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BP Process Safety Series

Hazards of Water

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.

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Contents

1

The nature of water and steam

Man can live only a few days without water—far less than he can live without food. Water makes up about 80 percent of the weight of our bodies, covers four-fifths of the surface of the earth, helps crops grow, produces power to light our homes and cook our food, and performs thousands of other valuable services for man.

Maybe you are saying, ‘So what—I know these things and a lot more too. I know that we couldn’t run a refinery even one minute without water.’ That’s right. A refinery requires a lot of water—water for cooling and heating, as steam to run pumps, and for many other process requirements.

We are all familiar with the old saying about fire—how it can be a servant to man but also his master, his destroyer. The same may be said of water. Water is necessary in a refinery; but at the wrong place in a process system, it can be hazardous.

What is the big danger from water that accidentally enters a refining unit? If the water is flashed to steam by hot oil, an explosion could result.

At 212°F (100°C) and atmospheric pressure, water expands about 1,600 times (Figure 1). In other words, one unit (gallon or litre) of water would expand to 1,600 units (gallons or litres) of steam.

Figure 1 *At 212°F (100°C) and atmospheric pressure, water expands about 1,600 times!*

Vaporizing a 5-gallon (19 litres) can of water produces enough steam to fill a tank car (Figure 2).

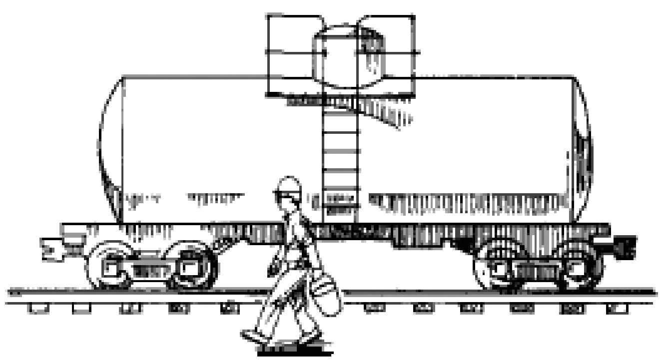
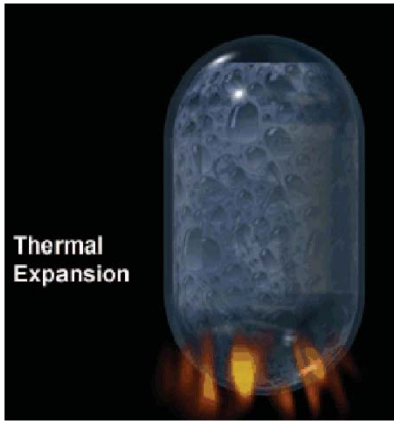


Figure 2 *A 5-gallon (19 litres) can of water produces enough steam to fill a tank car.*

At pressures higher than atmospheric, water boils above 212°F (100°C); however, at pressures lower than atmospheric, it boils below 212°F (100°C) and expansion is much greater.*

*See the BP Process Safety Booklet *Hazards of Steam*.



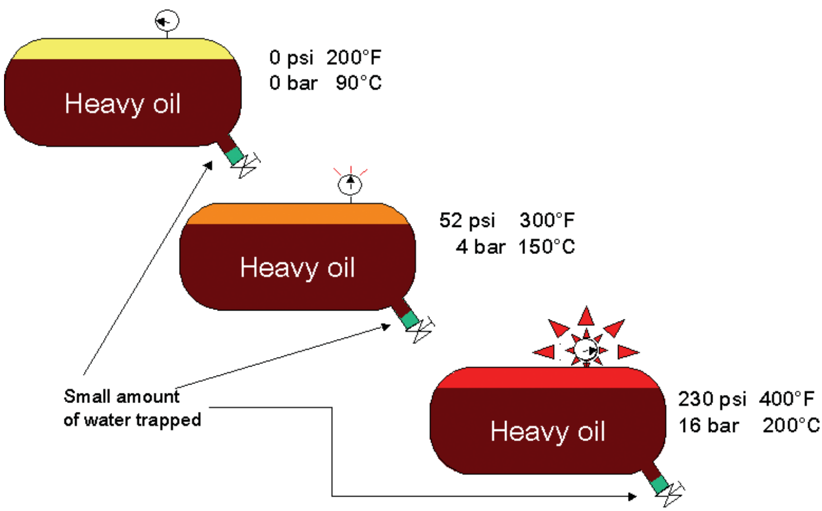


Figure 3 *Water can create very high pressures when heated in a closed vessel.*

This tremendous expansion shows why a small amount of water left in a refining vessel can be dangerous. Water can create very high pressures when heated in a closed vessel—even with a vapour space (see Figure 3).

Warming or heating vessels, exchangers, pipe or other equipment that is completely full of liquid can result in dangerously large pressure rises even before the boiling point is reached if means for pressure venting are not provided. This pressure rise is due to thermal expansion of the liquid. In a typical case using water (Figure 4, upper row), a 50°F (27.5°C) rise above room temperature results in a pressure of 2,500 psi (pounds per square inch) (172 bars), an average of 50 psi (3.4 bars) for each degree rise in temperature. At higher temperatures, the rate of pressure rise per degree is even greater because the expansion of water is greater.

When a vapour space is present (Figure 4, lower row), expansion of the water causes it to become compressed as the warming occurs. The pressure rises much more slowly until the vapour space becomes small due to compression, or it disappears entirely when all of the air or vapour dissolves in the water. Thereafter, the pressure rises abruptly at the higher temperature level—100 to 160 psi (7 to 11 bars) per degree Fahrenheit (0.55°C) of temperature rise.

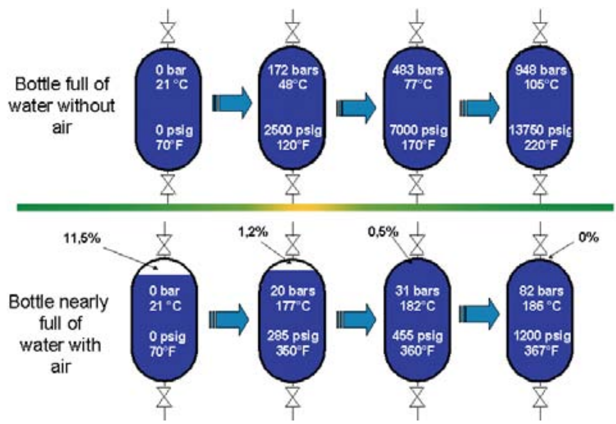


Figure 4 *Pressure rises in vessels with and without a vapour space.*

Dangerously high pressures—high enough to rupture almost any system not protected with a pressure-relief device—can develop when closed systems, nearly or completely filled with water, warm up. Also, the destruction resulting from a rupture is much greater if the water at the time of the rupture is above its atmospheric boiling point (212°F (100°C)).

Figures 5 and 6 demonstrate the destruction that can occur when steam is admitted to the tube side (Figure 5) or the shell side (Figure 6) of an exchanger without first opening the appropriate shell or tube drains and vents.

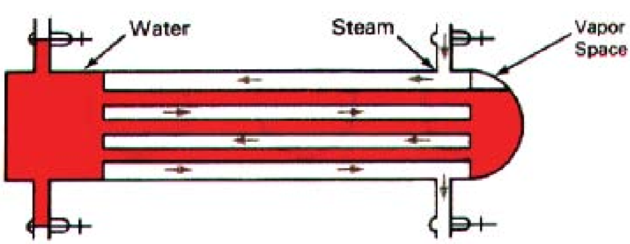


Figure 5 *Thermal expansion alone can rupture equipment. Thermal expansion plus steam pressure cause even greater destruction.*

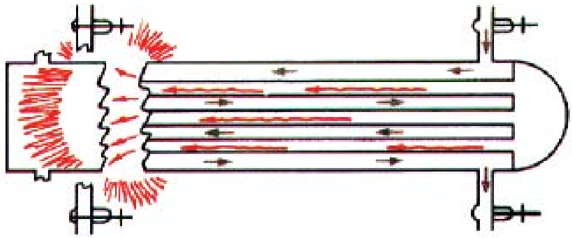


Figure 6 *Thermal expansion in this condenser resulted in serious injuries to personnel and caused extensive property damage. The condenser was opened and cleaned. The heads were replaced, followed by a hydrostatic test to the tube side. Without venting the water, a steam hose was connected to the shell side for testing. Thermal expansion plus vapour pressure ruptured the condenser with a jetlike thrust. Note rupture points marked by short arrows.*

You might ask, 'Why is water so dangerous? Why isn't it just as dangerous to mix cold oil with hot oil?' The differences between the physical properties of water and oil explain why.

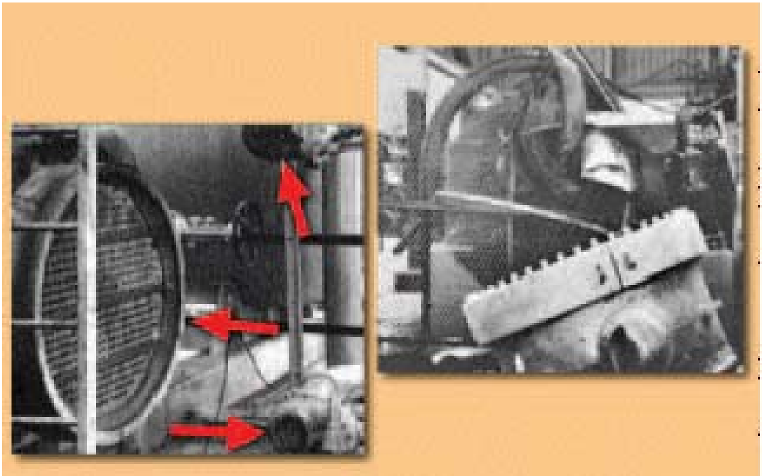
Water at 400°F (204°C) in a closed container produces steam having a pressure of 230 psi (16 bars), whereas kerosene produces a pressure of only a few pounds (tenths of bars). Heating a heavier oil would give an even lower pressure. Oils such as crude oil and gasoline are complex mixtures of different chemical compounds. Each compound has a specific boiling point. We can illustrate this by heating a typical crude, 12 percent of which will boil off at 212°F (100°C). Some compounds boil off at 100°F (38°C), more of them at 200°F (93°C).

As the temperature rises, others boil off—at 800°F (427°C), most of them are gone.

Thus, if we put an average oil into a hot system, only the part of it that boils below the temperature of the system would vaporize. In contrast, all of the water would vaporize at 212°F (100°C) at atmospheric pressure.

Let us take an example. A low-pressure crude fractionating tower is being brought onstream. Much of the oil is slightly above 212°F (100°C).

Accidentally, we introduce a barrel of water. As it flashes, it will produce hundreds of barrels of vapour. The resulting pressure surge can upset trays, pop the relief valves and cause other damage. Instead of water, suppose we introduce a barrel of cold crude. Only the 12 percent that boils below 212°F (100°C) flashes to vapour—an expansion of somewhat less than 340 times. Thus, we produce less than 41 barrels of vapour instead of several hundred as in the case of water (see Figure 7).



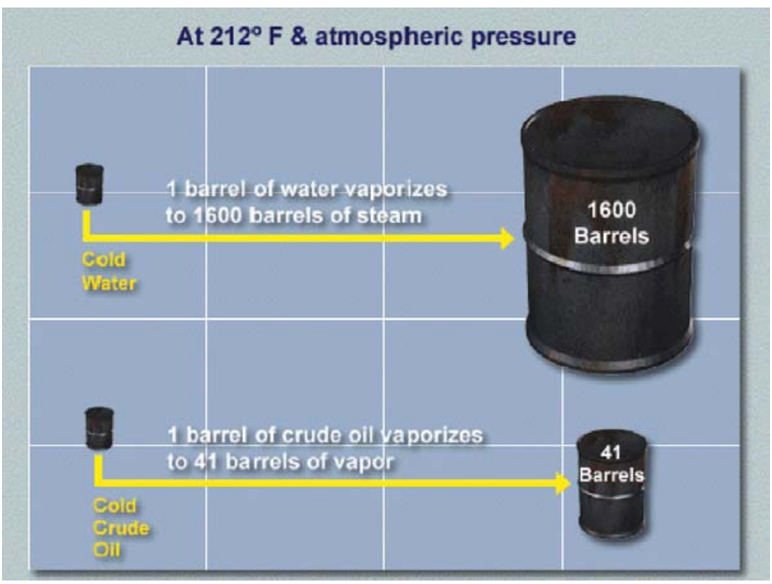


Figure 7 *At atmospheric pressure, a barrel of water will flash to 1,600 barrels of steam at 212°F (100ºC). A typical barrel of crude oil will flash to only 41 barrels of vapour at the same temperature.*

2

Water in process units

The hazard of water is always present in a start-up. Water may be used directly to expel air from process equipment. In such cases, the weight of the water can be a hazard unless vessels and structures have sufficient strength and foundations are heavy enough to withstand the weight safely (Figure 8a). Water filling should not be attempted until the structural specifications are studied carefully to detect any weaknesses that may make the use of water unsafe. If water enters a riser or pipe extending above the top of a vessel, the total pressure at the bottom equals the hydrostatic head from the bottom of the tank to the water level in the riser.

ACCIDENT

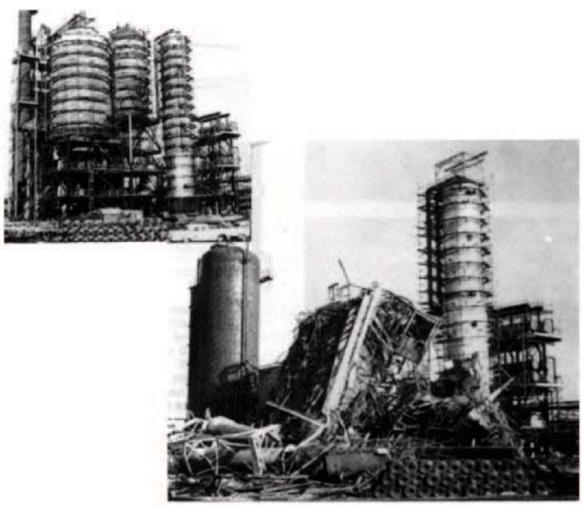


Figure 8a *Failure of structure under water load.*

It is also very important to make sure that structures are able to withstand other loads during hydrostatic tests (for example, there is often a wind limit at which a high tower can be hydraulically tested; snow and ice . . .) and that they are still well inside their original characteristics (e.g. no corrosion, etc.)—see Figure 8b.

ACCIDENT A 20-year old, 12,580 bbls (2,000 m^3) sphere was taken out of service for an internal inspection and hydrotest. It was approximately 75% full of water in preparation for the hydrotest when the legs collapsed (see Figure 8b). One death and one injury occurred as a result of the structural failure. The legs of the sphere were coated with fireproof concrete and salt water was used in the water deluge fire protection system on the spheres. The water sprays were tested at periodic intervals.

The legs had suffered severe corrosion underneath the fireproofing. The same incident occurred at another refinery back in the 1970s.

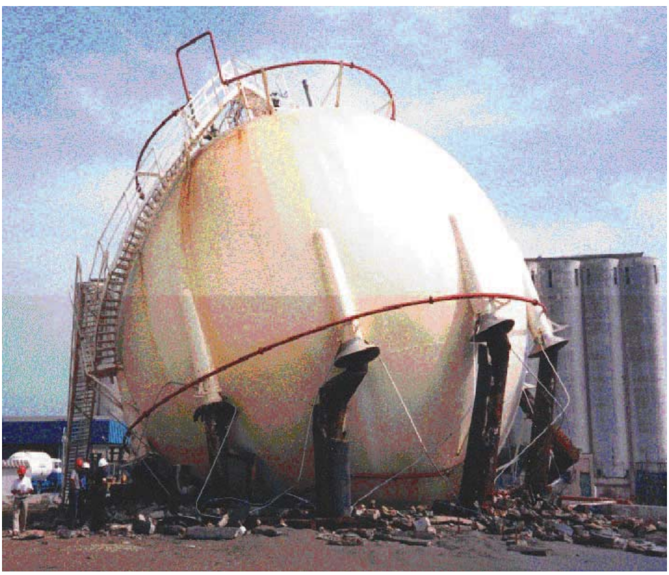


Figure 8b *This sphere collapsed during an hydraulic test because legs were corroded behind fireproofing concrete. An inspector was killed.*

If vents are inadequate or become blocked during filling, pressure can be built up in excess of the weight of water. To avoid excessive pressure, a pressure gauge installed close to the lowest point of the equipment being filled with water should be observed closely. After the use of water, careful draining is necessary to prevent trapping water in the unit or pulling a vacuum by allowing the water to drain too fast.

The start-up procedure of most units requires feeding steam through vessels, drums and lines to purge air from the system. Also, vessels may be steam tested to detect leaks. During the steaming, water forms in trapout pans, bottoms of vessels, low spots of lines, behind orifice plates, above horizontal valve bodies and in exchangers. This water must be removed initially by draining (see Figure 9). To be sure the drain is open, the operator must actually see liquid coming out of the drain line.

To assure complete removal of the water, circulate oil—first cold, then warm and finally hot—through the system.

When water—an efficient condenser of steam—is already in a vessel being steamed, more purging steam is needed than if no water were present. Likewise, if steam is being used for pressuring a vessel to prevent drawing a vacuum as water is drained, enough steam must be used to compensate for condensation.*

*See the BP Process Safety Booklet *Hazards of Steam*.

To ensure that proper pressure is maintained, a pressure indicator should be installed in the top of the vessel.

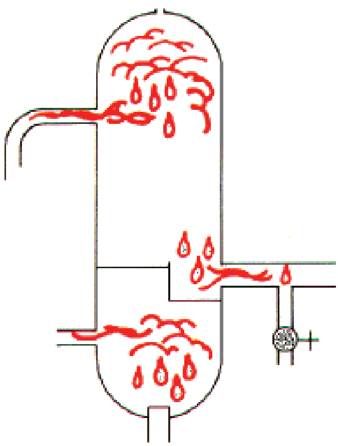
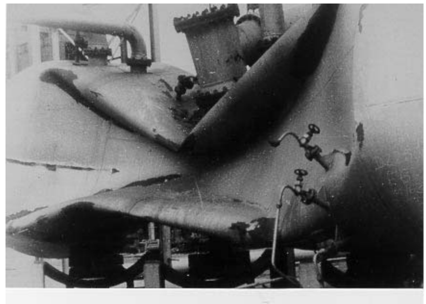


Figure 9 *When steam is used to purge air or test for leaks, condensation occurs and water collects. This water must be removed by draining and by circulating oil through the system.*

Figure 10 *A vacuum vent and one open hatchway were not enough to prevent damage when steam condensed and pulled in the top two courses of this 35 ft (10 m) diameter by 21 ft (6 m) high wash tank.*

ACCIDENT Before a shutdown, steam was introduced in the blow-down system of a combined crude-vacuum distillation unit to gas free it. After several hours of steaming, the blow-down 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.

Small drain lines become plugged. Every effort must be made to ensure that they are clean before the unit starts up. If there is no flow of any kind from every drain opened during the start-up, operators must safely remove the blockage immediately so that water will not be trapped (Figure 11).

When equipment, such as an exchanger on a unit, is cleaned while the unit is in operation, extra care must be taken to remove all traces of water before returning the equipment to hot-oil service.

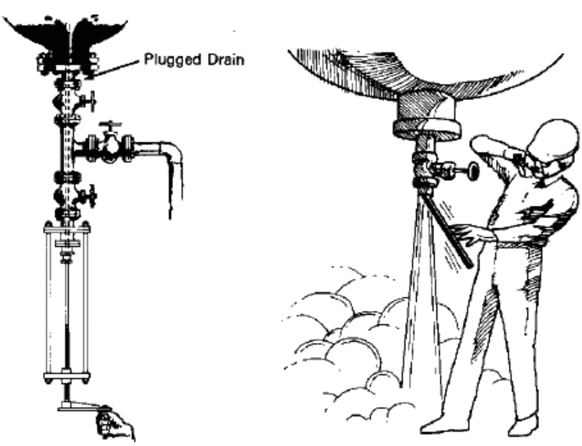


Figure 11 *All plugged drains must be opened safely.*

Water expands as it freezes. Always remember that ice takes more volume than the original water. This is a very common source of incidents, particularly in dead-leg pipes where water can accumulate.

Therefore, in cold climates, operators must be constantly alert to prevent equipment damage or hazards because of water freezing. Normally, freeze-ups occur only during shutdown periods when water flow is low or shut off completely. However, in severe weather, even lines flowing at normal rates may freeze up. Lines containing temperature-actuated flow-control valves are particularly susceptible to this danger. Because of the lessened cooling requirements due to the low air temperature, flow may be reduced markedly. It may be necessary to open a bypass line or a drain to keep the flow high enough to prevent freezing.

When a unit is shut down during cold weather, water lines that would normally be blocked and full of water must be drained and blinded. Pumps and other equipment must be carefully drained. Opening the drain valve is not enough; drains should be rodded or otherwise checked to make sure that no plugs of ice or other material are present which would prevent free and complete drainage.

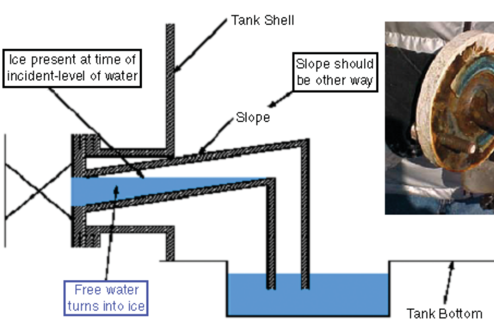
Steam lines and steam equipment that are shut off also must be carefully drained to remove condensate that could freeze and damage equipment. Steam traps left in service should be checked frequently to prevent their freezing. Condensed steam upstream of a frozen trap may freeze and damage piping and equipment in which it has accumulated.

When equipment is purged with steam during cold weather, care must be taken to block off instrument leads in which water could condense and freeze.

Figure 12 *Pump cover plate was broken by freezing water.*

ACCIDENT A cast iron deadhead flange on a pipe that was not fitted with a thermal relief valve burst/cracked at temperature in the low 30°Cs (80°F) spraying liquid hydrocarbons onto the adjacent ground. The spillage was limited by the amount between two block valves, approximately 20 gallons (75 litres).

ACCIDENT A flange gasket failed on a water draw-off line of a gasoline storage tank during a thaw following prolonged freezing temperatures. This led to the loss of 13,750 gallons (52,000 litres) of gasoline.



ACCIDENT A spill of about 8,200 bbls. of Jet-A fuel from a broken sight glass on a storage tank's water drainage piping occurred when the sight glass was broken due to expansive forces exerted as water in the piping froze.

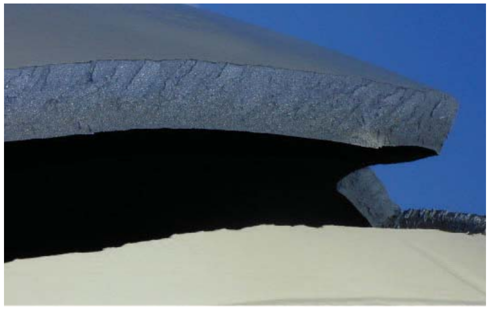
ACCIDENT An explosion and fire occurred in the pipe alley of a vacuum distillation unit. The incident was caused by the freeze-up and subsequent failure of a 2" carbon steel pipe which released a high pressure spray of light hydrotreated naphtha towards the vacuum furnace and transfer line, where it ignited.

Total cost of the incident is estimated at $14 million—$10.5 million in production losses, the remainder in maintenance and associated costs. The failed line had been taken out of service approximately 20 years before, but had never been fully isolated or decommissioned. The piping acted as a large pocket or 'dead leg,' allowing water to accumulate. As the result of an extreme cold front, the trapped water froze, expanded, and cracked the pipe. During a subsequent warm up of the weather the next day, the ice plug melted, releasing hydrocarbon.

ACCIDENT A section of utility piping failed in a distillate desulphurization unit. The failure was the result of internal over-pressure generated from water freezing in a dead leg section of piping. There was a release of hot product from the stripper section of the hydrotreater. The resulting vapour cloud ignited, and fire damage to nearby equipment released additional hydrocarbon. Although the unit was quickly isolated, there was extensive damage to pumps, several air coolers, analysers, instrumentation, electrical conduits, and process piping. Direct damage to the unit was $5.9 million, and the unit was down for 52 days.

Also, without going to freezing conditions, water temperature is critical when hydrotesting because it can cause brittle fracture. To avoid that, current standards for new pressure vessel fabrication, recommends that the metal temperature during hydrostatic pressure testing be maintained at least 30°F (16.5°C) above the minimum design metal temperature. For repairing boilers and pressure vessels, it is recommended that the metal temperature for the pressure test shall be in accordance with the original code of construction but not less than 60°F (15.5°C) unless toughness characteristic information indicating acceptability of lower test temperatures is made available.

ACCIDENT During a hydraulic test, a tower ruptured. It was concluded that the failure had been due to brittle fracture because of the low water temperature.



Besides causing dangerous icicles to form, water leaks lead to icing of platforms, stairways and access areas. Operators must be very alert to recognize possible freeze-up hazards due to changing conditions during the shutdown period.

ACCIDENT In one instance, equipment in a building was not drained because building temperature normally would have remained well above freezing during shutdown. However, a subsequent power failure shut down the steam plant, thereby permitting the building to cool down. Before emergency heaters could be installed in the building, the temperature inside dropped below freezing, and extensive damage to the equipment resulted.

Ice may form in process vessels or lines that are steamed or water-washed during shutdown. During start-up, all ice within vessels and lines must be melted, and the water must be removed before admitting hot oil. During start-up, all drain connections also should be checked carefully to make sure that they are not plugged with ice.

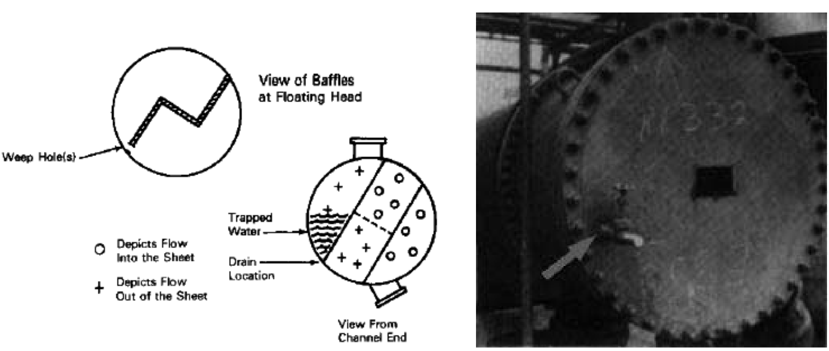


Figure 13 *A sometimes overlooked hazard is water trapped by exchanger baffles. A drain installed through the channel cover and/or weep holes installed in channel and floating-head baffles corrects this hazard.*

After a unit is fired, lines and vessels must be drained or flushed. At that time, the following also must be done:

- Reflux lines and manifolds must be flushed before the tower temperature, where the reflux enters, reaches 200°F (93°C).
- Both regular and spare pumps must be started up to flush out the suction and discharge lines.
- Heat exchangers and condensers must be flushed to slop or back to tankage, depending upon operating procedures.
- Blowdown and emergency lines must be flushed.

If telltales are used in the draining process to check the character of the liquid being drawn off, the telltale must be tended when open and plugged when not in use.

Figure 14 *Freezing water leaks create hazardous working conditions.*

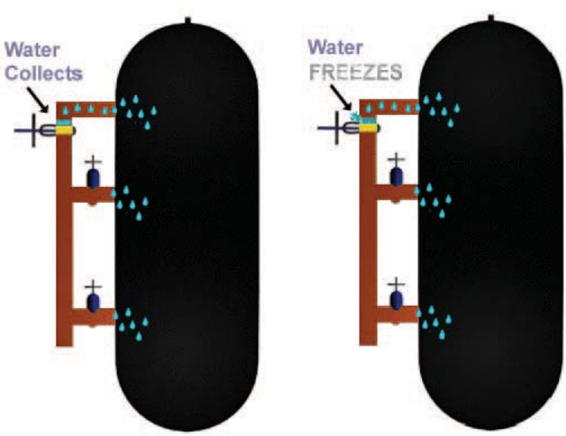


Figure 15 *Process lines often have branch connections which are used intermittently. Water may collect in the lines and freeze in some climates, fracturing lines or valves.*

ACCIDENT A restriction of cooling water flow at a refinery occurred due to the formation of ice at the water intake structure. The water flow into the intake was substantially restricted due to a build up of ice in the bay at the intake structure, severely reducing the flow at once through cooling water at the refinery.

The ice build formation was caused by the sudden change in weather conditions, the temperature dropping to 10°F (−12°C), with 20 mph (32 kmph) winds from the north which pushed the ice in the bay towards the intake. The incident caused partial shutdown of the refinery.

2.1 Water and steam connections

Water lines used for washing and cooling process unit vessels must be blinded before oil is charged to the vessels.

Steam connections to process vessels or lines must be blinded (see Figure 16) before oil is admitted to the vessel unless steam is used in the process. Where steam is injected into process vessels, there must be steam traps to eliminate the possibility of a water shot. These steam traps must always be in working order.

2.2 Asphalt (bitumen) oxidizing vessels, stills and tankage

To help eliminate water hazards in asphalt (bitumen) oxidizing vessels, stills and tankage, provisions should be made to prevent accidental introduction of water into hot asphalt. Double blocks and bleeders should be provided on all steam connections. If practicable, asphalt-charge tankage should be kept well above the boiling point of water to prevent water accumulation.

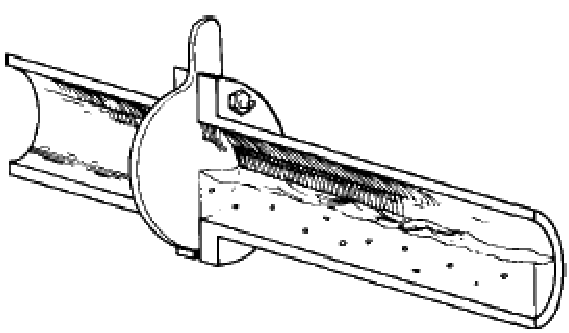


Figure 16a *Blind service water and steam connections.*

Temperatures of 212°F (100°C) to 265°F (130°C) should be avoided. Temperature of the storage asphalt should be greater than 265°F (130°C) to minimize foamovers and less than 500°F (260°C) to avoid thermal cracking (less than 450°F (232°C) if the tank is constructed according to API 650).

A bottom-fired asphalt still should be visually inspected before charging to determine that the still is free of water.

If a small amount of water remains which is not practicable to remove, the operating procedure should provide for the introduction of air as soon as the air coils are covered.

It is unsafe to dry out asphalt stills by firing a still when empty because the asphalt adhering to the shell will thermally crack (decompose). Gas produced by heating may then form an explosive mixture that could be ignited by the hot fire sheet of the still.

However, when the level of asphalt in the still is such that it covers the fire sheet, which usually is a depth of 3 to 4 feet (1 to 1.2 m), the still can be fired. If foaming occurs during this period, more air should be introduced into the still to strip out the water.

Heating and air blowing can be continued until the still is charged. This same procedure should be followed whether the water is in the still before charging or is in the charge stock.

A vertical oxidizer should be visually inspected for water prior to charging if it has been idle for an extended period, or if conditions are such that an accumulation of water is suspected. If water is found, it must be removed. If a small amount of water remains which is not practicable to remove, the operating procedures should provide for the initial introduction of charge stock through a bottom connection. As soon as the air coil is covered, or when there are 3 to 4 feet (1 to 1.2 m) in the vessel, air should be introduced at the rate of at least 1,000 cfm (cubic feet per minute) (1,700 m^3 per hour), and air agitation should continue throughout the entire charging period.

In general, the safest operating practice is to assume that there is always a small amount of water present prior to pumping into the empty vessel, and operating procedures should be written accordingly.

ACCIDENT During the start-up of a bitumen (asphalt) blower unit, the bitumen blowing column was overpressured. The bolt and safety pin mechanism on the top cover of the vessel broke and about 7 m^3 (1850 gallons) of residue was blown some 60 m (200 feet) in the air and for a distance of about 150 m (500 feet)—see Figure 16b.

There were no injuries sustained and no damage to plant, but there was a three-day loss in bitumen production.

The cause of the incident was an accumulation of water in the bottom of the blowing column and bottom line following flushing of the unit. The water came into the column either through a steam line or from the blowing air line. During the commissioning of the column, the water reached a high temperature zone, immediately flashed to steam and overpressured the column, causing the top cover to lift and release residue to the atmosphere.

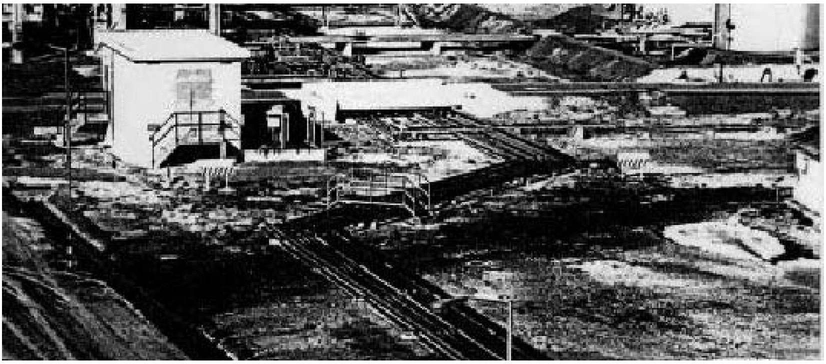


Figure 16b *Projection of bitumen over pipe-racks.*

2.3 Water in reflux drums

The water that collects in reflux drums in normal operations should be drained often to prevent it being pumped back to the tower with the reflux. This water, if not drained, may violently upset the unit.

Operators should be aware of the normal amount of water drawn each time. A greater than normal amount of water is a sign of a leaking overhead condenser or a leaking steam reboiler (when steam pressure is higher than tower pressure). More frequent draining will be required until repairs are made.

2.4 Controlled use of water

In some processes, water is introduced into heated oil or vapour at uniform and carefully regulated rates.

Such operations include catalytic polymerization, where water is admitted carefully into the system by proportioning pumps, and catalytic regenerators where quench water is provided. In these cases, the amount of water used is closely controlled.

The danger lies in uncontrolled mixing of water with hot oil.

2.5 Pipe stills

Water is a hazard in pipe stills, particularly in the start-up. Although eliminating places where water can be trapped is mainly an engineering problem, an operator thoroughly familiar with his unit can overcome the possibility of trapped water by proper start-up. Water drawoffs should be drained periodically during start-up. It is important to circulate cold charge stock, then heat gradually to the temperature at which water will vaporize, and continue circulating until all water is eliminated.

ACCIDENT Several years ago, two men were killed when an exchanger exploded. A pipe still was being brought onstream. During the procedure, a paraffin distillate exchanger (see Figure 17) was not properly drained. The vessel had an adequate drain connection in the bottom head, but it was not used. As a result, a stagnant pool of water accumulated in the head, up to the shell drawoff nozzle. When hot oil was introduced, an explosion occurred that blew the 7,000-pound (3,175 kg) exchanger shell high into the air. It landed 770 feet (235 m) away and buried itself in the ground (see Figure 18).

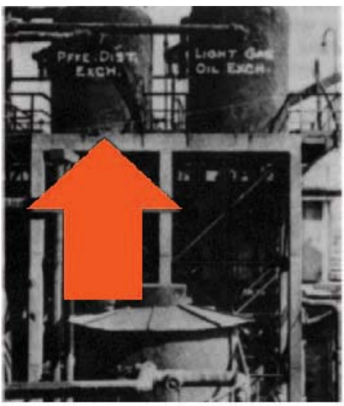


Figure 17 *Paraffin distillate exchange.*

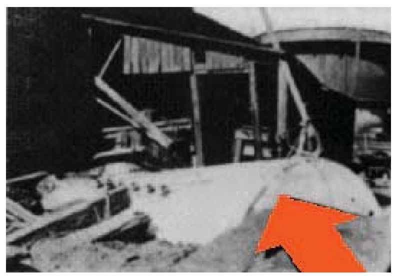


Figure 18 *Paraffin distillate exchanger after the explosion.*

2.6 Vacuum towers

Potential hazards exist in the start-up of vacuum towers that are not found in the start-up of other types of units.

Water flashing into steam can be particularly hazardous in a vacuum tower. The volume expansion upon vaporization is much greater because of the low pressure in the tower. For example, water expands in volume nearly 5,000 times upon vaporization at about 160°F (71°C) at 20 inches mercury vacuum (see Figure 19).

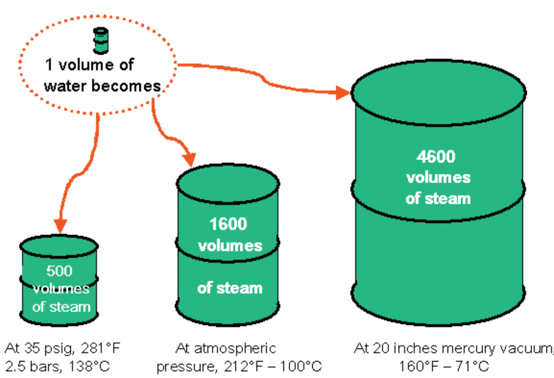


Figure 19 *A small amount of water can expand to a tremendous quantity of steam when heated.*

Furthermore, the large diameter of vacuum towers makes the trays especially vulnerable when exposed to the sudden flow caused by rapid vaporization.

Once the system is under vacuum, water can no longer be drained from low points. If draining is attempted, air rushes into the tower and may form an explosive mixture with hydrocarbon vapours. Pulling a vacuum does not evaporate water left in the system unless the temperature is high enough to boil the water. The water must be removed by circulating oil, which is gradually heated, until all water is vaporized and eliminated. Carefully developed procedures are available to accomplish this difficult task.

ACCIDENT During a start-up all trays in a large vacuum tower were upset and dropped to the bottom of the tower. The tower had been properly drained, evacuated and then charged with oil. Cold-oil circulation had been started through the tower, and the temperature gradually had been raised to about 500°F (260°C). At this time, normal flow of oil was to be established by opening a valve at the bottom of the tower to bring oil to a pump.

Before this particular start-up, a second valve had been installed in the line to the pump to give double blocks for safety in maintenance work (see Figure 20). It was not realized, however, that the second valve created a dead space between the two block valves and that water had been trapped between them. When the valve at the bottom of the tower was opened, the water in the piping between the valves mixed with the hot oil and flashed to steam, which surged upward through the tower. Excessive pressures caused by this surge of steam seriously damaged the trays.

This incident shows not only how damaging small quantities of water in vacuum towers can be, but also why the effect of any changes made in a process unit must be carefully analyzed. Thus, adding a single valve for safety created a hazardous condition when the prescribed start-up procedure was followed. *Even minor design changes must be considered carefully to determine if any change in procedure is needed to prevent hazardous operations.*

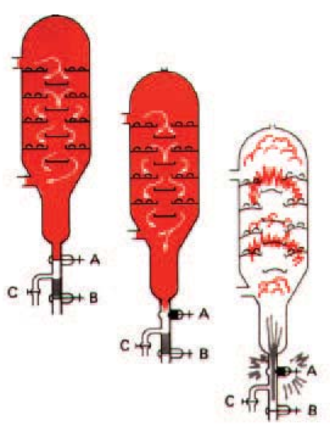


Figure 20 *Oil temperature was raised to 500°F (260°C) with water trapped between valves 'A' and 'B.' Valve 'A' was opened and allowed hot oil and water to mix. Water flashed to steam and upset trays. Position of valve 'C' connection prevented draining.*

ACCIDENT Another incident occurred in a Vacuum Distillation Unit (VDU) when inventories in the Light Gas Oil (LGO) and Heavy Gas Oil (HGO) accumulators were returned to the tower. It is believed that water from condensed steam collected in the accumulators along with the LGO and HGO. On returning this oil/water mixture or applying vacuum to the tower with its temperature above the boiling point of water, the water rapidly flashed off. It is concluded that the expanding water vapour produced a water hammer effect on the gas oil and slightly subcooled water surrounding the vapour, and these slugs of liquid pounding on the trays and beams contributed to the damage sustained.

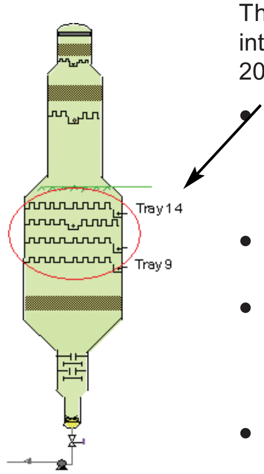


Figure 20b Vacuum tower internals.

The following damage to the vacuum tower internals was subsequently discovered (see Figure 20b):

- Trays 9–14 and their support beams were destroyed, and beams were sheared off from the braces welded to the tower shell and the trays had collapsed over the beams.
- The gussets under the braces were crumpled and the braces were in a downward position.
- The beams had experienced a significant downward force leading to buckling of several cross members of the beams—the ends of the beams experienced extensive damage.
- The position of internals suggested that the force had centred at the southern section above tray 14, the LGO return tray.

Production losses and cost of repairs were in excess of $7,000,000.

2.7 Other fractionating towers

The water problem in catalytic crackers, reformers and other more complex units is no different from that of simple units, except there may be more places for water to accumulate and thus more places to check. A problem may arise in a fractionating tower if there is water in the charge stock. This water may become steam in the tower and seriously damage the tower internals.

Towers, low spots in lines and other equipment are most likely to contain water after a unit has been shut down for maintenance and repair. Special care must be exercised to make sure that water is removed before it is suddenly vaporized. In cold weather, the equipment may be steamed to melt ice that may have formed in water pockets. Flushing with warm—not hot—oil, helps remove both water and ice. Draining low points and slowly warming equipment effectively removes water. Sudden vaporization of relatively small quantities of water may upset trays, pop relief valves or even damage the vessel.

ACCIDENT A number of incidents occurred in a combination tower in recent years. In one of them, nearly all the trays were upset. The cause of these upsets was water from an overhead vapour line from a coke drum.

This line had a long horizontal run with a vertical leg at the coke drum. The tower, supported at the bottom, was heated prior to heating the coke drums. The tower expanded and brought the line out of its horizontal position, trapping water at the base of the vertical leg. When the coke drums were heated, the vertical section of the line lifted, and the water spilled into the hot combination tower and vaporized (see Figure 21). Pressure increased suddenly; the relief valves opened but could not prevent costly damage to the tower.

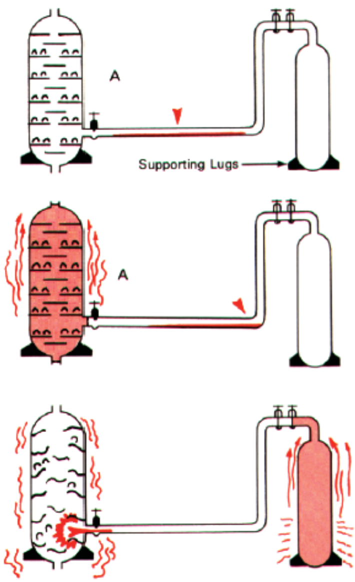


Figure 21 *Combination tower 'A' was connected by a long horizontal line with a vertical leg to coke drum 'B.' Tower 'A' was heated, and it expanded, lifting the tower end of the line. Condensation from steam testing and water driven off the oil collected at the coke drum end of the line. When coke drum 'B' was heated, it expanded and dumped water into tower 'A', where it flashed and damaged tower internals.*

The picture (in Figure 22) of the upset trays, taken through the combination tower manway, shows the great damage a little water can do when it is suddenly flashed to steam in such a tower.

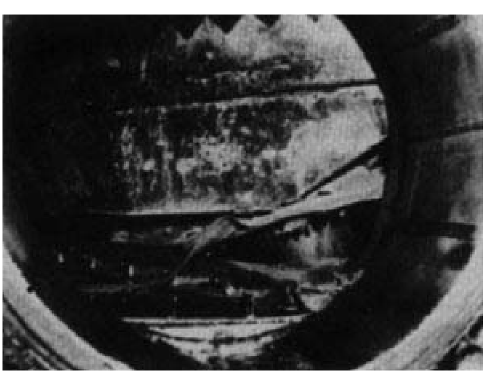


Figure 22 *Damage caused in a combination tower when a small amount of water was flashed to steam.*

The start-up procedure was altered to require that oil be flushed through the horizontal line to drive out water before the line and tower become hot. In such situations, positive drainage in lines running between two vessels must be assured to prevent any water from being trapped.

Fractionators that are prepared for start-up by using steam to expel air should not be placed on hot-oil circulation until condensate is carefully removed and precautions are taken against further steam condensation. After steaming, fuel gas should be backed into the tower and all condensate drained. In an alternative procedure, the entire tower is heated above 300°F (150°C) before hot oil is introduced so that steam in the tower or bleed steam does not condense and drain into the hot oil.

ACCIDENT Another incident dramatically emphasizes how a block valve incorrectly located provided a trap for water. It occurred during a start-up of a catalytic cracker. A motor-operated block valve in the vertical section of the 40-inch (1 m) line between the reactor and the fractionator isolated the two vessels during warm up. Above the valve was a 3/4-inch (20 mm) line for draining condensate (Figure 23a).

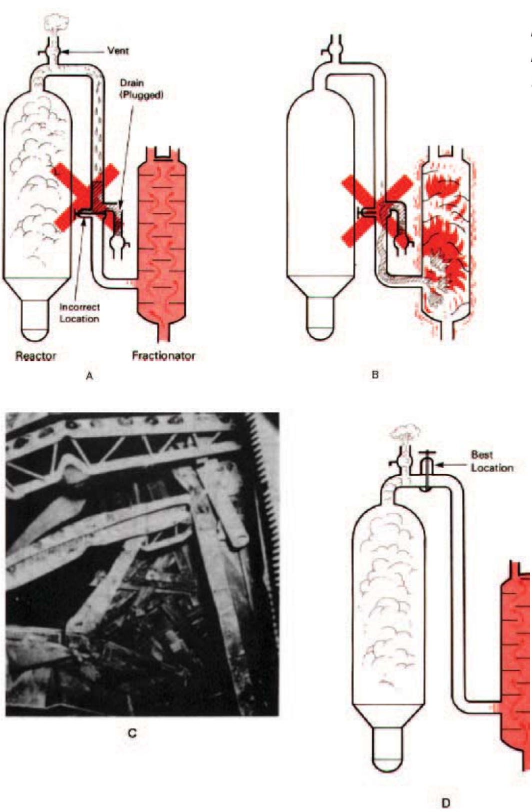


Figure 23 *Incorrectly located block valve provided a water trap.*

continued

Catalyst circulating through the reactor and regenerator had been heated to 700°F (370°C). Hot gas oil circulating through the fractionator and preheat furnace provided a bottom temperature of 470°F (243°C) in the fractionator. Then the block valve between the reactor and regenerator was opened.

Because of its location in the vertical line and *because the 3/4-inch (20 mm) drain was plugged,* steam condensate trapped above the block valve flowed into the hot oil in the fractionator, flashed to steam (Figure 23b), and severely damaged trays, support trusses and internal piping (Figure 23c).

This incident could have been avoided by careful and complete draining of the condensate before the valve was opened. Two 2-inch (50 mm) drains have been installed to prevent a recurrence. Relocating the block valve in the horizontal run on the line (shown in Figure 23d), would permit the condensate to drain back into the reactor where it would re-evaporate safely.

ACCIDENT In another refinery, trays in a combination tower were extensively damaged during start-up. Hot gas oil was introduced on the third tray from the bottom after air had been expelled by steaming. Steam bleeds had been left open to keep the upper part of the tower and the overhead line free from air. However, because the upper tower and the lines were still relatively cold, this bleed steam condensed. Ultimately enough water drained into the hot oil in the bottom of the tower to cause damage.

To prevent similar occurrences, the start-up procedure was revised. Fuel gas is backed into the tower after steaming, and a stock with a lower-boiling front end is used for start-up. Thus, the upper part of the tower is heated sooner, thereby driving water overhead before the temperature of the oil in the bottom exceeds 300°F (150°C).

ACCIDENT Another incident that upset the trays in a tower arose from the failure to provide adequate drainage for a trap-out pan in a combination tower. The equipment was actually two towers, one on top of the other. Vapour travelled upward from the bottom stripping section through a chimney into the fractionating section. The head of the lower vessel served as the bottom of a trap-out pan for gas oil.

Note in the sketch in Figure 24a, that the drawoff line did not leave the tower at the bottom of the trap-out pan.

A ring of water 3 inches (75 mm) deep collected in the space below the trap-out line. Hot oil filled the pan and mixed with the water; a sudden pressure surge upset the upper trays (Figure 24b). After this accident, a drain line was installed so that all of the water could be removed from the trap-out pan (Figure 24c).

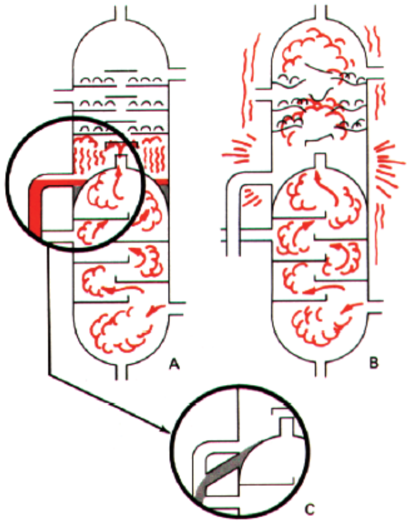


Figure 24 *Inadequate draining allowed water to accumulate in the gas-oil trap-out pan shown in diagram 'A.' Hot oil caused water to flash and upset trays as shown in diagram 'B.' This was corrected by adding a new drain line, shown in diagram 'C.'*

Engineers must thoroughly study piping installations and vessel diagrams (see Figure 25) of operating units during the design stages to eliminate all unnecessary pockets where water may collect. Occasionally eliminating a pocket is not practical. It may be necessary to install drains to remove water or steam-trace lines to prevent freezing. Operators must always be alert in looking for low points that may be caused by expansion, sagging, misalignment or design oversight.

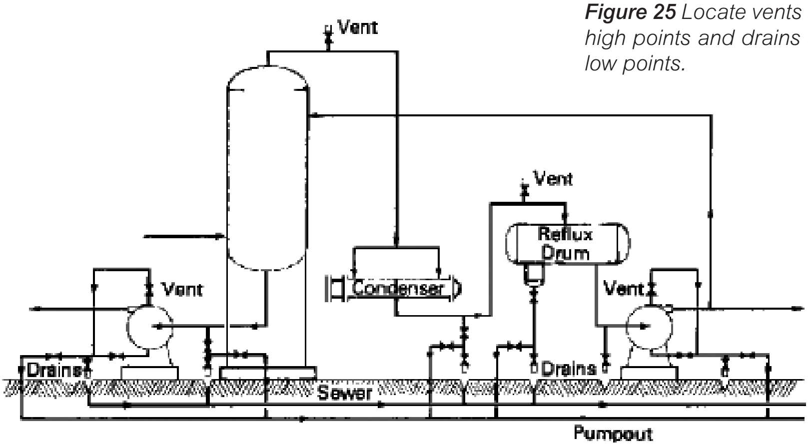


Figure 25 *Locate vents at high points and drains at low points.*

3

Water in tankage

Types and sizes of storage tanks are many and varied. They comprise much of the refinery investment; however, their contents are of even greater value. The primary function of these tanks is to hold petroleum products before, between and after various refinery operations. Since the tanks are essential to the operation of process equipment, a look at how they may affect the water problem and how such problems may be minimized or eliminated is in order.

3.1 Swing lines

Most oil storage tanks have a layer of water below the oil. So that oil and not water may be pumped from the tank, some older installations use a 'swing' line. The movable swing line may be operated by a winch and a cable passing through a packing gland near the top of the tank. The movable joint on the swing line is usually made of screwed pipe ells or commercially available flanged swivel joints.

Swing lines are normally left in one position in the tank, but they may have to be moved during certain operations.

In catalytic and thermal cracking units and other equipment sensitive to water in the feed, the arrangement shown in Figure 26 may be used. The suction line should enter the tank shell a few feet above the bottom. The end of the swing line should be supported so that it cannot drop to the tank floor in case of cable failure. Locating the suction nozzle on the tank well above the water level prevents water from entering in case the movable joint leaks.

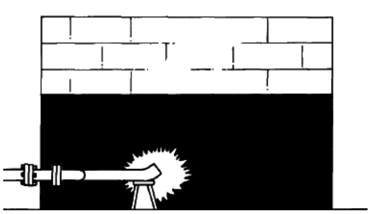


Figure 26a *Swing line.*

Figure 26b *Suction line elbow.*

Another version of the swing line is the floating suction line. It is usually attached to the internal tank suction nozzle flange in a similar manner to that described for the swing line. However, the other end of the floating suction line does just that—it 'floats' just below the liquid surface so that suction is always in that portion of the hydrocarbon liquid that should contain the least water. Flotation is provided by pontoons near the free end of the line. This technique has been widely used in floating-roof storage tanks for crude service.

3.2 Periodic draining of water in feed tanks

The water level in feed tanks must always be kept well below the suction line. Checking for water frequently and draining it regularly are extremely important (see Figure 27).

When water is drawn from naphtha or gasoline tanks, oil can easily be mistaken for water unless some special means of detection is used.

Wood tends to absorb naphtha or gasoline, whereas drops of water tend to stand on the surface. Therefore, frequent testing of the stream with a stick or small board prevents losing oil to the sewer (Figure 27). The use of detection paste is another method for checking water drawn from tanks. The paste changes colour in the presence of water.

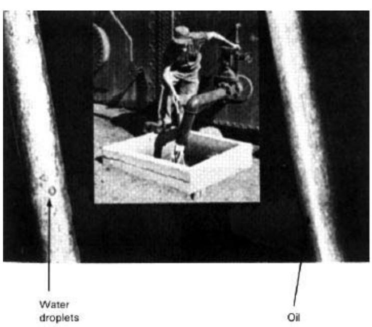


Figure 27: *Drain water frequently and don't leave a draining operation unattended.*

Water can enter tanks in many ways—through open hatches, gauge-board cable openings, leaking steam heaters and leaking roofs. Water also can enter by circulating oil through units and back to feed tanks during start-ups (Figure 28).

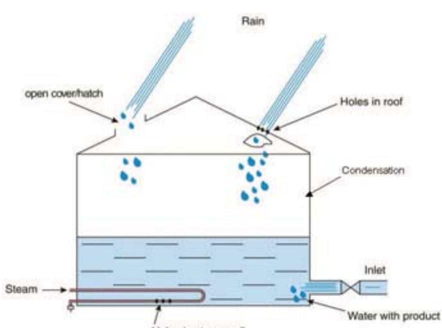


Figure 28 *Usual sources of water in tankage.*

Hatches and gauge-board cable openings must be kept covered. Heaters, roofs and roof drain lines should be kept in good condition. It is usually best to pump start-up stock to storage tanks where it can settle instead of circulating it back to feed tanks.

Drain lines and valves for drawing water from tanks and other storage vessels must be protected from freezing. Otherwise, water in these lines and valves may freeze and rupture them, and the stock may be lost when the ice melts. Oil flowing from such a line could create a hazard. Also, water freezing in a valve may prevent its operation and make it impossible to drain equipment properly.

Proper drain lines are particularly important for spheres used to store light products, such as butane. A fire that could have had serious consequences occurred at a butane sphere equipped with external bottom drains (Figure 29). During a sudden and unexpected cold wave, a makeshift heating device was used to prevent the external lines and drain cock from freezing. When water was drained from the sphere, some butane escaped and was ignited by the heating device. Fortunately, the drain was closed quickly, thereby preventing enough butane from escaping to cause a serious fire.

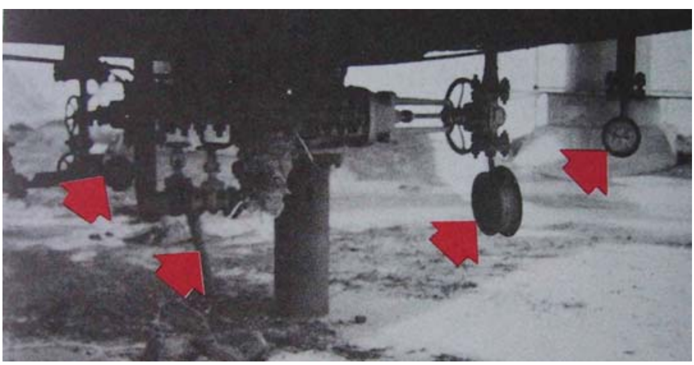


Figure 29 *Unprotected sphere connections may freeze.*

An internal drain connection (see Figure 30), solves this very serious problem. Water can be drained back away from the drain cock and no external means of freeze protection is needed. Each time water is drained through this piping arrangement, it is preceded by a slug of the sphere's stock. Make sure there is no source of ignition in the area.

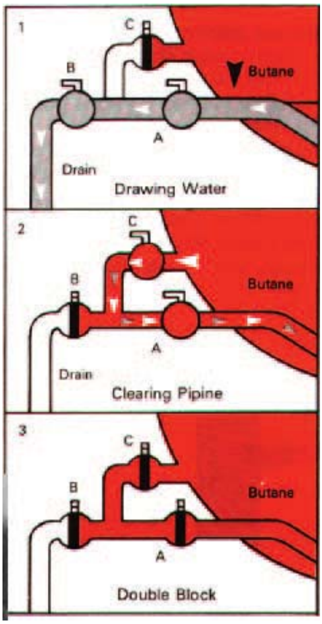
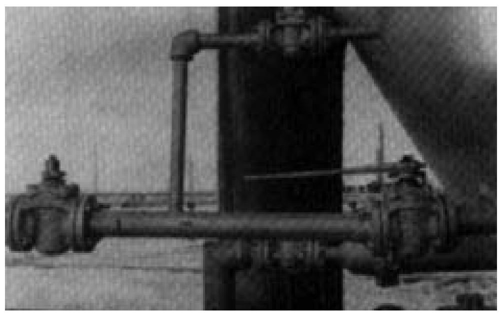


Figure 30 *To operate internal water drain open valves 'A' and 'B' (1); liquid head pushes out water. When water draw is complete, close valve 'B' and open valve 'C' to permit clearing lines of remaining water (2). When lines are clear of water, close valves 'A' and 'C' (3).*



3.3 Bottom settlings and water (BS&W)

Besides the normal water bottoms, most feed tanks contain an emulsified material called *bottom settlings and water.* BS&W can be hazardous because of its water content. The percentage of BS&W in the oil can be determined by taking a representative sample of oil from the tank and mixing it with an equal amount of toluene and centrifuging the mixture (see Figure 31).

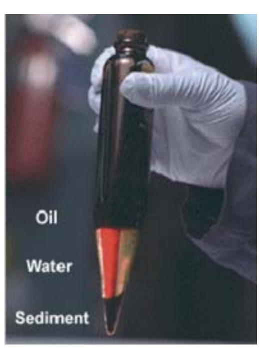
Process unit operators must be constantly alert to signs of water in incoming stock. A water and oil emulsion, or water in small amounts from tankage, creates a steady pressure rise through the unit. If this occurs, a sample of the incoming stock should be taken and checked for water and BS&W. If either is excessive, the pumping station should be notified immediately and the situation corrected.

Normally, feed should not be charged to a unit if the BS&W content is greater than a specified value, depending on whether it is crude, FCCU feed, etc. Feeds with amounts higher than the specified value can be charged safely only under carefully controlled conditions. Some emulsions can be and are broken by special emulsion treating facilities, and the water may thus be eliminated. Other emulsions are difficult or impossible to break.

Another condition that sometimes exists in tankage is that the water layers out (see Figure 32). This can only occur with viscous oils and oils near the gravity of water (API gravity 10). When the API gravity of the oil is higher than 10, this usually can be corrected by warming the oil so that the water settles to the bottom. Tank mixers will also help eliminate this problem.

Figure 31a *Sample from tank.*

b. Centrifuge.



c. Centrifuged sample.

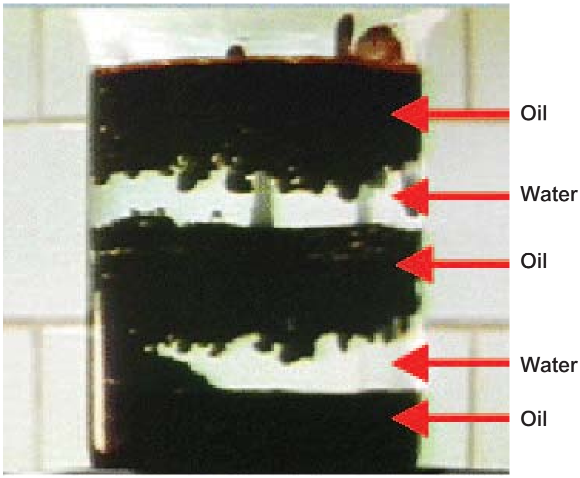


Figure 32 *Water and viscous oil may 'layer out'.*

In cold weather, a wax-like material often builds up around the wall of gasoil and crude tanks. This material usually contains some water and sediment. When the weather warms sufficiently, the wax softens and slides towards the centre of the tank. A suction line may be temporarily submerged in this material, especially if bottom settlings have been allowed to build up in the tank. This condition presents serious hazards to units fed by such tanks. Periodic cleaning of tanks and the use of tank mixers help to eliminate this hazard.

3.4 Changing feed tanks

Two of the critical points in the operation of a unit are the changeover from one feed tank to another and the use of a new suction line-up. Water may be found in either the new stock or the new suction line-up. If feed lines which have been inactive are to be included in the line-up, they should be flushed out just prior to being put in service.

When changing feeds or when making a new suction line-up, the person making the change must notify the unit operator well before the change is made. The operator must then be alert to any pressure and temperature irregularities or any change in the colour of distillates. Of particular importance is the feed pump. Here any increase above the normal discharge pressure may indicate that water has reached the furnace. The feed rate can be decreased to help overcome the pressure increase.

3.5 Processing crude oil

Crude oil in refinery tanks frequently has small drops of water suspended in it. This is especially true of low-gravity crudes. The water does not settle out easily because it has been so thoroughly dispersed throughout the oil by tank mixers. Operators, if alert to the danger, can overcome irregularities and minor upsets that can occur if the BS&W content is between 0.4 percent and 1 percent.

Any amount above 1 percent may substantially upset a refining unit.

Sometimes a desalter may be used to reduce the BS&W content of a crude before it enters a tower, and many crude processing units are equipped with desalting systems. They remove not only water but also chemicals that would cause excessive fouling and corrosion. Operators must check the water level in a desalter regularly to see that the automatic level controller is operating properly; otherwise, the water might rise high enough to enter the unit.

Slops, skimmings and other oil-water mixtures must be handled with caution to be sure that the BS&W content is low before they are charged to units.

3.6 Tank foamovers and boilovers

When water vaporizes below the surface of hot asphalt (bitumen) or heavy oil, a foam usually forms. A foam volume may be many times that of the oil (under severe conditions, 20 to 30 times). The foamover may overflow not only the tank but also firewalls and spread into adjacent areas.

ACCIDENT A destructive fire at Signal Hill, California, illustrated graphically the result of uncontrolled outflow of oil from a tank. Originating from the foamover of the tank, the outflow moved over a large open area and then engulfed the high-value process area. Spread of the oil upon the ground outside the tank dike is indicative of its reduced velocity and the possibility of retaining such flows with secondary diking.

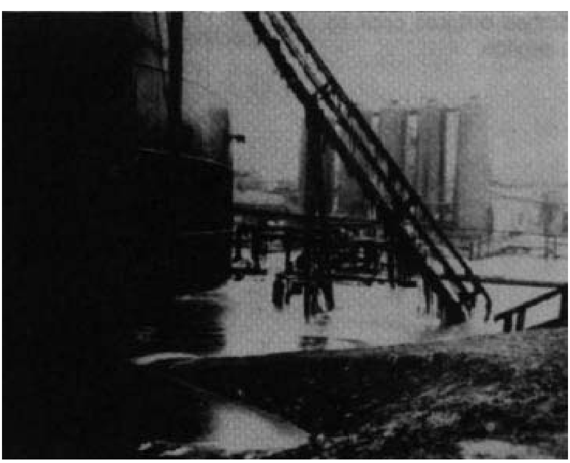


Figure 33 *Hot asphalt and a leaking steam coil result in a foam-over.*

The picture (Figure 33) shows what happened when the delivery line to the bottom of a heated asphalt (bitumen) storage tank was blown out with air. When agitated by air, water in the bottom of the tank contacted the 220°F (105°C) asphalt, flashed to steam and caused a foamover of 500,000 gallons of product (1,900 m^3). The water came from a leaking steam coil.

If hot asphalt or heavy oil is pumped into a tank that contains even a small amount of water or emulsion, substantial foaming may result. If the pumping does not result in mixing, however, it may take some time for the water to become hot enough to start vaporizing. Consequently, the foamover may be delayed. Hot asphalt is loaded into tank trucks and tank cars at temperatures which may be well above 212°F (100°C), the boiling point of water. Loading must not be started until an inspection of the tank truck or tank car has been made and the absence of water has been confirmed.

If asphalt (bitumen) in seasonal storage is permitted to cool, water may accumulate. When the contents are again heated, the heat must be applied slowly, or a foamover may result.

The most common source of water is from leaking steam coils or suction heaters. Water may also enter the tank through the roof hatch, holes in the roof, around the gauge cable, or through any other unprotected openings. Periodic checking and good maintenance of tanks and heaters will do much to eliminate this hazard.

ACCIDENT Figure 34a shows a tank which was damaged when the water in a wax emulsion at 260°F (127°C) flashed to steam. Wax, water and steam spouted to a height of 35 feet (11 m) from four hatches on the top of the tank. The tank was about 40 percent filled at the time of foamover. The roof was bulged and ripped in two places. Stock loss was estimated at 21,000 gallons (79,000 litres).

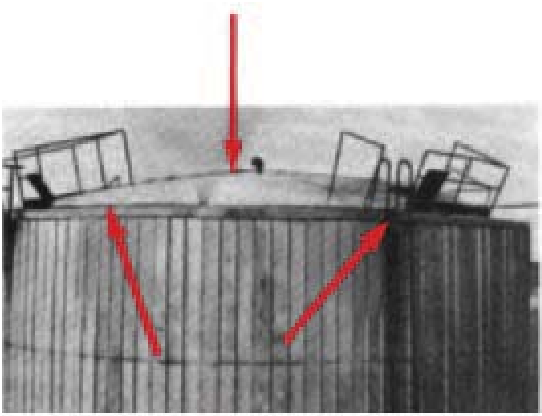


Figure 34a *Note bulged and ripped roof on this wax tank.*

ACCIDENT Figure 34b shows a similar incident which occurred when 15 bars steam heating was mistakenly left on for days, on an atmospheric residue tank containing water (as is often the case with product received from ships). When the temperature was high enough to vaporize the trapped water, this happened instantly and damaged the tank beyond repair. Hot product was also projected over a large area.

Figure 34b *Atmospheric residue tank damaged by steam heating.*

ACCIDENT A cone-roofed atmospheric tank in vacuum bottoms service, violently ruptured at the roof to shell seam. The roof was cleanly blown off and landed on the ground. A white/grey plume developed, as wide as the tank and some 120 feet (36 m) up into the night sky. Within a minute a violent frothover occurred. About 2,500 barrels of oil were lifted from the tank, the majority of which fell within a 100 yard (90 m) radius of the tank.

A mist of oil apparently lifted to the atmosphere, was carried off-site, and resulted in some claims for vehicles being affected.

The incident occurred when water trapped by a layer of set-up vacuum bottoms reached its boiling point and rapidly expanded to steam. The resultant increase in volume, caused a rupture of the tank roof-to-shell seam. The agitation and disturbance caused a subsequent violent frothover as more water mixed with the oil. The water entered the tank from the normal tank breathing and condensation from variations in atmospheric temperature over an inactive service period of a year.

There are many ways to minimize the hazard of flooding refinery units or adjacent property by a tank foamover, oil carried on water from fire fighting, tank leakage or rupture. During plant layout or modernization, consideration should be given to the ideas illustrated in Figures 35 to 38.

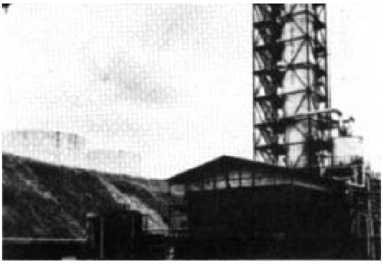



Figure 35 *Location of operating units above adjacent tankage (right illustration) is preferred to location of units below tankage (left illustration).*

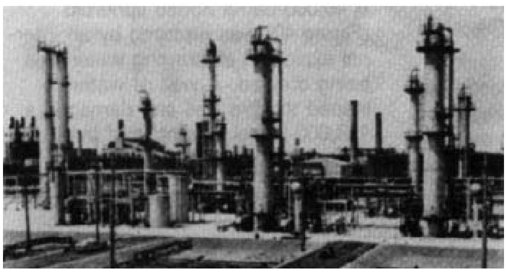


Figure 36 *Grade against oil-water flow. For example, if unit dock is at normal ground elevation, pipe alley should be below unit grade and combination fire wall and road above unit grade.*

Figure 37 *Provide adequate fire walls.*

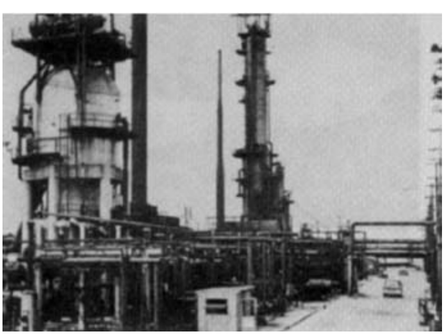


Figure 38 *With unit docks above surrounding areas, provide curbs and sewer capacity to take unit spills.*

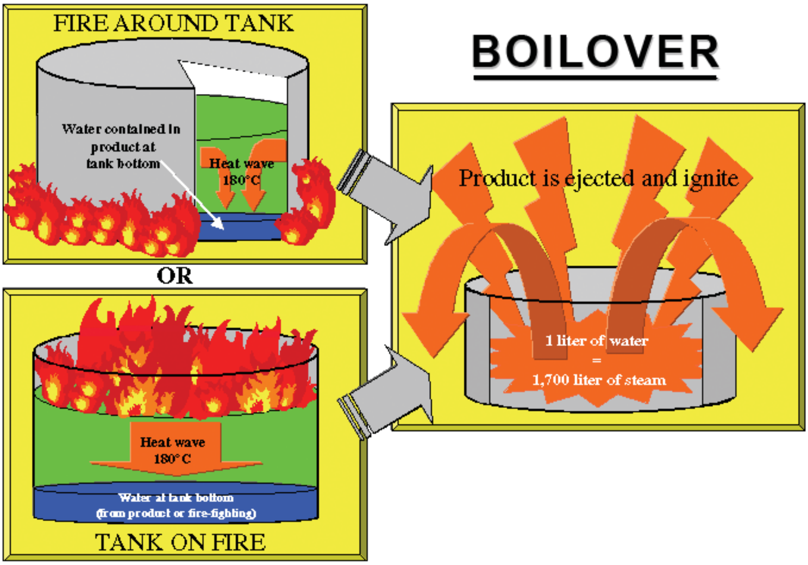


***Figure 38b** Conditions leading to a boilover.*

Foamover can occur during normal operations. A similar phenomenon called boilover can occur when a tank is on fire. Boilover is the term given to the expulsion of burning oil from an open top tank involved in a full surface fire or a superheated tank involved in a bund fire (such as the Port E. Herriot 1987 fire).

A boilover occurs when the hot residues from the surface of the burning liquid become denser than the unburnt oil and sink below the surface to form a hot layer which sinks much faster than the level of liquid drops due to the rate of burning. See Figure 38 b.

As it sinks towards the bottom of the tank, the heat layer increases in size and density with temperatures in the range of 300 to 600°F (150 to 315°C).

When this heated layer reaches a water or water emulsion layer, it first superheats the water then causes a steam explosion. The water flashes to steam at temperatures in excess of 212°F (100°C) and will expand by as much as 2000 to 1.

It is estimated that this steam explosion can propel burning oil and vapour to a height of ten times the tank diameter. See Figure 38c.

To be liable to boilover, oils must have components containing a wide range of boiling points. Most crude oils fall into this category.

The three elements necessary for a boilover are:

- A fire in an open top tank, involving all or most of the surface, or a tank fully involved in a bund fire;
- A layer of water or water-oil emulsion in the tank;
- The development of a heat layer which is determined by the properties of the stored material.

When a fire in an open top tank containing a flammable liquid with a wide range of boiling points, such as crude oil, begins to burn, the components with the higher boiling points sink below the surface and form a heavy heated layer. In some crude oils, this layer travels downward into the oil at only 3 inches (75 mm) per hour, while in others it may be as much as 50 inches (1.3 m) per hour. In most crudes the rate is from 12 to 18 inches (300 – 450 mm) per hour faster than burnoff.

Pre-fire plans should take into account the fact that pumping out a tank on fire that contains a boilover fuel may bring forward the time when a boilover would occur. However, the amount of fuel involved in the boilover would be reduced by pumping out.

Additional signs of a potential boilover are:

- increase in flame height and brightness;
- a change in sound to crackling or frying;
- blobs of burning material may be ejected a few metres from the tank.

ACCIDENT

Figure 38c *Typical example of a boilover.*

3.7 Water testing and water flooding

Water used for leak testing and for flooding to remove hydrocarbon liquids or vapours can present unexpected and unusual problems.

ACCIDENT A new 117 ft (35m) by 42 ft (13m) tank (see Figure 39) was being hydrostatically tested. Water started running from the incompleted foam lines and continued by siphon action because the foam-line diaphragm was not in place. Before the water flow was stopped, it had washed away part of the berm and damaged the concrete ring foundation and the bottom tank plates.

Figure 39 *Flowing water caused washout.*

ACCIDENT A 45,000-barrel (7,200 m^3) noded spheroid (see Figure 40) was ruptured by an internal explosion as purging water was being drained. A wall of water leaped the fire wall and damaged a 118,000-barrel (18,800 m^3) floating-roof tank (see arrow in Figure 41). The spheroid was being purged preparatory to inspection. Oil was pumped out, leaving not more than 25 barrels (4 m^3). Then the spheroid was water filled (46 ft (14 m) gauge) and over-flowed through the overhead vent (51 ft (15.5 m) level) until no oil was found in the effluent. The top manway cover was removed next and drainage started. On removal of the manway cover, a black scum about 1/2 inch (12 mm) thick was noted, and bubbles were seen breaking through the scum. An odour was evident, but no gas test was made. Draining continued for almost ten hours, lowering the water to about the 37 ft (11.3 m) level. The internal explosion caused a split which extended 60 ft (18 m) horizontally and 32 ft (10 m) downward.

Investigation and sampling indicated that the probable source of ignition was iron sulphide. Air entered the spheroid via the open top manway.

Fuel was provided by the trapped oil and vapour in the dome and nodes shown in Figure 42.

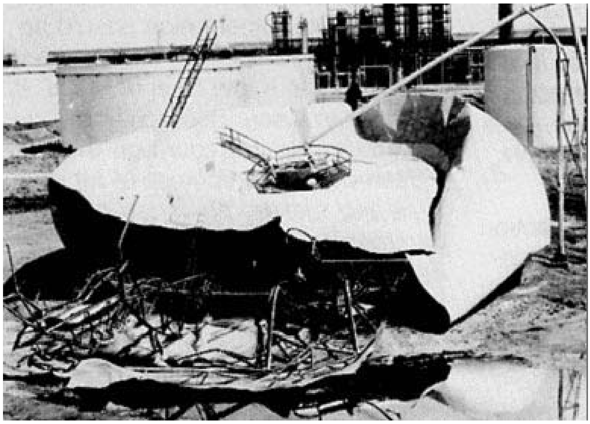


Figure 40 *Spheroid rupture was caused by low-grade explosion. Vacuum damage is due to outrush of water following explosion.*

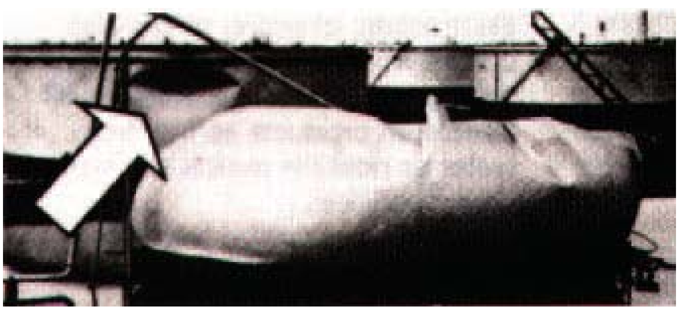


Figure 41 *Water wave from collapsed spheroid overflowed fire wall and damaged tank in the background.*

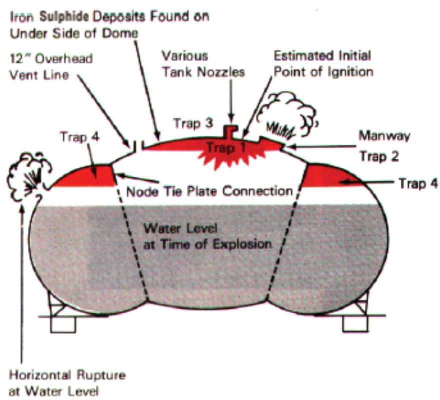


Figure 42 *A schematic cross-section of the noded-type spheroid showing traps for oil and vapour. Trap 1 existed because the overhead vent nozzle was not located at the top-most point of the spheroid. Traps 2 and 3 were occupied by vapour and oil confined in the manway and other nozzles. Trap 4 was a pocket running entirely around the spheroid in the space enclosed by the node tie-plate connection, the spheroid shell and the rising water. The design made it impossible to eliminate all vapour and oil from the spheroid by overflowing with water, and it violates the principle that purging cannot be satisfactory unless vents are at the high points of the vessels and traps are avoided. Had proper connections been provided at high points in each trap, all oil and vapour could have been removed from the spheroid by overflowing with water until clear water flowed from each overflow connection.*

Also, like it was said for process units, before testing a system with water, structural specifications should be studied carefully to detect any weaknesses that may make the use of water unsafe.

ACCIDENT An incident occurred when firefighters tested foam sytems on a tank fitted with an internal floating roof—the tank had been emptied, cleaned and inspected and a check of the firefighting systems was due before it could be back in service. As the internal roof was not designed to withstand the weight of water, it collapsed when foam was applied.

Figure 42b *Collapse of a tank with internal floating roof due to excess weight applied.*

4

Other water hazards

4.1 Water as a source of air

Water used for process washing or for flushing can carry air into a hydrocarbon system.

ACCIDENT In an alkylation unit, air transferred from washwater to reactor effluent. Oxygen from the propane stream—part of it from this air—accumulated in the vapour space of propane storage drums to form a propane-oxygen mixture which detonated, seriously damaging the unit (Figure 43).

Water used to flush hydrocarbons from a vessel normally filled completely with liquid may bring air into the vessel and create a vapour space which may contain a flammable air-hydrocarbon mixture.

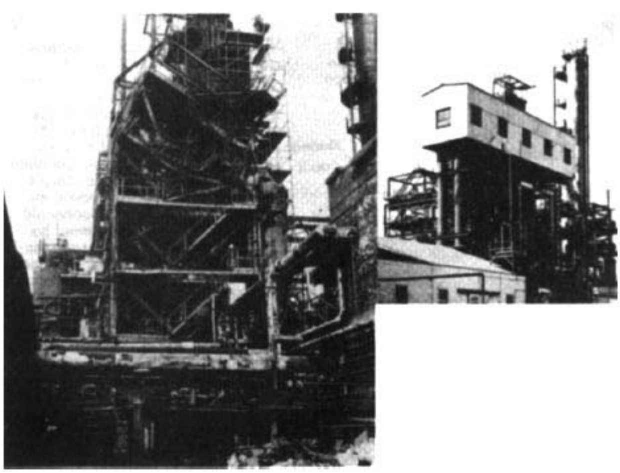


Figure 43 *Damage caused to alkylation unit by washwater carrying air into the system.*

4.2 Water as a static generator

Petroleum products in motion, such as when being pumped through a pipeline, become electrostatically charged. Fortunately, with most of them, these static charges do not become dangerously large unless the flow velocity is high. If water is present in the oil, the hazard increases greatly because even small amounts of water in flowing oil can cause a dangerous build-up of static charges. Static sparks produced in this manner have caused many accidents. Electrostatic charging of oils also occurs when droplets of water settle through oil in tankage. Keeping all petroleum products as free from water as possible avoids this hazardous condition.

ACCIDENT Some years ago, a tanker was loaded with naphtha from a shore tank after which the loading line was flushed back with water. An explosion occurred in the shore tank soon after flushing began. The explosion was probably caused by static electricity generated by the mixed flow of water and naphtha.

ACCIDENT A MTBE tank explosion occurred during a tank cleaning job. When the cleaning started, the vapour in the tank contained 73% nitrogen and 27% MTBE. During the last phase of cleaning, the vacuum truck started to suck in vapours from out of the tank. This caused some underpressure in the tank. Air entered the tank through the top manhole. By introducing air in the tank an explosive mixture could be formed. The explosive limits for MTBE in air ranges from 1.5% to 8.5%.

When most of the liquid was removed a high pressure cleaning device (rotating high pressure water nozzle) was put into the top manhole. Shortly after, an explosion in the tank occurred. The operator was blown off the roof and was most likely killed by his falling from height 33 ft (10 m). The tank roof (1.4 metric tons) landed 330 ft (100 m) away between two other tanks.

The most likely source of ignition is a spark caused by a static discharge from the high speed fine particle water mist from the high pressure head.

It has become apparent that a number of tank fires which hitherto have been recorded as ‘cause unknown’ have been caused by static electricity generated during the application of foam from firemen’s nozzles or remote monitors. Indeed, the re-ignition of fires may be related to foam application.

In case of a large exposed surface of refined product (for example, a sunken roof on a jet tank):

1 *Stop all transfer of product on or out of the tank:*

- Assess the situation and determine the hazardous area using gas testers.
- Make sure that there is no close ignition source and evacuate personnel.

2 *Do not use foam unless:*

- there is a higher probability of ignition by a non-removable ignition source (e.g. lightning storm);
- personnel must be protected against fire during the subsequent operations (removal of product, roof repairs . . .);
- the product involved has a high conductivity (such as crude oil).

3 *If the decision is made to apply foam:*

- If possible, use fixed pourers so as to apply foam as gently as possible down the tank shell.
- Foam generated by monitors or hand held nozzles should be applied on the internal shell of the tank before going on the product.
- Prefer fire appliances with integrated foam proportioners rather than portable foam proportioners.
- If portable foam proportioners are used, the maximum foam flow must first be generated outside the tank and then applied as gently as possible on the internal shell of the tank before going on the product.
- Never apply directly foam or water on the surface of the hydrocarbon product.

4 *If a foam cover was established on a refined product (after a fire or after conditions of the list):*

- Once the foam cover is created, maintain it regularly and gently.
- Keep a close watch on the tank until all product is removed.
- The natural degradation of the foam cover may lead to an electrostatic ignition by the foam and water sinking through the hydrocarbon product.

ACCIDENT An accident was caused by foam application on exposed naphtha after the floating roof of a storage tank sank. Static created by foam application ignited the fire that it was supposed to prevent. As a result of escalation, three naphtha tanks were destroyed (see Figure 43 a to e).

***a.** Roof sunk.*

***b.** Tank ignited by foam application.*

***c.** Adjacent tank beginning to burn.*

***d.** Two tanks fully involved.*

***e.** Three tanks fully involved.*

4.3 Water-vapour fog

In cold weather, water vapour from open drains or cooling towers may produce a dense, hazardous fog.

Cooling towers in particular produce clouds of water vapour which can extend over large areas, both within and out of the refinery. Towers should be carefully located so that prevailing winds will not cause fog to drift over process units or to obscure principal roads (Figure 44).

If temperatures are below freezing, fog can make roads, walkways and stairways icy, increasing the hazard. Within a unit, warm water in open drains can produce the same condition on a smaller scale.

Figure 44 *Examples of water vapour creating a dense fog.*

4.4 Water and acid

In many processes, such as alkylation for instance, strong acids are used in large quantities. A rule taught early in every chemistry course should be remembered in handling these acids:

Pour acid into water—never pour water into acid

This laboratory maxim is even more important when applied to the large quantities of acid found in refining units. Operators should avoid introducing water into vessels containing acid. Occasionally, water-washing is required of equipment which is in acid service. The method of doing this job must be carefully developed and vigorously followed. Equal care should be used with acid in lines or in sample containers.

Serious overheating or dangerous eruptions of the acid can occur if water or water solutions are added to the strong acids. Dilution of strong acid also makes the acid more corrosive. The corrosion not only may damage equipment (Figure 45), but also the acid reaction with metals produces hydrogen, which is potentially dangerous. For this reason, steaming of acid-handling equipment should be avoided whenever possible.

Figure 44 *Corrosion damage.*

4.5 Water and fire fighting

Water is a very useful tool in fighting fires. It cools heated surfaces, extinguishes fires in high flash point oil, and protects fire fighters from flame and radiant heat. In addition, it can divert the flow of oil away from a fire, or it can cut off the flow of oil from a leak in a tank by floating the oil above the leak.

However, some limitations in fighting fire with water must be recognized:

- Uncontrolled flooding can cause burning oil to move to an area where it can cause damage.
- Water, applied as a stream from an ordinary fire-hose nozzle, cannot extinguish a fire in low-flash-point petroleum products such as gasoline.
- The conductivity of water may make its use dangerous near high-voltage electric lines or equipment.
- At low temperatures, water will freeze and cause a slipping hazard to the fire fighters as well as increase the loads on structures already weakened by the fire.
- The sudden application of water to hot steel piping or tankage may create severe thermal stresses in the steel. These stresses may cause dangerous reductions in the strength of the steel.
- The flooding with water of pressure and/or vacuum relief vents on tanks and vessels can prevent the release of internal pressure as the contents are heated, or a vacuum could be formed as the contents are cooled.

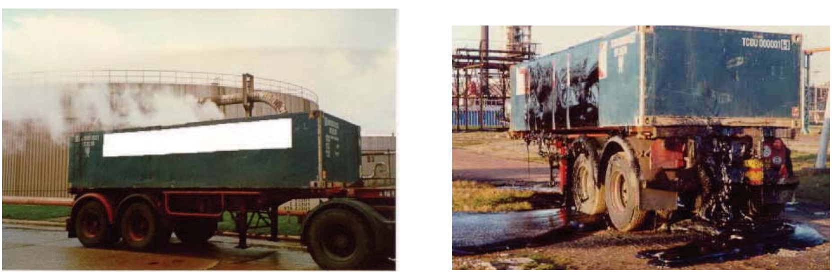
Refer to BP Process Safety Booklet *Liquid Hydrocarbon Tank Fires* for more details.

4.6 Water and loading operations

What was said for process unit and tankage is also true for rail or road car loading. If water is present in a cistern and hot oil or asphalt (bitumen) is introduced (or vice-versa), the damages can be tremendous.

ACCIDENT An accident occurred when hot asphalt was added into a trailer that had recently been cleaned with water. Unfortunately, the excess water was not removed from the trailer before the asphalt was added—the water rapidly turned to steam and expanded in volume about 1600 times. The result—significant damage (see figures 45b).

Another consideration that is applicable to any fluid transfer is to be aware of the forces applied by the weight of the liquids being stored in one compartment. Many ships were broken by a wrong repartition of cargos, some with huge loss of life.



Just after loading . . . *A few minutes later!*

***Figure 45b** Damage caused by adding hot asphalt to a recently cleaned trailer.*

ACCIDENT Another less tragic incident is illustrated by Figure 46. The job comprised pumping residual water-based mud from the ships tanks to a compartmentalized tank wagon onshore. The tanker, positioned on the quayside, did not have a tractor unit and was supported by the trailers support legs. The discharge hose from the suction pump was placed into the tank wagon forward tank. Ten minutes after the beginning of the operation, the tanker tipped off on its forward end, luckily without hurting anyone.

***Figure 46** Care must be taken when unloading compartmentalized tank wagons!*

4.7 Burn hazard from hot water

Who has never burnt oneself with hot water, either when cooking, in the shower or using a hot tap? Pain begins around 140°F (60°C). It's an alarm signal, but it's often too late (see Figure 47).

Do you know that in the US, 112,000 persons per year suffer from scald burns?

Turning down the temperature on home hot water heaters is the law in some countries. They require hot water heaters in new homes to be set lower, instead of the usual 60 degrees Celsius or 140 degrees Fahrenheit, to a lower and safer limit of 49 degrees Celsius, or 120 degrees Fahrenheit. And since these laws are enforced, they have led to a major drop in hot water burns. What is the setting at your home and at your workplace?

Remember: hot water burns like fire—it can kill you.

> **ACCIDENT** A contractor's employee sustained scalds to his legs and hands while endeavouring to blank off a sewer box. It was thought that all streams to the sewer box had been diverted but in fact hot water was entering from an undefined source. This was not apparent at the cool surface of the water in the box. When the man entered the sewer box, he became aware of the hot water below the surface. After several attempts to carry out the blanking he had to leave the box due to the hot water.

Length of time for hot water to cause burns

temperature FAHRENHEIT	temperature CELSIUS	2nd Degree burn[1]	3rd Degree Burn[2]
113°F	45°C	2 hours	3 hours
117°F	47°C	20 minutes	45 minutes
118°F	48°C	15 minutes	20 minutes
120°F	49°C	8 minutes	10 minutes
124°F	51°C	2 minutes	4 minutes
131°F	55°C	17 seconds	30 seconds
140°F	60°C	3 seconds	5 seconds
149°F	65°C	instant	2 seconds
156°F	69°C	instant	1 second

1 - no permanent tissue damage
2 - tissue destroyed

Figure 47 *Burn hazards from hot water*

> **ACCIDENT** A contractor was in the process of dismantling a hot water pump. The lock out/tag out program was deficient for what was regarded as a 'low risk' product, he was doused with hot water and became severely scalded. Unfortunately, he died the next day.

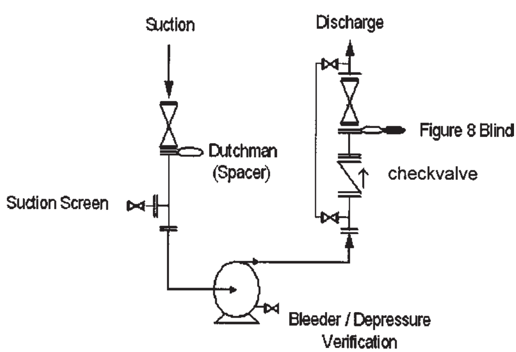
ACCIDENT A work request was issued for maintenance on one of three pumps (A, B, C) which are in boiler feed water service. All three pumps had one common suction line and one common discharge line. Pumps are always flooded at their suction under 1.2 kg/cm (17 psi), with a discharge pressure of about 8 kg/cm (116 psi). In normal operation, only one pump is in service, with the other two pumps in a hot stand-by condition, i.e., their suction and discharge valves are open.

The pumps can be isolated individually by their own suction and discharge valves, in addition to a check valve in each discharge. The temperature of water in this service is around 102ºC (215ºF). That morning, two mechanics had taken a Cold Work Permit from the responsible field operator to maintain pump C, assuming and accepting that the pump was properly and safely isolated from the one in operation. They started to dismantle the pump body to reach the impeller section; and, when they removed the driver part side of the pump shroud, hot water under pressure splashed out. The two mechanics were scalded with hot water, resulting in first and second degree burns. Both men were hospitalized for treatment, one remained in hospital for two days.

The mechanics had accepted and signed the permit, and started to work on the pump considering it as ready for dismantling. In reality none of the written control items on the cold work permit had been physically done by the area operator. The suction and discharge valves of the pump had not been closed, and the pump body was not drained

The area operator had given the permit to the mechanics before doing the physical isolation, intending to do it after issuing the permit; but he forgot.

ACCIDENT Another pump maintenance incident had tragic consequences. In order to troubleshoot boiler feed water pump flow issues, the pump was shut down and prepared for maintenance and isolated by closing off two chain operated block valves. The pump case drains were opened. During the process of removing a 10 inch check valve, three pipe-fitters were scalded with hot water and steam. All three men were hospitalized and one died the day after the incident.



ACCIDENT An electrical contractor was carrying out preparatory work for running a cable to a new fan. Whilst working on a portable staging on the ground floor, he was sprayed by hot condensate from a vent pipe on a blow down header.

The pipe, about 3m above ground level, is from a blow-down header which in turn carries a number of aqueous process streams, including an automatic blowdown from steam drums. The area was fenced off until the vent could be made safe.

ACCIDENT A quarry worker was seriously burnt from hot water when a hose blew off a pump supplying water to sprays. The control valve for the water sprays was closed. The water spray circuit had a pressure relief valve and a manually operated flow control valve that returned all water to the suction side of the pump. Therefore, the water kept recirculating through the pump. This generated enough heat and pressure to eventually blow the delivery hose off (see Figure 48).

Figure 48 *The operator's station, water spray pump and hydraulic lines.*

ACCIDENT Numerous days away from work incidents occurred from burns sustained when using steam/water mixers to produce hot water to clean petrochemical or refining units. This type of mixer should be banned.

ACCIDENT An operator assisting with the modification of some pipework, lost his balance and submerged his right foot and lower part of his leg into a steam condensate sump. The technician immediately made his way to a nearby emergency shower where, with the assistance of a supervisor, he removed his boots and socks, before being taken to the refinery medical centre for treatment. The severity of the burns was such that it became a lost time accident.

Treatment for burns

Minor burns

- Hold burned area under cool running water for 15 minutes.
- DO NOT apply ointments or butter.
- Cover the area with dry gauze.
- DO NOT pop blisters.

Consult a doctor if burns occur on the face, hands, genitalia, feet, or for any burn on an infant.

Severe burns

- Have one person call the emergency services while another person runs cool water over the burned area. DO NOT use ice.
- DO NOT put ointment or grease on the burn and DO NOT try to remove pieces of cloth from the burned area.
- DO NOT break blisters.
- DO NOT give the victim anything to eat or drink.
- DO raise the burned limbs to minimize swelling.
- DO keep the victim from being chilled or overheated

Risk of burns from eruptions of hot water overheated in microwave ovens

Reports of serious skin burns or scalding injuries around people's hands and faces as a result of hot water erupting out of a cup after it had been overheated in a microwave oven were received in recent years. Over-heating of water in a cup can result in superheated water (past its boiling temperature) without appearing to boil.

This type of phenomena occurs if water is heated in a clean cup. If foreign materials such as instant coffee or sugar are added before heating, the risk is greatly reduced. If superheating has occurred, a slight disturbance or movement such as picking up the cup, or pouring in a spoon full of instant coffee, may result in a violent eruption with the boiling water exploding out of the cup.

What can you do to avoid super-heated water?

- Follow the precautions and recommendations found in the microwave oven instruction manuals, specifically the heating time.
- Do not use excessive amounts of time when heating water or liquids in the microwave oven.
- Determine the best time setting to heat the water just to the desired temperature and use that time setting regularly.
- Mix the water with foreign materials (sugar, coffee …) before heating.
- Do not put your face above a clean cup of water before it has been mixed/stirred or cooled—use extreme caution.

4.8 Drowning hazard

This chapter may seem incongruous in a booklet on safety in refineries and petrochemical plants, but unfortunately experience has shown that drowning incidents can occurs in places like:

- jetties;
- water treatment plant;
- fire water ponds;
- cooling water pumping stations;
- storm retention ponds or lagoons;
- sewers;
- deep trenches or valve pits that can be flooded;
- bottom of process vessels;

ACCIDENT A tragic accident occurred when a contractor entered alone into the flash area of a vacuum distillation column to take a look at the underside of the first trays. The column had been water washed during the night but not drained. The contractor fell into the water and was unable to gain access to the internal ladder (see Figure 49). He drowned before the emergency services could rescue him.

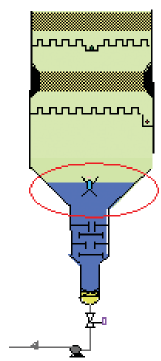


Figure 49 *Drowning incident in a water-filled vacuum distillation column.*

ACCIDENT An operator drowned in a mud pit at a well site. There was no 'orange barrier', let alone a strong fence, and the individual had slipped in during a snowstorm.

ACCIDENT Three children drowned in an unsecured water filled pit on a construction site. Coming back from school, they had decided to take a swim. Only a fourth child managed to escape unhurt.

Figure 50 *Tragedy in an unsecured water filled pit.*

All areas which have the possibility of holding water or other liquid shall be:

- covered with weight-proof materials; or
- barricaded with handrails (no plastic tape); or
- continuously supervised; or
- drained and backfilled.

Emergency rescue equipment (life buoys . . .), warning signs and alert systems (telephone, break glass point . . .) should be available near areas where such a risk exists. Also, a job safety analysis should be performed against each task in these areas to determine adequate safety precautions to be taken (PPE . . .).

ACCIDENT A similar tragic incident occurred when two children drowned in a trench on a pipeline project (see Figure 51). The trench was left open during the weekend and became filled with water due to summer storms.

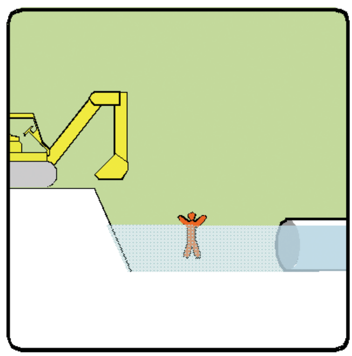


Figure 51 *Drowning tragedy in a pipeline trench.*

4.9 High pressure jet hazards

High pressure water jets are used in many applications, from cleaning jobs (see section 4.2) to cutting operations (for example, to remove coke from delayed coker drums; to cut steel plates without hot work).

These high pressure water jets are extremely dangerous as they can cut through a body effortlessly (high pressure jets are used to cut through metal!) and even a minor cut can kill by infection as contaminated water is pushed far in the blood system.

ACCIDENT A technician received fatal injuries when the decoking cutting head exited the top of the coke drum while it was still operating under 2,300 psig (160 bars) pressure. The technician was standing adjacent to the drum's open top operating the cutting head and received the full impact of the cutting water jets (see Figure 52).

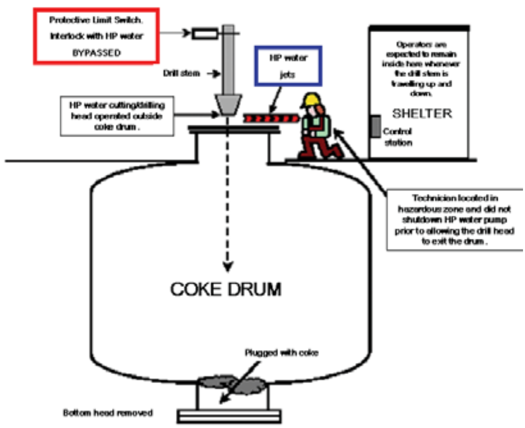


Figure 52 *Fatality due to technician being caught in cutting water jets.*

4.10 Archimede's principle hazard

Archimede's principle states that a body immersed in a fluid is buoyed up with a force equal to the weight of the displaced fluid. Therefore, any large piece of equipment can be lifted by water surrounding it if it is empty enough and not firmly anchored. Some depots or refineries have been unpleasantly surprised to find tanks or process vessels being lifted during a flooding storm.

Figure 53 *Small tank is washed away in a flood!!!*

ACCIDENT A violent storm hit a petrochemical complex. A flare drum lifted from the ground damaging attached piping (see Figure 54) and there were limited gas leakages. This flare drum was located in an underground concrete basin, which was completely overflowed during the big storm.

Figure 54 *Flare drum lifted during a flood, damaging piping.*

4.11 Water as a disease vector

It has been known for centuries that water can contain hazardous micro-organisms, especially in waste water systems. A more recently discovered hazard in industrial environments is Legionnaires' disease. It is a potentially fatal pneumonia caused by legionella bacteria (see Figure 55). It is the most well-known and serious form of a group of diseases known as legionellosis. Legionella is widespread throughout nature and has been found in almost any source of fresh water, including streams, lakes and even moist soil. In order for Legionella to grow the water must be between 68–113°F (20–45°C), relatively stagnant, with a supply of both inorganic and organic nutrients. It is possible that Legionella lives as a parasite on other micro-organisms in the water, such as amoebae.

To date, approximately 40 species of the legionella bacterium have been identified, Legionella pneumophilla causing about 90% of cases of Legionnaires' disease.

Breathing in small droplets of water contaminated by the bacteria causes infection. The disease cannot be passed from one person to another. Everyone is potentially susceptible to infection but some people are at higher risk such as those over 45 years of age, smokers and heavy drinkers, those suffering from chronic respiratory or kidney disease, and people whose immune system is impaired.

Figure 55 *Legionella bacteria.*

Several outbreaks of Legionnaires' disease have occurred since 1976, mostly associated with air-conditioning or hot water systems in large buildings such as hospitals and hotels. Some outbreaks have been associated with industrial wet cooling systems.

ACCIDENT A serious outbreak of 'Legionnaires' disease' occurred outside a petrochemical plant. 17 people died as a direct result of the outbreak and another 69 non-fatal cases of the disease were identified. All of these cases related to members of the public around the plant, the bacteria being carried by the wind from the site cooling towers. It was suggested that this long range may be attributed to a new and more virulent strain of the legionella bacteria.

The site was closed as a direct result of the incident, temporarily at first, then permanently. The incident attracted considerable regulatory interest across Europe.

A potential legionella hazard exists at all facilities that utilize any type of water system. This should be recognised and appropriate risk-based prevention and control processes established (in the absence of any existing country-specific legislation, the UK Health & Safety Executive Regulatory requirements on legionella prevention and control should be taken as the 'benchmark' [reference L8—'*The control of legionella bacteria in water systems*', Approved Code of Practice and guidance, ISBN 0 7176 1772 6]).

The main questions to consider are:

- Are conditions present that will encourage bacteria to multiply (water temperature 68–113°F (20–45°C))?
- Is there a means of creating and disseminating breathable droplets? For example, aerosols generated by a cooling tower or shower.
- Who may be exposed (particularly susceptible groups)?

Key control factors to prevent the appearance of the disease include:

- water presence, nutrients and temperature;
- time (stagnant water);
- water treatment;
- cleaning and disinfection;
- aerosol generation;
- monitoring and records.

Are you aware of your site procedures to control legionella bacteria in water systems?

5
Conclusion

The hazards of water in process units have been present throughout the entire history of petroleum refining. Many persons have been injured or killed because of the uncontrolled mixing of water with hot oil or the heating of bottled-in liquids with no provision for pressure relief. Stills have been ruptured, vessels have exploded, and exchangers have been blown apart.

Operators must realize that letting water get into a hot process system is much more dangerous than putting cold oil in the same place. This is true because of two principles:

- Water produces a much greater volume of vapour than the same amount of oil when flashed at the same pressure.
- Water in a closed vessel boils away with a rise of only a few degrees in temperature, whereas oil may not boil away until the temperature has risen several hundred degrees.

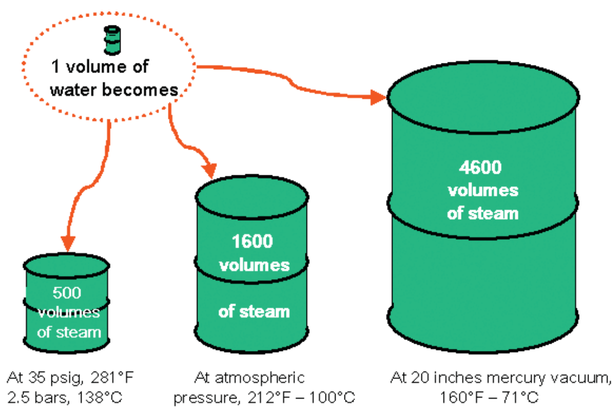
Operators must know how to guard against water in feed tanks, in new suction line-ups, and in units during start-ups. They must know what steps to take when water unexpectedly enters their unit.

A knowledge of how water reacts, where it can be expected and how to eliminate or control it will make your unit safer and your job easier.

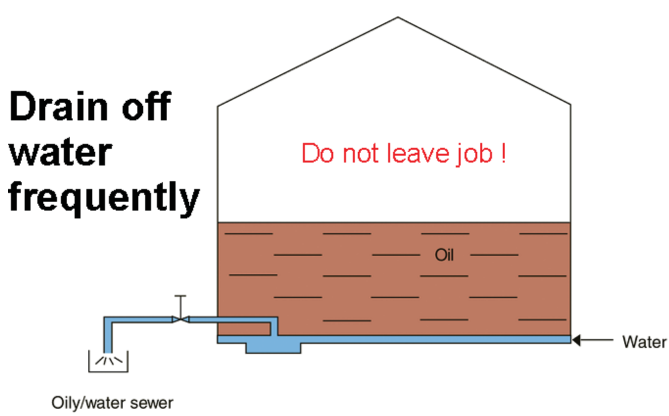
6

Some points to remember

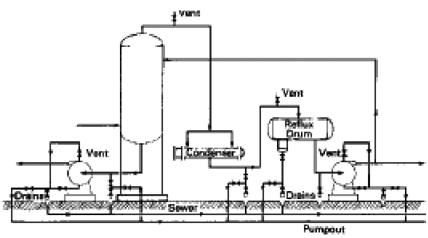
1. Water will vaporize and expand in volume 1,600 times when it contacts hot oil at atmospheric pressure. Expansion is much greater in a vacuum and at lower temperatures. For example, at 20 inches of Hg vacuum, one volume of water vaporizes to 4,600 volumes at 160°F (71°C).



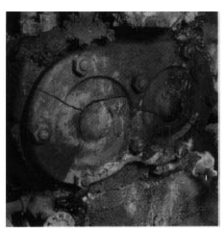
2. Draw water from feed tanks regularly.



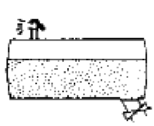
3. Be on the alert for water when feed or charging tanks are changed or when new suction line-ups are used.
4. Draw water regularly from bottoms of vessels, low spots of lines and exchangers during steaming and start-up periods. In cold weather, be sure that ice is melted and flushed out early in the start-up.
5. Flush all reflux lines before start-up; and drain lines, vessels and other equipment before putting reflux pump in service.
6. Run idle pumps where required during start-up to flush water from suction and discharge lines.
7. Draw water from reflux drums frequently.



8. Blind water and steam lines to vessels before charging unit with oil, unless these lines are used continuously during operation.
9. Protect equipment against freeze damage by draining, heating or circulating.



10. Guard against thermal expansion by adequate vapour space or pressure relief.



11. Make sure that equipment can withstand weight or pressure of water used for flushing or testing and that water will not cause harmful or dangerous chemical reaction.
12. Hot water burns like fire: it can kill you! Don’t regard it as a low risk product.

Acronyms and abbreviations

BS&W	Bottom Settlings and Water
O_2	Oxygen
CO_2	Carbon dioxyde
FCCU	Fluid Catalytic Cracker Unit
HGO	Heavy gasoil
LGO	Light gasoil
LPG	Liquefied Petroleum Gas (Propane – Butane)
PPE	Personal Protective Equipment
VDU	Vacuum Distillation Unit

Test yourself!

1. At 212°F (100°C) and atmospheric pressure, water expands about 1,600 times

   True ☐ **False** ☐

2. Warming or heating vessels, exchangers, pipe or other equipment that is completely full of liquid can result in dangerously large pressure rises.

   True ☐ **False** ☐

3. Ice takes less volume than the original water.

   True ☐ **False** ☐

4. The volume expansion upon vaporization is much greater in vacuum columns than in atmospheric ones.

   True ☐ **False** ☐

5. Draining operations can be left unattended for a few minutes.

   True ☐ **False** ☐

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

   True ☐ **False** ☐

7. Water hammer can destroy equipment and cause injuries.

   True ☐ **False** ☐

8. To be liable to boilover, oils must have components containing a wide range of boiling points.

   True ☐ **False** ☐

9. Electrostatic charging of oils cannot occur when droplets of water settle through oil in tankage

   True ☐ **False** ☐

10. Hot water cannot harm.

    True ☐ **False** ☐

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