ion-exchange treated whey.

The SMR process has the following characteristics:

- Low running costs due to recovery of the regeneration chemicals
- Low losses of whey solids and only half the salt discharge compared to a classical ion exchange process
- Small variations in pH during ion exchange (6,5 – 8,2), resulting in minimum damage to the whey proteins
- High demineralisation efficiency, over 90 %
- Low operating temperature (5 – 6 °C), enhancing the bacteriological status of the end product

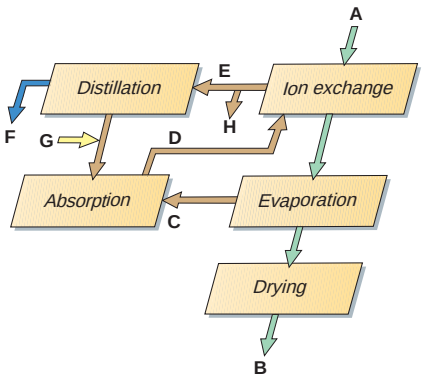


Fig. 15.12 *Unit operations of the SMR process.*

A *Whey feed*
B *Demineralised whey powder*
C *Condensate with NH_3 and CO_2*
D *Amonium bicarbonate NH_4HCO_3*
E *Used regeneration solution*
F *Waste water*
G *CO_2 + NH_3 addition*
H *Magnesium ammonium phosphate*

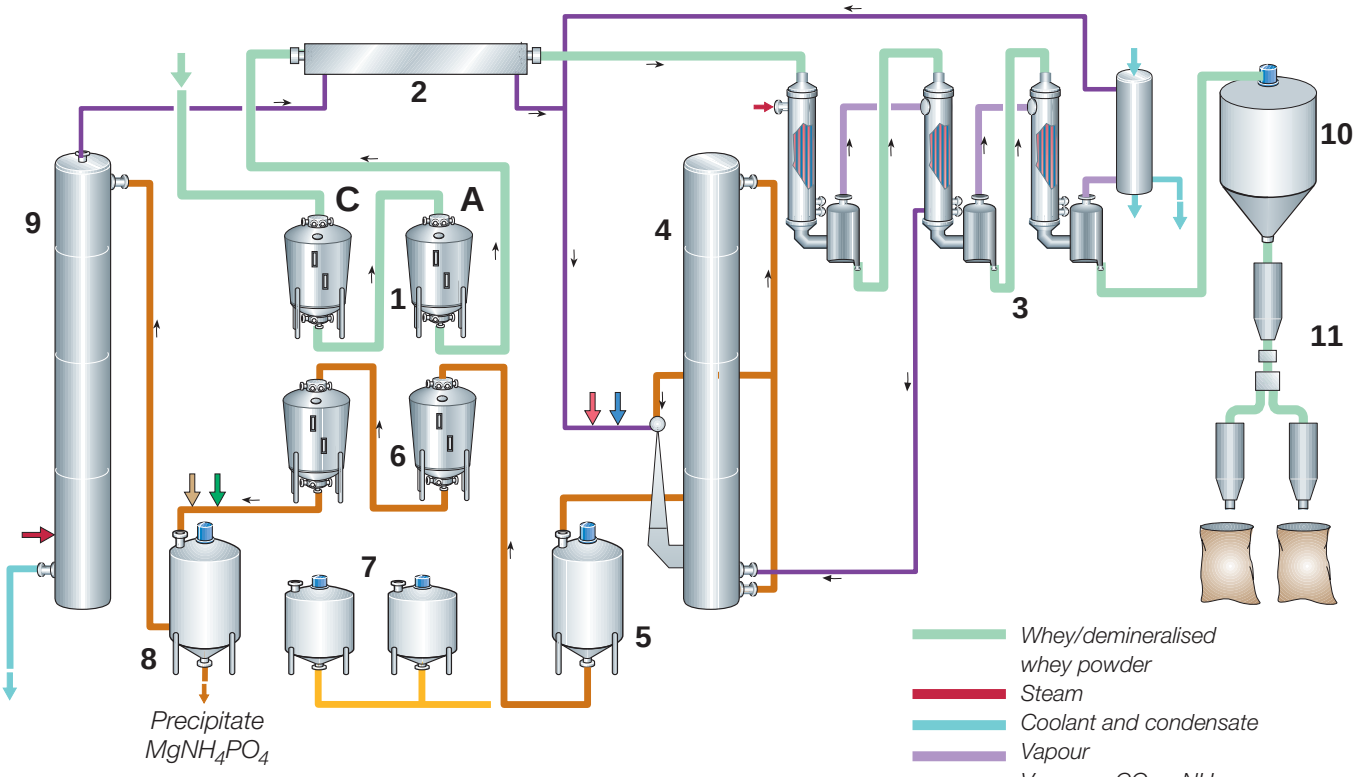


Fig 15.13 *Flow diagram of a full-scale production plant for demineralisation of whey powder.*

A *Anion exchanger*
C *Cation exchanger*

1 *Ion exchangers treating whey*
2 *Condenser*
3 *Evaporator*
4 *Absorption tower*
5 *Tank for new regeneration solution*
6 *Ion exchangers on regeneration*
7 *Tanks for NH_3 and HCl*
8 *Tank for used regeneration solution*
9 *Distillation tower*
10 *Spray dryer*
11 *Bagging*

- High yield of whey solids compared to classical ion exchange and electrodialysis
- Optimum heat recovery

Process limitations and costs

In most cases, depending on the costs of chemicals, the operating costs of the SMR process are 30 – 70 % lower than those of the classical ion exchange process. Like all systems of demineralisation, electrodialysis and traditional ion exchange, this process is sensitive to high Ca contents in the feed stream, so it is advisable to use pH adjustment and heating as pre-treatment stages before demineralisation. With this technique, 80 % of the calcium phosphate in the acid whey can easily be precipitated and refined for use in animal fodder or even for human consumption.

The equipment for the process includes more components than the classical ion exchange process. The capital costs are therefore higher, but these must be weighed against the benefits of low operating costs and improved plant environment.

Lactose conversion

Lactose hydrolysis

Lactose is a disaccharide consisting of the monosaccharides glucose and galactose, as shown in Figure 15.14. Lactose exists in two isomeric forms, α-lactose and β-lactose. They differ in the spatial arrangement of the hydroxyl group at the C atom in the glucose molecule, and thereby also, amongst other things in:

- Solubility
- Crystal shape
- Melting point
- Physiological effect

Lactose can be split hydrolytically, *i.e.* by bonding of water, or by an enzyme. The lactose-splitting enzyme β-galactosidase belongs to the hydrolase group. Figure 15.14 shows enzymatic splitting of lactose into galactose and glucose.

Lactose is not nearly as sweet as other types of sugar. Figure 15.15,

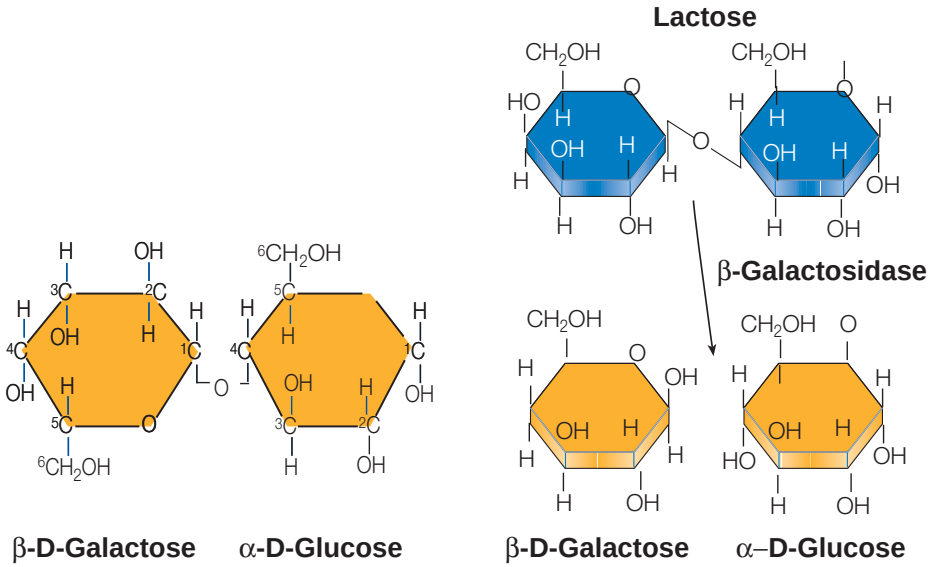


Fig. 15.14 *Chemical structure of lactose and lactose splitting.*

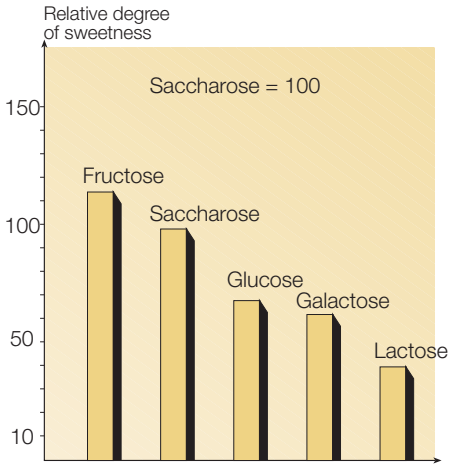


Fig. 15.15 *Degree of sweetness of different types of sugar.*

which indicates the relative degree of sweetness of different types of sugar. Hydrolysis of lactose consequently results in considerably sweeter products.

Some people lack the enzyme that decomposes lactose and therefore cannot drink or eat any significant quantities of milk products. This is called *lactose intolerance*. Hydrolysis of the lactose in the milk products allows these people to utilise the high-quality proteins, vitamins, etc. in milk products.

Some defects, such as sandy texture in ice-cream (crystallisation of lactose) are practically eliminated by lactose hydrolysis.

Enzymatic hydrolysis

Figure15.16 shows a process for enzymatic hydrolysis of lactose in whey.

Pre-treatment in the form of demineralisation is not essential, but it improves the taste of the final product. After hydrolysis the whey is evaporated. A syrup with a dry solids content of 70 – 75 % is then obtained. 85 % of the lactose in this syrup is hydrolysed and can be used as a sweetener in the baking industries and in the manufacture of ice-cream.

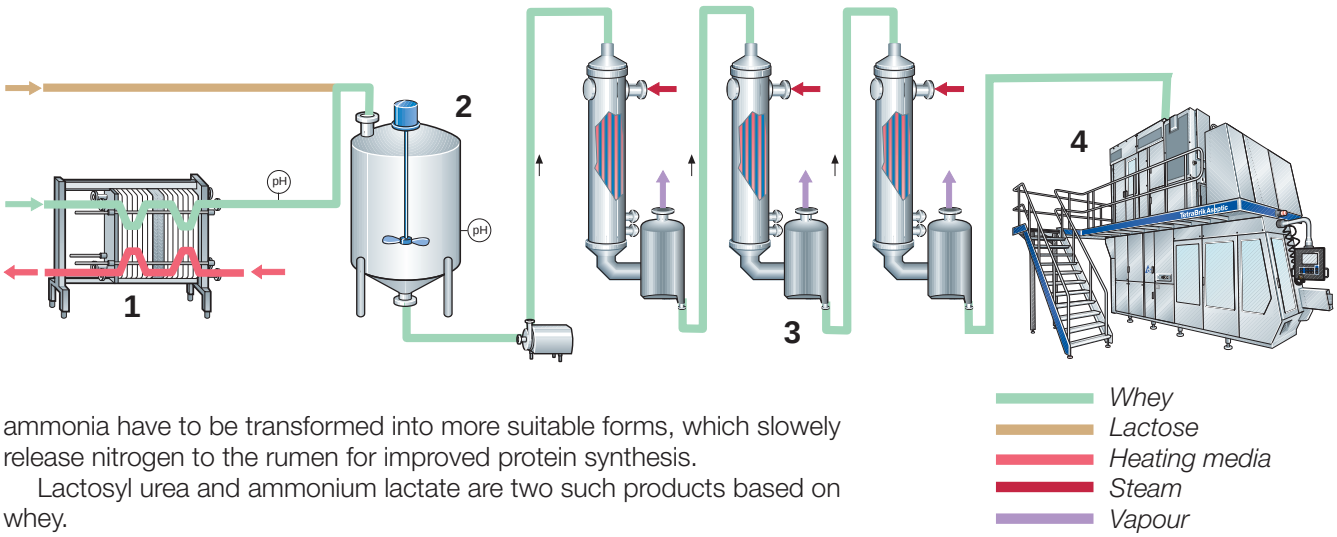
During production, the enzyme is inactivated by heat treatment or by pH adjustment. It cannot be used again. Instead of using free enzymes, it is now possible to bind the enzyme to different types of water-soluble and non-water-soluble carriers. Such systems with immobilised enzymes can be used for continuous lactose hydrolysis. The enzyme, which is expensive, is not consumed and can be used to hydrolyse large amounts of product. This increases the profitability. The technique has not yet been developed to any great extent.

Acid hydrolysis

Lactose can also be split by means of acids in conjunction with heat treatment or by passing a cation exchanger in hydrogen form at high temperature, around 100 °C. The required degree of hydrolysis is determined by selection of pH, temperature and holding time. As brown discoloration occurs during hydrolysis of the whey, active carbon treatment is recommended.

Chemical reaction

It has been established that non-protein nitrogen products can be used as partial replacement for natural protein in ruminants because certain microbes in the cattle rumen can synthesize protein from urea and ammonia. However, in order to get a balanced feed of nitrogen and energy, urea and



ammonia have to be transformed into more suitable forms, which slowely release nitrogen to the rumen for improved protein synthesis.

Lactosyl urea and ammonium lactate are two such products based on whey.

Lactosyl urea

Briefly, the procedure for production is as follows: after separation the whey is concentrated up to 75 % DM, typically in two steps. After addition of urea and edible sulphuric acid, the whey concentrate is held at 70 °C for 20 hours in a jacketed tank provided with agitator. Under these conditions the urea reacts with the lactose to form lactosyl urea.

Following the reaction period, the product is cooled and transported to a factory producing concentrated feed (pellets for instance) or direct to farmers.

Ammonium lactate

The process technique involves fermentation of the lactose in whey into lactic acid and maintaining the pH with ammonia, resulting in formation of ammonium lactate. After concentration to 61,5 % DM, the product is ready for use.

Fig. 15.16 *Plant for enzymatic hydrolysis of lactose in whey.*

1 *Pasteuriser*
2 *Tank for hydrolysis*
3 *Evaporator*
4 *Filling*

Chapter 16

Condensed milk

The method of preserving milk by sterilising evaporated milk in sealed containers was developed at the beginning of the 1880s. Earlier, in about 1850, the method of preserving evaporated milk by the addition of sugar had been perfected by an American. The manufacture of condensed milk, using these two methods, has developed into a large-scale industry. During the last years production by using continuous heating systems followed by aseptic packaging technology has been introduced.

A distinction is made between two different types; unsweetened and sweetened condensed milk. Both products can be made from fresh milk or recombined milk (milk powder, fat and water).

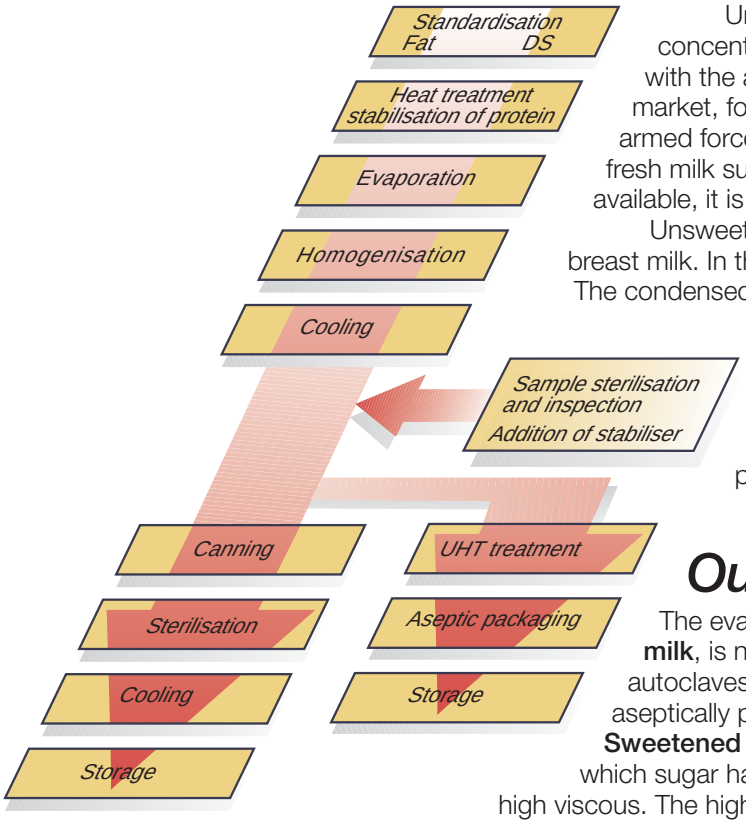


Fig. 16.1 *Process steps for unsweetened condensed milk.*

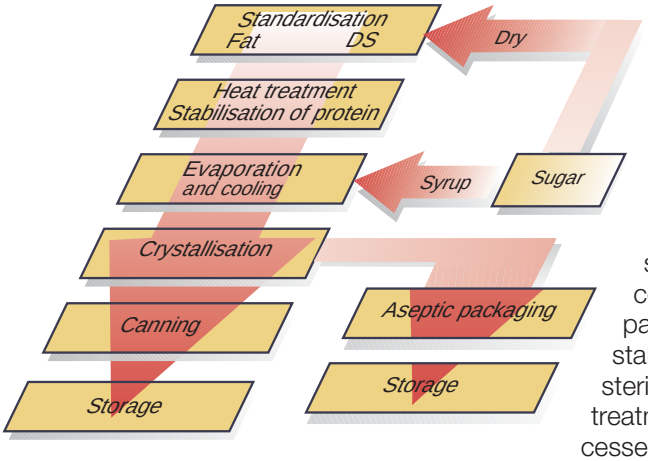


Fig. 16.2 *Process steps for sweetened condensed milk.*

Unsweetened condensed milk (also called double concentrated milk) is a sterilised product, light in colour and with the appearance of cream. The product has a large market, for example in tropical countries, at sea and for the armed forces. It is also used where fresh milk is not available as a fresh milk substitute. In many countries where normal milk is available, it is used as a coffee whitener.

Unsweetened condensed milk is also used as a substitute for breast milk. In this case, vitamin D is added.

The condensed milk is made from whole milk, skim milk or recombined milk with skim milk powder, anhydrous milk fat (AMF) and water (see also Chapter 18, *Recombined milk products*). The increased dry matter is reached by either evaporation of fresh milk or by recombination by milk powder.

Outline of condensed milk

The evaporated product, the **unsweetened condensed milk**, is normally packed in cans, which are then sterilised in autoclaves or horizontal sterilisers, or UHT-treated and aseptically packed in paperboard packages.

Sweetened condensed milk is basically concentrated milk, to which sugar has been added. The product is yellowish in colour and high viscous. The high sugar concentration in sweetened condensed milk increases the osmotic pressure to such a level that most of the micro-organisms are destroyed. This product is not heat treated after packaging as its high sugar content preserves it for a long shelf-life. The sugar concentration in the water phase must not be less than 62,5 % or more than 64,5 %. At the latter level, the sugar solution reaches its saturation point and some sugar may then crystallise, forming a sediment.

The manufacturing processes for these two products are shown as block diagrams in Figures 16.1 and 16.2. The first stage, in both cases, comprises precision standardisation of the milk fat content and the dry matter content. This is followed by heat treatment, which serves partly to destroy the micro-organisms in the milk, and partly to stabilise the milk, so that it will not coagulate in the subsequent sterilisation process. Raw material requirements and the initial treatment are identical for both products. After that, the processes differ slightly.

Unsweetened condensed milk

In the manufacture of unsweetened condensed milk (also called evaporated milk), the heat-treated milk is pumped to an evaporator, where it is concentrated. The concentrate is then homogenised and cooled. Checks are carried out on the coagulation stability, and a stabiliser, usually disodium or trisodium phosphate, is added if necessary. In the case of canned product, the concentrate is packed and sterilised in an autoclave. The cans are cooled before being placed in storage.

In the case of UHT treated product, the stabilised concentrate is first sterilised and then packed aseptically.

Figure 16.3 shows the process stages in the manufacture of unsweetened condensed milk from fresh milk as raw material. Similar technology is utilised also when production of concentrated milk is based on recombination. In this case, standardisation is taking place during recombination or reconstitution.

Raw material

The quality of the raw material for condensed milk is basically the same as that used in the manufacture of ordinary long-life milk products. There are two important considerations for the manufacture of condensed milk:

- The number of spores and heat-resistant bacteria in milk
- The ability of the milk to tolerate intensive heat treatment without coagulating (thermal stability).

Bacteriological quality of the raw material

Evaporation takes place under vacuum at a temperature which should not exceed 65 – 70 °C. At temperatures below 65 °C, spores and heat-resistant bacteria will have ideal growth conditions, which could result in the entire process being spoiled. Precise control of the bacteria in the process is thus an essential requirement in the manufacture of condensed milk.

Thermal stability of the raw material

The ability of milk to withstand intensive heat treatment depends to a great extent on its acidity, which should be low, and on the salt balance in the milk. The latter is affected by seasonal variations, the nature of the fodder and the stage of lactation. It is possible to improve the ability of the milk to withstand the required level of heat treatment by additives or pre-treatment.

Pre-treatment

Pre-treatment is essentially for the final quality and includes standardisation of fat content, solids-non-fat, as well as heat treatment.

Standardisation

Condensed milk is marketed with a stipulated content of fat and dry solids. The figures vary with the applicable standard, but are normally 7,5 % fat and 17,5 % solids-non-fat. This product is often called “double concentrated milk” (25 % total solids). Another common standard is “triple concentrated milk“ with 33 % total solids (often 4 – 10 % fat content).

Modern automatic standardisation systems permit continuous and extremely accurate standardisation of both fat content and the relation between fat content and solids-non-fat of the basic milk. More information on standardisation will be found in Chapter 6.2, *Centrifugal machines and milk fat standardisation systems*.

Pre-heating

Before being sterilised, the standardised milk undergoes intensive heat treatment to destroy micro-organisms and to improve its thermal stability. The heat treatment, often integrated in the evaporation plant, takes place in a tubular or plate heat exchanger at a temperature of 100 –120 °C for 1 – 3 minutes, followed by chilling to about 70 °C before the milk enters the evaporator.

During heat treatment a great part of the whey proteins is denatured, while calcium salts are precipitated. In this way, the protein complex of the milk is stabilised so that it can withstand subsequent sterilisation, without coagulation taking place during the process or subsequent storage.

The nature of the heat treatment will largely determine the viscosity of the end product, and is thus extremely important for the product quality.

Evaporation

The evaporator is usually of the multistage falling-film type. The milk passes through steam-heated tubes under vacuum. Boiling takes place at between 65 and 70 °C. The dry matter content of the milk increases as the water is boiled off. The density is checked continuously.

Homogenisation

The concentrated milk is pumped from the evaporator to a homogeniser,

1 Evaporation
2 Homogenisation
3 Cooling
4 Intermediate tank
5 Canning
6 Sterilisation
7 Storage

Alternative processing to point 5 and 6:
8 UHT treatment
9 Aseptic filling

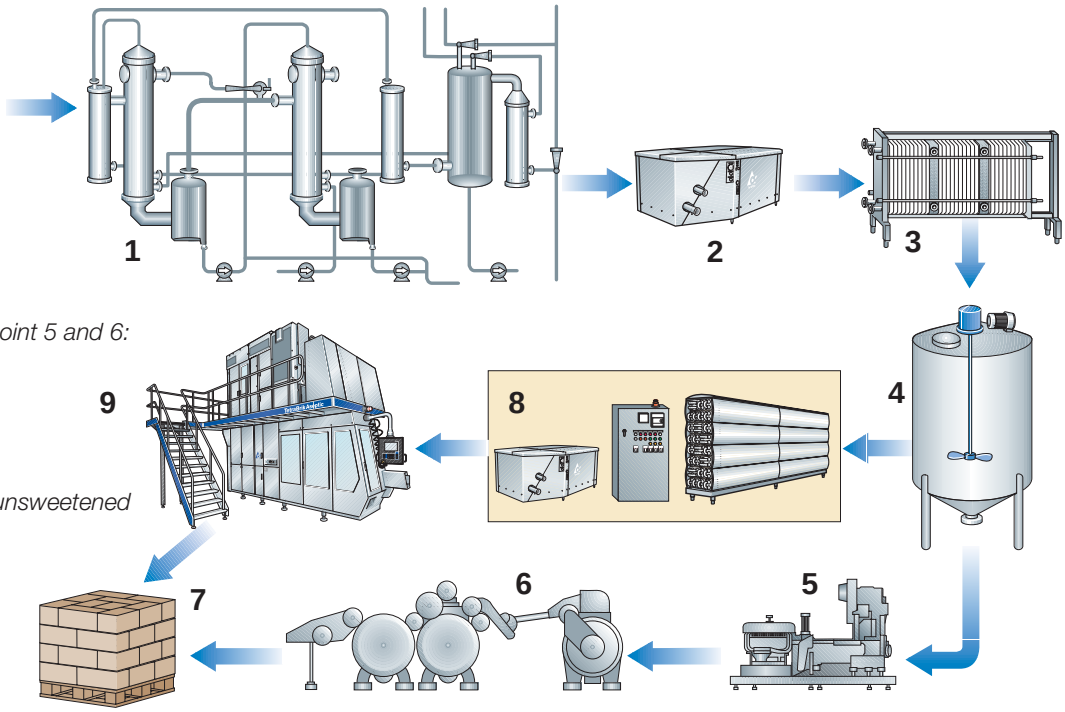


Fig. 16.3 *Process line for unsweetened condensed milk.*

which operates at a pressure of 5 – 25 MPa (50 – 250 bar). Homogenisation disperses the fat and prevents the fat globules from coalescing during subsequent sterilisation.

Homogenisation should not be too intensive, because that might impair the stability of the protein, with the consequent risk of the milk coagulating during sterilisation. It is therefore necessary to find the exact homogenisation pressure that is high enough to produce the required fat dispersion, yet low enough to eliminate the risk of coagulation.

For in-can sterilisation, the pressure is generally between 125 – 250 bar (two-stage). In UHT processing, homogenisation during pre-treatment is normally low, in order to avoid separation during storage of the concentrate prior the final heat treatment. The main homogenisation then takes place in the UHT treatment.

Final standardisation and intermediate storage

After homogenisation the pre-treated milk is cooled to about 14 °C before packaging, or to 5 – 8 °C, if it will be stored to await sample sterilisation. A final check of the fat content and the solids-non-fat is usually made at this stage.

As mentioned previously, the heat stability of the condensed milk can be improved by the addition of stabilising salts, usually disodium or trisodium phosphate. The quantity of phosphate to be added is determined by sample sterilisation, to which varying amounts of stabilising salts are added. Tests are needed because variations occur between batches of milk. It is a time-consuming test-procedure and further processing must wait until the results are available. In the meantime, the concentrate must be stored. However, long-term storage should be avoided, not only to prevent bacterial growth, but long cold storage may increase the tendency of age gelation.

Any addition of vitamins is also done at this stage.

Canning

Canning machines for condensed milk automatically fill and seal the cans before sterilisation. The canning temperature is selected to give the lowest possible froth formation.

Sterilisation

The filled and sealed cans pass from the filling machine to the autoclave, which operates either continuously or on the batch principle. In the *batch autoclave*, the cans are first stacked in special crates, which are then stacked inside the autoclave. In the *continuous autoclave*, the cans pass through on a conveyor belt at a precisely controlled speed (see also Figures in Chapter 9, *Long-life milk*).

In both types, the cans are kept in motion during sterilisation, to distribute the heat more quickly and more evenly through the cans. Any protein precipitated during heat treatment is uniformly distributed throughout the milk. After a certain period of heating, the milk reaches the sterilisation temperature of 110 – 120 °C. This temperature is maintained for 15 – 20 minutes, after which the milk is cooled to storage temperature.

The heat treatment is intense. This results in a light brown colouration, because of chemical reactions between the protein and the lactose (Maillard reaction or browning reaction).

UHT treatment

UHT treatment, mainly in tubular heat exchanger plants (described in Chapter 9, Long-life milk), can also be used for high heat treatment of condensed milk. In this case, following sample sterilisation and addition of a stabiliser, if required, the milk is pumped to the UHT plant, where it is heated to 122 –140 °C for a period ranging from 4 seconds to 8 minutes.

The time/temperature combination of the UHT treatment as well as the homogenising conditions (mainly conducted aseptically, but sometimes in both aseptic and non-aseptic modes) are to main extent determining the final product colour, viscosity and storage stability. After cooling, the milk is packed in aseptic paperboard packages and stored.

Storage and inspection

The canned condensed milk can be stored for practically any length of time at a temperature of 0 – 15 °C. The milk goes brownish if the storage tempera-ture is too high, and protein may precipitate if the storage temperature is too low.

UHT treated condensed milk has normally a shelf-life of 6 – 9 months.

Sweetened condensed milk (SCM)

Sweetened condensed milk can be made from whole milk or skim milk, or recombined condesed milk – based on skim milk powder, anhydrous milk fat (AMF) and water.

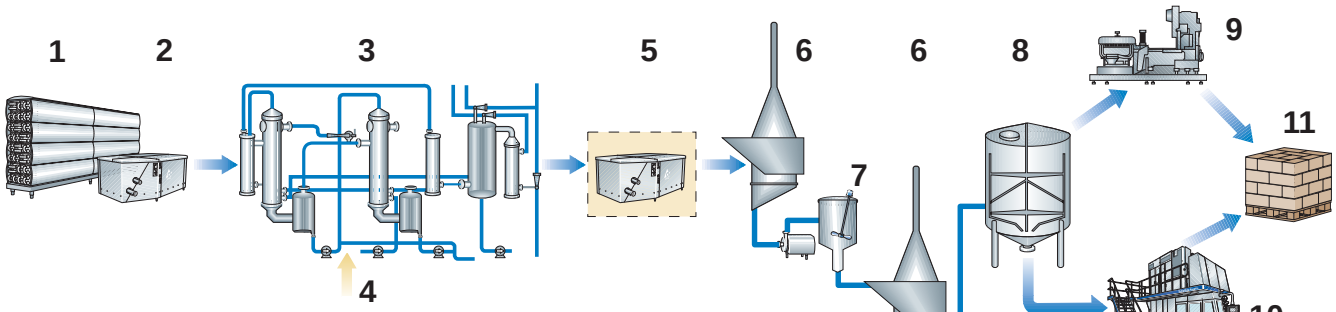
In the manufacture of sweetened condensed milk the heat-treated milk is pumped to the evaporator, where it is concentrated. Sugar in solution is

Table 16.1

Composition of sweetened condensed milk

	American standard	British standard
Fat content, %	8	9
Milk solids-non-fat, %	20	22
Lactose, %	10,3	11,4
Sucrose, %	45	43,5
Water, %	27	25,5
Lactose, g/100 g water	38,3	44,6
Sucrose, g/100 g water	167	171
Concentrator factor Q	4,60	5,00

Source: P. Waltra et al. Dairy Technology (1999)



1 Pasteurisation
2 Homogenisation
3 Evaporation
4 Sugar addition
5 Homogensiation, option
6 Flash cooler
7 Lactose seeding
8 Crystallisation tank
9 Canning
10 Aseptic paperboard packaging
11 Storage

Fig. 16.4 *Process line for sweetened condensed milk.*

Stages in the manufacture of *sweetened* condensed milk:
- Addition of sugar and evaporation
- Cooling to about 30 °C
- Seeding and subsequent cooling to 15 – 18 °C (crystallisation)
- Canning (or packing) and inspection

usually added to the concentrate during evaporation, but the sugar can also be added dry, in the correct proportion calculated on dry substance, before evaporation. After concentration, the product is cooled in such a way that the lactose forms very small crystals in the supersaturated solution. These crystals must be so small, less than 10 µm, that they cannot be detected by the tongue. After cooling and crystallisation, the sweetened condensed milk is packed.

Figure 16.4 shows a process line for sweetened condensed milk manufactured from fresh milk. Before evaporation, the fat and solids-non-fat values of the milk have been standardised to predetermined levels in the same way as for unsweetened condensed milk. The milk has also been heat-treated to destroy micro-organisms and enzymes which could cause problems and to stabilise the protein complex. Heat treatment is important to the development of product viscosity during storage, and is particularly important in the case of sweetened condensed milk. A gel can form if the heat treatment is too severe. The milk is usually heat-treated at 82 °C for 10 minutes if a product with a relatively high viscosity is required. If a low-viscosity product is required, the temperature/time combination should be 116 °C/30 sec.

The addition of sugar is a key step in the manufacture of sweetened condensed milk. It is important that the correct proportion is added, as the shelf life of the milk depends on its osmotic pressure being sufficiently high. A sugar content of at least 62,5 % in the aqueous phase is required to produce an osmotic pressure high enough to inhibit the growth of bacteria.

Two methods are used for addition of sugar:
- Addition of dry sugar before heat treatment
- Addition of sugar syrup in the evaporator.

The stage at which the sugar is added affects the viscosity of the end product. One theory maintains that early addition of sugar can cause the product to become too viscous during storage.

Evaporation

Evaporation of sweetened condensed milk is carried out in essentially the same way as for unsweetened. When sugar is added in the evaporator, the syrup is drawn into the evaporator and mixed with the milk at the half-way stage of the process. Evaporation then continues until the required dry matter content has been reached. The dry matter content is checked indirectly by determining the density of the concentrate.

Some manufacturers homogenise the concentrate at 5 – 7,5 mPa (50 – 75 bar) immediately after evaporation, as a measure to regulate the viscosity of the end product.

Cooling and crystallisation

Sweetened condensed milk must be cooled after evaporation. This is the most critical and important stage in the whole process. The water in the condensed milk can only hold half the quantity of lactose in solution. The

remaining half will therefore be precipitated in the form of crystals. If the surplus lactose is allowed to precipitate freely, the sugar crystals will be large and the product will be gritty and unsuitable for many applications. It is consequently preferable to control the crystallisation of lactose, so that very small crystals are obtained. The largest crystal size permitted in first-grade milk is 10 μm. These crystals will remain dispersed in the milk under normal storage temperatures, 15 – 25 °C, and are not felt on the tongue.

The required crystallisation is accomplished by cooling the mixture rapidly under vigorous agitation, without air being entrapped, and very often by flash cooling. Seed crystals, in the form of finely ground lactose crystals, are added at a rate of about 0,05 % of the total mix, either as powder or as a slurry, when the milk has cooled to crystallisation temperature (about 30 °C). This is the temperature at which the sugar solution is supersaturated, so that the seed lactose does not dissolve. However, the temperature must not be so low that spontaneous nucleation can occur before the seed crystals are mixed in.

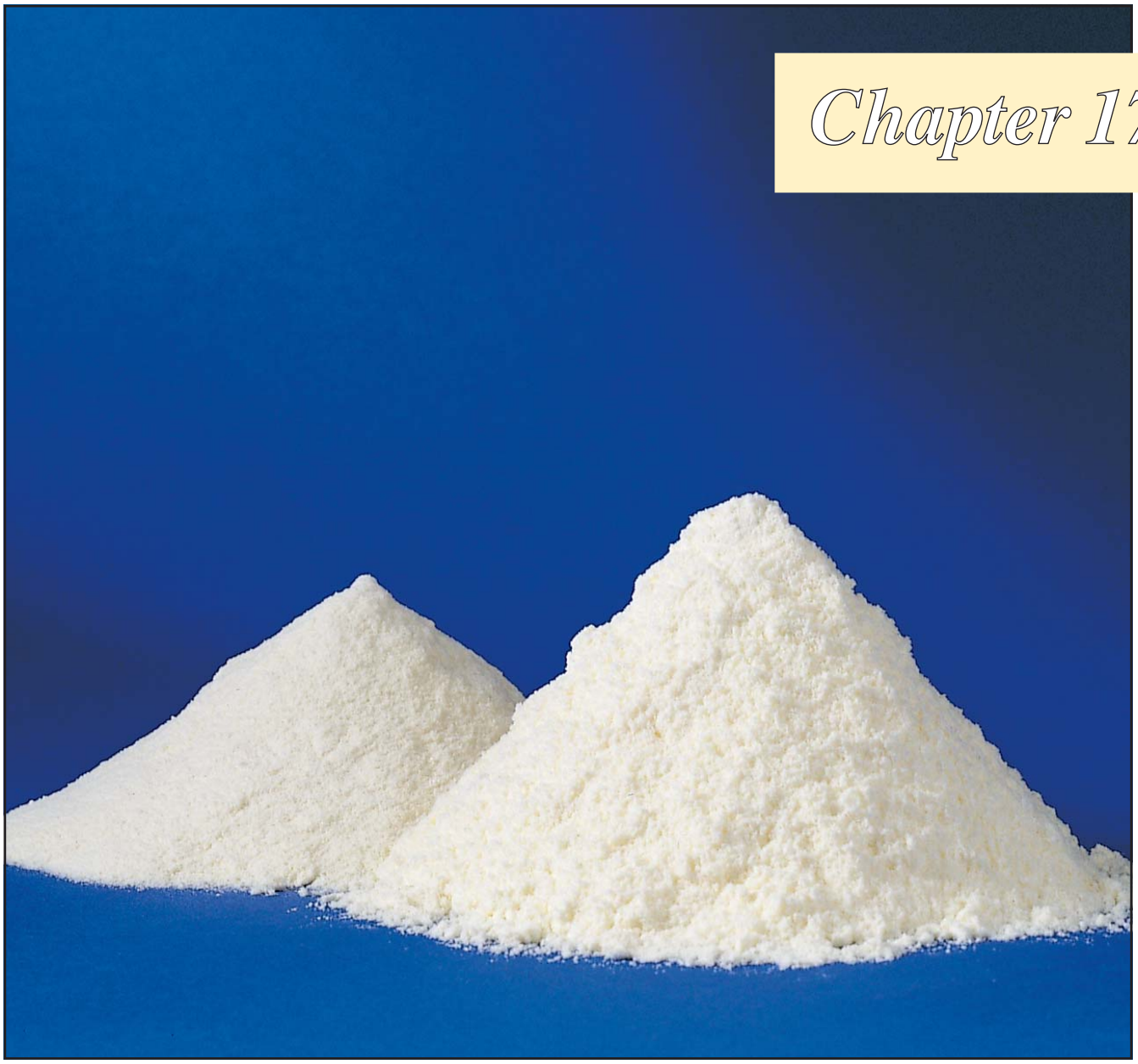
The viscosity of sweetened condensed milk is high, which means that a very robust agitator is needed.

Packing and inspection

Sweetened condensed milk should be yellowish in colour and has a high viscosity. Traditionally, it is packed in cans, which in this case must be cleaned and sterilised before filling, as no sterilisation takes place after canning.

Nowadays, it is also possible to pack sweetened condensed milk in aseptic paperboard packages.

The product is also packed in beech-wood barrels, holding about 300 kg, for supply to large-scale users.



Chapter 17

Milk and whey powder

The method of preserving foodstuffs by drying them, and thereby depriving micro-organisms of the water necessary for their growth, has been known for centuries. According to Marco Polo's accounts of his travels in Asia, Mongolians produced milk powder by drying milk in the sun.

Skim milk powder has a maximum shelf life of about three years, while whole milk powder has a maximum shelf life of six months. This is because the fat in the powder oxidises during storage, with consequent deterioration in flavour. However, the shelf life can be extended by using appropriate packaging technology, i.e. packing the powder under an inert gas such as N_2.

Drying

Drying means that the water in a liquid product – in this case milk concentrate – is removed, so that the product takes on a solid form. The water content of milk powder ranges between 1,5 and 5 %. Micro-organisms are unable to reproduce at such a low water content. Drying extends the shelf life of the milk, simultaneously reducing its weight and volume. This reduces the cost of transporting and storing the product.

Freeze-drying has been used to produce very high quality powder. In this process, the product is deep-frozen and the water frozen in the product is evaporated under vacuum. This ensures high product quality as, among other things, no protein denaturing takes place. When drying milk at higher temperatures, the proteins are denatured to a greater or a lesser extent. Freeze-drying is not widely used for the production of milk powder because of the high energy demand.

Commercial methods of drying are based on heat being supplied to the product. The water evaporates and is removed as vapour. The residue is the dried product – the milk powder. Nowadays, *spray drying* is the method primarily used for drying in the dairy industry. *Roller drying* is also used for a few special products. In spray drying, the milk is first concentrated by evaporation and then dried in a spray tower.

During the first stage of drying, the excess water – in free form between the particles of the dry solids – is evaporated. In the final stage, the water in the pores and capillaries of the solid particles is evaporated.

The first stage is relatively quick, whereas the last stage demands more energy and time. The product will be significantly affected by the heat if this drying is carried out in such a way that the milk particles are in contact with the hot heat transfer surfaces – as in the case of roller drying. The powder may then contain charred particles, which impair its quality.

Various uses of milk powder

Dried milk can be used for various applications, such as:

- Recombination of milk and milk products
- In the bakery industry to increase the volume of bread and improve its water-binding capacity. The bread will then remain fresh for a longer period of time
- Substitute for eggs in bread and pastries
- Producing milk chocolate in the chocolate industry
- Producing sausages and various types of ready-cooked meals in the food industry and catering trade
- In baby foods
- Production of ice cream
- Animal feed, calf growth accelerator

Skim milk powder

Skim milk powder is by far the most common type of milk powder.

Table 17.1

Typical properties of spray-dried milk powder

Product	Whole milk powder	Skim milk powder
Solubility, ml	0,1 – 0,5	0,1 – 0,5
Scorced particles, ADMI Disc	A	A
Residual moisture, max. %	3,0	4,0
Bulk density, tapped, g/ml	0,45 – 0,57	0,45 – 0,6
Total spore count, max. n/g	10 000	10 000

Each field of application makes its own specific demands of milk powder. If the powder is to be mixed with water for direct consumption (recombination), it must be readily soluble and have the correct taste and nutritive value. For this application, the product has to be dried very carefully in a spray dryer. Some degree of caramelisation of the lactose is beneficial in chocolate production. Here, the powder can be subjected to intensive heat treatment in a roller dryer. Two types of powder are therefore distinguishable:

- Spray-dried powder
- Roller-dried powder

Depending on the intensity of the heat treatment, milk powder is classified into categories related to the temperature/time combinations to which the skim milk has been exposed prior to and during evaporation and drying.

Heat treatment denatures whey proteins, the percentage denaturated increasing with the intensity of the heat treatment. The degree of denaturation is normally expressed by the Whey Protein Nitrogen Index (WPNI), *i.e.* in milligrams of undenatured whey protein nitrogen per gram of powder.

Information about the various categories of spray dried skim milk powder is summarised in Table 17.2.

Table 17.2

Categories of spray-dried skim milk powder.

Category	Temp/time	WPNI mg/g
Extra low-heat	<70 °C	*)
Low-heat (LH) powder	70 °C/15 s	> 6,0
Medium-heat (MH) powder	85 °C/20 s	5 – 6,0
”	90 °C/30 s	4 – 5,0
”	95 °C/30 s	3 – 4,0
Medium high-heat (HH)	124 °C/30 s	1,5 – 2,0
High-heat (HH)	appr. 135 °C/30 s	<1,4
High-heat high stable (HHHS) (from selected milk)	appr. 135 °C/30 s	<1,4

*) Not measurable

Table by Sanderson N.Z., J. Dairy Technology, 2, 35 (1967)

Whole milk powder

Spray dried whole milk powder is normally produced from standardised milk. After standardisation of the fat content, the milk need not be homogenised, provided that it is thoroughly agitated, without air inclusion. Homogenisation is normally carried out between evaporation and spray drying.

Fat standardised milk for the production of roller dried powder is normally homogenised.

Whole milk powder, unlike skim milk powder, is not categorised. Milk intended for whole milk powder is pasteurised at 80 – 85 °C in order to inactivate most of the lipolytic enzymes that would otherwise degrade the milk fat during storage.

Instant-milk powder

Special methods for the production of both skim milk and whole milk powder with extremely good wettability and solubility – known as instant powder – are also available. This powder is agglomerated into larger particles. A number of particles are combined to form a larger grain (agglomerate). The average grain size of the product increases. This instant powder, as it is known, dissolves instantly, even in cold water.

Bulk density

When powders are shipped over long distances, it is important that they have a high bulk density as the reduced volume saves on transportation costs and packaging. However, in some instances, producers may be interested in low bulk density in order to supply visibly larger amounts of powder than their competitors. Low bulk density, as influenced by agglomeration, is also an important characteristic of instant powders.

Definition

Bulk density is the weight of a unit volume of powder; in practice it is expressed as g/ml, g/100 ml or g/l.

Production of milk powder

In the production of *roller-dried* powder, the pre-treated milk is fed to a roller dryer after evaporation and the whole drying process takes place in one stage.

In the production of *spray-dried* powder, the milk is first evaporated in a vacuum evaporator to a DM content of 48 – 50 % and then dried in the spray tower. Spray-dried skim milk powder is manufactured in two basic qualities:

- Ordinary product
- Agglomerated (instant) milk powder by various spray drying processes

Following roller or spray drying, the powder is packed in cans, paper bags, laminated bags or plastic bags, depending on the quality and the requirements of the consumers.

Raw material

Very strict demands are made of the quality of the raw material for the production of milk powder.

Since spray powder production involves vacuum evaporation, it is very important to keep heat-resistant bacteria under control so that they cannot multiply during evaporation. *Bactofugation* or *microfiltration* of the milk can therefore partly be used to remove bacteria spores from the milk, thereby improving the bacteriological quality of the end product.

Strict demands are made on the quality of the raw material for production of milk powder.

Milk for powder production must not be subjected to excessive thermal impact prior to evaporation and drying. This could denature whey proteins and thereby impair the solubility, aroma and flavour of the milk powder. The milk is subjected to a peroxidase test or a whey protein test to determine the degree of heat treatment.

General pre-treatment of the milk

In the production of *skim milk* powder, the milk is clarified in conjunction with fat separation. This is also the case if the fat content is adjusted in a

Table 17.3
Composition of milk powder

Product	Whole milk	Skim milk
Fat, % solids content	26 – 29	max. 1,25
Protein, % solids content	25 – 27	34 – 38
Lactose, % solids content	35 – 38	48 – 56
pH	6.6 – 6.7	6.6 – 6.7
Acid value, %	< 0,16	< 0,16
Total spore count, max. n/ml	10 000	10 000

direct standardisation system. Standardised milk used for producing *whole milk* powder is normally homogenised.

Whole milk and skim milk are pasteurised at various temperatures depending on the powder quality requirements.

Roller drying

In roller drying, the milk concentrate is distributed as a film on rotating, steam-heated drums or rollers. The water in the concentrated milk evaporates, and the vapour is drawn off. The high temperature of the heating surfaces denatures the proteins, solubility deteriorates and brown discolouration may occur.

On the other hand, this intensive heat treatment increases the water-binding properties of the powder. This characteristic is useful in the production of ready-cooked meals, sausages and bread, cakes and pastries. Roller powders are used in the chocolate industry in particular due to their special properties.

The pre-treated milk is applied to the hot roller surface as a thin film. The dried milk is scraped off the rollers and removed by means of a screw conveyor, at which point the milk is broken down into flakes. The flakes are then transferred to a grinder which is used to create the desired grain size. After that, hard and burned particles are sifted off.

Depending on the desired capacity, the roller dryer is 1 – 6 m long and has a roller diameter of 0,6 – 3 m. Its performance is dependent on film thickness, roller surface temperature, roller speed and the DM content of the supplied milk.

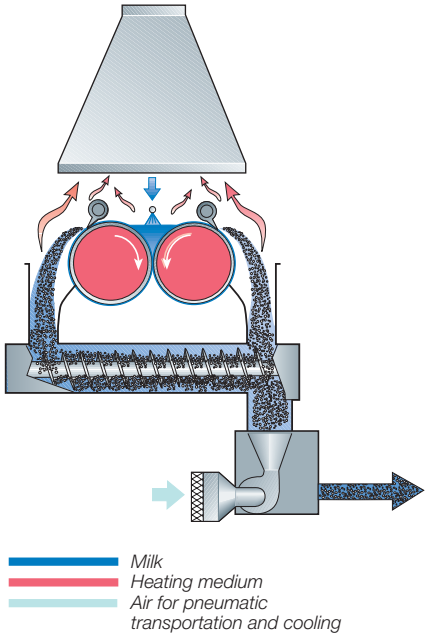


Fig. 17.1 *Principle of the trough-fed roller dryer.*

Spray drying

Powder production is carried out in two phases. In the first phase, the pre-treated milk is evaporated to a DM content of 48 – 52 %. Whey is concentrated to a DM content of 58 – 62 %. In the second phase, the concentrate is turned into powder in a spray tower. Likewise, drying is also a multiple-stage process:

- Atomisation of the concentrate into very fine droplets in a hot air stream
- Water evaporation
- Separation of the powder from the drying air

Evaporation is necessary to produce high-quality powder. Without prior concentration, the powder particles will be very small and have a high air content, poor wettability and a short shelf life. The process would then also be extremely uneconomical.

Falling-film tubular evaporators are generally used for concentration, which is carried out in one or more effects. See Chapter 6.5.

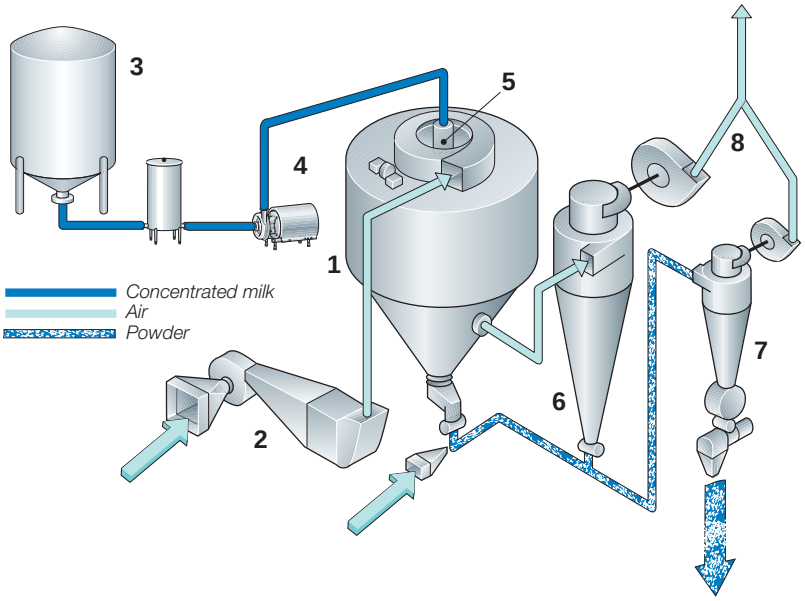


Fig. 17.2 *Conventional spray dryer (one-stage drying) with conical base chamber.*

1 *Drying chamber*
2 *Air heater*
3 *Milk concentrate tank*
4 *Feed pump*
5 *Atomiser*
6 *Main cyclone*
7 *Transport system cyclone*
8 *Air suction fans and filters*

Basic drying installations

Single-stage drying

The simplest installation for producing a powder consists of a drying chamber with an atomisation system, the air heater, a system for collecting the finished powder from the dry air and a fan which sucks the necessary amount of air through the entire system. An installation of this type is known as single-stage dryer as the entire drying process takes place in a single unit, the drying chamber. A powder with a small grain size and a high fines content is produced here.

Two-stage drying

The system described above is extended by means of a fluid bed dryer. The powder leaves the drying chamber with a higher residual moisture. In the fluid bed, drying ends at relatively low temperatures, and the powder may also be cooled. In terms of energy, this installation is better than a single-stage dryer as it is possible to work with considerably lower air exit temperatures. The quality of the powder can be improved by separation of the fine powder in the fluid bed.

Three-stage drying

Three-stage drying is an extension of the two-stage concept, developed to achieve greater savings in process costs and to meet various product quality demands more effectively.

Operating principle of spray drying

In all configurations, most of the air required for drying is sucked through the installation by centrifugal fans. The air for building up the fluidized layer in an integrated and/or external fluid bed and the air for optional recirculation of the fine powder is brought into the system via fresh air ventilators.

The temperature of the outgoing air is the reference variable for the residual moisture in the powder. Attempts must be made to avoid high outgoing air temperatures and thus high product temperatures which have an adverse effect on the quality of the powder, *e.g.* deterioration of solubility.

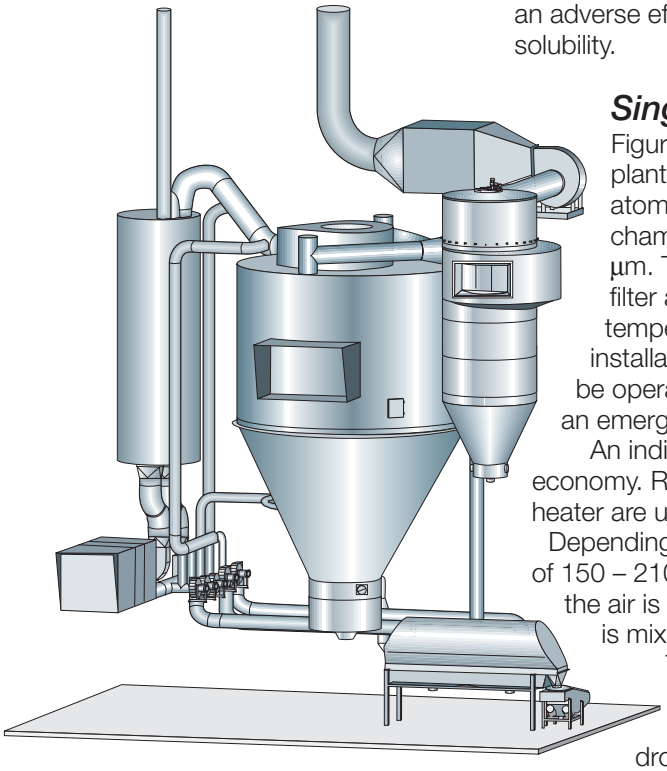


Fig. 17.3 *Multi-stage dryer set up. (CPS)*

Single-stage drying

Figure 17.2 shows the arrangement of a single-stage spray drying plant. The concentrate is fed via a high-pressure pump (4) to an atomisation system (5) integrated centrically in the roof of the chamber. This system produces very small droplets, Ø 40 – 125 µm. The drying air is normally sucked through a pre-filter and fine-filter and then passes an air heater. Depending on the desired air temperature, the air is steam-heated up to 190 – 200 °C. New installations are mostly provided with an indirect air heater which can be operated by means of a combined fuel burner for natural gas or, in an emergency, with light fuel oil.

An indirect heat recovery system can be provided to improve energy economy. Residual heat from the outgoing air and the flue gas from the heater are used to pre-heat the incoming air.

Depending on the product, the incoming air is heated to a temperature of 150 – 210 °C. The hot air flows through a distributor which ensures that the air is travelling at a uniform speed into the drying chamber, where it is mixed with the atomised product in the straight flow.

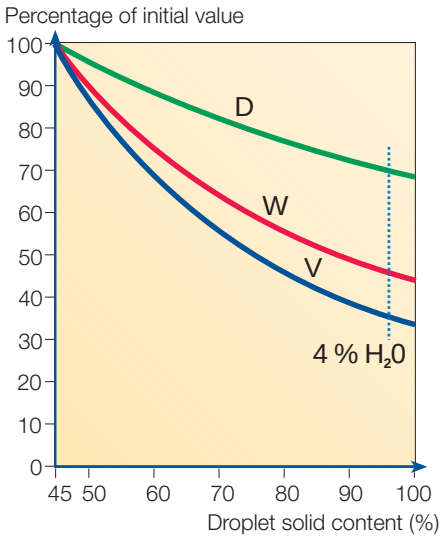
The free water evaporates immediately when the atomised product enters the drying chamber. Surface water evaporates very quickly, as does the moisture from the inside of the droplets which quickly reach the surface by capillary action. Then heat is transferred into the particles by convection. This results in the evaporation of bound water, diffusing it onto the surface of the particles.

Because the heat content of the hot air is continuously consumed by evaporation of the water, the product heats up to a maximum temperature of only 15 – 20 °C less than the temperature of the air when it exits the drying chamber; under normal conditions 60 – 80 °C.

The evaporation of the water from the droplets leads to a considerable reduction in weight, volume and diameter. Under ideal drying conditions, weight will decrease by about 50 % and the volume by about 40 %. The diameter is reduced to 75 % of the droplet size after leaving the atomiser, Figure 17.4.

During the drying process, the powder settles in the bottom cone of the chamber and is discharged from the system. It is conveyed to a silo or packing station by a pneumatic conveyor which uses cold air to cool the hot powder. The powder is then separated from the transport air by means of a cyclone.

Small, light particles may be sucked out of the drying chamber, mixed in with the air. This powder is separated in one or more cyclones (6, 7 in Figure 17.2) and fed to the main flow of powder.



D = Diameter
W = Weight
V = Volume

Fig. 17.4 *Weight, volume and diameter decrease of droplet under ideal drying conditions down to 4 % H_2O.*

Atomisation

The more finely the product is atomised, the larger their specific area will be and the more effective the drying process. One litre of milk in a spherical shape has a surface area of about 0,05 m^2. If this quantity of milk is atomised in the spray tower, each of the small droplets will have a surface area of 0,05 – 0,15 mm^2, *i.e.* atomising increases the specific area by a factor of about 700.

The type of atomisation depends on the product, the desired particle size and the properties required of the dried product. These may include texture, grain size, bulk density, solubility, wettability and density. There is an important functional differentiate between nozzle and centrifugal atomisation. A stationary nozzle which sprays the milk in the same direction as the flow of air is shown in Figure 17.5. A centrifugal disc for atomisation is shown in Figure 17.6.

The pressure at the nozzle determines the particle size. At high pressures, up to 30 MPa, (300 bar), the powder will be very fine and have a high density. At low pressures, 5 – 20 MPa, (50 – 200 bar), larger particles will be formed and the fines content will be lower. The pressure is built up by means of multi-plunger high-pressure pumps. These are mostly homogenisers, which are needed for many products and can also operate as high-pressure pumps with by-passed homogenisation devices.

The centrifugal atomiser consists of an electric drive which rotates a disc with a number of horizontal passages. The product is fed into the middle of the disc and forced through the passages at high speed by centrifugal force. The discs rotate at speeds of 5 000 to 25 000 rpm depending on their diameter. Peripheral speeds of between 100 – 200 m/s are achieved.

The flow of product is atomised into very fine droplets upon its exit from the passage due to the high speed. The size of the droplets – and thus also the grain size of the powder – can be influenced directly by changing the atomiser speed. A centrifugal pump is normally sufficient to feed this type of atomiser.

Essentially, a larger grain size can be achieved by means of nozzle atomisation, 150 – 300 µm as compared to 40 – 150 µm with centrifugal atomisation. However, centrifugal atomisation is straightforward to operate and not sensitive to variations in product viscosity and quantity supplied.

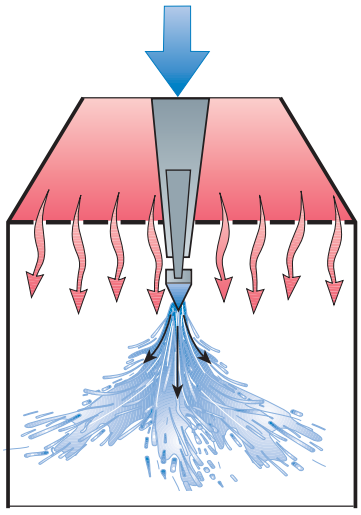


Fig. 17.5 *Stationary nozzles for atomising the milk in a spray drying chamber.*

Two-stage drying

Two-stage drying in the fluid bed dryer, which is divided into a number of zones, ensures that the desired residual moisture is achieved and that the powder is cooled. Final drying in the integrated fluid bed dryer ensures that the desired residual moisture is achieved. After final drying the powder is cooled in a pneumatic cooling and conveying duct.

The installations can be operated with both nozzle and centrifugal atomisers.

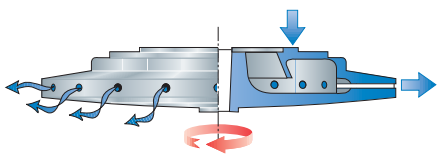


Fig. 17.6 *Rotating disc for atomising milk in the spray drying chamber.*

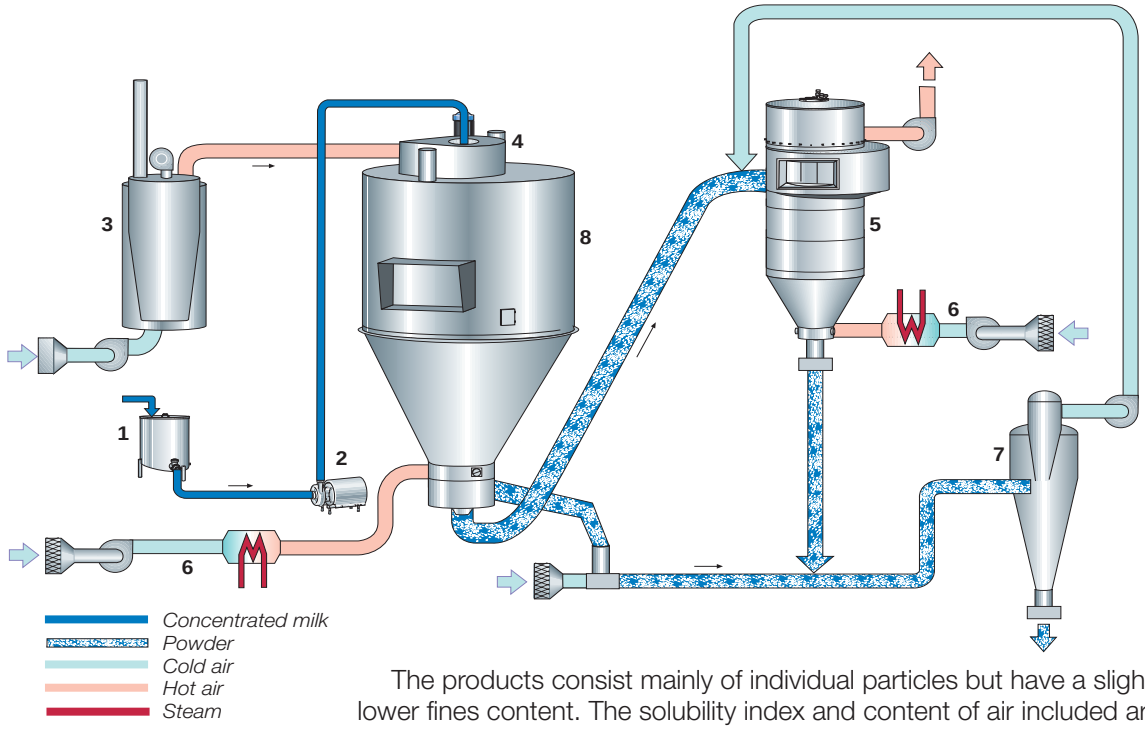


Fig. 17.7 *Two-stage dryer with integrated fluid bed. (CPS)*

1 *Balance tank for concentrated milk*
2 *Feed pump*
3 *Air heater*
4 *Atomiser*
5 *Filter for fines recovery*
6 *Air fans and heaters*
7 *Transport system cyclone*
8 *Drying chamber*

The products consist mainly of individual particles but have a slightly lower fines content. The solubility index and content of air included are smaller in the case of powders dried using the two-stage method on account of the lower thermal impact overall, although the bulk density is higher.

Air and the fine powder are transported out of the chamber via a vertical duct placed in the center of the integrated fluid bed.

The biggest advantage over single-stage drying is the improved efficiency achieved by increasing the temperature difference between supply air and outgoing air. The energy required for drying is about 10 – 15 % lower than in the single-stage process.

Table 17.4 shows a comparison between single-stage and two-stage drying systems.

Three-stage drying

If the pneumatic cooling and conveying duct in a two-stage dryer with integrated fluid bed is replaced with an external fluid bed with a drying and a cooling section, this is known as a three-stage dryer. A large number of agglomerated and non-agglomerated dairy and food products can be manufactured using this process. If agglomerated products are produced the fine powder is recirculated to the wet atomisation zone. This configuration allows the supply air temperature to be increased and the outgoing air temperature to be lowered. This reduces the specific energy requirement by a further 10 – 15 % compared with two-stage drying. A large number of plants installed work to this principle. Mass-produced products such as skim milk powder and whey powder are manufactured cost-effectively in this way.

Multi-function dryers

This system is based on two-stage or three-stage drying. Transporting the drying air out through the roof of the chamber is characteristic of this structure, which represents the current state of the art in drying technology. This optimised air conduction carries the fine powder directly back into the atomisation zone, so recirculating large amounts of fine powder which would otherwise remain in the loop between the chamber and the cyclone or filter, is no longer necessary in order to achieve good agglomeration.

Nozzle atomisation systems in particular are used which are made up of a number of pressure nozzles, one central one and the others in a circle. The central pressure nozzle is provided with an outer tube through which the fine powder can be aimed into the core atomisation zone. Suitable selection of a nozzle structure and correct adjustment of the movable

Table 17.4
Comparison of one-stage and two-stage drying systems.

Drying system	One-stage Inlet temp. 200 °C	Two-stage Inlet temp. 200 °C	Inlet temp. 230 °C
Spray dryer (First stage)			
Evaporation in chamber, kg/h	1 150	1 400	1 720
Powder from chamber:			
6,0 % moisture, kg/h	–	1 460	1 790
3,5 % moisture, kg/h	1 140	–	–
Energy consumption, spray drying total, Mcal	1 818	1 823	2 120
Energy/kg powder, kcal	1 595	1 250	1 184
Fluid Bed (Second Stage)			
Drying air, kg/h	–	3 430	4 290
Inlet air temperature, °C	–	100	100
Evaporation in fluid bed, kg/h	–	40	45
Powder from fluid bed			
3,5 % moisture, kg/h	–	1 420	1 745
Energy consumption, kW	–	20	22
Energy consumption, total in fluid bed, Mcal	–	95	115
Total plant			
Energy consump. total, Mcal	1 818	1 918	2 235
Energy/kg powder total, kcal	1 595	1 350	1 280
Energy relation	100	85	80

Basis: Same drying chamber size with inlet air flow = 31 500 kg/h.
Product: skim milk, 48 % solids in concentrate.

Source: Evaporation, Membrane Filtration, Spray Drying - North European Dairy Journal, 1985 Copenhagen, Denmark. ISBN No. 87-7477-000-4.

nozzle heads allows optimum agglomeration for practically every product.

Difficult products, even those with a very high fat content, are possible to produce. The result is a practically fines-free powder with a high degree of mechanical agglomerate stability. Centrifugal atomisers can also be used.

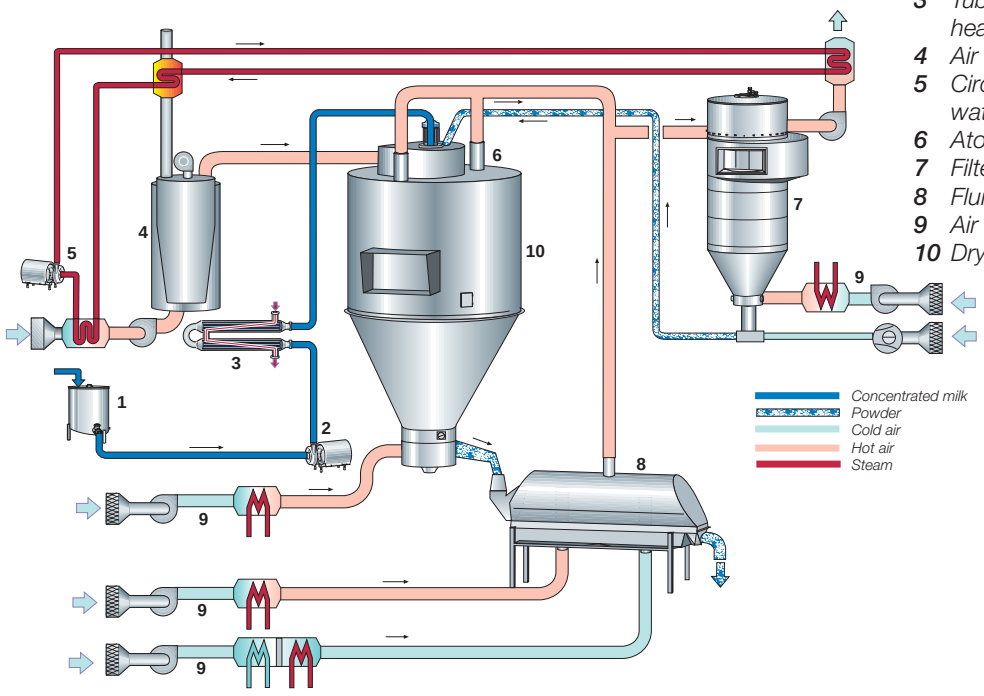


Fig. 17.8 *Three-stage dryer with filter for fines recovery and integrated external fluid bed. (CPS)*

1 *Balance tank for concentrated milk*
2 *Feed pump*
3 *Tubular heat exchanger for pre-heating*
4 *Air heater*
5 *Circulation pump for heat recovery water circuit*
6 *Atomiser*
7 *Filter for fines recovery*
8 *Fluid bed*
9 *Air fans and heaters*
10 *Drying chamber*

Appropriate design of the roof of the chamber means that an exchange takes only a short time, making rapid product changes possible.

The structure of the overall plant permits very compact installation with short powder transport paths.

Additional equipment for spray dryers

Powder separation

The classic system for the separation of powder and drying air is a cyclone or an arrangement of a number of cyclones in series or in parallel. The residual fines content in the outgoing air is very high, 100 – 200 mg/Nm^3. Introducing bag filters allowed the residual fines content to be lowered to less than 10 mg/Nm^3. The filtering bags are dedusted by means of regular pulses of compressed air. The residual fines accumulated in the filter are waste as far as food is concerned.

The use of washable filters, which are linked to the CIP system, are the current state of the art. Regular cleaning ensures that the residual fines are not contaminated and remain suitable as food, which leads to an increase in yield and thus a reduction in powder manufacturing costs.

Most dairy powders can be produced without the cyclone or cyclones if the surface area of the filter is dimensioned appropriately. This means a considerably lower pressure loss in the air system, which is why the capacity of the main fan can be reduced by up to 20 %. The economic efficiency of a drying plant of this type is very clearly improved.

Systems for avoiding deposits

A lot of drying plants have to process difficult products which can cause deposits in the cylindrical and/or conical part of the drying chamber. These deposits are not only unpleasant due to any contamination they cause: because of the temperatures in the chamber, they may possibly lead not only to burnt particles, but they could also form dangerous smoulder spots which could cause fires, or – in a worst-case scenario – explosions.

To avoid this, slot nozzles can be incorporated into the wall of the chamber in the lower cylindrical part and/or the cone which produce a hot air curtain with a high radial velocity directly on the wall of the chamber, thereby preventing or at least delaying deposits.

Another design element which prevents deposits is an air broom. It is used in particular in multifunction dryers. This is a tube arranged centrically in the integrated fluid bed which is driven by electricity and rotates along the chamber wall at about 1 rpm. It is fitted very close to the wall and coats the cone and cylinder wall of the chamber with air, which is blown into the tube from below and emerges from the tube at high speed through overlapping slot nozzles.

Air conditioning

Depending on the ambient conditions, the water content of the drying air may be so high that it is unable to absorb any more moisture, particularly in the case of final drying at low temperatures in the integrated and external fluid bed. At this point, dehumidification of the air is necessary. This can be carried out by cooling the air flow to below dew point by means of chilled water. The water condenses and is separated from the air flow via a mist collector. The air is then heated up to the desired temperature again. This also applies in particular to product cooling air.

Fire and explosion protection

The powder-air mixture in the drying chamber may be inflammable or it may, as mentioned above, lead to fires due to smoulder spots. Fires can be extinguished by installing fire extinguishing nozzles in the chamber roof, the fluid beds and the bag filter. Carbon oxide (CO) detectors or photoelectric cells are used to detect fires.

Destruction and thus long-term loss of plant function can be avoided by

installing pressure relief apertures or rupture discs which keep the pressure on the wall of the chamber low in the event of explosions. Ducts and filters can be protected by extinguishing barriers which are triggered by means of pressure detectors. These include fire extinguishers pre-filled to about 50 bar and mounted permanently at strategically important locations and filled with inert powder (sodium hydrogen carbonate). In the event of an explosion, a detonator blows up the partition disc between the extinguishing container and the dryer. The extinguisher is blown into the plant instantaneously and brings the area where it was blown in into a non-flammable state by changing the powder to air ratio. The explosion front thereby stops from spreading. Depending on the product, plant safety must be prioritised as early as the planning stage. Relevant regulations are available to plant constructors.

Heat recovery

A large amount of the heat is lost with the outgoing air in the drying process. Some of this heat can be recovered in suitable heat exchangers. The outgoing air from the dryer and the flue gas from the air heater are the main sources for heat recovery. The heat transfer is carried out indirectly, *i.e.* the heat in the hot air is transferred to the air heater via a liquid cycle with its own circulation. This can improve the thermal efficiency of a spray dryer by 10 – 15 %.

Concentrate heating

The thermal efficiency of the dryer is improved if the temperature of the feed product is increased. However, this increase in temperature has to take place very carefully to avoid unwanted thermal impact and an increase in viscosity. Heating from 55 °C to 75 – 80 °C can generally take place, but must be performed immediately before atomisation. It is appropriate to mount the concentrate heater on the roof of the chamber near to the atomiser. The heater, which can be supplied for high-pressure and low-pressure atomisation, is designed as twin tubular heat exchangers in a shared casing so that cleaning can be carried out without having to interrupt operation.

The product is heated very carefully by means of vacuum steam. If the chamber size and peripheral equipment remain the same, an increase in performance of about 5 % is possible. This is also true of the retrofitted equipment in existing plants.

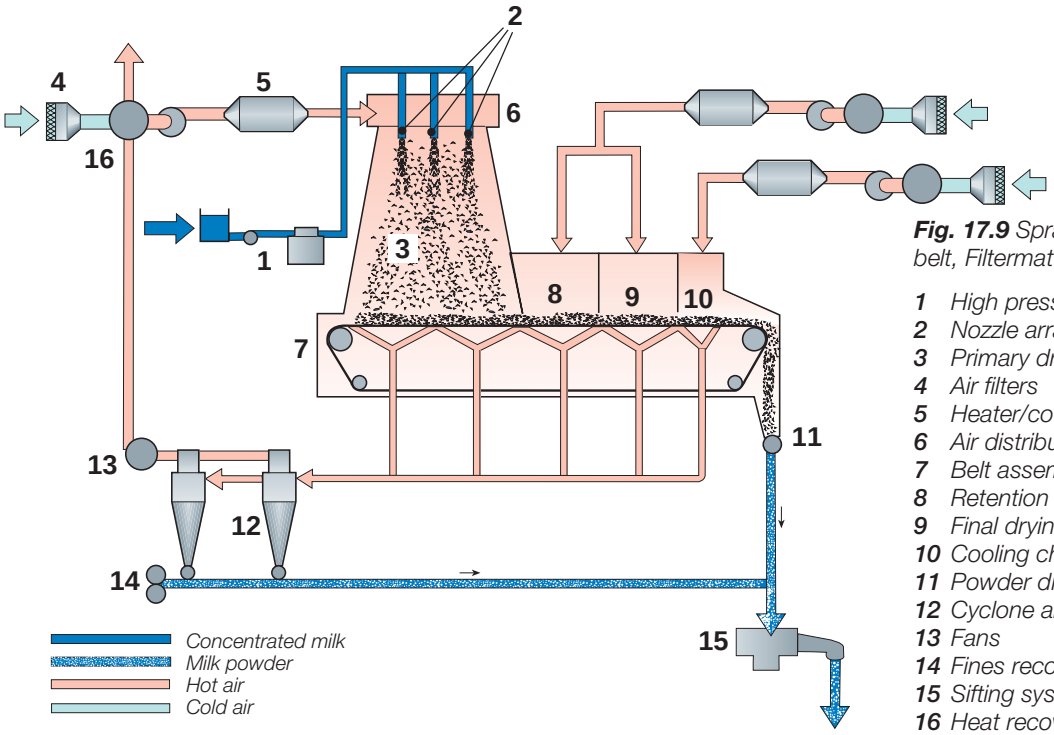


Fig. 17.9 *Spray dryer with integrated belt, Filtermat (three-stage drying).*

1 *High pressure feed pump*
2 *Nozzle arrangement*
3 *Primary drying chamber*
4 *Air filters*
5 *Heater/cooler*
6 *Air distributor*
7 *Belt assembly*
8 *Retention chamber*
9 *Final drying chamber*
10 *Cooling chamber*
11 *Powder discharge*
12 *Cyclone arrangement*
13 *Fans*
14 *Fines recovery system*
15 *Sifting system*
16 *Heat recovery system*

Spray belt dryer

A spray belt dryer is shown in Figure 17.9. It consists of a main drying chamber (3) and three smaller chambers for crystallisation (when required, *e.g.* for the production of whey powder), final drying and cooling (8, 9 and 10).

The product is atomised by nozzles located above the main chamber of the dryer. The feed is conveyed to the nozzles by a high pressure pump. Atomisation pressure is up to 200 bar.

Agglomeration in the fluid bed

To obtain the correct porosity, the particles must first be dried so that most of the water in the capillaries and pores is replaced by air. The particles are then humidified so that the surfaces of the particles swell quickly, closing the capillaries. The surfaces of the particles will then become sticky and the particles will adhere to form agglomerates.

One efficient method of instantisation is rehumidifying agglomeration in a fluid bed as shown in Figure 17.10. The fluid bed is connected to the discharge opening of the drying chamber and consists of a casing with a perforated bottom. Air at a suitable temperature is blown in through the floor at a velocity which is sufficient to suspend the powder and fluidise it.

The casing is mounted in a spring bearing and can be vibrated by a motor. The holes in the bottom plate are shaped as nozzles in the product flow direction and the product is fed in the direction of the outflow. The vibration supports fluidisation and conveys the powder. Weirs between the individual sections and at the outlet determine the height of the fluidised powder layer, and the length of the fluid bed determines the residence time.

The powder is conveyed from the spray tower into the first section, where it is humidified by steam. An air flow and vibrations convey the powder through the individual drying sections, where hot air at decreasing temperatures is fed through the powder bed. Agglomeration takes place in the first stage of drying when the moistened particles adhere to each other to form agglomerates. The water is evaporated from the agglomerates during their passage through the drying sections. The powder is then

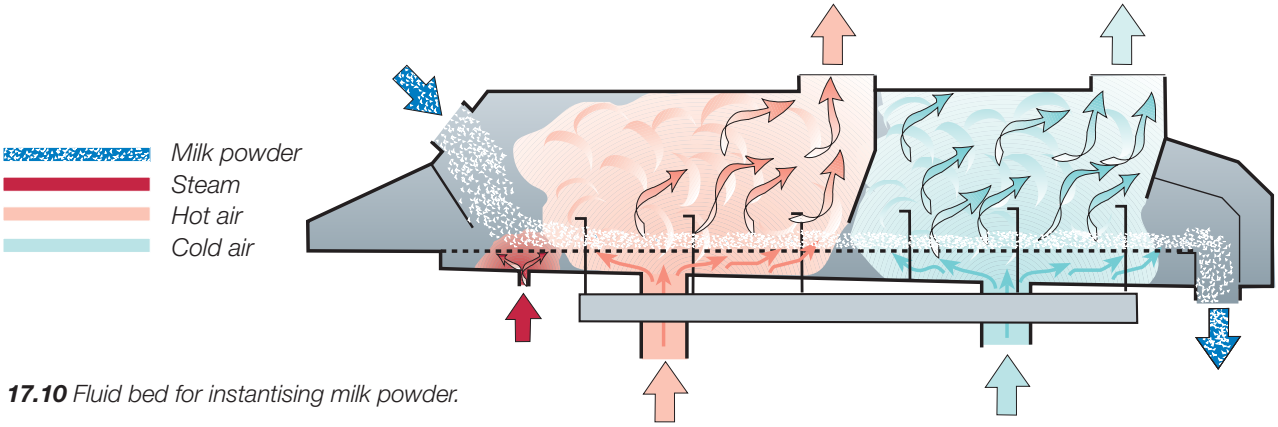


Fig. 17.10 *Fluid bed for instantising milk powder.*

cooled and leaves the fluid bed with the desired residual moisture.

Large grains and fine grains are screened. The screened and instantised powder is then conveyed to filling by a gentle transport system. The outgoing air from the fluid bed, containing a certain amount of fine powder, is blown to the cyclone or filter of the main air system of the drying plant.

Agglomeration in the drying chamber

A simpler method of rehumidifying agglomeration is to carry out instantisation immediately in the drying chamber. This is particularly effective in the multifunction dryer described above in Figure 17.8. Due to the air conduction, pre-dried fine powder is constantly circulating about the atomisation zone, where it coats particles which are still moist and forms agglomerates. However, the essential part of agglomeration is achieved by

deliberately blowing in fine powder out of the filter in the centre of a nozzle atomisation spray zone, Figure 17.11.

The entirely dry fine powder immediately attaches itself to wet particles and moist air, consequently resulting in sticking the particles together. This results in stable agglomerates, with almost no fines content.

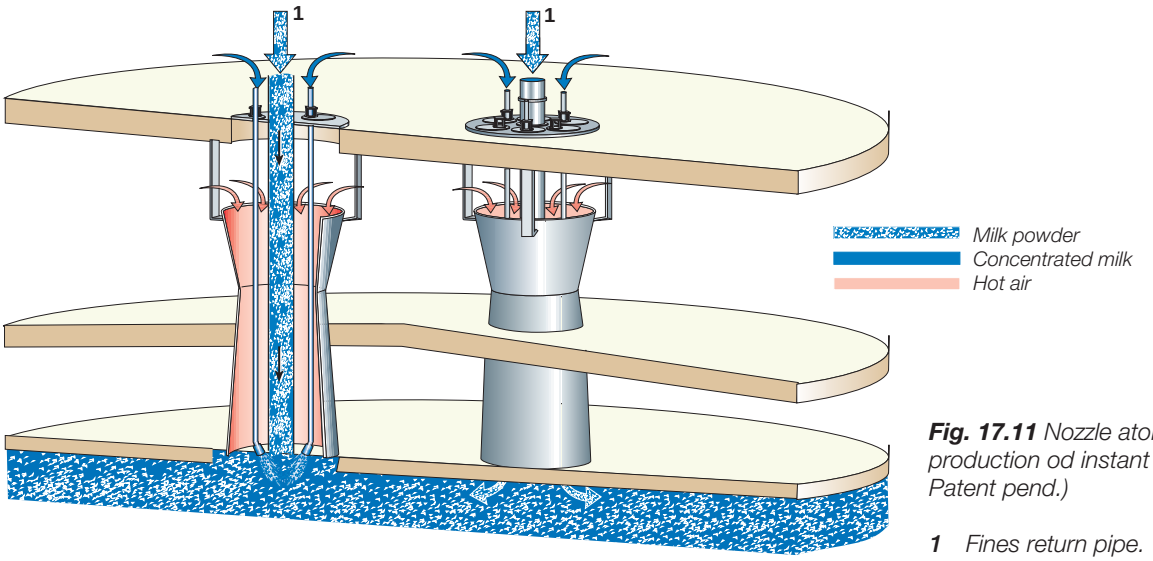


Fig. 17.11 *Nozzle atomiser designed for production od instant powder. (CPS Patent pend.)*

1 *Fines return pipe.*

Packing milk powder

The types and sizes of packages vary from one country to another. The powder is often packed in paper bags with an inner bag made of polyethylene. This polyethylene bag is welded, and so this package is relatively impervious to oxygen and steam. The most common bag sizes are 15 and 25 kg, although other sizes are also used.

Milk powder for households and similar small-scale consumers is packed in tin cans, laminated bags or plastic bags which, in turn, are packed in cartons.

Changes in milk powder during storage

The milk fat in whole milk powder oxidises during storage. The shelf life can be extended by special pre-treatment of the milk, *i.e.* by the addition of antioxidants or by filling under inert gas.

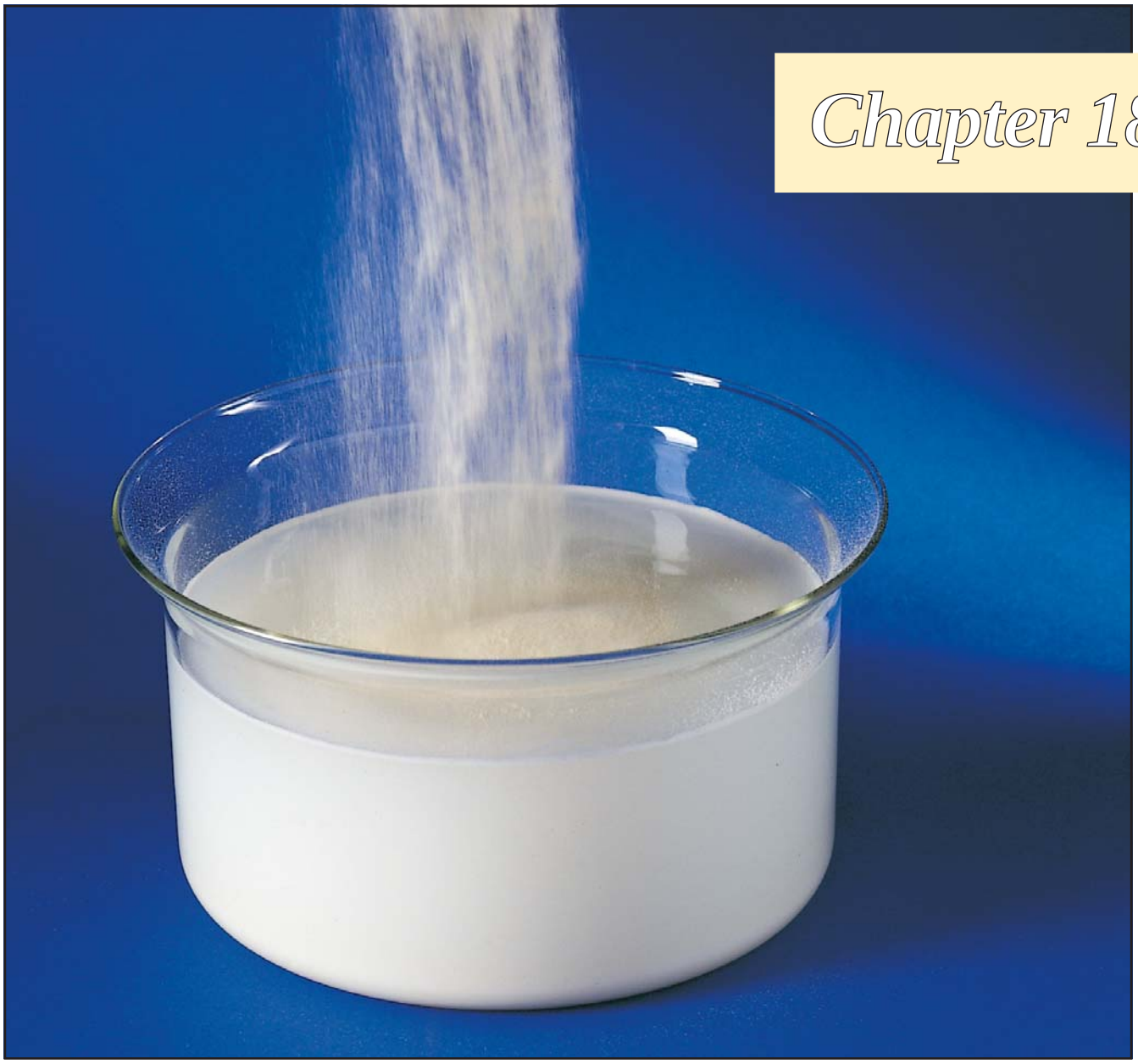
Milk powder should be stored in a cool, dry place. All chemical reactions in milk powder, at room temperature and with a low water content, take place so slowly that the nutritive value is not affected, even after several years of storage.

Dissolving milk powder

One part of a spray-dried milk powder is mixed with about ten parts of water at a temperature of 30 – 50 °C and stirred. The dissolving time can take from a few seconds to a few minutes.

If instantised powder is used, the required quantity of water is poured into a tank and the powder is then added. The powder dissolves after very brief stirring, even if the water is cold. The milk is then immediately ready for use.

The water quality is very important for dissolving. It must be noted that during drying, including the first concentration phase (evaporation), pure (distilled) water has been evaporated off from the milk. Read more about water quality in Chapter 18, *Recombined milk products*.



Chapter 18

Recombined milk products

Milk is a perishable commodity, and therefore scarce in many countries with little or no dairy production of their own. Fresh milk has a very limited shelf life and is easily spoiled by bacteria enzymes and exposure to direct sunlight. Distribution is especially difficult in tropical climates and in regions where the distance between producer and consumer is great. In such places, fresh milk is replaced by more durable forms of milk, such as condensed or UHT-sterilised milk.

Recombination is an alternative method of supplying a product that closely resembles fresh dairy milk to markets where the genuine article is not available. The manufacture of recombined milk and milk products has been

well established in many countries around the world, and a variety of processes and equipment have been developed for this purpose.

The principles of the processes are much the same. The initial applications were fluid milk, but this was followed by production of recombined evaporated milk and sweetened condensed milk. Today recombination also includes yoghurt, butter and cheese.

The processes have been developed over the years from simple batch operations to sophisticated systems with high capacities.

The main processes in the basic reconstitution and recombining operations are:

- Raw material handling
- Weighing and mixing
- Filtration, homogenisation and pasteurisation

Definitions

The following definitions are given as a guide to clarify certain expressions used in the industry.

Reconstituted milk is the liquid milk obtained by adding water to skim milk powder or whole milk powder.

Recombined milk is the liquid milk obtained by adding water to skim milk powder and adding milk fat separately in such a quantity that the desired fat content is achieved.

Reconstituted milk is the liquid milk obtained by adding water to skim milk powder (SMP) or whole milk powder (WMP).

Recombined milk is the liquid milk obtained by adding water to SMP and adding milk fat separately in such a quantity that the desired fat content is achieved.

Reconstituted milk products are the products resulting from addition of water to the dried or condensed form of product in the amounts necessary to re-establish the specified water/solids ratio.

Recombined milk products are manufactured by mixing milk fat and milk solids-non-fat (MSNF), with water. This combination must be made so as to re-establish the specified fat to MSNF ratio and dry matter (DM) to water ratio.

Recombined, modified milk and milk products are products made from dairy-product ingredients with compositions other than normal dairy products, *e.g.* flavoured products, butter from fractionated fat, or dietary evaporated or condensed milk.

Filled milks and milk products are “semi-dairy” products in which the milk fat is replaced by vegetable oils, *e.g.* liquid milk, evaporated milk, condensed milk or cheese. Alternative terms could be called “imitation” or “substitute” milk products.

Fortified milk is made from fresh milk, reconstituted milk or recombined milk with the addition of one or more ingredients of dairy products.

Toned milk is fresh milk mixed with reconstituted or recombined skim milk in order to prepare normal composition milk or modified milk from high-fat milk, by adjusting the MSNF.

Anhydrous milk fat (AMF) is a pure fat product obtained from fresh milk, cream or butter to which no neutralising substances have been added.

Anhydrous butter oil is an all-fat product made from cream or butter of unspecified age.

Butter oil is a product made from cream or butter of unspecified age which may have a lower fat content.

Vegetable oils are refined, bleached, deodorised oils, preferably coconut, palm and soybean oils.

Raw material

Milk powder

Non-fat solids for recombined milk are usually supplied in the form of skim milk powder. This is made by skimming the fat from the whole milk in centrifugal separators and then removing the water from the skim milk by evaporation and drying. The powder can be stored for months, or even

years, without being spoiled, and dissolves easily in water to form reconstituted skim milk.

The most commonly used method of classifying skim milk powder (SMP) is to refer to the processing technique, and consequently the heat treatment, to which the skim milk has been exposed prior to evaporation and spray drying.

During the heat treatment of milk, the whey proteins are denatured to different degrees, depending on the temperature/time relationship. The degree of denaturation can be classified according to the Whey Protein Nitrogen Index (WPNI), which was discussed in Chapter 17.

Table 18.1

Skim milk powders for reconstituted and recombined products

Typical powder qualities

Type and Characteristics	Extra low heat Extra LH < 70 °C/15 s	Low heat LH 70 °C/15 s	Medium heat MH 85–90 °C/20–30 s	Medium high heat MHH 96–124 °C/30 s	High heat HH ≈135 °C/30 s	High heat HHHS* ≈135 °C/30 s
WPN index, mg/g	–	> 6,0	5,9 – 4,5	4,4 – 1,5	< 1,4	<1,4
Heat number	–	< 80,0	80,1 – 83,0	83,1 – 88,0	> 88,1	> 88,1
Recombined product						
Hard cheese	Antibiotic-free, good rennet ability					
Semi-hard cheese	Antibiotic-free, good rennet ability					
White/Feta cheese	Antibiotic-free, good rennet ability					
Fresh cheese	Antibiotic-free, good rennet ability					
Pasteurised milk		Antibiotic-free				
UHT milk			Low CFU count:<5 x 10^5/ml			
Sterilised milk			Antibiotic-free			
Sweet condensed milk		Antibiotic-free				
Evaporated milk					Antibiotic-free	
Cultured milks		Antibiotic-free				
Standard ice cream		Antibiotic-free				

* High heat high stability powder from specially selected milk

The different recombined milk products usually require skim milk powder of various types of heat classification, (see Table 18.1).

Milk powder is typically supplied in 25 kg plastic lined laminated bags.

In smaller plants, the powder is often emptied by hand, direct from the bags into the mixing system, but in the larger plants, the bags are emptied automatically. Even more sophisticated is the use of silo tanks to which the powder from the emptied bags is transferred pneumatically.

There are also rational methods for transporting milk powder to recombining plants in bulk bins containing 200 – 1 000 kg. The size of the containers is limited by the handling facilities in the locality receiving the powder.

Dissolving of milk powder

The dissolving properties of milk powders are very important for the recombined product quality and are affected by the following factors:

- Wettability
- Ability to sink
- Dispersability
- Solubility

Analytical methods for these properties are given in:

- Standards for Grades of Dry Milk, Including Methods of Analysis, American Dairy Products Institute, Inc., USA
- Evaporation, Membrane Filtration and Spray Drying in Milk Powder and Cheese Production, North European Dairy Journal, Denmark

Factors affecting the dissolving of milk powder are:

- Wettability
- Ability to sink
- Dispersability
- Solubility

Wettability

The degree of wettability is very much a function of the particle volume, and especially of the capillarity.

Agglomerated powders have improved capillarity, resulting in increased wettability. Increased particle size (130 – 150 μm) also results in improved wettability. Good wettability is less than 30 seconds.

Ability to sink

The ability to sink is a function of specific volume and particle size. Agglomerated powders normally have the best ability to sink.

Dispersability

Good dispersability is obtained when powders added to the water are distributed as single particles, leaving no lumps. The structure of the powder particles, as well as the configuration of the protein molecules, is of importance. A powder with a high content of denatured proteins is very difficult to disperse. A dispersability of at least 90 % is normal for milk powders for recombination.

Solubility

This property describes how well the powders dissolve and form a stable suspension. How good the solubility is depends very much on the technology used for production of the powder.

A good solubility index should be as low as 0,25 ml undissolved sediment in 50 ml recombined milk.

Fats and oils

Unsalted butter can be used in the manufacture of recombined milk products, but it must be kept under refrigerated storage.

The most common source of milk fat for recombination is anhydrous milk fat (AMF), which does not require such storage. It is typically packed in 19,5 kg cans or 196 kg drums. Provided that care is taken in the manufacture of the product, and that air is excluded by packing the product under inert gas (nitrogen), AMF will keep for 6 – 12 months even at elevated ambient temperatures of 30 – 40 °C.

Milk fat packed in cans can be melted by immersion in hot water at 80°C for 2 – 3 hours. Drums of AMF, however, require longer melting times. The normal method is to store the drums in a hot room at 45 – 50 °C for 24 – 28 hours before use, or to use a steam chest or tunnel which can melt the contents of the drums in about 2 hours. Once melted, the AMF should be transferred to a jacketed holding tank with facilities for maintaining the temperature.

Similar handling systems can also be employed when non-liquid vegetable oils are used in production of recombined “filled“ milk products.

Water

Water is one of the raw materials of all types of reconstituted and recombined milk products. It must be of good drinking quality, free from

harmful micro-organisms and of acceptably low hardness, expressed as calcium carbonate ($CaCO_3$), *i.e.* <100 mg/l, corresponding to about 5°dH. As only "distilled" water is removed in the production of milk powder, the water used for reconstitution or recombination must also be pure; an excessive mineral content will jeopardise the salt balance of the reconstituted or recombined product, which in turn will cause problems in pasteurisation, not to mention sterilisation or UHT treatment.

Too much copper or iron in the water may cause off-flavours, due to oxidation of fat. The maximum levels recommended are therefore:

- Cu (copper), mg/l 0,05
- Fe (iron), mg/l 0,1

See also Chapter 6.11, Table 6.11.1 regarding specifications for water.

Additives

Dry additives such as sugar, stabilisers and emulsifiers can be handled in the same way as the milk powder, *i.e.* they are dumped from the bags either directly into the mixing vessel or into the mixing system.

Recombination of milk products

Temperature and hydration time

The solubility of the powder increases when the water temperature increases from 10 to 50 °C. There is no increase between 50 and 100 °C, possibly the opposite. Low-heat powder is easier to dissolve than high-heat powder. It is important that the proteins obtain their normal state of hydration, which takes less than 20 minutes at 40 – 50 °C.

As a rule fresh, high-quality powder requires the shortest hydration time. Insufficient hydration time may lead to a "chalky" defect in the final product. Recombined milk for cheese manufacture should be given two hours' hydration time.

It is possible to reconstitute at 10 °C and then store the milk at this temperature overnight to obtain maximum hydration. However, more powder particles remain undissolved at a mixing temperature of 10 – 20 °C compared to 35 – 45 °C, even if the mix is kept for 24 hours. In milk with 8 % dry solids, the difference is very small. The proportion of undissolved powder in milk that is heated to at least 40 °C after reconstitution is very small, even in a mix with 26 % dry solids.

The air content of reconstituted milk increases at lower mixing temperatures.

The fat must be added at a temperature above its melting point. To assure this, AMF must be added at above 40 °C. The recombined milk should not be kept at this high mixing temperature for more than two hours because of bacterial growth.

The air content of reconstituted milk increases at lower mixing temperatures.

Fat addition and emulsification

Incorporation of fat into recombined products has always been a relatively difficult operation. The fat has to be properly dispersed and emulsified, and this places certain requirements on the processing equipment and process parameters.

Traditionally, the melted fat is metered into the line during continuous operation, followed by thorough mixing in a static or mechanically operated mixer before entering a homogeniser.

In modern systems using high-shear mixing devices, fat can be dosed directly into the mixing vessel of the unit. The dispersion of fat is sufficient to create a stable emulsion, which allows eliminating homogenisation at this stage of the process. Later on, the recombined products will be finally homogenised during pasteurisation or UHT processing.

In small scale batch production, fat is sometimes added to the milk in a

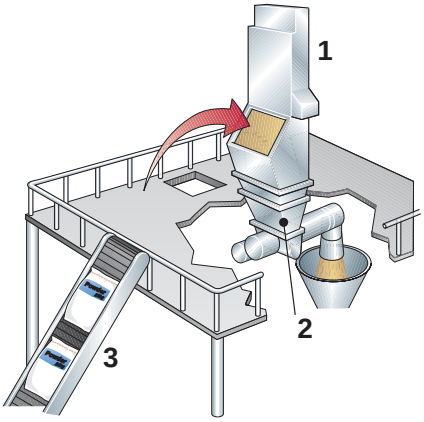


Fig. 18.1 *Equipment for handling powder in sacks.*
1 *Dust collecting unit*
2 *Sifter*
3 *Sack elevator*

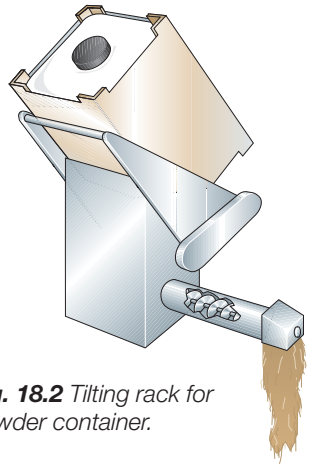


Fig. 18.2 *Tilting rack for powder container.*

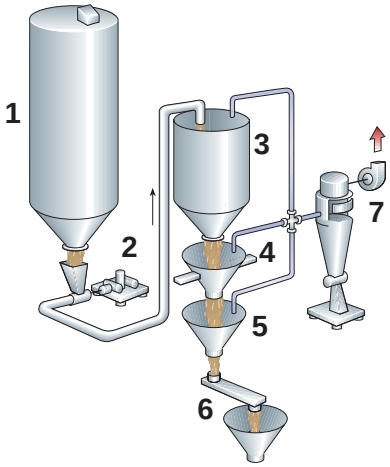


Fig. 18.3 *Equipment for bulk powder handling in large plants.*
1 *Silo for powder*
2 *Blower*
3 *Day bin*
4 *Weighing hopper*
5 *Hopper*
6 *Screw feeder*
7 *Dust filter*

mixing tank. To ensure that the composition of the product is uniform when it is pumped to downstream processing, the milk has to be thoroughly agitated, often with a high-shear agitator. Even when a homogeniser is integrated into the system, it is important that the fat in the feed is uniformly distributed.

An emulsifier is sometimes added to facilitate and improve the emulsification of milk fat.

Recombined cream can be made from skim milk powder or buttermilk powder and anhydrous milk fat to a fat content of about 40 %. The stability is improved by addition of emulsifiers and stabilisers.

Air content

Skim milk powder normally contains a total of about 40 % air by volume, consisting of occluded and interstitial air. The mixing equipment may also cause air addition if not properly maintained.

Tests indicate that the air content in reconstituted skim milk, dissolved at 50 °C and with 14 to 18 % dry solids, is the same as in normal skim milk. At a mixing temperature of 30 °C, the air content is 50 – 60 % higher even after a holding time of one hour. With 41 % dry solids, the air content of the mix was 10 times higher than in normal skim milk.

Too much air in the recombined milk has the following disadvantages:

- Foaming
- Burning-on in the pasteuriser
- Cavitation in the homogeniser
- Whey formation in cultured-milk products
- Increased risk of oxidation of fat

As recombination is accompanied by foaming, the volume of the mixing tank(s) should be about 20 % larger than the volume of the batch, to avoid foam forcing its way out of the manhole.

Some mixing equipment make it possible to recombine products under vacuum. By constantly extracting air from the mixing vessel, a certain vacuum is maintained, which reduces foaming to a minimum.

Powder handling

Proportioning of skim milk powder is based on the simple rule that the weight of the powder is one tenth of the weight of milk produced. For small plants, manual emptying of a calculated number of sacks of a given weight into the mixing tank is the easiest and most practical solution, but production can be mechanised for higher capacities.

Milk powder handling creates a lot of dust. Large-scale sack-emptying therefore requires special equipment, including a dust collecting unit, as seen in Figure 18.1.

Powder can also be supplied in containers. In this case, suitable equipment comprises a variable-speed screw feeder, which takes powder from the bottom of the container and discharges it into the mixer. The container can be lifted into position by a tilting rack, (Figure 18.2), or by a hoist.

In highly mechanised plants, the powder is supplied in bulk. It is stored in bulk silos and transferred pneumatically to a day bin, from which it is batched into the process via a weighing hopper and a screw feeder. The system in Figure 18.3 also includes a unit for central dust collection.

When a vacuum mixing system is used, the powders are sucked into the mixing vessel from specially designed powder silo tanks. It is also possible to prepare mixtures of different dry ingredients in these silos before dissolving takes place.

Design of recombination plants

Recombination plants are built for capacities of up to 20 000 l/h. In larger plants, parallel lines are installed to meet higher capacity requirements.

The sequence in a large plant is essentially the same as in a small one,

except that it requires more tanks for storage and melting of fat, mixing, and buffer storage of the finished product. The degree of mechanisation may also differ as described above.

In large plants, it is necessary to use weighing tanks for fat dosage, in order to achieve the necessary accuracy. In a smaller plant, the weighing tank can often be replaced by a proportioning pump.

Deaeration

In small plants, where mixing of material in a processing tank is just enough, the product will be naturally and satisfactorily deaerated if a reconstitution temperature of approx. 40 °C has been maintained and, when all powder has been dissolved, the resultant solution is allowed to stand for 20 minutes with the agitator switched off.

The same procedure should also be applied in large-scale production. To maintain uninterrupted production, however, it is advisable to deaerate the product by vacuum treatment in connection with heat treatment.

Heat treatment

The design of the plant is influenced not only by its capacity, but also by the method of heat treatment of the recombined milk. Three alternative methods are used:

- Pasteurisation at a temperature of at least 72 °C for 15 seconds followed immediately by cooling to 4 °C.
- In-container sterilisation of milk for 30 to 45 minutes at around 110 °C followed by cooling to 38 to 54 °C in the steriliser.
- UHT treatment by direct or indirect heating to 132 – 149 °C for a few seconds, followed by cooling to approximately 20 °C prior to aseptic packing.

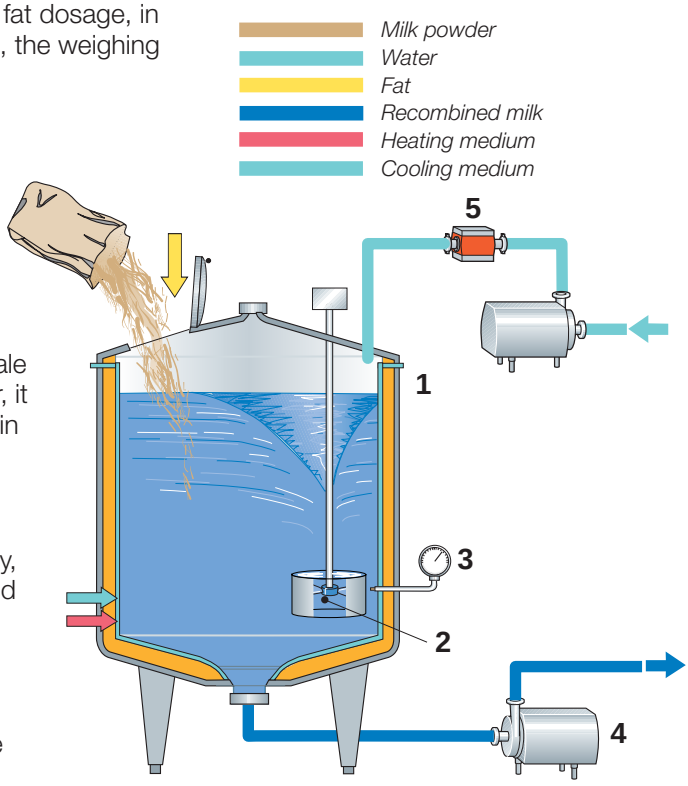


Fig.18.4 *Recombination plant for batch processing.*
1 *Mixing tank with heating/cooling jacket*
2 *High-shear two-speed agitator*
3 *Thermometer*
4 *Emptying pump*
5 *Flow meter*

Small-scale production

In small-scale production, 1 000 – 2 000 l, batch processing is most common. Mixing and processing are carried out in a jacketed mixing tank with a two-speed shearing agitator and with heating and cooling facilities. The plant is shown in Figure 18.4.

After a suitable volume of water has been measured into the tank and heated to 43 – 49 °C, powder is added steadily and agitation applied until all the powder has dissolved. The resulting solution should be allowed to stand for 20 minutes with the agitator switched off. At the end of this time, the agitator is restarted and the temperature is raised to 54 – 65 °C, before milk fat is added. This has previously been liquefied by being held in a warm room at 38 – 45 °C. If processing is to be continued in the tank, the agitator is switched to high speed for several minutes to disperse the fat. The agitator is then switched to the stirring position, and the process concludes with pasteurisation and homogenisation followed by cooling to packing temperature.

Large-scale production

Figure 18.5 shows a large recombination plant for continuous operation, where the fat is dosed into the vessel of the mixer.

Water of food quality is metered into one of the mixing tanks (5). On the way, it is heated in a plate heat exchanger, as the skim milk powder dissolves more easily in warm water than in cold.

The circulation pump (4) is started when the tank is half full and water flows through a bypass line from the mixing tank to a high-shear mixer (3).

In the high-shear mixing unit shown in Figure 18.6, the dry ingredients and fat are added to a mixing vessel filled with water at a rate determined by the size of the selected module. Anhydrous milk fat is added from the fat storage tank (1).

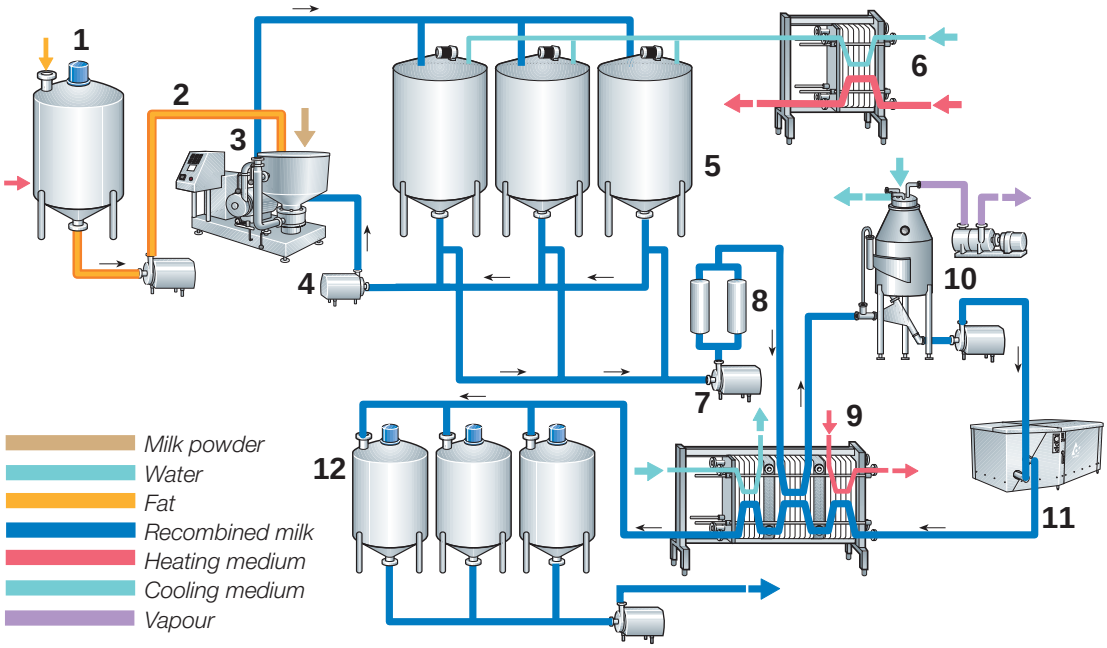


Fig.18.5 *Recombination plant with fat supply to mixing vessel.*

1	*Tank for fat*	**5**	*Mixing tanks*	**9**	*Plate heat exchanger*
2	*Insulated pipe for fat*	**6**	*Water heater*	**10**	*Vacuum deaerator*
3	*Mixer with high-shear mixing unit*	**7**	*Discharge pump*	**11**	*Homogeniser*
4	*Circulation pump*	**8**	*Filters*	**12**	*Storage tanks*

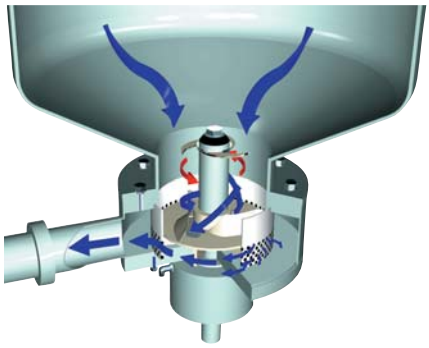


Fig. 18.6 *High-shear mixer with mixing unit positioned underneath a waterfilled vessel.*

The heart of the mixing system is the mixing head (Figure 18.6), which is located at the bottom of the mixing vessel. It consists of a rotor and perforated stator, and is designed for three functions; mixing, pumping and dispersing. The ingredients and the liquid are sucked down into the mixing unit by a pump wheel and pressed out through the holes in the perforated ring by impeller wings underneath the pump wheel. When passing the perforated stator, high shear forces will effectively dissolve and disperse the added ingredients. As the outlet of the mixer is positioned after the mixing unit, all added ingredients have to pass through the mixing unit at least once.

The agitator in the mixing tank (5) is started at the same time as the circulation pump (4). Water continues to flow into the tank while mixing is in progress until the specified quantity has been supplied.

When all the powder has been added, the agitator and the circulation loop are stopped and the contents of the tank are given a certain resting interval for hydration of the proteins. This will take about 20 minutes at a temperature of 35 – 45 °C. At the end of this period, the agitator is restarted.

When all the ingredients have been added to the first batch, the process is repeated in the next tank.

The skim milk/fat mixture is drawn from the full mixing tank by pump (7), which forwards the mixture through duplex filters (8) where any foreign objects such as pieces of string or sacking are trapped. After being pre-heated in the heat exchanger (9), the product is pumped to the homogeniser (11), where the dispersion of fat globules is completed.

During the powder-mixing operation, the product may pick up large volumes of air, which can cause burning-on in the pasteuriser as well as homogenisation problems. A vacuum deaerator vessel (10) can be installed in the line before the homogeniser to eliminate this. The product is pre-heated to 7 – 8 °C above homogenisation temperature before being flashed in the deaerator, where the vacuum is adjusted so that the outgoing product has the correct homogenisation temperature, typically 65°C.

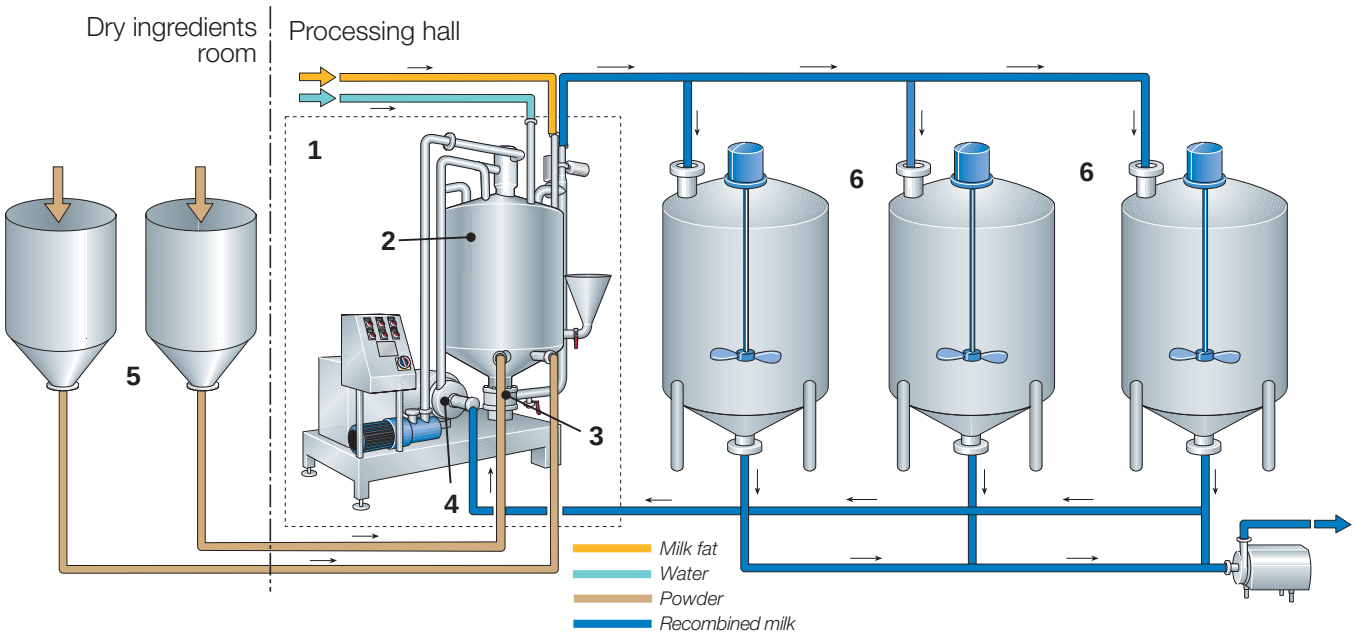


Fig. 18.7 *Recombination plant with vacuum mixing.*
1 *Vacuum mixer (within dotted line)*
2 *Vessel filled with water*
3 *Mixing unit*
4 *Circulation pump*
5 *Silo tanks for powder*
6 *Circulation tanks*

The homogenised milk is pasteurised and chilled in a plate heat exchanger (9) before being pumped to storage tanks (12) and further to packaging or to UHT treatment.

When the fat can not be added in the mixing step, the fat has to be added through an in-line injector just before homogenisation. All steps are the same as in Figure 18.5, except that the liquid fat is continuously metered into the flow by a positive displacement proportioning pump. A static mixer completes the blending downstream the injector and before entering the homogeniser.

Vacuum mixing

In some mixing equipment, mixing under vacuum is possible. In Figure 18.7 a recombination plant with a vacuum mixer is shown. Since vacuum is applied in the mixing vessel, very little air will be incorporated in the product during the mixing process, and foaming will also be minimised. When using vacuum during mixing, the ingredients are sucked into a vessel filled with water (2) at a point below the liquid surface. The wetting of the powders is thus improved and the risk of floating powder lumps on the surface is eliminated. Another benefit of vacuum mixing is that it facilitates automatic powder addition, as the powders are sucked directly from silo tanks (5) into the mixing vessel (2). This also makes it possible to organise the handling of the dry ingredients in a separate room, and to have the mixer and mixing plant in the processing hall.

Milk handling

It is necessary to consider the handling of the recombined milk in conjunction with the planning of the plant. This ensures that the product reaches the consumer in good condition.

Storage

Recombined milk normally flows direct from the production line to packing. A buffer tank may be needed to compensate for temporary stoppages in the production or packing lines. In the case of sterilised milk, this tank must be of aseptic design (Figure 18.8), to avoid the risk of reinfection.

Once sterile milk has been packed, it can be stored in any conditions provided that the packages are intact. Pasteurised milk must be kept in cold storage rooms. UHT-treated and sterilised milk are to be preferred in markets where the refrigeration chain is absent or incomplete.

Fig. 18.8 *An aseptic tank eliminates the risk of reinfection.*

Packing

The milk should be packed as soon as possible after production. UHT-treated milk must flow in a closed aseptic system to the aseptic carton- or can-filling machine.

Pasteurised milk can be packed in paper or plastic packs or glass bottles. If bottles are used, they should be of dark glass, which prevents the flavour of the milk from being spoiled by exposure to light.

The package must always be airtight to protect the milk from oxidation. It should also be strong enough for stacking in crates or boxes.

Distribution

UHT-treated and sterilised milk is much more tolerant of ambient temperature and other conditions than pasteurised milk. The time factor is not so important. UHT-treated milk can, for example, be transported on an ordinary lorry for long distances and exposed for sale in a shop with no refrigeration facilities where people come to buy perhaps once a week. Pasteurised milk, on the other hand, requires a refrigeration chain of insulated distribution vans, chilled counters in the shops, daily shopping and, preferably, home refrigerators.

Chapter 19

Ice cream

No one knows exactly when ice cream was first produced. Ancient manuscripts tell us that the Chinese liked a frozen product made by mixing fruit juices with snow – what we now call water ice. This technique later spread to ancient Greece and Rome, where the wealthy in particular were partial to frozen desserts.

After disappearing for several centuries, ice cream in various forms reappeared in Italy in the Middle Ages, most probably as a result of Marco Polo returning to Italy in 1295 after some 17 years in China, where he had acquired a liking for a frozen dessert based on milk. From Italy, ice cream spread through Europe during the 17th century, long remaining a luxury product for the royal courts. Industrial ice cream production began at the end of the 19th century when the first mechanical refrigerators were pioneered.

Categories of ice cream and related products

Ice cream and related products can be divided into a number of categories. As legislation varies from one country to another, the following should be regarded as a guideline only.

The fat content of ice cream typically determines the category to which it belongs. In some countries fat content has to exceed 9 % to ”qualify” for the ice cream category. Below this level, the product is typically called milk ice, whereas ice cream with more than 12 – 13 % fat is often categorised as either luxury or premium.

The fat can be either of animal or vegetable origin. If the latter, legislation in a number of countries dictates that the product cannot then be called ice cream, but must be labelled, for example, non-dairy ice cream. In Denmark the special term “ermol” has to be used.

Table 19.1
Typical ice cream formulas

Type of ice cream	Fat % wt	MSNF % wt	Sugar % wt	E/S % wt	Water % wt	Overrun % vol
Dessert ice	15	10	15	0,3	59,7	110
Ice cream	10	11	15	0,5	63,5	100
Milk ice	4	12	13	0,6	70,4	85
Sherbet	2	4	22	0,4	71,6	50
Water ice	0	0	22	0,2	77,8	0
Sorbet	0	0	22	0,5	77,5	30-50

Fat	Milk, cream, butter or vegetable fat
MSNF	Milk solids-non-fat (protein, lactose, salts)
Sugar	Sucrose (10 % of sugar may be glucose, dextrose or sweetener)
E/S	Emulsifier and stabiliser, *e.g.* monoglycerides, logust bean gum (LBG), goar gum
Overrun	Amount of air in product
Other ingredients	Flavours, colours, fruit, nuts and chocolate pieces may be added during processing

Categories of related products

Sorbet is the term used for a frozen, typically juice-based product with a certain amount of overrun. The mix passes through a continuous freezer where air is incorporated. Sorbet products are characterised by fresh eating properties and do not contain fat or milk solids-non-fat (MSNF).

In order to obtain a final product with more body, ice cream producers also produce *sherbet* that contains a small amount of fat or MSNF. Sherbet still retains the fresh eating properties associated with sorbet.

Yoghurt ice cream gained enormous popularity in the US during the 1980s due to its relatively low fat and calorie content. Weight and cholesterol watchers were delighted. Typically a blend of standard ice cream mix and yoghurt milk with live bacteria, yoghurt ice cream tends to have a fresher taste than standard ice cream

Water ice is a blend of sugar, fruit concentrates, stabilisers, flavour and colour. The finished mix is pasteurised and filled into moulds (or pockets) on a rotary or in-line machine. Freezing takes place in the pockets, which pass through cold brine (salt solution). When frozen solid, the water ice, is extracted from the pocket. It is a typical children’s product.

The development of extrusion technology has created a new category known as *extruded water ice*. Basically, a water ice containing a special stabiliser, is pumped to the continuous freezer, where air incorporation and freezing take place before extrusion. The final product typically contains 20 – 30 % air and is very fresh and cold to the taste.

Ice cream terminology

Depending on the filling method, ice cream products are termed one of the following:

Moulded

Ice cream or water ice mix is filled into moulds and frozen to produce stick novelties. After extraction, the products can be dipped in chocolate or other coatings.

Filled

Ice cream is filled into cups, containers or cones and may be decorated with chocolate, cream, ripple and dry materials.

Extruded

Ice cream is typically extruded onto a tray by means of a time-elapse filler. A wide variety of products can be produced including stick novelties, sandwiches, desserts, ball-top cones and so on. As extruded ice cream

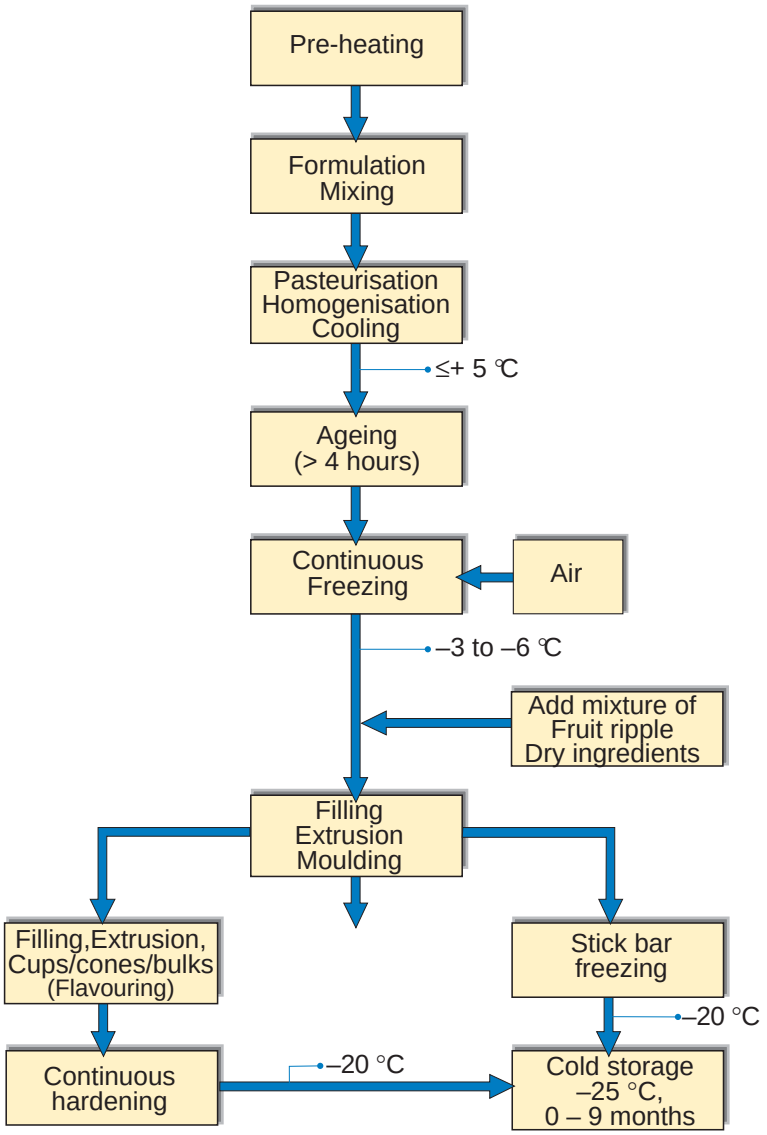


Fig. 19.1 *The ice cream process.*

can be more viscous (= stiffer and colder) than moulded or filled ice cream, the quality is generally higher. Extruded products have a creamier texture and more mouthfeel than moulded or filled products with a similar composition. Decoration and coating is possible.

Preparing the ice cream mix

The basic steps of the ice cream process are shown in Figure 19.1.

Reception and storage of raw materials

The manner in which raw materials and ingredients are received varies from one factory to another depending on its facilities and capacity.

Dry products are usually delivered in bags. Bulk materials such as sugar and milk powder can be delivered in containers and blown into storage silos using compressed air.

Liquid products are often delivered in tankers. Milk products are stored below 5 °C during storage, while sweetened condensed milk, glucose and vegetable fat must be heated to a relatively high temperature (30 – 50 °C) to keep the viscosity low enough for pumping. Milk fat is delivered in the form of anhydrous milk fat (AMF) or blocks of frozen butter, which are melted prior to use and pumped into storage tanks, where a temperature of 35 – 40 °C must be maintained.

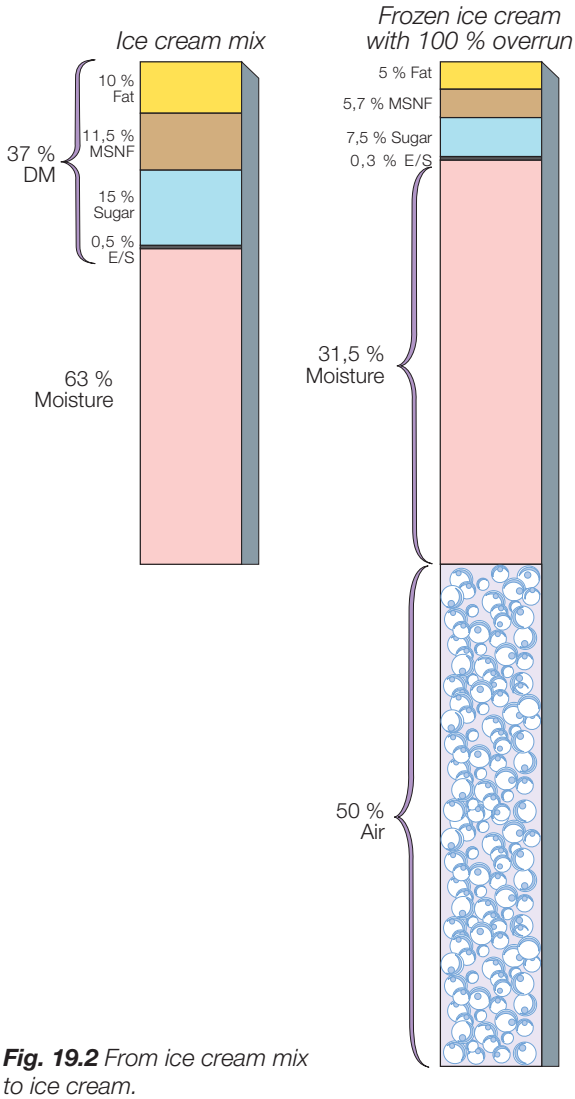


Fig. 19.2 *From ice cream mix to ice cream.*

Raw materials and ingredients

The ingredients used in ice cream production are:

- Fat
- Milk solids non fat (MSNF)
- Sugar/non-sugar sweetener
- Emulsifiers/stabilisers
- Flavours
- Colours
- Other ingredients

Fat

Fat makes up about 10 – 15 % of an ice cream mix and may be milk or vegetable fat. The fat gives creaminess and improves melting resistance by stabilising the air cell structure of the ice cream.

Milk fat is used in the form of whole milk, cream, butter or anhydrous milk fat (AMF). Where the milk fat is replaced by vegetable fat, hydrogenated (hardened) coconut oil and palm kernel oil are most commonly used. The use of vegetable fat in ice cream is regulated by legislation in many countries.

Milk solids-non-fat (MSNF)

MSNF consist of proteins, lactose and mineral salts derived from whole milk, skim milk, condensed milk, milk powders and/or whey powder. In addition to its high nutritional value, MSNF helps to stabilise the structure of ice cream due to its water-binding and emulsifying effect. The same effect also has a positive influence on air distribution in the ice cream during the freezing process, leading to improved body and creaminess.

In a well-balanced recipe, the quantity of MSNF should always be in proportion to the water content. The optimal level is 17 parts MSNF to 100 parts water:

$$\% \text{ MSNF} = \frac{17\,(100 - \text{other solids in percent})}{117}$$

The MSNF content is typically around 11% in an ice cream mix with a fat content of 10 – 12 %.

Sugar

Sugar is added to increase the solids content of the ice cream and give it the level of sweetness consumers prefer. Ice cream mix normally contains between 12 – 20 % sugar. Many factors influence the sweetening effect and product quality, and many different types of sugar can be used, such as cane and beet sugar, glucose, dextrose and invert sugar (a mixture of glucose and fructose).

The consistency of the ice cream can also be adjusted by selecting different types of sugar. This makes it possible to produce ice cream that is easy to scoop.

In the production of sugar-free ice cream, sweeteners are used to replace sugar. Aspartame, sorbitol and glycerol or manitol are the most commonly used sweeteners and are applied in conjunction with a bulking agent such as malto-dextrin.

Emulsifiers and stabilisers

Emulsifiers and stabilisers are typically used as combined products at dosages of 0,5 % in the ice cream mix. Traditionally, these products were produced by dry blending, but nowadays integrated products are preferred due to their high performance and improved storage stability.

Emulsifiers

Emulsifiers are substances that assist emulsification by reducing the surface tension of liquid products. They also help stabilise the emulsion during the homogenisation process by creating smaller, more uniform fat globules. Egg yolk is a well-known emulsifier, but is expensive and less effective than the most commonly used types. These are mainly non-ionic derivatives of natural fats, which have been esterified so they attract water molecules at one end and fat molecules at the other. The main components of the emulsifiers used in ice cream production are mono and diglycerides of fatty acids.

Stabilisers

A stabiliser is a substance that has the ability to bind water when dispersed in a liquid phase. This is called hydration and means the stabiliser forms a matrix that prevents the water molecules from moving freely. Generally speaking there are two types: protein in the form of gelatine, and carbohydrates, including seaweed colloids, hemi-cellulose and modified cellulose compounds. Stabilisers are used in ice cream production to increase the viscosity of the mix and create body and texture. They also control the growth of ice crystals and improve melting resistance.

Flavours

Flavours are a very important factor in the customer's choice of ice cream and can be added at the mixing stage or after pasteurisation. The most popular flavours are vanilla, chocolate and strawberry.

In the EU, flavours are classified in three groups: natural, nature-identical and artificial. Nature-identical flavours are the most commonly used.

The most common ice cream flavours are vanilla, nougat, chocolate, strawberry and nut.

Colours

Natural or artificial colours are added to the mix to give the ice cream an attractive appearance. Local legislation exists in most countries regarding the use of colours in food.

Other ingredients

Many moulded and extruded ice cream products are coated with chocolate. Generally speaking, two types of chocolate coatings are used: real chocolate and chocolate compound, the latter containing cocoa powder instead of cocoa mass and cocoa butter, and vegetable fat such as coconut or palm kernel oil.

Ripples (sauces) are incorporated in ice cream for taste and appearance. They can also be applied for pencil filling and top decoration.

Dry ingredients are added through an ingredient feeder. A great variety of products are used: chocolate, nuts, dried fruit pieces, candies, cookies, Smarties, caramel pieces, etc.

The mix composition and resulting ice cream are illustrated in Figure 19.2.

Mixing

The tank-stored raw materials are heated and blended to form a homogenous mix that is then pasteurised and homogenised. Large production plants often have two mix tanks with a volume corresponding to the hourly capacity of the pasteuriser, in order to maintain a continuous flow. The dry ingredients, especially the milk powder, are generally added via a mixing unit, through which water is circulated, creating an ejector effect that sucks the powder into the flow. Before returning to the tank, the mix is normally heated to 50 – 60 °C to facilitate dissolution. Liquid ingredients such as milk, cream, liquid sugar, etc. are measured into the mix tank.

Homogenisation and pasteurisation

In large-scale production the ice cream mix flows through a filter to a balance tank. From there it is pumped to a plate heat exchanger, where it is pre-heated to 73 – 75 °C. After homogenisation at 14 – 20 MPa (140 – 200 bar), the mix is returned to the plate heat exchanger and pasteurised at 83 – 85 °C for about 15 seconds. The pasteurised mix is then cooled to 5 °C and transferred to an ageing tank.

The purpose of pasteurisation is to destroy bacteria and dissolve additives and ingredients.

The homogenisation process results in uniformly small fat globules, and improves the whippability and texture of the ice cream mix.

Ageing

The mix must be aged for at least 4 hours at a temperature of 2 – 5 °C with continuous gentle agitation. Ageing allows the milk proteins and water to interact and the liquid fat to crystallise. This results in better air incorporation and improved melting resistance.

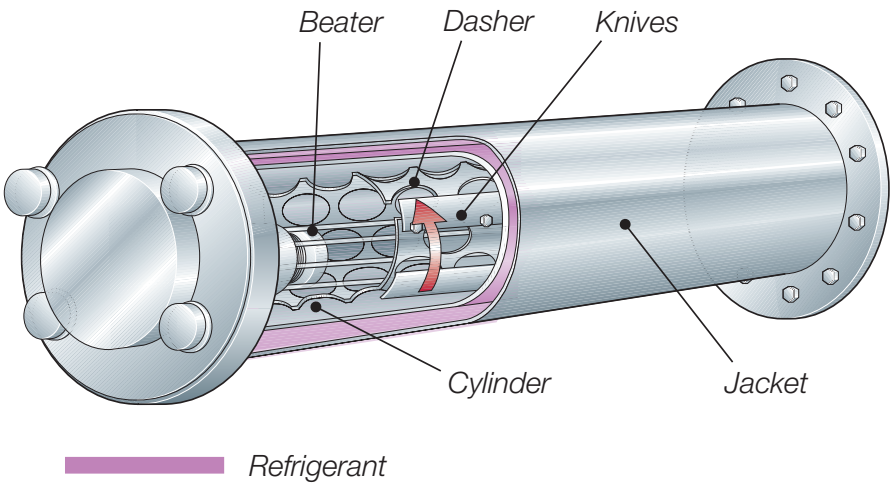


Fig. 19.3 *Principle of a continuous ice cream freezer.*

Ice cream processing and packaging

Continuous freezing and ingredient feeding

Continuous freezing

The continuous freezer, Figure 19.4, has two functions:

- To whip a controlled amount of air into the mix
- To freeze the water content in the mix in a large number of small ice crystals

The ice cream mix is metered into the freezing cylinder by a gear pump. At the same time, a constant airflow is fed into the cylinder and whipped into the mix by a dasher.

Figure 19.3 shows the interior of the freezer cylinder with the dasher and beater. The refrigerant surrounding the cylinder generates the freezing process. The layer of frozen mix on the inside cylinder wall is continuously scraped off by the rotating dasher knife, and a second gear pump drives the ice cream forward either to an ingredient feeder or a filling machine. The output temperature is –3 to –6 °C depending on the type of ice cream product.

The increase in volume following the incorporation of air in the mix is called overrun, and is normally 80 – 100 %, *i.e.* 0,8 to 1 litre of air per litre of mix. The ice cream leaving the continuous freezer has a texture similar to soft ice, and about 30 – 55 % of the water content is frozen.

Figure 19.4 shows the front of the freezer with, from bottom, mixing pump, cream pump and control panel.

Fig. 19.4 *Continuous ice cream freezer, automatically controlled.*

Ingredient feeding

The function of the ingredient feeder, Figure 19.5, is to add ingredients continuously and accurately to the ice cream. The pump is designed to ensure the ingredients are gently fed into the ice cream flow from the freezer. A wide range of ingredients can be accommodated by the feeder:

- Dry ingredients (*e.g.* nuts, cookies, chocolate)
- Soft ingredients (*e.g.* pieces of fruit, cookie dough, marzipan)
- Liquid ingredients (*e.g.* marmalade, jam, caramel)

The ingredient feeder is designed to handle all three kinds of ingredient. Dosing accuracy is controlled by the use of ingredient-weighing cells.

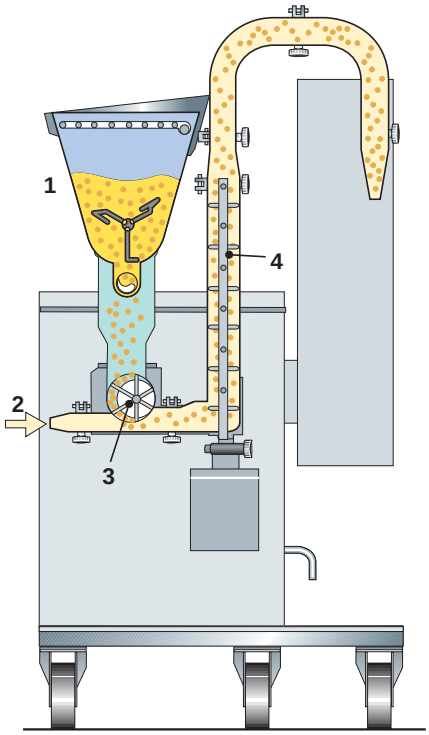


Fig. 19.5 *Ingredient feeder for granulated products.*
1 *Funnel for ingredient*
2 *Ice cream feed*
3 *Dosing wheel*
4 *In-line mixer*

Filling lines

A rotary or in-line filling machine fills ice cream, sorbet and water ice directly from the freezer into cups, cones and containers of varying design, shape and size.

Filling takes place by means of a time-elapse filler, a volumetric filler or an extrusion filler. In the case of extrusion filling, a cutting mechanism is provided.

Decoration with various ingredients is possible, including nuts, fruits, chocolate, jams or gum balls.

Lids are put on the packs before leaving the machine, after which they are passed through a hardening tunnel where final freezing to –20 °C takes place.

Before or after hardening, the products can be manually or automatically packed in cartons or bundles. Plastic tubes or cardboard cartons can be filled manually by means of a can-filling unit equipped to supply single or twin flavours.

Moulded stick novelty lines

Ice cream or water ice bars are made in special machines, also known as stick novelty freezers, where the ice cream or water ice is moulded in pockets. The ice cream is supplied directly from the continuous freezer at a temperature of approx. –3 °C. The filled moulds are conveyed through a brine solution with a temperature of –40 °C, which freezes the ice cream or water ice solution.

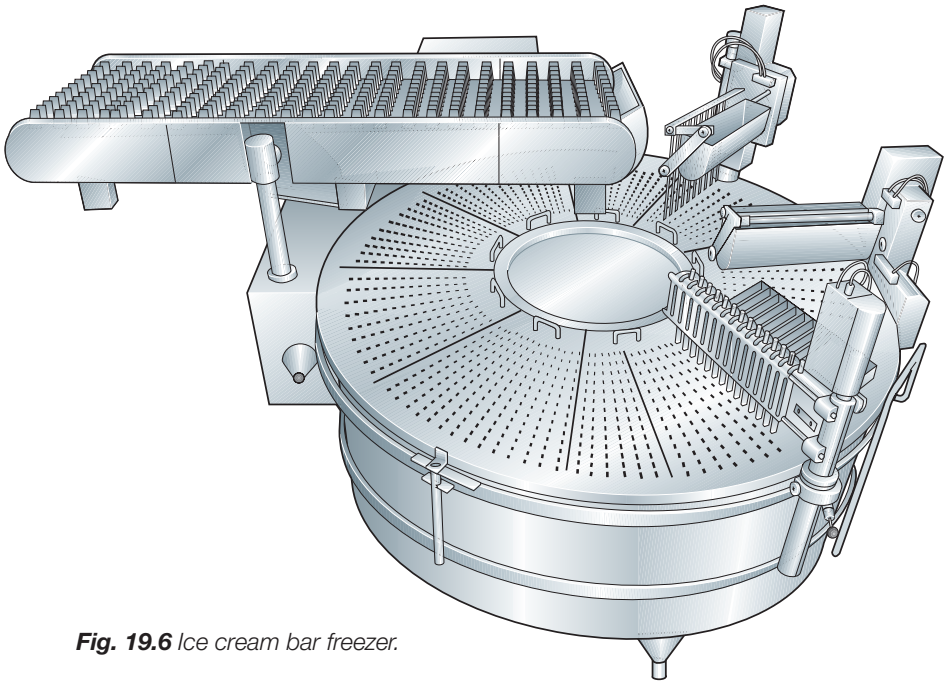


Fig. 19.6 *Ice cream bar freezer.*

Sticks are inserted before the moulds are completely frozen.

The frozen products are removed from the moulds by passing them through a warm brine solution which melts the surfaces of the products and enables them to be removed automatically by an extractor unit. After extraction the products may be dipped in chocolate and coated with nuts or other dry ingredients before being transferred to the wrapping machine. Since the products are fully frozen, they can be taken straight to the cold store after wrapping and cartoning.

A variety of shaped products can be produced on stick novelty freezers as well as products with one, two or three flavours and products with an ice cream core covered by a water ice shell.

Figure 19.6 shows a moulded stick novelty freezer for manufacturing ice cream and water ice bars. The cutaway view of an ice cream bar in Figure 19.7 shows the texture of the ice cream.

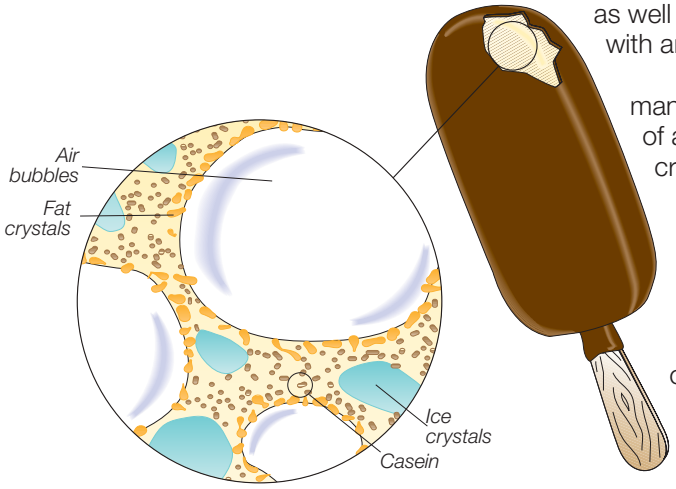


Fig. 19.7 *Texture of an ice cream bar.*

Extrusion lines – tray tunnel systems

Extruded premium stick products are among the most classic products on a tray tunnel system. Indeed, the combination of an extrusion temperature of –5 – –6 °C, hardening to approx –20 °C and enrobing in real chocolate has produced one of the most successful products of recent years.

Extruded stick products are only one of the product types which can be produced on a tray tunnel system. Using different filling and handling equipment, a wide range of products can be produced, such as sandwich products, ball-top cones, filled wafer cups, ice cream cakes, ice cream logs and bite-size products.

The basic tray tunnel process is illustrated in Figure 19.8.

Extruded ice cream products are normally produced on a tray tunnel extruder. The ice cream can be extruded directly onto trays in a variety of shapes and sizes, into a cup or cone or onto a sandwich wafer. An extrusion unit is shown in Figure 19.9.

After decoration, the products are carried on the trays through a hardening tunnel, illustrated in Figure 19.10, where they are frozen to –20 °C. The products are then removed from the trays ready for wrapping and packing in cartons, either manually or automatically. Such a system is continuous. Depending on the capacity of the extruder and product type, 5 000 – 33 000 units can be produced an hour.

Continuous Freezer	Freezing of ice cream to –5 – –6 °C
Worktable	Extrusion Filling Shaping/Embossing Adding of biscuit, decoration, dry stuff, jam, chewing balls, etc
Tray Tunnel	Hardening of ice cream to –20 – –25 °C
Handling	Enrobing by e.g compound, chocolate, juice
Wrapping	Flow rapping of products into sealed bags
Cartoning	Cartoning into boxes

Fig. 19.8 *Processing functions in an extrusiion and tray tunnel system.*

Wrapping and packaging

Cups, containers, etc. are either bundled or packed in cartons. Hand-held products like stick novelties, cones and bars are wrapped in a single or multi-lane wrapping machine before being packed in cartons. The design of the wrapping and packaging section of an ice cream processing line depends on the type of product and the capacity. Varying degrees of manual and automatic operation can be employed.

Hardening and cold storage

The manufacture of ice cream is not complete until it has been thoroughly hardened at a temperature of around –20 °C. For products made on an extrusion line or a stick novelty freezer, the hardening operation is included in the process. However, products packed immediately after freezing must be transferred to a hardening tunnel. The faster the hardening, the better the texture. After hardening, the products are transferred to the cold store, where they are stored on shelves or pallet racks at a temperature of –25 °C. The storage life of ice cream depends on the type of product, the packaging, and maintenance of a constant low temperature. The storage period ranges from 0 to 9 months.

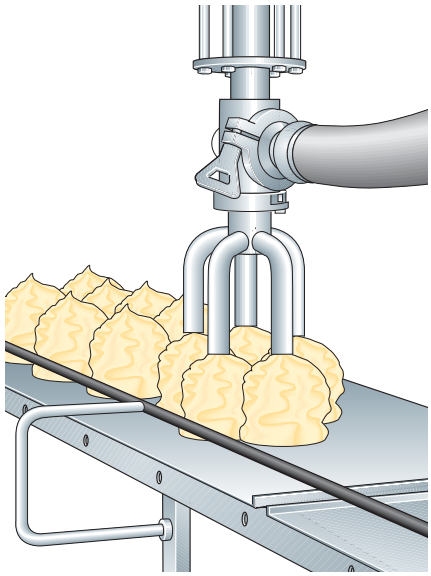


Fig. 19.9 *A tray tunnel extruder.*

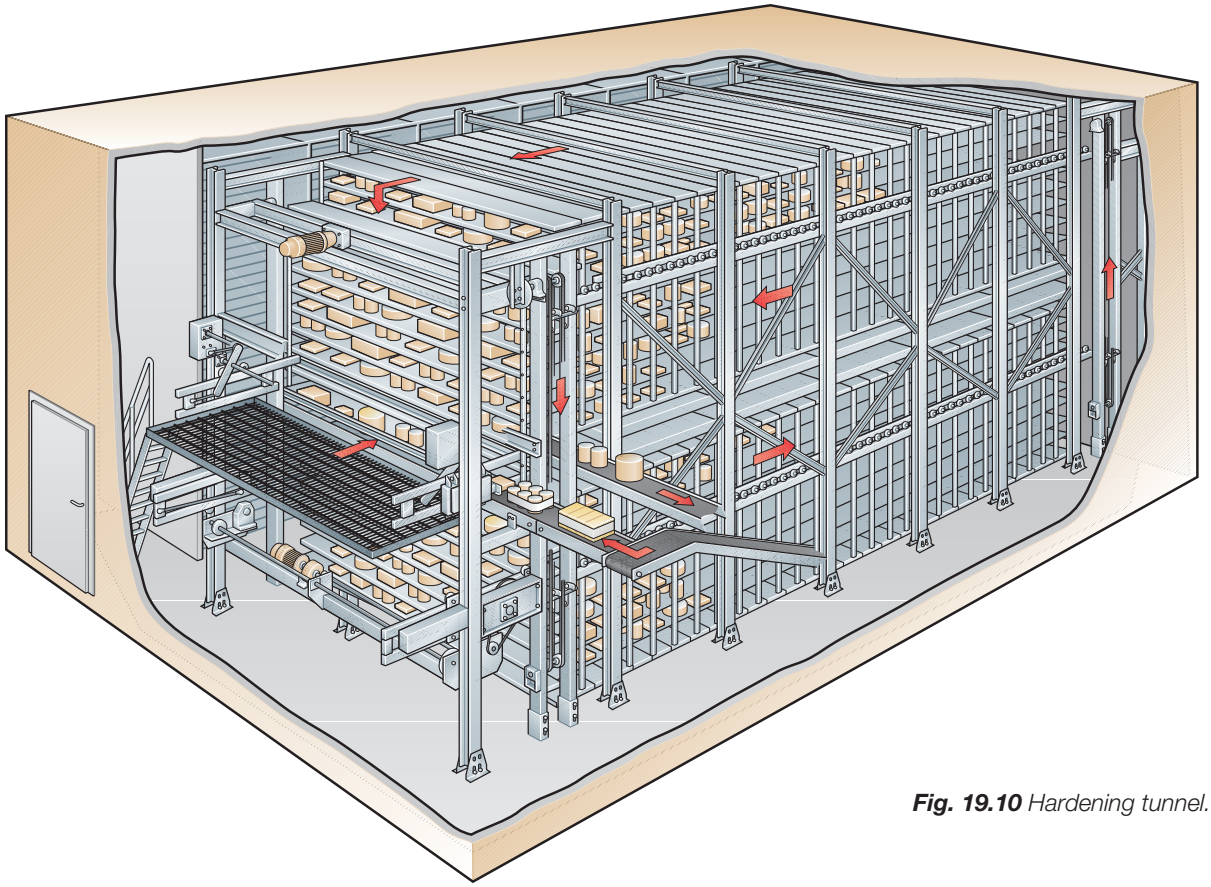


Fig. 19.10 *Hardening tunnel.*

Examples of production plants

The two plants illustrated give an idea of the product flow in ice cream production. One of the plants is relatively small with an hourly capacity of 500 litres of ice cream, Figure 19.11, while the other, Figure 19.12, is a large plant producing 5 000 – 10 000 litres of ice cream an hour.

In the small plant, the packaged and cartoned products are typically hardened in the cold store at a temperature of –35 to –40 °C. To shorten the hardening period as much as possible, the cartons must be openly spaced on pallets.

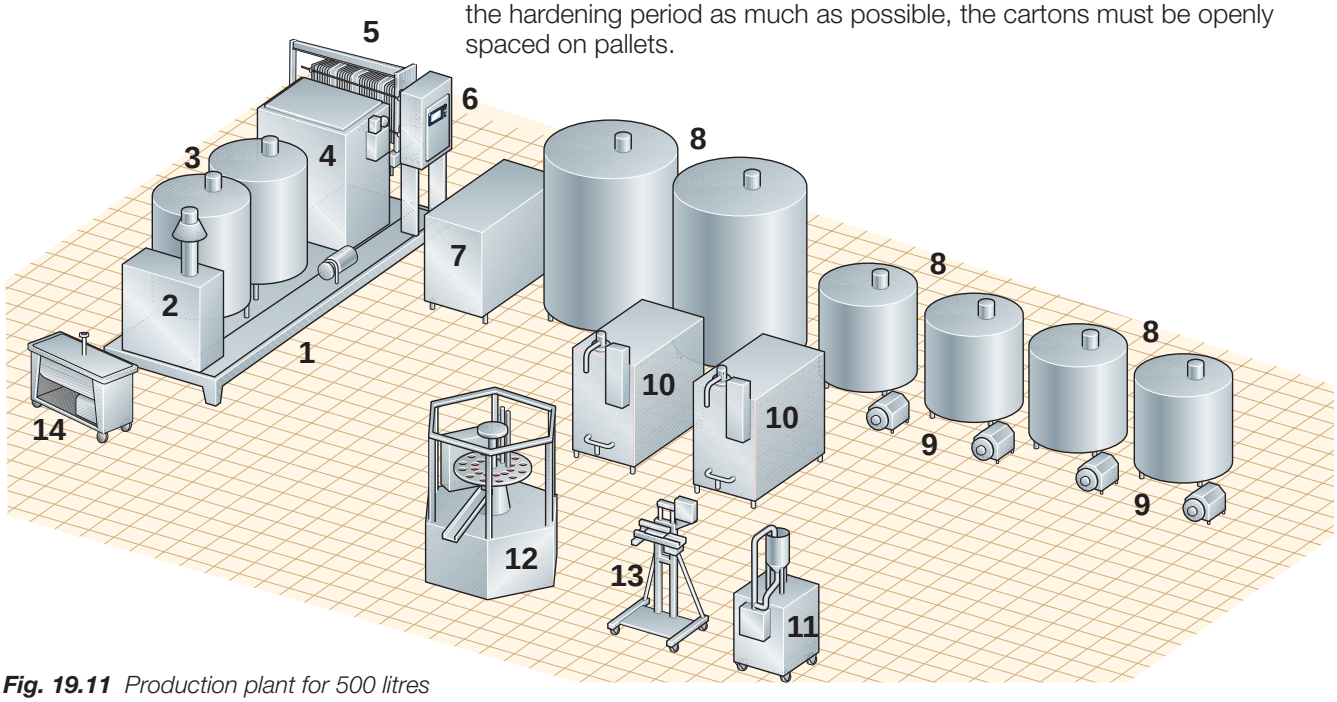


Fig. 19.11 *Production plant for 500 litres per hour of ice cream products.*

1 *Ice cream mix preparation module*
2 *Water heater*
3 *Mixing and processing tank*
4 *Homogeniser*
5 *Plate heat exchanger*
6 *Control panel*
7 *Cooling water unit*
8 *Ageing tanks*
9 *Discharge pumps*
10 *Continuous freezers*
11 *Ripple pump*
12 *Rotary filler*
13 *Can filler, manual*
14 *CIP unit*

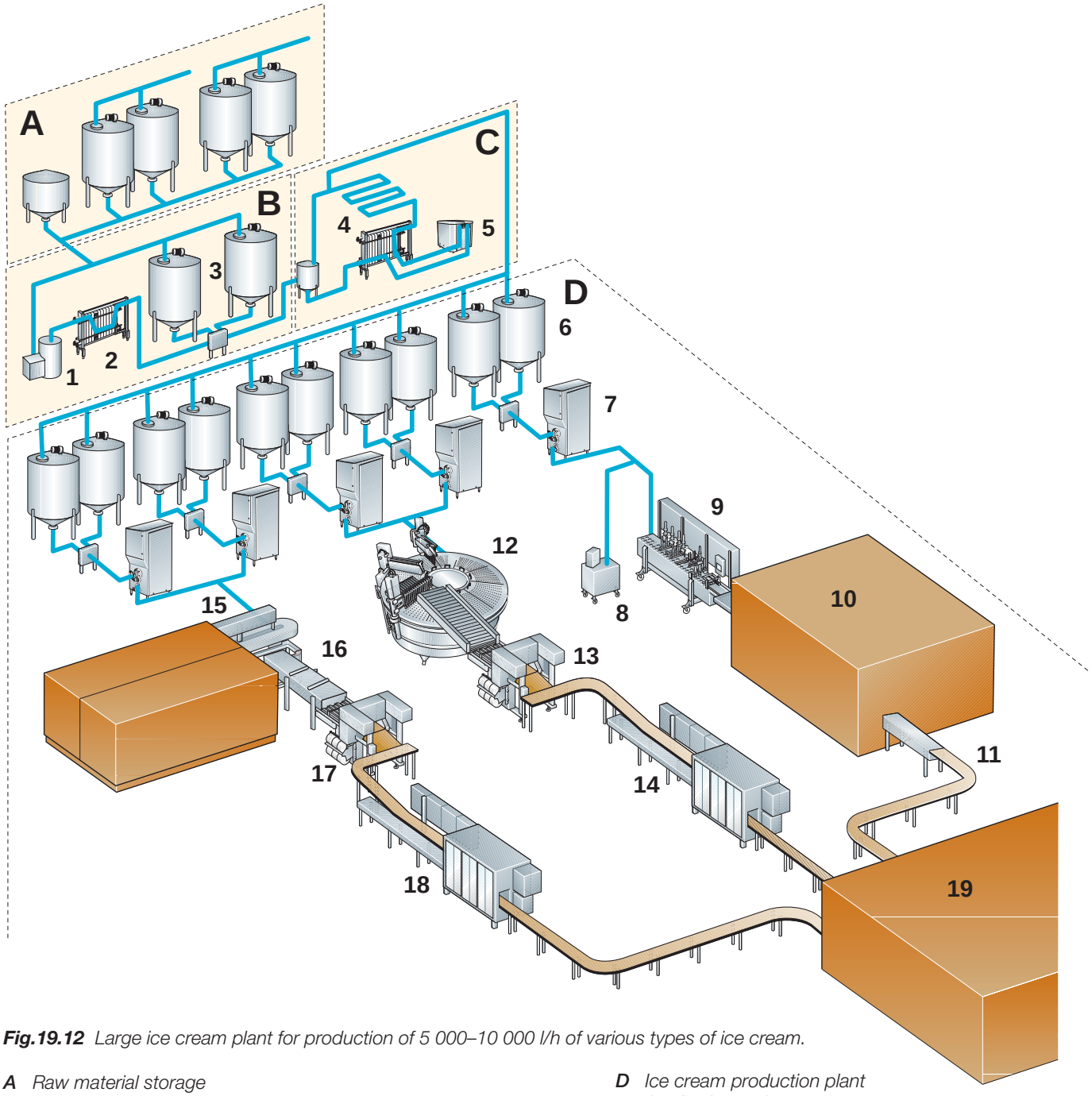


Fig.19.12 *Large ice cream plant for production of 5 000–10 000 l/h of various types of ice cream.*

A *Raw material storage*

B *Dissolving of ingredients and mixing*
- ***1*** *Mixing unit*
- ***2*** *Plate heat exchanger*
- ***3*** *Mixing tanks (at least two for continuous processing)*

C *Pasteurisation, homogenisation and fat standardisation of the mix*
- ***4*** *Plate heat exchanger*
- ***5*** *Homogeniser*

D *Ice cream production plant*
- ***6*** *Ageing tanks*
- ***7*** *Continuous freezers*
- ***8*** *Ingredient feeder*
- ***9*** *Cup/cone filler*
- ***10*** *Hardening tunnel*
- ***11*** *Cartoning line*
- ***12*** *Bar freezer*
- ***13*** *Wrapping unit*
- ***14*** *Cartoning unit*
- ***15*** *Tray tunnel extruder*
- ***16*** *Transfer and enrobing unit*
- ***17*** *Wrapping unit*
- ***18*** *Cartoning unit*
- ***19*** *Cold storage*

Chapter 20

Casein

Casein is the major protein in cows' milk, and comprises about 80 % of the total protein content of which the rest, some 20 %, are the whey or serum proteins.

Casein is the basic component of ordinary cheese. In the cheese-making process, casein is precipitated by the action of rennet enzymes, and a coagulum is formed consisting of casein, whey proteins, fat, lactose and the minerals of the milk.

Commercial casein is made from skim milk by one of two general methods – precipitation by acid or coagulation by rennet. As much of the fat, whey proteins, lactose and minerals as possible must be removed by multistage washing in water, as they reduce the quality of the casein as well as its

keeping quality. Dried, properly produced casein has a relatively good keeping quality and is used mainly in the food and chemical industries.

Types of casein

Casein is usually divided into the following types:

- Rennet casein, obtained by enzymatic precipitation
- Acid casein, obtained by acidifying skim milk to the isoelectric point (pH 4,6 – 4,7)

In addition to these two main types, there are other commercially available casein products of importance, such as:

- Co-precipitate, made by heating skim milk to a high temperature and then precipitating the casein/whey protein complex, usually with calcium chloride. The co-precipitate also contains whey proteins and calcium.
- Caseinates, commonly sodium caseinate, obtained from acid casein dissolved in sodium hydroxide

Influence of raw material

In order to produce high-quality casein, the raw material, skim milk, must be of good quality. If bacteria have had time to act on the protein in the milk as a result of a change in acidity, this will affect the colour and consistency of the casein, which will acquire a greyish colour and a smoother consistency. Excessive heating of the milk before precipitation will not only cause assorted interactions among the lactose, casein and whey protein constituents, but also give the casein a yellow or at worst a brownish colour.

In order to produce casein of good bacteriological quality, without high heat treatment of the skim milk, the pasteurisation plant may also contain a microfiltration (MF) plant. To satisfy the high demands on the quality of casein intended for use in the food industry, not only must the production line be carefully planned right from the reception of the milk, but the treatment and handling of the raw material prior to this stage must also be carefully controlled.

Rennet casein

Skim milk, normally pasteurised at 72 °C for 15 – 20 seconds, is used for the production of rennet casein, as well as other types of casein. Small amounts of fat are detrimental to the quality. It is therefore important that the milk has been separated efficiently.

Figure 20.1 shows the various stages of rennet casein production. Renneting takes place with the help of the enzyme chymosine in the rennet. The milk is heated for a short period of time and then cooled to about 30 °C. Then the rennet is added. A gel forms after 15 – 20 minutes. It is cut and the coagulum is stirred while being heated to about 60 °C. The high temperature is needed to deactivate the enzyme. Cooking time is around 30 minutes.

Batch washing

The whey is drained off when the final temperature has been reached, and the remaining casein, while in the vat, is washed with water to remove whey proteins, lactose and salt. Washing takes place in two or three stages at a temperature between 45 and 60 °C.

After the water has been drained off, the casein is further dewatered in sieves or separators. It is then dried with hot air until the water content is 12 %, and finally ground to a powder. The drying temperature depends on the method used. In a two-stage drying process, the temperature is 50 – 55 °C in the first stage and about 65 °C in the second.

Rennet casein should be white or slightly yellow. A darker colour is a sign of inferior quality and may be caused by too high a lactose content.

Continuous washing

Rennet casein was originally produced in batches in special casein tanks, but nowadays continuous processes are also used. In a continuous plant, drainage of whey takes place before the casein passes through two or three washing tanks with agitators. Dewheying is normally done in a decanter centrifuge to reduce consumption of wash water. The casein is dewatered between washing stages, either on *inclined static strainers* or in *decanters*. After leaving the washing stages, the water/casein mixture goes through another decanter to discharge as much water as possible before final drying.

In large scale production, coagulation of the casein is still done batchwise with a calculated number of casein vats emptied in sequence to feed the continuous de-wheying and washing plant.

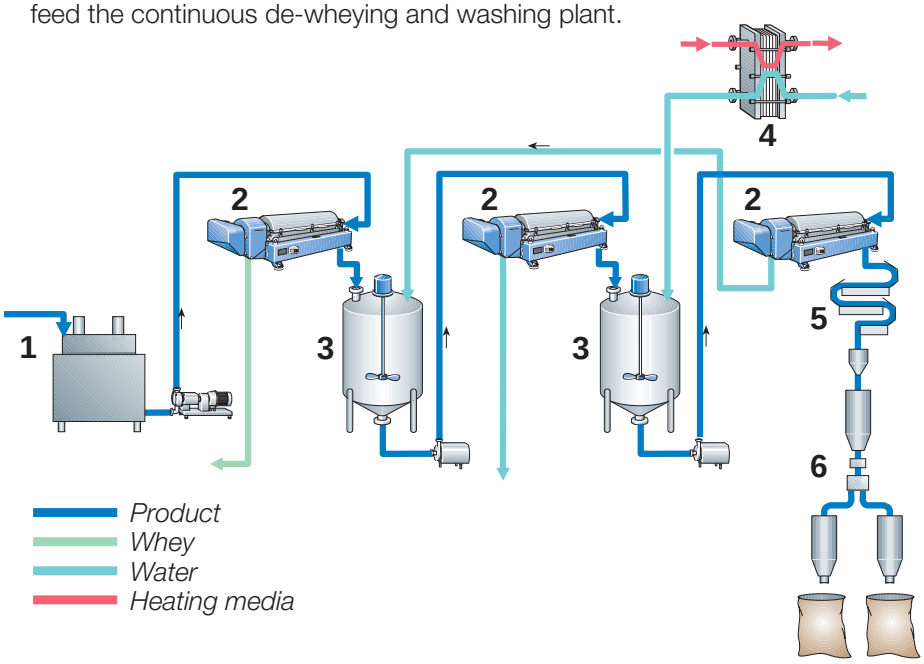


Fig. 20.1 *Process line with counter-current washing of rennet casein.*

1 *Vat for casein production*
2 *Decanter*
3 *Washing tank*
4 *Heater*
5 *Drying*
6 *Milling, sieving and bagging*

Washing takes place in countercurrent, which uses water more economically than concurrent washing. The latter system uses one litre of water per litre of skim milk, whereas only about 0,3 – 0,4 litre of water per litre of skim milk is needed in countercurrent washing. The number of washing stages is dependent on the requirements on the product. Two stages are the minimum. Fresh water is supplied in the last stage only. After washing, the casein is dewatered in a decanter to a DM content of 45 – 40 %. After drying, for example in a vibration dryer, the casein is ground to a particle size corresponding to 40, 60, or 80 mesh and packed in sacks. (Mesh = number of screen lines per inch; 40 mesh thus corresponds to 0,64 mm.)

Acid casein

The milk is acidified to the isoelectric point of casein, which is thought to be pH 4,6, but it is shifted by the presence of neutral salts in solution and may be anywhere within a range extending from pH 4,0 to pH 4,8. The isoelectric point is the stage where the hydronium ion concentration neutralises the negatively charged casein micelles, resulting in precipitation (coagulation) of the casein complex. Such acidification can be carried out biologically or by addition of a mineral acid, *e.g.* hydrochloric acid (HCl) or sulphuric acid (H_2SO_4).

Biological acidification – lactic acid casein

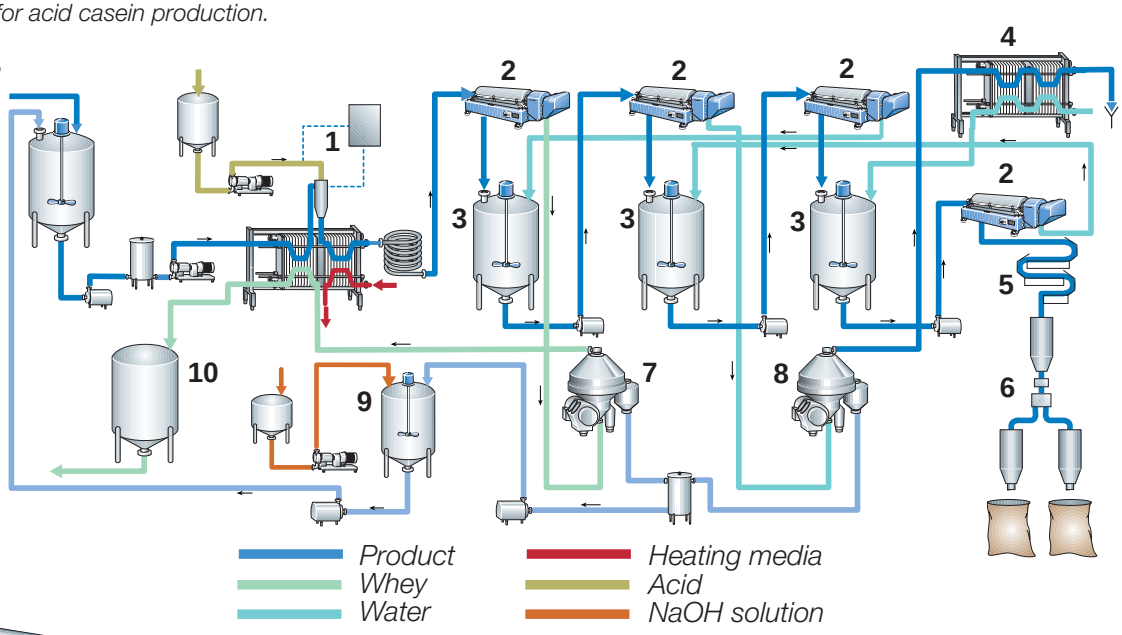
Lactic acid casein is produced by microbiological acidulation. The milk is pasteurised and cooled to 27 – 23 °C. A mesophilic, non-gas-producing starter is then added. Acidulation to the required pH takes about 15 hours.

Fig. 20.2 *Process line for acid casein production.*

1 pH control
2 Decanter centrifuge
3 Washing tank
4 Heat exchanger
5 Drying
6 Milling, sieving and bagging

Optional:

7 Fines recovery from whey
8 Fines recovery from wash water
9 Fines dissolving
10 Whey storage



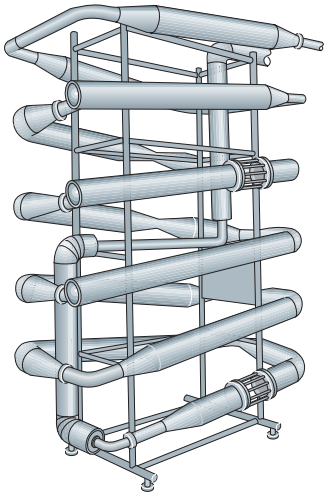


Fig. 20.3 *Continuous coagulation, cooking, and syneresis unit for lactic acid, acid and rennet caseins (Pillet).*

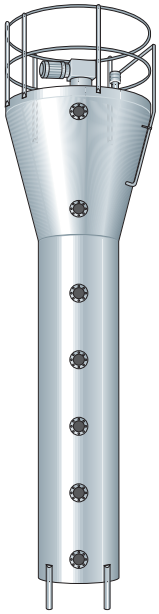


Fig. 20.4 *Curd washing tower for lactic acid, acid and rennet caseins (Pillet).*

If the acidulation process is too rapid, it can result in problems such as uneven quality and reduced casein yield. Large tanks are usually used. This means that it can take such a long time to empty the tank that the degree of acidity may vary.

When the required acidity has been reached, the milk is stirred and heated to 50 – 55 °C in a plate heat exchanger. After a short hold, the continued treatment – washing and drying – is practically the same as for rennet casein.

Mineral acidification – acid casein

The milk is heated to the required temperature, approx. 32 °C. Mineral acid is then added to bring the pH of the milk to 4,3 – 4,6. Following the pH check, the milk is heated to 40 – 45 °C in a plate heat exchanger and held for about two minutes, when smooth aggregates of casein are formed. To remove as much as possible of the whey before washing starts, the whey/casein mixture is passed through a decanter. In this way, less water is needed for washing.

Figure 20.2 shows a flow chart for a process line for the manufacture of acid casein. As can be seen, the plant downstream of acidification is almost identical to the one used for production of rennet casein.

Before leaving the plant, the whey and wash water can be separated and the casein sludge is collected in a tank. When mixed with a lye solution, the casein dissolves and is then remixed with the skim milk intended for casein production.

After dewatering, the acid casein is ground and packed in sacks.

The technique for production of acid casein developed by Pillet, France, should also be mentioned.

After pre-heating to 32 °C, the skim milk is acidified and introduced into a coagulation unit (Figure 20.3). Coagulation is completed after heating to about 45°C by direct steam injection. Dewheying in a decanter is followed by countercurrent washing in one or two specially designed washing towers (Figure 20.4).

Before being dried in a vibro-fluidised unit, the casein is dewatered in a decanter.

Co-precipitate

Co-precipitate contains practically all the protein fractions of milk.

Following the addition of small quantities of calcium chloride or acid to the skim milk, the mixture is heated to 85 – 95 °C and held at that temperature for a period of 1 – 20 minutes to allow interaction between the

caseins and the whey proteins. Precipitation of the proteins from the heated milk is then effected by controlled addition of either calcium chloride solution (to produce high-calcium co-precipitate) or diluted acid (to produce medium-calcium or low-calcium co-precipitate, depending upon the amount of acid added and the pH of the resulting whey). The curd is subsequently washed and either dried to produce granular, insoluble co-precipitates or dissolved in alkali as described for the methods for the manufacture of caseinates to produce soluble or “dispersible” co-precipitates.

Caseinate

Caseinate may be defined as a chemical compound of casein and light metals, *e.g.* monovalent sodium (Na^{+}) or divalent calcium (Ca^{++}).

Caseinates can be produced from freshly precipitated ("wet") acid casein curd or from dry acid casein by reaction with any of several diluted solutions of alkali as outlined in Figure 20.5.

Sodium caseinate

The most commonly used alkali in the production of sodium caseinate is sodium hydroxide (NaOH) solution, with a strength of 2,5 M or 10 %. The quantity of NaOH required is generally 1,7 – 2,2 % by weight of the casein solids in order to reach a final pH, generally about 6,7.

Other alkalis, such as sodium bicarbonate or sodium phosphates, may be used, but the amounts required and their cost are both greater than those of NaOH. They are therefore generally used only for specific purposes, such as in the manufacture of citrated caseinates.

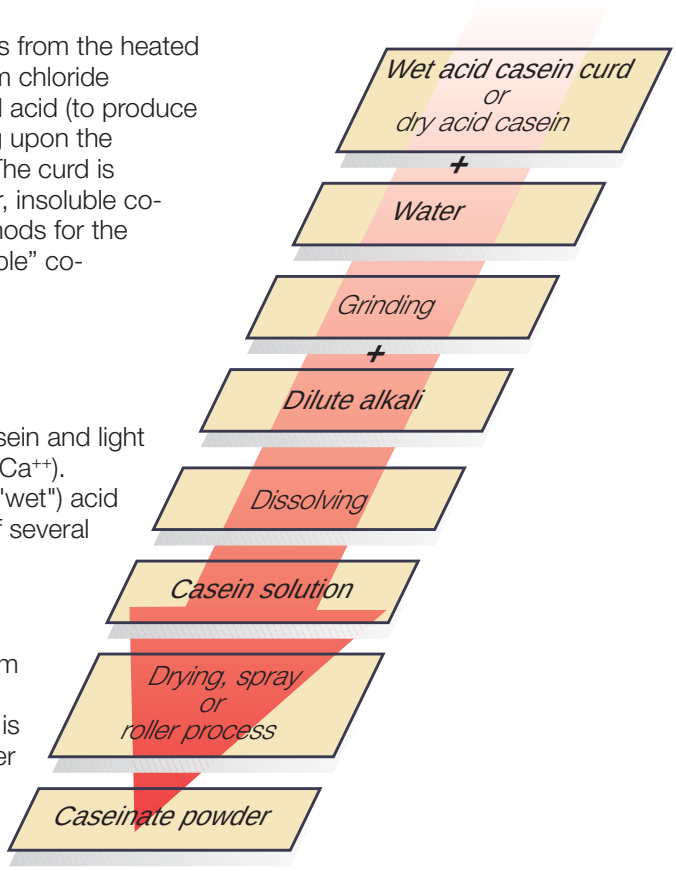


Fig. 20.5 *Basic steps involved in the manufacture of spray or roller dried caseinates from acid casein curd or dry acid casein. Alkali may be sodium hydroxide, potassium hydroxide, calcium hydroxide, or ammonia.*

The very high viscosity of sodium caseinate solutions of moderate concentration limits their solids content for spray drying to about 20 %.

Regarding the processing procedures, it should be mentioned that the dissolving time is directly related to the particle size and that particle size reduction prior to addition of sodium hydroxide rather than afterwards produces a more rapid reaction. Consequently, the curd is passed through a colloid mill prior to addition of alkali.

After the final casein wash, the curd may be dewatered to about 45 % solids and then remixed with water (to 25 – 30 % solids) before entering the colloid mill. The temperature of the emerging slurry should be below 45 °C, since it has been observed that milled curd can re-agglomerate at higher temperatures. Generally the slurry is collected in a jacketed tank provided with an effective agitator and also integrated in a circulation system with a high capacity pump.

The addition of diluted alkali must be carefully controlled with the aim of reaching a final pH of about 6,7. Preferably, the alkali is dosed into the recirculation line just upstream of the pump.

Once the alkali has been added to the slurry, it is important to raise the temperature as quickly as possible to 60 – 75 °C, to reduce the viscosity.

The dissolving time for sodium caseinate prepared in batches is usually 30 – 60 min.

For efficient atomisation, the sodium caseinate solution must have a constant viscosity when it is fed to the spray drier. It is common practice to minimise the viscosity by pre-heating the solution to 90 – 95 °C just prior to spray drying.

Calcium caseinate

The preparation of calcium caseinate follows the same general lines as for sodium caseinate, with a couple of important exceptions. Calcium caseinate solutions are liable to be destabilised by heating, especially at pH values below 6.

It has been found that during the dissolving process, the reaction

between acid casein curd and calcium hydroxide proceeds at a much slower rate than between curd and sodium hydroxide. To increase the rate of reaction between casein and calcium hydroxide, the casein may first be dissolved completely in ammonia. Calcium hydroxide in sucrose solution is then added, and the calcium caseinate solution is dried on rollers. Most of the ammonia evaporates during this process.

Other caseinates

Magnesium caseinate has been briefly mentioned in the literature.

Compounds of casein with aluminium have been prepared for medical use or for use as an emulsifier in meat products.

Heavy metal derivatives of casein which have been used principally for therapeutic purposes include those containing silver, mercury, iron, and bismuth. Iron and copper caseinates have also been prepared by ion exchange for use in infant and dietic products.

Extruded sodium caseinate

It is possible to produce sodium caseinate from casein in the presence of a limited amount of water by using extrusion techniques.

Some European companies dealing with extrusion cooking – Werner & Pfleiderer GmbH (Germany), Clextral (France) and a few others – report good results from production of sodium caseinate by extrusion cooking.

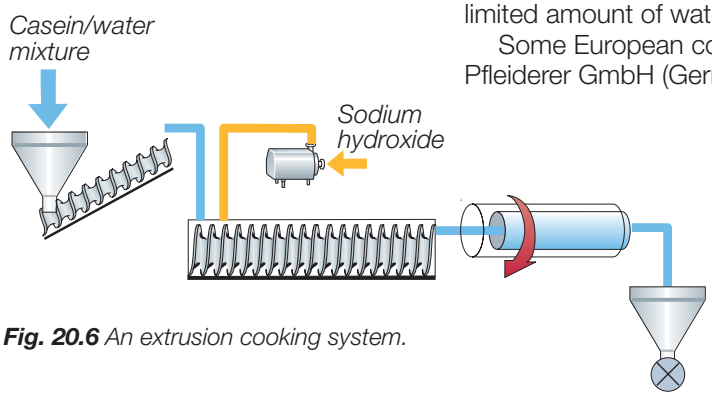


Fig. 20.6 *An extrusion cooking system.*

Most of the published information gives dry casein as the starting material. Water and alkali are added to form a mixture for extrusion. The casein/water mixture may have a moisture content of 10 – 30 %.

The extrusion technique used in production of caseinates is likely to become highly competitive with the traditional batch technique.

Furthermore, extrusion processing has also been tested in production of acid casein from skim milk powder. J Fichtali and F R van der Vort have run trials in a pilot plant at the MacDonald College of McGill University, Quebec, Canada. They summarise the results of their trials (1990) as follows:

"Our initial work on the production of an acid curd from SMP (skim milk powder) by extrusion processing indicated that significantly more effort had to go into developing the process to produce a quality product. The United States, Canada and the European Economic Community have at times experienced a chronic oversupply of milk, of which substantial amounts are converted into skim milk powder. By modifying the extrusion process conditions, studying high solids coagulation and optimising the coagulation and washing steps, acid casein of an acceptable quality can be produced by extrusion. This process is continuous, controllable, uses high solid SMP and may reduce labour and floor space requirements relative to conventional processes. This material can serve as a feed for further conversion by extrusion to sodium caseinate, which will be discussed in a succeeding paper."

Uses of caseins and caseinates

Rennet casein

Rennet casein is a product different from acid casein. In industry, it is used principally in the production of artificial substances in the plastics category. Casein polymerised with formalin is known as galalith, and synthetic fibres of casein are known as lanital. In spite of the large supply of various plastics which compete directly with galalith, there is still some demand for casein for galalith production. Small quantities of rennet casein are also used as a raw material for processed cheese. Rennet casein is insoluble in water.

Acid casein

Acid casein dominates the world markets. It is used in the chemical industry as an additive in paper manufacture for the glazing of paper of fine quality. For paper industry applications, it is particularly important that the casein is free from fat and contains no particles of foreign or burnt matter that might make spots on the paper. To obtain extremely low fat content in skim milk, it should be passed through a microfiltration plant (MF) in combination with pasteurisation. Each industry has its own strict quality specifications. The paint and cosmetic industries are also large users of casein.

Tabel 20.1

Typical composition of caseins, caseinates, and co-precipitates

	Standards for acid casein by grade	
Quality	**Extra grade**	**Standard grade**
Moisture (max), %	10	12
Fat (max), %	1,5	2
Free acid (max), ml	0,20	0,27
Ash (max), %	2,2	2,2
Protein content. dry basis, %	95	90
Plate (max), count/g	30 000	100 000
Coliform, count (max)/0,1 g	0	0

	Standards for rennet casein	
Quality	**Extra grade**	**Standard grade**
Moisture (max), %	12	13
Fat (max), %	1,0	1,5
Ash, %	7,5	7,0
Colour	A	C

	Typical composition of caseinates	
	Sodium caseinate	**Calcium caseinate**
Moisture, %	3,8	3,8
Protein (N x 6,38), %	91,4	91,2
Ash, %	3,6	3,8
Lactose, %	0,1	0,1
Fat, %	1,1	1,1
Sodium, %	1,2 – 1,4	< 0,1
Calcium, %	0,1	1,3 – 1,6
Iron, mg/kg	3 – 20	10 – 40
Copper, mg/kg	1 – 2	1,2
Lead, mg/kg	< 1	< 1
pH	6,5 – 6,9	6,8 – 7,0

Sodium caseinate

A casein application of growing importance is its use as a raw material for the manufacture of sodium caseinate. The casein is easily dissolved in a diluted alkali, and the liquid is then spray-dried to a powder. This powder is much more soluble than casein and is being increasingly used by the food industry. It is often used as an emulsifier in cured meats and is found in a number of new products, such as milk and cream substitutes.

As sodium caseinate is highly viscous when dissolved, the maximum obtainable concentration is 20 % at 55 – 60 °C.

Calcium caseinate

For certain applications, calcium caseinate may be chosen instead of sodium caseinate, one reason being the wish to reduce the sodium content of the product to a minimum.

The viscosity of calcium caseinate is somewhat lower than that of sodium caseinate at the same concentration.

Calcium co-precipitate

This product can also be dissolved in alkali and spray dried, and has much the same field of application as caseinate, but with the difference that in the production of calcium co-precipitate, it is possible to adapt the process for the purpose of regulating colour, solubility, and ash content in closer conformity to the users' requirements.

One of the most important advantages of casein and caseinate from a nutritional point of view is the relatively high content of the essential amino acid *lysine*. Moreover, tests have shown that the lysine keeps much longer, thanks to the absence of lactose in the environment. This suggests that milk proteins can be more conveniently stored in the form of casein and caseinate than, for example, as dried milk powder.

Casein produced for industrial use must satisfy long-established demands for chemical purity. The new trend shows that casein and precipitate are intermediate products which find their way into a host of food products and must therefore satisfy strict demands in respect of bacteriological as well as chemical purity.

Process lines must be so designed and constructed that they ensure hygienic manufacturing conditions. As casein is a seasonal product to a much greater extent than many other dairy products, the possibility must be provided to run the production line in multiple shifts without an undue demand for manual labour. Water consumption must also be kept within reasonable limits.

Therefore, in these circumstances, it is of interest to be able to plan continuous production lines, *e.g.* incorporating centrifugal machines for dewatering the casein and recovery of casein losses from the whey and wash water.

Table 20.2

Approximate composition analysis of granular co-precipitates and casein[1]

	Lactic and sulphuric acid casein	Co-precipitate		
		High-calcium	Medium-calcium	Acid
Moisture, %	11,5	9,5	9,5	9,5
Fat, %	1,4	0,5	0,7	0,9
Ash, %	1,8	7,7	3,7	2,4
Protein:				
– Nx 6,38, %	85,0	81,7	85,6	86,7
– dry basis, %	96,0	90,3	94,5	95,8
Lactose, %	0,1	0,5	0,5	0,5
Calcium, %	< 0,1	2,81	1,13	0,54
pH	4,6 – 5,4	6,5 – 7,2	5,6 – 6,2	5,4 – 5,8
pH of whey after curd separation	4,3 – 4,6	5,8 – 5,9	5,1 – 5,3	4,9 – 5,1

[1] *Source: Southward & Aird, 1978*

References: A large part of the information concerning caseinates is drawn from a review made by C R Southward, NZDRI, and published in the N.Z.J. of D. Science and Technology, 20, 79 – 101 (1985).

Chapter 21

Cleaning of dairy equipment

Aspects of cleaning

The arrangements for cleaning equipment that comes in contact with products are an essential part of a food processing plant. It must be kept in mind that food manufacturers are always obliged to maintain high hygienic standards; this applies both to the equipment and, naturally, to the staff involved in production. This obligation can be considered under three headings:

1 Trade obligation
2 Moral obligation
3 Legal obligation

Trade obligations

Good, wholesome, clean products that keep well and are free from health hazards are obviously good for trade; customers will buy the same product again. However, if a product is contaminated, does not keep well or is the subject of complaints to the authorities, the reverse is true, and the resulting publicity is very damaging.

The potential effects of poor cleaning, poor standards and poor quality must be kept in mind at all times.

Moral obligation

Most of the customers who consume the products never see the factory or how the products are handled. They trust the company, rely on its reputation, and take it for granted that operations are carried out under the cleanest of conditions by well-trained staff who are continually aware and conscious of these factors

Legal obligation

The law attempts to protect the customer and purchaser in respect of health and quality. Failure to meet legal obligations, national or local, can result in very severe action, and prosecution proceedings can be very costly.

Prevention is better than cure, and companies are obliged to meet legal requirements and maintain high standards. Milk and milk products by their nature are ideal media for the growth of micro-organisms, including many pathogens. As a result of this, there is more legislation concerning milk – its production, handling, processing, packaging, storage and distribution – than any other food product. Each country has its own national and perhaps local legislation standards.

Cleaning objectives

Talking about cleaning results, the following terms are used to define the degree of cleanliness:

- Physical cleanliness – removal of all visible dirt from the surface
- Chemical cleanliness – removal not only of all visible dirt but also of microscopic residues which can be detected by taste or smell but are not visible to the naked eye
- Bacteriological cleanliness – attained by disinfection
- Sterile cleanliness – destruction of all micro-organisms

It is important to note that equipment can be bacteriologically clean without necessarily being physically or chemically clean. However, it is easier to achieve bacteriological cleanliness as a matter of routine if the surfaces in question are first rendered at least physically clean.

In dairy cleaning operations, the objective is nearly always to achieve both chemical and bacteriological cleanliness. The equipment surfaces are therefore first thoroughly cleaned with chemical detergents and then disinfected.

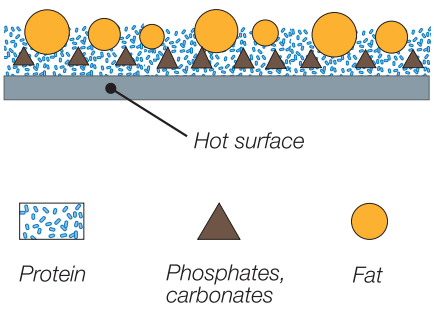


Fig. 21.1 *Deposits on a heated surface.*

Dirt

What kind of dirt is it that is present on the surfaces of dairy equipment and needs to be removed?

It consists of deposits stuck to a surface and its composition, in this particular case, is based on milk components which are utilised by bacteria 'hidden' in the dirt.

Heated surfaces

When milk is heated above 60 °C, *milk stone* starts to form. This is a deposit of calcium (and magnesium) phosphates, proteins, fat, etc. You can easily see the result on heat exchanger plates after a long production run, in the heating section and the first part of the regenerative section to follow. The deposits stick tight to the surfaces, and after runs of more than eight hours, a change of colour from whitish to brownish can also be observed. An attempt to visualise the dirt on a heated surface has been made in Figure 21.1.

Table 21.1
Chemical effects and soil characteristics

Component on surface	Solubility	Ease of removal	
		Low/medium pasteurisation	High pasteurisation/UHT
Sugar	In water	Easy	*Caramelisation* Difficult
Fat	Not in water	Difficult In alkali	*Polymerisation* Difficult
Protein	Not in water	Very difficult In alkali Slightly in acid	*Denaturation* Very difficult
Mineral salts	Varies in water Most salts in acid	Varies	Varies

It is important to note that equipment can be bacteriologically clean without necessarily being physically or chemically clean.

Cold surfaces

A film of milk adheres to the walls of pipelines, pumps, tanks, etc. ('cold' surfaces). When a system is emptied, cleaning should start as soon as possible, or otherwise this film will dry out and be harder to remove.

Cleaning procedures

Cleaning of dairy equipment was formerly done (and still is in some places) by people armed with brushes and detergent solutions, who had to dismantle equipment and enter tanks to get at the surfaces. This was not only laborious but also ineffective; products were often reinfected from imperfectly cleaned equipment.

Circulatory cleaning-in-place (CIP) systems adapted to the various parts of a processing plant have been developed to achieve good cleaning and sanitation results.

Cleaning operations must be performed strictly according to a carefully worked out procedure in order to attain the required degree of cleanliness . This means that the sequence must be exactly the same every time.

The cleaning cycle in a dairy comprises the following stages:

- Recovery of product residues by scraping, drainage and expulsion with water or compressed air
- Pre-rinsing with water to remove loose dirt
- Cleaning with detergent
- Rinsing with clean water
- Disinfection by heating or with chemical agents (optional); if this step is included, the cycle ends with a final rinse, if the water quality is good.

Each stage requires a certain length of time to achieve an acceptable result. In Table 21.1 some chemical effects and soil characteristics are listed.

Recovery of product residues

All product residues should be recovered from the production line at the end of the run. This is important for three reasons:

- Minimise product losses
- Facilitate cleaning
- Reduce the load on the sewage system, which often means a considerable saving in sewage treatment costs

Time must be allowed for the product to drain from tank walls and pipes. Surfaces coated with solid residues, *e.g.* in butter-printing machines, must be scraped clean. Before cleaning starts, the remaining milk is forced out of the production lines with water. Wherever possible, the milk in the piping systems is blown or flushed with water to collecting tanks.

Pre-rinsing with water

Pre-rinsing should always be carried out immediately after the production run. Otherwise, the milk residues will dry and stick to the surfaces, making them harder to clean. Milk fat residues are more easily flushed out if the pre-rinsing water is warm, but the temperature should not exceed 55 °C, to avoid coagulation of proteins.

Pre-rinsing must continue until the water leaving the system is clear, as any loose dirt left will increase detergent consumption and inactivate chlorine, if used, in the detergent. If there are dried milk residues on the surfaces, it may be an advantage to soak the equipment. Soaking softens the dirt and makes cleaning more efficient.

The mixture of water and milk from the initial pre-rinsing can be collected in a tank for special processing. At least 90% of the unencrusted residues, normally 99 % of the total residues, can be removed by efficient pre-rinsing.

As a rule of thumb, cleaning with alkaline detergent should be done at the same temperature as the product has been exposed to, but at least 70 °C.

Cleaning with detergent

The dirt on heated surfaces is normally washed off with alkaline and acid detergents, in that order or the reverse order, with intermediate water flushing, whereas cold surfaces are normally cleaned with alkalis and only occasionally with an acid solution.

To obtain good contact between the *alkaline* detergent solution – typically *caustic soda (NaOH)* – and the film of dirt, it is necessary to add a *wetting agent* (surfactant) which lowers the surface tension of the liquid. Teepol (alkyl aryl sulphonate), an anionic surfactant, is usually used.

The detergent must also be capable of *dispersing* dirt and *encapsulating* the suspended particles to prevent flocculation. Polyphosphates are effective emulsifying and dispersing agents which also soften water. The most commonly used are sodium triphosphate and complex phosphate compounds.

A number of variables must be carefully controlled to ensure satisfactory results with a given detergent solution. These are:

- Concentration of the detergent solution
- Temperature of the detergent solution
- Mechanical effect on the cleaned surfaces (velocity)
- Duration of cleaning (time)

Detergent concentration

The amount of detergent in the solution must be adjusted to the correct concentration before cleaning starts. During cleaning, the solution is diluted with rinsing water and milk residues. Some neutralisation also takes place. It is therefore necessary to check the concentration during cleaning. Failure to do this can seriously affect the result. Checking can be done either manually or automatically. The dosage must always be according to the detergent supplier's instructions, as increasing the concentration does not necessarily improve the cleaning effect – it may indeed have the reverse effect due to foaming, etc. Using too much detergent simply makes cleaning needlessly expensive.

Detergent temperature

Generally speaking, the effectiveness of a detergent solution increases with increasing temperature. A blended detergent always has an optimum temperature which should be used.

As a rule of thumb, cleaning with alkaline detergent should be done at the same temperature as the product has been exposed to, but at least 70 °C. Temperatures of 68 – 70 °C are recommended for cleaning with acid detergents.

Mechanical cleaning effect

In manual cleaning, scrubbing brushes are used to produce the required mechanical scouring effect, (Figure 21.2). In mechanised cleaning of pipe systems, tanks and other process equipment, the mechanical effect is supplied by the flow velocity. The detergent feed pumps are dimensioned for higher capacities than the product pumps, with flow velocities of 1,5 – 3,0 m/s in the pipes. At these velocities, the liquid flow is very turbulent. This results in a very good scouring effect on the surfaces of the equipment.

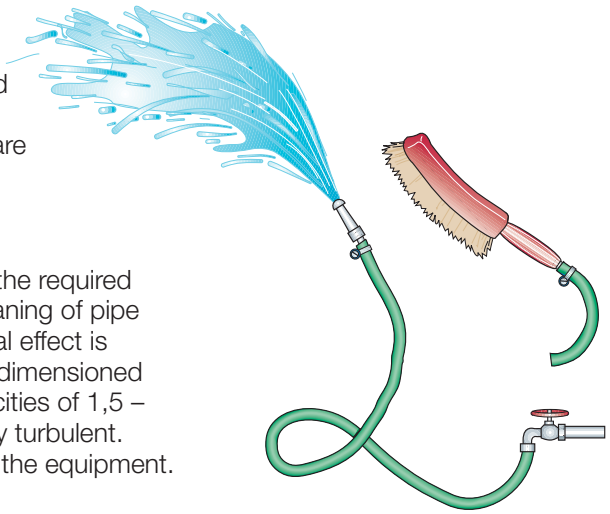


Fig. 21.2 *Examples of mechanical cleaning effects.*

The mechanical effect can be provided either by scrubbing brushes in a manual cleaning system, or by the flow velocity in a mechanised system.

Duration of cleaning

The duration of the detergent cleaning phase must be carefully calculated to obtain the optimum cleaning effect. At the same time, the costs of electricity, heating, water and labour must be taken into consideration. It is not sufficient to flush a pipe system with a detergent solution. The detergent must circulate long enough to dissolve the dirt. The time this takes depends on the thickness of the deposits (and the temperature of the detergent solution). Heat exchanger plates encrusted with coagulated protein must be exposed to circulating nitric acid solution for about 20 minutes, whereas 10 minutes' treatment with alkaline solution is enough to dissolve the film on the walls of a milk tank.

Rinsing with clean water

After cleaning with detergent, the surfaces must be flushed with water long enough to remove all traces of the detergent. Any detergent left in the system after cleaning can contaminate the milk. All parts of the system must be thoroughly drained after rinsing.

Softened water is preferred for rinsing. This prevents deposition of lime scale on the cleaned surfaces. Hard water with a high content of calcium salts must therefore be softened in ion exchange filters to 2 – 4 °dH (German degrees of hardness).

The equipment and pipe systems are practically sterile after the treatment with strong alkaline and acid solutions at a high temperature. It is then necessary to prevent overnight growth of bacteria in the residual rinsing water in the system. This can be done by acidifying the final rinse water to a pH of less than 5 by adding phosphoric or citric acid. This acid environment prevents the growth of most bacteria.

Disinfection

Properly carried out cleaning with acid and alkaline detergents renders the equipment not only physically and chemically but also, to a large extent, bacteriologically clean.

The bacteriological cleaning effect can be further improved by disinfection. This leaves the equipment virtually free from bacteria. For certain products (UHT milk, sterile milk), it is necessary to sterilise the equipment to render the surfaces completely free from bacteria.

Dairy equipment can be disinfected in the following ways:

- Thermal disinfection (boiling water, hot water, steam)
- Chemical disinfection (chlorine, acids, iodophors, hydrogen peroxide, etc.)

Disinfection can be done in the morning, immediately before milk processing begins. The milk can be admitted as soon as all the disinfectant has been drained from the system.

If disinfection takes place at the end of the day, the disinfectant solution should be flushed out with water to avoid leaving any residues that may attack the metal surfaces.

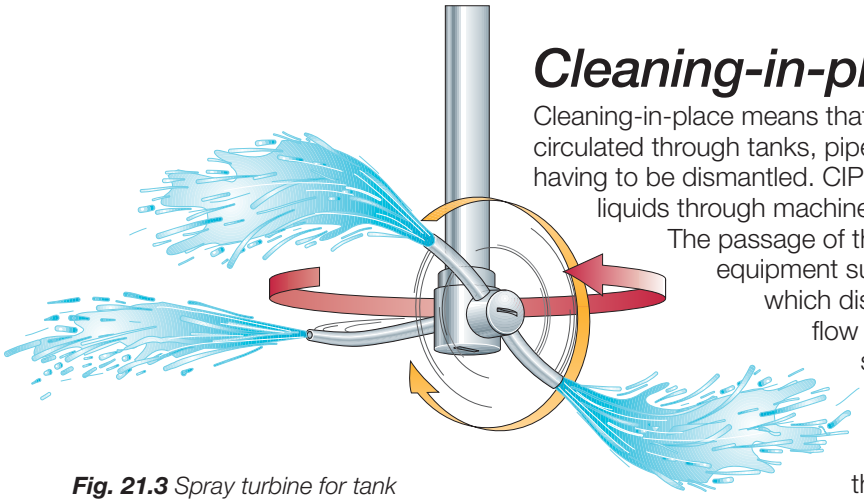


Fig. 21.3 *Spray turbine for tank cleaning.*

The spray turbine consists of two rotating nozzles on the same pipe. One rotates in the horizontal plane and the other in the vertical. Rotation is produced by jet reaction from the backward-curved nozzles.

Cleaning-in-place systems

Cleaning-in-place means that rinsing water and detergent solutions are circulated through tanks, pipes and process lines without the equipment having to be dismantled. CIP can be defined as circulation of cleaning liquids through machines and other equipment in a cleaning circuit. The passage of the high-velocity flow of liquids over the equipment surfaces generates a mechanical scouring effect which dislodges dirt deposits. This only applies to the flow in pipes, heat exchangers, pumps, valves, separators, etc.

The normal technique for cleaning large tanks is to spray the detergent on the upper surfaces and then allow it to run down the walls. The mechanical scouring effect is then often insufficient, but the effect can to some extent be improved by the use of specially designed spray devices, one of which is shown in Figure 21.3. Tank cleaning requires large volumes of detergent, which must be circulated rapidly.

CIP circuits

The question of the type of equipment that can be cleaned in the same circuit is determined according to the following factors:

- The product residue deposits must be of the same type, so that the same detergents and disinfectants can be used
- The surfaces of the equipment to be cleaned must be of the same material or, at least of materials compatible with the same detergent and disinfectant
- All components in the circuit must be available for cleaning at the same time.

Dairy installations are therefore divided for cleaning purposes into a number of circuits which can be cleaned at different times.

Compatible materials and system design

For effective CIP, the equipment must be designed to fit into a cleaning circuit and must also be easy to clean. All surfaces must be accessible to the detergent solution. There must be no dead ends which the detergent cannot reach or through which it cannot flow (Figure 21.4). Machines and pipes must be installed in such a way that they can be efficiently drained. Any pockets or traps from which residual water cannot drain will provide sites for rapid multiplication of bacteria and cause a serious risk of infecting the product.

Materials in process equipment, such as stainless steel, plastics and elastomers, must be of such quality that they do not transmit any odour or taste to the product. They must also be capable of withstanding contact with detergents and disinfectants at the cleaning temperatures.

In some cases, the surfaces of pipes and equipment may be chemically attacked and contaminate the product. Copper, brass and tin are sensitive to strong acids and strong alkalis. Even small traces of copper in milk result in an oxidized flavour (oily, train-oil taste). Stainless steel is the universal material for product-wetted surfaces in modern dairies. Metallic contamination is therefore normally no problem. Stainless steel can, however, be attacked by chlorine solutions.

Electrolytic corrosion is common when components made of copper or brass are built into systems of stainless steel. In such conditions, the risk of contamination is great. Electrolytic corrosion may also occur if a system with steels of different grades is cleaned with cation-active agents.

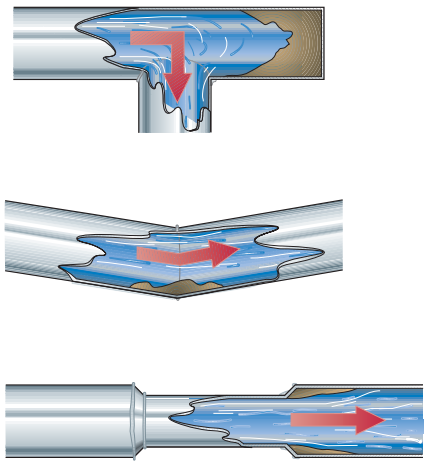


Fig. 21.4 *Examples of positions difficult to clean in a pipe system.*

Elastomers (*e.g.* rubber gaskets) can be attacked by chlorine and oxidising agents, which cause them to blacken or crack and release rubber particles into the milk.

Various types of plastic in process equipment may present a contamination hazard. Some of the constituents of some types of plastics can be dissolved by the fat in milk. Detergent solutions can have the same effect. Plastic materials for use in dairies must therefore satisfy certain criteria regarding composition and stability.

CIP programs

Dairy CIP programs differ according to whether the circuit to be cleaned contains heated surfaces or not. We distinguish between:

- CIP programs for circuits with pasteurisers and other equipment with heated surfaces (UHT, etc.)
- CIP programs for circuits with pipe systems, tanks and other process equipment with no heated surfaces

The main difference between the two types is that acid circulation must always be included in the first type to remove encrusted protein and salts from the surfaces of heat-treatment equipment. A CIP program for a pasteuriser, *hot components*, circuit can consist of the following stages:

1 Rinsing with warm water for about 10 minutes
2 Circulation of an alkaline detergent solution (0,5 – 1,5 %) for about 30 minutes at 75 °C
3 Rinsing out alkaline detergent with warm water for about five minutes
4 Circulation of (nitric) acid solution (0,5 – 1,0 %) for about 20 minutes at 70 °C
5 Post-rinsing with cold water
6 Gradual cooling with cold water for about eight minutes

The pasteuriser is usually disinfected in the morning, before production starts. This is typically done by circulating hot water at 90 – 95 °C for 10 – 15 minutes after the returning temperature is at least 85 °C.

In some plants, after pre-rinsing with water, the CIP system is programmed to start with the acid detergent. This removes precipitated salts and thus breaks up the dirt layer to facilitate dissolving of proteins by the subsequent alkaline detergent. If disinfection is going to be done with chlorinated chemicals, there is an imminent risk of fast corrosion problems if any residues of the acid detergent remain. Therefore, when starting with alkaline cleaning and ending with acid cleaning after an intermediate water rinse, the plant should be flushed with a weak alkaline solution to neutralise the acid before disinfection with a chlorinated chemical can start.

A CIP program for a circuit with pipes, tanks and other '*cold components*' can comprise the following stages:

1 Rinsing with warm water for three minutes
2 Circulation of a 0,5 – 1,5 % alkaline detergent at 75 °C for about 10 minutes
3 Rinsing with warm water for about three minutes
4 Disinfection with hot water 90 – 95 °C for five minutes
5 Gradual cooling with cold tap water for about 10 minutes (normally no cooling for tanks)

Steps for CIP cleaning of 'cold' components:

1 Rinsing with water
2 Circulation of alkaline detergent
3 Rinsing with water
4 Disinfection with hot water
5 Cooling with tap water

Design of CIP systems

In practice, there is no limitation to satisfy stringent individual demands as to the size and complexity of CIP plants.

The CIP station in a dairy consists of all necessary equipment for storage, monitoring and distribution of cleaning fluids to the various CIP circuits. The exact design of the station is determined by many factors, *e.g.*:

- How many individual CIP circuits are to be served from the station. How many are 'hot' and how many are 'cold'?
- Are the milk rinses to be collected? Are they to be processed (evaporated)?

- What method of disinfection is to be used? Chemical, steam or hot water?
- Will the detergent solutions be used only once or recovered for reuse?
- What is the estimated steam demand, momentary and total, for cleaning and sterilisation?

Looking back over the history of CIP, we find two schools of thought:

1 Centralised cleaning
2 Decentralised cleaning

Until the end of the 1950s, cleaning was decentralised. The cleaning equipment was located in the dairy, close to the process equipment. Detergents were mixed by hand to the required concentration – an unpleasant and hazardous procedure for the personnel involved. Detergent consumption was high, which made cleaning expensive.

The centralised CIP system was developed during the 1960s and 1970s. A central CIP station was installed in the dairy. Rinsing water, heated detergent solutions and hot water were supplied from this unit by a network of pipes to all the CIP circuits in the dairy. The used solutions were then pumped back to the central station, and from there to the respective collecting tanks. Detergents recovered in this way could be topped up to the correct concentration and reused until they were too dirty and had to be discarded.

Centralised CIP works well in many dairies, but in large dairies, the communication lines between the central CIP station and the peripheral CIP circuits have grown excessively long. The CIP pipe systems contain large volumes of liquids, even when they are “drained”. The water remaining in the pipes after pre-rinsing dilutes the detergent solution, which means that large amounts of concentrated detergent must be added to maintain the correct concentration. The greater the distance, the greater the cleaning cost. A move back towards decentralised CIP stations therefore began in large dairies at the end of the 1970s. Each department had its own CIP station. Examples of the two systems are shown below.

Centralised CIP

Centralised systems are used mainly in small dairy plants with relatively short communication lines, an example is shown in Figure 21.5.

Water and detergent solutions are pumped from the storage tanks in the central station to the various CIP circuits.

The detergent solutions and hot water are kept hot in insulated tanks. The required temperatures are maintained by heat exchangers. The final rinse water is collected in the rinse-water tank and used as pre-rinsing water in the next cleaning program. The milk/water mixture from the first rinsing water is collected in the rinse-milk tank.

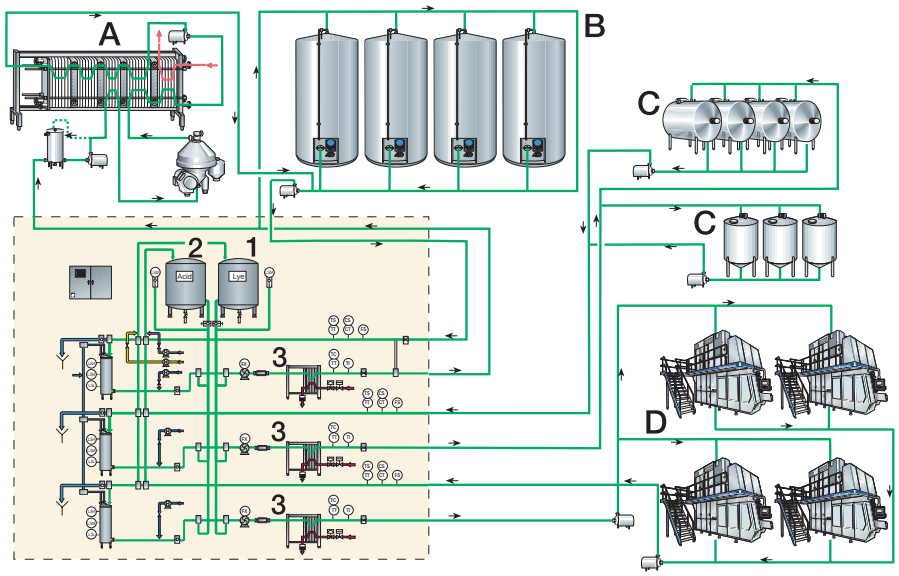


Fig. 21.5 *Principle of the centralised CIP system.*

Cleaning unit (within the broken line)
1 *Tank for alkaline detergent*
2 *Tank for acid d etergent*
3 *Plate heat exchanger*

Object to be cleaned:
A *Milk treatment*
B *Silo tanks*
C *Tank gardens*
D *Filling machines*

The detergent solutions must be discharged when they have become dirty after repeated use. The storage tank must then be cleaned and refilled with fresh solutions. It is also important to empty and clean the water tanks, especially the rinse-water tank, at regular intervals to avoid the risk of infecting an otherwise clean process line.

An example of the design of a central CIP station is illustrated in Figure 21.6.

A station of this type is usually highly automated. The tanks have electrodes for high and low level monitoring. Returning of the cleaning solutions is controlled by conductivity transmitters. The conductivity is proportional to the concentrations normally used at dairy cleaning. At the phase of flushing with water, the concentration of detergent solution becomes lower and lower. At a pre-set value, a change-over valve routes the liquid into the drain, instead of the relevant detergent tank. CIP programs are controlled from a computerised sequence controller. Large CIP stations can be equipped with multiple tanks to provide the necessary capacity.

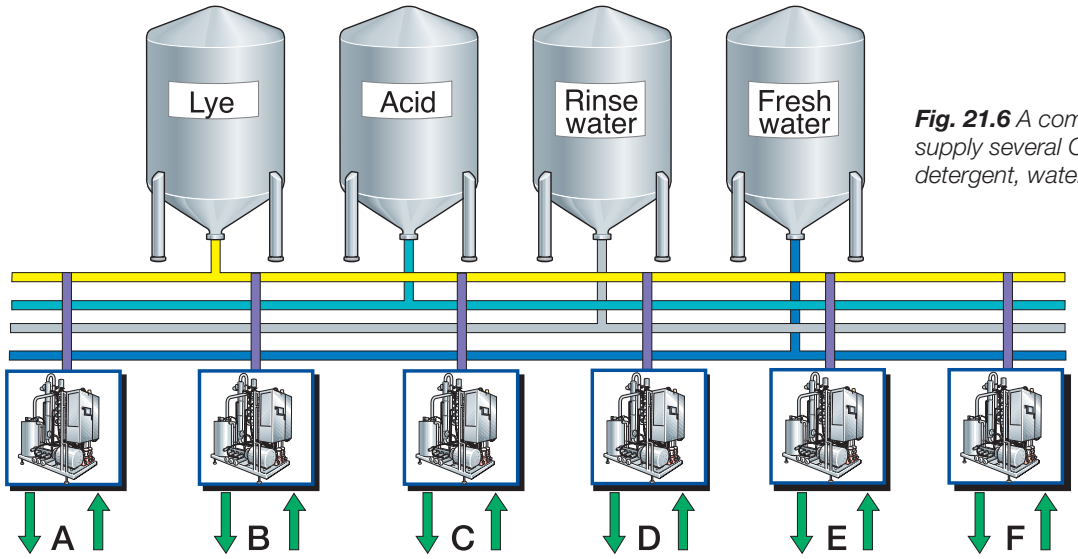


Fig. 21.6 *A common tank garden can supply several CIP stations (A to F) with detergent, water and other solutions.*

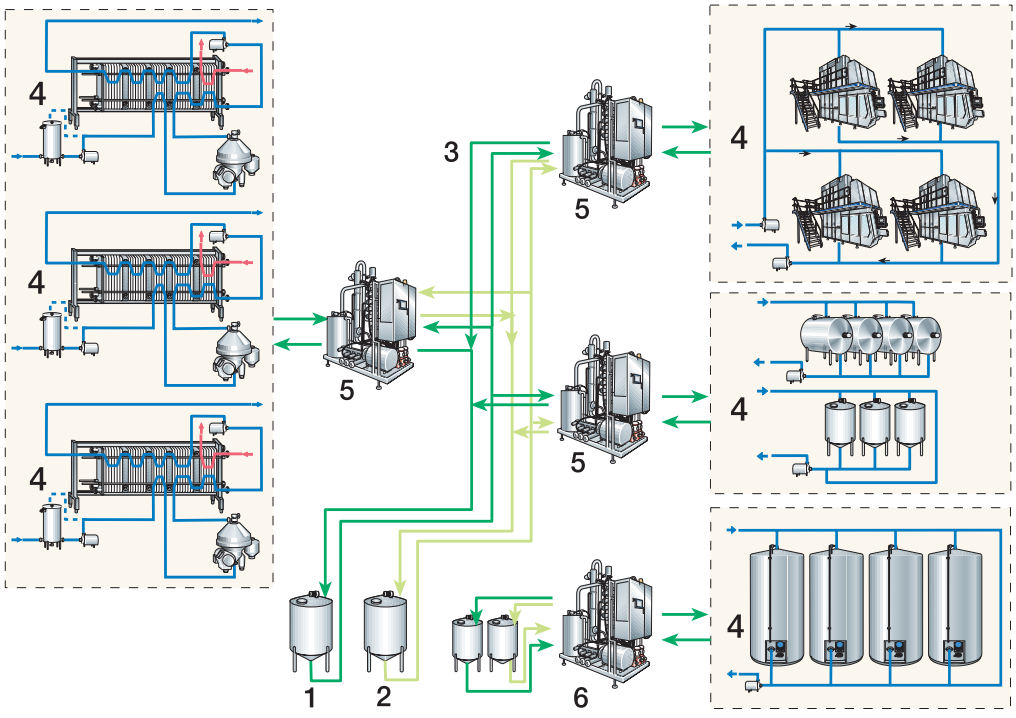


Fig. 21.7 *Satellite CIP system*

1 *Storage tank for alkaline detergent*
2 *Storage tank for acid detergent*
3 *Ring lines for detergents*
4 *Objects to be cleaned*
5 *Satellite CIP unit*
6 *Decentralised CIP system with its own detergent tanks*

Decentralised CIP

Decentralised CIP is an attractive alternative for large dairies, where the distance between a centrally located CIP station and peripheral CIP circuits would be extremely long. The large CIP station is replaced by a number of smaller units located close to the various groups of process equipment in the dairy.

Figure 21.7 illustrates the principle of a decentralised CIP system, also called a satellite CIP system. This still has a central station for storage of the alkaline and acid detergents, which are individually distributed to the individual CIP units in main lines. Supply and heating of rinsing water (and acid detergent, when required) are arranged locally at the satellite stations, one of which is shown in Figure 21.8.

These stations operate on the principle that the various stages of the cleaning program are carried out with a carefully measured minimum volume of liquid – just enough to fill the circuit to be cleaned. A powerful circulation pump is used to force the detergent through the circuit at a high flow rate.

The principle of circulating small batches of cleaning solutions has many advantages. Water and steam consumption, both momentary and total, can be greatly reduced. Milk residues from the first rinse are obtained in a more concentrated form and are therefore easier to handle and cheaper to evaporate. Decentralised CIP reduces the load on sewage systems as compared to centralised CIP, which uses large volumes of liquid.

The concept of single-use detergents has been introduced in conjunction with decentralised CIP, as opposed to the standard practice of detergent recycling in centralised systems. The one-time concept is based on the assumption that the composition of the detergent solution can be

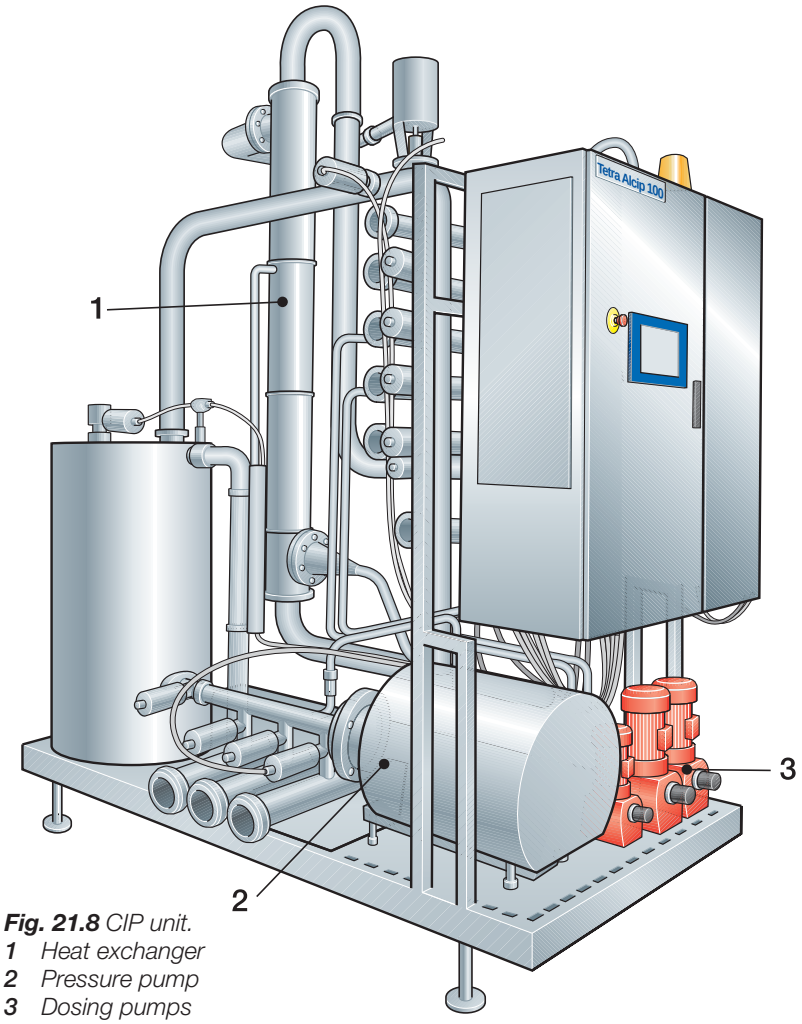


Fig. 21.8 *CIP unit.*
1 *Heat exchanger*
2 *Pressure pump*
3 *Dosing pumps*

optimised for a certain circuit. The solution is considered spent after having been used once. In some cases, however, it may be used for pre-rinsing in a subsequent program.

Verifying the cleaning effect

Verification of the effect of cleaning must be regarded as an essential part of cleaning operations. It can take two forms: visual and bacteriological inspection. Because of the advance of automation, process lines today are seldom accessible for visual inspection. This must be replaced by bacteriological monitoring, concentrated to a number of strategic points in the line. CIP results are usually checked by cultivating coliform bacteria. When a swab test of a surface is made, the criterion is less than *one coli bacterium per 100 cm*^{2} of the checked surface. The result is unacceptable if the count is higher. These tests can be made on the surfaces of the equipment after completion of the CIP program. This applies to tanks and pipe systems, especially when excessively high bacteria counts have been detected in the products. Samples are often taken from the final rinse water or from the first product that passes through the line after cleaning.

All products must be checked for bacteriological quality in their packages to obtain full quality control of the manufacturing process. The complete quality control program, in addition to the coliform test, also includes determination of the total count of micro-organisms and organoleptic control (tasting).

Chapter 22

Dairy effluent

Water used in domestic and industrial applications can become polluted to varying degrees. Water is also used as a transport medium to carry away waste products. As awareness of the importance of improved standards of water treatment grows, process requirements become increasingly exacting. The food industry contributes significantly to pollution, particularly as the pollutants are of organic origin. Organic pollutants normally consist of 1/3 dissolved, 1/3 colloidal and 1/3 suspended substances, while inorganic materials are usually present mainly in solution.

Organic pollutants

The normal way to express the concentration of a pollutant is to specify the total quantity per unit volume of sewage. Another, more modern way of analysing the presence and quantities of organic substances in sewage effluent is the use of chromatography, such as High-Performance Liquid Chromatography (HPLC).

However, the quantity of organic substances is normally determined in the form of;

- Biological oxygen demand (BOD)
- Chemical oxygen demand (COD)
- Calcining loss
- Total organic carbon (TOC)

Biological oxygen demand (BOD)

BOD is a measure of the content of biologically degradable substances in sewage. The substances are broken down by micro-organisms in the presence of (and therefore with consumption of) oxygen. Oxygen demand is measured in terms of the quantity of oxygen consumed by micro-organisms over a period of five days (BOD_5) or seven days (BOD_7), in decomposing the organic pollutants in waste water at a temperature of 20 °C. BOD is measured in mg oxygen/l or g oxygen/m^3.

BOD is a measure of the content of biologically degradable substances in sewage.

The following relationship is assumed for municipal sewage:

$BOD_7 = 1{,}15 \times BOD_5$

Chemical oxygen demand (COD)

COD indicates the quantity of the pollutants in waste water that can be oxidised by a chemical oxidant. The normal reagents used for this purpose are strongly acid solutions (to ensure complete oxidation) of potassium dichromate or potassium permanganate at high temperature. Consumption of oxidant provides a measure of the content of organic substance and is converted to a corresponding quantity of oxygen, expressing the result as mg oxygen/l or g oxygen/m^3.

COD indicates the quantity of the pollutants in waste water that can be oxidised by a chemical oxidant.

The COD/BOD ratio indicates how biologically degradable the effluent is. Low values, *i.e.* < 2, indicate relatively easily degradable substances, while high values indicate the contrary. However, this relationship cannot be used generally, but a typical value of COD/BOD for municipal sewage effluent is often < 2.

In the FIL-IDF Bulletin about Dairy Effluents, Document 138, 1981, reported (Doedens) that the COD/BOD_5 ratio for effluent generated in different groups of dairies producing liquid milk, butter or cheese ranged from 1,16 to 1,57, at an average of 1,45. In other groups of dairy plants producing milk powder, whey powder, lactose and casein, the ratio varied from 1,67 to 2,34, with an average of 2,14. However, the general conclusion of the FIL-IDF Bulletin was that a COD:BOD ratio established in one dairy plant could not be transferred with sufficient reliability to another plant.

Calcining loss

Calcining loss is obtained by first determining the dry solids content in a sample, and then calcining it so that the organic substance is burnt. The difference in weight before and after calcining represents the quantity of organic substance. The value is expressed as a percentage.

Total organic carbon (TOC)

TOC is another measure of the quantity of organic materials, determined by measuring the quantity of carbon dioxide produced from combustion of a sample. The unit is mg/l.

Inorganic pollutants

The inorganic components of sewage consist almost entirely of salts, and are determined largely by the ionic composition and salt concentration in the mains water. The presence of these salts in sewage is normally unimportant. Present-day effluent treatment processes concentrate on the reduction of nitrogen, phosphorus salts and heavy metals.

Nitrogen and phosphorus compounds are important, as they are nutrients for organisms, *e.g.* algae, in recipients. As a result of the growth of algae, secondary processes can proceed in the recipient, forming further organic substances which, when they decompose, can result in considerably higher oxygen demand than is caused by primary organic pollutants in the sewage effluent.

Heavy metals may be toxic in high concentrations and may disturb the ecosystems also in low concentrations.

Dairy waste water

Dairy waste water can be divided into three categories:

1 Cooling water
2 Sanitary waste water
3 Industrial waste water

Cooling water

As cooling water is normally free from pollutants, it is discharged into the storm water piping system *i.e.* the system for run-off water from rain and melting snow, etc.

Sanitary waste water

The sanitary waste water is normally piped direct to the sewage treatment plant with or without first having being mixed with industrial waste water.

Industrial waste water

Industrial waste water emanates from spillage of milk and products thereof, and from cleaning of equipment that has been in contact with milk products. The concentration and composition of the waste depends on the production programme, operating methods and the design of the processing plant.

Table 22.1

BOD of some milk products

Product		BOD_5 mg/ l	BOD_7 mg/ l
Cream	40 % fat	400 000	450 000
Whole milk	4 % fat	120 000	135 000
Skim milk	0,05 % fat	70 000	80 000
Whey	0,05 % fat	40 000	45 000
Whey conc.	60 % DM	400 000	450 000

Sewage treatment plants are dimensioned to treat a certain quantity of organic substances and also to be able to deal with certain peak loads. However, one organic substance – fat – presents particularly difficult problems. Besides having a high BOD (cream with 40 % fat has a BOD_5 of about 400 000 mg oxygen/l while skim milk has 70 000 mg/l), fat sticks to the walls of the mains system, as well as causing sedimentation problems in the sedimentation tank as it rises to the surface.

Dairy waste water should therefore pass a flotation plant where it is

Drinking water

The table below is extracted from *Guidelines for drinking-water quality*, 2nd ed. Vol. 2 Health criteria and other supporting information, 1996 Geneva, World Health Organization (WHO).

In WHO:s Guidelines for drinking-water quality, also a large number of microbiological and other chemical parameters affecting the water quality can be found.

Table 22.2

Guideline values for drinking-water quality

Element value	Abbr.	Guideline mg/l
Cadmium	Cd	< 0,003
Arsenic	As	< 0,01
Chromium	Cr	< 0,05
Lead	Pb	< 0,01
Mercury	Hg	< 0,001

aerated with “dispersion water” (the method of supplying finely-dispersed air bubbles to the water at a pressure of 400 – 600 kPa is called dissolved-air flotation). The air bubbles attach themselves to the fat, carrying it rapidly to the surface where it is strained off, manually or mechanically depending on the size of the plant. The flotation plant is often located close to the dairy building and the waste passes through it in a continuous flow.

The defatted effluent can then be mixed with the sanitary waste water going to the sewage treatment plant. Table 22.1 lists the BOD of some milk products.

pH of dairy effluent

Waste water with a pH of over 10 or below 6,5 must not be discharged to the sewage system.

The pH of dairy effluent varies between 2 and 12, as a result of the use of acid and alkaline detergents for plant cleaning.

Both low and high pH values interfere with the activity of the micro-organisms that break down organic pollutants in the biological treatment stage of the sewage treatment plant, transforming them into biological sludge (cell detritus).

As a rule, waste water with a pH of over 10 or below 6,5 must not be discharged to the sewage system, as it is liable to corrode the pipes. Used detergents are therefore normally collected in a mixing tank, often located close to the cleaning plant, and the pH is measured and regulated to about pH 7,0 before it is discharged to the drain.

Table 22.3

Guideline values for advanced treated sewage water

	Outlet in river/lake	Outlet in sea	Outlet in municipal WWTP
Ammonia-nitrogen, mg/l	1 – 5	< 10	< 100
Total-nitrogen, mg/l	< 25	10 – 15	80 – 100
Total-phosphorus, mg/l	0,3 – 0,5	0,5 – 1,5	10 – 30
BOD_7, mg/l O_2	10 – 15	15 – 20	500 – 2000
pH	6 – 9	6 – 10	> 6,5
Grease, mg/l	< 1	< 1	< 100

Specific regulations adopted to the recipient has to be defined in discussions with local and national environmental authorities. As a fundamental rule, the water quality of the receiveing water must not be adversely affected by the treated sewage water.
WWTP stands for Waste Water Treatment Plant.

Reducing the quantity of pollutants in waste water

There are many solutions for minimising the amount of pollutants in dairy waste water. Closed systems, reuse of water, recirculation of product/water mixture over membrane filters are just a few examples to reduce pollutants in waste water. Ultrafiltration and microfiltration are in many dairy plants used for purifying and reuse of CIP solutions. Condens water from evaporators can preferably be reused for other purposes in the plant.

It is constantly necessary to control and prevent wastage of water and product in the processing plant.

Hidden losses of water in subfloor and underground piping can be detected by reading the water meter and recording the quantity used at the end of the day.

Daily records of water consumption should then be compared with the daily quantity of milk that has been processed. The water consumption, expressed as cubic metres per tonne of treated milk, should be plotted on a graph kept in an easily accessible place. A typical water:milk ratio is 2,5:1,

but with intense saving of water, it is possible to come down to a ratio of 1:1.

The following general recommendations can serve as a guide to reducing wastage of water and product:

General milk treatment

- In reception of milk, particularly when tankers are emptied, it is important that the outlet from the tankers is at least 0,5 m above the receiving container or tank, and that the connecting hose is well stretched, to ensure that the tankers are completely drained.
- All pipelines must be identified and marked, to avoid wrong connections that would result in unwanted mixing of products, as well as leakage of milk.
- When pipes are installed, they should be laid with a slight and correctly calculated gradient to make them self-draining. In addition, the pipes must be well supported to prevent vibration, which could cause the couplings to work loose and thus cause leakage.
- All tanks should be equipped with level controls to prevent overflow. When the highest permitted level is reached, either the feeding pump is automatically stopped and the plant operator alarmed, or an automatic valve system is activated to route the product to another pre-selected tank.
- It is better to prevent wastage of product in the first place than to flush it away with a hose afterwards. Try to keep the floors dry; this also makes leaks easier to detect.
- Make sure that the piping system and tanks are properly emptied before they are rinsed out with water.
- Check that couplings are airtight; if air leaks into the piping system, it will cause increased burning-on in heaters, erosion problems in homogenisers and foaming in milk and cream tanks (which will then be harder to empty completely).

Cheese production area

- Make sure that open cheese vats are not filled to the top; stop filling when the milk level is at least 10 cm below the rim.
- Collect whey carefully, and try to find commercial uses for it instead of discharging it as waste.
- Curd on the floor should be swept up and treated as solid waste – not flushed into the gutter with water.

Butter production area

- Cream and butter stick more readily than milk to surfaces they come in contact with, and will aggravate contamination of waste water unless they are removed before cleaning starts.
- After the end of a butter production run, all accessible surfaces should be manually scraped clean.
- Cream and remaining butter can then be removed with steam and hot water and collected in a container for separate treatment.

Milk powder production area

- The evaporators should be run at the lowest possible level to prevent overcooking.
- Re-use the condensate as cooling water after circulation through a cooling tower, or as feed water to the boiler.
- Spilled dry products should be swept up and treated as solid waste.

Milk packaging area

- The filling machines can be provided with drains discharging into one or more containers.
- Returned packages can be emptied into containers and the mixture of sweet and sour liquids used as animal feed.

Outlet control

Disposal of waste water is subject to regulation in many countries. Outlet control, for example, must be arranged so that the volume of waste water is continuously measured and recorded and an aliquot part, in proportion to the volume of the flow, is sampled.

Figure 22.1 illustrates a system for measuring the flow in an open canal with a venturi flume. For information about the venturi flume and other measuring systems, please contact the municipal authorities dealing with sewage water treatment. As for sampling, one example of the procedure is shown in Figure 22.2.

Signals indicating the volume of water measured in the flume are transmitted via a control unit to the sampling device. An aliquot volume of the flow is sampled whenever a pre-determined volume of water (say 100 l) has passed the flow transmitter. The daily samples are mixed, and after an optional period a smaller volume of the mixed samples is analysed.

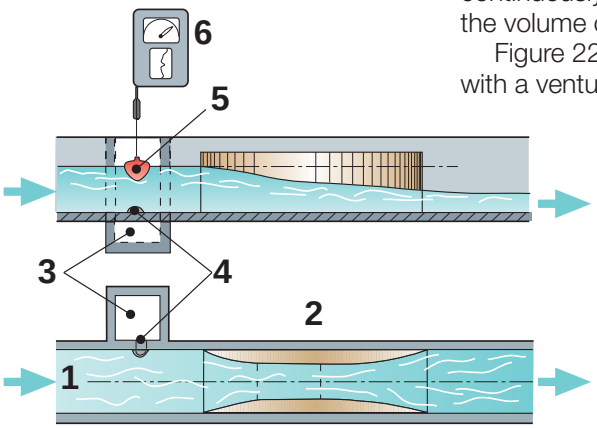
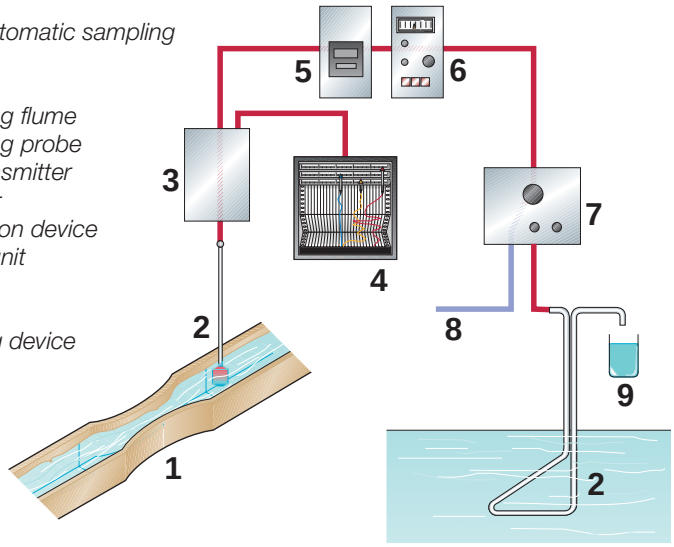


Fig. 22.1 *System for measuring the flow in an open canal with a venturi flume.*

1 *Waste water canal*
2 *Venturi flume*
3 *Measuring pit*
4 *Connection between the canal and measuring pit*
5 *Float*
6 *Measuring and recording device*

Fig. 22.2 *Automatic sampling system.*

1 *Measuring flume*
2 *Measuring probe*
3 *Flow transmitter*
4 *Recorder*
5 *Summation device*
6 *Control unit*
7 *Subunit*
8 *Air*
9 *Sampling device*



Sewage treatment, a general survey

Various arrangements are possible; the choice of treatment is determined by the required degree of pollutant reduction. Figure 22.3 shows four possible systems. When planning a new plant, contact the local authorieties at an early stage fore a discussion about effluent treatment and sewage BOD levels.

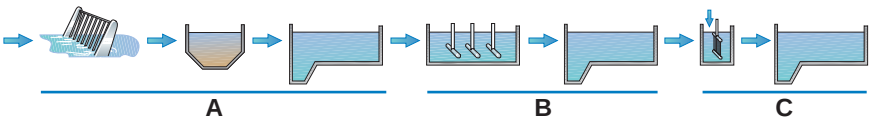
Sewage treatment, in its original form, consisted simply in removing the bulk of solid impurities by mechanical sedimentation (A). When this treatment was judged to be insufficient, it was supplemented with biological treatment (B) to decompose the organic compounds.

Many sewage treatment plants were later extended with a third stage for chemical treatment (C) when emission of phosphorus became a serious problem. The process in plants of this type is called post-precipitation because the chemical precipitation step comes last.

Later experience has, however, proved that it is possible to obtain the same result if chemical precipitation is combined with mechanical treatment in the first step. This system is called pre-precipitation (see Figure 22.3.2).

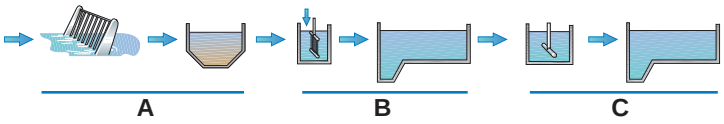
This arrangement also represents a major rationalisation of the process, as most of the sewage treatment is done in one step. The phosphorus content is already reduced by 90 % and the BOD by 75 % in the pre-sedimentation basins. As a result, the biological stage has a much lighter load to deal with and requires less basin volume and energy input.

Figure 22.4 shows a typical sewage plant layout with pre-precipitation.



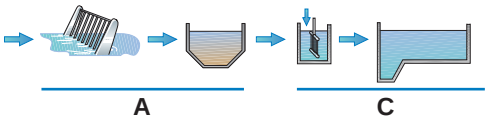
1 Post-precipitation

*Conventional three-stage process with **A** mechanical, **B** biological, and **C** chemical treatment. Effective and reliable, but fairly expensive.*



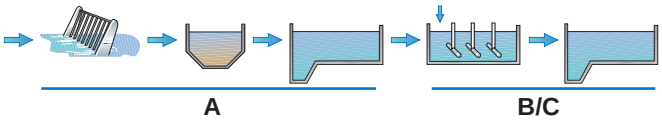
2 Pre-precipitation

*A two-stage process developed during the 1980s. **C** chemical treatment is combined with **A** mechanical sedimentation in the first stage, which results in high-grade phosphorus reduction as well as about 70 % BOD reduction. This relieves the load on the **B** biological stage, which thus requires much less basin volume and energy input than with conventional post-sedimentation.*



3 Direct precipitation

*A single-stage process, with combined **A** mechanical and **C** chemica treatment as in pre-precipitation, but with no succeeding biological treatment stage.*



4 Simultaneous precipitation

*A two-stage process with **A** mechanical treatment followed by a combined **B/C** biological-chemical stage. A fairly cheap method of satisfying the demand for phosphorous reduction without expensive additional basin capacity, but less efficient than if the biological and chemical treatments are performed separately.*

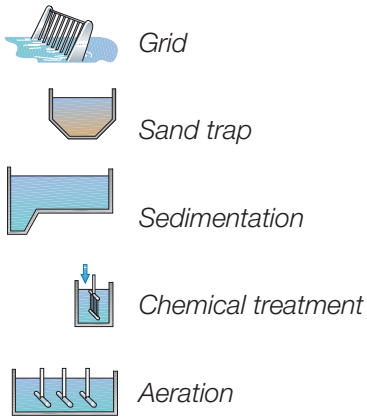


***Fig. 22.3** The various stages of sewage treatment can be combined in several ways.*

Mechanical treatment

The primary (mechanical) stage of sewage treatment comprises strainer grid, sand trap and primary sedimentation basins.

The *grid traps* coarse solid matter: plastic, rags, food residues, etc. This matter is continuously scraped off the grid and disposed of separately, usually as landfill.

The *sand trap* is a basin in which coarse separation takes place. It is dimensioned and operated in such a way that sand and other heavy particles have time to settle to the bottom, while fat and other impurities that are lighter than water float to the surface. The sediment is pumped away, and the floating scum is removed by scrapers. These waste products are likewise disposed of separately.

Air is blown into the sand trap, partly to keep finer parfticles in suspension and partly to prevent putrefaction processes that cause bad smells.

Chemical treatment

The principal purpose of chemical sewage treatment, also known as precipitation, is to rid the water of phosphorus. Municipal sewage systems normally collect 2,5 – 4,0 grams of phosphorus per person per day, mainly in the form of phosphates. Detergents account for about 30 % of the phosphate content; the remaining 70 % comes mainly from human excreta and food residues.

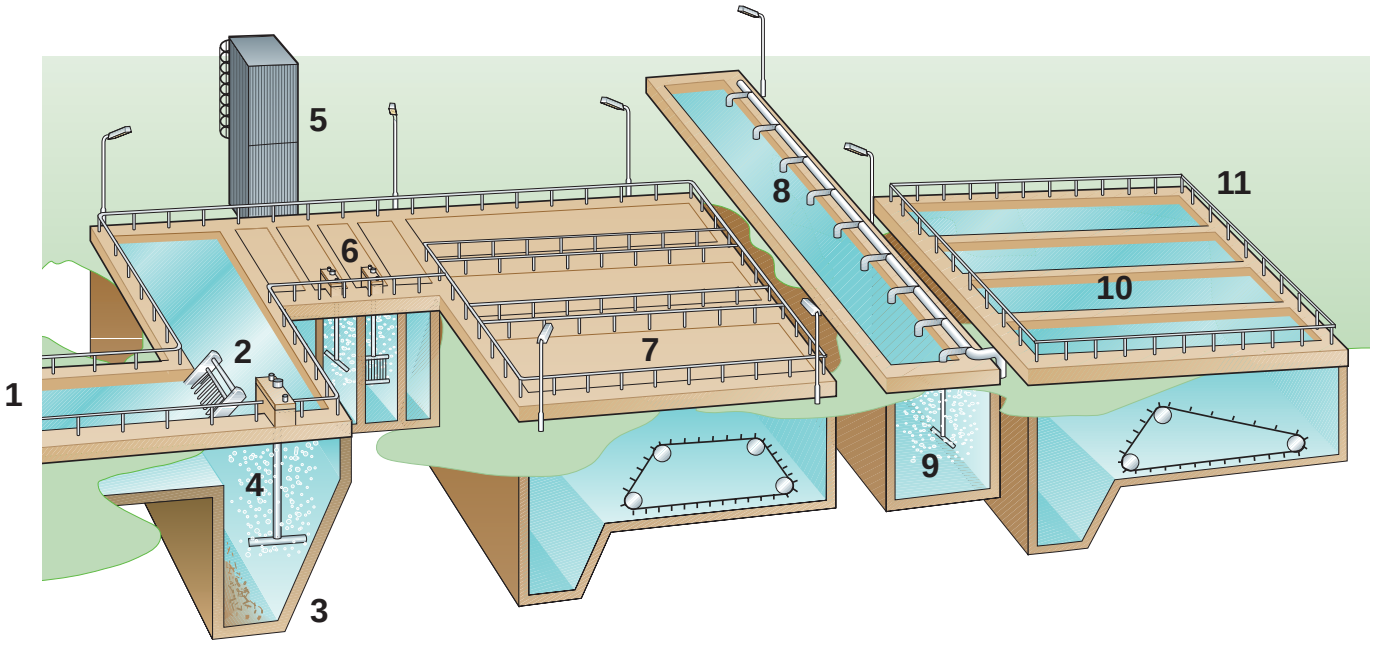


Fig. 22.4 *The various stages of a sewage treatment plant.*

1 *Inlet channel*
2 *Grid*
3 *Sand trap*
4 *Aeration*
5 *Silo for flocculant*
6 *Pre-precipitation*
7 *Pre-sedimentation*
8 *Biological treatment*
9 *Aeration*
10 *Post-sedimentation*
11 *Clarified effluent to recipient*

Chemical precipitation with iron, and aluminium-based flocculants can remove almost 100 % of the phosphorus present in waste water, while conventional biological trreatment only reduces the phosphorus content by 20 – 30 %.

The precipitation stage starts with *flocculation tanks,* where the flocculants are added and vigorously mixed into the water by agitators. This results in precipitation of insoluble phosphates, initially in the form of very fine particles which, however, gradually aggregate into larger flocs. The flocs settle out in *pre-sedimentation basins*, from which a clear effluent overflows into the basin for biological treatment.

Pre-sedimentation is the final step in the combined mechanical and chemical treatment. The water is allowed to flow slowly through one or more basins where the finer particles gradually settle to the bottom as *primary sludge.*

The sedimentation basins are equipped with devices that continuously scrape the sediment into a sump, and transverse gutters that carry off water from the clarified surface layer.

Biological treatment

The remaining organic impurities in the "overflow" from the chemical treatment are broken down with the help of micro-organisms, *e.g.* bacteria, which feed on the organic substances present in the water.

The micro-organisms must have access to oxygen to perform their function. This is supplied in the form of air blown into the *aeration basin*.

The micro-organisms reproduce continuously, forming an *active sludge*. This sludge is removed from the water by settling in *post-sedimentation basins*. Most of it is recirculated to the aeration basins, to keep the biological breakdown process going; the excess sludge is removed from the process for further treatment and the clarified effluent is discharged to the recipient.

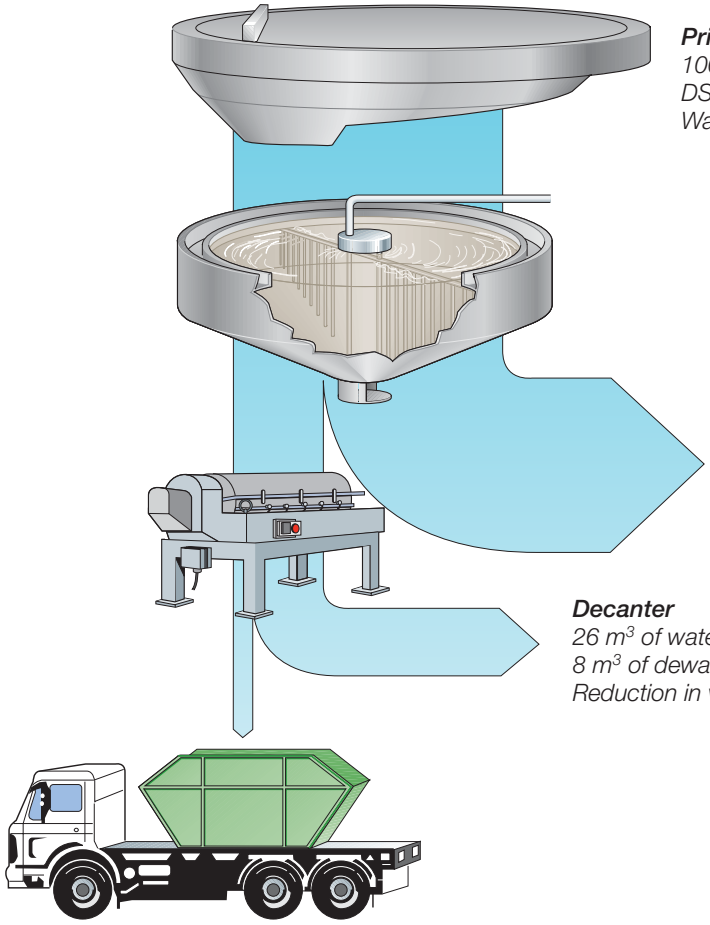
An alternative to the aeration basin is the *biological filter*, which is a container filled with pieces of stone or plastic. The water is sprinkled over the filter by a rotating distributor, trickles down through the filter bed, and is oxygenated by air circulation. A “skin” of micro-organisms builds up on the surfaces of the stones, etc., breaking down the organic impurities in the water.

Sludge treatment

Since the beginning of 1990s the development of sludge treatment has been in focus. In some countries there has been a demand for thermophil treatment of the sludge at 70 – 75 °C in order to destroy harmfull micro-organisms.

The sludge from the various stages of treatment is collected in thickening tanks to which chemicals are added to facilitate further aggregation of the solid particles.

To further break down organic matter and to reduce foul-smelling substances, the sludge is eventually pumped into a digester where the organic subtances are broken down under anaerobic conditions into carbon dioxide and methane and very small amounts of hydrogen gas, ammonia and hydrogen sulphide.



Primary sedimentation basins
100 m^3 of sludge from primary sedimentation basins.
DS 2 %
Water content 98 %

Sludge thickener
66 m^3 of water removed in the sludge thickener.
34 m^3 of sludge with 6 % DS continues to centrifuge plant.

Decanter
26 m^3 of water removed in decanter centrifuge.
8 m^3 of dewatered sludge with 25 % DS is discharged.
Reduction in volume in centrifuge stage is 76 %.

Fig. 22.5 *Reduction in volume of wet sludge from the primary settling stage after treatment in a sludge thickener and decanter centrifuge. The amount of dewatered sludge discharged from the decanter centrifuge is only 8 % of the volume of the wet sludge from the sedimentation basins.*

Carbon dioxide and methane are the main components of digester gas, which can be utilised as fuel for heating.

Digester sludge is a homogeneous, practically odourless, dark-coloured substance which still has a high moisture content of around 94 – 97 %. It is therefore dewatered, most effectively in a decanter centrifuge, which discharges a solid phase of about one-eighth of the original volume, as shown in Figure 22.5.

The dewatered sludge can then be utilised as fertiliser or landfill, or simply deposited as waste. The sludge can be an integrated part of cultivation of energy forest (*e.g.* Salix) as the sludge contains lots of valuable nutition for the crofps.

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