General Engineering

Unit 2

STEAM GENERATION SYSTEM AND BOILERS

Steam

- When water is heated at atmospheric pressure, its temperature rises until it reaches 212°F (100°C), the highest temperature at which water can exist at this pressure.
- Additional heat does not raise the temperature, but converts the water to steam. This ‘phase change’ requires a tremendous amount of additional energy input.
- The ability of steam to carry large amounts of thermal energy is the property that makes it so desirable as a working fluid.

Properties of steam

- Water can exist in the form of solid, liquid and gas as ice, water and steam respectively. If heat energy is added to water, its temperature rises until a value is reached at which the water can no longer exist as a liquid.
- We call this the "saturation" point and with any further addition of energy, some of the water will boil off as steam.
- This evaporation requires relatively large amounts of energy, and while it is being added, the water and the steam released are both at the same temperature.
- Equally, if steam is made to release the energy that was added to evaporate it, then the steam will condense and water at same temperature will be formed.

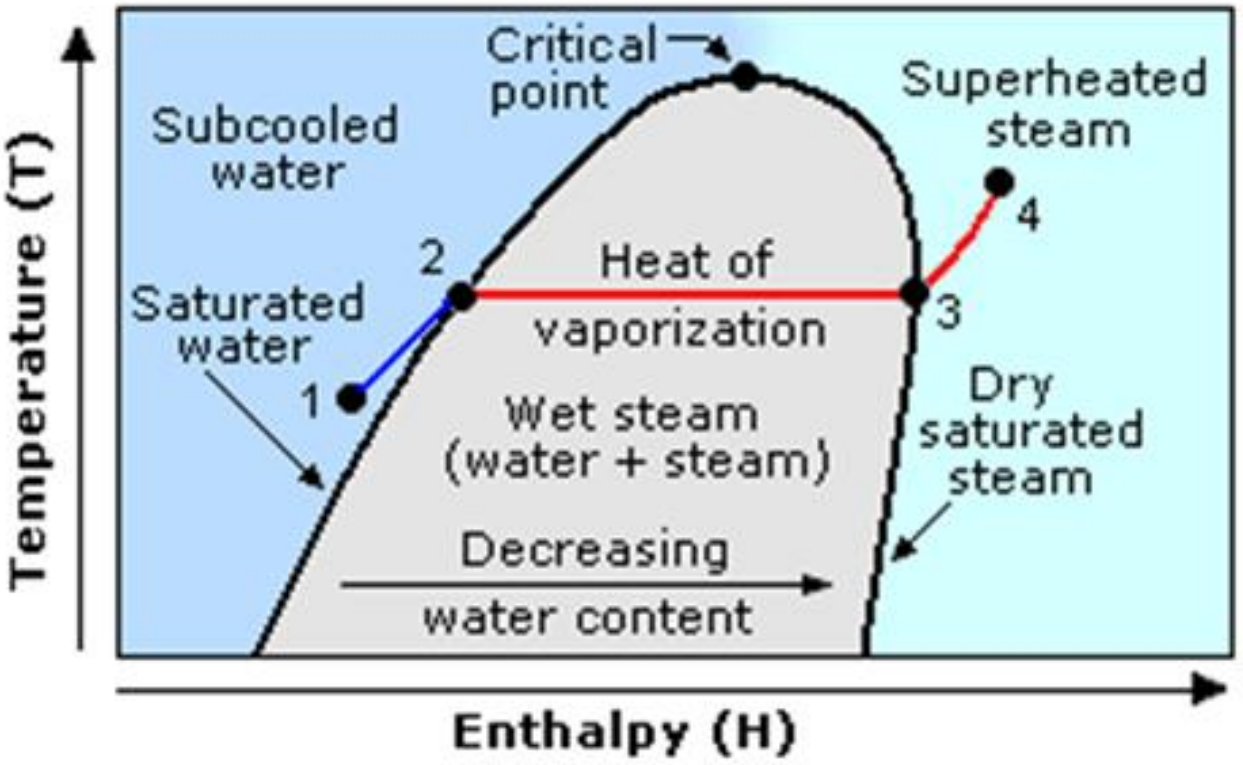
Properties of steam

1 to 2 : Water is heated from T_1 to T_2

2 to 3 : Water vaporized into dry steam at constant temperature and pressure

3 to 4 : Dry steam is superheated to T_4

—— : A line of constant pressure (isobar)



T-H DIAGRAM OF WATER TO STEAM
(Converting water into superheated steam)

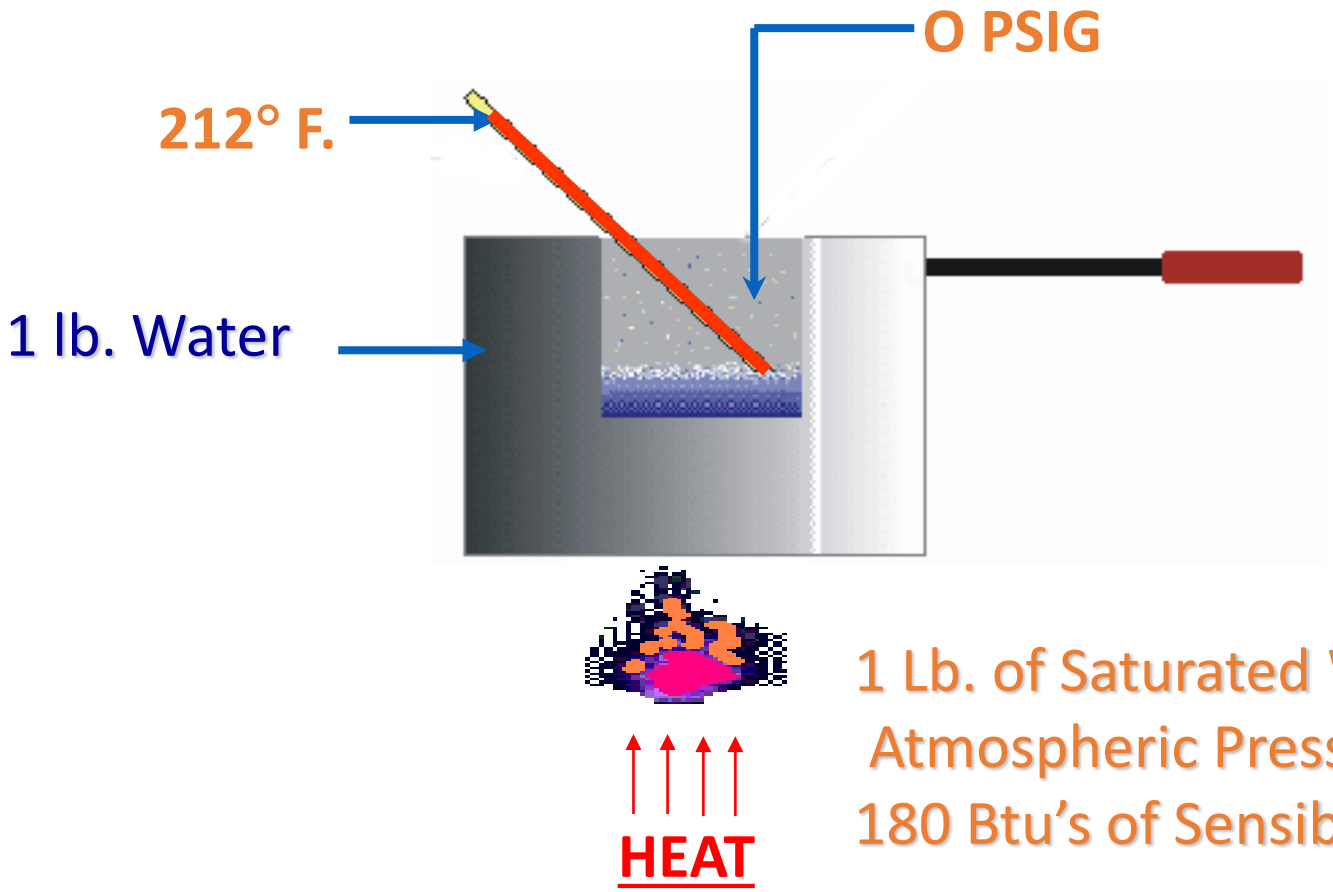
Properties of steam

- When the water is heated up, its temperature increased till its reaches the boiling point. Up to this point, all the heat supplied to the water is used for rise in temperature. This is indicated by water going from point 1 to point 2 in the T-H diagram above.
- At boiling point, water starts to vaporize and all the newly added heat is used for this phase change. This is represented by the path from point 2-3. During this part there is increase in temperature, as all the added heat is utilized for phase change. Temperature stays at the boiling point.
- When all of the water is boiled off (point3), the heat added next to this dry steam is used for raising its temperature above the boiling point. This additional heat that raises the steam temperature is the 'superheat' added to the steam. And the excess temperature of the steam above the boiling point is - 'degree of superheat'.

Sensible heat

- Sensible Heat is the amount of Heat Energy required to raise the temperature of water from 32°F to the boiling point (saturated liquid) at a given pressure.
- Sensible Heat raises the temperature of the water and can be sensed with a thermometer.

Sensible heat

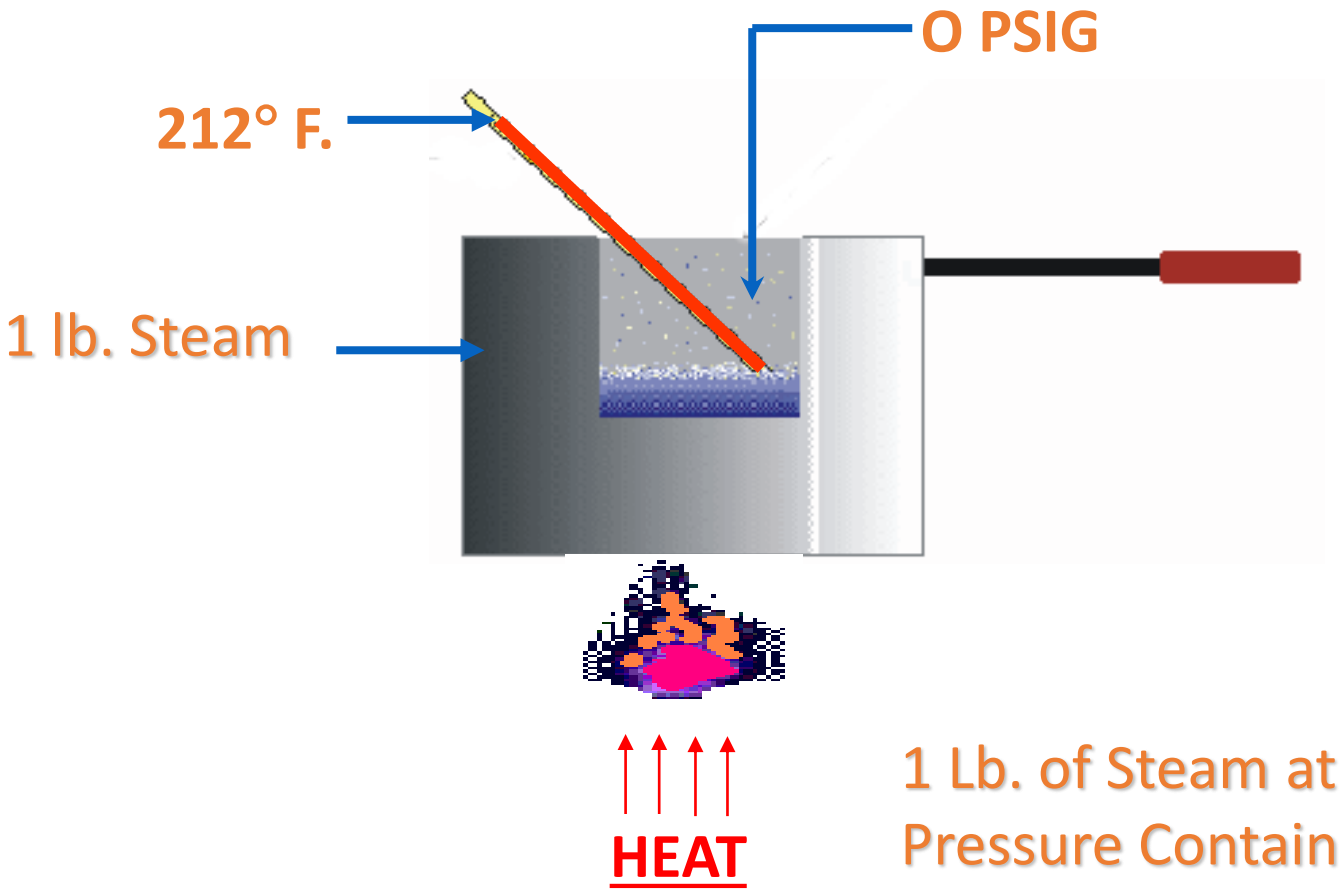


1 Lb. of Saturated Water at Atmospheric Pressure Contains 180 Btu's of Sensible Heat

Latent heat

- Latent Heat is the amount of Heat Energy required to transform water at the boiling point (saturated liquid) to steam.
- Adding Latent Heat does not raise the temperature – saturated liquid and steam have the same temperature for a given pressure.

Latent heat



1 Lb. of Steam at Atmospheric Pressure Contains 970 Btu's of Latent Heat

WET STEAM

- Both the water molecules and steam coexist to form a two phase mixture, called wet steam.
- This is the most common form of steam actually experienced by most plants. When steam is generated using a boiler, it usually contains wetness from non-vaporized water molecules that are carried over into the distributed steam.
- Which will be in thermal equilibrium because both of them will be at the same saturation temperature.
- As the water approaches the saturation state and begins to vaporize, some water, usually in the form of mist or droplets, is entrained in the rising steam and distributed downstream.

DRY STEAM

- A steam at the saturation temperature corresponding to a given pressure and having no water molecules in it is known as dry steam.
- Since the dry steam does not contain any water molecules in it, its dryness fraction will be unity.
- Dry steam has many properties that make it an excellent heat source, particularly at temperatures of 100 °C (212°F) and higher.

Property	Advantage
Rapid, even heating through latent heat transfer	Improved product quality and productivity
Pressure can control temperature	Temperature can be quickly and precisely established
High heat transfer coefficient	Smaller required heat transfer surface area, enabling reduced initial equipment outlay
Originates from water	Safe, clean, and low-cost

SATURATED STEAM

- When heat is applied to water, its temperature continues to rise until it reaches its boiling point at that pressure.
- As further heat is added, the water vaporizes and converts to steam. The steam that exists at the same temperature as the water from which it is formed is known as saturated steam.
- In other words, saturated steam exists at approximately 100°C (212°F) at atmospheric pressure.

SUPERHEATED STEAM

- When a dry saturated steam is heated further at the given constant pressure, its temperature rise beyond its saturation temperature.
- The steam in this state is said to be superheated.
- This yields steam that has a higher temperature and lower density than saturated steam at the same pressure.
- Superheated steam is mainly used in propulsion/drive applications such as turbines, and is not typically used for heat transfer applications.

Total heat of steam

DRY SATURATED STEAM: The state of steam after complete evaporation of water at saturation temperature is called dry saturated steam. The amount of heat energy, needed to convert 1kg of water at 0°C into dry-saturated steam.

hg = hf + hfg

SENSIBLE HEAT OF WATER: The amount of heat energy to be supplied to convert 1kg of water at 0°C to its saturation temperature (ts) corresponding to a given steam pressure(P). It is denoted by hf and its unit is kJ/kg.

hf = Cpw (ts-to)

TOTAL ENTHALPHY OF STEAM: The Enthalpy is defined as the total heat content in the system. The amount of heat required to convert the water in to the superheated steam is called as the total Enthalpy of steam

Total enthalpy= Enthalpy of saturated liquied + Enthalpy of dry saturated steam

h= hf + x hfg

Superheat and dryness fraction

Dryness fraction is defined ratio of the mass of the dry steam present in the total mass of steam.

m_s =Mass of dry steam contained in steam considered and

m_w=weight of water particles in suspension in the steam considered

Then,

$$\mathbf{x = m_s / (m_s + m_w)}$$

Thus if in 1 kg of wet steam 0.9 kg is the dry steam and 0.1 kg water particles then x=0.9.

Boiler

- A boiler is defined as a closed vessel which is used to heat liquid usually water or to generate vapour or steam or any of such combination under pressure for external use by combustion of fossil fuels.
- The heated or vaporized liquid exits the boiler for use in various processes or heating applications, such as cooking, water or central heating, or boiler-based power generation.
- Boilers (or more specifically steam boilers) are an essential part of thermal power plants.

Boiler

- The boiler is essentially a closed vessel inside which water is stored. Fuel (generally coal) is burnt in a furnace and hot gasses are produced.
- These hot gasses come in contact with water vessel where the heat of these hot gases transfer to the water and consequently steam is produced in the boiler.
- Then this steam is piped to the turbine of thermal power plant.

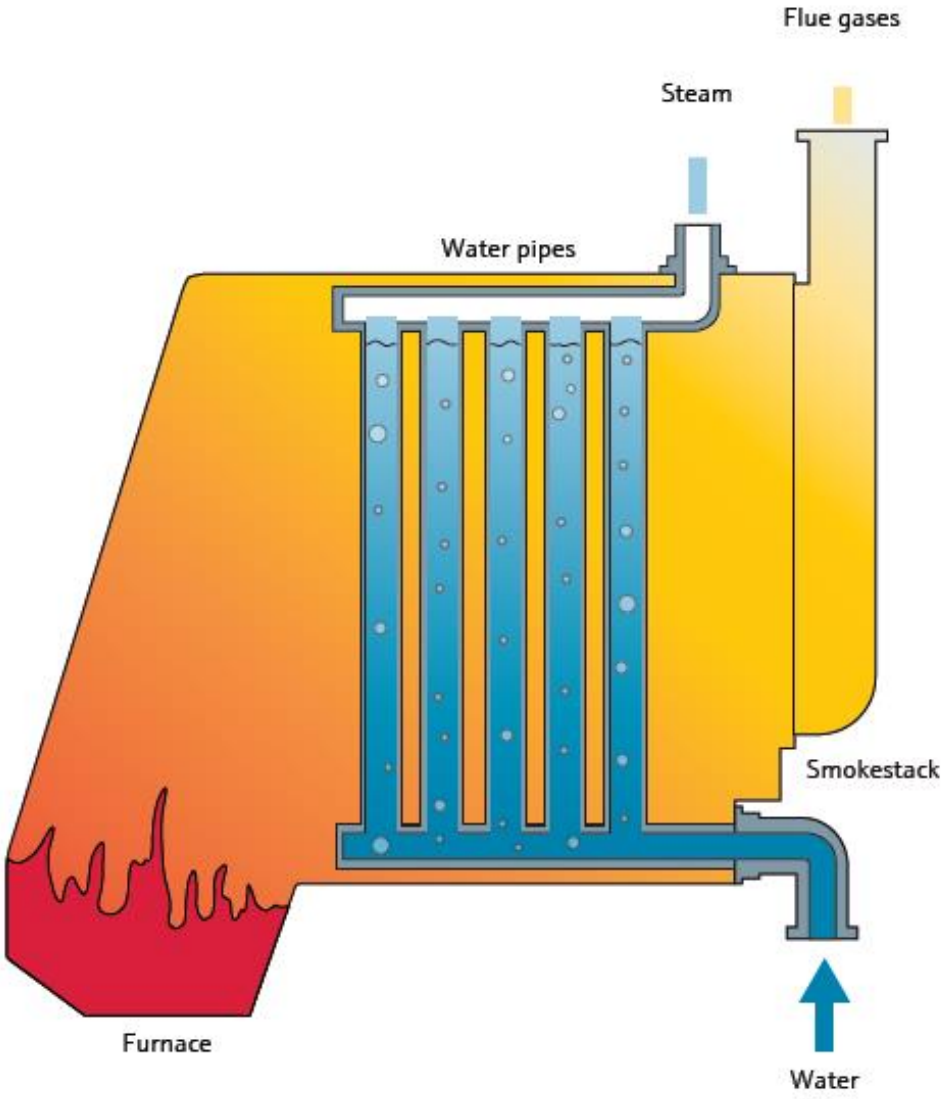
Function of boiler

- The main function of a boiler is to heat water to generate steam. Steam produced in a boiler can be used for a variety of purposes including space heating, sterilisation, drying, humidification and power generation.
- The temperature or condition of steam required for these applications is different, so boiler designs vary accordingly.

Water tube boiler

- The water is injected into a drum known as the water or mud drum and then flows through the tubes and into the steam drum located at a higher level boiling to form steam. Very high outputs and pressures (including supercritical steam) can be obtained from this type of boiler.
- Power stations operating this type of boiler generate approximately half of the world's electricity.
- Water-tube boilers are used almost exclusively in the generation of electricity due to the high temperatures (and therefore efficiencies) which can be obtained.

Water tube boiler



Water tube boiler

- It consists of mainly two drums, one is upper drum called steam drum other is lower drum called mud drum. These upper drum and lower drum are connected with two tubes namely down-comer and riser tubes as shown in the picture.
- Water in the lower drum and in the riser connected to it, is heated and steam is produced in them which comes to the upper drums naturally. In the upper drum the steam is separated from water naturally and stored above the water surface.
- The colder water is fed from feed water inlet at upper drum and as this water is heavier than the hotter water of lower drum and that in the riser, the colder water push the hotter water upwards through the riser. So there is one convectional flow of water in the boiler system.

Water Tube Boilers

Advantages

- There are many advantages of water tube boiler due to which these types of boiler are essentially used in large thermal power station.
- Larger heating surface can be achieved by using more numbers of water tubes.
- Due to convectional flow, movement of water is much faster than that of fire tube boiler, hence rate of heat transfer is high which results into higher efficiency.
- Very high pressure in order of 140 kg/cm2 can be obtained smoothly.

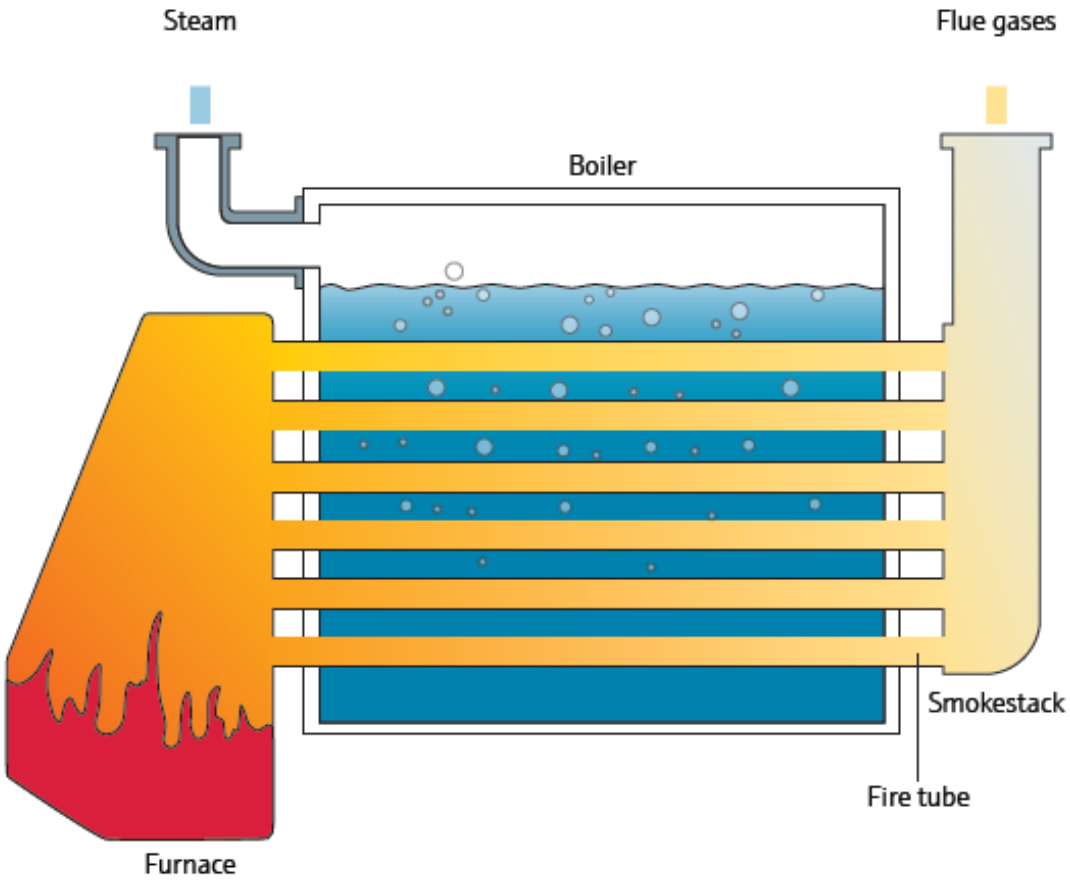
Disadvantages

- The main disadvantage of water tube boiler is that it is not compact in construction.
- Its cost is not cheap.
- Size is a difficulty for transportation and construction.

Fire Tube boilers

- In fire tube boiler, the fuel is burnt inside a furnace. The hot gases produced in the furnace then passes through the fire tubes.
- The fire tubes are immersed in water inside the main vessel of the boiler.
- As the hot gases are passed through these tubes, the heat energy of the gasses is transferred to the water surrounds them.
- As a result steam is generated in the water and naturally comes up and is stored upon the water in the same vessel of fire tube boiler.

Fire Tube boilers



Fire Tube boilers

Advantages of Fire Tube Boiler

- Compact in construction.
- Fluctuation of steam demand can be met easily.
- Cheaper than water tube boiler.

Disadvantages of Fire Tube Boiler

- Due to large water the required steam pressure rising time quite high.
- Output steam pressure cannot be very high since the water and steam are kept in same vessel.
- The steam received from fire tube boiler is not very dry.
- In a fire tube boiler, the steam drum is always under pressure, so there may be a chance of huge explosion which resulting to severe accident.

Difference between fire tube boiler and water tube boiler

FIRE TUBE BOILER	WATER TUBE BOILER
Hot flue gases flow inside the tube and the water outsides the tubes.	Water flows inside the turbine and hot flue gases outside the tube.
These boilers are generally internally fired.	These boilers are generally extra really fired.
The boiler pressure limited to 20 bar.	The boiler pressure is limited to up to 100 bar.
The fire-tube boiler has a lower rate of steam production.	A higher rate of steam production.
Not suitable for larger power plants.	Suitable for larger power plants.
Involves lesser risk of explosion due to low pressure.	The risk of the explosion is higher due to high boiler pressure.
For a given power, it occupies large floor space.	For a given power, it occupies small floor space.
This boiler is difficult to construct.	Simple in construction.

Difference between fire tube boiler and water tube boiler

FIRE TUBE BOILER	WATER TUBE BOILER
Difficult in transportation.	Simple in transportation.
They require less skill to operate, as compare to the water tube boiler.	They required a skilled operator.
They are difficult to repair and cleaning as they are internally fired.	They are easy to repair and clean as they are externally fired.
They required a large shell diameter. Because the firetube situated inside the shell.	They required a small shell diameter.
The efficiency of the fire tube boiler is less as compared to the water tube boiler.	The efficiency of the water tube boiler is more.
The maintenance of this boiler is costly. It requires regular inspection.	They are easy to maintain as they are externally fired.

Low Pressure Boiler

- In a low-pressure boiler the pressure does not go beyond 15 psi, and hot water heating boilers are not designed to go beyond 260 psi.
- The temperature in a low-pressure boiler will not rise above 250° F.
- Because these types of boilers operate at lower pressures, they don't need to be checked regularly and only have to be checked when the appliance begins to break down.

High Pressure Boiler

- High-pressure boilers will heat steam above 15 psi and water at pressures that go beyond 160 psi.
- Temperatures in high-pressure boilers will go beyond 250 °F. Because of the elevated pressure at which these boilers operate, to ensure safety at all times it need to be observed.
- High-pressure boiler operators must audit safety devices, switches, valves, and leaks on a regular basis.
- To prevent further occurring damage any malfunctions need to be fixed immediately.

Difference between low pressure and high pressure boiler

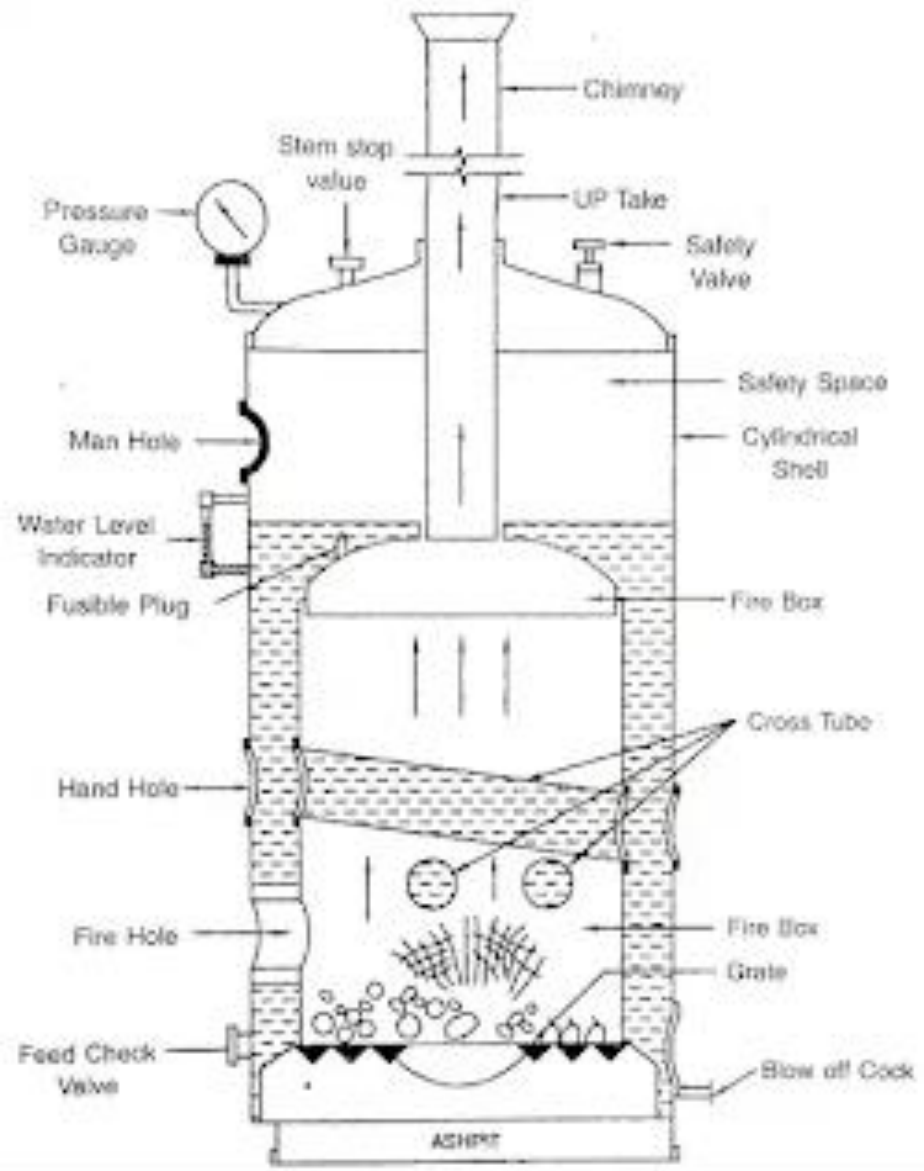
HIGH PRESSURE BOILER	LOW PRESSURE BOILER
In high pressure boilers, steam pressure is above 15 psi	In low pressure boilers, steam pressure never goes beyond 15 psi.
Hot water pressure always go beyond 260 psi	Water pressure never go beyond 260 psi
Temperature in high pressure boiler will always be greater than 250oC.	Temperature in low pressure boiler will never be greater than 250oC.
For the safety due to high working pressures, these boilers are required to be checked all the time.	Since these boilers work on low working pressure, they don't need continuous check.
Applications involve production of steam in power plant and in industries	These are used for water heating and steam which is used to heat rooms.
In high pressure boilers for similar size, the output is relatively high.	In low pressure boilers for similar size, the output is relatively less.
It requires high maintenance	It requires low maintenance
The operating costs are comparatively high	The operating costs are comparatively low.

Various Steam specifications

	Pressure (bar)	Superheated temperature (C)	Enthalpy (Id/kg)	Saturation Temperature (C)
VHP	100	500	3375	311
HP	40	400	3216	250
MP	15	300	3039	198
LP	4.5	200	2858	148
CONDENSATION	0.12		2591	50

Simple Vertical Boiler

- Simple Vertical Boiler is a boiler in which water is boiled inside a large vertical cylindrical shell and steam is produced.
- This is the simplest type of fire tube boiler.
- This boiler produces low pressure and a small quantity of steam.
- This boiler produces a pressure of nearly 10 bar.
- The construction of this boiler is very simple and easier than any other boiler.
- This boiler occupies very little space, so it is used where less land is available for operation.
- The steam produces in this boiler is used in low working conditions like small power plants for producing current.



Main Parts of Simple Vertical Boiler

- Cylindrical shell
- Tubes
- Firebox
- Grate
- Ash pit
- Fire hole
- Water level and steam indicator

Main Parts of Simple Vertical Boiler

1. Cylindrical shell: In this shell, cross-tubes are arranged.

2. Tubes: These tubes are placed at an angle of 15 to 30 degrees with the horizontal axis.

3. Firebox: The firebox is provided at the bottom of the shell. This fire-box is fitted with a grate (a platform on which coal is placed and burnt).

4. Grate: The grate is made of a number of steel or C.I. bars. These bars are fixed in such a way that an air space is provided between bars. The air space will help the ashes produced by the combustion of coal or any other fuel to fell down.

Main Parts of Simple Vertical Boiler

5. Ash pit: An ash pit or ash pan is placed below the grate. The function of the ash pit is to collect the ashes.

6. Fire hole: A fire hole is provided on one side of the grate. The function of this fire hole is to add the coal as and when needed.

7. Water level and steam indicator: A large portion of the shell is filled with water. The firebox is also surrounded by water. The quantity of water is quite substantial. The remaining portion of the shell contains steam. The firebox is provided with two cross-tubes. This increases the heating surface and circulation of water.

Main Parts of Simple Vertical Boiler

- It consists of a cylindrical shell surrounding a nearly cylindrical firebox. The firebox is slightly tapered towards the top to allow the ready passage of the steam to the surface. At the bottom of the firebox, is a grate. The firebox is provided with two or more inclined cross tubes F, F.
- The inclination of the cross tubes is provided to improve the heating surface as well as to increase the circulation of water. An uptake tube passes from the top of the firebox to the chimney. The handhole is fitted opposite to the end of each water tubes for cleaning the depositions.
- A manhole is located at the top portion of the boiler for a man to enter and to clean the boiler. A mudhole is provided at the bottom of the shell to remove the mud, that settles down. The space between the boiler shell and firebox is filled with water to be heated.

Working of Simple Vertical Boiler

- When fuel is placed in the furnace and burns then hot flue gas is generated.
- Then these hot flue gases pass through the fire tube and heat surrounding water. When water becomes heated then it converted in saturated steam.
- You can call this saturated steam as primary steam. This saturated steam is stored at the steam chamber.
- From the steam, the chamber is transferred to the boiler super heater.
- This superheating process makes saturated steam to working steam.
- After that superheated steam is transfer to the prime mover.
- All hot burn flue gases, smoke, and ash are release out from the boiler by a chimney.
- Boiler chimney creates a natural draft to increase boiler efficiency.

Function of boiler mountings - safety valve

- The safety valve is an instrument which prevents the boiler pressure from rising above its normal working pressure by automatically opening when the boiler pressure exceeds the normal working pressure, thus allowing excess steam to escape into the atmosphere until the pressure comes down to its normal value.
- Safety valves are fitted on every boiler to avoid over pressurizing. Normally three safety valves are fitted on the boiler with one on the super heater and rest two on steam drum. In no condition these valves be less than two in number and must lift at a pressure 3% above boiler working pressure irrespective of boiler types.

Function of boiler mountings - Water level indicator

- It is an important device, which indicates the water level inside the boiler.
- It is a safety device upon which the safe working of the boiler depends.

Function of boiler mountings - Water level indicator

- A pair of water level indicator is installed directly to the boiler shell with an additional remote reading gauge installed at convenient position. They are installed directly on the front end of all boiler types; showing water level in boiler drum. It consist of a glass tube with three independent valves (Steam valves, water valves and drain valves).
- Steam and water valves separates the glass tube with boiler steam and water respectively. Drain valves on other hand used to drain water from glass tube. A metal ball is provided on the water side of the gauge glass to avoid subsequent accident and water loss; by water flashing off steam in event of glass rapture / failure.
- Under normal condition both steam and water valves is open allowing water and steam pressure to balance. In event of incorrect reading we need to blow through; by closing the water valves and opening drain valves. A strong blow will indicate the steam valves is clear; now repeat the process with steam valves closed and water valves opened. Strong blow of steam with hissing sound indicate the water valves is clear. Now close the drain valves and let water fill in; slowly open the steam valves equalizing the pressure.

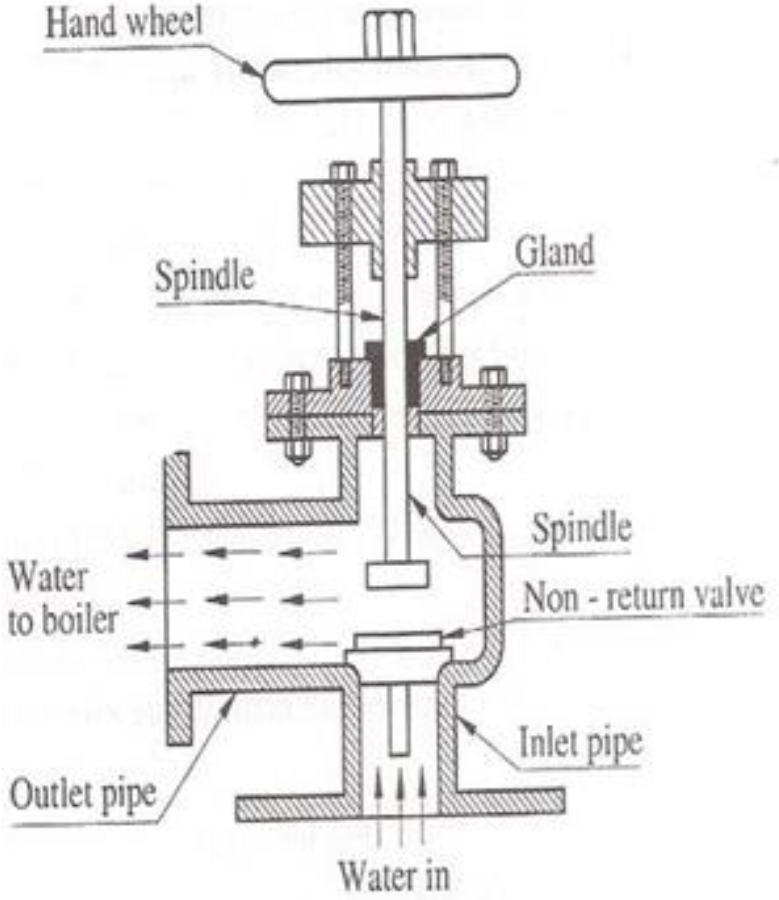
Function of boiler mountings - pressure gauge

- The pressure gauge is used to measure the pressure of the steam inside the boiler.
- It is arranged in front of the boiler.
- The pressure gauge displays the pressure inside the boiler.
- Pressure gauge are fitted to the steam drum and super heater to indicate steam pressure inside.
- These gauge are fitted on the front top of the boiler shell and represent pressure in bar.

Function of boiler mountings - feed check valve

- A feed check valve is a non return valve type fitted on the boiler shell just below the normal water level.
- It regulates the flow of feed water restricting possible back flow to the feed pump.
- These valves are usually fitted with extended spindle for remote operation.
- The inlet and outlet point of these valves are exposed to different pressure.
- When the feed pump is operational; sufficient pressure is build at the inlet point of the valve.
- When the inlet pressure is more than the outlet point the valve lift allowing water to pass to the boiler.

Function of boiler mountings - feed check valve



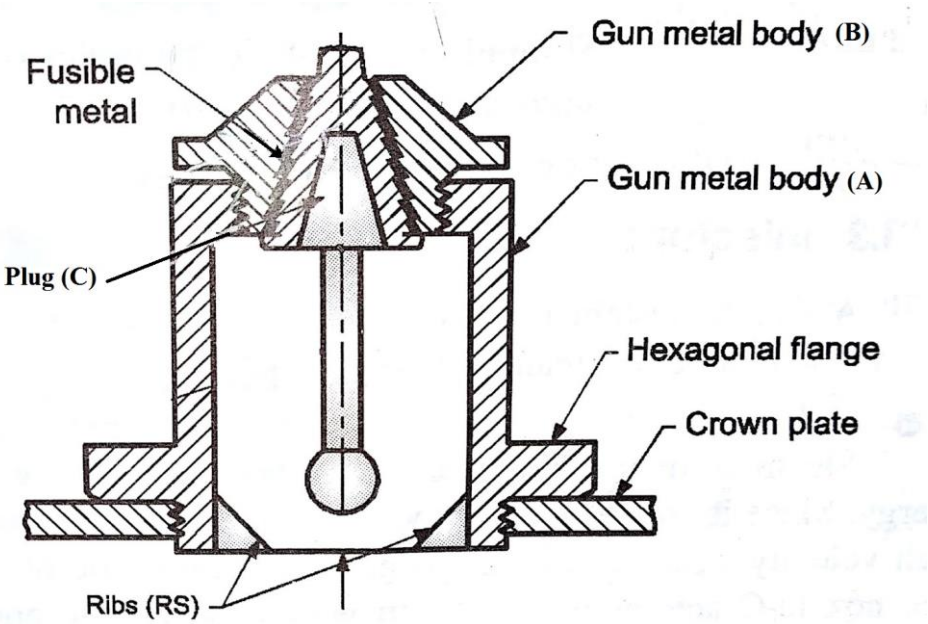
Function of boiler mountings - fisible plug

A fusible plug is the threaded gunmetal cylinder with conical plug and tappet hole drilled into it. This This hole is then filled with an alloy of low melting point such as tin. The plug can be of either fire actuated or steam actuated type fitted over the combustion chamber.

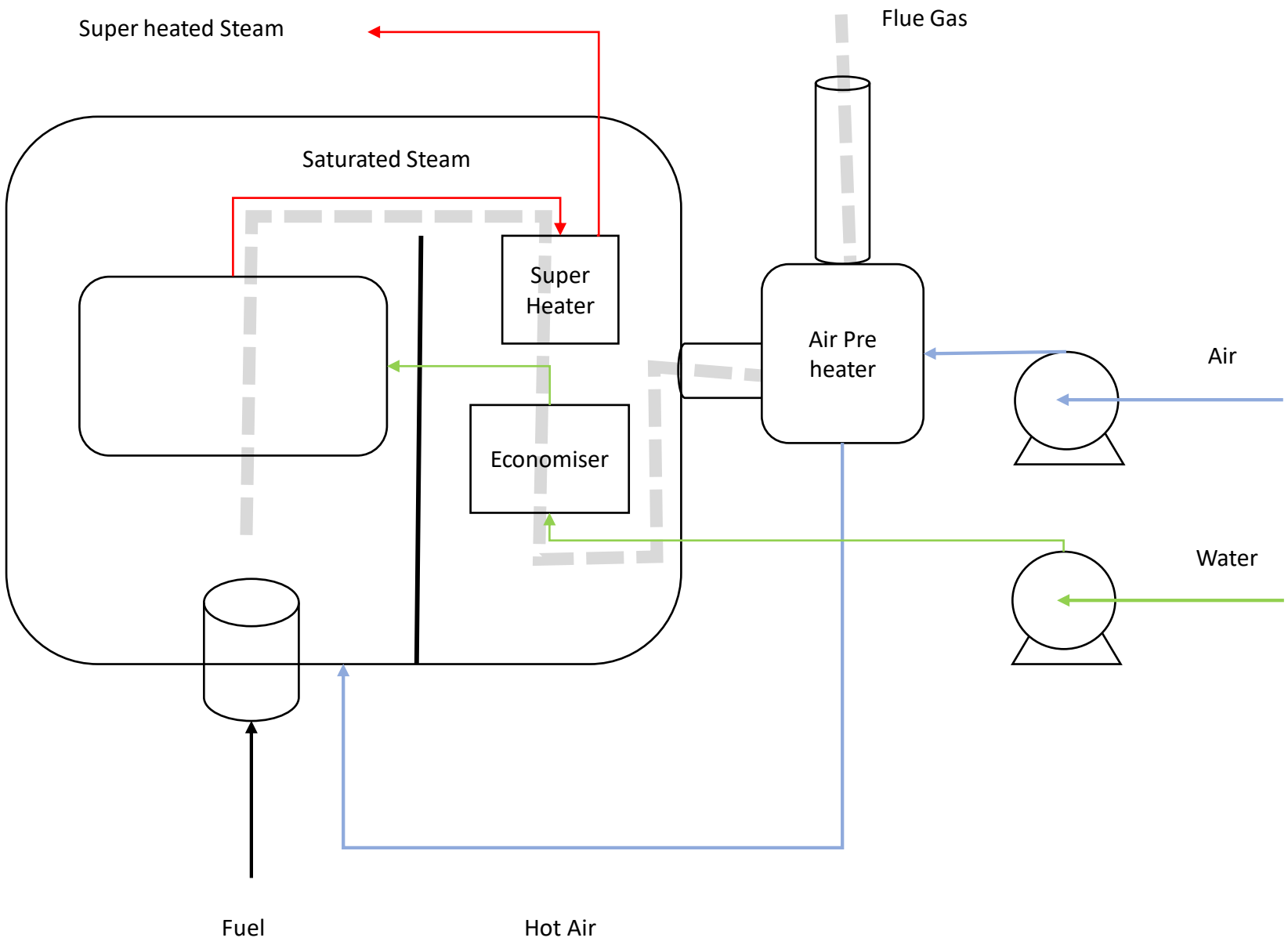
Under normal condition one side of the plug is exposed to extreme temperature while the other submerged under water; keeping it cool. This low melting point alloy can not melt away till submerged and so remain intact even under extreme condition.

In event of water level reach below a safe limit and plug tip is exposed to steam; the tin alloy will melt exposing combustion chamber with steam. As steam is not effective coolant and convection medium the tin alloy can't transfer heat to the steam leading it to melt away. This sudden injection of steam into the furnace will stop the combustion protecting boiler from any damage.

Function of boiler mountings - fisible plug



Function of Boiler accessories



Function of Boiler accessories - Economizer

- The combustion gases coming out of the boiler contain a large quantity of heat. Therefore the maximum amount of heat from the gases should be recovered before it escapes to the chimney.
- The economizer is a plant in which the feed water is preheated before it enters into a boiler, the heat is taken from the waste flue gases of the boiler.
- A economiser improves the economy of the steam boilers.

Advantages:

- Saving of fuel
- The increase in the evaporative capacity of the boiler.
- The long life of the boiler.

Function of Boiler accessories - Feed pump

- A feed pump is a boiler accessory required to force the feed water at high pressure into the boiler. Commonly used pumps are,
    - Reciprocating pumps
    - Rotary pumps
- The reciprocating pumps are driven directly by coupling them to the steam engine. The rotary pumps are driven by the steam turbines or by electric motors.

Function of Boiler accessories - Super heater

- The superheater is used in boilers to increase the temperature of the steam above the saturation temperature.
- It is placed in the path of hot flue gases from the furnace.
- The dry saturated steam generated in the boiler is passed through a set of tubes placed in the path of the flue gases, in which it will be heated further by the hot gas to increase its temperature about the saturation temperature.
- A superheater is an important accessory used in the boiler. Its main function is to increase the temperature of saturated steam without raising its pressure.

Function of Boiler accessories - Air pre heater

- The air preheater is an accessory that recovers the heat in the exhaust gas by heating the air supplied to the furnace of the boiler.
- Supplying preheated air into the furnace produces a high furnace temperature and accelerates the combustion of the fuel.
- Thus the thermal efficiency of the plant will be increased.
- It is used to recover heat from the exhaust gases.
- It is Installed between the economiser and the chimney.
- The advantages of air pre-heater are,
  - Increase in the steam generation rate.
  - Better combustion with less soot, smoke and ash, and
  - Low-grade fuels can be used.