Institute: Jnan Chandra Ghosh Polytechnic
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Topic : BOILERS, BOILER PARTS, & PERFORMANCE OF BOILERS.

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The equipment used for producing steam is called *steam generator* or *boiler*. The American Society of Mechanical Engineers (A.S.M.E.) gives the following definition of the steam generating unit :

"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 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.

This chapter is devoted to the study of the constructinal and operational features of the boilers and the associated mountings and accessories.

14.1. CLASSIFICATION OF BOILERS

Boilers are mainly classified according to the following :

1. *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 (Fig. 14.1)

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 (Fig. 14.2).

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.

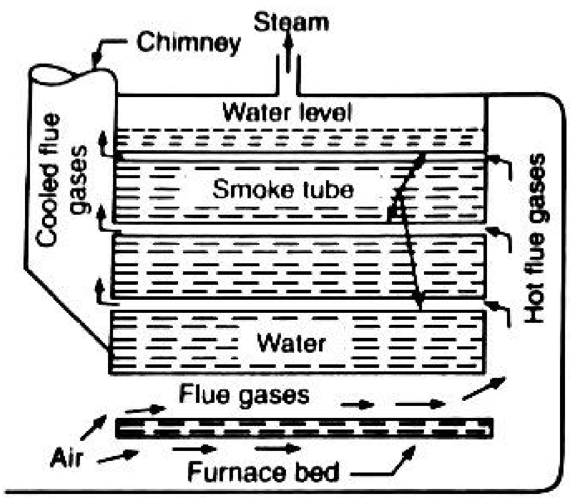

Fig. 14.1. Principle of fire tube boiler

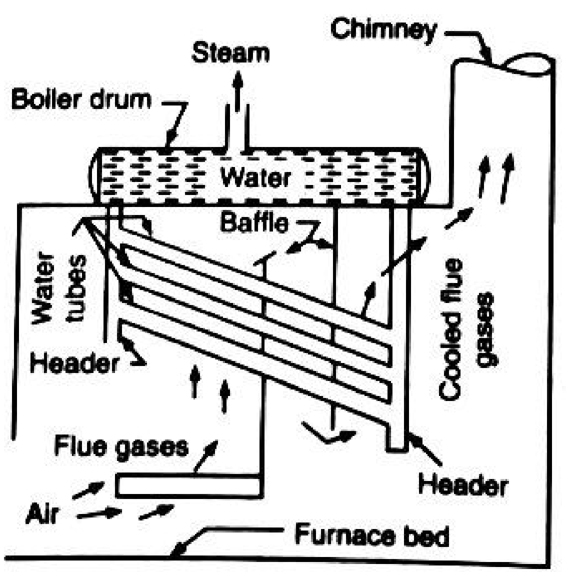

Fig. 14.2. Principle of water tube boiler

2. *Method of Firing*

(*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 as 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. The distinction between internally fired and externally fired boiler is illustrated in Fig. 14.3.

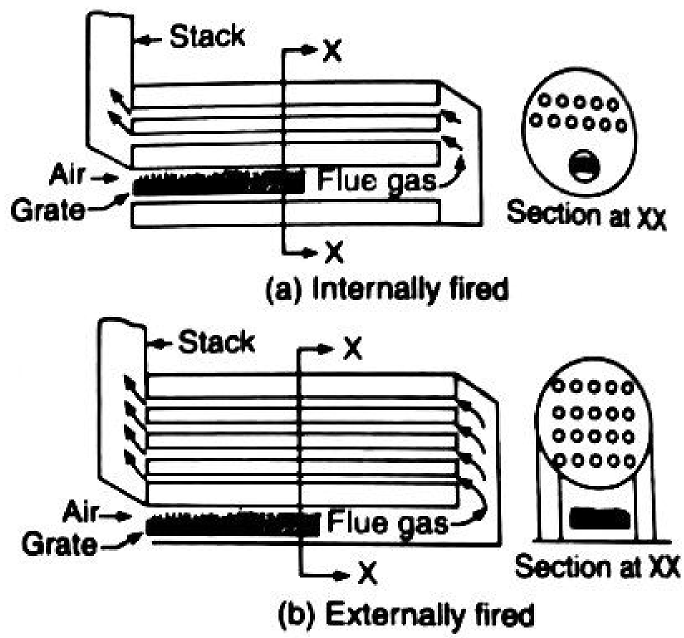

Fig. 14.3. Distinction between internally fired and externally fired boiler

3. *Pressure of steam* : Boilers producing steam at a pressure of 80 bar 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 bar are called low pressure boilers. Examples are Cochran, Cornish, Lancashire and Locomotive boilers.

4. *Method of circulatian 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. For effective circulation, pump (forced) circulation is employed in place of natural circulation. Forced circulation is also sometimes employed at low pressures to give freedom in tube layout.

5. *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.*

6. *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.

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

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

9. *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.

10. *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

11. *Fluid used* : The boilers are classified as steam boilers using water as fluid, mercury boilers using mercury as fluid, and the boilers which are used for heating special chemicals.

12. *Material of construction of boiler shell* : Depending upon the material used for the construction of boiler shell, we classify the boilers 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.

14.2. FIRE TUBE BOILERS

These boilers essentially consist of one or more fire tubes passing through a cylindrical shell which may be horizontal or vertical and is filled to at least half of its volume with water.

(*A*) Cochran Boiler

Simple vertical boilers of the fire tube type find favour in small plants requiring small quantities of steam and where the floor area is limited. The most common applications are steam rollers, pile drivers, steam shovells, portable hoisting rigs and certain other mobile applications.

Cochran boiler, illustrated in Fig. 14.4, provides an excellent example of the improved design of vertical, multitubular, internally fired natural circulation boiler.

The Cochran boiler essentially consists of :

(*i*) Boiler shell with hemispherical crown,

(*ii*) Furnace, fire box and grate,

(*iii*) Combustion chamber and flue pipes,

(*iv*) Smoke box and chimney, and

(*v*) Connections for boiler mounting and accessories.

Constructional and operational details

The unit consists of a cylindrical shell with a dome shaped top where the space is provided for steam. The shell is formed of steel plates joined together with the rivets. Both the circumferential and longitudinal joints are lap joints made steam tight by fullering or caulking operation. The fuel is burnt on grate in the furnace provided at the bottommost part of boiler. The furnace has no riveted seams exposed to flame and is pressed hydraulically from one plate to finished shape. This makes the furnace suitable to resist the intense heat produced by the combustion of fuel. The grate consists of iron bars which are arranged with spacing between them. The spacing allows the air to pass onto the fuel for combustion. The firebox is hemispherical so that the unburnt fuel, if any, is deflected back to the grate and

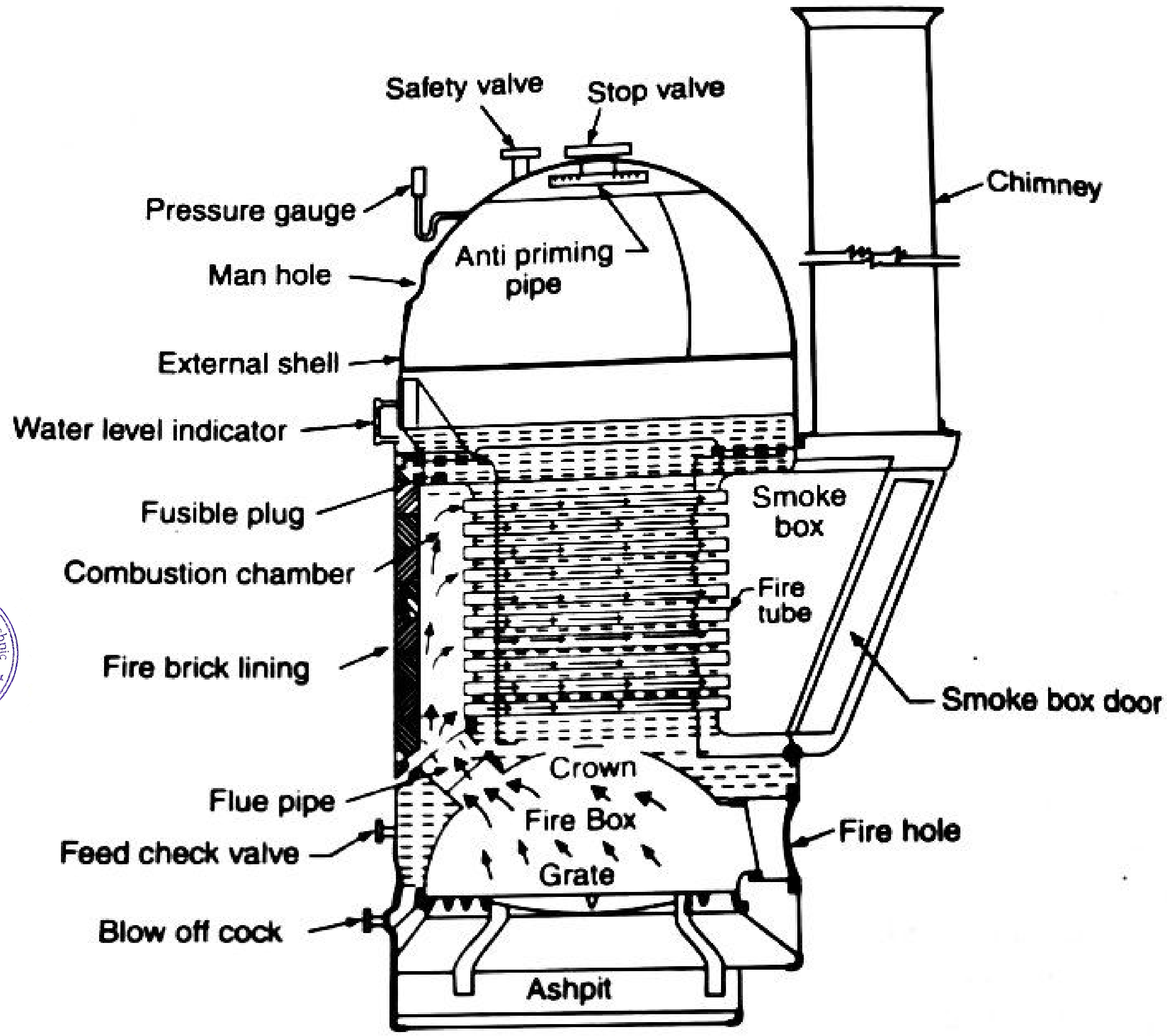

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Fig. 14.4. Cochran boiler

complete combustion is achieved. An ash pit is attached beneath the furnace for collecting ash after regular intervals. The boiler can be arranged to burn almost any kind of fuel including wood, paddy husk and oil fuel. For operation as an oil fired unit, an oil burner is fitted at the fire hole. The grate is then dispensed with and a lining of fire brick is provided beneath the furnace.

The coal, on burning, produces hot flue gases and these hot products of combustion from the fire box enter through the small flue pipe into the combustion chamber which is lined with fire bricks on the outer wall of the boiler. The lining prevents the shell from being damaged due to the overheating.

The dome shaped furnace and the combustion chamber prevent the loss which could otherwise occur because of combustion being retarded and much unburnt and combustible matter leaving the furnace. The unburnt fuel is deflected back to the grate and complete combustion is achieved in combustion chamber where the high temperatures are maintained.

The hot gases passing through the horizontal smoke tubes give their heat to the water and in doing so convert water into steam which gets accumulated in the upper portion of the shell from where it can be supplied to the user. The flue tubes are generally of 65.5 mm external diameter and are 165 in number. The crown of the shell is made hemispherical in shape which gives the maximum space and strength for a certain weight of material in form of plates.

Finally the flue gases are discharged to the atmosphere through the smoke box and the chimney. The smoke box door enables the cleaning and inspection of the smoke box and fire tubes. Through a manhole provided at the crown of the shell, a man can enter the boiler for periodic cleaning and maintenance of the boiler. There are connections provided at appropriate places for fixing the usual boiler mounting such as pressure gauge, water level indicator, safety valve, steam stop valve, feed check valve and blow off cock etc.

Typical specifications of Cochran boiler are :

Size = 1 m diameter × 2 m high (evaporation 20 kg/hr)

= 3 m diameter × 6 m high (evaporation 3000 kg/hr)

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Heating surface = 10 to 25 times grate area

Steam pressure = upto 20 bar

Efficiency = 70 to 75%

The Cochran boiler is compact in design and there is good external and internal accessibility.

14.3. WATER TUBE BOILERS

Among the water tube boilers, Babcock and Wilcox boiler and Stirling boiler are the most common type used in thermal power houses for generation of steam in large quantities.

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(A) Babcock and Wilcox Boiler

This is a horizontal, externally fired, water tube, natural circulation type of stationary boiler.

Constructional features : The salient aspects of the constructional features of the Babcock and Wilcox boiler have been shown in Fig. 14.7.

(*i*) It consists of a welded steel high pressure drum mounted at the top. From each end of drum connections are made with the uptake header and a down take header. The headers are joined to each other by a large number of tubes which are kept inclined at an angle of about 15° to the horizontal. The water tubes are straight, solid drawn steel tubes about 10 cm in diameter and are expanded into the bored holes of the headers. Due to serpentine (sinusoidal) form of headers, the tubes are staggered and this exposes the complete heating surface to flue gases.

(*ii*) The furnace is arranged below the uptake header. The unit has a grate for fuel burning, provided with a chain gate stoker. The coal is fed to the chain gate stoker through the fire door. The chain speed is so adjusted that by the time coal reaches the other end of the grate, its combustion has been complete. The residual ash falls into the ashpit.

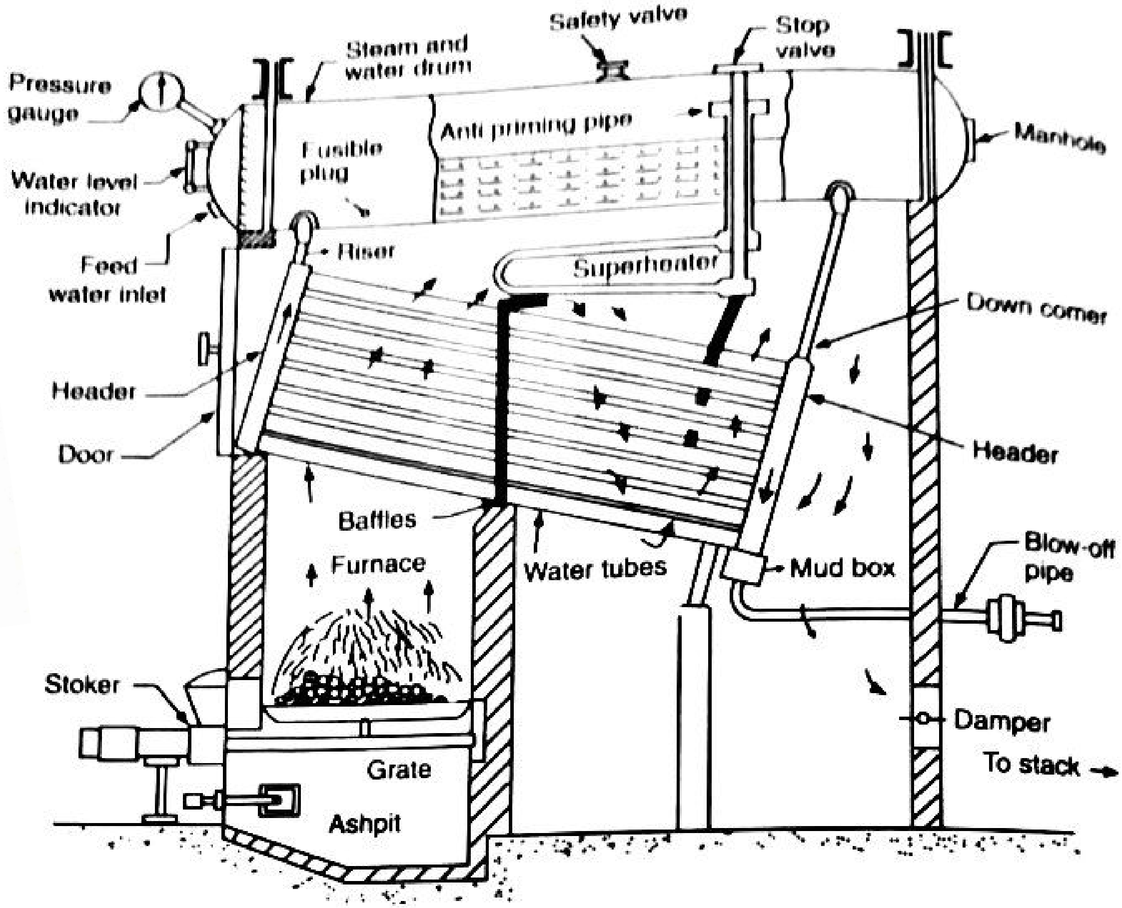

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Fig. 14.7. Babcock and Wilcox boiler

(*iii*) Baffles are provided across the water tubes to act as deflectors to the flue gases and to provide them with gas passes.

(*iv*) At the bottom of the rear header is the mud box. The foreign matter held in suspension in water gets collected in it and can be blown off from time to time. The access to the interior of boiler is provided by the doors. This is necessary to clean the tubes and remove the soot. The draught is regulated by a damper which is provided in the back chamber.

(*v*) For getting the superheated steam, the unit is fitted with superheater tubes which are arranged in the combustion chamber above the water tubes.

Vents are also provided for mountings and accessories such as safety valve, pressure gauge, water level indicator, fusible plug and feed check valve etc.

The entire assembly of water tubes is hung along with the drum from steel girder frame by steel rods called slings in a room made of masonry brick lined with fire bricks.

Working : The boiler drum shell is filled with water through feed valve and a constant water level is maintained upto about 2/3rd part in the shell. The water from the drum flows through inclined tubes via downtake header and then goes back into the shell in the form of water and steam via uptake header. Obviously the circulation of water is maintained by convective currents. The hottest water and steam rise from the tubes to the uptake header and then through riser enter the boiler drum. The steam vapours escape through water to the upper half of the drum. The cold water flows from the drum to the rear header and that completes the water circuit.

The hot combustion gases produced by burning fuel on the grate rise upwards up to the water drum and then downwards. They again move upwards and downwards between the baffles. Baffle plates make the hot gases move in such a way that a longer contact time is maintained between hot gases and inclined water tubes. During their travel, the gases give their heat to water and steam is formed. Finally, the hot gases escape to chimney through the smoke chamber.

The steam collected in the water drum is next led to the superheater tubes via antipriming pipe. Since the superheater tubes are exposed to hot gases, the steam passing through them gets superheated. When steam is raised from cold boiler, the superheater should be flooded (filled with water) to avoid its burning. The superheated steam is finally taken out through the stop valve and supplied to the engine when needed.

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Capacity and utility : Evaporative capacity of such boilers ranges from 20,000 to 40,000 kg/hr and operating pressures from 11.5 to 17.5 bar are quite common. The steam from such boilers is primarily used to run steam turbines and generate electric power.

Salient aspects : The notable aspects of Babcock and Wilcox boiler in the context of merits and demerits are :

(*i*) The unit has the capability to quickly cope with high peak loads which are generally needed at thermal power stations.

(*ii*) The inspection of the boiler can be carried even when the boiler is in operation.

(*iii*) Draught loss is minimum.

(*iv*) The replacement of defective tubes can be made readily.

Further, since the boiler unit (except furnace) is suspended, any expansion or contraction of the boiler has no harmful effects on the masonry work enclosing the furnace and the boiler.

14.4. COMPARISON BETWEEN WATER TUBE AND FIRE TUBE BOILER

The salient points of each are enumerated below:

1. The two types differ from each other with regard to the manner or order of conducting hot flue gases and the water. Fire tube boilers have products of combustion passing through tubes which are immersed in water. In water tube boilers the flue gases surround the tubes through which the fluid flows under pressure.

2. Fire tube boilers have large ratio of water content to steam capacity. Larger water capacity makes the boiler slow in reaching the operating pressure and less immune to failure in any feed water arrangement.

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Comparatively small ratio of water content to steam capacity helps in reaching the steaming temperature in short time but any failure in feed water supply is liable to make the boiler overheated.

3. Because of simple and rigid construction, the fire tube boilers have greater reliability and are low in first cost. These boilers require skill for economical and efficient operation.

Complexity in design of water tube boiler requires periodic examination by skilled hands.

4. Large diameter of shell (2-4 m), limit of maximum thickness of 30 mm and stress considerations (maximum 12 kN/m^2) limit the pressure range from 17.5 bar (Lancashire boiler) and 24.5 bar (Economic boiler). Evaporative rate of these fire tube boilers is also limited to 900 kg/hour.

Because of small drum diameters, the water tube boilers can withstand high internal pressures for the same wall thickness and stress. These boilers can operate up to pressure as high as 200 bar and have wide ranges in capacity. Boiling temperature at 200 bar is about 640 K. Good carbon steel can safely stand this temperature and still keep the stresses within the limits of 8 kN/m^2.

5. With water contained in a large number of small tubes in a water tube boiler, the heating surface area is increased and evaporation rate is considerably enhanced. All large power plants use water tube boilers.

Slow rate of steam generation renders the fire tube boilers unsuitable for use in steam power plants.

6. Circulation is more positive in water tube boilers and as such there is less tendency of the deposits to settle on the heated surfaces. This positive circulation also helps in quick steam raising. However, with high pressures and high temperatures in water tube boilers, the use of pure feed water becomes essential.

7. Due to large cylindrical drums of fire tube boiler, there is ample water surface from which the steam can be quickly raised. Simple antipriming devices serve the purpose very well.

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14.7. BOILER MOUNTINGS AND ACCESSORIES

For efficient operation and maintenance of safety, the boilers are equipped with two categories of components or elements.

First category includes the fittings which are primarily intended for the safety of the boiler and for complete control of the process of steam generation. These units are called *boiler mountings*. The mountings form an integral part of the boiler and are mounted on the body of the boiler itself. In accordance with Indian Boiler Regulations, the following mountings are usually installed on the boiler.

(1) Two safety valves

(2) Two water level indicators

(3) Pressure gauge

(4) Fusible plug

(5) Steam stop valve

(6) Feed check valve

(7) Blow-off cock

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(8) Man and mud holes

Out of the above mentioned mountings, safety valve, water level indicator and fusible plug are called *safety fittings* and the remaining are the *control fittings*.

Second category includes the components which are installed to increase the efficiency of the steam power plant and help in the proper working of the boiler unit. These fittings are called *boiler accessories*. Usually a boiler has the following accessories attached to it.

(1) Air preheater

(2) Economiser

(3) Superheater

(4) Feed pump

(5) Injector

(6) Steam separator and steam trap

Some of the above mentioned boiler mountings and accessories are discussed in the following sections with particular reference to their function, location, construction and operation.

(A) Safety Valves

Function : The function of the safety valve is to permit the steam in the boiler to escape to atmosphere when pressure in the steam space exceeds a certain specified limit. Thus the safety valve prevents the building up of excessive pressure in the boiler.

As per Boiler Regulations, each boiler must be fitted atleast with two safety valves.

Location : The safety valve is located above the steam space in the boiler.

The safety valves operate on the principle that a valve is pressed against its seat through some agency such as strut, screw or spring by external weights or force. When the steam force due to boiler pressure acting under the valve exceeds the external force, the valve gets lifted off its seat and some of the steam rushes out until normal pressure is restored again.

The commonly used safety valves are described below :

(i) Dead weight safety valve

Construction and operation : The unit consists of a vertical steel pipe the flange of

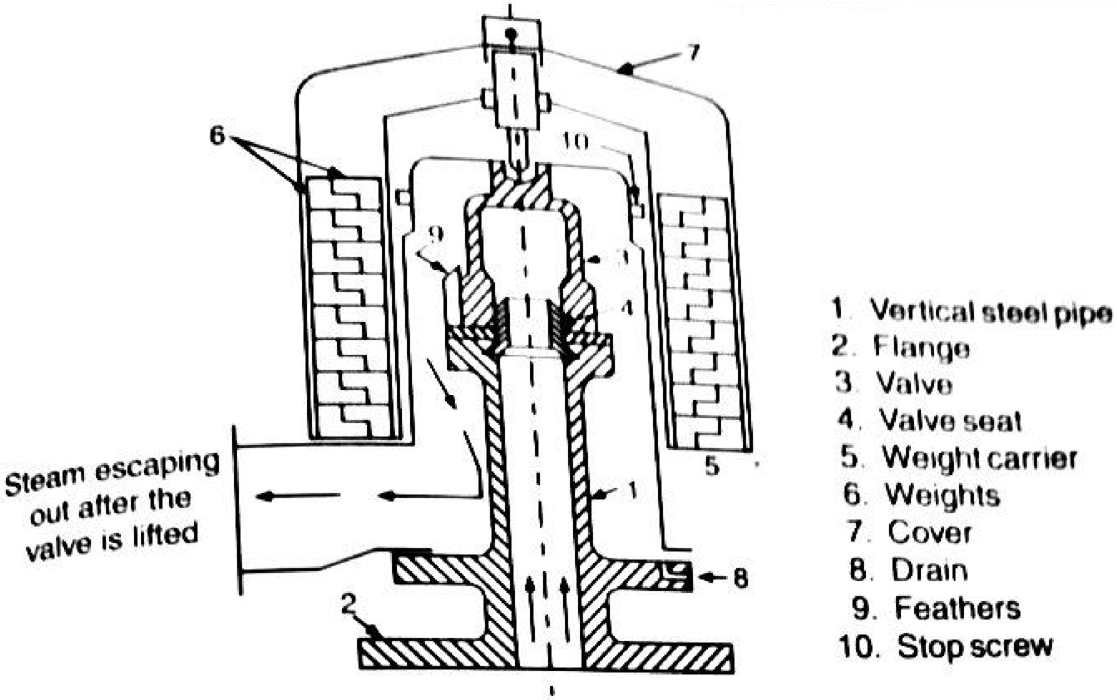


Fig. 14.9. Dead weight safety valve

which is bolted to a mounting block on the boiler shell. The gun metal valve rests on the gun metal valve seat which has been screwed to the top of the vertical pipe. A carrier on casting suspended from the top of the valve acts as a weight carrier. The dead weights consisting of cast iron rings are placed on the weight carrier. These weights are surrounded by a cast iron cover which is attached to the weight carrier. This is necessary to protect the weights from being tampered with.

Under normal working conditions the upward force exerted by steam in the boiler is balanced by the downward force equivalent to the total weights on the valve. The downward weight includes the weight of the carrier, weight of the ring, weights and the weight of the cover. With the increase in pressure beyond a certain permissible limit, the valve along with the weight carrier is lifted off its seat. The steam then escapes through the discharge pipe.

The steam which gets condensed when passing through the valve is drained by a drain pipe connected to the bottom. The feather guides the movement of the valve and the stop screw fittings on the discharge casing prevent the blowing away of the valve and the weight carrier, in case the steam pressure becomes too high.

For the valve in equilibrium position,

$$W = \frac{\pi}{4} d^2 p$$

where p is the steam pressure and d is the diameter of the valve. The total downward weight W calculated above is equivalent to

W = weight of valve + weight of cover + weight of carrier + dead weights mounted

Merits and demerits :

- Simplicity of design and construction.
- Reliable with regard to satisfactory performance during operation.
- Safe from the possibility of any tempering in the context of pressure adjustment.

However the dead weight safety valves are unsuitable for boilers which are non-stationary. It is because in portable boilers, there is the danger of weights being displaced. Moreover there occurs a reduction in the effective weights when the moving unit is negotiating a slope. Further its use is restricted only to low pressure boilers because the high pressure boilers would necessitate very heavy weights to balance the steam pressure.

(*B*) Water Level Indicator

Function **:** The function of the water level indicator is to ascertain constantly and exactly the level of water in the boiler shell.

Location **:** The water level indicator, also called water gauge, is fitted in the front of the boiler from where it is easily visible to the operator. The top of the mounting is connected with steam space and the bottom with water space.

Construction and operation **:** The unit (Fig. 14.13) consists of a strong glass tube whose ends pass through stuffing boxes in the gun metal castings having flanges at the ends. The stuffing boxes consist of heat resisting rubber packings to prevent leakage of steam and water. The flanges are bolted to front end plate of the boiler, the upper flange being fitted to the steam space and the lower to water space in the boiler. There are two cocks namely steam cock and water cock which communicate the boiler shell spaces to the gauge glass tube. When the handle of the cocks are vertical, they are in operation and the water level in the tube corresponds to water level in the shell. A red mark on the glass tube indicates the safe water level.

The unit has an automatic arrangement to shut off the steam and water supply to the glass tube in case the tube gets broken. For this purpose a hollow metal tube is connected between the upper and lower gun metal castings. Under normal operating conditions the balls are in position as shown in Fig. 14.13. When the glass tube breaks the rush of steam in the upper casting carries the ball to fit into the opening. As such no steam escapes to the glass tube. Similarly the ball in the lower casing closes the water opening and prevents the flow of water to the glass tube. Now the cocks can be closed for repairs and the replacement of the gauge glass is made.

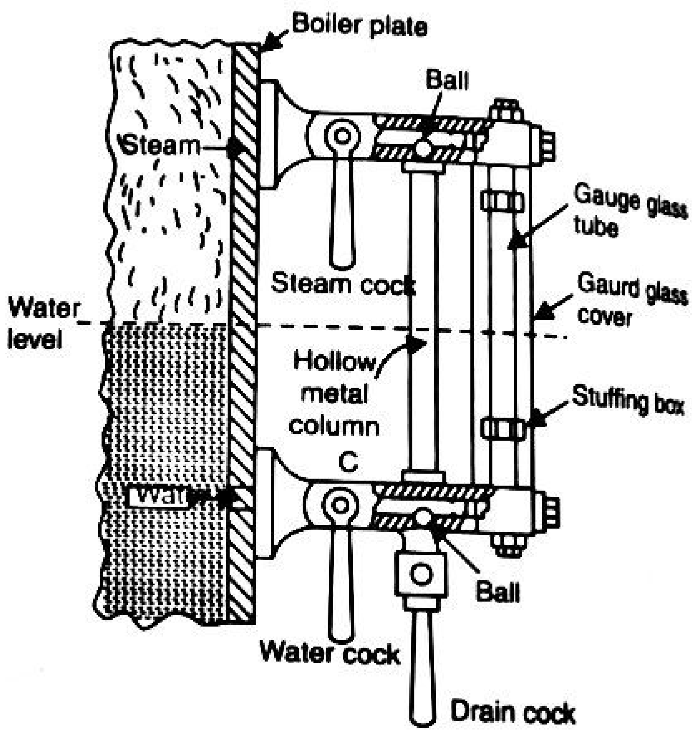


Fig. 14.13. Water level indicator

The draincock serves to blow out water at regular intervals so that there is no accumulation of sediments and foreign deposits. When closed, the handle of the cock is kept in vertical position. The various screw plugs provide access to different passages for cleaning purposes.

The protection from the flying glass pieces in the event of breakage of the tube is provided by enclosing the glass tube by a thick guard glass cover. Usually the boilers are provided with two water level indicators, one placed on each side of the boiler shell.

(C) Fusible Plug

Function : The function of the fusible plug is to extinguish the fire in the event of water level in the boiler shell falling below a certain specified limit. We know that when the water on heating transforms into steam, the level of water in the boiler falls down. If the water is not replenished and the steam generation continues then the parts which have been uncovered by water may get overheated and subsequently get melted. To safeguard against this eventuality we use fusible plug.

Location : The fusible plug is inserted at the box crown or over the combustion chamber at the lowest permissible water level.

Construction and operation : The unit (Fig. 14.14) comprises three plugs A, B and C. The hollow gun metal A having hexagonal flanges is screwed to a fire box crown plate.

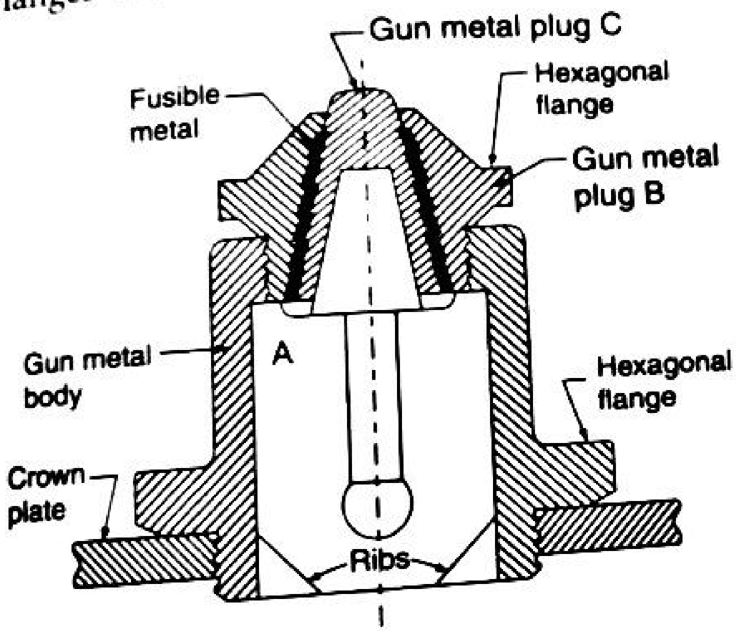


Fig. 14.14. Fusible plug

The plug B, also made of gun metal is screwed into plug A and the plug C is locked to plug B by a metal like tin or lead which has a low fusing point. The plug C is made of copper and has a conical top and round bottom.

When the boiler is operating under normal conditions, the fusible plug is covered with water and the temperature of fusible metal is below its melting point. However, when the water level falls below a certain limit, the plug gets uncovered from water and is then exposed to steam. This overheats the plug, with the result that the fusible metal melts and the plug C falls. This makes a passage and the water steam mixture rushes into the furnace and the fire is extinguished. The ribs cast integral with gun metal body A hold the falling copper plug C and prevent its falling into the combustion chamber.

Before refiring the boiler, the operator either inserts a new plug or the same plug after doing necessary repairs.

Since the plug is subjected to heat on one side and scale deposits on the other side, it is likely to become defective. So during normal running operations, the plug is usually replaced after every two to three years service.

(D) Pressure Gauge

Function : Each boiler has to be provided with a pressure gauge which records the pressure at which the steam is being generated in the boiler.

Location : The gauge is usually mounted at the front top of the boiler shell or drum. The gauge has to be clearly visible to the attendant so that he can easily record the pressure reading.

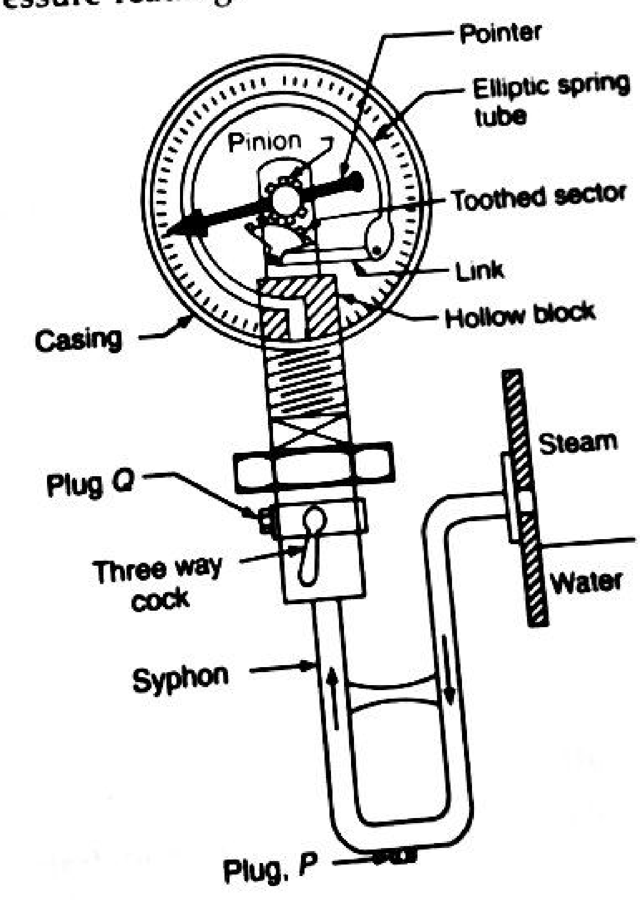


Fig. 14.15. Pressure gauge

Construction and operation : The most important pressure sensing element of Bourden's pressure gauge (Fig. 14.15) is the elliptic spring tube called Bourden tube. This tube is made of a special quality of phosphor bronze and is solid drawn. One end of this tube is closed by a plug and the other end is secured firmly to a hollow block which forms passage for steam. This block is in communication with the steam space of the boiler through a syphon. The U-shaped syphon contains condensed water and the water also fills the spring tube. When the pressure of steam is applied to the interior of the bourden tube, it has a tendency to assume a circular shape. In doing so it causes pull on the link which operates the toothed sector. The link mechanism is designed in such a way that a slight movement of the link is magnified considerably and the pointer gives a maximum deflection which can be easily read on the graduated scale.

It may be pointed out that the gauge records only the pressure difference between the steam and that of atmosphere. In order to get the absolute value the atmospheric pressure ($\simeq$ 1.033 bar) has to be added to the pressure value being shown by the gauge.

The water in the syphon prevents the steam from entering into the spring tube and thus the tube remains comparatively cool. If the steam is allowed to come into contact with the gauge tube, it would overheat the tube causing it to expand and this would affect the accuracy of the gauge. The accuracy of the pressure gauge during working of the boiler can be tested by connecting the inspector's steam pressure test gauge to the plug Q. By means of a three way cock, the pressure of steam in the boiler can be communicated either to pressure gauge or the plug Q.

A plug P is provided for cleaning the syphon.

(E) Blow off Cock

Function : The blow off cock serves to drain out the water from the boiler periodically for any one of the following reasons:

(*i*) to discharge mud, scale and other impurities which settle down at the bottom of the boiler.

(*ii*) to empty the boiler for internal cleaning and inspection.

(*iii*) to lower the water level rapidly if the level becomes too high.

Location : The unit is fitted at the lowest portion of the boiler. It may be mounted directly to the boiler shell or through an elbow pipe which is fitted to the boiler shell.

Construction and operation : The unit (Fig. 14.16) comprises a gun metal plug having a hole or slot in it. The casing, sometimes called shell, is bored to receive the plug.

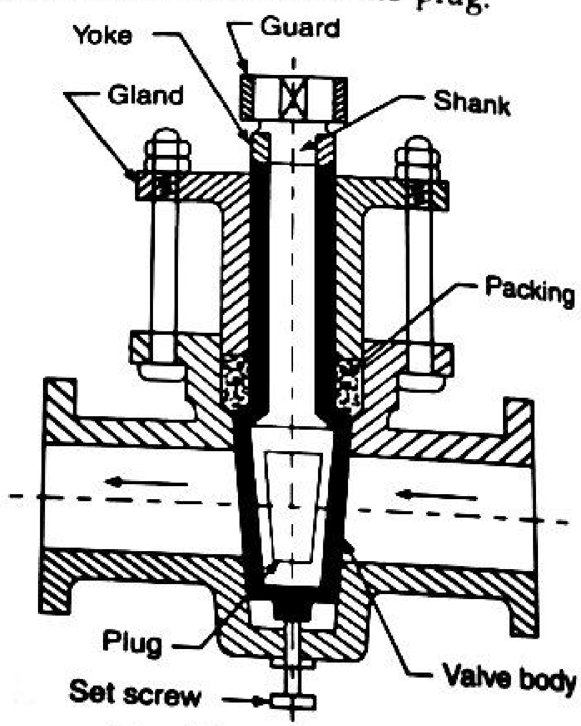


Fig. 14.16. Blow off cock

The shell is provided with two flanges, one of the flanges is connected to the boiler and the other flange is connected to a pipe which takes the blow off water out of the boiler house. The shank of the plug passes through glands and stuffing boxes. Packing and glands have to be provided so as to make the valve leak proof when the boiler is steaming.

To discharge water, the plug is rotated so that the slot made in the plug comes in line with inlet and outlet duct. In the off position the hole is at right angles to the direction of flow. This brings the solid portion of the valve in front of duct and this prevents the flow.

A set screw provided at the bottom of the plug is used to force the plug off its seat in case it gets jammed. The yoke provided at the top has two vertical slots in which the projections of the spanner, used for operating the valve, can fit. The guard prevents the spanner from being removed when the cock is in open position. This avoids the possibility of damage which may occur to the boiler by draining out water.

When it is required to take the discharge from more than one boiler through the same discharge pipe, an isolating valve has to be fitted in between the boilers. This valve is necessary to prevent the discharge of one boiler rushing into the other.

(F) Feed Check Valve

Function : The feed check valve has the following two functions to perform:

(*i*) to allow the feed water to pass into the boiler.

(*ii*) to prevent the back flow of water from the boiler in the event of the failure of the feed pump.

Location : The valve is installed between the feed pump and the water space of the boiler shell.

Construction and operation : The unit (Fig. 14.17) comprises two valves-valve V_1 called the *feed valve* and the valve V_2 known as *check valve*. The check valve allows the water to flow in one direction only and that too from the feed pump side to the boiler side. When the feed pump is working properly the pressure on the feed pump side is more than on the boiler side. Consequently the valve V_2 lifts off its seat, the delivery

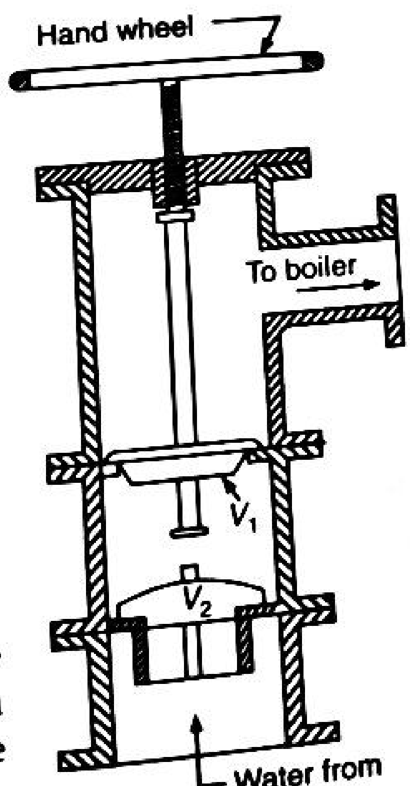


Fig. 14.17. Feed check valve

passage opens and the water flows to the boiler to maintain a constant water level. The lift of the valve V_2 and hence the supply of water to the boiler can be controlled by adjusting the position of the feed valve V_1. The valve V_1 can be raised or lowered by means of a hand wheel.

If by chance the feed pump fails, the pressure reduces on the water side. The valve V_2 then closes under the pressure of steam and this prevents the back flow of water from the holder.

In case it is felt that the check valve is not giving a satisfactory performance, sufficient water is pumped into the boiler and the feed valve is pressed closed onto its seat. The check valve is then removed and replaced after doing the necessary repair and cleaning of the valve and the valve seat.

(G) Stop Valve

Function : The function of the steam stop valve is to shut off or regulate the flow of steam from the boiler to the steam pipe or from the steam pipe to the engine. When used for the former purposes, it is called junction valve. Usually the junction valve means a regulating valve of larger size and a stop valve refers to a regulating valve of smaller size.

Location : The junction valve is mounted on the highest part of the steam space of the boiler and is connected to the steam pipe which carries the steam to the engine.

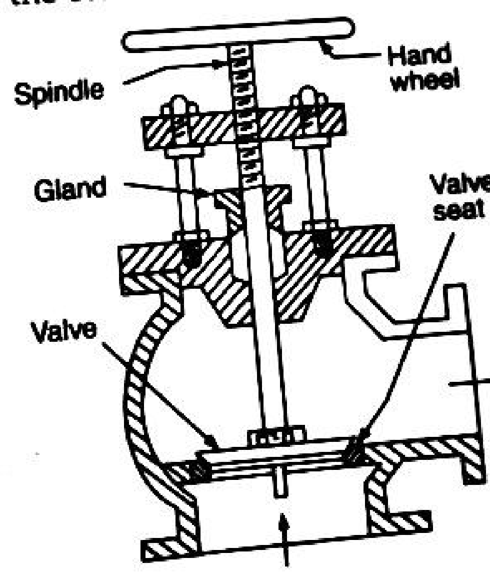


Fig. 14.18. Stop valve

Construction and operation : Fig. 14.1 shows the different elements of a common typ of stop valve. The valve body usually made of cast iron or cast steel has two flanges, one flange is bolted to the boiler at the highest point of the steam space and the other flange is connected to the steam outlet pipe. There is a spindle which passes through glands and stuffing box. The glands and packing are necessary to make the valve leak proof. The upper portion of the spindle is threaded and it passes through a nut in a cross bar or yoke rests on a valve seat pillars screwed to the valve body by the lugs. The valve disc is screwed to the valve spindle by a nut. The lower edge of the nut comes in contact with the collar provided at the lower end of the spindle. It is obvious that by this arrangement the spindle is free to rotate within the valve disc. The rotation given to a hand wheel fixed to the spindle top, raises or lowers the spindle and this operation makes the valve disc to be put on and off its seat.

The usual convention to quote the size of the valve is the diameter of the steam pipe to which it is connected, *i.e.*, 50, 75 and 100 mm stop valves.

(*H*) Manholes

These are doors to allow men to enter inside the boiler for inspection and repair.

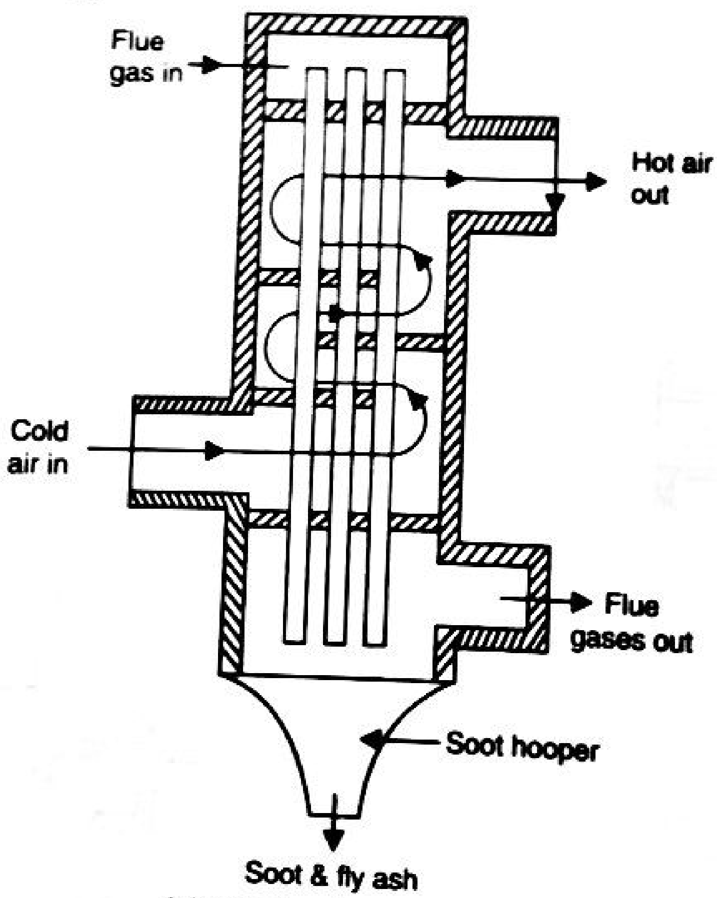
(*I*) Air heaters

Air heaters or air preheaters are waste heat recovery devices in which the air on its way to the furnace is raised in temperature by utilizing the heat of the exhaust gases.

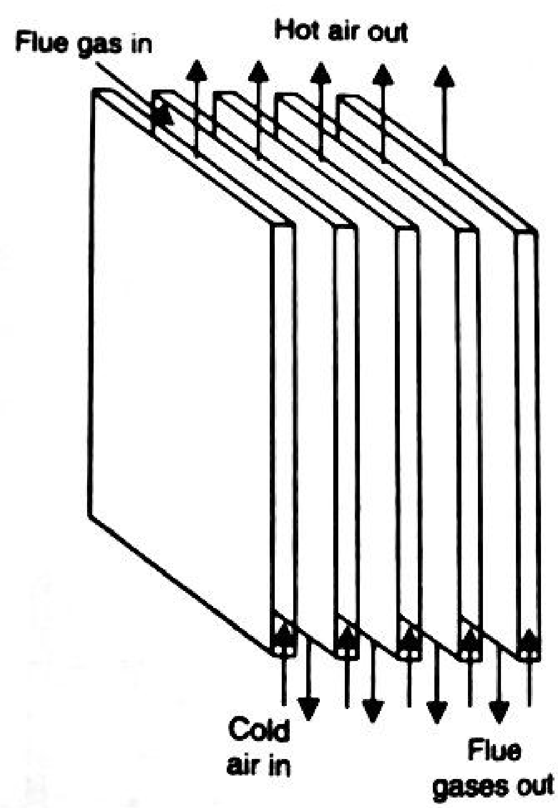
Air preheaters are classified into the following two categories :

(*a*) *Recuperative* air heaters in which the heat transfer is through a metal wall. The flue gases pass through one side and the combustion air passes on the other side. Air is made to follow a *zig-zag* path so that it passes a number of times. The recuperative air heaters are subdivided into tubular type or plate type depending upon whether the tubes or plates are used for carrying the hot flue gases. Tubular air heaters are in the greatest favour.

(*b*) *Regenerative* air heaters in which the flue gases and the air are made to pass



(a) Tubular air pre-heater



(b) Plane air-preheater

Fig. 14.19. Air preheaters

space of the boiler *via* feed check valve. When the water flows upwards inside the tubes, it gains heat from the hot flue gases which are made to pass over the external surface of the tubes.

For efficient heat transfer, the surface of the tubes has to be kept clean from soot and volatile ash deposits. This is achieved by scrapers which are kept slowly moving up and down to clean the surfaces. A pair of scrapers for adjacent tubes are coupled together by a chain which passes over pulley. The pulley is driven by mechanical drive. It is obvious that the simultaneous action of adjacent pair of scrapers is opposite in direction, *i.e.*, when one scraper is moving up, the other is going down.

The safety valve opens when the pressure of water becomes 10-15% higher than the boiler pressure.

A bypass arrangement is provided to isolate the economiser when it is not required or when it is to be cleaned and repaired. Fig. 14.21 shows such an arrangement for two Lancashire boilers fitted with an economiser. When the economiser is in service the damper A is closed and the dampers B and C are open. For isolating the economiser we close the dampers B and C and open the damper A.

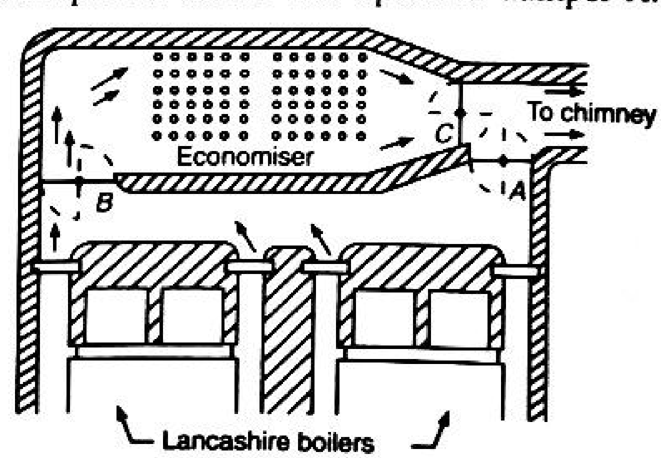


Fig. 14.21. Bypass arrangement of flue gases

(K) Steam superheater

The steam generated by a simple boiler is generally wet or at the most dry saturated. Steam superheater is a surface heat exchanger in which the wet stream is first dried at the same temperature and pressure and then raised to temperature above the saturation temperature at constant pressure. Heat of flue gases is utilized in superheating the steam and as such the superheater is placed in the path of flue gases. However in bigger installations, the superheater may be placed in an independently fired furnace. Such superheaters are known as separately fired or portable superheaters.

Since superheating results in the increased efficiency and economy of the steam plant, it has become the most important accessory of the steam power plants. The advantages of using superheated steam are :

(*i*) Increase in the amount of work output for the same weight of steam and consequently increase in cycle efficiency.

(*ii*) Loss due to condensation of steam in reciprocating steam engines is minimised to an appreciable extent.

(*iii*) No condensation of steam in the pipe line connecting the boiler to the appliance.

(*iv*) Absence of moisture in the steam reduces the friction and the erosion of steam turbine blades.

Superheaters are classified according to the mode of heat reception.

(*i*) In *convective superheaters*, the heat of the combustion gases is transferred to the surface of superheater tubes by convection.

(*ii*) In *radiation superheater*, the heat from the furnace is transferred by radiation to the superheater tubes which are placed in one or more walls of the boiler furnace.

(*iii*) In *combination type* the steam first enters the radiant superheater and then the convection one.

The superheaters are also classified according to the movement of gases and steam in the superheater. The three categories are counterflow, parallel flow and the combined flow.

The superheaters mainly follow a counter-flow arrangement in order to reduce the temperature of outgoing flue gases to the lowest possible limit. The counter flow superheater has a small size and is light in weight for the same heat transfer to the steam

Further the superheaters are also classified according to the arrangement of superheater tubes in the boiler :

(*i*) Overdeck superheater is placed in the space over the water tubes.

(*ii*) Interdeck superheaters are placed between the water tubes which are located near the furnace.

(*iii*) Inter-tube superheaters are placed between the bank or row of water tubes.

All superheaters are essentially coil pipes made from seamless steel.

Fig. 14.22 illustrates the principle of operation of Sudgen's hair pin type superheater which is used in most of the low pressure boilers namely Cornish, Lancashire and Babcock and Wilcox boiler.

The path of flow of steam and the gases is indicated respectively by solid and dotted arrows. When the superheater is in operation, the valve V_3 is closed and the steam goes to the header H_1 *via* valve V_1. The steam when flowing inside the U shape tubes receives heat from the flue gases which are made to pass over the external surface of the tubes. The superheated steam from the header H_2 is then supplied to the steam main *via* valve V_2. For isolating the superheater when it is not needed or when it is to be cleaned and repaired, the valve V_1 is closed and the steam from the boiler is fed directly to the steam main *via* valve V_3.

The temperature control of superheated steam can be carried out by keeping the damper in some intermediate position. In that case a part of the hot flue gases passes over the superheater tubes and the remaining portion passes directly to the bottom flue.

The temperature control of superheated steam can be carried out by keeping the damper in some intermediate position. In that case a part of the hot flue gases passes over the superheater tubes and the remaining portion passes directly to the bottom flue.

Fig. 14.23. indicates the position of an economiser, an air preheater, and a superheater in a steam generating plant.

(*L*) Feed water equipment

The pressure inside a steaming boiler is high and so the feed water has to be raised in pressure before its entry can be affected in the boiler. Feed pump is a device which raises the pressure of water and forces it into the

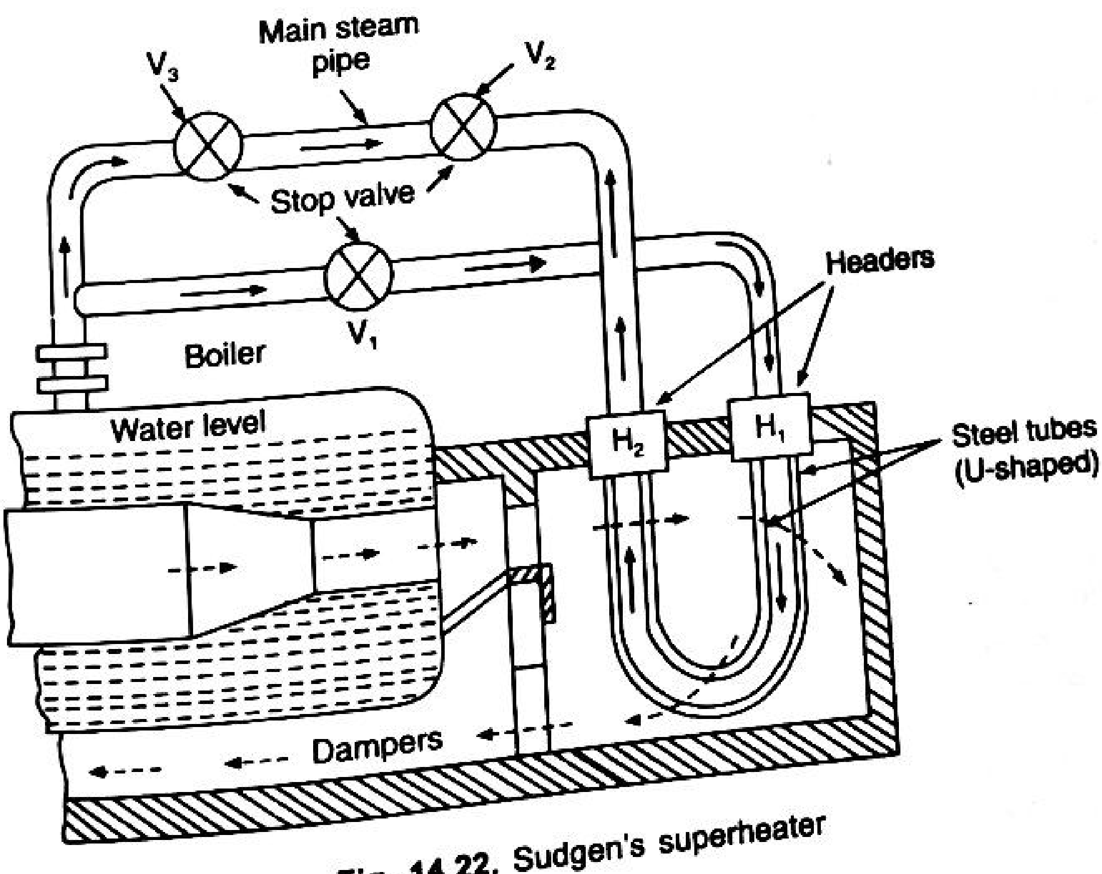


Fig. 14.22. Sudgen's superheater

alternatively through the same path. Initially when the hot gases pass through a certain medium called matrix, the matrix receives heat from the gases and stores in itself. Next when air is made to traverse the same path, the matrix transfers the heat stored in it to the air. This heater has a small size and is light in weight.

Roughly there is again of about 2% in the boiler efficiency for each 35-40°C rise of the temperature of combustion air. The other advantages of using preheated air are :

(i) increase in the evaporation rate,

(ii) better combustion with less soot, smoke and ash,

(iii) low grade and inferior fuels can be used.

(J) Economiser

Function : The economiser is a device which serves to recover some of the heat being carried by exhaust flue gases. The heat thus recovered is utilized in raising the temperature of feed water being supplied to the boiler. If the feed water at raised temperature is supplied to the boiler, it needs less heat for its conversion into steam and thus there is a saving in the consumption of fuel.

The other advantages claimed by installing an economiser are :

(i) Improvement in the thermal efficiency of the steam plant. It has been estimated that for each 5 to 6°C rise in the temperature of feed water, there is a gain of about 10% in the plant efficiency.

(ii) Reduction in the losses of heat with flue gases.

(iii) Increase in the steaming capacity of the boiler.

(iv) Less thermal stresses in the boiler parts and consequently long life of the boiler.

Location : The economiser unit is installed in the path of the flue gases between the boiler and the chimney.

Construction and operation : Fig. 14.20 shows the details of the Green economiser used with the boilers of medium pressure range upto 25 bar.

The system comprises a number of vertical tubes which are pressed hydraulically into the top and bottom header. The feed water from the feed pump on its way to the boiler enters the bottom header, passes through the vertical tubes and reaches the upper header. The upper header is in communication with the water

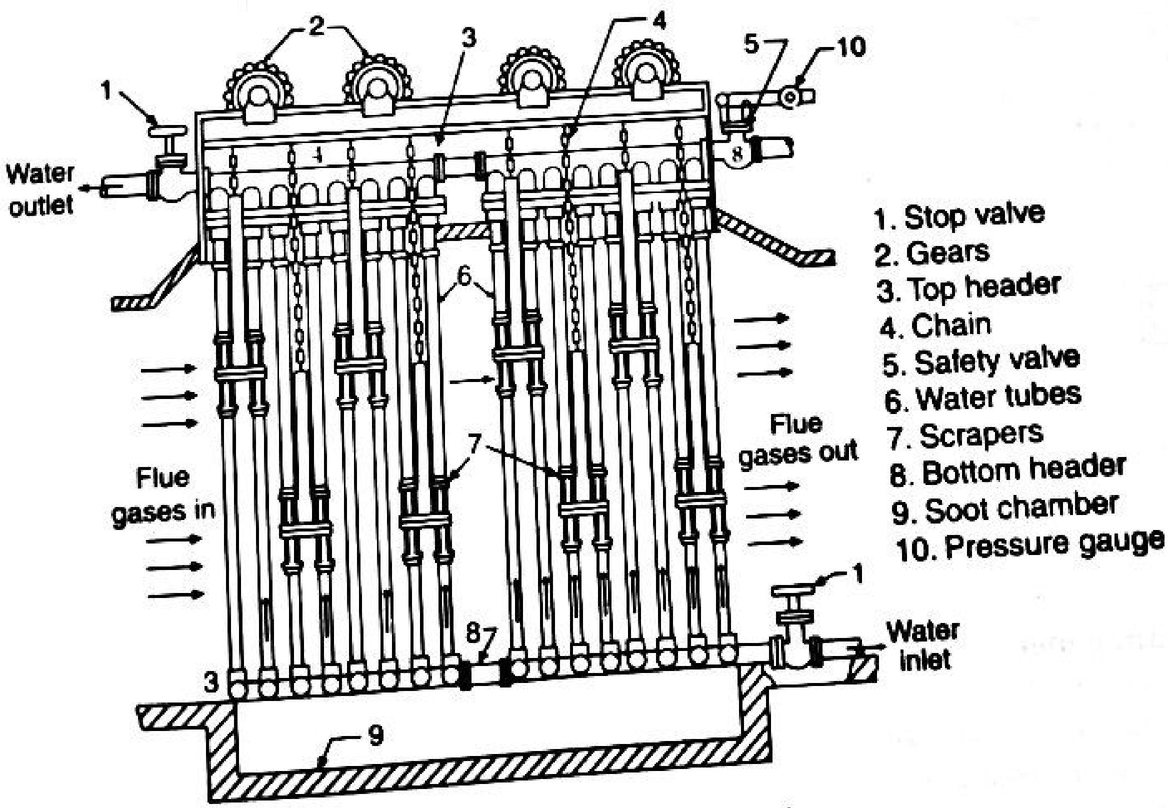


Fig. 14.20. Green's economiser

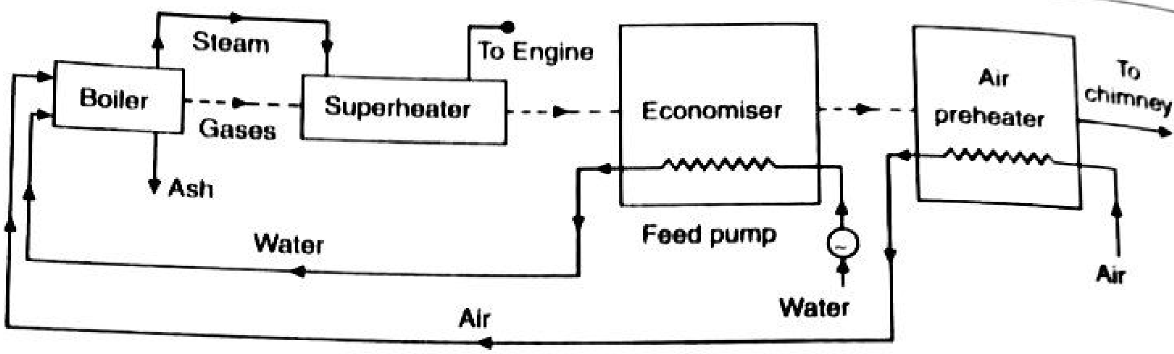


Fig. 14.23.

boiler. The commonly employed pumping devices are :

(*i*) Centrifugal pumps which run at high speeds and are driven either by electric motor or small steam turbines. The electrical driven pumps are primarily used for high capacity boilers which need a large quantity of feed water (250-300 m^3/hour). The steam turbine driven pumps too are used with medium and high steam generating capacity boilers with an output of 30 to 270 m^3/hour.

(*ii*) The reciprocating steam piston pumps are used with stationary boiler installations with a capacity of 10-15 ton/hour.

Usually a boiler house has two feed water pipe lines, one working and the other as stand-by and the output of each pump is approximately 50% more than the capacity of the boiler.

(*iii*) In vertical and locomotive boilers, the water is mainly fed with the help of injector.

With reference to Fig. 14.24, the steam enters the steam chamber whose outlet is in the form of a converging nozzle. In the nozzle section, the steam expands with a consequent gain in velocity at the expense of pressure. The resulting jet mixes with water in the mixing tube. The steam condenses and a vacuum is created in the mixing chamber. Due to vacuum, more water is drawn from the feed tank into the mixing chamber. The jet of water then enters the diverging cone where the kinetic energy of the mixture is converted into pressure. The increase of pressure is sufficient to force the water into the boiler through feed check valve.

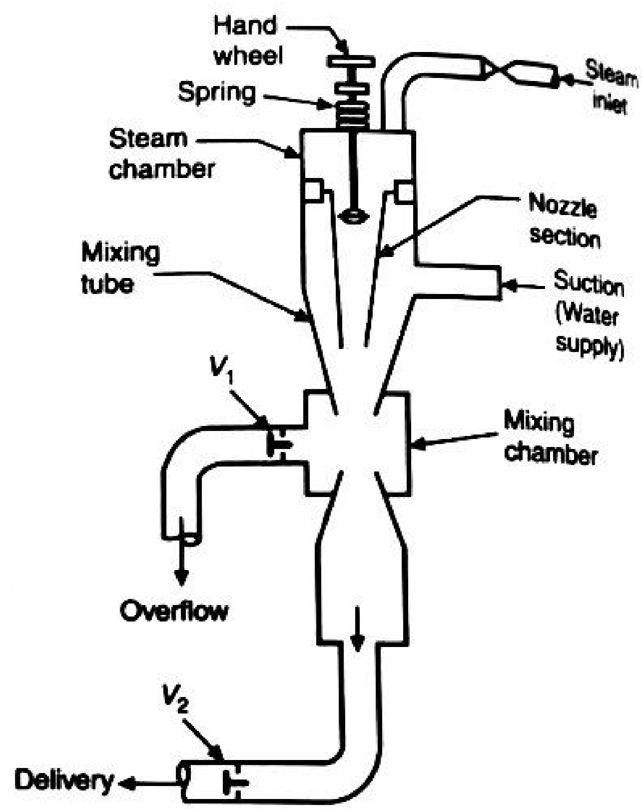


Fig. 14.24. Steam injector

To start with, the pressure in the mixing chamber is higher than the atmospheric pressure. Consequently the water and the uncondensed steam escape to atmosphere through the non-return valve V_1. The hand wheel is then turned and the annular opening between the nozzle and mixing tube is altered so as to establish a jet action. This results in the creation of rarefaction in the mixing chamber resulting in the closure of the valve V_1. The water from the feed tank rushes with high velocity to the mixing cone and regular operation of the injector is established.

The injector though limited in use to small boilers has the following advantages :

(i) Occupies minimum space.

(ii) Comparatively cheap in first cost and every day maintenance.

(iii) The steam consumption though more than that in case of pumps, advantage lies in the fact that entire heat of steam is recovered and returned to boiler in the feed water pumped. The injector is thus thermally much more efficient.

(iv) Since the injector supplies hot feed water to boiler, the boiler parts are free from thermal stresses.

In addition to the fittings described above, the boilers are also fitted with an *antipriming pipe, water separator* and the *steam trap*. We know that when a boiler is required to raise steam quickly, the steam is bound to carry water particles with it. Before being supplied to the engine, arrangements are made to separate the water particles going along with steam.

An *antipriming pipe* is a cast iron box which is fitted in the steam space of the boiler shell and under the mounting block on which the steam stop valve is to be bolted. When the steam with water particles passes through the perforations made in the upper half of the antipriming pipe, the heavier water particles separate out and are collected at the bottom of the pipe. The water thus collected is later on drained to the boiler through the holes which are made at the ends of the pipe.

The *steam separator* or drier also serves the purpose to remove the water particles being carried along with steam and the water particles resulting from a certain amount of condensation in the steam pipe between the boiler and the engine. The steam is led to pass through a chamber in which it strikes the baffle plate, gets deflected and made to change its direction. The water particles are thrown out because of greater inertia. The water collected at the bottom of the chamber is drained out at regular intervals.

Steam traps are used to collect and automatically drain away the water resulting from the partial condensation of steam without allowing any steam to escape with it. The steam condensed in the steam pipe flows to the steam trap by gravity. When the level of water in the trap becomes sufficiently high, a valve opens a passage through which the water is forced out. After the water has been discharged the passage is again closed and this prevents the escape of steam which follows water.

14.8. HIGH PRESSURE BOILERS

For high efficiency of a steam power plant, the carnot theory suggests that :

(i) The heat addition be at the highet possible average temperature. The average heat addition temperature is increased by increasing steam pressure and temperature.

(ii) The heat rejection be at the lowest possible temperature. The temperature of heat rejection is reduced by producing and maintaining high vaccum in the condenser.

Apparently, the modern trend in central power stations is to generate and use steam at higher pressures and temperatures. Boilers have been built which operate with pressure ranging from 60 bar to 200 bar and temperature upto above 600°C. The super critical boilers have pressures in excess of the critical pressure of steam (221.2 bar). Since the properties of steam in critical range are quite different, the boilers working in the supercritical range differ from the subcritical boilers both in design and operation.

The special features in the design of high pressure boilers are:

(i) An external pump is employed in the high pressure boilers to force water as steam through the boiler circuit. The circulation so setup is in addition to the natural circulation due to static head and convection currents. This positive circulation has been recommanded and is normally employed with boilers operating at pressure above 160 bar.

(ii) The high pressure boilers have parallel set of tube arrangement and this minimises resistance to flow of current. Further these boilers are characterised by the use of very small steam separating drum or by the complete absence of any drum. The supercritical pressure boilers or once through boilers, do not require any boiler drum since the water is directly converted into steam at supercritical conditions (pressure 221.2 bar and temperature 374.15°C).

(*iii*) The high pressure boilers employ certain improved arrangements of heat supply and these are:

(*a*) heating water by superheated steam

(*b*) saving of latent heat of vaporation by operating at pressures above critical range

(*c*) increasing the heat flow rate through the tube walls by using hot gases travelling at supersonic speeds.

Other special features are :

- sufficient volume of the furnace
- protection of water tubes from intense heat radiant zone
- very large combustion chamber
- sufficient area for the furnace water cooling surface

Following are the advantages of forced circulation wich is employed with boilers that operate at pressures in excess of 160 bar.

(*i*) elimination of high head needed for natural circulation. As a result, the components can be arranged horizontally giving greater accessibility and operational convenience.

(*ii*) freedom in arrangement of furnace, boiler components and tube layout.

(*iii*) due to large water velocities, size pf the tubes is small. This aspect coupled with less number of drums (or no drums as in once - through boiler) makes the unit compact and results in less weight of material for a given output.

(*iv*) reduced erection time and cost due to less weight and space requirement.

(*v*) greater possibility to operate the forced circulation boilers at other than design conditions because the circulation is not dependent on pressure and temperature.

(*vi*) less tendency of scaling due to high circulation velocity.

(*vii*) steam can be raised quickly and load changes not rapidly.

(*viii*) uniform heating of all parts and that eliminates the danger of overheating and thermal stress.

(*ix*) maintenance of uniform temperature minimises differential expansion. This eliminates leakage of gas and air, and helps in pressurising the combustion.

However, in systems with forced circulation

- the circulating pumps consume extra power
- the safety of boiler depends on the pumping equipment
- the water has to be of highest purity

Some of the high pressure boilers are explained below regarding their construction and operation.

14.8.1. Lamont boiler

Refer Fig. 14.25 which shows the schematics of Lamont high pressure steam boiler which is of the water tube type and employs forced circulation.

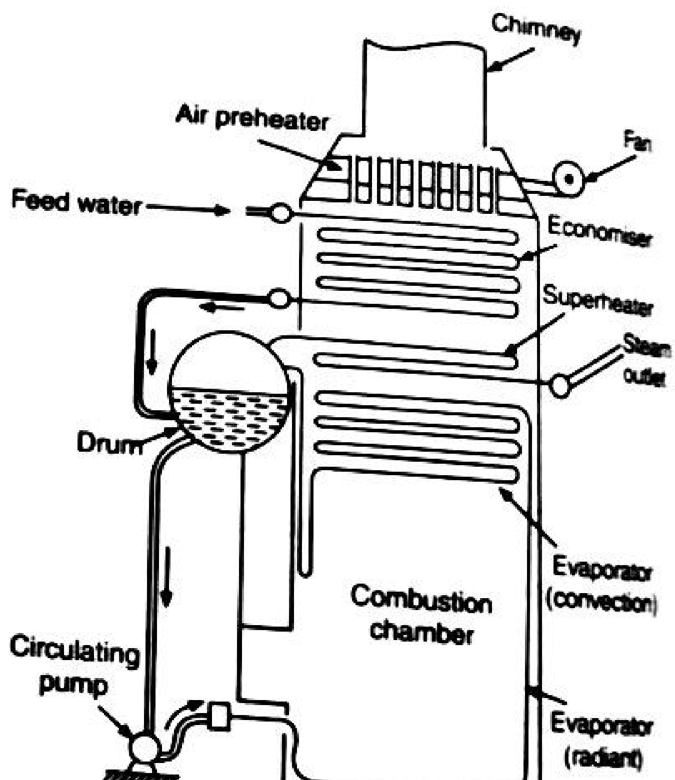


Fig. 14.25. Schematics of Lamont boiler

(*i*) The feed water from the hot well is made to pass through the economiser with the help of a feed pump. While passing through the economiser, the feed water is heated by the hot exhaust gases and is then supplied to the evaporating (steam separating) drum which is set external to the boiler.

(*ii*) The circulating pump operates at 2 to 3 bar above the boiler pressure, draws the feed

The term draught refers to the small pressure difference that causes and maintains a continuous flow of fresh air into the combustion chamber/furnace of a boiler. Essentially the draught means a force required to :

(*i*) maintain a continuous and sufficient supply of air through the fire bed to aid in the proper and complete combustion of fuel.

(*ii*) draw the resulting hot gases through the system comprising fuel bed, furnace, boiler passes and settings.

(*iii*) exhaust the flue gases to the atmosphere after they have given their energy content to the water being evaporated.

This chapter is devoted to essential aspects of natural draught produced by chimney, and the artificial draught produced by fan or steam jet. The various parameters related to performance of a boiler have also been explained.

15.1. DRAUGHT: ITS NECESSITY AND CLASSIFICATION

The amount of draught necessary for a certain boiler installation depends upon :

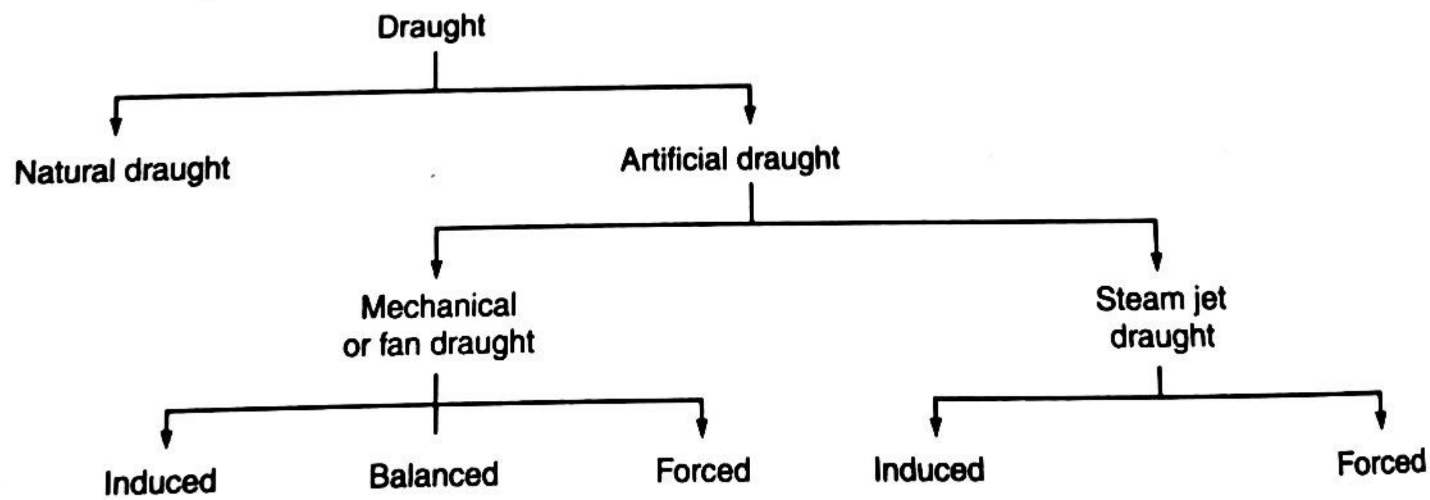
(*i*) nature of fuel and its depth on the grate

(*ii*) rate at which combustion is required to take place

(*iii*) design and shape of combustion chamber

(*iv*) method of burning of fuel

(*v*) resistance in the flue gas circuit offere by baffles, tubes, superheaters, economiser, a pre-heaters and dampers etc.



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Based on the system adopted for its creation, the draught is classified as per the chart given above:

15.2. NATURAL (CHIMNEY) DRAUGHT

The natural draught is produced by the use of chimney and is accordingly referred to as chimney draught. The chimney is a vertical tubular structure made either of brick masonry, reinforced concrete or steel. The chimney carries the flue gases (combustion products) to such a height before discharging that it causes no harm to the surrounding atmosphere :

The natural draught is caused by the difference in temperature (and so density) between a column of hot gases inside the chimney and a similar column of normal atmospheric air outside the chimney.

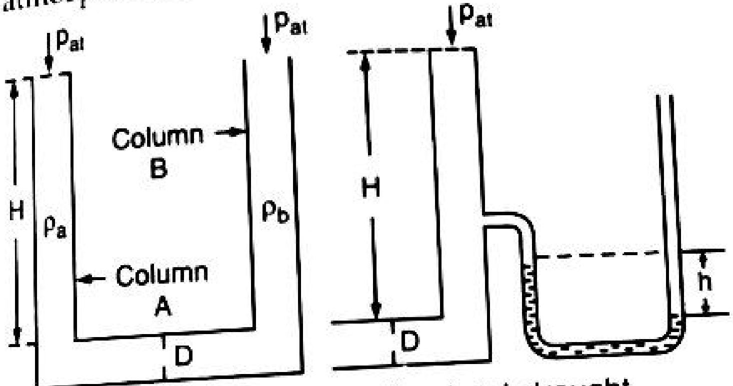

Fig. 15.1. Concept of natural draught

Consider two columns A and B containing gases of different densities ρ_a and ρ_b respectively as shown in Fig. 15.1. These densities are assumed to remain constant through the entire height H of the column. With atmospheric pressure p_{at} being exerted at the open ends of the columns, we have

Pressure at the base of column A

$$= p_{at} + \rho_a gH$$

Pressure at the base of column B

$$= p_{at} + \rho_b gH$$

Then pressure difference Δp at the base is given by :

$$\Delta p = (\rho_a - \rho_b)\, gH \qquad ...(15.1a)$$

With cold air at atmospheric conditions filling the column A and hot fire gases filling the column B, the column A becomes unnecessary and the arrangement can be depicted as shown in Fig. 15.1b.

Equation 15.1 can then be rewritten as

$$\Delta p = (\rho_a - \rho_f)\, gH \qquad ...(15.1b)$$

where ρ_a and ρ_f represents density of cold air and hot flue gases respectively.

Since the density of hot flue gases is less than the density of outside atmospheric air, a pressure difference would exist across the duct. When the duct is opened , the draught will be created and this will cause the outside air to flow into the furnace.

The draught (pressure difference between the gases at the base of chimney and the outside atmospheric air) is measured in mm of water column indicated by the manometer which is placed at the base of the chimney. In an ordinary chimney, the draught is less than 12 mm of water column which means a pressure difference

$$\Delta p = 1000 \times 9.81 \times \frac{12}{1000}$$

$$= 117.72 \text{ N/m}^2$$

between the outside air and gases at the base of chimney. This pressure difference causes the flow of air to the combustion place.

15.2.1. Height of chimney

The amount of natural draught produced by chimney depends on the height of chimney, the temperature of hot flue gases and that of atmospheric air.

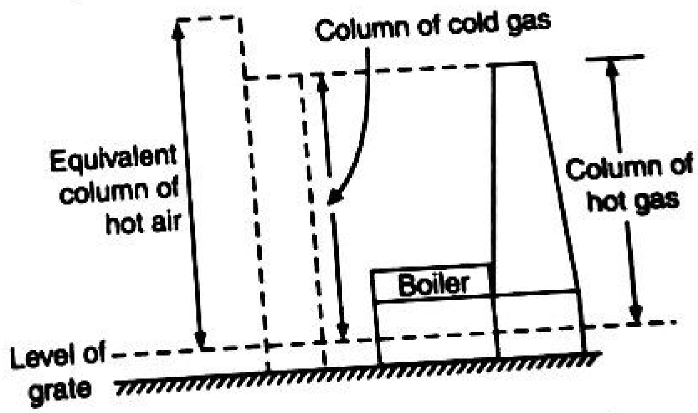

Fig. 15.2. Schematic arrangement for natural draught

Refer Fig. 15.2 for the schematic arrangement of natural draught produced by a chimney placed at a certain height above the grate. Let

15.4. BOILER PERFORMANCE

The purpose of the boiler is to generate steam at the predetermined pressure and temperature by using heat produced by the combustion of fuel. The evaporation (steam raising) capacity of the boiler depends upon

(a) grate area, *i.e.*, the amount of fuel the boiler can consume

(b) heating surface, *i.e.*, the quantity of heat the boiler can absorb

The evaporation capacity may be expressed as kg/hr-m² of heating surface or kg/kg of fuel burnt. If the grate area and heating surface are kept constant, the amount of water which a boiler can evaporate further depends upon :

(a) pressure and temperature conditions under which the boiler is operating

(b) quality of steam being raised (wet, dry or superheated)

(c) temperature of feed water being supplied to boiler.

Apparently it may be realized that the number of kg of water evaporated per hour is not an exact measure of the performance of the boiler. For making comparison of the relative evaporation capacity of the boiler, the water is supposed to evaporate under the following standard conditions:

(i) feed water is a supplied to the boiler at 100°C

(ii) evaporation of water (steam raising) takes place at the same temperature of 100°C

(iii) the steam raised is just dry and saturated.

When water evaporates under these conditions, it requires 2256 kJ/kg of heat which equals the latent heat of steam at 100°C under atmospheric pressure of 1 bar.

Equivalent evaporation of water is then defined as "Evaporation which would be obtained if the feed water were supplied at 100°C and converted into dry saturated steam at 100°C at the standard atmospheric pressure of 1 bar."

Let W_a = weight of water actually evaporated into steam per kg of coal burnt at the boiler working pressure.

h_s = specific enthalpy of steam at the working pressure

h_w = specific enthalpy (sensible heat) of feed water.

Then : heat absorbed by water at the boiler working pressure,

$$= W_a (h_s - h_w) \quad \text{...(a)}$$

If W_e denotes the equivalent evaporation, then heat absorbed under standard conditions,

$$= W_e L_o \quad \text{...(b)}$$

where L_o is the enthalpy of evaporation (latent heat) of steam at 1 bar and 100°C, and it equals 2256 kJ/kg.

Equating expressions (a) and (b), use obtain.

$$W_e = \frac{W_a(h_s - h_w)}{L_o} \text{ kg/kg of coal burnt} \quad \text{...(15.11)}$$

The factor $\left\{\frac{h_s - h_w}{L_o}\right\}$ in the above expression is always greater than unity and is known as *factor of evaporation* or *generation factor*. The factor of evaporation may be defined as the ratio of heat absorbed by 1 kg of feed water under working conditions to heat absorbed by 1 kg of water from and at 100°C (standard conditions).

Boiler efficiency is defined as the ratio of heat energy utilized by feed water in converting it into steam in the boiler to the heat energy produced by complete combustion of fuel during the same time. Thus

$$\eta_{\text{boiler}} = \frac{\text{energy absorbed by feed water}}{\text{energy produced by fuel}}$$

$$= \frac{W_a(h_s - h_w)}{W_f \times \text{calorific value of fuel}} \quad \text{...(15.12)}$$

where W_f is the weight of fuel consumed during the time the weight W_a of water is actually evaporated.

If the boiler is equipped with an economizer and a superheater, then the efficiency of the unit is expressed in terms of

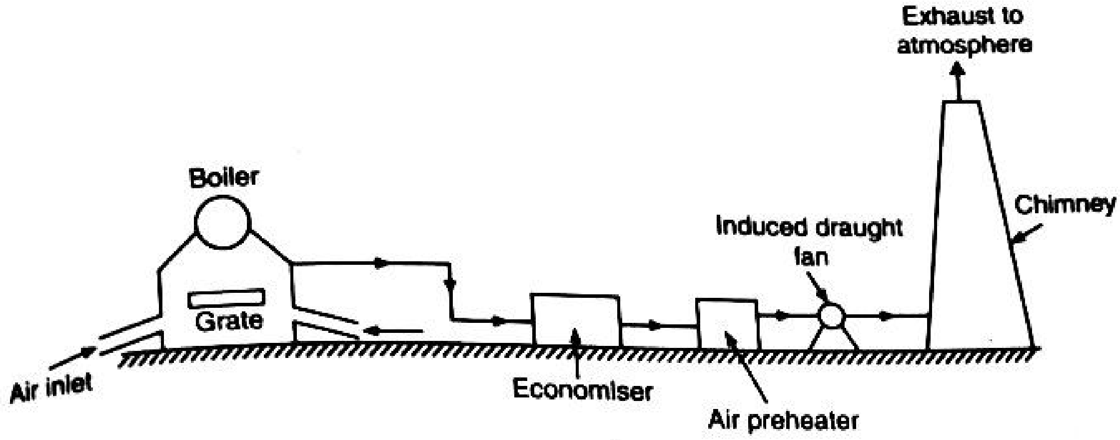

Fig. 15.3. Schematics of induced fan draught

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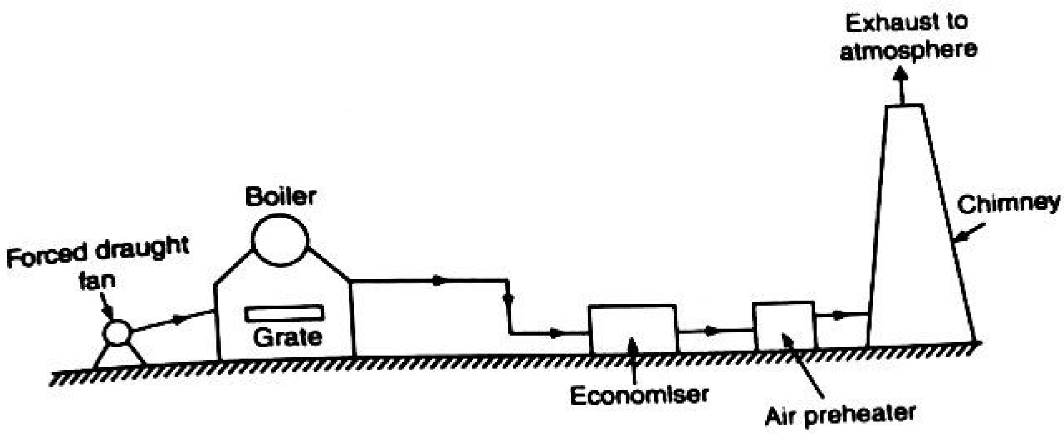

Fig. 15.4. Schematics of forced fan draught

of sufficiently high draught, some mechanical system has to be adopted. The draught so produced by a fan or steam jet is known as artificial draught.

15.3.1. Fan draught

The draught produced by a fan is called the fan draught or mechanical draught. The fan draught is of three types namely (*i*) induced (*ii*) forced (*iii*) balanced draught.

In the *induced draught* system, the fan is placed near or at the base of the chimney. The fan creates the depression which induces the flow of air through the grate. The air sucked in makes it possible to burn a large amount of fuel in a limited combustion space. The induced draught augments the draught created by the existing chimney and the system is usually employed when the boiler is provided with economisers and pre-heaters.

In the *forced fan draught*, a fan or blower installed near or at the base of boiler grate delivers air to the furnace under pressures varying from 2.5 cm to about 7.5 cm of water. The pressure helps in circulation of flue gases through components of the boiler and then through chimney to atmosphere.

The comparison between induced and forced draught systems can be made with respect to following aspects:

(*i*) Induced draught fan handles hot gases which have greater volume because of low density at elevated temperatures. As such the fan size will be greater than that of a forced fan for the same boiler. For the same reason, the induced draught system requires greater fan power.

(*ii*) Induced draught fan needs water cooled bearings since it is to withstand high temperature of gases being handled by it.

(*iii*) With induced draught, the furnace and boiler gases are at a pressure lower than that of atmosphere. Consequently when the doors are opened for firing and cleaning, there will be inrush of cold air into the furnace. This air infiltration reduces draught through the system, cools the flue gases and impairs the transmission efficiency of heating surface. However, this inward leakage of air prevents the danger of blow out of flames and ashes.

(*iv*) With forced draught fan, there is more uniform flow of air through the grate. The air penetrates into the fire bed better and this improves the rate of burning of fuel.

(*v*) With forced draught, all leakages are outward. When the fire doors are opened and the fan is operating, there will be serious danger of blow out.

Sometimes a combination of induced and forced draught system, called *balanced draught*, is employed. In this combination, the induced draught removes the gases from the furnace and the forced draught overcomes the resistance of the fuel bed so that sufficient air is supplied to the fuel for its complete and proper combustion. Slight negative pressures are maintained on the fire bed so that leakage is inwards and there is less danger of blow out of flames and ash.

15.3.2. Steamjet draught

The draught produced by steamjet is called steamjet draught and it is of two types namely forced and induced.

In forced draught, the jets of steam after having been throttled to 1.5 to 2.5 bar gauge are applied below the ashpit which is located under the fire grate of the furnace. The surrounding air is dragged along the fuel bed, furnace, fire tubes and finally to atmosphere through chimney.

In induced draught there is a blast of low pressure exhaust stream in the smoke box, *i.e*, at the base of chimney. The partial vacuum thus created forces the flue gases out through the chimney. This arrangement has been successfully employed in a locomotive boiler.

Steamjet draught has the following advantages :

- simplicity of operation
- cheapness in cost
- comparatively maintenance free ; no maintenance cost
- requires little space for installation
- capability to use low grade fuels

However the steamjet draught can be operated only when steam has been raised at proper pressure. Further, the draught produced is low (20-25 mm of water column) and the system can be installed only on small boilers.

15.3.3. Comparison between artificial and natural draughts

The mechanical or artificial draught is better and economical than the natural or chimney draught as becomes apparent from the following aspects :

(1) The artificial draught has increased rate of combustion due to high draught. Less quantity of air is then needed for complete combustion of fuel. This reduces the weight

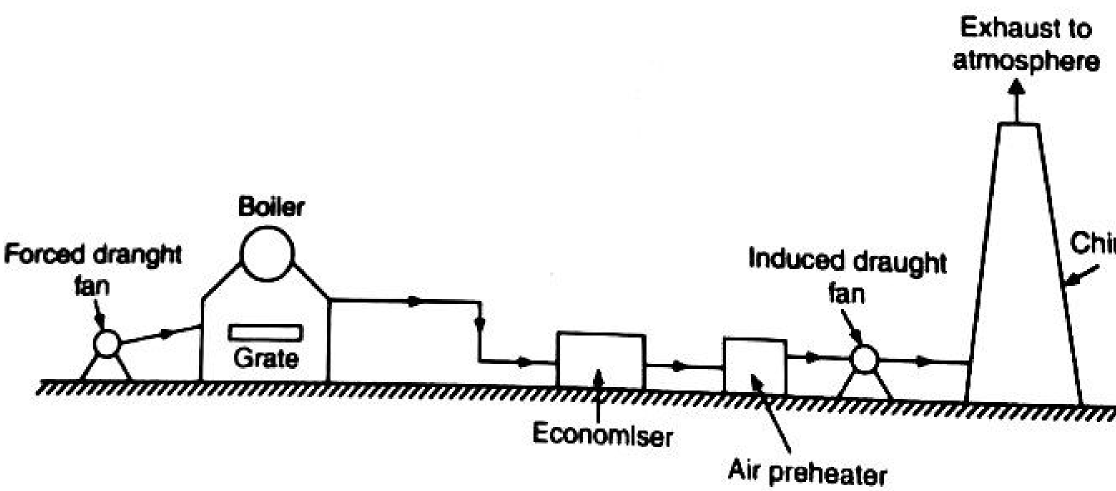

Fig. 15.5. Schematics of balanced fan draught

of flue gases per kg of fuel which means less loss of heat to exhaust gases.

(2) The artificial draught is flexible which means that the draught pressure can be controlled by regulating the flow of air or steamjets.

(3) The artificial draught is independent of climatic conditions which often seriously affect the chimney draught.

(4) Economical use of low grate fuel is possible with artificial draught due to higher intensity of draught.

(5) The function of chimney with high intensity artificial draught is only to discharge the hazardous smoke and gases high up in the atmosphere. Creation of draught is then only a secondary function and as such the chimney height can be kept small.

(6) Smoke formation and tendency for air leakage in the furnace is less with artificial draught.

(7) Efficiency of fan draught is about 7% whereas that of chimney draught is less than 1%.

EXAMPLE 15.1

Calculate the height of chimney required to generate a pressure difference of 100 mm of water column. The temperature of outside air is 30°C and the average temperature of flue gases in the chimney is 150°C. Neglect friction losses in the chimney and assume appropriate value of gas constant for air.

Solution :

$$\Delta P = 100 \text{ mm of water column}$$

$$= 100 \times g \times \frac{100}{1000}$$

$$= 100\, g \text{ N/m}^2 \qquad (\because P = \rho g h)$$

The draught in terms of presence difference in N/m^2 is given by

$$\Delta P = gH(\rho_{air} - \rho_{gases}) \qquad ...(i)$$

Density of air,

$$\rho_{air} = \left(\frac{p}{RT}\right)_{air} = \frac{1.01325 \times 10^5}{287 \times (273 + 30)}$$

$$= 1.165 \text{ kg/m}^3$$

Density of flue gases,

15.2.4. Advantages / disadvantages of chimney draught

- The chimney is very easy to construct, has a long life, requires no maintenance and needs no auxiliay power for its operation.
- The draught produced by chimney varies with external weather conditions and the temperature of flue gases. The draught decreases with increase in outside air temperature and for producing sufficient draught, the flue gases have to be discharged at comparatively high temperatures and this results in loss of overall plant efficiency. Further, the chimney has no flexibility to create more draught to take peak loads.

15.3. ARTIFICIAL DRAUGHT

The use of chimney for producing draught of the order of 25-350 mm of water column needed for bigger power plants is neither economical nor convenient. This is because the chimney height has to be increased considerably and chimney draught depends on climatic conditions. To meet the requirements

$$\rho_{gases} = \left(\frac{p}{RT}\right)_{gases} = \frac{1.01325 \times 10^5}{287 \times (273 + 150)}$$

$$= 0.835 \text{ kg/m}^3$$

Substituting the relevant data in expression (i)

$$100\, g = g \times H\ (1.165 - 0.835)$$

Then height of chimney

$$H = \frac{100}{1.165 - 0.835} = \mathbf{303\ m}$$

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overall efficiency which takes into account the efficiency of all the three units namely the boiler, the economizer and the superheater.

Economizer efficiency is a measure of the heat absorbed by feed water from the flue gases which are on way to chimney.

$$\eta_{economizer} = \frac{\text{heat asbrobed by feedwater in the economiser}}{\text{heat content of flue gases entering the economiser}}$$

$$= \frac{W_w c_{pw} (t_{w_2} - t_{w_1})}{W_f c_{pf} (t_f - t_a)} \quad ...(15.13)$$

where

W_w and W_f = weights of water and flue gases respectively

c_{pw} and c_{pf} = specific weights heats of water and flue gases respectively

t_{w2} and t_{w1} = temperature of water entering and leaving the economizer

t_f = temperature of flue gases entering the economizer

t_a = temperature of air being supplied to boiler.

Boiler horse power is the term used for the performance unit equivalent to evaporation of 15.653 kg of water in one hour from and at 100°C. Thus

Boiler horse power

$$= \frac{\text{equivalent evaporation/hr from and at } 100°C}{15.653} \quad ...(15.14)$$

EXAMPLE 15.9.

A boiler generates 45 × 10³ kg/hr of wet steam at 10 bar pressure and 0.95 dryness fraction. The boiler receives water at 40°C and the coal burns in the furnace at the rate of 5 × 10³ kg/hr. Calculate the equivalent evaporation of boiler per kg of coal burnt.

Solution : Mass of steam generated per kg of coal burnt,

$$m = \frac{\text{mass of steam generated/hr}}{\text{mass of coal burnt/hr}}$$

$$= \frac{45 \times 10^3}{5 \times 10^3} = 9 \text{ kg /kg of fuel}$$

At 10 bar pressure, the properties of steam as read from the steam tables are :

h_f = 762.6 kJ/kg

and h_{fg} = 2013.6 kJ/kg

At 40°C feed water temperature;

h_w = 167.6 kJ/kg

Enthalpy of steam

$$h = h_f + x\, h_{fg}$$
$$= 762.6 + 0.95 + 2013.6$$
$$= 2675.52 \text{ kJ/kg}$$

Equivalent evaporation

$$= \frac{m(h - h_w)}{\text{latent heat at } 100°C}$$

$$= \frac{9(2675.52 - 167.6)}{2257}$$

= **10** kg/kg of coal

EXAMPLE 15.10.

A boiler evaporates 5 kg of water per kg of coal burnt on the fire grate in the combustion chamber. The temperature of feed water is 30°C and the steam is raised at 10 bar absolute pressure. Calculate the equivalent evaporation from and at 100°C per kg of coal as well as the factor of evaporation if the steam produced is (a) 0.95 dry (b) superheated to 250°C.

Take specific heat of superheated steam = 2.1 kJ/kg K

Solution : From steam-tables,

At 30°C feed water temperature :

h_w = 125.77 kJ/kg

At 10 bar absolute pressure :

h_f = 762.79 kJ/kg

h_{fg} = 2015.3 kJ/kg

and T_{sat} = 179.91°C

Mass of water evaporated

m = 5 kg/kg of coal

(a) Enthalpy of steam

$$h = h_f + x h_{fg}$$
$$= 762.79 + 0.95 + 2015.3$$
$$= 2677.32 \text{ kJ/kg}$$