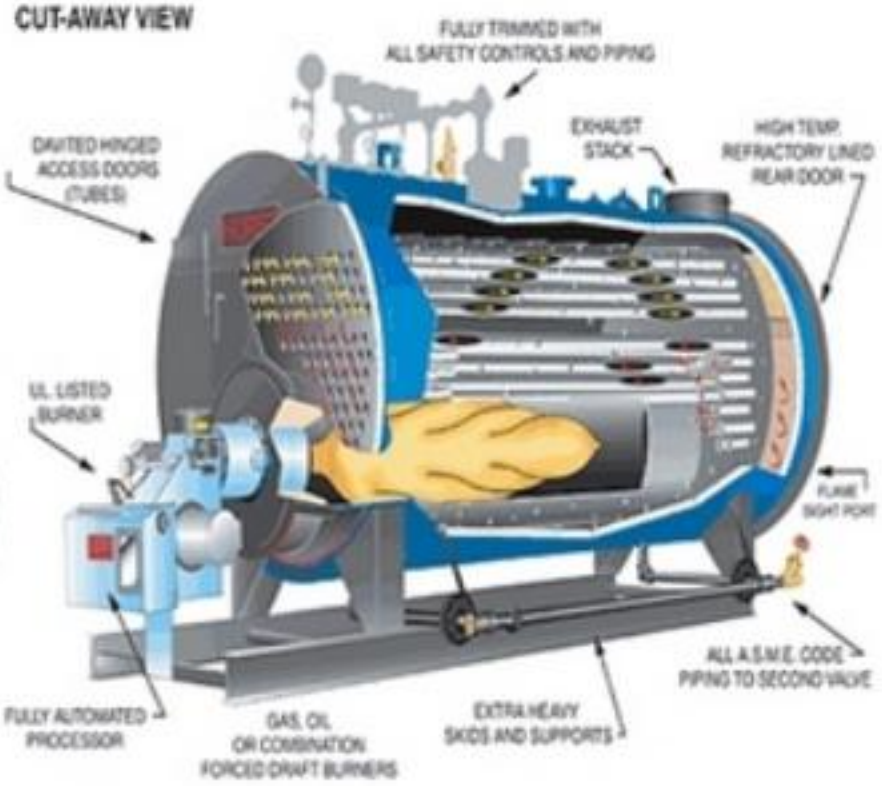
STEAM BOILERS



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Boiler

According to Indian Boiler Regulations (I.B.R.), a boiler is a closed pressure vessel with capacity exceeding 22.75 litres used for generating steam under pressure.

It is used for generating steam from water. This steam is utilized for power generation, for process heating or for space heating.

Sometimes only hot water is produced in a boiler and utilized for heating purposes.

QUALITIES OF A GOOD BOILER

(1) It should produce maximum steam with minimum fuel consumption, i.e. it should have higher efficiency.

(2) It should be able to deliver desired quantity of steam quickly after starting.

(3) It should be able to meet large load fluctuations. (It should be able to vary steam production rate as per the requirement, in a wide range)

(4) It should be light and simple in construction It should occupy less space.

(5) It should be easy to maintain and inspect.

QUALITIES OF A GOOD BOILER

(6) The joints should be accessible for inspection and should not face the impact of flame directly.

(7) The velocity of water and that of flue gases should be minimum.

(8) Tubes should be sufficiently strong to resist wear and corrosion.

(9) Mud and other deposits should not collect on heated plates.

(10) It should comply with safety regulations laid by competent authority. (I.B.R. in India)

CLASSIFICATION OF BOILERS

According to Relative Position of Water and Hot Gases

Fire Tube Boilers : The Cochran, Locomotive and Lancashire boiler are fire tube boilers.

Water Tube Boilers : e.g. Babcock & Wilcox boiler, Stirling boiler.

CLASSIFICATION OF BOILERS

According to Geometric Orientation of Boilers

Horizontal Boiler : **T**heir principal axis (axis of boiler shell) horizontal or slightly inclined. e.g. Locomotive boiler, Lancashire boiler.

Vertical Boilers : They have their principal axis (axis of boiler shell) vertical. e.g. Cochran boiler

CLASSIFICATION OF BOILERS

Externally Fired Boilers : The furnace is placed outside the boiler shell. This type of boilers have the advantage that the fire place is simple and may be enlarged easily. Water-tube boilers are always externally fired e.g. Babcock and Wilcox boiler.

Internally Fired Boilers : The furnace is placed inside the boiler shell. Most of the fire-tube boilers are of this type. e.g. Lancashire boiler, Cochran boiler.

CLASSIFICATION OF BOILERS

According to Method of Water Circulation

Natural Circulation Boilers : The water convection currents are set up due to the temperature difference. The water from steam drum falls under gravity to header where its temperature rises and density reduces. So it travels upward to steam drum through evaporator.

Forced Circulation Boilers : Water is circulated through boiler circuit by a pump. Low capacity boilers use natural circulation, while only high pressure–high capacity boilers use forced circulation.

CLASSIFICATION OF BOILERS

According to Working Pressure :

High Pressure Steam Boiler : The working pressure more than 25 bar. e.g. Babcock and Wilcox boiler.

Medium Pressure Steam Boiler :

working pressure range: 10 bar to 25 bar. e.g. Lancashire boiler and Locomotive boiler.

Low Pressure Steam Boiler :

working pressure is between 3.5 to 10 bar. e.g. Cochran and Cornish boiler.

CLASSIFICATION OF BOILERS

According to Mobility of Boiler :

Stationary Boiler : Most industrial boilers and boilers used for power generation are stationary boilers. e.g. Lancashire boiler, Babcock and Wilcox boiler.

Mobile Boiler : They are used to run locomotives and ships e.g. Locomotive boiler.

FACTORS AFFECTING THE SELECTION OF A BOILER :

- Type (quality) of steam to be produced, i.e. wet steam, dry steam or superheated steam.
- Steam generation rate and steam pressure required.
- Quality and quantity of fuel and water available.
- Cost of installation and erection (Initial cost).
- Cost of operation and maintenance.
- Availability of floor space.

PARTS OF A BOILER:

Cylindrical Shell : It is the shell in which different parts of the boiler are enclosed and on which the mountings are fitted.

Grate : It is the platform on which the fuel is burnt.

Fire Hole : It is the hole through which coal is added to the furnace, when needed.

Fire Box : This chamber contains hot gases produced by combustion of fuel. This chamber is surrounded by water. The walls of fire box are at very high temperature due to radiative heat transfer from flames and due to contact with hot gases. These walls conduct heat to water surrounding them.

Ash Pan (Ash Pit) : It is the area in which the ash of burnt coal is collected.

PARTS OF A BOILER:

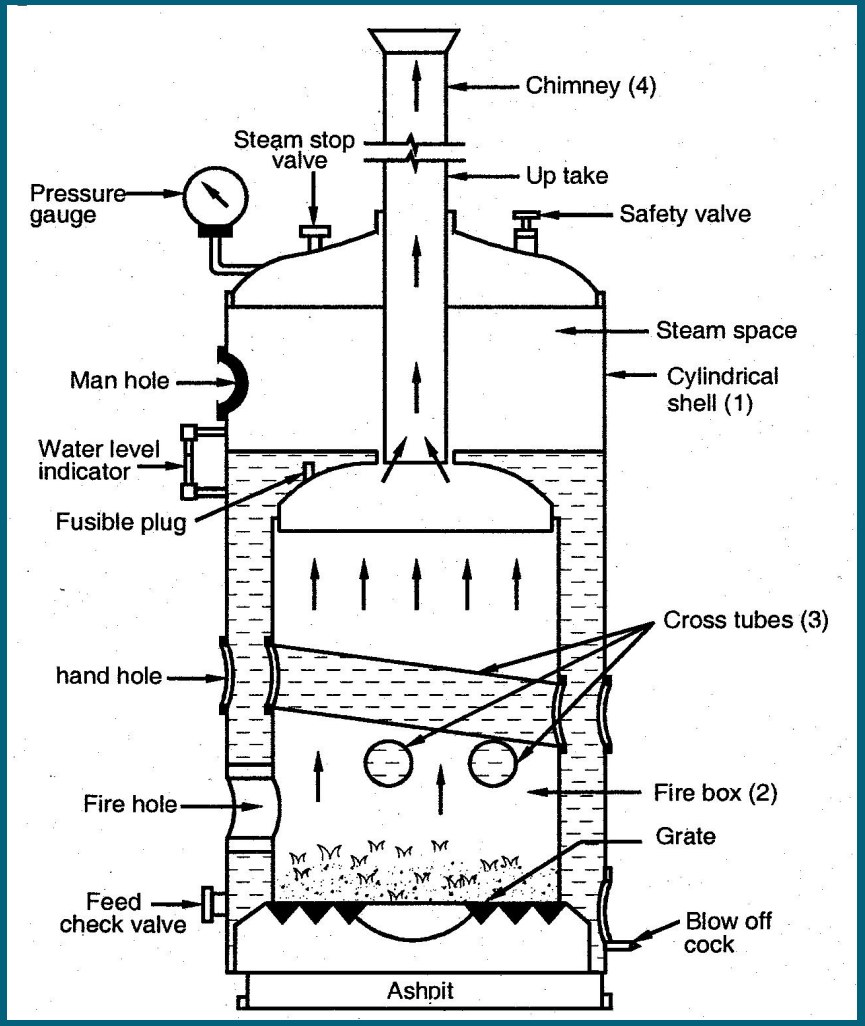
Smoke Box (Smoke Chamber) : After using the heat available with the flue gases (hot gases that are produced due to combustion in furnace/ firebox) to raise steam, they enter a chamber called smoke box. They are then released to atmosphere through chimney.

Man Hole : It is a hole provided in the boiler shell so that a workman can go inside the boiler for inspection, cleaning and maintenance. It is generally oval in shape and a door is provided to close it.

SIMPLE VERTICAL BOILER

Main parts of the boiler are :

(1) Cylindrical shell
(2) Fire box
(3) Cross tubes and
(4) Chimney.
(5) Ash pit or ash pan
(6) Grate for collecting ashes of the burnt fuel.
(7) Chimney
(8) Manhole
(9) Hand holes
(10) Feed check valve,
(11) Blow off cock,
(12) Fusible plug,
(13)water level indicator,
(14) steam stop valve,
(15)safety valve
(16) Pressure gauge



Advantages and Limitations

of simple vertical boiler:

Advantages

This boiler is compact and requires less floor space.

Can be transported easily

Does not require heavy foundation.

Limitations:

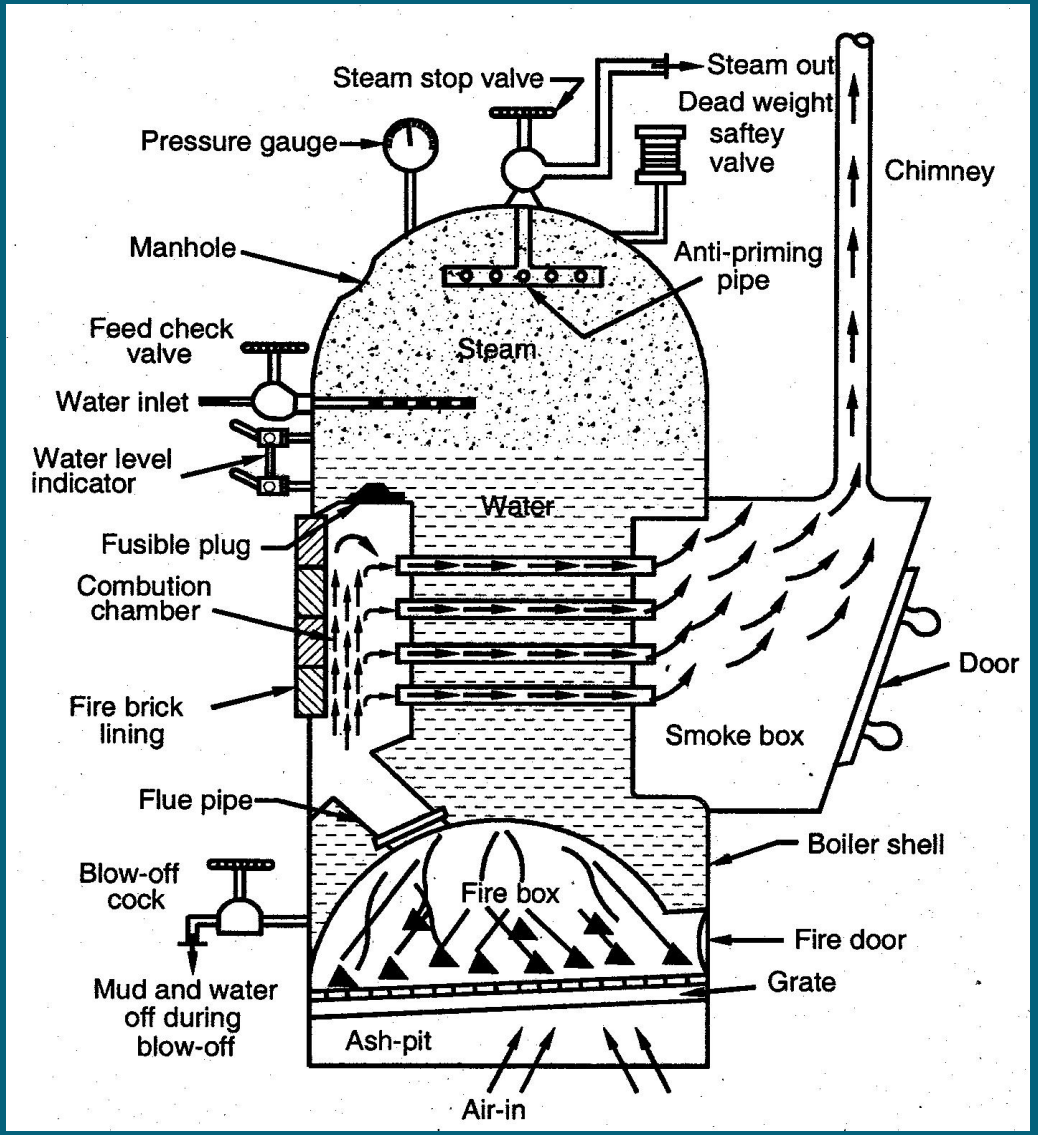
As the gases move directly towards chimney, the heat transfer efficiency is very low. Much of the heat with hot gases is wasted.

This boiler can produce pressure upto 7 bar and steam rate of around 300 kg/hour.

Cochran Boiler (Vertical Multi-tubular Boiler)

Cochran boiler is a vertical, multi fire-tube boiler used for low rate steam generation.

It is made in different sizes with steam evaporation capacity ranging from 150 to 3000 kg per hour and working pressure upto 20 bar.



Cochran Boiler (Vertical Multi-tubular Boiler)

Cochran Boiler (Vertical Multi-tubular Boiler)

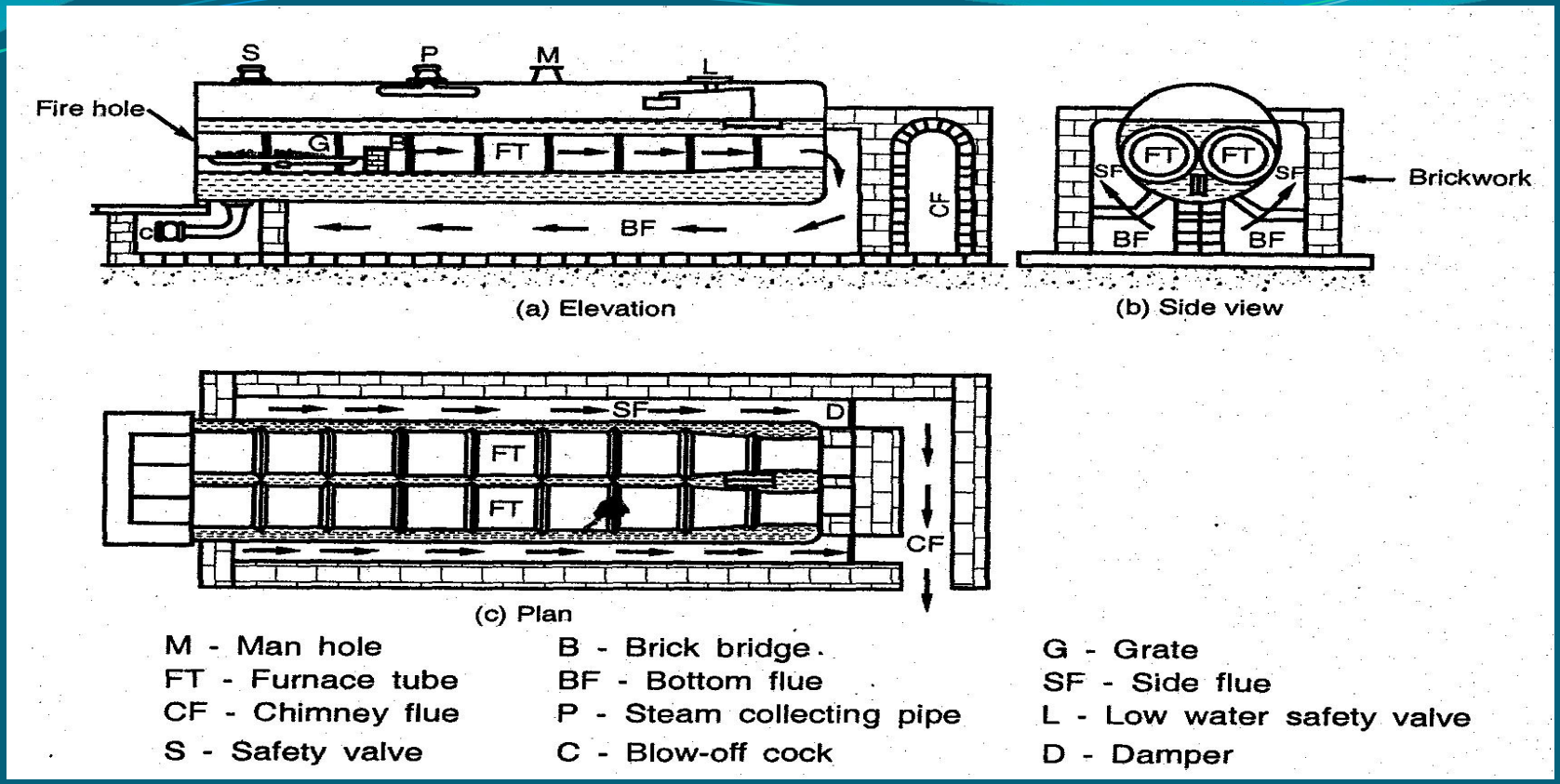
Advantages:

- Compactness and portability
- Low first cost
- Little floor space required per unit power produced
- Quick and easy installation

Disadvantages:

- The interior is not easily accessible for cleaning, inspection and repair.
- Water capacity is small, making it difficult to keep a steady steam pressure.
- Water along with steam may enter the steam pipe under heavy loads due to small steam space.
- Efficiency is low in smaller sizes.

Lancashire Boiler



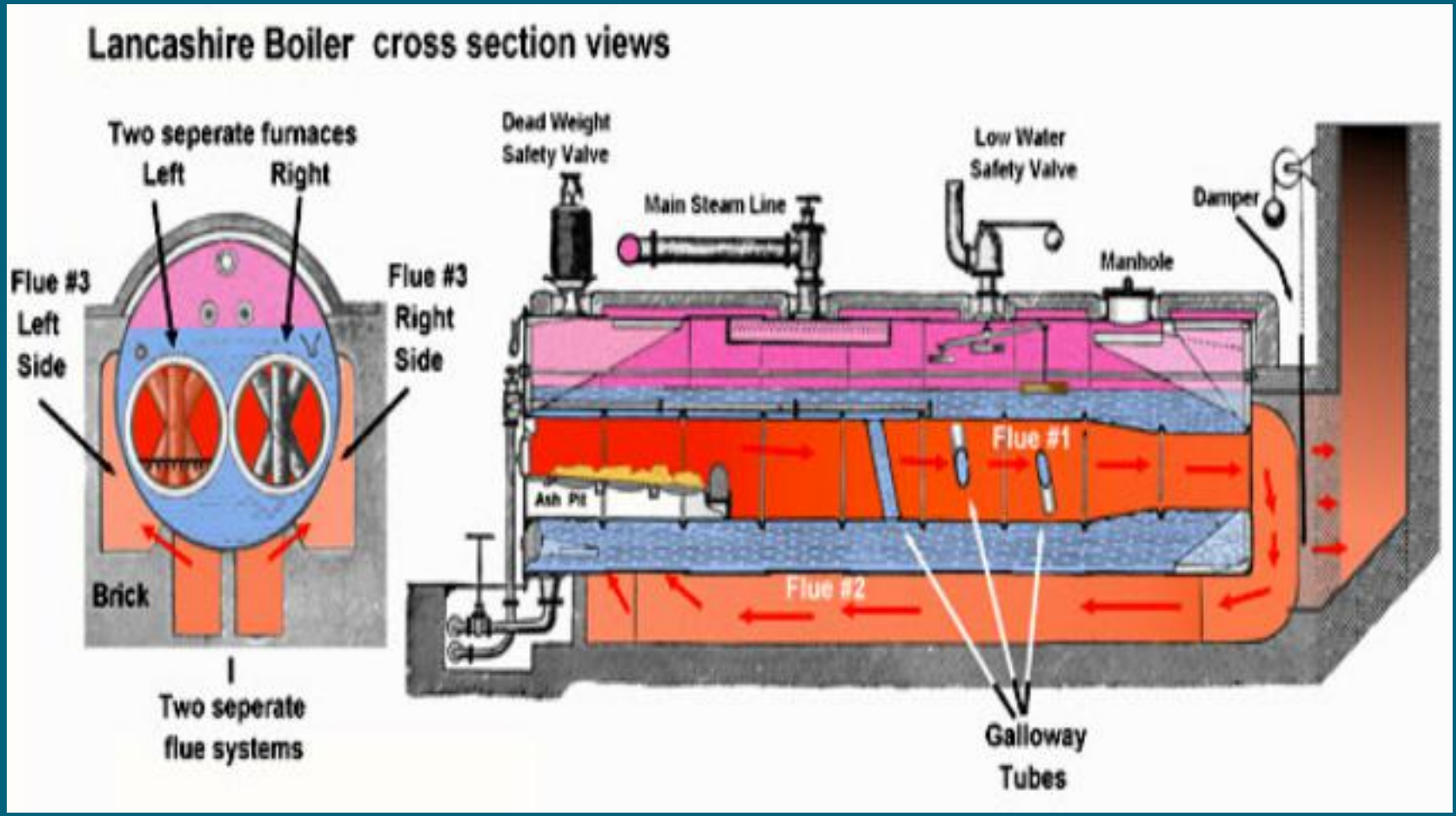
Lancashire boiler is internally fired and flue gases have three passes-one from inside of boiler, second from below and third from the sides of boiler shell.

The boiler has good steaming quality as it is heated from three sides.

It can burn inferior quality coal also.

The boilers have a cylindrical shell of 2 m diameter and length of 8 m to 10 m.

Lancashire Boiler



Lancashire Boiler

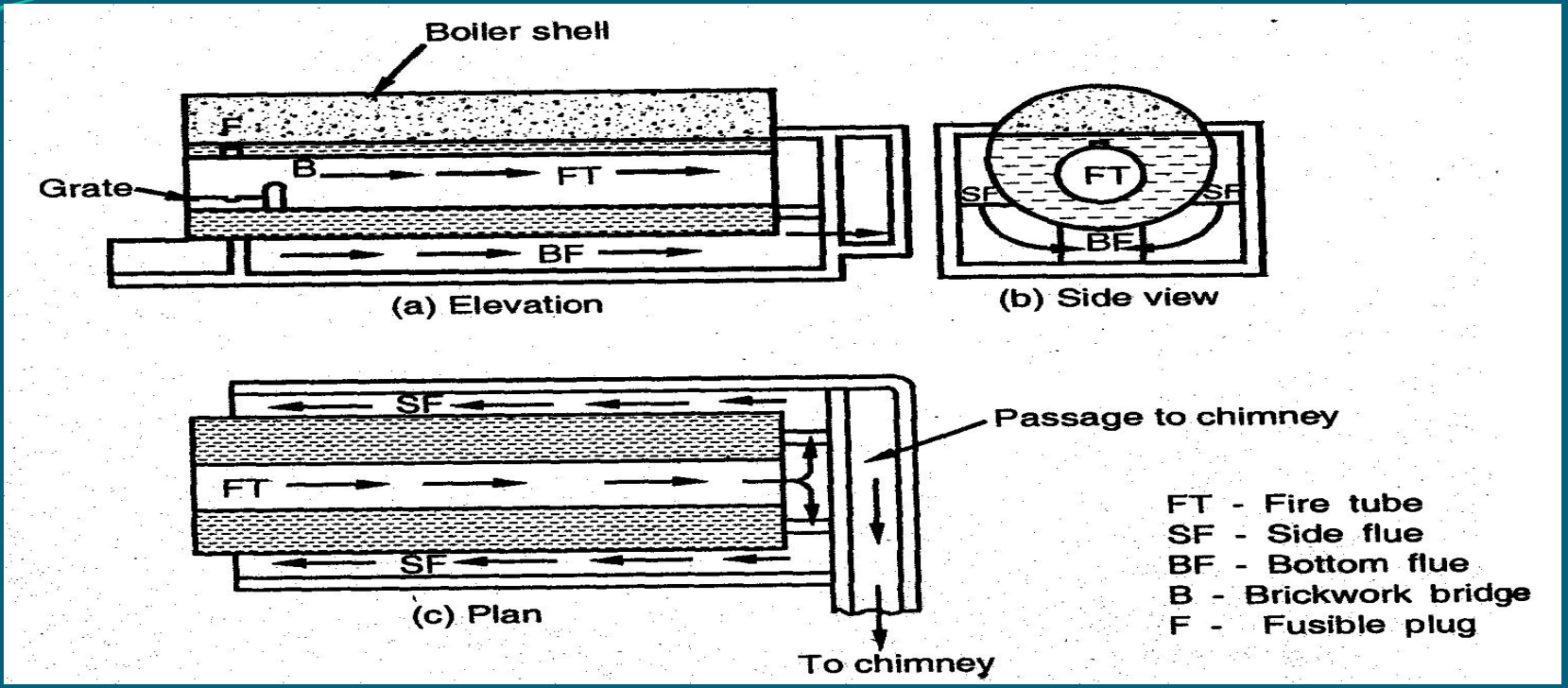
Advantages

- The heating surface area per unit volume of the boiler is considerably large.
- Its maintenance is easy.
- Load fluctuation can be easily met by this boiler due to large reserve capacity for water.
- By incorporating economizer or and super-heater, the efficiency of the boiler can be increased.

Limitations

- It occupies large floor space due to brick work.
- It takes more time to deliver steam at : required pressure and rate.
- The grates are inside the flue tubes. So their area is restricted.
- The maximum pressure is limited to around 15 bar due to shell

Cornish boiler



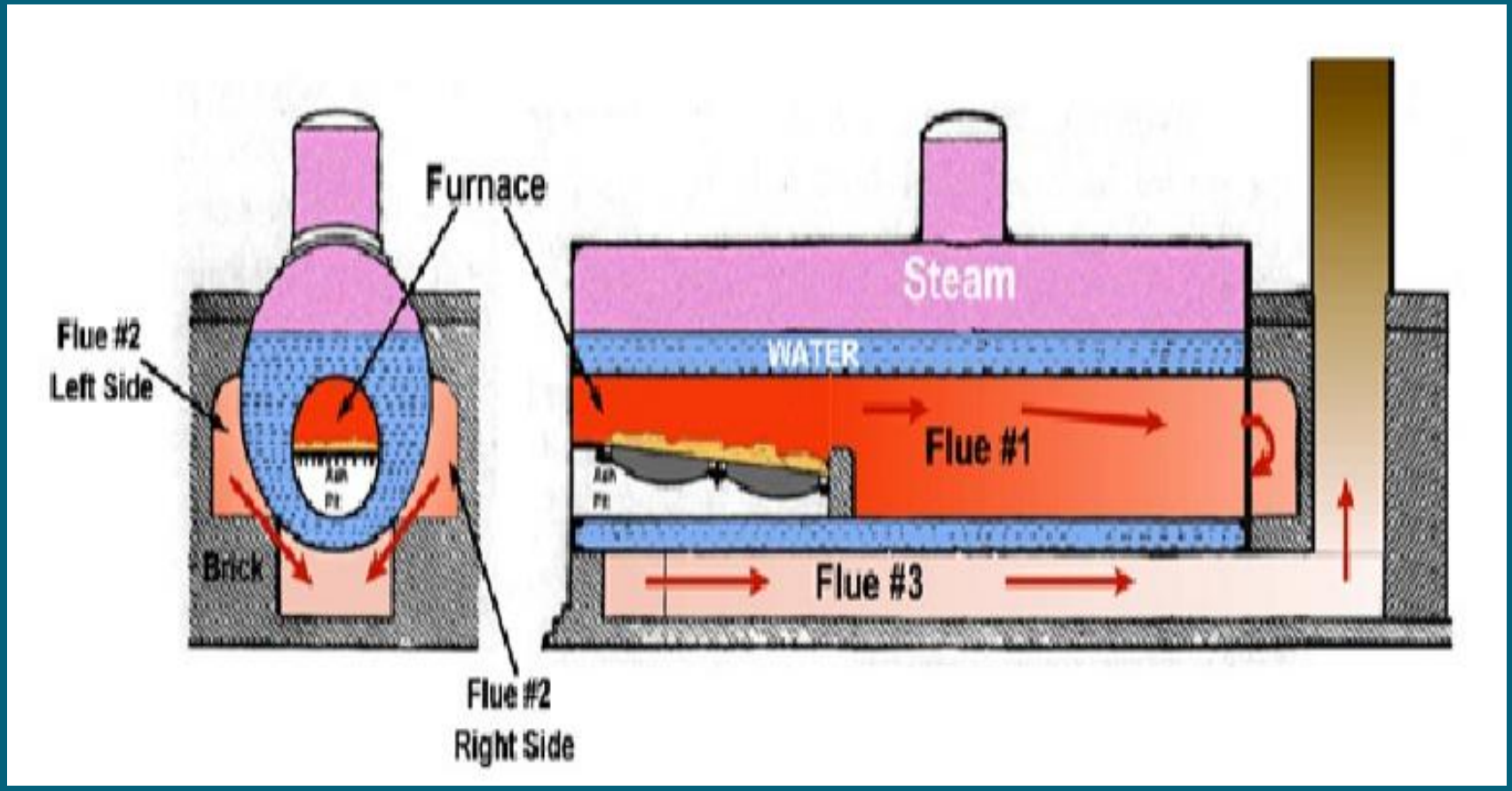
Cornish boiler is similar to the Lancashire boiler in appearance and construction. But it is smaller in size.

It can generate, steam up to 12 bar pressure.

The diameter of shell is around 1.5 m while the length is 4 to 7 meters. The coal is burnt on the grate inside the fire tube.

The brickwork bridge stops coal particles and ash from entering the interior of the fire-tube.

Cornish boiler



Cornish boiler

Advantages

Large steam generation rate per unit heating surface area.

Compact and portable

It can satisfy sudden and fluctuating demands due to variation of power and speed.

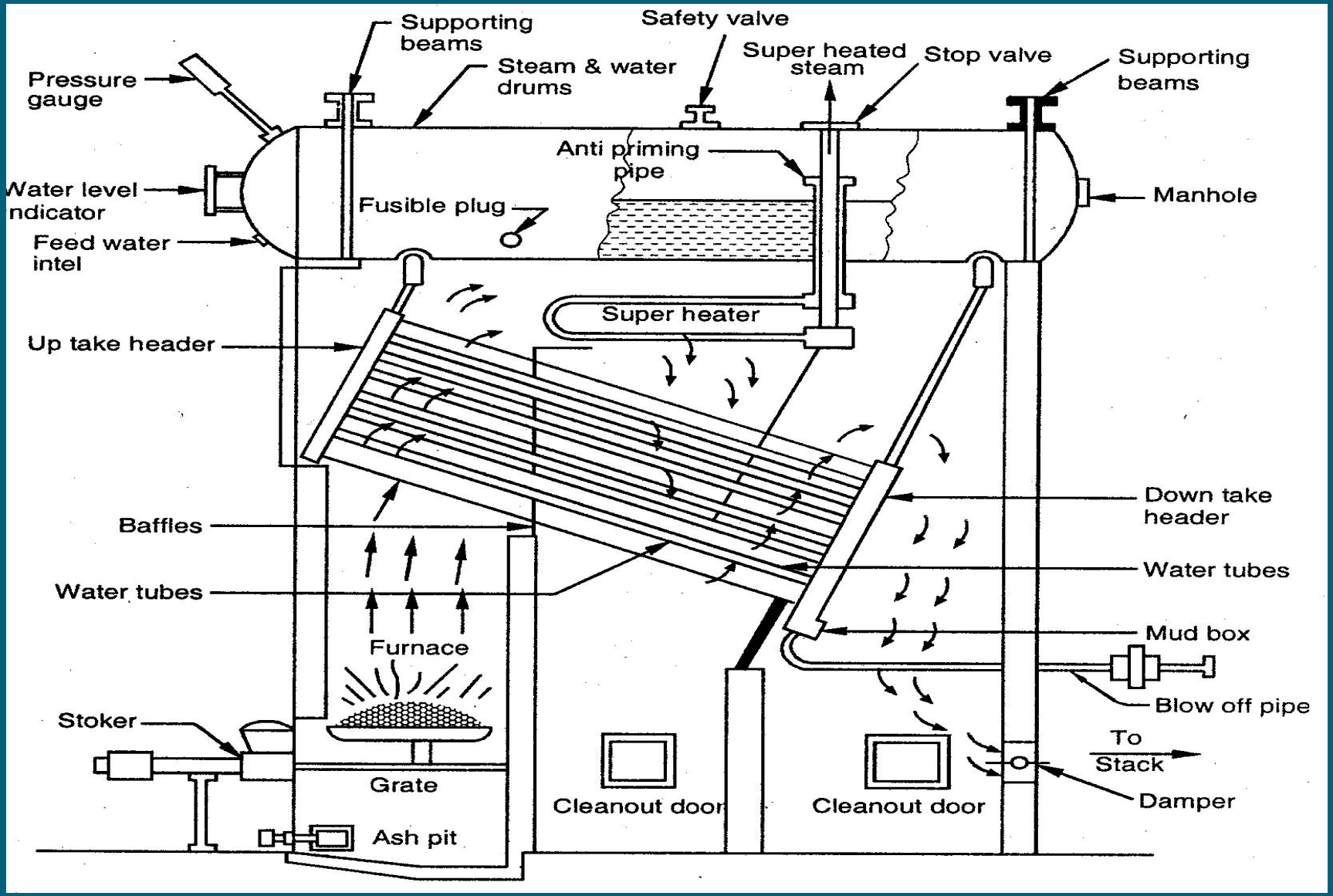
Disadvantages :

Sediments and mud particles may accumulate in the narrow water spaces (water legs) which may lead to scale formation and corrosion. To avoid this, the feed water has to be pure.

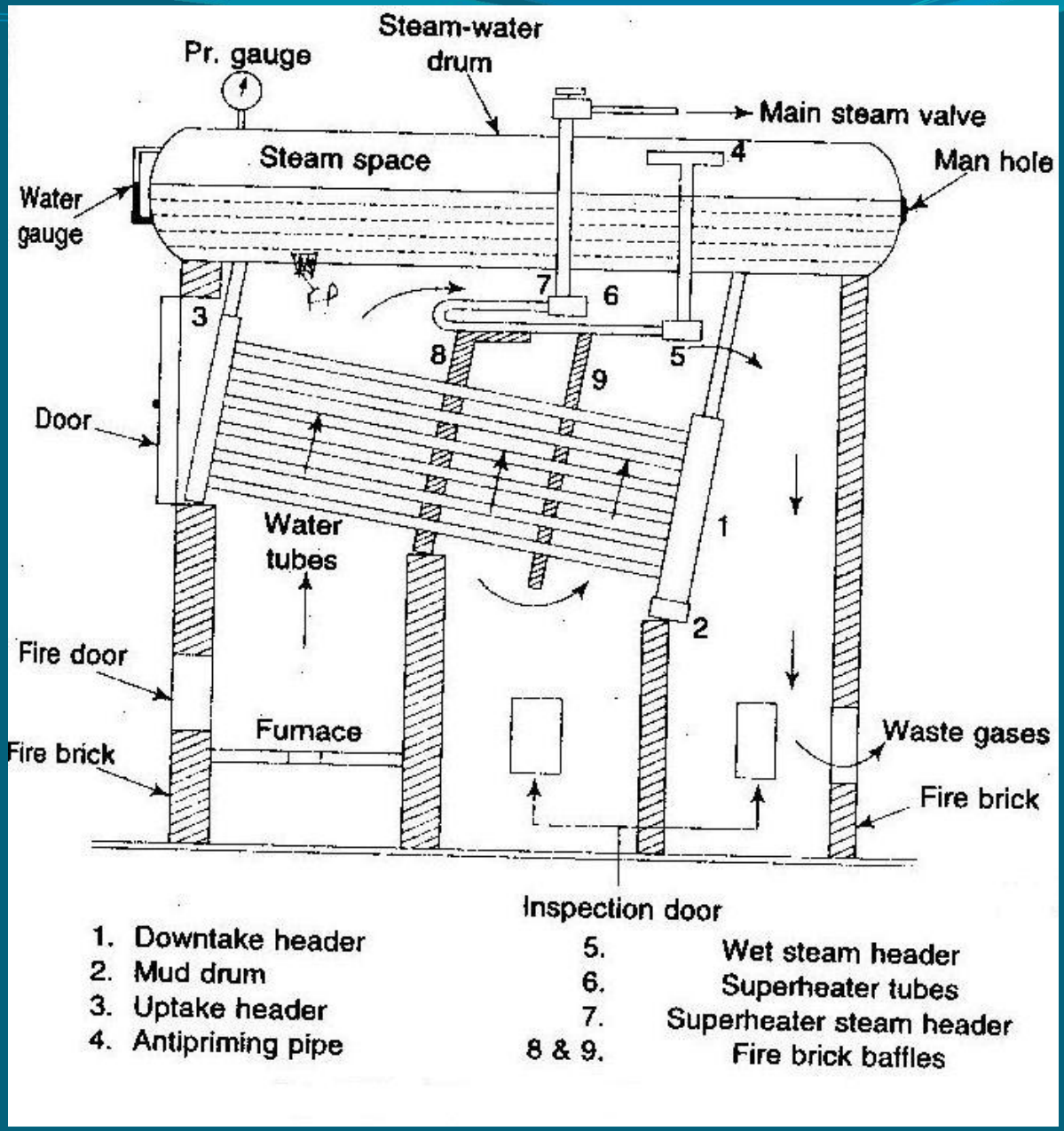
It is difficult to clean some water spaces.

Leakage at tube joints and plates is a problem.

Babcock and Wilcox Boiler



Babcock and Wilcox Boiler



Babcock and Wilcox Boiler

This is a water tube boiler

The steam and water drum (boiler shell) run from front to rear of boiler. It is made of high quality steel. The inclined steel tubes of around 4 inch diameter are connected with pressed steel headers on either side. A short pipe (riser) connect the front header while a longer pipe (down comer) connect the back header with the drum. The headers- are provided with hand holes which are covered with caps. The hand holes are useful to clean the tubes. The mud box collects sediments which are blown away frequently through blow-off valve.

Babcock and Wilcox Boiler

Babcock and Wilcox Boiler :

Advantages of the boiler :

- The steam generation capacity of the boiler is very high (20000 to 40000 kg/hr) as compared to other boilers.
- The defective tubes can be easily replaced.
- The boiler rests over an iron structure, independent of brickwork. So it can expand or contract freely.
- The draught loss (pressure drop of gases) is much less.
- It can generate high quality steam in large amount. So it is used in power stations.
- It occupies less space per unit power generation and offers greater operational safety.

High Pressure Boilers:

A boiler which generates steam at a pressure of 85 bar or above are termed a `high pressure boiler'.

For pressures up to 140 bar, natural circulation is adopted in boilers.

Above 140 bar pressure, the density difference between steam and water is very less and natural circulation is not effective. So forced circulation is adopted for such boilers. High pressure boilers are factory built water-tube boilers.

Boilers generating steam above 100 bar pressure and upto 600°C temperature are called `Modern boilers'.

The boilers that work above the critical pressure

Advantages of High Pressure Boilers

The plant efficiency as high as $40 - 42\%$ can be achieved. This is due to higher specific enthalpy and temperature of steam.

Less scaling on tube walls due to high velocity of feed water.

Can supply steam at operating pressure and temperature quickly after cold start. So it can meet variable load quickly.

Light–weight tubes with better heating characteristics is used to reduce the cost, erection time and space requirement for tube layout.

All parts are uniformly heated in boiler. So there is less danger of overheating and thermal shock.

In forced circulation boilers, there is more liberty in the layout of furnace, tubes and boiler compartments. Forced circulation also increase evapourative capacity.

Boiler are compact and require less floor space per unit power produced. Now we describe different types of high pressure boilers.

BOILER PERFORMANCE

Evaporation :

It is defined as amount of steam produce by a boiler in one hour at full load. It's unit is kg/hr. ,

Evaporation Capacity :

It is defined with reference to heating surface area, furnace volume or amount of fuel burnt.

Evaporation capatity or Evaporation Rate

$$= \frac{\text{Steam produced/hr}}{\text{m}^2 \text{ of heating surface}} = \frac{\text{kg of steam}}{\text{hr} \cdot \text{m}^2}$$

$$= \frac{\text{Steam produced/hr}}{\text{m}^3 \text{ of furnace volume}} = \frac{\text{kg of steam}}{\text{hr} \cdot \text{m}^3}$$

$$= \frac{\text{Steam produced/hr}}{\text{fuel burnt in kg}} = \frac{\text{kg of steam}}{\text{hr} \cdot \text{kg of fuel}}$$

BOILER PERFORMANCE

Comparison of any two boiler is possible only when they operate under same conditions, use same fuel, have same feed water temperature.

In practice these parameters vary considerably. So it is necessary to adopt standard reference working condition (steam pressure and temperature) and feed water temperature.

The Standard pressure is taken as 1.01325 bar (t_{sat} = 100°C), condition after evaporation is dry saturated steam at this pressure and feed water temperature is 100°C.

Under this condition amount of heat required to produce 1 kg of steam is equal to latent heat at 1.01325 bar, which is equal to 2256.9 kJ/ kg. This quantity is known as `Standard Evaporation Unit'.

Equivalent Evaporation

A certain amount of heat say Q kJ is required to produce m kg of steam at given pressure and temperature.

The same quantity of heat is supplied to feed water at standard temperature produces m_e kg of steam at standard pressure and temperature adopted.

This quantity of steam m_e is known as `equivalent evaporation' of m kg of the steam.

Equivalent Evaporation From and At (F & A) at 100°C :

A certain amount of heat say Q kJ is required to produce m kg of steam at given pressure and temperature. The same heat is supplied to feed water at 100°C produces m_e amount of dry saturated steam at 1.01325 bar pressure (100°C). This quantity m_e is known as equivalent evaporation F & A 100°C of m kg of steam.

Since latent heat of evaporation at 1.01325 bar (T_{sat} = 100°C) is 2256.9 kJ/ kg, which is taken as 2257 kJ/kg for all practical calculation

Equivalent Evaporation From and At (F & A) at 100°C :

$$m_e = \frac{Q}{2257} \text{ kg}$$

Let m = mass of water actually evaporated in kg

m_a = mass of water evaporated in kg/hr

m_f = mass of fuel burnt in kg/hr

m_s = mass of water evaporated per kg of fuel burnt in kg of steam/ kg of fuel

h_{fw} = specific enthalpy of feed water

h = specific enthalpy of steam at boiler pressure and temperature

$\therefore$ Q = heat required to produce m kg of steam

$= m (h - h_{fw})$

$$\therefore \quad m_e = \frac{m (h - h_{fw})}{2257} \text{ kg}$$

We have $m_s = \frac{m_a}{m_f}$ = kg of steam/kg of fuel

If we replace m by m_s we can write

$$m_e = \frac{m_s (h - h_{fw})}{2257} \text{ kg/kg of fuel}$$

5.9.5 Factor of Evaporation or Generation Factor :

It is given by following equation

$$\text{Factor of evaporation or Generation factor} = \frac{m_e}{m_s} = \frac{h - h_{fw}}{2257}.$$

Boiler efficiency and Boiler Power

5.9.6 Actual Evaporation (m_a) :

Amount of steam produced by boiler in kg/hr at given pressure and temperature from given feed water temperature is known as actual evaporation.

5.9.7 Boiler Efficiency :

It is ratio of heat energy utilized in converting feed water in to steam to heat liberated by combustion of fuel.

$$\therefore \quad \eta_{boiler} = \frac{m_a\,(h - h_{fw})}{m_f \times C.V.} = \frac{m_s\,(h - h_{fw})}{C.V.}$$

5.9.8 Boiler Power :

It is defined as follow

$$\text{Boiler power} = \frac{\text{Equivalent evaporation / hr F and A } 100^{\circ}C}{21.296} \text{ kW}$$

here m_e is corresponding to m_a, since equivalent evaporation/hr (rather than kg of steam/kg of fuel) is to be substituted.

$$m_e = \frac{m_a\,(h - h_{fw})}{2257} \text{ kg/hr}$$