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BP Process Safety Series

Hazards of Steam

A collection of booklets describing hazards and how to manage them

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This booklet is intended as a safety supplement to operator training courses, operating manuals, and operating procedures. It is provided to help the reader better understand the 'why' of safe operating practices and procedures in our plants. Important engineering design features are included. However, technical advances and other changes made after its publication, while generally not affecting principles, could affect some suggestions made herein. The reader is encouraged to examine such advances and changes when selecting and implementing practices and procedures at his/her facility.

While the information in this booklet is intended to increase the store-house of knowledge in safe operations, it is important for the reader to recognize that this material is generic in nature, that it is not unit specific, and, accordingly, that its contents may not be subject to literal application. Instead, as noted above, it is supplemental information for use in already established training programmes; and it should not be treated as a substitute for otherwise applicable operator training courses, operating manuals or operating procedures. The advice in this booklet is a matter of opinion only and should not be construed as a representation or statement of any kind as to the effect of following such advice and no responsibility for the use of it can be assumed by BP.

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Foreword

Steam is used in nearly all parts of the Chemical or Oil Industries. Despite the extensive experience accumulated in handling it, we still see incidents occurring with operators being burned by steam, equipment being damaged by condensing steam and incidents resulting from water hammer etc.

I strongly recommend you take the time to read this book carefully. The usefulness of this booklet is not limited to operating people; there are many useful applications for the maintenance, design and construction of facilities.

Please feel free to share this with others since this is one of the most effective means of communicating lessons learned and avoiding safety incidents in the future.

Greg Coleman, Group Vice President, HSSE

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1

Introduction

Steam is the 'most seen' utility used in a modern refinery. White clouds of escaping steam, large and small, are seen over every refinery, even from a considerable distance. Steam is used extensively because it can do many things:

- it furnishes power for pumps and turbines;
- it heats reboilers, kettles, tanks and buildings;
- it purges air or hydrocarbons from equipment in preparation for start-up or shutdown;
- it directly enters into process operations;
- it snuffs fires in furnaces and other equipment; and
- it even warms the operator's pot of coffee.

Because steam has so many uses, including some which increase safety, how can we think of it as a hazard? Like many other things, steam is not a hazard if it is used correctly. It can and will be a hazard if we use it with insufficient knowledge of its limitations and dangers.

We are going to take a close look at the problems which can arise involving the use of steam. By understanding and applying the principles discussed, you will contribute to the safety of your job.

2

Properties of steam

Before we consider the uses of steam and the hazards which may arise, we should review very briefly the properties which cause steam to be so widely used.

Technically, steam is water in vapour form, and it is both odourless and invisible. If you were to put a window in an insulated steam line and look in, you would think the line was empty. What we normally see and call 'steam' are clouds of tiny drops of water which have condensed from the steam and are carried along by the invisible vapour. People who work in power houses know that a high-pressure steam leak often can be heard but not seen.

When water is heated at atmospheric pressure at sea level, it will boil when the temperature reaches 212°F (100°C). As long as water is present in the vessel at this pressure and is heated, it will continue to boil at 212°F (100°C), and the steam generated will also be 212°F (100°C). If the escape of steam is restricted, as in a boiler, a pressure higher than atmospheric will be developed. As the pressure is increased, the boiling temperature of the water and the temperature of the steam increase; and the temperature always corresponds to the pressure as long as water or condensing steam is present.

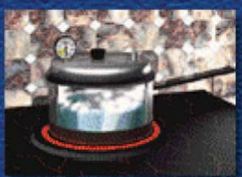
The steam is at its ‘saturation’ temperature, and we can predict the temperature if we know the pressure. However, steam removed from the presence of water can be heated further, becoming ‘superheated’ steam.

At any given pressure, steam may have a temperature higher than the ‘saturation’ temperature only if it is removed from the presence of boiling water and is superheated. Table 1 shows the temperature of ‘saturated’ steam corresponding to various pressures.

Table 1 *Pressure and temperature of saturated steam at sea level*

Pressure and Temperature of Saturated Steam at Sea Level

Gauge Pressure: inches of mercury vacuum (Hg vac) or pounds per square inch gauge.



Gauge Pressure		Temp. °F	°C
25 Hg vac	0.15 bar_a	134	57
20 Hg vac	0.32 bar_a	161	72
10 Hg vac	0.66 bar_a	192	89
5 Hg vac	0.83 bar_a	203	95
0 Hg vac	1 bar_a	212	100
25 psig	1.7 bar_g	267	131
50 psig	3.5 bar_g	298	148
100 psig	6.9 bar_g	338	170
150 psig	10.3 bar_g	366	186
200 psig	13.8 bar_g	388	198
300 psig	20.7 bar_g	422	217
400 psig	27.6 bar_g	448	231
600 psig	41.4 bar_g	488	253
1300 psig	89.6 bar_g	578	303

Table 1 is in terms of gauge pressure, the pressure you normally read on a gauge (see Figure 1).

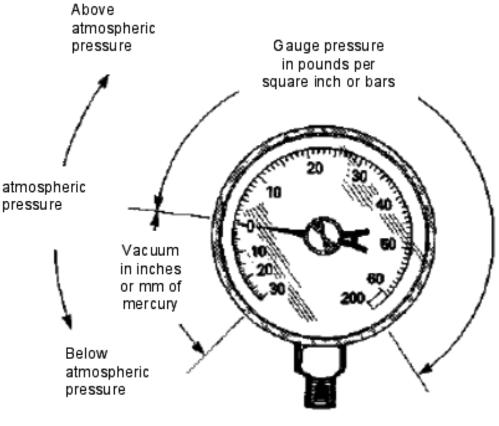
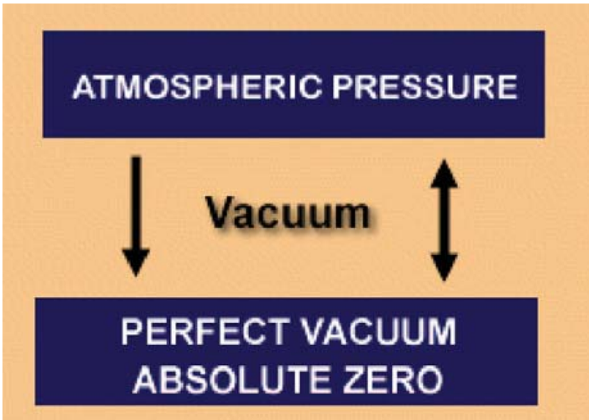


Figure 1 *This compound gauge dial scale is calibrated in pounds per square inch or bars for pressures above atmospheric and in inches or millimeters of mercury for pressures below atmospheric.*

Pressure can be expressed with respect to either of two reference points—a perfect vacuum or atmospheric pressure. When a pressure is referenced to that of a perfect vacuum as zero pressure, then it is called *absolute pressure.* When a pressure is referenced to that of the atmosphere as zero pressure, it is called *gauge pressure.* The relation between absolute and gauge pressure is illustrated in Figure 2.



	Absolute Pressure	Gauge Pressure
Reference Point	Perfect Vacuum	Atmospheric Pressure
Meaning of Zero	Zero = True Zero	Zero = Pressure of the Atmosphere
Unit of Measure	bar_a psia	bar_g psig

***Figure 2** Relation between gauge and absolute pressure.*

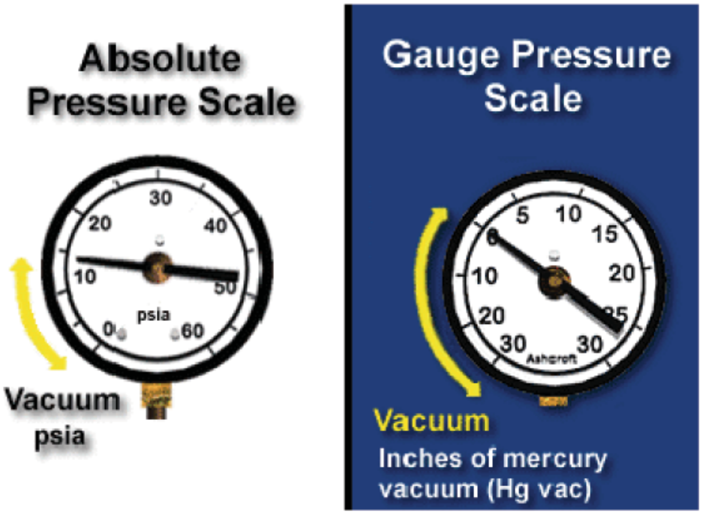


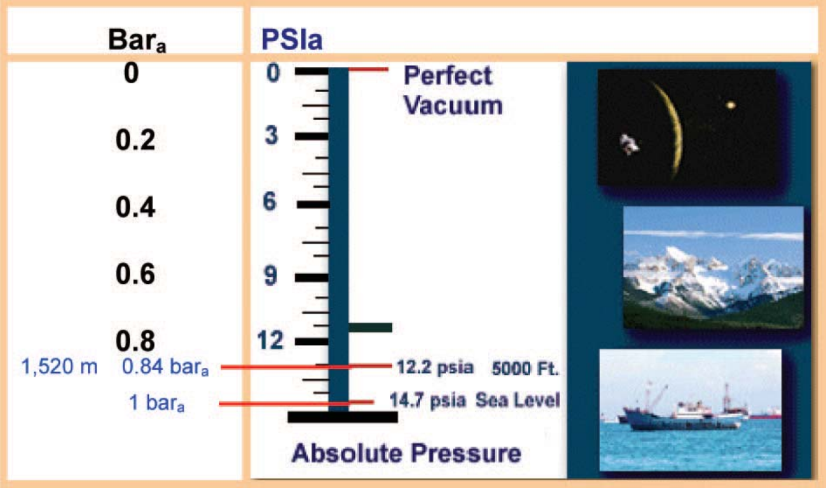
Figure 2 *(Contd.)*

Any pressure less than zero gauge is called a *vacuum.* The greatest vacuum possible, called a *perfect vacuum,* is zero absolute pressure, or -14.7 psig (-1 bar_g).

Vacuums are generally expressed in inches or millimeters of mercury. Thus, the expression '10 inches vacuum' means a pressure that is below the atmospheric pressure by the amount equivalent to a 10 inch (25.4 cm) head or column of mercury (0.67 bar). Since one inch (2.5 cm) of mercury = 0.49 pounds per square inch (abbreviated *psi*) (33.7 mbar*),* such a vacuum is 10×0.49 or 4.9 psi (0.34 bars) below atmospheric pressure. A 10 inch vacuum, then, is equivalent to an absolute pressure of 14.7 (atmospheric pressure) minus 4.9, or 9.8 pounds per square inch *absolute* (abbreviated *psia*) (0.67 bar_a). A 30 inch (76.2 cm) vacuum is equal to $14.7 - 30 \times 4.9$, or 0 psia (0 bar_a), a perfect vacuum.

Since the atmospheric pressure is lower than 14.7 psia (1 bar_a) at higher altitudes, the steam temperature, which depends on the absolute pressure, would be lower at higher altitudes at a given gauge pressure.

For example, the atmospheric pressure, 0 gauge pressure, at 5,000 feet (1,520 m) above sea level is 12.2 psia (0.84 bar_a). Therefore, the temperature of saturated steam at 0 gauge pressure at 5,000 feet (1,520 m) is 203°F (95°C). The temperature of saturated steam at 100 pounds (6.9 bars) gauge pressure at 5,000 feet (1,520 m) is 336°F (169°C) versus 338°F (170°C) at sea level.



Heat is required to increase the temperature of water to its boiling point. (A *Btu,* British thermal unit, is the amount of heat required to raise the temperature of one pound of water 1°F). (A calorie is the amount of heat required to raise the temperature of one gram of water 1°C. One calorie equals 4.168 Joules).

Additional heat must be supplied to *vaporize* water after it reaches its boiling point. To condense steam to water, this same amount of heat must be removed. The heat which must be supplied to vaporize water, or removed to condense steam to water, is known as its *latent heat.* This latent heat amounts to nearly 1,000 Btu (252 kcalories; 1,055 kjoule) per pound (450 g) of water or steam. The reason steam is an excellent heating medium is that the heat required to vaporize or condense a pound of water is much greater than the amount of heat required to raise it to its boiling point. For example, one pound (450 g) of steam condensing at 100 psig (7 bar$_g$) pressure will furnish enough heat to raise the temperature of more than 6 pounds (2.7 kg) of water from room temperature to its normal boiling point.

Steam is not combustible, nor will it support combustion. For this reason, it is used as an 'inert' gas. Since steam is always hot, it warms equipment at the same time as it is purging air at start-up and will also melt ice which may have formed in vessels and lines in winter weather. At shutdown, steam condensing on the surfaces helps to clean vessels and lines as well as displacing gaseous and liquid hydrocarbons before the equipment is opened. Steam will strip the light ends from petroleum mixtures. It is readily available in refineries and is usually cheaper than other inert gases.

It is easy to see why steam is a most desirable material for many uses.

ACCIDENT Designers should consider how all equipment is operated, including during non-routine phases such as start-up and shutdown. The example below shows a typical outcome of 'getting the design wrong'. A refinery propane vessel in Propane Deasphalting unit was to be fitted with Passive Fire Protection (PFP). During a turnaround, the old insulation was taken off, the vessel inspected and the coat of primer paint applied. The rest of the PFP was to be put on after start-up. For start-up, the operator steam-purged the vessel to take the air off. As this vessel was supposed to work at ambient temperature, the paint specification didn't include any heat resistance... look at the picture...

Similarly, operators should know the design limits for each piece of equipment they work with (this is also called the operating envelope).

3

Purging with steam

Steam is very commonly and very successfully used for removing air from vessels and lines prior to start-up because of the many advantages already discussed.

However, a greater volume of steam may have to be used to make sure that the purge is complete than if inert gas or nitrogen were used. When steam enters a cold vessel or line, all or part of the steam condenses. Only after the equipment is thoroughly heated does the steam remain as an inert vapour to push the air out of the vessel. With an inert gas or nitrogen, each volume introduced into the equipment forces out an equal volume of a mixture of the inert gas and air or vapours from the open vent.

Because of condensation, however, steam introduced into a vessel may initially displace very little of the air or gas. The total amount of steam necessary for effective purging depends upon the rate at which the steam is introduced, the temperature and weight of the vessel being purged, the outside temperature, and other factors. Therefore, greatly varying volumes of steam may be required to purge the same piece of equipment at different times.

A visible plume of steam at the vent is *not a* reliable sign that a vessel has been thoroughly purged. Figure 3 shows a jet composed of 36 percent by volume of air and 64 percent by volume of steam. The jet which is about one third air is almost identical in appearance to the jet in Figure 4, which is

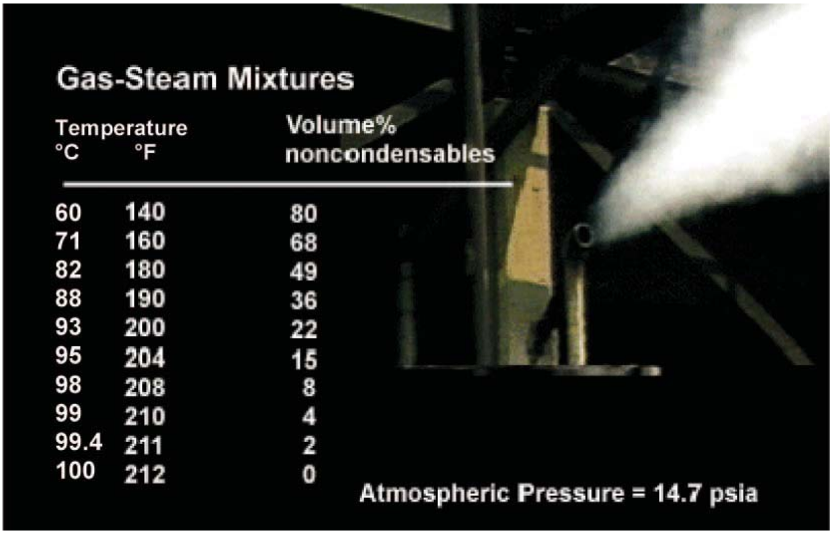
Figure 3 *The gas coming out of the pipe nipple contains 64 percent steam and 36 percent air. The dial thermometer measuring the mixture temperature reads 190°F (88°C). The temperature outside was 60°F (15.5°C) when the picture was taken.*

Figure 4 *The gas coming out of the pipe nipple is pure steam. The dial thermometer indicates that the steam is at 212°F (100°C). The temperature outside was 60°F (15.5°C) when the picture was taken.*

100 percent steam. Both jets would have appeared denser and been harder to tell apart if the pictures had been taken in cold weather instead of at 60°F (15.5°C) as they were.

The temperature of a saturated steam-air mixture at any pressure is an indication of its air content. Table 2 indicates the temperature and corresponding volume percent air or other noncondensables in various mixtures at atmospheric pressure.

Table 2 *Gas-steam mixtures*



Gas-Steam Mixtures

Temperature °C	°F	Volume% noncondensables
60	140	80
71	160	68
82	180	49
88	190	36
93	200	22
95	204	15
98	208	8
99	210	4
99.4	211	2
100	212	0

Atmospheric Pressure = 14.7 psia

Temperature is a better indication of purging completion than the appearance of the plume, but temperature measurements are neither simple nor completely reliable. The difficulty in using temperature is in locating the thermometer inside the vessel. Temperatures outside the vessel are not a reliable measure of conditions inside.

The time required to purge a vessel is partially determined by the size and weight of the vessel. For any particular vessel, changes in either the inlet steam pressure, the amount of water in the inlet steam, outside air temperature or wind can greatly change the time required for safe purging.

Therefore, operating procedures which call for steam purging for a definite time should specify the time required for safe purging under the least favourable conditions: for example, high wind, cold weather, low-pressure wet steam, etc. Purging for the minimum time required under the worst conditions will, under normal conditions, mean continuing the purge after the air content in the vessel has reached a safe level. The additional time and accompanying steam consumed are a price worth paying for safety in timed purges.

The value of the time and steam consumed to ensure safety of a timed purge is much greater than the cost of an instrument which can ensure safety without long purging. This instrument, the air-in-steam analyser (Figure 5a), was available commercially from Mine Safety Appliances Company (MSA) for a number of years, although it is not presently in production. A number of these analysers are currently in use in the Amoco heritage refineries and the drawings are available from these sites. The instrument measures the amount of air in steam and, therefore, ensures safety with the minimum use of steam and loss of time.

Figure 5a *MSA air-in-steam analyser. A simple, rugged instrument for measuring the quantity of noncondensables in steam was developed by the American Oil Company MSA. It works on the principle that the pressure of a steam-noncondensable mixture at a certain temperature indicates the percentage of non-condensables present.*

Specific precautions must be taken before and during the purging of some units. For example, taps leading to instruments which would be damaged by steam must be closed (Figure 5b).

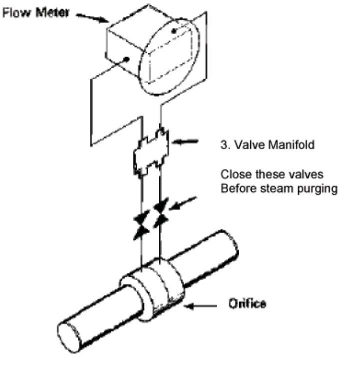


Figure 5b *Instruments which would be damaged by steam must be shut off during a steam purge.*

If synthetic rubber such as neoprene or buna-N is used in pump seals, the steam must be bypassed around the pumps to prevent damage to the seal material. Purging of lines with check valves and systems with parallel flow paths must be planned to ensure complete purging. Pressures must be checked to be certain that hydrocarbons or fluids under higher pressure do not back up into steam lines as the steam valves are opened. If steam is used in one side of heat exchangers, the other side should not be blocked in, as excessive pressures may develop (See Section 7, 'Thermal expansion' on page 22). Lines connected to a vessel being purged must be vented at the end away from the tower, otherwise there is no assurance that the steam will enter and purge the line. Alternatively, the lines may be blinded off and purged separately.

It is essential that a condensate drain be provided at the low point of each vessel being purged. A combined steam inlet condensate drain should be avoided since it can cause accumulation of large quantities of water in the vessel being purged.

4

Blanketing with steam

It was once common practice to protect vessels containing flammable liquids by filling the space above the liquid with steam. This practice is much less common now and is not recommended because of the difficulties encountered in actually safeguarding the vessel. An additional disadvantage of steam blanketing is that it adds water to the liquid in the vessel being safeguarded.

Blanketing is still used occasionally as an emergency measure. There is a possibility that the difficulties of steam blanketing will be forgotten, and the practice will be suggested in the future as a simple means of increasing safety. Therefore, the following discussion of blanketing is included despite the rarity of the practice at the present time.

Steam is an 'inert gas' so far as combustion is concerned. Therefore, it is useful for blanketing the vapour space above the liquid when a vessel must be opened and when it is not practical to pump out and gas-free the vessel.

Blanketing with steam is done to prevent air backing in and forming flammable hydrocarbon-air mixtures.

However, a substantial amount of steam must be used to prevent this. Hydrocarbon vapours require 30 to 50 volume-percent steam in the mixture to be nonflammable. Hydrogen requires even more—about 60 percent. This means at least 50 percent steam is necessary to make a safe vapour space in most refinery equipment. A steam-air mixture with at least 50-percent steam would have a temperature of at least 180°F (82°C) at atmospheric pressure (see Figures 6 and 7).

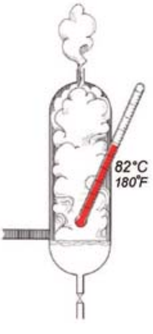


Figure 6 *A safe vessel.*

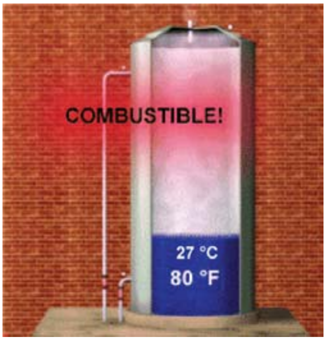


Figure 7 *An unsafe one.*

Any air-steam atmosphere with a temperature below 180°F (82°C) should not be considered safe. A common error is to add only enough steam to provide a good show of steam at the vent. As we have seen before in connection with steam purging, this show of steam can be misleading. The sequence of photographs in Figure 8 demonstrates this fact. The series of pictures printed from a motion-picture film show a drum supplied with a flammable hydrocarbon-air mixture and with steam. As can be seen, enough steam was added to produce a visible vapour cloud at the vent. In spite of this, an explosion was set off within the vessel by a spark plug.

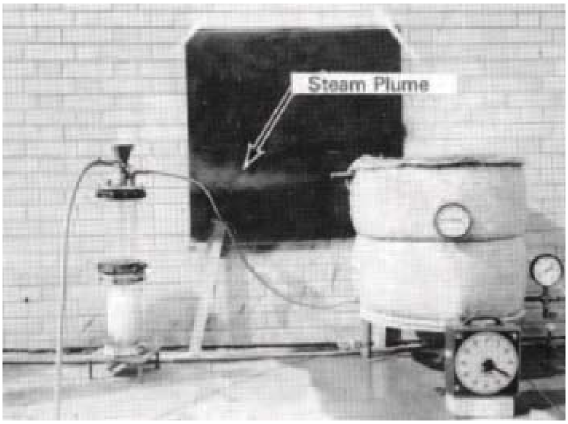


Figure 8a *A mixture of steam and air is being fed into the drum. There is a show of steam at the vent. The thermometer in the vessel reads 140°F (60°C), indicating the vessel contains only 20 percent by volume steam.*

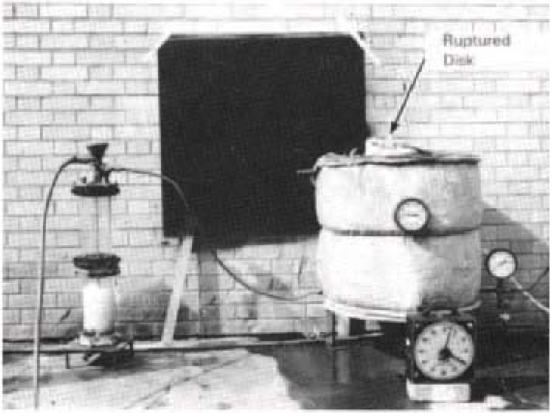


Figure 8b *A spark plug in the vessel was energized in the interval between this and the previous picture. Note the ruptured disc on the top of the vessel failing due to the internal explosion.*

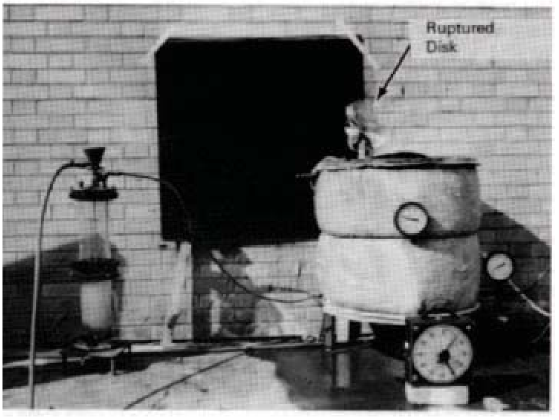


Figure 8c *The remains of the ruptured disc at the top of the vessel leave no doubt that there was an explosion inside the vessel.*

It must be remembered that a good show of steam at a vent is no guarantee that safe conditions exist within the vessel. As in the case of steam purging, safety can be assured only by making an analysis of the vent gases to determine if adequate steam is being supplied. At least, as a bare minimum safety requirement, a temperature measurement should be made within the vapour space to determine if sufficient blanketing steam is being supplied.

Insufficient blanketing steam may actually increase the hazard. In the case of heavier stocks which have flash points above the processing or storage temperature, adding insufficient steam may only heat the stocks above their flash points without inerting the vapour space. This was the cause of an agitator fire several years ago.

There is rarely enough steam capacity in a tank field to safely blanket a storage tank. Therefore, attempts to blanket a storage tank usually result in increasing the hazard by heating the liquid in the tank above its flash point without adding enough steam to the air space to prevent combustion.

The hazard may also be increased if blanketing steam is used and then is allowed to decrease to the point that the steam condensing in the vessel becomes greater than the quantity being added.

The pressure in the vessel will decrease, and air may be drawn in at the vent.

Steam is very useful as an 'inert gas' for blanketing and in extinguishing small fires such as at flange or exchangerhead leaks. In this use, many of the hazards of blanketing vessels are not present.

Care must be taken to bleed all the condensate out of a steam-hose lance before turning it onto a hot line or flange. Also be careful not to have the lance pointed at your feet or at another person in the rush to get the steam turned on. Aim the lance at the base of the flames, and operate it much the same as you would a carbon dioxide (CO_2) or dry powder extinguisher. Do not use steam on electrical equipment, as the moisture may cause short circuits and internal damage to the equipment.

5

Hazards from condensing steam

Steam will condense. This is a fact known to everyone, but it must be kept in mind in order to prevent damage to equipment or creation of hazards. When air in vessels and lines that operate at atmospheric pressure or above is being purged with steam prior to start-up, fuel gas or other suitable gas must be backed into the vessel when purging is completed in order to displace the steam as it condenses and to prevent formation of a vacuum. If the vessel is left full of steam with valves closed, condensation can produce a vacuum great enough to collapse the vessel (Figures 9a and 9b).

Figure 9a *Too much vacuum damaged this catalyst storage drum.*

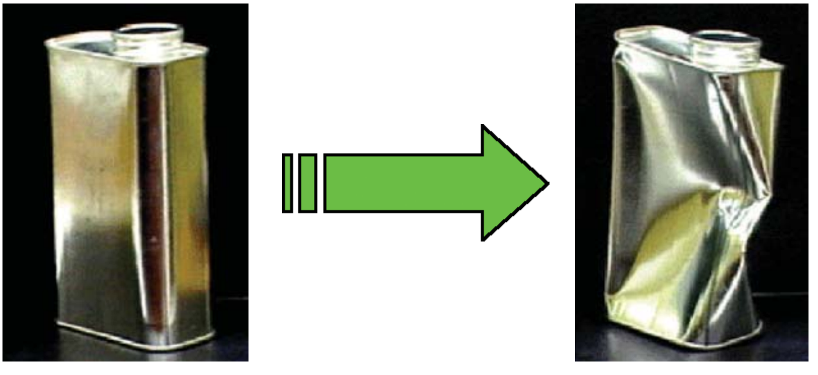


Figure 9b *Result of condensation. This can was filled with steam and then closed. The steam condensed, and the resulting vacuum caused the damage shown.*

ACCIDENT Before a shutdown, steam was introduced in the blowdown system of a combined Crude-Vacuum distillation unit to gas free it. After several hours of steaming, the blowdown vessel was isolated with hot steam inside, by closing valves. When the steam condensed, the vessel collapsed dramatically.

ACCIDENT A rail tank car was being steamed for cleaning and gas freeing before inspection. Again, valves were closed while hot steam was still inside the cistern.

Since valves frequently do not close tightly, the vacuum may draw in air, thereby creating a hazard if hydrocarbons are subsequently introduced into the equipment.

Fuel gas or other gas lines must not be opened into the vessel for backfilling until the steam pressure in the vessel is lower than the gas-line pressure. On the other hand, to ensure against a vacuum, the steam pressure must not be allowed to fall to a pressure lower than 5 or 10 psig (0.35 or 0.7 bar_g) before the backfilling is started.

Pressure gauges should be checked to be sure they register correctly at this low range on the scale.

Steam may be used to prevent a vacuum in a vessel as water or other liquid is drained. Since the steam can condense, it must be supplied at a rate greater than the rate of condensation plus the rate of liquid withdrawal to be of any benefit for vacuum breaking.

The drum shown in Figure 10 failed as a result of an internal explosion. The drum had been washed and left filled with water. A one-inch steam hose was connected with a $^1/_2$-inch (13 mm) pipe and fittings to the top of the vessel. Steam was supplied from a nearby 100 psi (6.7 bars) main before water was drained. Shortly after draining was started, sufficient vacuum developed in the vessel to cause air to be drawn in through the open bottom drain, thereby forming a flammable mixture with the residual hydrocarbon. The mixture exploded and fractured the shell.

Subsequent calculations indicated that steam was condensing as fast as it entered the vessel because of the large condensing area and the limited flow through the $^1/_2$-inch connections.

Thus, the steam did not accomplish anything in the way of vacuum-breaking and was an indirect cause of the explosion.

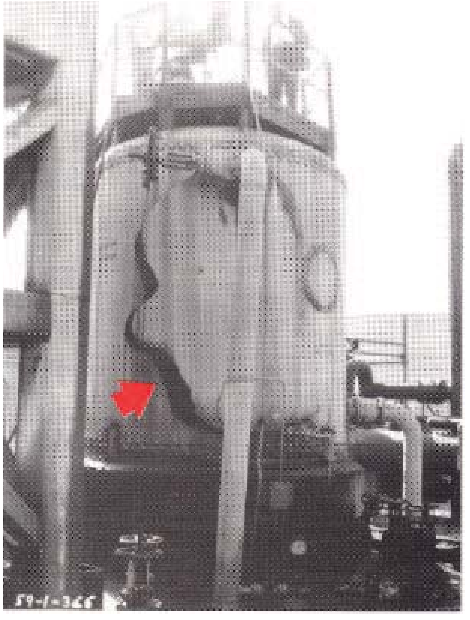


Figure 10 *This salt drum full of water was being drained. Steam was admitted at the top of the vessel to break the vacuum which otherwise would have been caused by the water being drained. However, the steam condensed more rapidly than was expected. As a result, a partial vacuum was formed and air leaked in, causing a flammable mixture that later exploded, ripping the vessel.*

Experimentation on similar vessels showed that water could be drawn without creating a vacuum only when the steam was introduced for a long enough period to heat the top of the vessel and reduce the rate of condensation. On a moderately cold day, with a wind of only 15 miles per hour (6.7m/s), it was found impossible to add steam fast enough through such a small connection to permit any water to be drawn without forming a vacuum.

When steam is used for vacuumbreaking, a compound (pressure-vacuum) gauge should be connected at the top of the vessel to show top pressure so that the water drawing can be controlled to prevent pulling a vacuum.

6

Water from steam

The BP Process Safety Booklet *Hazards of Water* points out many ways in which water can be a hazard if it remains in equipment or is introduced improperly into equipment.

Condensing steam is a very common source of water. Another common, and often overlooked, source of water is the condensate carried along with the steam. It is common for a line carrying saturated steam to have as much as 10 percent water entrained in the steam.

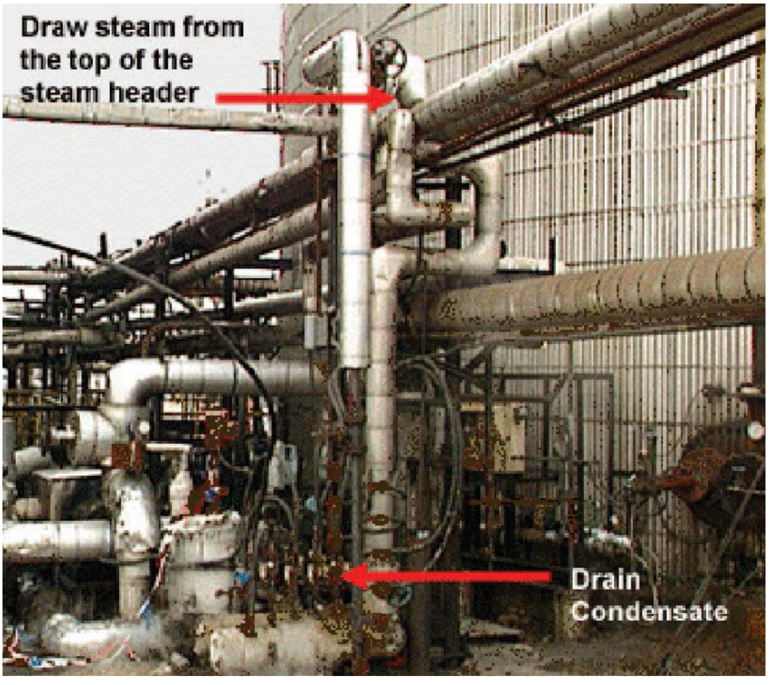
Water is usually removed from the steam lines and vessels by means of steam traps. Typical steam-trap installations are shown in Figure 11.

Figure 11 *Steam traps.*

Steam traps are designed so that water will pass through them but steam will not. Selection, installation and initial operation of steam traps must be done properly or else the trap will not remove all the water or will waste steam.

Steam traps often are booby traps. If it is necessary for a steam trap to discharge to the atmosphere, the discharge piping must be arranged so that persons in the vicinity will not be sprayed with scalding water when the trap discharges. Often underground discharge piping corrodes through and the steam and water wash out through a subsurface cavity. There may be little indication of this on the surface, and an unwary passerby may fall through into a cavity filled with hot water.

Difficulty is often encountered when the steam line to a unit or piece of equipment is connected to the bottom of the steam main. Water, condensing in the main, collects at the bottom and runs into the line, flooding or otherwise interfering with the unit's operation. It is, therefore, good practice to draw off steam from the top of the main.



Condensate or water in the steam-drive cylinder of a reciprocating compressor or pump can cause serious damage. The water cannot be compressed and, therefore, is as destructive as a loose block of steel would be. The momentum of the piston and attached parts causes extremely high stresses when the water stops the piston. Figure 12 (see page 20) shows the damage that can result.

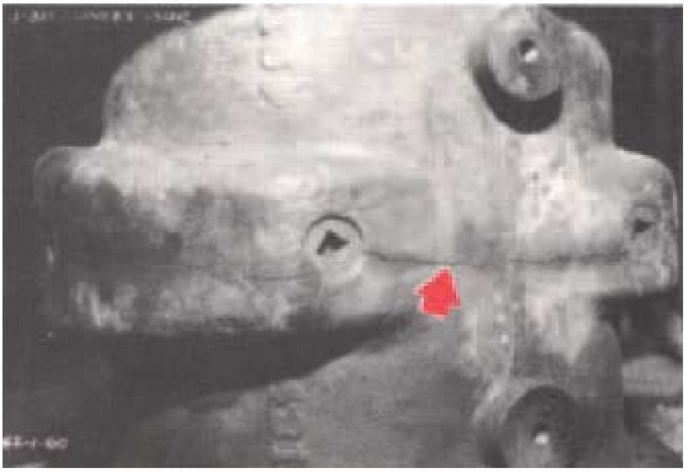


Figure 12 *Water damage to a compressor cylinder head. A leaking valve allowed water to enter the steam-driving cylinder of a large compressor. The water stopped the piston as it neared the cylinder head. The stresses resulting from the sudden stop cracked the cylinder head.*

Water in the steam to a turbine also can be destructive. Drops of water are speeded up as they go through the nozzles and strike the blades with the same effect as small stones striking the blades. Even small amounts of water can cause erosion of the blades. Therefore, water should normally be kept out of the steam to a turbine. Occasionally, small quantities of water are added to the steam going into a turbine to wash out internal deposits. Extreme care must be taken during such addition to prevent damage to the turbine.

Water coming into contact with hot oil can flash into steam and cause serious damage. Figure 13 (see page 21) shows the result of blowing water into a tower containing hot oil. The water was condensed in some cool furnace tubes and then blown into the tower.

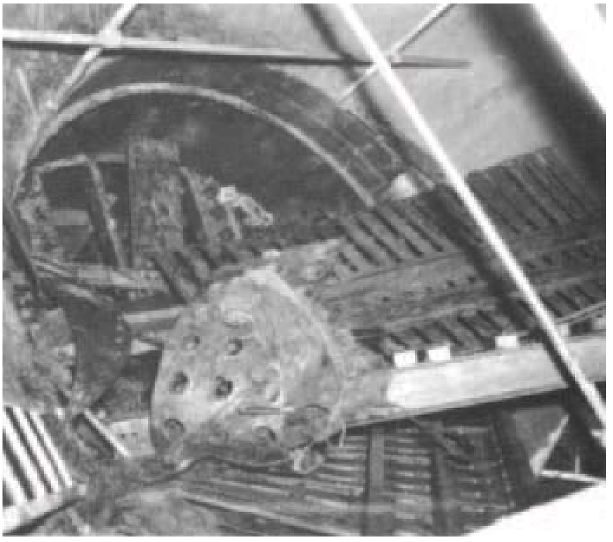
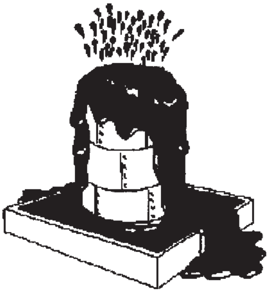


Figure 13 *This picture was taken through the manway of a large vacuum tower. The trays had been upset during a shutdown of the vacuum section of this crude unit. Pump difficulties delayed pumping out the vacuum tower bottoms. Hot primary tower bottoms were inadvertently leaking into the vacuum tower during this period. At the same time, the furnace was being steam purged into the vacuum tower. Condensate from this purge contacted the hot oil in the tower and flashed into steam, causing the serious internal damage.*

Water from a leaking coil in a hot reduced crude or asphalt (bitumen) storage tank can cause foaming of the oil over the top of the tank. It is preferable to keep heavy oils hot solely by insulation and residual heat of the oil rather than risk the introduction of water through leaking steam coils. If heat is required, circulation through an external furnace is preferred. If steam coils must be used, they should be maintained with great care to ensure freedom from leaks.



Steam introduced into hot furnace tubes must be thoroughly trapped to avoid slugging water into the hot tubes. Such slugging could lead to damaging pressure surges and to thermal shock that might damage the tubes.

7

Thermal expansion

Steam heating of blocked-in exchangers or steam tracing of pipe or other equipment *completely full* of liquid can result in dangerously high pressure rises if a means for venting the liquid is not provided. The very high pressures are produced by the liquid expanding more than the container.

The result is the same as if one tried by high pressure to force two gallons of liquid into a one-gallon tank. A vapour space in the equipment reduces the hazard only up to a point as indicated in the following example.

In a typical case of a vessel filled with water without a vapour space (see Figure 14), a 50°F (27.7°C) rise above the atmospheric temperature results in a pressure of 2,500 psig (172 bar_g), an average of 50 psi for each degree Fahrenheit rise in temperature (or of 6.2 bar for each degree Celsius). At higher temperatures, the rate of pressure rise per degree is even greater because the thermal expansion of water is greater.

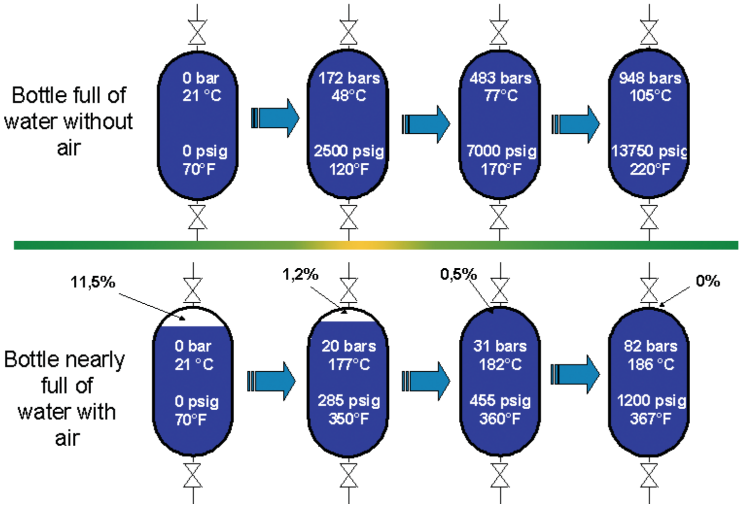


Figure 14 *Pictured here are steel vessels filled with water. The top vessel was completely filled with liquid, while 11.5 percent of the volume of the bottom vessel was filled with air. The rise in pressure as the vessels are heated is indicated.*

If too small a vapour space is present when the system is blocked in (Figure 14), expansion of the water causes the vapour space to be compressed as the warming occurs. The pressure rises much more slowly until the vapour space becomes small due to compression, or disappears entirely due to solubility of air or vapour in the water. Thereafter, the pressure at the high temperature level increases dramatically (as much as 100 to 160 psi per °F temperature rise).

Figure 15 shows what happened when an exchanger was blocked in and heated.

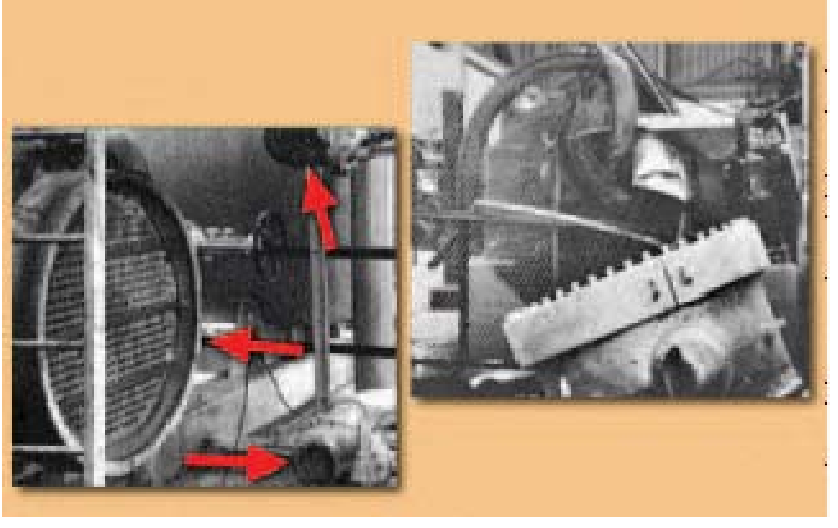
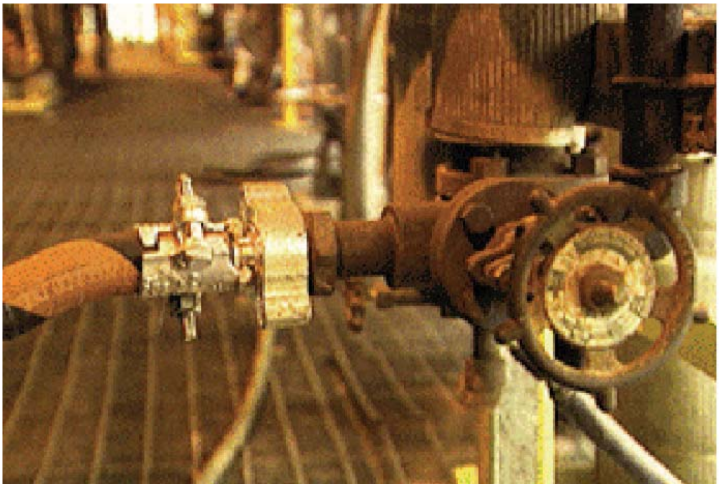


Figure 15 *Thermal expansion in this condenser resulted in serious injuries to personnel and caused extensive property damage. The condenser was opened and cleaned. The cast-iron heads were replaced followed by a hydrostatic test to the tube side. Without venting the water side, a steam hose was connected to the shell side for testing. Thermal expansion plus vapour pressure in the tubes ruptured the condenser with a jet-like thrust. See arrows marking rupture points.*

8

Stresses in equipment

The high temperature of steam can be undesirable. Water, air or fire hoses are not designed to withstand high temperature, and if used for steam service they will soon lose their strength and fail under pressure. Even a steam hose can be ruined if it is used for steam at too high a pressure.



Equipment with close clearances such as compressors, exhausters and meters should not be steam purged since the high temperature may cause permanent warping.

Cast-iron equipment is prone to crack when subjected to sudden changes in temperature. Therefore, steam used to purge cast-iron equipment should be admitted slowly and carefully.

Steam-turbine casings normally will fail if exposed to the full pressure of the inlet steam line. Therefore, the exhaust valve of a steam turbine must be opened before the inlet valve is opened.

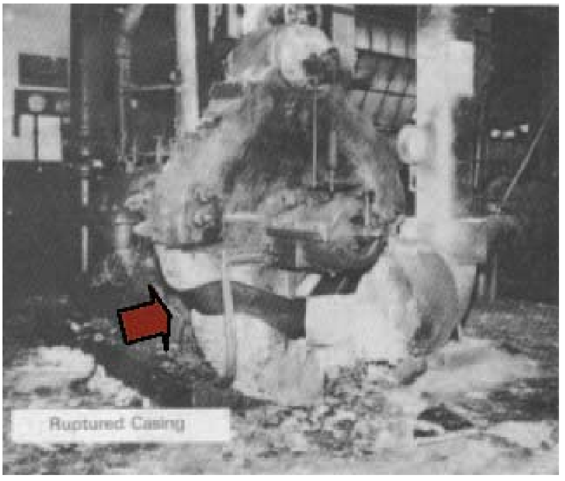


Figure 16a *This spare steam-turbine driven feed pump was required rapidly because of an electric power failure. The steam exhaust valve which was normally left open was closed because of previous maintenance work. Two operators, who were just arriving to work on a new shift, opened the steam inlet valves without noticing that the exhaust valve was closed. The casing ruptured, and two people were hurt.*

ACCIDENT Figure 16a shows what happened when, during an emergency which coincided with a shift change, a steam-turbine inlet valve was opened with the exhaust valve closed.

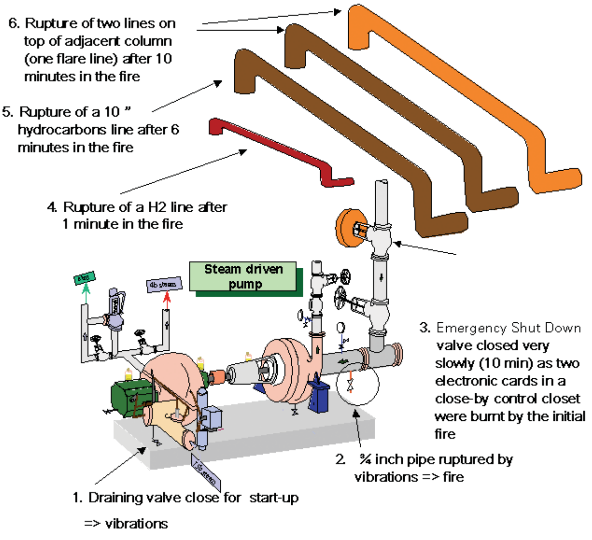


Figure 16b *Multiple pipe rupture and fire.*

ACCIDENT A similar incident occurred when an operator started a steam driven pump without first draining water from the turbine. The vibrations were transmitted to the pump and after a few hours, a 3/4-inch pipe ruptured (see Figure 16b). The ensuing fire burst multiples pipes in the vicinity and it took 18 hours to extinguish the fires. The unit was badly damaged.

Tags should be placed (see Figure 17a) near steam-turbine inlet valves warning the operator to check that the exhaust valve is open before opening the inlet valve. It is also good practice to locate the exhaust valve where it can be seen by anyone opening the inlet valve (see Figure 17b).

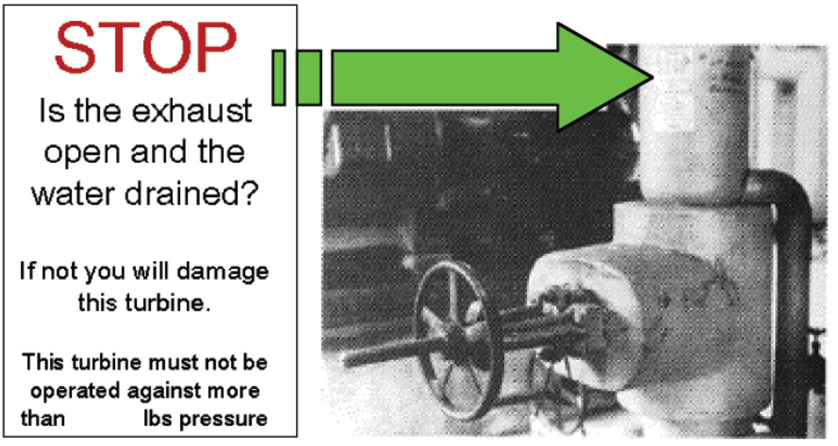


Figure 17a *Turbine inlet valve warning tag.*

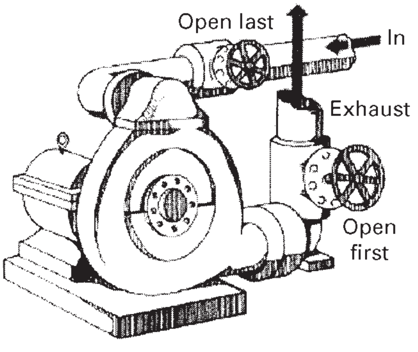


Figure 17b *Ensure that the exhaust valve is open before opening the steam-inlet valve.*

9

Static charge

Steam jets can produce large static electrical charges. The charges generated by these jets can be conveyed to an insulated object which would discharge electrically in the form of a spark and may ignite flammable mixtures. The insulated object need not be in the steam cloud to be charged. If the hydrocarbon stocks in a storage tank form a flammable mixture with air at the temperatures involved, precautions referred to later on are necessary when steaming to avoid the danger of igniting the flammable mixture.

ACCIDENT A few years ago, a tanker compartment which had contained naphtha exploded. This compartment measured $20 \times 15 \times 30$ feet ($6 \times 4.5 \times 9$ m) and was about to be cleaned with water using a tank cleaning machine consisting of a set of rotating nozzles. This machine was coupled to a new, dry water hose and lowered into the tank to a depth of approximately 20 feet (6 m) from the deck.

Contrary to the usual practice, the tank's steam-smothering system was turned on before putting the tank cleaning machine into operation. Steam was injected for about 10 minutes. Before the water valves of the tank cleaning machine could be opened, the tank exploded. The machine had formed an insulated object on which charge from the steam could collect.

It is often desirable to use steam for cleaning operations because it is so effective. However, precautions must be taken to avoid hazards from static charges. Before equipment is cleaned with steam jets, all internals and the nozzle of the steam hose should be carefully grounded. The hose nozzle should be either grounded by a separate external grounding wire or by an approved metal-braided hose. Braided hose should be checked periodically to ensure that the metal braid still forms a continuous electrical path. Vessels and drums should be grounded when they are normally insulated from ground. With these precautions, the hazards of steam cleaning may be considerably reduced.

10

Water in steam lines

The BP Process Safety Booklet *Hazards of Water* is concerned with the dangers resulting from mixing hot oil with water and the explosive effects of water when it is suddenly vaporized. The booklet also covers the need to drain steam condensate from all parts of systems during shutdowns in freezing weather.

Water vapour or steam can also be dangerous under certain conditions when it is suddenly condensed into water. This hazard is always present when cold lines, tank coils or vessels are pressured with steam.

Most of us have heard 'water hammer' in a steam line. Many of us have seen valve bodies and pipe fittings broken into pieces by 'water hammer.' If not properly controlled, water hammer can be extremely dangerous to both men and equipment.

Repressuring steam lines must be done very carefully to avoid possible injuries or damage to the line and connected equipment. Valves on traps and drains should be open when steam is admitted in order to speed up removal of air and to assist in controlling the warmup. The valves will normally have been left open if the weather is cold to prevent ice forming in the lines and damaging trap valves and piping. No one should be in front of an open drain or vent as they may be burned when steam is admitted.

Steam should be admitted to the line slowly at first. A small bypass around the main steam block valve should be installed and used to control the initial steam flow. Main steam block valves which are not bypassed should be cracked initially to limit the amount of steam entering the line being repressured. The admission of steam should be continued until the lines are warm and the air is out of the lines.

The best indication that the air is out of the line is when the temperature of the line is at least equal to the temperature of saturated steam at the pressure in the line. An air-in-steam analyser can be used if there is no thermometer in the line.

Once the air is out of the lines and the lines are warm, the drains and vents should be closed. The steam rate should then be increased slowly until the line is at its operating pressure.

All steam traps should be checked to ensure that they are functioning properly.

The traps should discharge at intervals, with the discharge made up of mainly water with a little steam. Bucket traps which discharge steam continuously can usually be made to function properly by closing the discharge valve for a short time. Closing the discharge valve allows condensate to build up in the trap, thus priming the trap.

The length of time required for warmup depends upon the size and length of the line and the temperature and pressure at which it is to operate. A fully warmed-up 100 psi (7 bars) line will have a temperature of 338°F (170°C). As a guide, steam should be admitted to a line slowly for at least an hour before it is fully pressured.

If steam is admitted into a cold system too rapidly, it will almost immediately fill the entire system and most of it will be in contact with pipe metal that is still cold. Some of the steam will contact the surface of any water left in the steam from previous use. Both the pipe metal and the water will pick up heat from the steam. The metal will pick up the heat faster than the water, but the water will pick up more heat per weight than the metal. When the heat is lost from the system, a large volume of steam in the system will condense into water. A tremendous reduction in volume occurs. Every 30 cubic feet (0.85 m^3) of steam will be reduced to about a cup of water. As the steam shrinks into a small volume of water, more steam rushes in to fill the vacuum thus created. In the process, very high steam velocities are generated. This fast-moving steam picks up water that has condensed in the lines and slams it up against fittings, bends or anything else that interferes with straight-line flow. It is these flying slugs of water that do the damage associated with ‘water hammer’ (see Figure 18).

In tests made by Detroit Edison Company in a 16-inch main, pressure surges as high as 6,000 to 7,000 psi (414 to 483 bars) were measured at the end of the main furthest from the steam inlet. It is no wonder that water hammer resulting from rapid admission of steam can damage fittings or even piping itself.

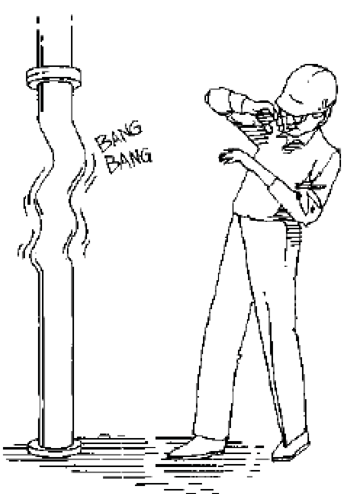


Figure 18 *Water hammer is dangerous.*

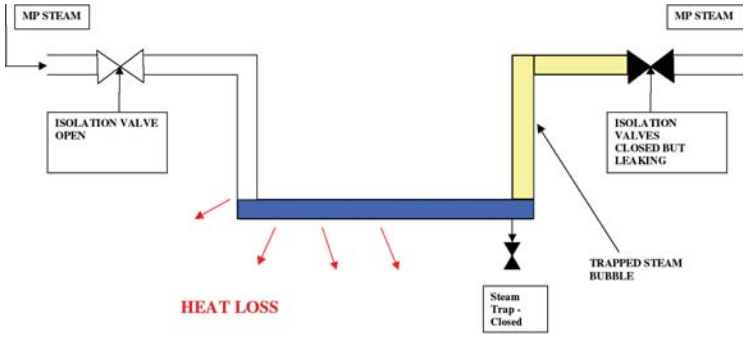
For more details on the stored energy hazard from steam, refer to the BP Process Safety Booklet *Hazards of trapped pressure and vacuum*.

It is less well appreciated that water hammer can also be caused by the rapid collapse, or imploding, of a steam bubble and the mechanism and theory of this are referred to as 'condensation induced water hammer'.

This mechanism occurs when steam comes into contact with relatively cold condensate or when condensate meets a trapped steam bubble. Due to temperature differences heat transfer between the two is rapid, causing a collapse of the steam (i.e. a significant reduction in volume occurs as steam vapour changes to a liquid condensate). This is followed by an inrush of more condensate at high velocity to fill the void. The nature of this mechanism is such that it inherently involves much larger volumes of water because lines need to be flooded to isolate a steam bubble. Thus when water hammer occurs, a large volume (and hence mass of water) travelling at high speed is rapidly decelerated. The high energy dissipated as a result of the rapid deceleration results in a pressure wave travelling at high speed back through the water column.

ACCIDENT In the period immediately prior to the incident a length of line was effectively a 'dead-leg' since the MP steam supply system had been isolated on the South Side but was open on the North Side. This allowed steam to continuously enter the section of MP steam main in the culvert. In the absence of a pathway through on the South Side MP steam entering the system therefore gradually cooled and condensed. The resulting change in state from vapour (steam) to liquid (hot condensate) resulted in a reduction in volume. This allowed more MP steam to enter the culvert section and hence to cool and condense. As a result steam was continuously entering the culvert section and condensate was continuously being produced.

As the steam trap at the lowest point in the system had been isolated it allowed condensate to accumulate in the system. A catastrophic failure occurred to a



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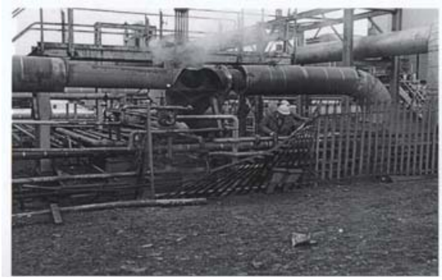
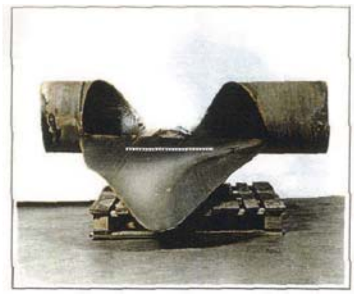
section of the MP steam pipeline. The failure, which occurred suddenly and without warning, involved the rupture of a tee piece on a 18" diameter (450 mm) section of line operating at a pressure of 200 psig (14 bar_g).





As a result of the U-configuration of the pipework beneath the road when the condensate built up to the point where it flooded the horizontal section, the steam present on the South Side was trapped between the condensate in the culvert and the isolation valves on the South Side. This effectively created a trapped steam bubble.

The geometry of the system was such that the condensate level eventually rose to a point where it ran underneath the steam bubble, creating a much larger surface area in contact with the steam. By this time the condensate had cooled significantly leading to rapid heat transfer and collapse of the steam bubble. The collapsing steam bubble created a differential pressure across the accumulated condensate causing it to accelerate into the void. The mass of condensate involved was in the region of 8,820 pounds (4 tons) and this was stopped abruptly when it reached the isolation valves. The resulting pressure wave is believed to have caused the failure of the tee piece. The investigation team concluded that the most likely reason for the pipeline failure was internal overpressure caused by ‘condensation induced water hammer’.

It is important to note that:

- The kinds of dead-legs that lead to this situation can be created by temporary isolations for a whole variety of reasons.
- Once the steam bubble is isolated, the gun is loaded and the trigger cocked. Unless the right actions are taken, the hammer will occur.
- Under these circumstances an ordinary steam trap can become safety critical and so can the isolations around it. Operators and engineers need to be able to identify vulnerable systems and recognise when the system configuration has been changed to introduce a new dead-leg. Valves need to be controlled by tagging or locking to ensure they don’t get tampered with.
- Only isometrics/linewalks can identify vulnerable systems—P&IDs don’t show the relevant detail.

11

Steam burns

Steam is hot! Uninsulated steam piping can be a source of serious burns (see Figure 19).

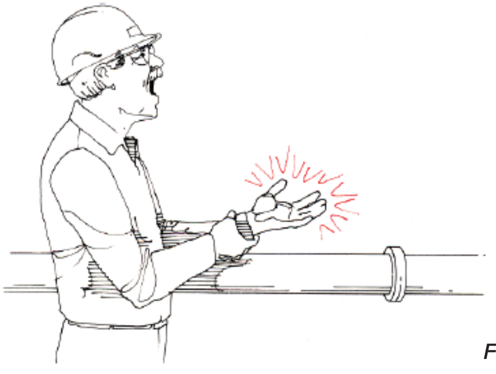


Figure 19 *Bare steam piping is hot!*

Steam itself, if breathed, can produce lung burns or suffocation. For this reason, snuffing-steam connections to pump rooms or other areas in which personnel might be present should not be turned on unless extreme precautions are taken to ensure that the people will get out before the steam is turned on.

Steam burns can be fatal. Numerous tragic incidents have occurred in all industries when sudden steam releases occurred. See also the BP Process Safety Booklet *Hazards of Water*; section 4, *Burn hazard from hot water*.

Steam connections to vessels can be seriously hazardous to maintenance personnel. In a chemical plant, a millwright entered a dryer to measure for new fire brick. An instrument mechanic working on the automatic fire steam equipment removed part of the control, allowing 400 psi (27.6 bars) steam to enter the dryer through the fire steam line. The millwright was fatally burned in the two or three minutes before the steam could be turned off at a manual control valve.

Many vessels present a similar hazard. Therefore, all steam lines to process vessels must be blinded off before workmen enter (see Figure 20).

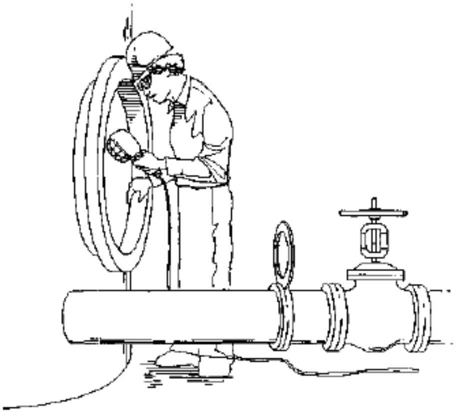


Figure 20 *Blind or disconnect steam lines before entering vessel.*

To allow anyone to enter a boiler, the preferred isolation is physical disconnection (removal of spool or valve) and blanked open ends. Failing this, spades fully rated for the line pressure must provide positive isolation. Valve isolation only, locked or not, is unacceptable for confined space working. This applies to any line into or out of the boiler (water side or furnace side). A permit must be issued with authorization by a responsible person, atmosphere testing must be conducted, verified and repeated as often as defined by the risk assessment and a stand-by person must be stationed at all times outside the vessel.

ACCIDENT The following incident illustrates the need for being certain that steam lines are fully depressured prior to opening the lines. Two mechanics were assigned the job of overhauling a 6-inch (150 mm), 50-pound (3.5 bars) steam control valve in place. The line had been isolated by closing four valves but had not been depressured. The employees removed the studs from the bottom cover plate of the valve; and, squatting by the valve, they were tapping the flange to break it loose, when it suddenly released. Both men were sprayed with condensate and steam. One fortunately sustained only minor burns. The other sustained disabling burns about the legs and arms.

The cause of the accident was failure to relieve the pressure. Always be sure that the equipment is depressured before it is opened. Wear long sleeves and gloves when working around uninsulated hot lines and fittings.

12

Miscellaneous hazards

Although the principal hazards resulting from the incorrect use of steam have been mentioned, everyone can think of other lesser hazards which may not lead to disastrous fires or explosions but which can result in discomfort or injury to personnel or cause minor fires and similar difficulties. Steam carelessly applied or incorrectly used for fire fighting can short out electrical equipment. Of course, steam should never be used on electrical fires for this reason.

Purging steam should not be used with acid systems, such as in alkylation units, where condensate could be a hazard when acid is added.

In cold weather, the steam clouds from various operations may obscure visibility and create a hazard (see Figure 21a). In cold weather, the condensation of steam from leaks, open vents or other sources may form ice (see Figure 21b), which can be a hazard to personnel.

Figure 21a *Steam clouds can obscure visibility.*

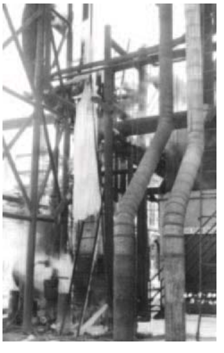


Figure 21b *Ice from steam traps.*

Steam admitted suddenly into hoses or swivelled piping can cause the hose or piping to swing rapidly. People have been hurt by such loose hose or piping. Even in these little things, steam should be used cautiously and intelligently.

High-pressure steam escaping from a leak is invisible and can cut its way through a solid object. Figure 22 shows a board being cut by 1,200 pound (83 bars) steam escaping from a nozzle. Care must be taken when searching for a steam leak—remember that what you cannot see may hurt.

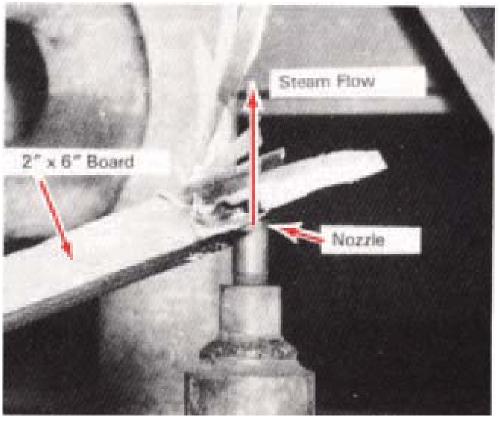


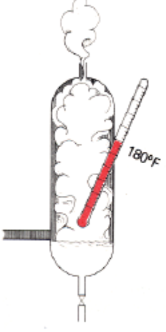
Figure 22 *High-pressure steam can cut through a solid object.*

High pressure steam leaks are also extremely noisy and can permanently hurt earing. Such a leak can occur without warning (e.g. relief valve opening, pipe rupture . . .) so adequate PPE must be worn when entering steam production plants.

13

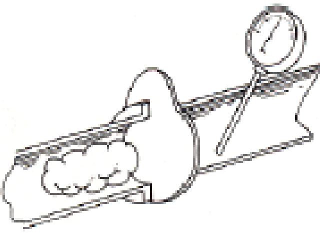
Some points to remember

1. Appearance of steam issuing from a vent is not a reliable way of telling the amount of air in the steam. Use a noncondensables meter to determine completeness of purging.



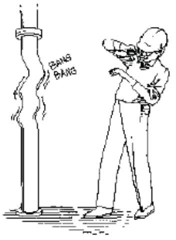
2. When steam is used for blanketing to exclude air, be sure that sufficient steam is used to keep the temperature up to at least 180°F (82°C).

3. Steam can damage pump seals and instruments. Block off or bypass equipment which can be damaged.

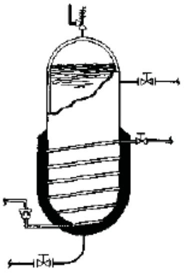


4. Steam can condense to 1/1600th of its original volume. This reduction in volume can cause high vacuums. Provide adequate vents or vacuum breakers.

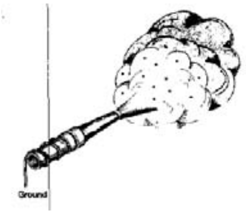
5. Use of steam is a frequent way of unintentionally adding water to hot oil, either by direct injection or through leaking steam coils. Take proper precautions to prevent foamovers.



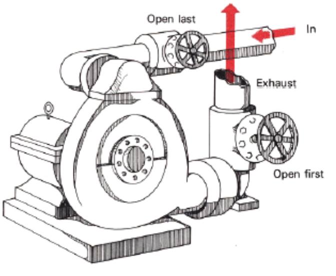
6. Sudden application of steam to cold equipment can cause equipment failure by thermal shock or water hammer. Turn steam on slowly.



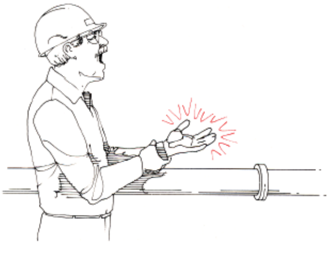
7. Steam heating can cause tremendous pressure in blocked-off vessels or pipes completely full of liquid. Make sure there is either adequate vapour space or a pressure-relief mechanism before applying steam.



8. Steam can generate static electricity. Take proper precautions, such as grounding, to reduce sparks.



9. Always open the exhaust valve of a steam turbine before the inlet valve is opened.



10. Steam is hot. It will burn badly.

Acknowledgements

The co-operation of the following in providing data and illustrations for this edition is gratefully acknowledged:

- BP Refining Process Safety Network
- Whiting Refinery Training Department
- Glyn Hawkins and Keith Wilson, HSE UK, IChemE Loss Prevention Panel member

Test yourself!

1. A steam leak is always visible.

   True ☐ False ☐

2. When steam is used for blanketing to exclude air, sufficient steam has been used when:

   a. steam is visible at vent ☐
   b. steam temperature at injection point is above 130°F (55°C) ☐
   c. steam inside the vessel is at least at 180°F (82°C) ☐

3. Steam can be used on all fires.

   True ☐ False ☐

4. Steam inerting systems, if mismanaged, can add water to hot product vessels, thus enhancing the hazard of froth-over.

   True ☐ False ☐

5. Steam burns are not severe injuries.

   True ☐ False ☐

6. Water hammer effects are frequent when steam is admitted into a cold system too rapidly.

   True ☐ False ☐

7. Water hammer can destroy equipment and cause injuries.

   True ☐ False ☐

8. Steam heating is safe and can't create overpressure in pipes, even full with closed valves.

   True ☐ False ☐

9. All vessels are designed to sustain the vacuum resulting from steam condensation.

   True ☐ False ☐

10. All refinery equipments are designed to endure a long steaming time.

    True ☐ False ☐

1F/2C/3F/4T/5F/6T/7T/8F/9F/10F