Steam

Module- 8
Lec-8

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Steam today is an integral and essential part of modern technology.

Food, textile, chemical, medical, power, heating and transport industries could not exist or perform as they do.

- Steam provides a means of transporting controllable amounts of energy from a central, automated boiler house, where it can be efficiently and economically generated, to the point of use.
- Steam is one of the most widely used commodities for conveying heat energy.

![Image of steam engine](image)

**Figure 1 18th century steam engine**

- Steam is efficient and economic to generate
- Water is plentiful and inexpensive.
- It is non-hazardous to health and environmentally sound.
- In its gaseous form, it is a safe and efficient energy carrier.

Steam can hold five or six times as much potential energy as an equivalent mass of water.

- Steam can easily and cost effectively be distributed to the point of use
- Steam is one of the most widely used media to convey heat over distances.
Steam flows in response to the pressure drop along the line, expensive circulating pumps are not needed.
Steam is easy to control
Because of the direct relationship between the pressure and temperature, the amount of energy input to the process is easy to control, simply by controlling the saturated steam pressure.

Energy is easily transferred to the process
Steam provides excellent heat transfer. When the steam reaches the plant, the condensation process efficiently transfers the heat to the product being heated.

The modern steam plant is easy to manage
Increasingly, industrial energy users are looking to maximize energy efficiency and minimize production costs and overheads.
Steam is flexible
Steam is an excellent carrier of heat.
It is also sterile, and thus popular for process use in the food, pharmaceutical and health industries.
It is also widely used in hospitals for sterilization purposes.
Steam is also intrinsically safe

THE BOILER HOUSE

Figure 4 Typical heat paths through a smoke tube shell boiler

- The boiler has a number of fittings and controls to ensure that it operates safely, economically, efficiently and at a consistent pressure.

Feedwater
The quality of water which is supplied into the boiler is important.
- It must be at the correct temperature, usually around 80°C, to avoid thermal shock to the boiler, and to keep it operating efficiently.
It must also be of the correct quality to avoid damage to the boiler.
Figure 5 Sophisticated feed tank systems where the water is being heated by steam injection

- Ordinary untreated potable water is not entirely suitable for boilers and can quickly cause them to foam and scale up.
- The boiler would become less efficient and the steam would become dirty and wet. The life of the boiler would also be reduced.

Both feedwater treatment and heating take place in the feedtank, which is usually situated high above the boiler.

- The feed pump adds water to the boiler when required.

Heating the water in the feedtank also reduces the amount of dissolved oxygen in it. This is important, as oxygenated water is corrosive.

**Blowdown**

Chemical dosing of the boiler feedwater will lead to the presence of suspended solids in the boiler.

- These usually collect in the bottom of the boiler in the form of sludge, and are removed by a process known as bottom blowdown.
- This can be done manually - the boiler attendant will use a key to open a blowdown valve for a set period of time, usually twice a day.

Other impurities remain in the boiler water after treatment in the form of dissolved solids.

- Level control
  If the water level drops too low and the boiler tubes are exposed, the boiler tubes could overheat and fail, causing an explosion.

If the water level becomes too high, water could enter the steam system and upset the process.

![Figure 6 Typical boiler control/alarm configuration](image)

- The flow of steam to the plant
- When steam condenses, its volume is reduced, which results in a localized reduction in pressure.
- This pressure drop through the system creates the flow of steam through the pipes.

- Steam quality
  It is important to ensure that the steam leaving the boiler is delivered to the process in the right condition.

To achieve this pipe work which carries the steam around the plant normally incorporates strainers, separators and steam traps.
Figure 7 cut section of a strainer

Figure 8 cut section of a separator showing operation
When steam from the distribution system enters the steam using equipment the steam will again give up energy by:

- a) warming up the equipment and
- b) Continuing to transfer heat to the process.
- As steam loses heat, it turns back into water (Condensate).
- Inevitably the steam begins to do this as soon as it leaves the boiler.

- Condensate must be removed from the lowest points in the distribution pipework for several reasons:
  - Condensate does not transmit heat effectively.
  - A film of condensate inside plant will reduce the efficiency with which heat is transferred.
  - When air dissolves into condensate, it becomes corrosive.

  Inadequate drainage leads to leaking joints.

- Steam trap is being used to release condensate from the pipework whilst preventing the steam from escaping from the system. It can do this in several ways:
  - A float trap uses the difference in density between steam and condensate to operate a valve.
  - Thermodynamic traps contain a disc which opens to condensate and closes to steam.
  - In bimetallic thermostatic traps, a bimetallic element uses the difference in temperature between steam and condensate to operate the main valve.
  - In balanced pressure thermostatic traps, a small liquid filled capsule which is sensitive to heat operates the valve.

- Once the steam has been employed in the process, the resulting condensate needs to be drained from the plant and returned to the boiler house.
The steam phase diagram

Figure 9 temperature enthalpy phase diagram

- **Flash steam**

Flash steam occurs whenever water at high pressure (and a temperature higher than the saturation temperature of the low-pressure liquid) is allowed to drop to a lower pressure.

Figure 10 Flash steam formed because $T_1>T_2$
- **Methods of Estimating Steam Consumption**

  The optimum design for a steam system will largely depend on whether the steam consumption rate has been accurately established.

  This will enable pipe sizes to be calculated, while ancillaries such as control valves and steam traps can be sized to give the best possible results.

  The steam demand of the plant can be determined using a number of different methods:

  - **Calculation** - By analysing the heat output on an item of plant using heat transfer equations, it may be possible to obtain an estimate for the steam consumption.

  - **Measurement** - Steam consumption may be determined by direct measurement, using flowmetering equipment. This will provide relatively accurate data on the steam consumption for an existing plant.

  - **Thermal rating** - The thermal rating (or design rating) is often displayed on the name-plate of an individual item of plant, as provided by the manufacturers.

- **The Boiler House**

  A well designed, operated and maintained boiler house is the heart of an efficient steam plant.

It is important to remember that the steam boiler is a pressurized vessel containing scalding hot water and steam at more than 100°C, and its design and operation are covered by a number of complex standards and regulations.

These standards vary as follows:

- **Location** - For example, the UK, Australia, and New Zealand all have individual standards.

  The variations between standards may seem small but can sometimes be quite significant.

- **Over time – Change of Technology**

  with ref. to safety

- **Environmental terms – Emmission standard and discharge temp of steam**

- **Cost terms - Fuel costs , alternative steam raising fuels, waste energy  management.**

  Generally, where more than one boiler is required to meet the demand, it becomes economically viable to house the boiler plant in a centralized location, as installation and operating costs can be significantly lower than with decentralized plant.
Centralization offers the following benefits over the use of dispersed, smaller boilers:

- More choices of fuel and tariff.
- Identical boilers are frequently used in centralized boiler rooms reducing spares, inventory and costs.
- Heat recovery is easy to implement for best returns.
- A reduction in manual supervision releases labor for other duties on site.
- Economic sizing of boiler plant to suit diversified demand.
- Exhaust emissions are more easily monitored and controlled.
- Safety and efficiency protocols are more easily monitored and controlled.
- Fuel for boilers
- The three most common types of fuel used in steam boilers, are coal, oil, and gas.
- Industrial or commercial waste is also used in certain boilers, along with electricity for electrode boilers.

Coal
Various forms
- Peat.
- Lignite or brown coals.
- Bituminous.
- Semi bituminous.
- Anthracite.
- The bituminous and anthracite types tend to be used as boiler fuel.

Factors affecting
- Availability and cost

Speed of response to changing loads

Discharges

Ash – To be remove, usually involving manual intervention and a reduction in the amount of steam available whilst de-ashing takes place.
The ash must then be disposed of, which in itself may be costly.

Emissions - Coal contains an average of 1.5% sulphur (S) by weight, but this level may be as high as 3% depending upon where the coal was mined.

- **Oil**
  
  Various grades are available, each being suitable for different boiler ratings; the grades are as follows:
  
  - Class D - Diesel or gas oil.
  - Class E - Light fuel oil.
  - Class F - Medium fuel oil.
  - Class G - Heavy fuel oil.
  
  - The advantages of oil over coal include:
    
    - A shorter response time between demand and the required amount of steam being generated.
    - Less energy had to be stored in the boiler water.
    - The boiler could therefore be smaller, radiating less heat to the environment, with a consequent improvement in efficiency.
    - The smaller size also meant that the boiler occupied less production space.
    - Oil contains only traces of ash, virtually eliminating the problem of ash handling and disposal.

The difficulties encountered with receiving, storing and handling coal were eliminated.

### Gas

Gas is a form of boiler fuel that is easy to burn, with very little excess air. Fuel gases are available in two different forms:

- Natural gas - Contains a high proportion of methane.
- Liquefied petroleum gases (LPG) –

- The advantages of gas firing over oil firing include:
  
  - Storage of fuel is not an issue; gas is usually piped right into the boiler house.
- Only a trace of sulphur is present in natural gas, meaning that the amount of sulphuric acid in the flue gas is virtually zero.
- Waste as the primary fuel

There are two aspects to this:
Waste material - Burned to produce heat, which is used to generate steam. The motives may include the safe and proper disposal of hazardous material. A hospital would be a good example:
- Waste heat - Hot gases from a process, such as a smelting furnace, may be directed through a boiler with the objective of improving plant efficiency.
- Which fuel to use?
- The choice of fuels is obviously very important, as it will have a significant impact on the costs and flexibility of the boiler plant.

Factors that need consideration include:
- Cost of fuel –
- Cost of firing equipment - The cost of the burner(s) and associated equipment to suit the fuel(s) selected, and the emission standards which must be observed.

Security of supply
- Fuel shortage

The issues include:
- How much is to be stored, and where.
- How to safely store highly combustible materials.
- How much it costs to maintain the temperature of heavy oils so that they are at a suitable viscosity for the equipment.
- How to measure the fuel usage rate accurately.
- Allowance for storage losses.
- Boiler design
The boiler manufacturer must be aware of the fuel to be used when designing a boiler. This is because different fuels produce different flame temperatures and combustion characteristics.

For example:

- Oil produces a luminous flame, and a large proportion of the heat is transferred by radiation within the furnace.
- Gas produces a transparent blue flame, and a lower proportion of heat is transferred by radiation within the furnace.

**Boiler types**

- The objectives of a boiler are:
  - To release the energy in the fuel as efficiently as possible.
  - To transfer the released energy to the water, and to generate steam as efficiently as possible.
  - To separate the steam from the water ready for export to the plant, where the energy can be transferred to the process as efficiently as possible.
  - A number of different boiler types have been developed to suit the various steam applications

**Definition of Boiler**

- The American Society of Mechanical- Engineers (A.S.M.E.) definition
- "A combination of apparatus for producing, furnishing or recovering heat together with the apparatus for transferring the heat so made available to the fluid being heated and vaporised."
- The fluid (water) is contained in the boiler drum called. *shell* and the thermal energy released during combustion of fuel, which may be solid, liquid or gaseous, is transferred to water and this converts water into steam at the desired temperature and pressure.
- The steam thus generated is used for:
(i) **Power generation:** Mechanical work or electric power may be generated by expanding steam in the steam engine or steam turbine.

(ii) **Heating:** The steam is utilized for heating the residential and industrial buildings in cold weather and for producing hot waters for hot water supply.

(iii) Utilization of steam for industrial processes such as for sizing and bleaching etc. in textile industries. Steam is also used in many other industries like sugar mills and chemical industries.

### Classification of boilers

- Boilers are mainly classified according to the following:
  
  - **Relative position of hot gases and water.** (a) *Fire tube boiler.* The hot gases pass through the tubes that are surrounded by water.
  
  - The products of combustion leaving the furnace are passed through fire (smoke) tubes which are arranged within the water space. The heat energy of the flue gas is transferred to water which is converted into steam. The spent gases are then discharged to atmosphere through chimney.
  
  - The fire tube boilers are known by certain common names such as horizontal return tubular, locomotive fire box, scotch marine and vertical tubular etc.
  
  - (b) *Water tube boiler.* The tubes contain water and the hot gases produced by combustion of fuel flow outside. A bank of water tubes (tubes containing water) is connected with steam-water drum through two sets of headers.
  
  - The hot flue gases from the furnace are made to flow around the water tubes a sufficient number of times.
  
  - The gases thus give up their heat to an appreciable extent, get cooled and are discharged to the stack. The steam formed separates from water in the drum and gets accumulated in the steam space
  
  - The water tube boilers are designated by the following common names.
  
  - (i) Babcock and Wilcox boiler which has usually straight but inclined tubes which connect the headers.
(ii) Stirling boiler which is a multitubular boiler having bent tubes that connect drums to headers.

(a) internally fired boiler: The furnace region (space in which combustion of fuel takes place) is provided inside the boiler shell and is completely surrounded by water cooled
surfaces. The method of internal firing is used in Lancashire, Locomotive and Scotch boilers.

- *(b) Externally fired boiler* : The furnace region' is provided outside or built under the boiler a in the case of Babcock and Wilcox boiler.
- The externally fired boiler has the advantage that its furnace region is simple to construct and can be easily enlarged.

**Pressure of steam**

- Boilers producing steam at a pressure of 80 kgf/cm² and above are called high pressure boilers. The high pressure boilers are Babcock and Wilcox, Lamont, Velox and Benson etc.
- The boilers which produce steam at pressures lower than 80 kgf/cm² are called low pressure boilers. Examples are Cochran, Cornish, Lancashire and Locomotive boilers.

**Method of circulation of water.**

- Majority of the boilers operate' with natural circulation *i.e.*, the circulation set up by convection currents or by gravity.
- However at higher steam pressures, the steam becomes dense and there is very little difference in the density of steam water mixture and water alone.

**Nature of service to be performed.**

- Boilers which are used with stationary plants are classified as land boilers. Boilers which can be readily dismantled and easily carried from one site to another are called portable boilers. Marine and Locomotive boilers belong to another category called *mobile boilers.*
Once through boilers (Benson) in which there is no recirculation of water *i.e.*, the feed water leaves the tube as steam, whereas in controlled circulation boilers only a part of water is evaporated and the remainder is circulated.

*Position and number of drums.* Single or multidrums may be positioned longitudinally or crosswise.

*Design of gas passages.* The gas may follow a single pass, return pass or multipass.

**Nature of draught.**

When the fuel burns in the furnace of the boiler, with the natural circulation of air, the draft is named as natural* .* draught. In artificial draught, the air is forced by means of a forced fan.

**Heat source.**

The heat energy utilized for the conversion of a fluid into a vapour may be derived from:

(i) combustion of solid, liquid or gaseous: fuel

(ii) electrical and nuclear energy.

(iii) hot waste gases of other chemical reactions.
Material of construction of boiler shell.

- Depending upon the material used for the construction of boiler shell, the boilers can be classify into cast iron boilers and steel boilers.
- Power boilers are usually fabricated from steel plates. Low pressure heating boilers are built either of cast iron or steel.
- Miniature boilers have been fabricated from metals such as copper and stainless steel.
- **Shell Boilers**

![Diagram of Shell Boiler Configurations](image)

**Figure 14 Shell boiler-Wet & dry back configurations**

- **Lancashire boiler**
- Sir William Fairbairn developed the Lancashire boiler in 1844
Figure 15 Lancashire boiler

- Economic boiler (two-pass, dry back)

Figure 16 Economic Boiler (two-pass, dry back)
- **Economic boiler (three-pass, wet back)**

  ![Economic boiler diagram]

  **Figure 17 Economic Boiler (three-pass, wet back)**

- Packaged boiler
- The packaged boiler, resulted from further development on the three-pass economic wet back boiler.
- Mostly, these boilers were designed to use oil rather than coal.

  The packaged boiler is so called because it comes as a complete package with burner, level controls, feed pump and all necessary boiler fittings and mountings.
- Four-pass boilers
- Reverse flame / thimble boiler

This is a variation on conventional boiler design. The combustion chamber is in the form of a thimble, and the burner fires down the centre. The flame doubles back on itself within the combustion chamber to come to the front of the boiler. Smoke tubes surround the thimble and pass the flue gases to the rear of the boiler and the chimney.
To guarantee its successful and efficient operation, the user must:

- Know the conditions, environment, and demand characteristics of the plant.
- Provide a boiler house layout and installation that promotes good operation and maintenance.
- Select the control systems that allow the boiler to operate safely and efficiently.
- Select the control systems that will support the boiler in supplying dry steam to the plant at the required pressure(s) and flowrate(s).
- Identify the fuel to be used and, if necessary, where and how the fuel reserve is to be safely stored.

Advantages of shell boilers:

- The entire plant may be purchased as a complete package,
- This package arrangement also means that it is simple to relocate a packaged shell boiler.
- A shell boiler contains a substantial amount of water at saturation temperature, and hence has a substantial amount of stored energy which can be called upon to cope with short term, rapidly applied loads.
- This can also be a disadvantage in that when the energy in the stored water is used, it may take some time before the reserve is built up again.
- The construction of a shell boiler is generally straight forward, which means that maintenance is simple.

Shell boilers often have one furnace tube and burner. This means that control systems are fairly simple.

Disadvantages of shell boilers

The package principle means that approximately 27 000 kg / h is the maximum output of a shell boiler. If more steam is required, then several boilers need to be connected together.

- If higher pressures are needed, then a water-tube boiler is required.

Water Tube Boiler

- Water-tube boilers differ from shell type boilers in that the water is circulated inside the tubes, with the heat source surrounding them.
- Water-tube boilers are used in power station applications.

![Diagram of Water-tube Boilers](image)

**Figure 20** water-tube Boiler

![Diagram of Natural Water Circulation](image)

**Figure 21** natural water circulation in a water-tube Boiler
- Water-tube boiler sections
  The energy from the heat source may be extracted as either radiant or convection and conduction
- The furnace or radiant section
  This is an open area accommodating the flame(s) from the burner(s).

![Figure 21 Heat transfer in the furnace or radiant section](image)

- Convection section
  This part is designed to absorb the heat from the hot gases by conduction and convection.

Large boilers may have several tube banks (also called pendants) in series, in order to gain maximum energy from the hot gases.

![Figure 22 Heat transfer in the convection section](image)
Alternative water-tube boiler layouts

**Longitudinal drum boiler**

![Figure 23 Longitudinal drum boiler](image)

**Cross drum boiler**

![Figure 24 Cross drum boiler](image)
Bent tube or Stirling boiler

The bent tube or Stirling boiler allows for a large surface heat transfer area, as well as promoting natural water circulation.

![Diagram of Bent tube or Stirling boiler](image)

**Figure 25 Bent tube or Stirling boiler**

- Advantages of water-tube boilers:
  - They have a small water content, and therefore respond rapidly to load change and heat input.
  - The small diameter tubes and steam drum mean that much higher steam pressures can be tolerated, and up to 160 bar may be used in power stations.
  - The design may include many burners in any of the walls, giving horizontal, or vertical firing options, and the facility of control of temperature in various parts of the boiler.

Disadvantages of water-tube boilers:

- They are not as simple to make in the packaged form as shell boilers, which means that more work is required on site.
- The option of multiple burners may give flexibility, but the 30 or more burners used in power stations means that complex control systems are necessary.
- Miscellaneous Boiler Types, Economisers and Superheaters
- Steam generators
Coil boiler

These are a ‘once through’ type of water tube boiler, and referred to in some regulations as, ‘boilers with no discernible water level’.

Figure 26 Coil boiler

Vertical tubeless packaged steam boiler

Figure 27 Vertical tubeless packaged steam boiler
- **Economisers**
  - The flue gases, having passed through the main boiler and the super heater, will still be hot.
  - The energy in these flue gases can be used to improve the thermal efficiency of the boiler. To achieve this the flue gases are passed through an economiser.
  - The economiser is a heat exchanger through which the feedwater is pumped.

![Diagram](image)

**Figure 28 Shell boiler with an economizer**

- **Superheaters**
  - Whatever type of boiler is used, steam will leave the water at its surface and pass into the steam space. Steam formed above the water surface in a shell boiler is always saturated and cannot become superheated in the boiler shell, as it is constantly in contact with the water surface.
  - If superheated steam is required, the saturated steam must pass through a superheater. This is simply a heat exchanger where additional heat is added to the saturated steam.
Figure 29 water tube boiler with a super heater

- Heat losses
- Heat losses in the flue gases
  
  This is probably the biggest single source of heat loss, and the Engineering Manager can reduce much of the loss.

The losses are attributable to the temperature of the gases leaving the furnace. Clearly, the hotter the gases in the stack, the less efficient the boiler.

The gases may be too hot for one of two reasons:

- The burner is producing more heat than is required for a specific load on the boiler:
- This means that the burner(s) and damper mechanisms require maintenance and re-calibration.

- The heat transfer surfaces within the boiler are not functioning correctly, and the heat is not being transferred to the water:
- This means that the heat transfer surfaces are contaminated, and require cleaning.
- Some care is needed here - Too much cooling of the flue gases may result in temperatures falling below the 'dew point' and the potential for corrosion is increased.
- Radiation losses
  
  Burners and controls

- Burners are the devices responsible for:
- Proper mixing of fuel and air in the correct proportions, for efficient and complete combustion.
- Determining the shape and direction of the flame
- Burners

**Pressure jet burners**

![Diagram of pressure jet burner]

*Figure 30 Pressure jet burners*

**Advantages of pressure jet burners:**

- Relatively low cost.
- Simple to maintain.

**Disadvantages of pressure jet burners:**

- If the plant operating characteristics vary considerably over the course of a day, then the boiler will have to be taken off-line to change the nozzle.
- Easily blocked by debris. This means that well maintained, fine mesh strainers are essential.
Figure 31 Pressure jet burner

- Because the atomisation is produced by the rotating cup, rather than by some function of the fuel oil (e.g. pressure), the turndown ratio is much greater than the pressure jet burner.

Advantages of rotary cup burners:
- Robust.
- Good turndown ratio.
- Fuel viscosity is less critical.

Disadvantages of rotary cup burners:
- More expensive to buy and maintain.
- Gas burners

At present, gas is probably the most common fuel used in the UK.

Being a gas, atomisation is not an issue, and proper mixing of gas with the appropriate amount of air is all that is required for combustion.

- Dual fuel burners
Boiler Fittings and Mountings
number of items must be fitted to steam boilers, all with the objective of improving:

- Operation.
- Efficiency.
- Safety.

Several key boiler attachments

- Boiler name-plate

In the latter half of the 19th century
The serial number and model number uniquely identify the boiler and are used when ordering spares from the manufacturer and in the main boiler log book.
Essentials of a good boiler

- The essentials of a good boiler are:
- (1) The boiler should be capable of generating steam at the required pressure and of the required quality quickly and with minimum fuel consumption.
- (2) The initial cost, installation cost and the maintenance cost of the boiler should not be too high.
- (3) The boiler should be light in weight, should need least amount of brick work construction and should occupy small floor area.
- (4) The boiler should meet the fluctuating demands on steam supply without being overheated.
- (5) The different parts of the boiler should be easily approachable for repairs.
- (6) The boiler should have only minimum joints and those too should be away from direct flames.
- (7) The boiler should offer the ease of dismantling the parts and erection at site within reasonable time and labour. This is necessary for a boiler which has to be transported quite often.
- (8) For efficient heat transmission rate, the water and flue gases should have maximum velocity without incurring heavy frictional losses.
■ (9) There should be no deposition of mud and other foreign particles on the heated surfaces.
■ (10) The boiler should conform to the safety regulations as laid down in the "Boilers Act".

SAFETY VALVES

An important boiler fitting is the safety valve.

Many different types of safety valves are fitted to steam boiler plant, but they must all meet the following criteria:
■ The total discharge capacity of the safety valve(s) must be at least equal to the ‘from and at 100°C’ capacity of the boiler.
■ If the ‘from and at’ evaporation is used to size the safety valve, the safety valve capacity will always be higher than the actual maximum evaporative boiler capacity.

The full rated discharge capacity of the safety valve(s) must be achieved within 110% of the boiler design pressure.

■ The minimum inlet bore of a safety valve connected to a boiler shall be 20 mm.
■ The maximum set pressure of the safety valve shall be the design (or maximum permissible working pressure) of the boiler.
■ There must be an adequate margin between the normal operating pressure of the boiler and the set pressure of the safety valve.
■ Safety valve regulations
■ A boiler shall be fitted with at least one safety valve sized for the rated output of the boiler.
■ The discharge pipework from the safety valve must be unobstructed and drained at the base to prevent the accumulation of condensate.
■ It will be quite normal for the internal diameter of the discharge pipework to be more than the internal diameter of the safety valve outlet connection, but under no circumstances should it be less.
- **Boiler stop valves**

A steam boiler must be fitted with a stop valve (also known as a crown valve) which isolates the steam boiler and its pressure from the process or plant. It is generally an angle pattern globe valve of the screw-down variety.

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**Figure 34 boiler safety valves**

**Figure 35 Boiler stop valves**
These valves usually been manufactured from cast iron, with steel and bronze being used for higher pressure applications.

The stop valve is not designed as a throttling valve, and should be fully open or closed.

It should always be opened slowly to prevent any sudden rise in downstream pressure and to help restrict the fall in boiler pressure and any possible associated priming. The valve should be of the ‘rising hand wheel’ type. This allows the boiler operator to easily see the valve position, even from floor level. The valve shown is fitted with an indicator that makes this even easier for the operator.

On multi-boiler applications an additional isolating valve should be fitted, in series with the crown valve.

At least one of these valves should be lockable in the closed position. The additional valve is generally a globe valve of the screw-down, non-return type which prevents one boiler pressurising another.

Alternatively, it is possible to use a screw-down valve, with a disc check valve sandwiched between the flanges of the crown valve and itself.

Feed water check valves

The feed water check valve is installed in the boiler feed water line between the feed pump and boiler.

A boiler feed stop valve is fitted at the boiler shell.

The check valve includes a spring equivalent to the head of water in the elevated feed tank when there is no pressure in the boiler.

This prevents the boiler being flooded by the static head from the boiler feed tank.
Under normal steaming conditions the check valve operates in a conventional manner to stop return flow from the boiler entering the feed line when the feed pump is not running. When the feed pump is running, its pressure overcomes the spring to feed the boiler as normal. Because a good seal is required, and the temperatures involved are relatively low (usually less than 100°C) a check valve with a EPDM (Ethylene Propylene) soft seat is generally the best option.

![Diagram of check valve](image)

Figure 37 location of feed check valve

- Boiler water quality control
- The maintenance of water quality is essential to the safe and efficient operation of a steam boiler.
- The measurement and control of the various parameters is a complex topic, which is also covered by a number of regulations.
- TDS control
- This controls the amount of Total Dissolved Solids (TDS) in the boiler water, and is sometimes also referred to as ‘continuous blow down’.

The system may be manual or automatic. Whatever system is used, the TDS in a sample of boiler water is compared with a set point; if the TDS level is too high, a quantity of boiler
water is released to be replaced by feed water with a much lower TDS level. This has the effect of diluting the water in the boiler, and reducing the TDS level.

On a manually controlled TDS system, the boiler water would be sampled every shift.

![Diagram of a typical automatic TDS control system.](image)

**Figure 38 Typical automatic TDS control system**

- Bottom blow down
- This ejects the sludge or sediment from the bottom of the boiler.

The control is a large (usually 25 to 50 mm) key operated valve. This valve might normally be opened for a period of about 5 seconds, once per shift.

![Diagram of a bottom blow down valve.](image)

**Figure 39 Bottom blow down valve**
**Pressure gauge**

- All boilers must be fitted with at least one pressure indicator. The dial should be at least 150 mm in diameter and of the Bourdon tube type, it should be marked to indicate the normal working pressure and the maximum permissible working pressure / design pressure.
- Pressure gauges are connected to the steam space of the boiler and usually have a ring type siphon tube which fills with condensed steam and protects the dial mechanism from high temperatures.
- Pressure gauges may be fitted to other pressure containers such as blow down vessels,

![Typical pressure gauge with ring siphon](image)

*Fig. 3.7.9 Typical pressure gauge with ring siphon*

**Figure 40 typical Pressure gauge with ring siphon**

**Gauge glasses and fittings**

- All steam boilers are fitted with at least one water level indicator, but those with a rating of 100 kW or more should be fitted with two indicators.
- A gauge glass shows the current level of water in the boiler, regardless of the boiler’s operating conditions.
- Gauge glasses should be installed so that their lowest reading will show the water level at 50 mm above the point where overheating will occur.
- They should also be fitted with a protector around them, but this should not hinder visibility of the water level.
- Gauge glasses are prone to damage from a number of sources, such as corrosion from the chemicals in boiler water, and erosion during blow down, particularly at the steam end.
- Any sign of corrosion or erosion indicates that a new glass is required.

When testing the gauge glass steam connection, the water cock should be closed.
- When testing the gauge glass water connections, the steam cock pipe should be closed

![Figure 41 Gauge glasses and fittings](image)

- To test a gauge glass, the following procedure should be followed:
- Close the water cock and open the drain cock for approximately 5 seconds.
- Close the drain cock and open the water cock
- Water should return to its normal working level relatively quickly. If this does not happen, then a blockage in the water cock could be the reason, and remedial action should be taken as soon as possible.
- Close the steam cock and open the drain cock for approximately 5 seconds.
- Close the drain cock and open the steam cock.

If the water does not return to its normal working level relatively quickly, a blockage may exist in the steam cock. Remedial action should be taken as soon as possible.
The authorized attendant should systematically test the water gauges at least once each day and should be provided with suitable protection for the face and hands, as a safeguard against scalding in the event of glass breakage.

- Gauge glass guards
  - The gauge glass guard should be kept clean. When the guard is being cleaned in place, or removed for cleaning, the gauge should be temporarily shut-off.

Satisfactory water level should be there before shutting off the gauge and take care not to touch or knock the gauge glass. After cleaning, and when the guard has been replaced, the gauge should be tested and the cocks set in the correct position.

- Maintenance
  - The gauge glass should be thoroughly overhauled at each annual survey.
  - Lack of maintenance can result in hardening of packing and seizure of cocks.
  - If a cock handle becomes bent or distorted special care is necessary to ensure that the cock is set full open.
  - A damaged fitting should be renewed or repaired immediately.
  - Gauge glasses often become discolored due to water conditions; they also become thin and worn due to erosion.

Glasses, therefore, should be renewed at regular intervals.

A stock of spare glasses and cone packing should always be available in the boiler house.

- Remember:
  - If steam passes are choked a false high water level may be given in the gauge glass.
  - After the gauge has been tested a false high water level may still be indicated.
  - If the water passages are choked an artificially high water level may be observed due to steam condensing in the glass.
  - After testing, the glass will tend to remain empty unless the water level in the boiler is higher than the top connection, in which case water might flow into the glass from this connection.
Gauge glass levels must be treated with the utmost respect, as they are the only visual indicator of water level conditions inside the boiler.

Any water level perceived as abnormal must be investigated as soon as it is observed, with immediate action taken to shut down the boiler burner if necessary.

Water level controls

The maintenance of the correct water level in a steam boiler is essential to its safe and efficient operation.

The methods of sensing the water level, and the subsequent control of water level is a complex topic that is covered by a number of regulations.

External level control chambers

Level control chambers are fitted externally to boilers for the installation of level controls or alarms

![Diagram of external level control chambers](image)

**Figure 42 external level control chambers**

Internally mounted level controls

Level control systems with sensors (or probes) which fit inside the boiler shell (or steam drum).

These provide a higher degree of safety than those fitted externally.

The level alarm systems may also provide a self-checking function on system integrity.
Protection tubes are fitted to discourage the movement of water around the sensor.

Figure 43 Internally mounted level controls

- Air vents and vacuum breakers
- When a boiler is started from cold, the steam space is full of air.
- This air has no heat value, and will adversely affect steam plant performance due to its effect of blanketing heat exchange surfaces.
- The air can also give rise to corrosion in the condensate system, if not removed adequately.
- The air may be purged from the steam space using a simple cock;
- An alternative to the cock is a balanced pressure air vent which not only relieves the boiler operator of the task of manually purging air (and hence ensures that it is actually done), it is also much more accurate and will vent gases which may accumulate in the boiler.
- When a boiler is taken off-line, the steam in the steam space condenses and leaves a vacuum.
- This vacuum causes pressure to be exerted on the boiler from the outside, and can result in boiler inspection doors leaking, damage to the boiler flat plates and the danger of...
overfilling a shutdown boiler. To avoid this, a vacuum breaker is required on the boiler shell.

Figure 44 Typical air vents and vacuum breakers

- Treatment, Storage and Blow down for Steam Boilers
- Water is the most important raw material on earth. It is essential to life, it is used for transportation, and it stores energy. It is also called the ‘universal solvent’. Pure water (H₂O) is tasteless, odorless, and colorless in its pure state; however, pure water is very uncommon. All natural waters contain various types and amounts of impurities. Good drinking water does not necessarily make good boiler feed water. The minerals in drinking water are readily absorbed by the human body, and essential to our well being. Boilers, however, are less able to cope, and these same minerals will cause damage in a steam boiler if allowed to remain.
Reduce heat transfer rates, leading to overheating and loss of mechanical strength.

Figure 45 Typical water cycle
Of the world's water stock, 97% is found in the oceans, and a significant part of that is trapped in the polar glaciers - only 0.65% is available for domestic and industrial use.

This small proportion would soon be consumed if it were not for the water cycle (see Figure 3.9.1). After evaporation, the water turns into clouds, which are partly condensed during their journey and then fall to earth as rain. However, it is wrong to assume that rainwater is pure; during its fall to earth it will pick up impurities such as carbonic acid, nitrogen and, in industrial areas, sulphur dioxide. Charged with these ingredients, the water percolates through the upper layers of the earth to the water table, or flows over the surface of the earth dissolving and collecting additional impurities. These impurities may form deposits on heat transfer surfaces that may: Cause metal corrosion.

**Table 1 Impurities in water**

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Common name</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium carbonate</td>
<td>CaCO₃</td>
<td>Chalk, limestone</td>
<td>Soft scale</td>
</tr>
<tr>
<td>Calcium bicarbonate</td>
<td>Ca(HCO₃)₂</td>
<td></td>
<td>Soft scale + CO₂</td>
</tr>
<tr>
<td>Calcium sulphate</td>
<td>CaSO₄</td>
<td>Gypsum, plaster of paris</td>
<td>Hard scale</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>CaCl₂</td>
<td></td>
<td>Corrosion</td>
</tr>
<tr>
<td>Magnesium carbonate</td>
<td>MgCO₃</td>
<td>Magnesite</td>
<td>Soft scale</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>MgSO₄</td>
<td>Epsom salt</td>
<td>Corrosion</td>
</tr>
<tr>
<td>Magnesium bicarbonate</td>
<td>Mg(HCO₃)₂</td>
<td></td>
<td>Scale, corrosion</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>NaCl</td>
<td>Common salt</td>
<td>Electrolysis</td>
</tr>
<tr>
<td>Sodium carbonate</td>
<td>Na₂CO₃</td>
<td>Washing soda or soda</td>
<td>Alkalinity</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>NaHCO₃</td>
<td>Baking soda</td>
<td>Priming, foaming</td>
</tr>
<tr>
<td>Sodium hydroxide</td>
<td>NaOH</td>
<td>Caustic soda</td>
<td>Alkalinity, embrittlement</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>Na₂SO₄</td>
<td>Glauber salts</td>
<td>Alkalinity</td>
</tr>
<tr>
<td>Silicon dioxide</td>
<td>SiO₂</td>
<td>Silica</td>
<td>Hard scale</td>
</tr>
</tbody>
</table>

- The common impurities in raw water can be classified as follows:
- Dissolved solids - These are substances that will dissolve in water.

The principal ones are the carbonates and sulphates of calcium and magnesium, which are scale-forming when heated.
There are other dissolved solids, which is non-scale forming.
In practice, any salts forming scale within the boiler should be chemically altered so that they produce suspended solids, or sludge rather than scale.

- Suspended solids - These are substances that exist in water as suspended particles. They are usually mineral, or organic in origin. These substances are not generally a problem as they can be filtered out.
- Dissolved gases - Oxygen and carbon dioxide can be readily dissolved by water. These gases are aggressive instigators of corrosion.
- Scum forming substances - These are mineral impurities that foam or scum. One example is soda in the form of a carbonate, chloride, or sulphate.

The amount of impurities present is extremely small and they are usually expressed in any water analysis in the form of parts per million (ppm), by weight or alternatively in milligrams per litre (mg/l).

**Hardness**

Water is referred to as being either ‘hard’ or ‘soft’. Hard water contains scale-forming impurities while soft water contains little or none. The difference can easily be recognized by the effect of water on soap. Much more soap is required to make lather with hard water than with soft water. Hardness is caused by the presence of the mineral salts of calcium and magnesium and it is these same minerals that encourage the formation of scale.

There are two common classifications of hardness:

- Alkaline hardness (also known as temporary hardness) - Calcium and magnesium bicarbonates are responsible for alkaline hardness. The salts dissolve in water to form an alkaline solution. When heat is applied, they decompose to release carbon dioxide and soft scale or sludge.

The term ‘temporary hardness’ is sometimes used, because the hardness is removed by boiling. This effect can often be seen as scale on the inside of an electric kettle.
- Non-alkaline hardness and carbonates (also known as permanent hardness) - This is also due to the presence of the salts of calcium and magnesium but in the form of sulphates and chlorides.

- These precipitate out of solution, due to their reduced solubility as the temperature rises, and form hard scale, which is difficult to remove.

In addition, the presence of silica in boiler water can also lead to hard scale, which can
react with calcium and magnesium salts to form silicates which can severely inhibit heat transfer across the fire tubes and cause them to overheat.

**Total hardness**

- Total hardness is not to be classified as a type of hardness, but as the sum of concentrations of calcium and magnesium ions present when these are both expressed as CaCO₃. If the water is alkaline, a proportion of this hardness, equal in magnitude to the total alkalinity and also expressed as CaCO₃, is considered as alkaline hardness, and the remainder as non-alkaline hardness.

- Non-scale forming salts Non-hardness salts, such as sodium salts are also present, and are far more soluble than the salts of calcium or magnesium and will not generally form scale on the surfaces of a boiler, Comparative unit. When salts dissolve in water they form electrically charged particles called ions. The metallic parts (calcium, sodium, magnesium) can be identified as cations because they are attracted to the cathode and carry positive electrical charges. Anions are non-metallic and carry negative charges - bicarbonates, carbonate, chloride, sulphate, are attracted to the anode. Each impurity is generally expressed as a chemically equivalent amount of calcium carbonate, which has a molecular weight of 100.

**pH value** Another term to be considered is the pH value; this is not an impurity or constituent but merely a numerical value representing the potential hydrogen content of water - which is a measure of the acidic or alkaline nature of the water. Water, H₂O, has two types of ions - hydrogen ions (H⁺) and hydroxyl ions (OH⁻).

If the hydrogen ions are predominant, the solution will be acidic with a pH value between 0 and 6. If the hydroxyl ions are predominant, the solution will be alkaline, with a pH value between 8 and 14. If there are an equal number of both hydroxyl and hydrogen ions, then the solution will be neutral, with a pH value of 7. Acids and alkalis have the effect of increasing the conductivity of water above that of a neutral sample. For example, a sample of water with a pH value of 12 will have a higher conductivity than a sample that has a pH value of 7.
Water for the Boiler

- The operating objectives for steam boiler plant include:
  - Safe operation.
  - Maximum combustion and heat transfer efficiency.
  - Minimum maintenance.
  - Long working life.
- The quality of the water used to produce the steam in the boiler will have a profound effect on meeting these objectives.

There is a need for the boiler to operate under the following criteria:

- Freedom from scale - If hardness is present in the feedwater and not controlled chemically, then scaling of the heat transfer surfaces will occur, reducing heat transfer and efficiency - making frequent cleaning of the boiler necessary. In extreme cases, local hot spots can occur, leading to mechanical damage or even tube failure.

- Freedom from corrosion and chemical attack - If the water contains dissolved gases, particularly oxygen, corrosion of the boiler surfaces, piping and other equipment is likely to occur.

If the pH value of the water is too low, the acidic solution will attack metal surfaces. If the pH value is too high, and the water is alkaline, other problems such as foaming may occur. Caustic embrittlement or caustic cracking must also be prevented in order to avoid metal failure. Cracking and embrittlement are caused by too high a concentration of sodium hydroxide. Older riveted boilers are more susceptible to this kind of attack; however, care is still necessary on modern welded boilers at the tube ends. Good quality steam. If the impurities in the boiler feedwater are not dealt with properly, carryover of boiler water into the steam system can occur. This may lead to problems elsewhere in the steam system, such as: Contamination of the surfaces of control valves - This will affect their operation and reduce their capacity. Contamination of the heat transfer surfaces of process plant - This will increase thermal resistance, and reduce the effectiveness of heat transfer. Restriction of steam trap orifices - This will reduce steam trap capacities, and ultimately lead to waterlogging of the plant, and reduced output.

- Carryover can be caused by two factors: Priming - This is the ejection of boiler water into the steam take-off and is generally due to one or more of the following:
- Operating the boiler with too high a water level.
- Operating the boiler below its design pressure; this increases the volume and the velocity of the steam released from the water surface.
- Excessive steam demand.
- Foaming - This is the formation of foam in the space between the water surface and the steam off-take. The greater the amount of foaming, the greater the problems which will be experienced.

The following are indications and consequences of foaming:
- Water will trickle down from the steam connection of the gauge glass; this makes it difficult to accurately determine the water level.
- Level probes, floats and differential pressure cells have difficulty in accurately determining water level. Alarms may be sounded, and the burner(s) may even ‘lockout’. This will require manual resetting of the boiler control panel before supply can be re-established.
- These problems may be completely or in part due to foaming in the boiler. However, because foaming is endemic to boiler water,
- Surface definition - Foam on a glass of beer sits on top of the liquid, and the liquid / foam interface is clearly defined. In a boiling liquid, the liquid surface is indistinct, varying from a few small steam bubbles at the bottom of the vessel, to many large steam bubbles at the top.
- Agitation increases foaming - The trend is towards smaller boilers for a given steaming rate. Smaller boilers have less water surface area, so the rate at which steam is released per square metre of water area is increased. This means that the agitation at the surface is greater. It follows then that smaller boilers are more prone to foaming.
- Hardness - Hard water does not foam. However, boiler water is deliberately softened to prevent scale formation, and this gives it a propensity to foam.
- Colloidal substances - Contamination of boiler water with a colloid in suspension, for example. milk, causes violent foaming. Note: Colloidal particles are less than 0.0001 mm in diameter, and can pass through a normal filter.
- TDS level - As the boiler water TDS increases, the steam bubbles become more stable, and are more reluctant to burst and separate.

The following alternatives are open to the Engineering Manager to minimise foaming in the boiler: Operation - Smooth boiler operation is important. With a boiler operating under constant load and within its design parameters, the amount of entrained moisture carried over with steam may be less than 2%. If load changes are rapid and of large magnitude, the pressure in the boiler can drop considerably, initiating extremely turbulent conditions as the contents of the boiler flash to steam. To make matters worse, the reduction in pressure also means that the specific volume of the steam is increased, and the foam bubbles are proportionally larger.

- Chemical control - Anti-foaming agents may be added to the boiler water. These operate by breaking down the foam bubbles. However, these agents are not effective when treating foams caused by suspended solids.

Control of TDS - A balance has to be found between:

- A high TDS level with its attendant economy of operation.
- A low TDS level which minimises foaming.

Safety - The dangers of overheating due to scale, and of corrosion due to dissolved gases, are easy to understand. In extreme cases, foaming, scale and sludge formation can lead to the boiler water level controls sensing improper levels, creating a danger to personnel and process alike.

**External water treatment**

- It is generally agreed that where possible on steam boilers, the principal feedwater treatment should be external to the boiler. A summary of the treated water quality that might be obtained from the various processes, based on a typical hard raw water supply,
- The external treatment plant has to deal with.

External water treatment processes can be listed as:

- Reverse osmosis - A process where pure water is forced through a semi-permeable membrane leaving a concentrated solution of impurities, which is rejected to waste.
- Lime; lime / soda softening - With lime softening, hydrated lime (calcium hydroxide) reacts with calcium and magnesium bicarbonates to form a removable sludge. This
reduces the alkaline (temporary) hardness. Lime / soda (soda ash) softening reduces non-
alcaline (permanent) hardness by chemical reaction.

- Ion exchange - Is by far the most widely used method of water treatment for shell boilers producing saturated steam. This module will concentrate on the following processes by which water is treated: Base exchange, Dealkalisation and Demineralisation.

**Ion exchange**

- An ion exchanger is an insoluble material normally made in the form of resin beads of 0.5 to 1.0 mm diameter. The resin beads are usually employed in the form of a packed bed contained in a glass reinforced plastic pressure vessel. The resin beads are porous and hydrophilic - that is, they absorb water. Within the bead structure are fixed ionic groups with which are associated mobile exchangeable ions of opposite charge. These mobile ions can be replaced by similarly charged ions, from the salts dissolved in the water surrounding the beads.

**Base exchange softening**

- This is the simplest form of ion exchange and also the most widely used.
- The resin bed is initially activated (charged) by passing a 7 - 12% solution of brine (sodium chloride or common salt) through it, which leaves the resin rich in sodium ions. Thereafter, the water to be softened is pumped through the resin bed and ion exchange occurs.
- Calcium and magnesium ions displace sodium ions from the resin, leaving the flowing water rich in sodium salts.
- Sodium salts stay in solution at very high concentrations and temperatures and do not form harmful scale in the boiler.

The total hardness ions are exchanged for sodium. With sodium base exchange softening there is no reduction in the total dissolved solids level (TDS in parts per million or ppm) and no change in the pH.
- All that has happened is an exchange of one group of potentially harmful scale forming salts for another type of less harmful, non-scale forming salts.
- As there is no change in the TDS level, resin bed exhaustion cannot be detected by a rise in conductivity (TDS and conductivity are related).
- Regeneration is therefore activated on a time or total flow basis.

Softeners are relatively cheap to operate and can produce treated water reliably for many years. They can be used successfully even in high alkaline (temporary) hardness areas provided that at least 50% of condensate is returned.
Where there is little or no condensate return, a more sophisticated type of ion exchange is preferable.

Sometimes a lime / soda softening treatment is employed as a pre-treatment before base exchange. This reduces the load on the resins.

**Dealkalisation**

- The disadvantage of base exchange softening is that there is no reduction in the TDS and alkalinity.
- This may be overcome by the prior removal of the alkalinity and this is usually achieved through the use of a dealkaliser.
- There are several types of dealkaliser

It is really a set of three units, a dealkaliser, followed by a degasser and then a base exchange softener.

![Dealkalisation Diagram](image)

*Figure 49 Dealkalisation*
**Demineralisation**

- This process will remove virtually all the salts.
- It involves passing the raw water through both cation and anion exchange resins
- Sometimes the resins may be contained in one vessel and this is termed ‘mixed bed’ demineralisation.

The process removes virtually all the minerals and produces very high quality water containing almost no dissolved solids.

- It is used for very high pressure boilers such as those in power stations.
  If the raw water has a high amount of suspended solids this will quickly foul the ion exchange material, drastically increasing operating costs.
- In these cases, some pre-treatment of the raw water such as clarification or filtration may be necessary.

![Diagram of demineralisation process](image)

**Fig 50 Demineralisation**
Shell boiler plant

- Generally, shell boilers are able to tolerate a fairly high TDS level, and the relatively low capital and running costs of base-exchange softening plants will usually make them the first choice.

If the raw water supply has a high TDS value, and / or the condensate return rate is low (<40%), there are a few options which may be considered:

- Pre-treatment with lime / soda which will cause the alkaline hardness to precipitate out of solution as calcium carbonate and magnesium hydroxide, and then drain from the reaction vessel.

- A dealkalisation plant to reduce the TDS level of the water supplied to the boiler plant. Water-tube boiler plant.

- Water-tube boiler plant is much less tolerant of high TDS levels, and even less so as the pressure increases. This is due to a number of reasons, including:
  - Water-tube boilers have a limited water surface area in the steam drum, relative to the evaporation rate.
  - This results in very high steam release rates per unit of water area, and turbulence.
  - Water-tube boilers tend to be higher rated, perhaps over 1 000 tonnes / h of steam. This means that even a small percentage blowdown can represent a high mass to be blown down.

Water-tube boilers tend to operate at higher pressures, usually up to 150 bar g. The higher the pressure, the greater the energy contained in the blowdown water. Higher pressures also mean higher temperatures. This means that the materials of construction will be subjected to higher thermal stresses, and be operating closer to their metallurgical limitations. Even a small amount of internal contamination hindering the heat transfer from tubes to water may result in the tubes overheating.

- Water-tube boilers often incorporate a superheater.

  The dry saturated steam from the steam drum may be directed to a superheater tubes situated in the highest temperature area of the furnace. Any carryover of contaminated water with the steam would coat the inside of the superheater tubes, and inhibit heat transfer with potentially disastrous results.
The above factors mean that:

High quality water treatment is essential for the safe operation of this type of plant.

It may be economically viable to invest in a water treatment plant that will minimize blow down rates.

In each of these cases, the selection will often be a demineralization or a reverse osmosis plant Controlling TDS in the Boiler Water

As a boiler generates steam, any impurities which are in the boiler feed water and which do not boil off with the steam will concentrate in the boiler water.

As the dissolved solids become more and more concentrated, the steam bubbles tend to become more stable, failing to burst as they reach the water surface of the boiler.

There comes a point (depending on boiler pressure, size, and steam load) where a substantial part of the steam space in the boiler becomes filled with bubbles and foam is carried over into the steam main.

This is obviously undesirable not only because the steam is excessively wet as it leaves the boiler, but it contains boiler water with a high level of dissolved and perhaps suspended solids. These solids will contaminate control valves, heat exchangers and steam traps.

Whilst foaming can be caused by high levels of suspended solids, high alkalinity or contamination by oils and fats, the most common cause of carryover (provided these other factors are properly controlled) is a high Total Dissolved Solids (TDS) level.

Careful control of boiler water TDS level together with attention to these other factors should ensure that the risks of foaming and carryover are minimised.

**Bottom Blowdown**

Suspended solids can be kept in suspension as long as the boiler water is agitated, but as soon as the agitation stops, they will fall to the bottom of the boiler.

If they are not removed, they will accumulate and, given time, will inhibit heat transfer from the boiler fire tubes, which will overheat and may even fail.

The recommended method of removing this sludge is via short, sharp blasts using a relatively large valve at the bottom of the boiler.
- The objective is to allow the sludge time to redistribute itself so that more can be removed on the next blowdown.
  For this reason, a single four-second blowdown every eight hours is much more effective than one, twelve-second blowdown in the first eight hour shift period, and then nothing for the rest of the day.
  Blowdown water will either pass into a brick-lined blowdown pit encased below ground, or a metal blowdown vessel situated above ground.
- The size of the vessel is determined by the flowrate of blowdown water and flash steam that enters the vessel when the blowdown valve is opened.
  The major influences on blowdown rate are:
  - The boiler pressure.
  - The size of the blowdown line.

The length of the blowdown line between the boiler and the blowdown vessel.

Figure 51 bottom blow down valve with Water Levels in Steam Boilers removable key
The task of any steam boiler is to provide the correct amount of high quality steam: safely, efficiently, and at the correct pressure.

Steam is generated by heat from the combustion of fuel in a furnace, or by waste heat from a process. The heat is transferred to water in the boiler shell, which then evaporates to produce steam under pressure.

A certain area of water surface is required in a boiler from which to release the steam. A certain height should also be allowed above the normal working level, to allow the water level to rise with increasing load, but still allowing sufficient area to release the steam without carryover of water taking place.

In horizontal shell boilers, the water level rises with increasing load (due to the presence of more steam being below the water level in the boiler). As it does so, the water surface area (steam release area) will decrease because, as the water level is above the centre line of the boiler, the sides of the containing shell converge.

The boilermaker will have designed the boiler to ensure that the area of the normal water level (NWL) is such that steam will be released at an acceptable velocity. The design will also allow a specific minimum height of the steam off-take above the NWL.

Clearly, as steam is generated, the water in the boiler evaporates, and the boiler must receive a supply of water to maintain the level. Because of the factors outlined above, water must be maintained at the correct level.

Safety is also of paramount importance. If the boiler operates with insufficient water, severe damage could occur and there is ultimately the risk of explosion.

For this reason, controls are required which will:
- Monitor and control the water level
- Detect if a low water level point is reached, and take appropriate action.

This action may include:
- Sounding an alarm, shutting down the feedwater supply and shutting down the burner(s).

It is also essential to provide an external indication of the water level.

- Water level indication and boiler water levels
  Water level indication applies to steam boilers where the water level can be detected.
- It includes most steam boilers, the exception being those of the ‘once through’ or coil type, where there is no steam drum. In such cases, steam outlet temperatures exceeding a pre-set value are taken to indicate insufficient water input.

In most cases, the simple gauge glass on the steam / water drum or boiler shell is used as the indicator.

Many standards stipulate the provision of two gauge glasses. Arrangements are usually required to prevent a breakage from causing a hazard to the operator. The most common form of protection is a toughened glass screen to the front and sides of the water gauge glass.

Water gauge glass constructed from flat or prismatic glass may be required for high-pressure boilers.

The gauge glass device, which has stood the test of time, is used on the vast majority of boilers and is usually arranged to give a visible range of water level above and below the normal water level.

![Figure 52 water gauge glass and mountings](image-url)
Methods of Detecting Water Level in Steam Boilers

On a steam raising boiler there are three clear applications for level monitoring devices:

- **Level control** - To ensure that the right amount of water is added to the boiler at the right time.
- **Low water alarm** - For safe boiler operation, the low water alarm ensures that the combustion of fuel does not continue if the water level in the boiler has dropped to, or below a predetermined level.
- **For automatically controlled steam boilers, national standards usually call for two independent low level alarms, to ensure safety.**

- **High water alarm** - The alarm operates if the water level rises too high, informing the boiler operator to shut off the feedwater supply.
- **Although not usually mandatory, the use of high level alarms is sensible as they reduce the chance of water carryover**

### Water Level Alarms

- **Where boilers are operated without constant supervision (which includes the majority of industrial boilers) low water level alarms are required to shut down the boiler in the event of a lack of water in the boiler. Low level may be caused by:**
  - A feedwater shortage in the feedtank.
  - Failure of a feedpump.
  - Accidental isolation of the feedwater line.
  - Failure of the level control system.
  - **The regulations covering boilers have built up over the years in response to boiler explosions, damage and loss of life.**
  - **Whilst boiler explosions are now very rare, damage to boilers which is attributable to low water level still occurs.**

The effect of low water level in a boiler is that the heated tubes or the furnace tube(s) become uncovered and are no longer cooled by the boiler water. The metal temperature rapidly increases, its strength is reduced and collapse or rupture follows.
**Low water alarm**

The action of the low water level alarms under UK regulations is as follows:

- **1st low level alarm** - Shuts down the burner at the alarm level, but allows it to re-fire if the level recovers.
- **2nd low level alarm** (often called lockout) - Also shuts down the burner at the alarm level, but the burner controls remain ‘locked out’ even if the water level recovers and any faults have been rectified. The lockout has to be manually reset to allow the burner to re-fire.

The rules and regulations covering boiler operation, and the controls required, will vary from country to country, although demands for higher levels of safety, plus a desire to run steam boilers without the permanent presence of a boiler attendant, are tending to drive the regulations in the same direction.

The action of low water alarms outlined above, relates to the regulations governing unattended steam boiler plant in the UK. However, they are similar to the rules which are applied in many European countries and further afield.

**High water alarm**

With the exception of one or two operating standards, the risks from a water level too high are treated very lightly, if not ignored altogether. The dangers of an excessively high water level in a steam boiler include:

- Increased carryover of water into the steam will result in poor operation and / or malfunction of the steam system components, due to dirt.
- Wet and dirty steam can contaminate or spoil the product where it is used directly.
- Wet steam can increase the water film thickness of the heat transfer surface, lower processing temperatures, perhaps interfering with proper sterilisation of food products or processing of pharmaceuticals, and causing wastage.
- At best, lower process and production efficiency will increase process time and unit costs.
- Overfilling the boiler can lead to waterhammer in the steam system, risking damage to plant and even injury to personnel.
All of these, taken together, can result in:

- Spoilt product.
- Lower production rates.
- Poor product quality.
- Increased plant and component maintenance.
- Damage to the steam system.
- Risk to personnel.

As can be seen, the dangers of an excessively high water level are too serious to ignore, and deserve equal consideration to that given to low water level conditions.

**A high water condition could:**

- Simply sound an alarm if the boiler house is manned.
- Shut-down the feedpump.
- Lockout the burner.
- Close the feedwater valve.
- The action to be taken largely depends on the individual plant requirements.

Safety Valves

Introduction

As soon as mankind was able to boil water to create steam, the necessity of the safety device became evident. As long as 2000 years ago, the Chinese were using cauldrons with hinged lids to allow (relatively) safer production of steam. At the beginning of the 14th century, chemists used conical plugs and later, compressed springs to act as safety devices on pressurised vessels.

Early in the 19th century, boiler explosions on ships and locomotives frequently resulted from faulty safety devices, which led to the development of the first safety relief valves. In 1848, Charles Retchie invented the accumulation chamber, which increases the compression surface within the safety valve allowing it to open rapidly within a narrow overpressure margin.

Today, most steam users are compelled by local health and safety regulations to ensure that their plant and processes incorporate safety devices and precautions, which ensure that dangerous conditions are prevented.
The primary function of a safety valve is therefore to protect life and property. The principle type of device used to prevent overpressure in plant is the safety or safety relief valve.

- The safety valve operates by releasing a volume of fluid from within the plant when a predetermined maximum pressure is reached, thereby reducing the excess pressure in a safe manner.

As the safety valve may be the only remaining device to prevent catastrophic failure under overpressure conditions, it is important that any such device is capable of operating at all times and under all possible conditions.

- In steam systems, safety valves are typically used for boiler overpressure protection and other applications such as downstream of pressure reducing controls. Although their primary role is for safety, safety valves are also used in process operations to prevent product damage due to excess pressure.
- Pressure excess can be generated in a number of different situations, including:
  - An imbalance of fluid flowrate caused by inadvertently closed or opened isolation valves on a process vessel.
  - Failure of a cooling system, which allows vapour or fluid to expand.
  - Compressed air or electrical power failure to control instrumentation
  - Transient pressure surges
  - Exposure to plant fires.
  - Heat exchanger tube failure.
  - Uncontrollable exothermic reactions in chemical plants.
  - Ambient temperature changes.
- The terms ‘safety valve’ and ‘safety relief valve’ are generic terms to describe many varieties of pressure relief devices that are designed to prevent excessive internal fluid pressure build-up.

A wide range of different valves is available for many different applications and performance criteria. Furthermore, different designs are required to meet the numerous national standards that govern the use of safety valves.
**Safety valve** –

- A valve which automatically, without the assistance of any energy other than that of the fluid concerned, discharges a certified amount of the fluid so as to prevent a predetermined safe pressure being exceeded, and which is designed to re-close and prevent the further flow of fluid after normal pressure conditions of service have been restored.

**Safety valve design**

- The basic spring loaded safety valve, referred to as ‘standard’ or ‘conventional’ is a simple, reliable self-acting device that provides overpressure protection.

The basic elements of the design consist of a right angle pattern valve body with the valve inlet connection, or nozzle, mounted on the pressure-containing system. The outlet connection may be screwed or flanged for connection to a piped discharge system. However, in some applications, such as compressed air systems, the safety valve will not have an outlet connection, and the fluid is vented directly to the atmosphere.

![Safety Valve Diagram](image)

**Figure 53 Safety valve design**
The valve inlet (or approach channel) design can be either a full-nozzle or a semi-nozzle type.

- A full-nozzle design has the entire ‘wetted’ inlet tract formed from one piece. The approach channel is the only part of the safety valve that is exposed to the process fluid during normal operation, other than the disc, unless the valve is discharging. Full-nozzles are usually incorporated in safety valves designed for process and high pressure applications, especially when the fluid is corrosive. Conversely, the semi-nozzle design consists of a seating ring fitted into the body, the top of which forms the seat of the valve.

- The advantage of this arrangement is that the seat can easily be replaced, without replacing the whole inlet. The disc is held against the nozzle seat (under normal operating conditions) by the spring, which is housed in an open or closed spring housing arrangement (or bonnet) mounted on top of the body. The discs used in rapid opening (pop type) safety valves are surrounded by a shroud, disc holder or huddling chamber which helps to produce the rapid opening characteristic.

- The closing force on the disc is provided by a spring, typically made from carbon steel. The amount of compression on the spring is usually adjustable, using the spring adjuster, to alter the pressure at which the disc is lifted off its seat. Standards that govern the design and use of safety valves generally only define the three dimensions that relate to the discharge capacity of the safety valve, namely the flow (or bore) area, the curtain area and the discharge (or orifice) area

  1. Flow area - The minimum cross-sectional area between the inlet and the seat, at its narrowest point. The diameter of the flow area is represented by dimension ‘d’ in Figure. Curtain area - The area of the cylindrical or conical discharge opening between the seating surfaces created by the lift of the disk above the seat. The diameter of the curtain area is represented by dimension ‘d1’ in Figure 9.1.4.

\[
\text{Flow area} = \frac{\pi d^2}{4}
\]

\[
\text{Curtain area} = \pi d_1 L
\]
Basic operation of a safety valve Lifting

When the inlet static pressure rises above the set pressure of the safety valve, the disc will begin to lift off its seat. However, as soon as the spring starts to compress, the spring force will increase; this means that the pressure would have to continue to rise before any further lift can occur, and for there to be any significant flow through the valve.

The additional pressure rise required before the safety valve will discharge at its rated capacity is called the overpressure.

- The allowable overpressure depends on the standards being followed and the particular application. For compressible fluids, this is normally between 3% and 10%, and for liquids between 10% and 25%.

In order to achieve full opening from this small overpressure, the disc arrangement has to be specially designed to provide rapid opening.

- This is usually done by placing a shroud, skirt or hood around the disc. The volume contained within this shroud is known as the control or huddling chamber.

![Diagram of a safety valve with a shroud]

**Figure 54 Typical disc and shroud arrangement used on rapid opening safety valve**

- As lift begins and fluid enters the chamber, a larger area of the shroud is exposed to the fluid pressure. Since the magnitude of the lifting force \( F \) is proportional to the product of the pressure \( P \) and the area exposed to the fluid \( A \); \( F = PA \), the opening force is...
increased. This incremental increase in opening force overcompensates for the increase in spring force, causing rapid opening.

- At the same time, the shroud reverses the direction of the flow, which provides a reaction force, further enhancing the lift.

These combined effects allow the valve to achieve its designed lift within a relatively small percentage overpressure.

- For compressible fluids, an additional contributory factor is the rapid expansion as the fluid volume increases from a higher to a lower pressure area.

This plays a major role in ensuring that the valve opens fully within the small overpressure limit. For liquids, this effect is more proportional and subsequently, the overpressure is typically greater; 25% is common.

**Reseating**

Once normal operating conditions have been restored, the valve is required to close again, but since the larger area of the disc is still exposed to the fluid, the valve will not close until the pressure has dropped below the original set pressure.

- The difference between the set pressure and this reseating pressure is known as the ‘blowdown’, and it is usually specified as a percentage of the set pressure. For compressible fluids, the blowdown is usually less than 10%, and for liquids, it can be up to 20%.

The design of the shroud must be such that it offers both rapid opening and relatively small blowdown, so that as soon as a potentially hazardous situation is reached, any overpressure is relieved, but excessive quantities of the fluid are prevented from being discharged.

- At the same time, it is necessary to ensure that the system pressure is reduced sufficiently to prevent immediate reopening.

The blowdown rings found on most ASME type safety valves are used to make fine adjustments to the overpressure and blowdown values of the valves.

- The lower blowdown (nozzle) ring is a common feature on many valves where the tighter overpressure and blowdown requirements require a more sophisticated designed solution.
The upper blowdown ring is usually factory set and essentially takes out the manufacturing tolerances which affect the geometry of the huddling chamber. The lower blowdown ring is also factory set to achieve the appropriate code performance requirements but under certain circumstances can be altered.

When the lower blowdown ring is adjusted to its top position the huddling chamber volume is such that the valve will pop rapidly, minimising the overpressure value but correspondingly requiring a greater blowdown before the valve re-seats.

When the lower blowdown ring is adjusted to its lower position there is minimal restriction in the huddling chamber and a greater overpressure will be required before the valve is fully open but the blowdown value will be reduced.

**Types of Safety Valve**

There is a wide range of safety valves available to meet the many different applications and performance criteria demanded by different industries. The ASME standard I and ASME standard VIII for boiler and pressure vessel applications and the ASME / ANSI PTC 25.3 standard for safety valves and relief valves provide the following definition. These standards set performance characteristics as well as defining the different types of safety valves that are used:

- **Lift safety valve** - The actual position of the disc determines the discharge area of the valve.
- **Full lift safety valve** - The discharge area is not determined by the position of the disc.
- **Full bore safety valve** - A safety valve having no protrusions in the bore, and wherein the valve lifts to an extent sufficient for the minimum area at any section, at or below the seat, to become the controlling orifice.
- **Conventional safety relief valve** - The spring housing is vented to the discharge side, hence operational characteristics are directly affected by changes in the backpressure to the valve.
- **Balanced safety relief valve** - A balanced valve incorporates a means of minimising the effect of backpressure on the operational characteristics of the valve.
- **Pilot operated pressure relief valve** - The major relieving device is combined with, and is controlled by, a self-actuated auxiliary pressure relief device.
Power-actuated safety relief valve - A pressure relief valve in which the major pressure relieving device is combined with, and controlled by, a device requiring an external source of energy.

Conventional safety valves

The common characteristic shared between the definitions of conventional safety valves in the different standards, is that their operational characteristics are affected by any backpressure in the discharge system. It is important to note that the total backpressure is generated from two components; superimposed backpressure and the built-up backpressure:

Superimposed backpressure - The static pressure that exists on the outlet side of a closed valve.

Built-up backpressure - The additional pressure generated on the outlet side when the valve is discharging.

Subsequently, in a conventional safety valve, only the superimposed backpressure will affect the opening characteristic and set value, but the combined backpressure will alter the blowdown characteristic and re-seat value. The ASME/ANSI standard makes the further classification that conventional valves have a spring housing that is vented to the discharge side of the valve.

If the spring housing is vented to the atmosphere, any superimposed backpressure will still affect the operational characteristics.

Figure which shows schematic diagrams of valves whose spring housings are vented to the discharge side of the valve and to the atmosphere.

Balanced safety valves

Balanced safety valves are those that incorporate a means of eliminating the effects of backpressure. There are two basic designs that can be used to achieve this:

Piston type balanced safety valve

Although there are several variations of the piston valve, they generally consist of a piston type disc whose movement is constrained by a vented guide. The area of the top face of the piston, AP, and the nozzle seat area, AN, are designed to be equal.
• This means that the effective area of both the top and bottom surfaces of the disc exposed to the backpressure are equal, and therefore any additional forces are balanced. In addition, the spring bonnet is vented such that the top face of the piston is subjected to atmospheric pressure,

![Diagram](image)

**Figure 55 Balanced safety valves**

**Bellows type balanced safety valve**

A bellows with an effective area \((AB)\) equivalent to the nozzle seat area \((AN)\) is attached to the upper surface of the disc and to the spindle guide.

The bellows arrangement prevents backpressure acting on the upper side of the disc within the area of the bellows. The disc area extending beyond the bellows and the opposing disc area are equal, and so the forces acting on the disc are balanced, and the backpressure has little effect on the valve opening pressure.
Figure 56 Bellows type balanced safety valve

The bellows vent allows air to flow freely in and out of the bellows as they expand or contract. Bellows failure is an important concern when using a bellows balanced safety valve, as this may affect the set pressure and capacity of the valve. It is important, therefore, that there is some mechanism for detecting any uncharacteristic fluid flow through the bellows vents. In addition, some bellows balanced safety valves include an auxiliary piston that is used to overcome the effects of backpressure in the case of bellows failure. This type of safety valve is usually only used on critical applications in the oil and petrochemical industries. In addition to reducing the effects of backpressure, the bellows also serve to isolate the spindle guide and the spring from the process fluid, this is important when the fluid is corrosive. Since balanced pressure relief valves are typically more expensive than their unbalanced counterparts, they are commonly only used where high pressure manifolds are unavoidable, or in critical applications where a very precise set pressure or blowdown is required.

**Pilot operated safety valve**

- This type of safety valve uses the flowing medium itself, through a pilot valve, to apply the closing force on the safety valve disc. The pilot valve is itself a small safety valve.
There are two basic types of pilot operated safety valve, namely, the diaphragm and piston type.

The diaphragm type is typically only available for low pressure applications and it produces a proportional type action, characteristic of relief valves used in liquid systems.

They are therefore of little use in steam systems, consequently, they will not be considered in this text.

The piston type valve consists of a main valve, which uses a piston shaped closing device (or obturator), and an external pilot valve.

![Diagram of a pilot operated safety valve](image)

**Figure 57 Pilot operated safety valve**
The piston and seating arrangement incorporated in the main valve is designed so that the bottom area of the piston, exposed to the inlet fluid, is less than the area of the top of the piston. As both ends of the piston are exposed to the fluid at the same pressure, this means that under normal system operating conditions, the closing force, resulting from the larger top area, is greater than the inlet force. The resultant downward force therefore holds the piston firmly on its seat. If the inlet pressure were to rise, the net closing force on the piston also increases, ensuring that a tight shut-off is continually maintained. However, when the inlet pressure reaches the set pressure, the pilot valve will pop open to release the fluid pressure above the piston. With much less fluid pressure acting on the upper surface of the piston, the inlet pressure generates a net upwards force and the piston will leave its seat. This causes the main valve to pop open, allowing the process fluid to be discharged.

When the inlet pressure has been sufficiently reduced, the pilot valve will reclose, preventing the further release of fluid from the top of the piston, thereby re-establishing the net downward force, and causing the piston to reseat.

Pilot operated safety valves offer good overpressure and blowdown performance (a blowdown of 2% is attainable). For this reason, they are used where a narrow margin is required between the set pressure and the system operating pressure. Pilot operated valves are also available in much larger sizes, making them the preferred type of safety valve for larger capacities.

One of the main concerns with pilot operated safety valves is that the small bore, pilot connecting pipes are susceptible to blockage by foreign matter, or due to the collection of condensate in these pipes. This can lead to the failure of the valve, either in the open or closed position, depending on where the blockage occurs

- Full lift, high lift and low lift safety valves
- The terms full lift, high lift and low lift refer to the amount of travel the disc undergoes as it moves from its closed position to the position required to produce the certified discharge capacity, and how this affects the discharge capacity of the valve.

A full lift safety valve is one in which the disc lifts sufficiently, so that the curtain area no longer influences the discharge area.

- The discharge area, and therefore the capacity of the valve are subsequently determined by the bore area.
- This occurs when the disc lifts a distance of at least a quarter of the bore diameter. A full lift conventional safety valve is often the best choice for general steam applications. The disc of a high lift safety valve lifts a distance of at least 1/12th of the bore diameter. This means that the curtain area, and ultimately the position of the disc, determines the discharge area.

- The discharge capacities of high lift valves tend to be significantly lower than those of full lift valves, and for a given discharge capacity, it is usually possible to select a full lift valve that has a nominal size several times smaller than a corresponding high lift valve, which usually incurs cost advantages. Furthermore, high lift valves tend to be used on compressible fluids where their action is more proportional.

In low lift valves, the disc only lifts a distance of 1/24th of the bore diameter. The discharge area is determined entirely by the position of the disc, and since the disc only lifts a small amount, the capacities tend to be much lower than those of full or high lift valves.

- Materials of construction
- Except when safety valves are discharging, the only parts that are wetted by the process fluid are the inlet tract (nozzle) and the disc.
- Since safety valves operate infrequently under normal conditions, all other components can be manufactured from standard materials for most applications.
- There are however several exceptions, in which case, special materials have to be used, these include:
- Cryogenic applications.
- Corrosive fluids.
- Where contamination of discharged fluid is not permitted
- When the valve discharges into a manifold that contains corrosive media discharged by another valve.

The principal pressure-containing components of safety valves are normally constructed from one of the following materials:

- Bronze - Commonly used for small screwed valves for general duty on steam, air and hot water applications (up to 15 bar).
- Cast iron - Used extensively for ASME type valves. Its use is typically limited to 17 bar g.
Cast steel - Commonly used on higher pressure valves (up to 40 bar g). Process type valves are usually made from a cast steel body with an austenitic full nozzle type construction.

**Table 2 Seating materials used in safety valves**

<table>
<thead>
<tr>
<th>Seal material</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDM</td>
<td>Water</td>
</tr>
<tr>
<td>Viton</td>
<td>High temperature gas applications</td>
</tr>
<tr>
<td>Nitrile</td>
<td>Air and oil applications</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>Standard material, best for steam</td>
</tr>
<tr>
<td>Stellite</td>
<td>Wear resistant for tough applications</td>
</tr>
</tbody>
</table>

**Safety Valve Selection**

- As there is such a wide range of safety valves, there is no difficulty in selecting a safety valve that meets the specific requirements of a given application. Once a suitable type has been selected, it is imperative that the correct relieving pressure and discharge capacity are established, and a suitably sized valve and set pressure is specified.

The selection of a specific type of safety valve is governed by several factors:

- **Cost** - This is the most obvious consideration when selecting a safety valve for a non-critical application. When making cost comparisons, it is imperative to consider the capacity of the valve as well as the nominal size. As mentioned in the previous module, there can be large variations between models with the same inlet connection but with varying lift characteristics.

- **Type of disposal system** - Valves with an open bonnet can be used on steam, air or non-toxic gas, if discharge to the atmosphere, other than through the discharge system, is acceptable. A lifting lever is often specified in these applications.

- For gas or liquid applications, where escape to the atmosphere is not permitted, a closed bonnet must be specified. In such applications, it is also necessary to use either a closed/gas tight cap or packed lever.
For applications with a significant superimposed backpressure (common in manifolds, typically seen in the process industry) a balancing bellows or piston construction is required.

■ Valve construction - A semi-nozzle type construction should be used for non-toxic, non-corrosive type media at moderate pressures, whereas valves with the full nozzle type construction are typically used in the process industry for corrosive media or for extremely high pressures. For corrosive fluids or high temperatures, special materials of construction may also be required.

■ Operating characteristics - Performance requirements vary according to application and the valve must be selected accordingly. For steam boilers, a small overpressure is required, usually 3% or 5%. For most other applications, 10% overpressure is required, but according to API 520, for special applications such as fire protection, larger valves with overpressures of 20% are allowed. For liquids, overpressures of 10% or 25% are common, and blowdown values tend to be up to 20%.

■ Approval - For many valve applications, the end user will state the required code or standard for the construction and performance of the valve. This is usually accompanied by a requirement for approval by an independent authority, to guarantee conformance with the required standard. Setting and sealing In order to establish the set pressure correctly, the following terms require careful consideration:

■ Normal working pressure (NWP) - The operating pressure of the system under full-load conditions. Maximum allowable working pressure (MAWP) - Sometimes called the safe working pressure (SWP) or design pressure of the system. This is the maximum pressure existing at normal operating conditions (relative to the maximum operating temperature) of the system.

■ Maximum allowable accumulation pressure (MAAP) - The maximum pressure the system is allowed to reach in accordance with the specification of the design standards of the system. The MAAP is often expressed as a percentage of the MAWP.

■ Set Pressure ($P_S$) - The pressure at which the safety valve starts to lift.

■ Relieving pressure ($P_R$) - This is the pressure at which the full capacity of the safety valve is achieved. It is the sum of the set pressure ($P_s$) and the overpressure ($P_o$).
- **Overpressure (P_o)** - The overpressure is the percentage of the set pressure at which the safety valve is designed to operate.

- There are two fundamental constraints, which must be taken into account when establishing a safety valve set pressure:
  1. The set pressure must be low enough to ensure that the relieving pressure never exceeds the maximum allowable accumulation pressure (MAAP) of the system.
  2. The set pressure must be high enough to ensure that there is sufficient margin above the normal working pressure (NWP) to allow the safety valve to close. However, the set pressure must never be greater than the maximum allowable working pressure (MAWP).

- In order to meet the first constraint, it is necessary to consider the relative magnitudes of the percentage overpressure and the percentage MAAP (expressed as a percentage of the MAWP). There are two possible cases:

  The percentage overpressure of the safety valve is less than or equal to the percentage MAAP of the system - This means that the set pressure can be made to equal the MAWP, as the relieving pressure will always be less than the actual MAAP.

  For example, if the safety valve overpressure was 5%, and the MAAP was 10% of the MAWP, the set pressure would be chosen to equal the MAWP. In this case, the relieving pressure (equal to the set pressure + 5% overpressure) would be less than the MAAP, which is acceptable. Note that if the percentage MAAP were higher than the percentage overpressure, the set pressure will still be made to equal the MAWP, as increasing it above the MAWP would violate the second constraint.

**Alternative Plant Protection Devices**

Although safety valves are by far the most common devices used for plant protection in steam systems, there are several other devices available to protect plant from overpressure conditions. Whilst some of them can be used in place of a safety valve, most have their own unique applications and indeed some devices, such as the bursting disc, may be used to complement the safety valve.

**Weighted pallet** - This is the simplest type of overpressure protection device, and it is on low-pressure tanks and condensers, for pressure relief, vacuum relief or both.
A weight is applied to the top of a disc, keeping it closed until the pressure acting on the underside of the pallet equals the weight. Due to the large weights required to keep a pallet closed, this type of valve is designed for low pressure applications below 0.1 bar. For higher set pressures, the weight required would be prohibitive and dangerous if oscillation of the pallet occurred at valve opening.

**Counterweight safety valve** - Although these have been largely superseded by spring-loaded safety valves, they are still sometimes used for low-pressure applications. The closing force of the safety valve is provided by a weight rather than a spring. As the closing force is provided by a weight, it will remain constant and once the set pressure is reached, the safety valve will open fully.

**Supplementary loaded safety valve** –

- A supplementary loaded safety valve consists of a conventional safety valve provided with an additional sealing force that is released once the set pressure is reached.
- One of the main concerns with this type of device is ensuring that the load is suitably released when the set pressure is reached.

Supplementary loaded safety valves tend only to be used where any leakage of the fluid below set pressure is unacceptable, or on very high pressure systems where maintaining a tight shut-off is otherwise difficult.

![Figure 58 Typical supplementary loaded safety valves](imageurl)
**Controlled safety pressure relief systems (CSPRS)** –

These are electric or electro pneumatic systems, which are not self-acting. When an overpressure situation is detected, a control device acts to correct the situation. Non-reclosing devices are those which are designed to remain open after operation. A manual means of resetting is usually provided.

Bursting or rupture discs - This consists of an elastomeric membrane or thin metal disk that will burst at a set pressure, relieving any overpressure. Although they can be used by themselves, on many applications, they are used in conjunction with a safety valve. A rupture disc can be installed either on the inlet or outlet side of the safety valve. If installed on the inlet, it isolates the contained media from the safety valve. When there is an overpressure situation; the rupture disc bursts allowing the fluid to flow into the safety valve, which will then subsequently lift. This arrangement is used to protect the internals of the safety valve from corrosive fluids. Alternatively, if the safety valve discharges into a manifold containing corrosive media, a rupture disc can be installed on the safety valve outlet, preventing any of the fluid from the manifold contacting the internals of the safety valve in normal use. Rupture discs can also be installed alongside a safety valve as a secondary relief device. Rupture discs are leak tight and low cost, but they require replacing after each operation. Most rupture disc installations contain a mechanism to indicate when the disc has ruptured and that it needs to be replaced. Typically, a pressure gauge is used.

Explosion panels or explosion rupture discs are similar to rupture discs but are designed for use at higher rates of pressure rise, and for larger capacities.

- Fusible plug devices - These consist of a plug with a lower melting point than the maximum operating temperature of the system that it is to protect. In old steam locomotives, this type of device was used to dump the boiler water onto the fire if over temperature occurred.
Breaking or shear pin devices –

- A breaking pin device is a non-reclosing pressure relief device actuated by inlet static pressure and designed to function by the breakage of a load carrying section of a pin, which supports a pressure-containing member.
- The force of overpressure forces the pin to buckle and the valve to open.
- The valve can then be reseated after the pressure is removed and a new pin can be installed.
- These devices are usually installed on low-pressure applications and large gas distribution systems.

They have limited process applications.

Introduction

- Steam is usually generated for one of two reasons:
- To produce electrical power, for example in power stations or co-generation plants.
- To supply heat for heating and process systems.
- When a kilogram of steam condenses completely, a kilogram of condensate is formed at the same pressure and temperature. An efficient steam system will reuse this condensate.
Failure to reclaim and reuse condensate makes no financial, technical or environmental sense. Saturated steam used for heating gives up its latent heat (enthalpy of evaporation), which is a large proportion of the total heat it contains.

- The remainder of the heat in the steam is retained in the condensate as sensible heat (enthalpy of water). As well as having heat content, the condensate is basically distilled water, which is ideal for use as boiler feed water. An efficient steam system will collect this condensate and either return it to a deaerator, a boiler feed tank, or use it in another process. Only when there is a real risk of contamination should condensate not be returned to the boiler.

- Even then, it may be possible to collect the condensate and use it as hot process water or pass it through a heat exchanger where its heat content can be recovered before discharging the water mass to drain. Condensate is discharged from steam plant and equipment through steam traps from a higher to a lower pressure.

- As a result of this drop in pressure, some of the condensate will re-evaporate into ‘flash steam’. The proportion of steam that will ‘flash off’ in this way is determined by the amount of heat that can be held in the steam and condensate.

- However, the percentage volumetric change can be considerably more. Condensate at 7 bar g will lose about 13% of its mass when flashing to atmospheric pressure, but the steam produced will require a space some 200 times larger than the condensate from which it was formed.

- This can have the effect of choking undersized trap discharge lines, and must be taken into account when sizing these lines. Steam produced in a boiler by the process of adding heat to the water is often referred to as live steam. The terms live steam and flash steam are only used to differentiate their origin. Whether steam is produced in a boiler or from the natural process of flashing, it has exactly the same potential for giving up heat, and each is used successfully for this purpose.

- The flash steam generated from condensate can contain up to half of the total energy of the condensate. An efficient steam system will recover and use flash steam. Condensate and flash steam discharged to waste means more make-up water, more fuel, and increased running costs.
An effective condensate recovery system, collecting the hot condensate from the steam using equipment and returning it to the boiler feed system, can pay for itself in a remarkably short period of time. Figure 14.1.4 shows a simple steam and condensate circuit, with condensate returning to the boiler feed tank.

![Figure 60 typical steam and condensate circuit](image)

**Layout of Condensate Return Lines**

No single set of recommendations can cover the layout of condensate pipework. Much depends on the application pressure, the steam trap characteristics, the position of the condensate return main relative to the plant, and the pressure in the condensate return main. For this reason it is best to start by considering what has to be achieved, and to design a layout which will ensure that basic good practice is met.
The prime objectives are that:

- Condensate must not be allowed to accumulate in the plant, unless the steam using apparatus is specifically designed to operate in this way. Generally apparatus is designed to operate non-flooded, and where this is the case, accumulated condensate will inhibit performance, and encourage the corrosion of pipes, fittings and equipment.

- Condensate must not be allowed to accumulate in the steam main. Here it can be picked up by high velocity steam, leading to erosion and waterhammer in the pipework. Drain lines to steam traps In the drain line, the condensate and any incondensible gases must flow from the drain outlet of the plant to the steam trap.

In a properly sized drain line, the plant being drained and the body of the steam trap are virtually at the same pressure and, because of this, condensate does not flash in this line. Gravity is the driving force and is relied upon to induce flow along the pipe. For this reason, it makes sense for the trap to be situated below the outlet of the plant being drained, and the trap discharge pipe to terminate below the trap. The type of steam trap used (thermostatic, thermodynamic or mechanical) can affect the piping layout.

The drain line should be kept to a minimum length, ideally less than 2 meters.

- Long drain lines from the plant to the steam trap can fill with steam and prevent condensate reaching the trap. This effect is termed steam locking. To minimize this risk, drain lines should be kept short.

- In situations where long drain lines are unavoidable, the steam locking problem may be overcome using float traps with steam lock release devices. The problem of steam locking should be tackled by fitting the correct length of pipe in the first place, if possible.

- With steam-using plant, the pipe from the condensate connection should fall vertically for about 10 pipe diameters to the steam trap. Assuming a correctly sized ball float trap is installed, this will ensure that surges of condensate do not accumulate in the bottom of the plant with its attendant risks of corrosion and water hammer.

- It will also provide a small amount of static head to help remove condensate during start-up when the steam pressure might be very low. The pipework should then run horizontally, with a fall in the direction of flow to ensure that condensate flows freely
Discharge lines from traps

- These pipes will carry condensate, incondensible gases, and flash steam from the trap to the condensate return system. Flash steam is formed as the condensate is discharged from the high-pressure space before the steam trap to the lower pressure space of the condensate return system. These lines should also fall in the direction of flow to maintain free flow of condensate. On shorter lines, the fall should be discernible by sight. On longer lines, the fall should be about 1:70, that is, 100 mm every 7 metres.

- Discharging into flooded return lines Discharging traps into flooded return lines is not recommended, especially with blast action traps (thermodynamic or inverted bucket types), which remove condensate at saturation temperature. Good examples of flooded condensate mains are pumped return lines and rising condensate lines. They often follow the same route as steam lines, and it is tempting to simply connect mains drainage steam trap discharge lines into them. However, the high volume of flash steam released into long flooded lines will violently push the water along the pipe, causing waterhammer, noise and, in time, mechanical failure of the pipe.
Common return lines

- Where condensate from more than one trap flows to the same collecting point such as a vented receiver, it is usual to run a common line into which individual trap discharge lines are connected.

**Blast discharge traps**

If blast discharge traps (thermodynamic or inverted bucket types) are used, the reactionary forces and velocities can be high. Swept tees will help to reduce mechanical stress and erosion at the point where the discharge line joins the common return line. Lifting Condensate and Contaminated Condensate

- It is sometimes necessary to lift condensate from a steam trap to a higher level condensate return line. The condensate will rise up the lifting pipework when the steam pressure upstream of the trap is higher than the pressure downstream of the trap. The pressure downstream of the trap is generally called backpressure, and is made up of any pressure existing in the condensate line plus the static lift caused by condensate in the rising pipework. The upstream pressure will vary between start-up conditions, when it is at its lowest and running conditions, when it is at its highest. Backpressure is related to lift by using the following approximate conversion:

  1 metre lift in pipework = 1 m head static pressure @ 0.1 bar backpressure

If a head of 5 m produces a backpressure of 0.5 bar, then this reduces the differential pressure available to push condensate through the trap; although under running conditions the reduction in trap capacity is likely to be significant only where low upstream pressures are used.

In steam mains at start-up, the steam pressure is likely to be very low, and it is common for water to back-up before the trap, which can lead to water hammer in the space being drained.

As the steam main is warmed, the condensate temperature rises, causing the liquid expansion trap to close. At the same time, the steam pressure rises, forcing the hot condensate through the ‘working’ drain trap to the return line.
- The discharge line from the trap to the overhead return line, preferably discharges into the top of the main rather than simply feed to the underside,

- This assists operation, because although the riser is probably full of water at start-up, it sometimes contains little more than flash steam once hot condensate under pressure passes through. If the discharge line were fitted to the bottom of the return line, it would fill with condensate after each discharge and increase the tendency for water hammer and noise.

It is also recommended that a check valve be fitted after any steam trap from where condensate is lifted, preventing condensate from falling back towards the trap. The above general recommendations apply not just to traps lifting condensate from steam mains, but also to traps draining any type of process running at a constant steam pressure. Temperature controlled processes will often run with low steam pressures. Rising condensate discharge lines should be avoided at all costs, unless automatic pump-traps are used.

**Contaminated condensate**

Occasionally, condensate is discharged from sources where it might have become contaminated by corrosive process liquids. This is unsuitable for boiler feedwater because of the dangers of foaming, scaling, and corrosion which it can cause in the boiler and distribution pipes. However, although contaminated, the condensate still carries the same useful heat as clean condensate which could be recovered if proper contamination detection equipment were employed.

Such equipment detects changes in condensate conductivity. When a change from the desired conductivity occurs then this may mean that the condensate is contaminated. A controller signals a dump valve to open, allowing the condensate to flow to drain.

**FLASH STEAM**

- What is flash steam and why should it be used?
- ‘Flash steam’ is released from hot condensate when its pressure is reduced. Even water at an ambient room temperature of 20°C would boil if its pressure were lowered far enough.
- It may be worth noting that water at 170°C will boil at any pressure below 6.9 bar g. The steam released by the flashing process is as useful as steam released from a steam boiler. As an example, when steam is taken from a boiler and the boiler pressure drops, some of the water content of the boiler will flash off to supplement the ‘live’ steam produced by the heat from the boiler fuel. Because both types of steam are produced in the boiler, it is impossible to differentiate between them.

- Only when flashing takes place at relatively low pressure, such as at the discharge side of steam traps, is the term flash steam widely used. Unfortunately, this usage has led to the erroneous conclusion that flash steam is in some way less valuable than so-called live steam.

  In any steam system seeking to maximise efficiency, flash steam will be separated from the condensate, and used to supplement any low pressure heating application. Every kilogram of flash steam used in this way is a kilogram of steam that does not need to be supplied by the boiler. It is also a kilogram of steam not vented to atmosphere, from where it would otherwise be lost.

The reasons for the recovery of flash steam are just as compelling, both economically and environmentally, as the reasons for recovering condensate.

- How much flash steam is available?

  If use is to be made of flash steam, it is helpful to know how much of it will be available.

  The quantity is readily determined by calculation, or can be read from simple tables or charts

Sub-cooled condensate

If the steam trap is of a thermostatic type, the discharged condensate is sub-cooled below saturation temperature. The heat in the cooler condensate will be slightly less, and the amount of flash steam produced would be less.

**Flash steam recovery vessel (flash vessel)**

Flash vessels are used to separate flash steam from condensate.

After condensate and flash steam enter the flash vessel, the condensate falls by gravity to
the base of the vessel, from where it is drained, via a float trap, usually to a vented receiver from where it can be pumped.

- The flash steam in the vessel is piped from the top of the vessel to any appropriate low pressure steam equipment.

![Flash steam recovery vessel (flash vessel)](image)

**Figure 62 Flash steam recovery vessel (flash vessel)**

Requirements for successful flash steam applications If full use is to be made of flash steam, some basic requirements must be satisfied: It is essential to have a continual supply of sufficient condensate from applications operating at higher pressures, to ensure that enough flash steam can be released for economic recovery.

- The steam traps and the equipment they are draining must be able to function satisfactorily against the backpressure applied by the flash system.

- Care must be taken when attempting flash steam recovery with condensate from temperature controlled equipment. At less than full-load, the steam space pressure will be lowered by the closing action of the steam control valve. If the steam pressure in the
equipment approaches or falls below the specified flash steam pressure, the overall amount of flash steam formed will be marginal, and one must question whether recovery is worthwhile in this instance.

It is important that there is a demand for low pressure flash steam that either equals or exceeds the flash steam being produced. Any deficit of flash steam can be made up by live steam from a pressure reducing valve. If the supply of flash steam exceeds its demand, surplus pressure will be created in the flash steam distribution system, which will then have to be vented to waste through a surplus sing valve.

- It is possible to utilize the flash steam from condensate on a space heating installation - but savings will only be achieved during the heating season. When heating is not required, the recovery system becomes ineffective.
- Wherever possible, the best arrangement is to use flash steam from process condensate to supply process loads - and flash steam from heating condensate to supply heating loads.
- Supply and demand are then more likely to remain in-step.
- It is preferable to actually use the flash steam close to the high pressure condensate source.
- Relatively large diameter pipes are used for low pressure steam, to reduce pressure loss and velocity, which can mean costly installation if the flash steam has to be piped any distance

**Typical applications for flash steam**

- Flash steam supply and demand in-step. This gives maximum utilization of the available flash steam.
- The condensate from approximately 90% of the heaters is collected and taken to a flash recovery vessel. This supplies low pressure steam to the remaining 10% of the heaters. With this system, the total heat output of the system is marginally reduced, as 10% of the heaters are operating at a lower steam pressure. However, it is rare to find an installation that does not have a sufficient margin of output above the normal load to accept this small reduction.
- Sometimes a problem arises where the use of available flash steam may require more than one heater but less than two.
- It would be better in this case to connect two heaters to the flash steam supply, rather than vent the excess flash steam off to waste.
- Two heaters together will usually pull the flash pressure down to a lower level, even to sub-atmospheric levels.
- To cope with this, the supply of flash steam can be supplemented with live steam from a pressure reducing valve.
- Another example where supply and demand are ‘in step’ is the steam heated hot water storage calorifier. Some of these incorporate a second coil, fitted close to the bottom of the vessel adjacent to where the cold feedwater enters.

Condensate and flash steam from the trap on the primary coil is passed directly to the secondary coil. Here, any flash steam produced by the drop in pressure across the trap is condensed, while giving up its heat to the feedwater.

![Figure 63 Secondary flash steam coil in storage calories](image)
Flash steam supply and demand not in-step Condensate from three jacketed pans and a drain pocket releases flash steam, but it can only be used to augment the supply of steam to the space heating installation. This is quite satisfactory during the heating season, as long as the heating load exceeds the availability of flash steam.

During the summer season the heating equipment will not be in use, and even during spring and autumn the heating load may not be able to use all the available flash steam. The arrangement is not ideal, although it is quite possible for the steam savings made during the winter to justify the cost of the flash steam recovery equipment.

Sometimes, surplus flash steam must be vented to atmosphere, and, as indicated, a surplussing valve is more suitable for this purpose than a safety valve, which usually has a ‘pop’ or ‘on / off’ action and a seat arrangement designed for infrequent operation. The surplussing valve will be set so that it begins to open slightly above the normal pressure in the system. When the heating load falls and the pressure in the system begins to increase, the pressure reducing valve supplying the make-up steam closes down. A further increase of pressure, perhaps of 0.15 to 0.2 bar, is then allowed before the surplussing valve begins to open to release the excess flash steam. A safety valve may still be required if the surplussing valve fails. It must be set to open at a pressure between the surplussing valve set pressure and the system design pressure. It is usually convenient to fit the safety valve onto the flash vessel. Occasionally, during summer conditions it may be preferable to bypass the flash system with a manual valve (not shown in Figure 14.6.9). The condensate and its associated flash steam will then pass directly to a condensate receiver, where the flash steam will be vented to atmosphere.

**Boiler blow down heat recovery applications**

Continuous blow down of boiler water is necessary to control the level of TDS (Total Dissolved Solids) within the boiler. Continuous blow down lends itself to the recovery of the heat content of the blow down water and can enable considerable savings to be made.
Boiler blow down contains massive quantities of heat, which can easily be recovered as flash steam. After it passes through the blow down control valve, the lower pressure water flows to a flash vessel. At this point, the flash steam is free from contamination and is separated from the condensate, and can be used to heat the boiler feed tank
The residual condensate draining from the flash vessel can be passed through a plate heat exchanger in order to reclaim as much heat as possible before it is dumped to waste.

- Up to 80% of the total heat contained in boiler continuous blow down can be reclaimed in this way.
- Spray condensing Finally, consideration should be given to those cases where flash steam is unavoidably generated at low pressure, but where no suitable load is available which can make use of it. The arrangement can be useful where the condensate receiver vent cannot be piped to outside, and where the presence of flash steam would be detrimental if left to discharge in a plant room. A lightweight stainless steel chamber is fitted to the receiver tank vent. Cold water is sprayed into the chamber in sufficient quantities to just condense the flash steam.
- The flow of cooling water is controlled by a simple self-acting temperature control, adjusted so that minimal amounts of flash steam appear from the vent. The process will use roughly 6 kilograms of cooling water per kilogram of flash steam condensed.
  If the cooling water is of boiler feed quality, then the warmed water is added to the condensate in the receiver and re-used. This will continue to make water savings throughout the year.
  If the cooling water is not suitable for recovery, the spray pipework can be installed as shown by the dotted arrangement. The cooling water and condensed flash will then fall to waste.

STEAM TRAPS

Steam traps Condensate is formed whenever steam gives up its enthalpy of evaporation (latent heat). The proper removal of condensate from steam plant of all types is vital if the plant is to work efficiently and this operation is commonly performed by a steam trap. Frequent causes of unsatisfactory condensate drainage include the choice of the wrong type of steam trap for the
application, the use of a trap that is incorrectly sized for the load and pressure conditions, and bad installation. Because any of these factors can seriously reduce plant output, it is worth spending some time studying how steam traps work and their application. Even so, the amount of ground that can be covered in this chapter is necessarily limited and the reader is referred to ref. 1 for additional information.

What is a steam trap?

A steam trap is an, automatic valve capable of distinguishing between condensate and live steam, opening to discharge the farmer but closing to trap the latter.

The difference between condensate and steam is sensed in several ways. One group of traps detect the difference in density, another group react to a difference in temperature, and a third rely on the difference in flow characteristics

- Thermostatic Steam Traps
- Liquid expansion steam trap
- This is one of the simplest thermostatic traps.

An oil filled element expands when heated to close the valve against the seat. The adjustment allows the temperature of the trap discharge to be altered between 60°C and 100°C, which makes it ideally suited as a device to get rid of large quantities of air and cold condensate at start-up.

![Figure 64 Liquid expansion steam trap](image-url)
**Typical application**

Because of its fixed temperature discharge characteristic, the liquid expansion trap may be usefully employed as a 'shutdown drain trap'. Here, its outlet must always point upwards, to enable continuous immersion of the oil filled element.

As the trap can only discharge between 60°C - 100°C it will only normally open during start-up. It can be installed alongside a mains drain trap which would normally be piped to a condensate return line.

![Typical application of steam trap](image)

**Figure 65 Typical application of steam trap**

- Advantages of the liquid expansion steam trap:

  Liquid expansion traps can be adjusted to discharge at low temperatures, giving an excellent 'cold drain' facility. Like the balanced pressure trap, the liquid expansion trap is fully open when cold, giving good air discharge and maximum condensate capacity on 'start-up' loads. The liquid expansion trap can be used as a start-up drain trap on low pressure superheated steam mains where a long cooling leg is guaranteed to flood with cooler condensate. It is able to withstand vibration and waterhammer conditions.
Disadvantages of the liquid expansion steam trap:
The flexible tubing of the element can be destroyed by corrosive condensate or superheat. Since the liquid expansion trap discharges condensate at a temperature of 100°C or below, it should never be used on applications which demand immediate removal of condensate from the steam space. If the trap is to be subjected to freezing conditions the trap and its associated pipework must be well insulated.

The liquid expansion trap is not normally a trapping solution on its own, as it usually requires another steam trap to operate in parallel. However, it can often be used where start-up rate is not an important consideration, such as when draining small tank heating coils.

**Balanced pressure steam trap**

A large improvement on the liquid expansion trap is the balanced pressure trap. Its operating temperature is affected by the surrounding steam pressure. The operating element is a capsule containing a special liquid and water mixture with a boiling point below that of water. In the cold conditions that exist at start-up, the capsule is relaxed. The valve is off its seat and is wide open, allowing unrestricted removal of air. This is a feature of all balanced pressure traps and explains why they are well suited to air venting.
As condensate passes through the balanced pressure steam trap, heat is transferred to the liquid in the capsule. The liquid vaporizes before steam reaches the trap. The vapor pressure within the capsule causes it to expand and the valve shuts. Heat loss from the trap then cools the water surrounding the capsule, the vapor condenses and the capsule contracts, opening the valve and releasing condensate until steam approaches again and the cycle repeats.

- Advantages of the balanced pressure steam trap:
  Small, light and has a large capacity for its size. The valve is fully open on start-up, allowing air and other non-condensable gases to be discharged freely and giving maximum condensate removal when the load is greatest. This type of trap is unlikely to freeze when working in an exposed position (unless there is a rise in the condensate pipe after the trap, which would allow water to run back and flood the trap when the steam is off). The modern balanced pressure trap automatically adjusts itself to variations of steam pressure up to its maximum operating pressure. It will also tolerate up to 70°C of superheat. Trap maintenance is simple. The capsule and valve seat are easily removed, and replacements can be fitted in a few minutes without removing the trap from the line.

- Disadvantages of the balanced pressure steam trap:
  The older style balanced pressure steam traps had bellows which were susceptible to damage by water hammer or corrosive condensate. Welded stainless steel capsules introduced more recently, are better able to tolerate such conditions. In common with all other thermostatic traps, the balanced pressure type does not open until the condensate temperature has dropped below steam temperature (the exact temperature difference being determined by the fluid used to fill the element).

This is clearly a disadvantage if the steam trap is chosen for an application in which water logging of the steam space cannot be tolerated, for example; mains drainage, heat exchangers, critical tracing.

**Bimetallic steam trap**

As the name implies, bimetallic steam traps are constructed using two strips of dissimilar metals welded together into one element. The element deflects when heated.
There are two important points to consider regarding this simple element:
Operation of the steam trap takes place at a certain fixed temperature, which may not satisfy the requirements of a steam system possibly operating at varying pressures and temperatures. Because the power exerted by a single bimetal strip is small, a large mass would have been used which would be slow to react to temperature changes in the steam system.

The performance of any steam trap can be measured by its response to the steam saturation curve. The ideal response would closely follow the curve and be just below it. A simple bimetal element tends to react to temperature changes in a linear fashion.

![At normal temperature](image1)

![Heat](image2)

**Figure 67 Simple bimetallic element**

- It needs to be noted that at pressures below P1, the steam trap operating temperature is actually above the saturation temperature. This would cause the steam trap to pass steam at these lower pressures.
- It may be possible to ensure the steam trap is adjusted during manufacture to ensure that this portion of the saturation curve is always above the operating line. However, due to the linear action of the element, the difference between the two would increase even more with system pressure, increasing the water logging effect. Clearly, this is not a satisfactory operation for any steam trap, and various attempts have been made by manufacturers to improve upon the situation. Some use combinations of two different sets of bimetal leaves in a single stack, which operate at different temperatures.
**Figure 68 Operation of a bimetal trap with two leaf element**

**Advantages of the bimetallic steam trap:**

Bimetallic steam traps are usually compact, yet can have a large condensate capacity. The valve is wide open when the steam trap is cold, giving good air venting capability and maximum condensate discharge capacity under 'start-up' conditions.

As condensate tends to drain freely from the outlet, this type of steam trap will not freeze up when working in an exposed position. The bodies of some bimetallic steam traps are designed in such a way that they will not receive any damage even if freezing does occur. Bimetallic steam traps are usually able to withstand water hammer, corrosive condensate, and high steam pressures.

The bimetal elements can work over a wide range of steam pressures without any need for a change in the size of the valve orifice.

If the valve is on the downstream side of the seat, it will tend to resist reverse flow through the steam trap. However, if there is any possibility of reverse flow, a separate check valve should be fitted downstream of the trap.

As condensate is discharged at varying temperatures below saturation temperature and, provided water logging of the steam space can be tolerated, some of the enthalpy of saturated water can be transferred to the plant. This extracts the maximum energy from the condensate before it drains to waste, and explains why these traps are used on tracer lines where condensate is often dumped to waste.
- Maintenance of this type of steam trap presents few problems, as the internals can be replaced without removing the trap body from the line. The flash steam produced whenever condensate is discharged from a higher to a lower pressure will tend to cause an increase in backpressure in the condensate line. The cooling leg allows the condensate to cool down, producing less flash steam in the condensate line and thus helping to reduce the backpressure.

**Disadvantages of the bimetallic steam trap:**

- As condensate is discharged below steam temperature, waterlogging of the steam space will occur unless the steam trap is fitted at the end of a long cooling leg, typically 1 - 3 m of unlagged pipe. Bimetallic steam traps are not suitable for fitting to process plants where immediate condensate removal is vital for maximum output to be achieved. This is particularly relevant on temperature controlled plants.
  Some bimetallic steam traps are vulnerable to blockage from pipe dirt due to low internal flow velocities. However, some bimetallic traps have specially shaped valve trims that capture the discharge energy to open the valve more. These tend to give an intermittent blast discharge characteristic rather than a continual dribble discharge, and as such tend to be self-cleaning. These valve trims are sometimes referred to as dynamic clacks.
  If the bimetallic steam trap has to discharge against a significant backpressure, the condensate must cool to a lower temperature than is normally required before the valve will open. A 50% backpressure may cause up to a 50°C drop in discharge temperature. It may be necessary to increase the length of cooling leg to meet this condition. Bimetallic steam traps do not respond quickly to changes in load or pressure because the element is slow to react.

**Mechanical Steam Traps/Ball float steam trap**

The ball float type trap operates by sensing the difference in density between steam and condensate. Condensate reaching the trap will cause the ball float to rise, lifting the valve off its seat and releasing condensate. As can be seen, the valve is always flooded and neither steam nor air will pass through it, so early traps of this kind were vented using a manually operated cock at the top of the body.
The automatic air vent uses the same balanced pressure capsule element as a thermostatic steam trap, and is located in the steam space above the condensate level. After releasing the initial air, it remains closed until air or other non-condensable gases accumulate during normal running and cause it to open by reducing the temperature of the air/steam mixture.

The thermostatic air vent offers the added benefit of significantly increasing condensate capacity on cold start-up. In the past, the thermostatic air vent was a point of weakness if water hammer was present in the system. Even the ball could be damaged if the water hammer was severe.

However, in modern float traps the air vent is a compact, very robust, all stainless steel capsules, and the modern welding techniques used on the ball makes the complete float-thermostatic steam trap very robust and reliable in water hammer situations.

In many ways the float-thermostatic trap is the closest to an ideal steam trap. It will discharge condensate as soon as it is formed, regardless of changes in steam pressure.

**Advantages of the float-thermostatic steam trap**

- The trap continuously discharges condensate at steam temperature. This makes it the first choice for applications where the rate of heat transfer is high for the area of heating surface available. It is able to handle heavy or light condensate loads equally well and is not affected by wide and sudden fluctuations of pressure or flow rate. As long as an automatic air vent is fitted, the trap is able to discharge air freely. It has a large capacity...
for its size. The versions which have a steam lock release valve are the only type of trap entirely suitable for use where steam locking can occur. It is resistant to water hammer.

**Disadvantages of the float-thermostatic steam trap**

- Although less susceptible than the inverted bucket trap, the float type trap can be damaged by severe freezing and the body should be well lagged, and / or complemented with a small supplementary thermostatic drain trap, if it is to be fitted in an exposed position.
- As with all mechanical type traps, different internals are required to allow operation over varying pressure ranges. Traps operating on higher differential pressures have smaller orifices to balance the buoyancy of the float.

**Inverted bucket steam trap**

As its name implies, the mechanism consists of an inverted bucket which is attached by a lever to a valve. An essential part of the trap is the small air vent hole in the top of the bucket. In (i) the bucket hangs down, pulling the valve off its seat. Condensate flows under the bottom of the bucket filling the body and flowing away through the outlet. In (ii) the arrival of steam causes the bucket to become buoyant, it then rises and shuts the outlet. In (iii) the trap remains shut until the steam in the bucket has condensed or bubbled through the vent hole to the top of the trap body. It will then sink, pulling the main valve off its seat. Accumulated condensate is released and the cycle is repeated. In (ii), air reaching the trap at start-up will also give the bucket buoyancy and close the valve. The bucket vent hole is essential to allow air to escape into the top of the trap for eventual discharge through the main valve seat The hole, and the pressure differential, are small so the trap is relatively slow at venting air. At the same time it must pass (and therefore waste) a certain amount of steam for the trap to operate once the air has cleared. A parallel air vent fitted outside the trap will reduce start-up times.
Advantages of the inverted bucket steam trap:

The inverted bucket steam trap can be made to withstand high pressures like a float-thermostatic steam trap, it has a good tolerance to water hammer conditions. It can be used on superheated steam lines with the addition of a check valve on the inlet. Failure mode is usually open, so it’s safer on those applications that require this feature, for example turbine drains.

Disadvantages of the inverted bucket steam trap

The small size of the hole in the top of the bucket means that this type of trap can only discharge air very slowly. The hole cannot be enlarged, as steam would pass through too quickly during normal operation.

There should always be enough water in the trap body to act as a seal around the lip of the bucket. If the trap loses this water seal, steam can be wasted through the outlet valve. This can
often happen on applications where there is a sudden drop in steam pressure, causing some of the condensate in the trap body to 'flash' into steam. The bucket loses its buoyancy and sinks, allowing live steam to pass through the trap orifice. Only if sufficient condensate reaches the trap will the water seal form again, and prevent steam wastage.

- If an inverted bucket trap is used on an application where pressure fluctuation of the plant can be expected, a check valve should be fitted on the inlet line in front of the trap. Steam and water are free to flow in the direction indicated, while reverse flow is impossible as the check valve would be forced onto its seat.

- The higher temperature of superheated steam is likely to cause an inverted bucket trap to lose its water seal. A check valve in front of the trap should be regarded as essential under such conditions. Some inverted bucket traps are manufactured with an integral check valve as standard.

- The inverted bucket trap is likely to suffer damage from freezing if installed in an exposed position with sub-zero ambient conditions. As with other types of mechanical traps, suitable lagging can overcome this problem if conditions are not too severe. If ambient conditions well below zero are to be expected, then it may be prudent to consider a more robust type of trap to do the job. In the case of mains drainage, a thermodynamic trap would be the first choice.

**Thermodynamic Steam Traps**

Traditional thermodynamic steam trap The thermodynamic trap is an extremely robust steam trap with a simple mode of operation. The trap operates by means of the dynamic effect of flash steam as it passes through the trap, The only moving part is the disc above the flat face inside the control chamber or cap. On start-up, incoming pressure raises the disc, and cool condensate plus air is immediately discharged from the inner ring, under the disc, and out through three peripheral outlets. Hot condensate flowing through the inlet passage into the chamber under the disc drops in pressure and releases flash steam moving at high velocity. This high velocity creates a low pressure area under the disc, drawing it towards its seat
At the same time, the flash steam pressure builds up inside the chamber above the disc, forcing it down against the incoming condensate until it seats on the inner and outer rings. At this point, the flash steam is trapped in the upper chamber, and the pressure above the disc equals the pressure being applied to the underside of the disc from the inner ring.

However, the top of the disc is subject to a greater force than the underside, as it has a greater surface area.

Eventually the trapped pressure in the upper chamber falls as the flash steam condenses. The disc is raised by the now higher condensate pressure and the cycle repeats.

The rate of operation depends on steam temperature and ambient conditions. Most traps will stay closed for between 20 and 40 seconds. If the trap opens too frequently, perhaps due to a cold, wet, and windy location, the rate of opening can be slowed by simply fitting an insulating cover onto the top of the trap.

Figure 71 Thermodynamic steam trap

Advantages of the thermodynamic steam trap

- Thermodynamic traps can operate across their entire working range without any adjustment or change of internals.
They are compact, simple, lightweight and have a large condensate capacity for their size.

- Thermodynamic traps can be used on high pressure and superheated steam and are not affected by waterhammer or vibration. The all stainless steel construction offers a high degree of resistance to corrosive condensate.

- Thermodynamic traps are not damaged by freezing and are unlikely to freeze if installed with the disc in a vertical plane and discharging freely to atmosphere. However, operation in this position may result in wear of the disc edge.

- As the disc is the only moving part, maintenance can easily be carried out without removing the trap from the line.

- The audible 'click' which occurs as the trap opens and closes makes trap testing very straightforward.

Disadvantages of the thermodynamic steam trap

Thermodynamic steam traps will not work positively on very low differential pressures, as the velocity of flow across the underside of the disc is insufficient for lower pressure to occur. They are subjected to a minimum inlet pressure (typically 0.25 bar g) but can withstand a maximum backpressure of 80% of the inlet pressure.

- Thermodynamic traps can discharge a large amount of air on 'start-up' if the inlet pressure builds up slowly. However, rapid pressure build-up will cause high velocity air to shut the trap in the same way as steam, and it will 'air-bind'. In this case a separate thermostatic air vent can be fitted in parallel with the trap. Modern thermodynamic steam traps can have an inbuilt anti-air-binding disc which prevents air pressure building up on top of the disc and allows air to escape.

- The discharge of the trap can be noisy and this factor may prohibit the use of a thermodynamic trap in some locations, e.g. outside a hospital ward or operating theatre. If this is a problem, it can easily be fitted with a diffuser which considerably reduces the discharge noise.

Care should be taken not to oversize a thermodynamic trap as this can increase cycle times and induce wear. Mains drainage applications often only need to be fitted with low capacity versions, providing proper consideration is given to siting the drain pockets correctly.

- Impulse steam trap
The impulse trap consists of a hollow piston (A) with a piston disc (B) working inside a tapered piston (C) which acts as a guide. At 'start-up' the main valve (D) rests on the seat (E) leaving a passage of flow through the clearance between piston and cylinder and hole (F) at the top of the piston.

Increasing flow of air and condensate will act on the piston disc and lift the main valve off its seat to give increased flow.

Some condensate will also flow through the gap between the piston and disc, through E and away to the trap outlet.

As the condensate approaches steam temperature some of it flashes to steam as it passes through the gap. Although this is bled away through hole F it does create an intermediate pressure over the piston, which effectively positions the main valve to meet the load. The trap can be adjusted by moving the position of piston (B) relative to the seat, but the trap is affected by significant backpressure. It has a substantial capacity, bearing in mind its small size. Conversely, the trap is unable to give complete shut-off and will pass steam on very light loads. The main problem however is the fine clearance between the piston and cylinder. This is readily affected by the dirt normally found in a steam system.

The use of impulse traps is relatively limited so they are not considered in some subsequent sections of this Module.

Advantages of the impulse steam trap

■ Impulse traps have a substantial condensate handling capacity for their size.
■ They will work over a wide range of steam pressures without any change in valve size and can be used on high pressure and superheated steam.
■ They are good at venting air and cannot 'air-bind'.

Disadvantages of the impulse steam trap

■ Impulse traps cannot give a dead tight shut-off and will blow steam on very light loads.
■ They are easily affected by any dirt which enters the trap body due to the extremely small clearance between the piston and the cylinder.
■ The traps can pulsate on light load causing noise, waterhammer and even mechanical damage to the valve itself.
■ They will not work against a backpressure which exceeds 40% of the inlet pressure.

Labyrinth steam trap
- It consists of a series of baffles which can be adjusted by means of a handwheel.
- Hot condensate passing between the first baffle and the trap body is subject to a drop in pressure and some of it 'flashes' to steam.
- The space around the next baffle has to cope with an increased volume of hot condensate and prevents the escape of live steam.
- The baffle plates can be moved either in or out using the handwheel, which alters their position relative to the body, effectively altering the overall size of the orifice.
- Advantages of the labyrinth steam trap
  - This type of trap is comparatively small in relation to its capacity and there is little potential for mechanical failure since there are no automatic parts.
- Disadvantages of the labyrinth steam trap
  - The labyrinth trap has to be adjusted manually whenever there is a significant variation in either steam pressure or condensate load. If the setting is not right for the prevailing conditions, steam wastage or waterlogging of the steam space will occur (like a fixed orifice trap).

**Fixed orifice traps**

- These are devices containing a hole of predetermined diameter to allow a calculated amount of condensate to flow under specific pressure conditions. In practice, condensate loads and steam pressures can vary considerably. For instance, start-up and running loads can differ considerably along with steam pressure which will change due to the actions of temperature controls. These varying conditions can result in the fixed orifice either holding back condensate in the process or passing live steam, which can affect plant performance and compromise safety.

  Fixed orifices are often sized on running conditions, so that they hold back enough condensate and do not pass steam. If this is so, at start-up, they are undersized to a greater degree and the steam space stands a good chance of waterlogging.

  The alternative is to size them so as not to waterlog during start-up. The hole is then effectively oversized for running conditions, and the device will pass steam. The size of
hole is usually a compromise between the two conditions, such that, at some points in between, the hole is correctly sized.

**Corrosion and service life of plant**

Continual waterlogging significantly increases the risk of corrosion in the steam space. It is not unusual to find that after fitting fixed orifice traps, plant service life is reduced below that which may be expected with proper steam traps.

A proper steam trap should be able to achieve just sufficient capacity at all pressures and flowrates present in the application. It can then pass hot condensate without leaking steam under any condition. To achieve this, the size of the hole must vary in the trap. It must be large enough to meet the worst condition, and then have some means of reducing the effective orifice flow area when the capacity becomes too great. This exactly describes the operation of a steam trap.

- **Advantages of a fixed orifice trap**
- Can be used successfully when pressures and loads are constant.
- There are no moving parts
- **Disadvantages of a fixed orifice trap**
- If sized on running load, fixed orifice traps will waterlog on start-up, reducing plant performance over this period, increasing start-up times and the risk of corrosion.
- If sized on start-up load, fixed orifice traps will waste steam when the plant is running, effectively increasing running costs.
- Fixed orifice traps often block with dirt due to the small size of orifice.

The cost of replacing a heat exchanger due to corrosion will be far higher than the cost of replacing the fixed orifice trap with a steam trap.

- **Selection of Steam Traps**
- **Considerations**
- By definition, a steam trap must trap or hold back steam whilst at the same time not restricting the passage of condensate, air, and other incondensible gases.
The basic requirements of good steam trapping have already been outlined but it is worth repeating that the performance of the plant is paramount. The trap selection follows on the basis that the requirements of pressure, condensate load and air venting have been met, in the provisional selection. However, system design and maintenance needs will also influence performance and selection.

Waterhammer

Waterhammer is a symptom of a problem in the steam system.

This could be due to poor design of the steam and condensate pipework, the use of the wrong type of trap or traps or a leaking steam trap, or a combination of these factors.

It is often futile to install the correct trap for an application if the system layout will not allow the trap to operate correctly.

It is equally pointless to install the correct layout and not pay proper attention to steam trapping.

Waterhammer can be caused in a number of ways, including:

- Failure to remove condensate from the path of high velocity steam in the pipework.

From an application which is temperature controlled and where condensate has to lift to a return line, or return to a pressurised system.

- The inability of condensate to properly enter or travel along an undersized return line, due to either (a) flooding, or (b) overpressurisation with the throttling effects of flash steam.

- Modern design and manufacturing techniques have produced steam traps which are more robust than those of their predecessors.

- This allows the steam trap to last longer under normal conditions, and will also be better able to withstand the effects of poorly designed systems.

- Basically, however well a steam trap is made, if it is installed in a poorly designed system it will be less effective and have a shorter working life.

If a steam trap persistently fails on an established system due to waterhammer, it is probably the fault of the system layout, rather than the trap.
The solution is to investigate and eradicate the true cause of the problem by correcting the system inadequacies.

Two important applications are the drainage of steam mains, and of temperature controlled heat exchangers.

As a general rule, steam mains should be drained at regular intervals of 30 to 50 metres with adequately sized drain pockets.

The bottom of any riser must also be drained.

Temperature controlled heat exchangers can only work effectively if condensate is allowed to drain freely from them. If there is a lift after the trap, there will always be a tendency for water hammer, whichever trap is fitted. In this situation, the trap should either be complemented with a pump, or changed for a pump-trap

Dirt

Dirt is another major factor which must be considered when selecting traps.

Although steam condenses to distilled water, it can sometimes contain trace products of boiler feed treatment compound and natural minerals found in water.

Pipe dirt created during installation and the products of corrosion also need to be considered.

An intermittent blast action trap is the least likely to be affected by dirt.

In thermostatic traps this means that the balanced pressure thermostatic trap is preferable, although the larger flat valve associated with some diaphragm traps can cause difficulties.

The dribbling action of bimetallic traps, coupled with the arrangement of the valve stem passing through the seat, means that these are most prone to malfunction (due to added friction) or even to blockage. It is sometimes claimed that the sensor element can be readily cleaned and is not subject to fouling. However, fouling of the element is rarely a problem: the relevant parts are the valve and seat.
Float-thermostatic steam traps are quite resistant to dirt. As an extreme example, when draining concrete curing autoclaves, the residual sand which precipitates into the condensate can be carried through large float-thermostatic steam traps quite successfully, due to the low velocity flow through a relatively large orifice.

The inverted bucket trap has an air vent hole in the bucket. If this blocks, it can cause the trap to air-bind and be slow to react. If this happens, the scale or dirt blocking the air vent must be dislodged, which requires the trap to be removed from service.

The impulse trap is intolerant of dirty conditions. The fine clearance between plug and tapered sleeve is susceptible to high velocity flow and the plug will frequently stick in an intermediate position. The trap seizes in a fixed position and will either pass steam or condensate depending on the rate of condensation.

The fixed orifice device is least suited to dirty conditions. The hole is inherently small and frequently blocks. Enlarging the hole (as is sometimes done in desperation) destroys the concept of sizing on a fixed orifice. It is wasteful and in some cases merely delays the time until blockage re-occurs. A strainer is often supplied and fitted but this has to be extremely fine to be effective.

This simply transfers the blockage from the orifice trap to the strainer, which, in turn, requires regular downtime for cleaning.

- **Strainers**
  These devices are frequently forgotten about in steam systems, often, it seems, in an effort to reduce installation costs.

- **Pipe scale and dirt** can affect control valves and steam traps, and reduce heat transfer rates.

- It is extremely easy and inexpensive to fit a strainer in a pipe, and the low cost of doing so will pay dividends throughout the life of the installation. Scale and dirt are arrested, and maintenance is usually reduced as a result.
Selection is simple. The strainer material is selected to match the type of installation and the system pressure up to which it is expected to operate.

- Different filter screen sizes may be considered for differing degrees of protection. The finer the filter, the more often it may need cleaning. One thing is certain, strainers are far easier and cheaper to buy and maintain than control valves or steam traps.

![Flow path](image)

**Figure 72 typical Y-type strainer (cut section)**

**Steam locking**
The possibility of steam locking can sometimes be a deciding factor in the selection of steam traps.

- It can occur whenever a steam trap is fitted remotely from the plant being drained.
- It can become acute when condensate is removed through a syphon or dip pipe.
- The steam pressure is sufficient to lift condensate up the syphon pipe, through the steam trap and away.
- Steam enters the syphon pipe and causes the steam trap (in this case a float type) to close.

The trap is temporarily 'steam locked'. Heat loss from the cylinder will result in the formation of more condensate which, as a result, is unable to reach the trap.
Figure 11.5.2 (iii) shows the cylinder becoming increasingly waterlogged which will result in a reduced drying rate from the cylinder and an increase in the power required to turn the cylinder.

In extreme cases the cylinder may fill to the centre line and damage may then result from mechanical overload.

![Diagram of cylinder with condensate and syphon tube](image1)

**Figure 72 Steam locking**

- To relieve this problem a trap is needed with a 'steam lock release' valve.
- This is an internal needle valve which allows the steam locked in the syphon pipe to be bled away past the main valve.
- The float trap is the only type of trap with this facility and is the correct choice on rotating machinery such as drying cylinders.
- Because the needle valve is just open enough to avoid steam wastage it has a limited capacity to vent air.
- Traps of this type are often provided with combined air vents and steam lock release
- The manually operated steam lock release mechanism works independently of the automatic air vent action.

- Other types of traps will open and eventually cope with a steam lock, however, the drainage and plant performance will be erratic. This is clearly unacceptable to users of process plant where batch times, quality and efficiency are of high importance.

**Group trapping**

Group trapping describes the use of one trap serving more than one application. Figure shows two batch processes (jacketed pans) operating at two different steam pressures with the drain line from each connected to one steam trap.

The higher pressure in plant B will allow condensate from this vessel to drain but will stop condensate being discharged from plant A as check valve C will be held closed. Plant A will waterlog and will suffer a severe drop in performance.

![Diagram of steam trap system](image)

**Figure 73 Group trapping**

Diffusers With steam traps draining to atmosphere from open ended pipes, it is possible to see the discharge of hot condensate.
A certain amount of flash steam will also be present relative to the condensate pressure before the trap. This can present a hazard to passersby, but the risks can be minimised by reducing the severity of the discharge. This may be achieved by fitting a simple diffuser to the end of the pipe which reduces the ferocity of discharge and sound. Typically, sound levels can be reduced by up to 80%.

**Testing and Maintenance of Steam Traps**

- Testing of Steam Traps
- Traditional and contemporary methods Indiscriminate maintenance of steam traps costs money. Steam traps will either be:
  - In good working order.
  - Leaking steam.
  - Blocking flow.

A major problem has always been the accurate identification of faulty traps. Wrong diagnosis can allow faulty traps to remain troublesome, and perfectly sound traps to be replaced unnecessarily. Accurate diagnosis is therefore important to any maintenance programme.

Historically, diagnostic methods have included listening devices, optical sight glasses, temperature monitoring, and ultrasonic techniques. All of these can give an indication of flow, but become inaccurate as system conditions change. Noise level will vary with disturbance from adjacent traps, and condensate load. Interpretation of signals is difficult even for experienced operators.

Sight glasses offer a partial solution, especially the combined sight/check valve that gives a visual indication of flow plus a non-return facility, however, glasses will require changing occasionally. The inadequacies of listening devices have led to temperature monitoring, but it is perfectly feasible (and normal) for condensate and steam to coexist at the same temperature in the same system, making accurate diagnosis difficult on temperature alone.

A modern version of the listening rod is the ultrasonic trap tester which detects ultrasound
generated by a leaking trap. It is, unfortunately, unable to differentiate between live steam and flash steam passing through the trap. It is also unable to detect the subtle differences explained above.

The unreliability of the above methods has prompted the development of an integrated steam trap testing device.

- Maintenance of steam traps
- Routine maintenance Routine maintenance depends on the type of trap and its application.
- The balanced pressure steam trap for example, has an element which is designed for easy replacement.
- Changing these on a regular basis, maybe once every three years or so, might seem wasteful in time and materials.

However, this practice reduces the need for trap checking and should ensure a trouble free system with minimal losses through defective traps.

- Routine maintenance which involves cleaning and re-using existing internals uses just as much labor but leaves an untrustworthy steam trap. It will have to be checked from time to time and will be prone to fatigue. Any routine maintenance should include the renewal of any suspect parts, if it is to be cost effective.

**Replacement of internals**

The renewal of internal parts of a steam trap makes good sense. The body will generally have as long a life as the plant to which it is fitted and it is only the internal parts which wear, depending on system conditions.

- There are obvious advantages in replacing these internals from time to time. It depends on the ease with which the new parts can be fitted and the reliability and availability of the refurbished trap.
- The elements of thermostatic traps can generally be changed by removing a screwed in seat. Replacement is simple and the remade trap will be reliable assuming the maintenance instructions are correctly carried out.
If the seat or disc faces of a thermodynamic trap become damaged, the disc can simply be replaced.

- Damage to seating faces can be rectified by lapping gently. Replacing the seats of some higher pressure thermodynamic traps is more complicated. Two separate gasketed joints may have to be made or a single gasket may have to cope with two or more steam/condensate passages.

- The weakest point is often the joint between trap body and seat, particularly if this has been allowed to blow steam.

  Always check with the manufacturer regarding the correct technique for any maintenance work required on steam traps.

- A reputable manufacturer will always be able to supply appropriate literature, advice, and spare parts.

- Replacement of traps On occasions, it will be easier and cheaper to replace traps rather than repair them. In these cases it is essential that the traps themselves can be changed easily.

- Flanged connections provide one solution, although the flanged trap is more expensive than the equivalent screwed trap. Mating flanges are an additional expense.

  A swivel connector allows rapid easy removal and replacement of the sealed trap.

- It comprises a pipeline unit or connector which remains in the pipeline during the maintenance procedure.

- The trap can be replaced simply by attending to two bolts.

- This type of trap can be matched to the same connector providing flexibility of choice and rationalization of spares.

Connectors are also available with integral piston isolation valves ensuring downtime is kept to a minimum.

- Energy Losses in Steam Traps

- A large amount has been written about this subject, much of which has been inaccurate or deliberately misleading in order to make the case for using various manufacturers' traps.
An argument is made in favor of replacing one type of trap with another and claiming a steam saving which may be real or imaginary.

- The truth is that replacing any group of traps with new ones will inevitably reduce steam consumption because any leaking traps are thereby eliminated.
- This says nothing about the old or new traps.

In other cases, tests have been carried out to establish 'steam wastage'. Some tests are carried out under unrealistic no-load conditions and attempt to overvalue and confuse the amount of energy lost through the trap.

- Energy loss from the trap due to radiation, which will also increase condensate load, is conveniently ignored. However, these losses will occur at all times and are directly related to the size and shape of the body.

Steam trap users are often confused by subjective information which is intended primarily to create interest in a product. It is therefore worth going back to objective principles and considering the inherent energy requirements of the main types.

- Thermostatic steam traps
  
  Under normal operating conditions, the thermostatic trap holds back condensate until it has cooled to a certain temperature.

- Steam does not reach the main valve so there is no apparent steam wastage.

However, waterlogging of plant can lead to reduced output. Operating times may be extended or additional heaters or heating surfaces may be required.

- More steam may be required although this will not appear as an energy requirement attributable to the steam trap.

  In some cases a cooling leg may be incorporated so that the steam space is kept clear of condensate.

- Energy is thereby lost due to radiation from the cooling leg and from the trap body. This in itself creates an additional condensate load, but there is no passage of live steam through the trap.

  The situation can change under no-load conditions. Heat loss from the trap body cools the condensate surrounding the element which then opens.
The minimal amount of condensate involved is discharged and is then replaced by steam. However, hysteresis means that the element has yet to respond and live steam is lost.

Laboratory tests indicate typical losses up to 0.5 kg/h. Ironically, under cold outdoor conditions there will be increased heat loss from the trap and steam loss through the trap is less likely. Any attempt to lag a thermostatic trap will result in a serious delay in the opening of the trap.

Severe water logging will result and hence lagging is not recommended for thermostatic traps.

**Mechanical steam traps**

- The float-thermostatic trap is another example where the valve and seat are normally flooded and there is no steam loss through the trap.
- Conversely, the float-thermostatic trap is relatively large in size, and there may be a noticeable loss from the trap caused by radiation. Mention should be made of the thermostatic air vent fitted in this type of trap.
- This will be situated in the steam space above the water level in the trap. Once initial air has been cleared this will normally remain tight shut and there will be no loss from this source.

The float-thermostatic trap can be lagged to reduce heat losses and this will not affect its operation. Lagging is normally recommended on outdoor applications to minimize the danger of damage due to freezing when steam might be turned off.

The inverted bucket trap has surprisingly little in common with the float type trap. The trap closes when steam enters and bubbles through into the bucket to make it buoyant. It will not open until the steam has been dissipated.

This will occur as the steam leaks away through the hole in the bucket which serves as an air vent. The steam will collect in the top of the trap itself and when the main valve opens, this steam is vented.

**Thermodynamic steam traps**
This type of trap has attracted most attention under the heading of steam wastage.

The operation depends on condensate approaching steam temperature, producing flash steam at the orifice and causing the trap to close. It does this with condensate on the upstream side and again the flooded valve means that there can be no loss through the trap. However the trap will open periodically as heat is lost from the cap.

Under no-load conditions, i.e. when condensate is being produced only by heat loss from the upstream pipeline, the condensate on the upstream side may exhaust and the trap will then require a small amount of live steam to cause it to close. Much will depend on ambient conditions but the loss will generally be around 0.5 kg/h and this could be doubled in severe weather. Conversely, such losses can be halved by simply fitting an insulating cover over the top cap.

It is important to remember that these losses disappear as the condensate load increases while the radiation losses from the trap are minimal due to its small size. Independent tests have shown that radiation losses are not more than 0.25 kg/h which is at least a quarter of that experienced by equal sized inverted bucket traps.

Mention should be made of misleading figures quoted by some sources. These have their origins in tests carried out simultaneously on a large number of thermodynamic traps. Some tests were carried out at minus 45°C with the cumulative steam loss being measured. The effect of testing at unusually low temperatures and under no-load conditions was to produce an accelerated life test. The loss through a small number of defects averages out to produce a curve showing losses increasing with time.