UNIT – 2 Steam Boilers and Draft

Classification of steam boilers, Comparison between fire and water tube boilers, Essentials of a good boiler, Constructional and operational details Low Pressure boilers - Locomotive, Lancashire Boilers, High pressure boilers – Benson, Lamont, Loeffler, Velox boilers, Boiler mountings and accessories, Boiler performance, Natural& Artificial drafts, Chimney height, Maximum draft, Chimney efficiency, Boiler heat balance sheet.

- **Steam Boiler:** It is a closed vessel in which steam is produced from water by the combustion of fuel.

  - **Conditions of Steam**: The steam must be safely delivered in desired conditions. As regards its pressure, temperature, quality and required rate of generation

  - **Classification of Boilers:**

1. According to their Axis (Horizontal, Vertical or Inclined)
- If the axis of the boiler is horizontal, the boiler is called as horizontal.
- If the axis is vertical, it is called vertical boiler.
- If the axis is inclined it is known as inclined boiler.

2. Fire Tube and Water Tube
- In the fire tube boilers, the hot gases are inside the tubes and the water surrounds the tubes.
  Examples: Cochran, Lancashire and Locomotive boilers.
- In the water tube boilers, the water is inside the tubes and hot gases surround them.
  Examples: Babcock and Wilcox boiler.

3. Externally Fired and Internally Fired
- The boiler is known as externally fired if the fire is outside the shell.
  Examples: Babcock and Wilcox boiler.
- The furnace is located inside the boiler shell.
  Examples: Cochran, Lancashire boiler etc.

4. Forced Circulation and Natural Circulation
- In forced circulation type of boilers, the circulation of water is done by a forced pump.
- In natural circulation type of boilers, circulation of water in the boiler takes place due to natural convention currents produced by the application of heat.

5. High Pressure and Low Pressure Boilers
- The boilers which produce steam at pressures of 80 bar and above are called high pressure boilers. Examples: Babcock and' Wilcox boilers.

- The boilers which produce steam at pressure below 80 bar are called low pressure boilers.
  Examples: Cochran, Lancashire and Locomotive boilers.

6. Stationary and Portable

- Stationary boilers are used for power plant-steam, for central station utility power plants, for plant process steam etc. (i.e. on Land)
- Mobile boilers or portable boilers include locomotive type, and other small units for temporary use at sites (i.e. Marine, Locomotive & Large Ships)

7. Single Tube and Multi-tube Boilers

- The fire tube boilers are classified as single tube and multi-tube boilers, depending upon whether the fire tube is one or more than one.

➢ Essentials of a Good Steam Boiler:

1. Produces maximum quantity of steam with the minimum fuel consumption.
2. Economical to install and rapidly meet the fluctuation of load.
3. Capable of quick starting and light in weight.
4. Occupy a small space and the joints should be few and accessible for inspection.
5. The mud and other deposits should not collect on the heating plates.
6. The refractory material should be reduced to a minimum. But it should be sufficient to secure easy ignition, and smokeless combustion of the fuel on reduced load.
7. The tubes should not accumulate soot or water deposits, and should have a reasonable margin of strength to allow for wear or corrosion.
8. The water and flue gas circuits should be designed to allow a maximum fluid velocity without incurring heavy frictional losses.
9. It should comply with safety regulations as laid down in the Boilers Act.

➢ Factor While Selection of A Boiler:

1. The working pressure.
2. Quality of steam required
3. Steam generation rate.
4. Floor area available.
5. Accessibility for repair.
6. Accessibility for inspection.
7. Comparative initial cost.
8. Erection facilities.
9. The portable load factor.
10. The fuel and water available.
11. Operating cost.
12. Maintenance costs.

➢ Comparison between Fire-Tube and Water-Tube Boilers:

S. No.	Water Tube Boilers	Fire Tube Boilers
1.	The water circulates inside the tubes which are surrounded by hot gases from the furnace.	The hot gases from the furnace pass through the tubes which are surrounded by water.
2.	It generates steam at a higher pressure upto 165 bar.	It can generate steam only upto 25 bar.
3.	The rate of generation of steam is high, i.e. upto 450 tonnes per hour.	The rate of generation of steam is low, i.e. upto 9 tonnes per hour.
4.	For a given power, the floor area required for the generation of steam is less, i.e. about 5 m^2 per tonne per hour of steam generation.	The floor area required is more, i.e. about 8 m^2 per tonne per hour of steam generation.
5.	Overall efficiency with economiser is upto 90%.	Its overall efficiency is only 75%.
6.	It can be transported and erected easily as its various parts can be separated.	The transportation and erection is difficult.
7.	It is preferred for widely fluctuating loads.	It can also cope reasonably with sudden increase in load but for a shorter period.
8.	The direction of water circulation is well defined.	The water does not circulate in a definite direction.
9.	The operating cost is high.	The operating cost is less.
10.	The bursting chances are more.	The bursting chances are less.
11.	The bursting does not produce any destruction to the whole boiler.	The bursting produces greater risk to the damage of the property.
12.	It is used for large power plants.	It is not suitable for large plants.

➢ Low Pressure Boilers: (Locomotive Boiler):

- **Introduction**: It is a multi-tubular, horizontal, internally fired and mobile boiler. The principal of this boiler is to produce steam at a very high rate. A modern type of a locomotive boiler is showing in below figure-1:

- **Construction:** It consists of a shell having 1.5 metres diameter and 4 metres in length. The coal is feed into the fire box through the fire door and burns on grate. The flue gases from the grate are deflected by a brick arch, and thus whole of the fire box is properly heated. There are about 157 thin tubes or fire tubes F (47.5 mm diameter) and 24 thick or superheated tubes G (130 mm diameter). The flue gases after passing through these tubes enter a smoke box. The gases are then lead to atmosphere through a chimney. The barrel contains water around the tubes, which is heated up by the flue gases and gets converted into steam.

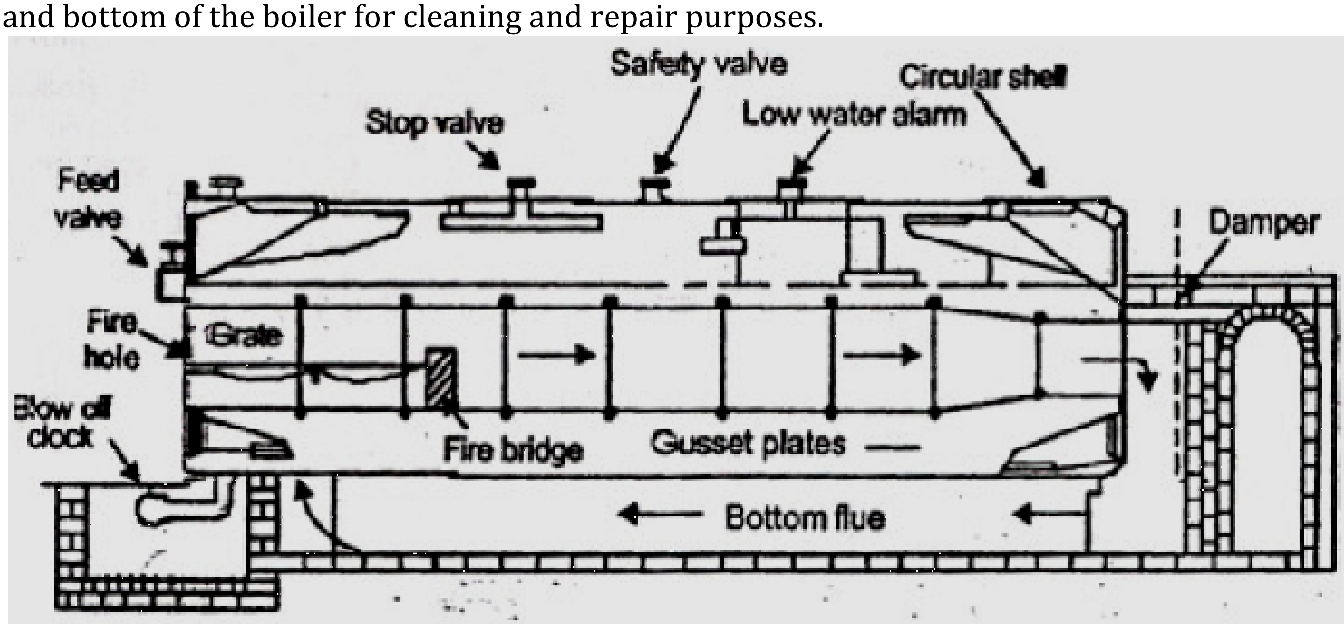
- **Working:** A stop valve as regulator is provided inside a cylindrical steam dome. This is operated by a regulator shaft from the engine room by a driver. The header is divided into two portions, one is the superheated steam chamber and the other is the saturated steam chamber. The steam pipe leads the steam from the regulator to the saturated steam chamber. It then leads the steam to the superheated tubes, and after passing through these tubes, the steam returns back to the superheated steam chamber. The superheated steam now flows through the steam pipe to the cylinder, one on each side. The draught is due to the exhaust steam from the cylinders, which is discharged through the exhaust pipe. The front door can be opened for cleaning or repairing the smoke box.

Lancashire Boiler

- **Introduction**: It is a stationary, fire tube, internally fired, horizontal and natural circulation boiler. It is used where working pressure and power required are moderate.

- **Construction:** These boilers have a cylindrical shell of 1.75 m to 2.75 m diameter. Its length varies from 7.25 m to 9 m. It has two internal flue tubes having diameter about 0.4 times that of shell. This type of boiler is set in brick work forming external flue so that part of the heating surface is on the external shell.

- **Working**: A Lancashire boiler with brick work setting is shown in below figure-2. This boiler consists of a long cylindrical external shell (1) built of steel plates, in sections riveted together. It has two large internal flue tubes (2). These are reduced in diameter at the back end to provide access to the lower part of the boiler. A fire grate (3) also called furnace, is provided at one end of the flue tubes on which solid fuel is burnt. At the end of the fire grate, there is a brick arch (5) to deflect the flue gases upwards. The hot flue gases, after leaving the internal flue tubes pass down to the bottom tube (6). These flue gases move to the front of the boiler where they divide and flow into the side flue (7). The flue gases then enter the main flue (9), which leads them to chimney. The damper (8) is fitted at the end of side flues to control the draught (i.e. rate of flow of air) and thus regulate the rate of generation of steam. These dampers are operated by chain passing over a pulley on the front of the boiler. A spring loaded safety valve (10) and a stop valve (11) are mounted as shown in Figure-2. The stop valve supplies steam to the engine as required. A high steam and low water safety valve (12) is also provided. A perforated feed pipe (14) controlled by a feed valve is used for feeding water uniformly. When the boiler is strongly heated, the steam generated carries a large quantity of water in the steam space, known as priming. An anti-priming pipe (15) is provided to separate out water as far as possible. The stop valve thus receives dry steam. A blow-off cock (16) removes mud, etc., that settles down at the bottom of the boiler, by forcing out some of the water. It is also used to empty water in the boiler, whenever required for inspection. Manholes are provided at the top and bottom of the boiler for cleaning and repair purposes.

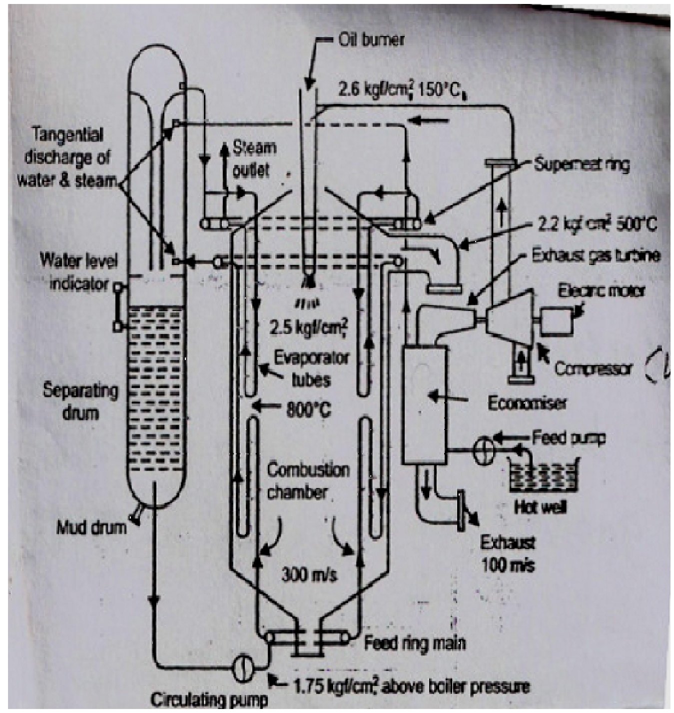


- **Velox Boiler**

  - **Introduction**: It is a fire tube boiler having forced circulation.

  - **Components**: It has a gas turbine, compressor, generator, feed pump, and circulating pump. Thus it is a compact steam generating plant.

  - **Working**: Boiler unit has a compressor supplying high pressure at about 3 bar into the oil burns so as to produce combustion products at high pressure and thus have hot flue gasses flowing through the fire tubes at a very high velocity of the order of supersonic velocity (of speed greater than the speed of sound in a given medium (especially air). Overall efficiency is about 55% to 60%. It is capable of handling 100 tons/hr water which is limited by limitation of maximum power requirement in compressor.



- **Boiler Mountings:** These are the fitting and devices which are necessary for the operation and safety of a boiler.

- **Boiler Accessories:** These are auxiliary plants required for steam boilers for the proper operation and for the increase of their efficiency.

- **Types of Mountings**:

  1. Safety valves
  2. Water level indicator
  3. A pressure gauge
  4. A steam stop valve
  5. A feed check valve
  6. A Fusible plug
  7. A blow-off cock

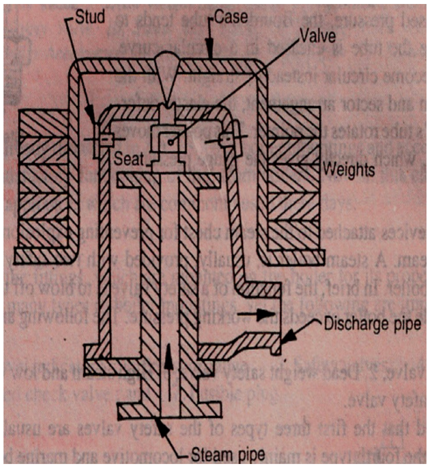
- **Types of Accessories**:

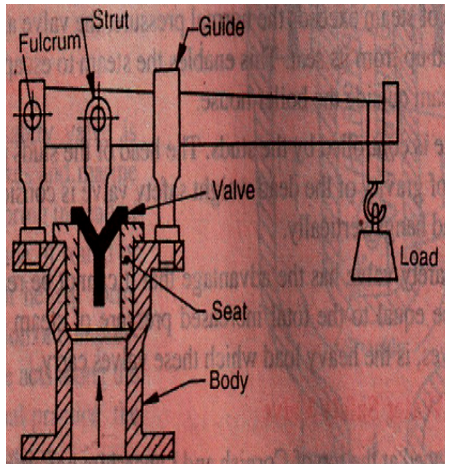
  1. Feed pumps
  2. Injector
  3. Economiser
  4. Air preheater
  5. Superheater
  6. Steam separator

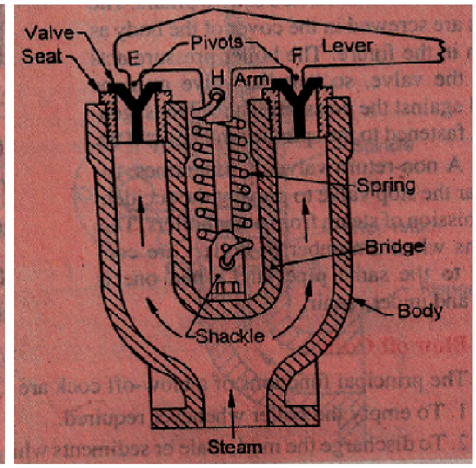
- **MOUNTINGS**:

  1. **Safety Valves**: It is use for release the excess steam when the pressure of steam inside the boiler exceeds the rated pressure. Types of safety valve are the following:

1. Dead weight safety valve
2. Lever safety valve
3. Spring loaded safety valve







2. **Water Level Indicator**: It is use to indicate the level of water in the boiler constantly.

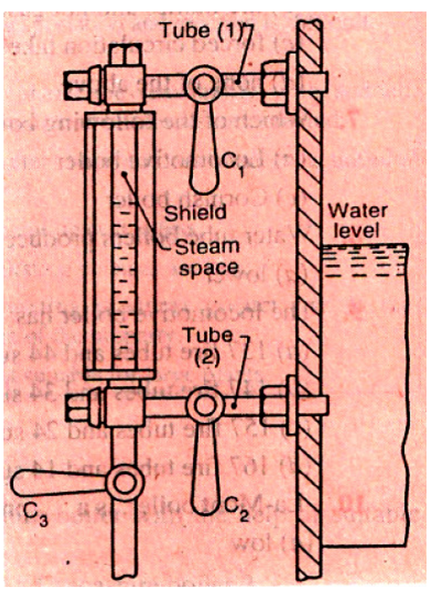
3. **Pressure Gauge**: It is use to measure the pressure exerted inside the vessel.

4. **Steam Stop Valve**: It is use to regulate the flow of steam from the boiler to the steam pipe.

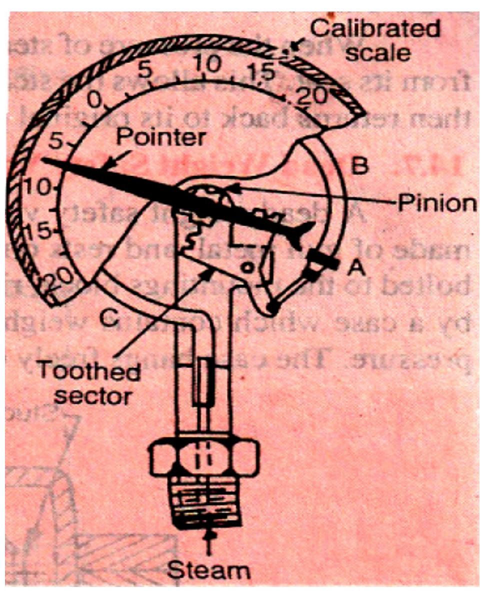
5. **Feed Check Valve:** It is use to control the supply the water to the boiler and to prevent the escaping of water from the boiler when the pump is stopped.

6. **Fusible Plug:** It is use to protect the boiler against damage due to overheating for low water level.

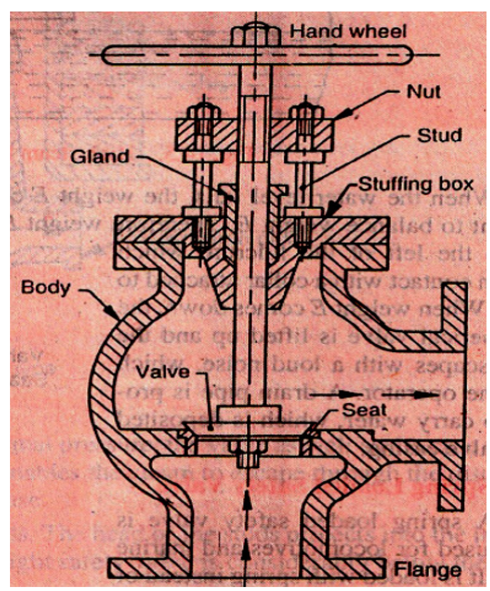
7. **Blow-Off Cock:** It is use to discharge a portion of water when the boiler is empty when necessary for cleaning, inspection, repair, mud, scale and sludge.



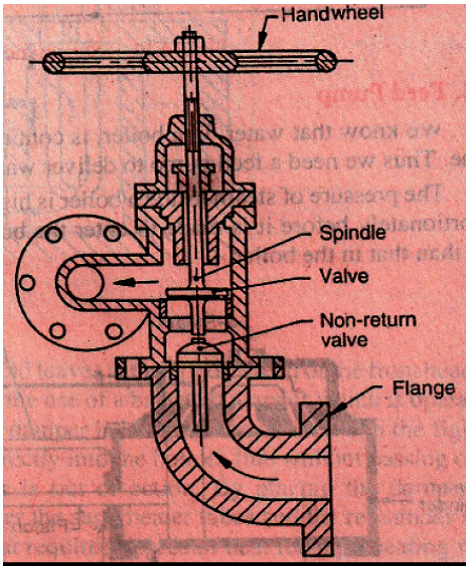
Water level indicator



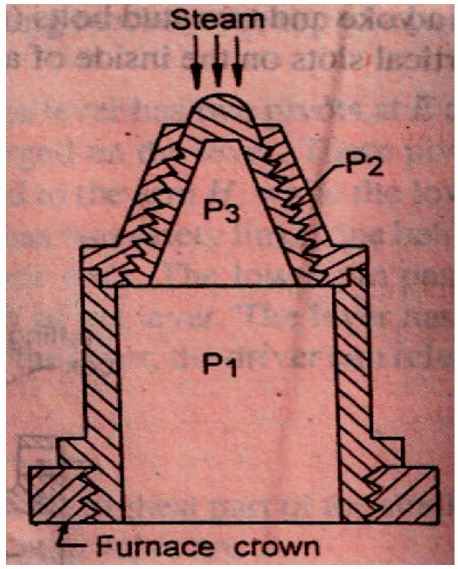
Pressure Gauge



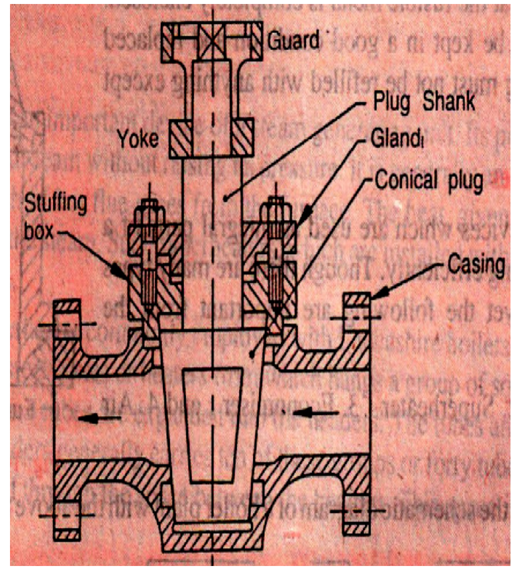
Steam Stop Valve



Feed Check Valve



Fusible Plug



Blow-off Cock

Accessories:

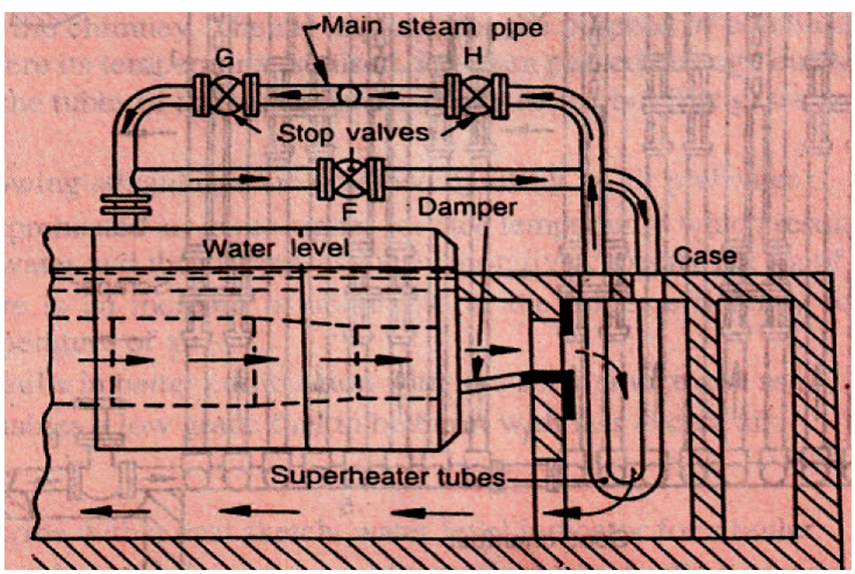
1. **Feed Pumps**: It is used to deliver feed water to the boiler by the pump.

2. **Injector**: The water is delivered to the boiler by steam pressure; The Kinetic energy of steam is used to increase the pressure and velocity of feed water.

3. **Economiser:** It is a device in which the waste heat of flue gases is utilized for heating the feed water.

4. **Air Preheater**: It is use to increase the temperature of air before it enters the furnace.

5. **Superheater:** It is use to increase the temperature of steam above it saturation point.



Superheater

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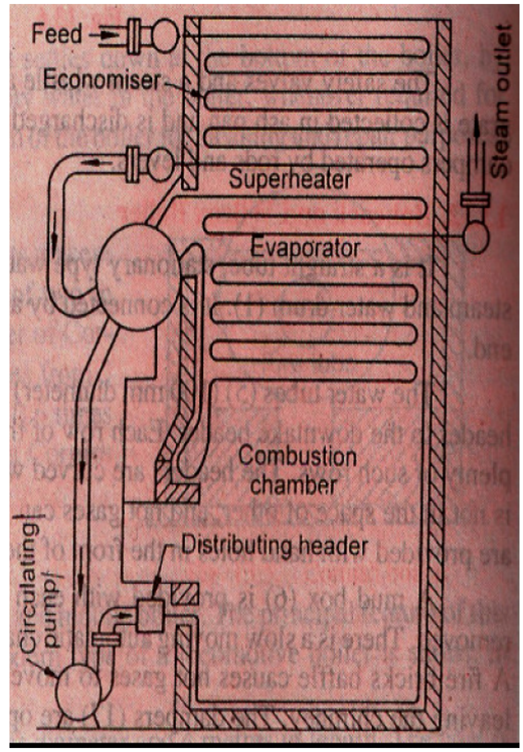
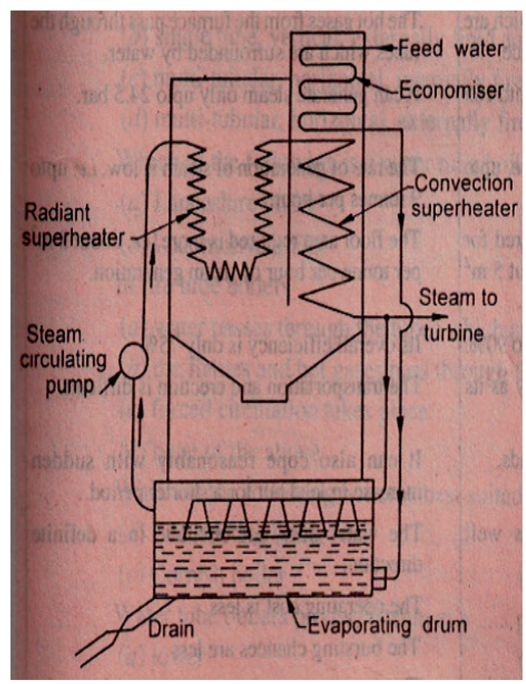
➢ High Pressure Boilers:

➢ La-Mont Boiler:



La-Mont boiler is a high pressure, water tube steam boiler working on a forced circulation. The circulation is maintained by a centrifugal pump, driven by a steam turbine, using steam from the boiler. The forced circulation causes the feed water to circulate through the water walls and drums. This prevents the tubes from being overheated. The feed water passes through the economiser to an evaporating drum. It is then dragged to the circulation pump through the tubes. The pump delivers the feed to the headers, at a pressure above the drum pressure. The header distributes water through nozzles into the generating tubes acting in parallel. The water and steam from these tubes passes into the drums. The Steam in the drum is then dragged through the superheater. And steam leaves the boiler via steam outlet passage with the help of steam stop valve which regulates the flow of steam which is discharged from the boiler to the steam turbine which is connected to the generator which produces the electricity with the help of many electrical circuits.

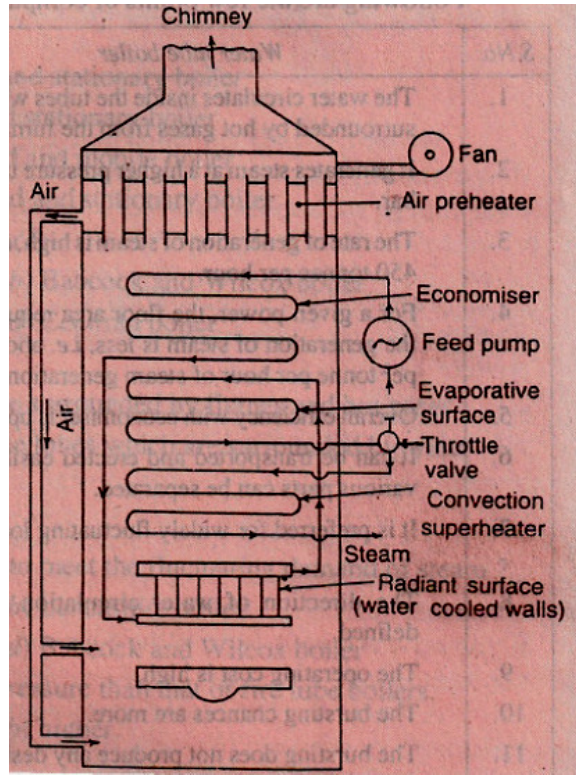
➢ Loeffler Boiler:



This is a water tube boiler using a forced circulation. Its main principle of working is to evaporate the feed water by means of superheated steam from the superheater. The hot gases from the furnace are used for superheating. The feed water from the economiser tubes is forced to mix with the superheated steam in the evaporating drum. The saturated steam, thus formed, is drawn from the evaporating drum by a steam circulating pump. This steam passes through the tubes of the combustion chamber walls and then enters the superheater. From the superheater, about one-third of the superheated steam passes to the turbine and the remaining two-third is used to evaporate the feed water in the evaporating drum. And then steam leaves the boiler via steam outlet passage with the help of steam stop valve which regulates the flow of steam which is discharged from the boiler to the steam turbine which is connected to the generator which produces the electricity with the help of many electrical circuits.

➢ Benson Boiler:

It is a high pressure drum less, water tube steam boiler using forced circulation. In this boiler, the feed water enters at one end and discharges superheated steam at the other end. The feed pump increases the pressure of water to supercritical pressure *(i.e.* above the critical pressure of 225 bar) and thus the water directly transforms into steam without boiling. The feed water passes through the economiser to the water cooled walls of the furnace. The water receives heat by radiation and the temperature rises to almost critical temperature. It then enters the evaporator and may get superheated to some degree. Finally, it is passed through the superheater to obtain desired superheated steam. The Benson boiler is also known as light-weight boiler as there is no large water and steam drum. The thermal efficiency upto 90 percent may be achieved by this boiler. The average operating pressure and capacity of such boilers are 250 bar and 135 tonnes/h. It can be started within 15 minutes.



➢ **Boiler Performance: Boiler trial:** The main objects of a boiler trial are:

1. To determine the generating capacity of the boiler.
2. To determine the thermal efficiency of the boiler when working at a definite pressure.
3. To prepare heat balance sheet for the boiler.

We have already discussed the first two objects in the previous articles. Now we shall discuss the third object, *i.e.* to prepare heat balance sheet.

Heat utilised in rasing steam per kg of fuel:

$m_e = m_s / m_f$

Heat utilised in rasing steam per kg of fuel

$= m_e (h_f + x\, h_{fg} - h_{f1})$

Where, m_e = mass of water actually evaporated per kg of fuel
m_s = total mass of water evaporated into steam in kg
m_f = mass of fuel used in kg
h_f = specific enthalpy of water in kJ/kg
h_{fg} = specific enthalpy of evaporation in kJ/kg
h_{f1} = specific enthalpy of steam in kJ/kg

Heat Losses in the Boiler: We know that the efficiency of a boiler is the ratio of heat utilised in producing steam to the heat liberated in the furnace. Also the heat utilised is always less than the heat liberated in the furnace. The difference of heat liberated in the furnace and heat utilised in producing steam is known as heat lost in the boiler. The loss of heat may be divided into various heads, but the following are important from the subject point of view:

1. **Heat lost in dry flue gases:**

Heat lost to dry flue gases per kg of fuel
$= m_g \times c_{pg} (t_g - t_b)$

Where, m_g = Mass of dry flue gases per kg of fuel,
c_{pg}: = Mean specific heat of dry flue gases,
t_g: = Temperature of flue gases leaving chimney, and
t_b= Temperature of boiler room.

- This loss is max. in a boiler.

2. **Heat lost in moisture present in the fuel:** It is assumed that the moisture is converted into superheated steam at atmospheric pressure (1.013 bar).

Heat lost in moisture present in the fuel

$= m_m (h_{sup} - h_b) = m_m [h_g + c_p (t_g - t) - h_b]$
$= m_m [2676 + c_p (t_g - 100) - h_b]$

……... [From steam tables, corresponding to 1.013 bar, h_g = 2676 kJ/kg and t = 100° C]

Where, m_m = Mass of moisture per kg of fuel,
c_p = Mean specific heat of superheated steam in flue gases, p
t_g = Temperature of flue gases leaving chimney,
t_b = Temperature of boiler room, and
h_b = Enthalpy of water at boiler room temperature.

3. **Heat lost to steam formed by combustion of hydrogen per kg of fuel**

Let H_2 = Mass of hydrogen present per kg of fuel.
Mass of steam formed = $9H_2$
Then the heat lost to steam per kg of fuel = $9H_2 [2676 + c_p (t_g - 100) - h_b]$

Note: Heat lost to steam and moisture per kg of fuel = $(9H_2 + m_m) [2676 + c_p (t_g - 100) - h_b]$

Where, m_m = mass of moisture per kg of fuel,
h_b = enthalpy of evaporation obtained from steam table at boiler temperature.

4. **Heat lost due to un-burnt carbon in ash pit**

The heat lost due to un-burnt carbon per kg of fuel = $m_1 \times C_1$

Where, m_1 = Mass of carbon in ash pit per kg of fuel
C_1 = Calorific value of carbon

5. **Heat lost due to incomplete combustion of carbon to carbon monoxide (CO)**

   This loss, generally, occurs in a boiler due to insufficient air supply.

   Heat lost due to incomplete combustion = = m_2 x C_2

   Where, m_2 = Mass of carbon monoxide in flue gas per kg of fuel
   C_2 = Calorific value of carbon monoxide

6. **Heat lost due to radiation:** There is no direct method for finding the heat lost due to radiation. This loss is calculated by subtracting the heat utilised in raising steam and heat losses from the heat supplied.

➢ **Heat Balance Sheet:** A heat balance sheet shows the complete account of heat supplied by I kg of dry fuel. And heat consumed. The heat supplied is mainly utilised for raising the steam and the remaining heat is lost. We know that heat utilised in raising steam per kg of fuel = $m_e (h - h_{f1})$. The heat balance sheet for a boiler trial per kg of fuel is drawn as below:

Heal supplied	KJ	Heat Consumed	KJ	%age
Heat supplied by 1kg of dry fuel	X	1. Heat utilisied in raising steam.	X_1	
		2. Heat lost in dry flue gases.	X_2	
		3. Heat lost in moisture in fuel.	X_3	
		4. Heat lost to steam by combustion of hydrogen.	X_4	
		5. Heat lost due to un-burnt carbon in ash pit.	X_5	
		6. Heat lost due to incomplete combustion.	X_6	
		7. Heat lot due to radiation, etc. (by difference)	$X - (x_1+x_2+x_3+x_4+x_5+x_6)$	
Total	X	Total	Y	100 %

Student Notes: ____

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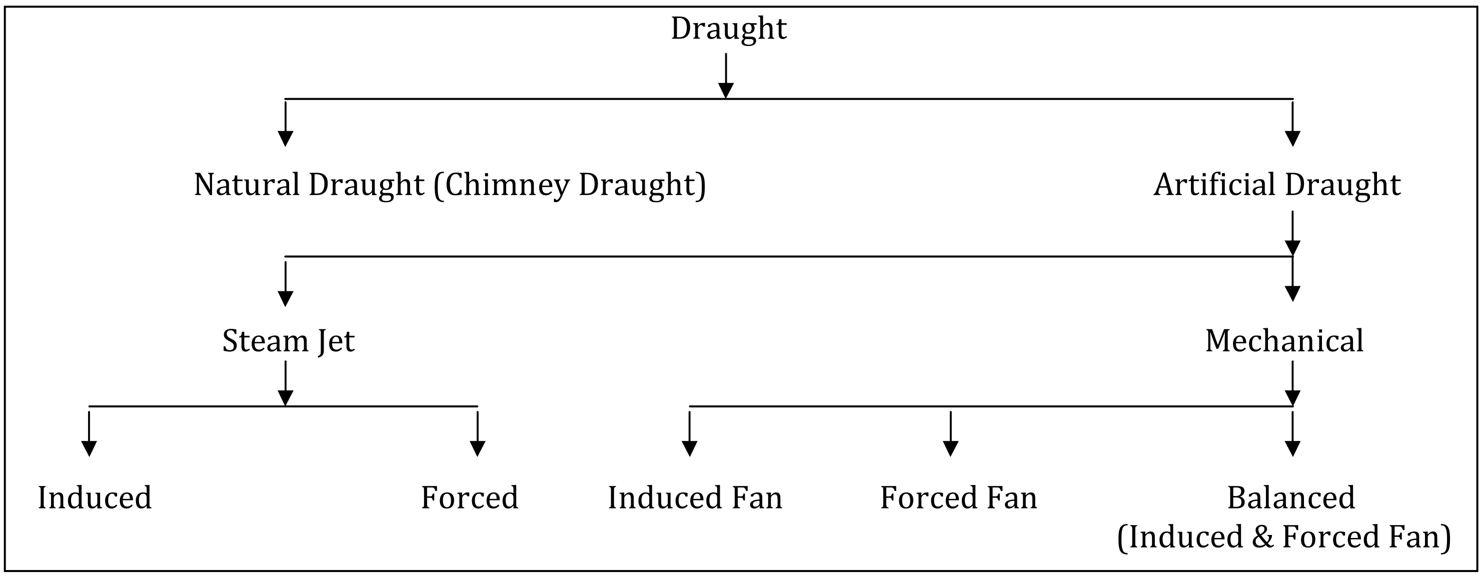
- **Boiler Draught**

  - **Draught**: The small pressure difference which cause a flow of gas to take place in the steam power plant.

  - **The main objects of producing draught in a boiler are:**

1. To provide an adequate supply of air for the fuel combustion
2. To exhaust the gases of combustion from the combustion chamber
3. To discharge these gases to the atmosphere through the chimney

- **Types of Boiler Draught:**



- **Chimney Draught:** The draught produced by means of a chimney alone is known as chimney draught. It is a natural draught and has self-induced effect. Since the atmospheric air (outside the chimney) is heavier than the hot gases (inside the chimney), the outside air will flow through the furnace into the chimney. It will push the hot gases to pass through the chimney. The chimney draught varies with climatic conditions, temperature of furnace gases and height of chimney.

- **Artificial Draught**: This draught produced by means of some external device which creates a pressure difference is known as artificial draught. It is not a self induced effect.

- **Steam Jet Artificial Draught**: In a steam jet draught, the exhaust steam, from a non-condensing steam engine, is used for producing draught. It is mostly used in locomotive boilers, where the exhaust steam from the engine cylinder is discharged through a blast pipe placed at the smoke box and below the chimney.

  - **Induced type**: In this type the steam jet issuing from a nozzle is placed in the chimney.

- **Forced type**: In this type the steam jet issuing from a nozzle is placed in the ash pit under me fire grate of the furnace.

➢ **Mechanical Type Artificial Draught**: The draught, produced by means of a fan or blower, is known as mechanical draught or fan draught. The fan used is, generally, of centrifugal type and is driven by an electric motor.

- **Induced Fan Draught**: a centrifugal fan is placed in the path of the flue gases before they enter the chimney. It draws the flue gases from the surface and forces them up through the chimney. The action of this type of draught is similar to that of the natural draught.

- **Forced Fan Draught**: The fan is placed before the grate, and air is forced into the grate through the closed ash pit.

- **Balanced Fan Draught**: It is an improved type of draught, and is a combination of induced and forced draught. It is produced by running both induced and forced draught fans simultaneously.

➢ **Height of Chimney**: We have already discussed that natural draught is produced by means of a chimney. Since the amount of draught depends upon the height of chimney, therefore its height should be such that it can produce a sufficient draught.

Let:

H = Height of chimney above the fire gate in meter.
h = Draught required in term of mm of water.
T_1 = Absolute temperature of air outside the chimney in K.
T_2 = Absolute temperature of flue gas inside the chimney in K.
V_1 = Volume of outside air at temperature T_1 in m3/kg of fuel.
V_2 = Volume of flue gases inside the chimney at temperature T_2 in m^3/kg of fuel.
m = mass of air actually used in kg/kg of fuel.
$m+1$ = mass of flue gases in kg per kg of fuel.

Let us find the volume of outside air per kg of fuel at N.T.P (i.e. Normal Temperature Pressure at 0 ^{0}C temperatures and 1.0313 bar pressure).

Let V_0 = volume of air at 0 ^{0}C
Absolute Temperature $T_0 = 0^0 + 273 = 273$ K
Atmospheric Pressure P_0 = 1.013 bar = 1.013 X 10^5 N/m^2 ($\therefore$ 1 bar = 10^5 N/m^2)

We know that $PV = mRT$

$V_0 = (mRT_0)/P_0$
$= (m \times 287 \times 273)/1.013 \times 10^5$
$= 0.773(m)$ m^3/kg of fuel ($\therefore$ for air, R = 287 J/kg K)

Volume of outside air at T1,

$V_1 = V_0 \times T_1/T_0$ ($\therefore$ $(V_0/T_0) = (V_1/T_1)$)

$= 0.773m \times T_1/273$
$= mT_1/ 353\ m^3/kg$ of fuel

Density of outside air at T1

$\rho_1 = m/(mT_1/353)$
$= 353/T_1\ kg/m^3$ ($\therefore$ Density = Mass/Volume)

$\therefore$ Pressure due to a similar column of outside (cold) air, P_1 = Density X height X g = $\rho_1 H g$
$= (353/T_1) \times H \times 9.81 = 3463H/T_1\ N/m^2$

According to Avogadro's law, the flue gas at N.T.P occupies the same volume as that of air used at N.T.P.

$\therefore$ Volume of flue gases at 0 ^{0}C = 0.773m m^3/kg of fuel

And Volume of flue gases at T_2; $V_2 = mT_2 / 353\ m^3/kg$ of fuel
Density of flue gases at T_2; $\rho_2 = (m+1)/(mT_2/353) = 353(m+1)/T_2(m)\ kg/m^3$

$\therefore$ Pressure due to column of hot gases at the base of chimney, P_2 = Density X height X g = $\rho_2 H g$
$= (353(m+1) \times H \times 9.81/T_2)$
$= 3463\ (m+1)\ H/T_1(m)\ N/m^2$

We know that the draught pressure is due to pressure difference b/w the hot column of gas in the chimney and a similar column of cold air outside the chimney. Therefore draught pressure,

$$P = P1 - P2 = \{ [3463H/T_1] - [3463\ (m+1)\ H/T_1(m)] \}\ N/m^2$$
$$= 3463\ H \{ (1/T_1) - ((m+1)/(mT_2) \}\ N/m^2 \qquad \ldots\ldots\ldots\ldots(1)$$

In actual practices, the draught pressure is expressed in mm of water as indicated by a manometer. Since 1 N/m^3 = 0.101937 mm of water, therefore

$$\boxed{h = 353\ H \{ (1/T_1) - ((m+1)/(mT_2) \}\ \text{mm of water}} \qquad \ldots\ldots\ldots\ldots(2)$$

The draught also expressed in the term of column of hot gas. If H' is the height in meter of the hot gas column which would produce the draught pressure P, then

$$P = \text{Density} \times H' \times g$$
$$= [353\ (m+1) \times H' \times 9.81] / mT_2$$
$$= [3463\ (m+1) \times H'] / mT_2\ \ N/m^2$$

Substitute this value in (1) equation, we get;

$$\boxed{H' = H \{ [(m/m+1) \times (T_2 / T_1)] - 1 \}} \qquad \ldots\ldots\ldots\ldots(3)$$

➢ **Chimney Efficiency**:

It is the ratio of the energy required to produce the artificial draught to the mechanical equivalent of extra heat carried away per kg of flue gases due to the natural draught.

Let H' = Height of the flue gas column or the artificial draught produced in meter.
T_2 = Temperature of flue gases in the chimney with the natural draught in K.
T = Temperature of flue gases in the chimney with the artificial draught in K.
C_p = Specific heat of flue gases in Kj/kg K. its value may be taken as 1.005 KJ/kg K.

We know that the energy required producing the artificial draught, per kg of flue gas
= H' g J/kg of flue gas

And extra heat carried away per kg of flue gas due to natural draught = 1 X Cp (T2 – T1) KJ/kg

Mechanical equivalent of extra heat carried away = 1000 Cp (T2 – T1) J/kg of flue gas

$$\text{Efficiency, } \eta = H' g / 1000\, C_p (T_2 - T_1)$$