Steam Power Plant

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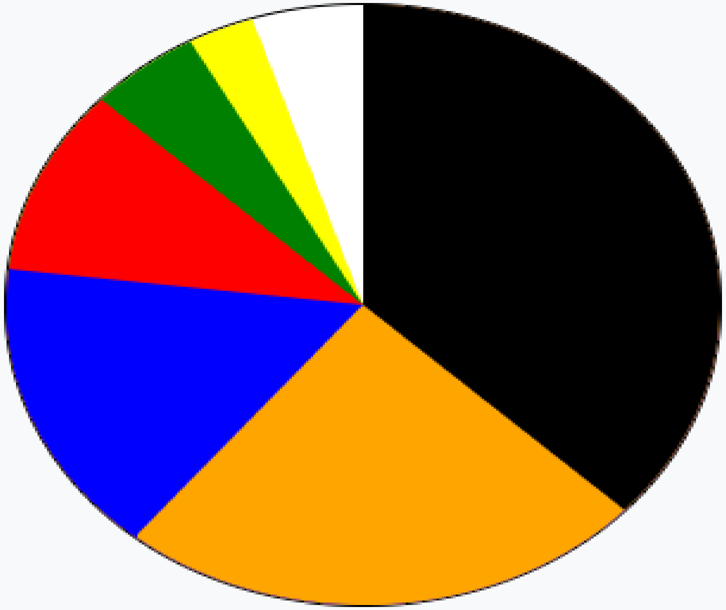
Power plant

Steam power plants form the largest contribution for electricity generation. Water is heated in a boiler with the help of a fuel or steam generator in a nuclear reactor to form superheated steam. This high pressure and high temperature steam rotates a steam turbine to produce mechanical work and then electrical power. The steam power plants can operate as:

1. Thermal power plants where chemical energy of a fossil fuel (coal, oil, gas) is released into heat by combustion to raise steam.
2. Nuclear power plants where nuclear reactions of fission or fusion release heat to generate steam.
3. Geothermal power plants where springs of hot water or steam from the interior earth can be directly used to turn a turbine.
4. Solar power plants where solar rays are focused and collected to raise steam.

In ocean thermal power plants, the hot water at the water surface of the sea can be used to run a power plant.

Coal is most abundantly available in India and other countries and is the main fuel for steam power plants.



2019 world electricity generation

- Coal (37%)
- Natural gas (24%)
- Hydro (16%)
- Nuclear (10%)
- Wind (5%)
- Solar (3%)
- Other (5%)

➢ Thermal energy is the major source of power generation in India.
More than 60% of electric power is produced by steam plants in India. India has large deposit of coal (about 170 billion tonnes), 5th largest in world. Indian coals are classified as A-G grade coals.

➢ In Steam power plants, the heat of combustion of fossil fuels is utilized by the boilers
to raise steam at high pressure and temperature. The steam so produced is used in driving the steam turbines or sometimes steam engines couples to generators and thus in generating electrical energy.

➢ Steam turbines or steam engines used in steam power plants not only act as prime movers but also as drives for auxiliary equipment, such as pumps, stokers fans etc.

➢ Steam power plants may be installed either to generate electrical energy only or generate electrical energy along with generation of steam for industrial purposes such as in paper mills, textile mills, sugar mills and refineries, chemical works, plastic manufacture, food manufacture etc.

➢ The steam for process purposes is extracted from a certain section of turbine and the remaining steam is allowed to expand in the turbine. Alternatively the exhaust steam may be used for process purposes.

➢ Thermal stations can be private industrial plants and central station.

Advantages And Disadvantages Of A Thermal Power Plant

Advantages:

- Less initial cost as compared to other generating stations.
- It requires less land as compared to hydro power plant.
- The fuel (i.e. coal) is cheaper.
- The cost of generation is lesser than that of diesel power plants.

Disadvantages:

- It pollutes the atmosphere due to the production of large amount of smoke. This is one of the causes of global warming.
- The overall efficiency of a thermal power station is low (less than 30%).
- Requires long time for errection and put into action.
- Costlier in operating in comparison with that of Hydro and Nuclear power plants.
- Requirement of water in huge quantity.

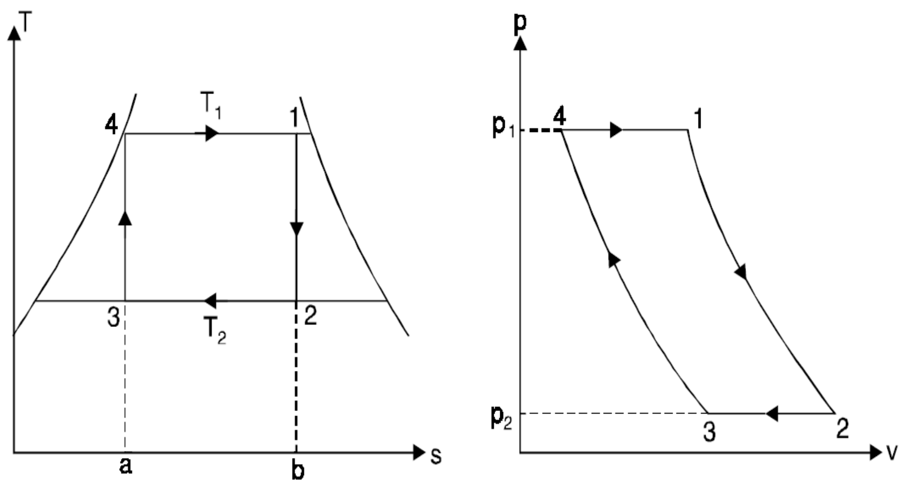
CARNOT CYCLE

1. **Operation (4-1).** 1 kg of boiling water at temperature $T1$ is heated to form wet steam of dryness fraction $x1$. Thus heat is absorbed at constant temperature $T1$ and pressure $p1$ during this operation.

2. **Operation (1-2).** During this operation steam is expanded isentropically to temperature $T2$ and pressure $p2$. The point '2' represents the condition of steam after expansion.

3. **Operation (2-3).** During this operation heat is rejected at constant pressure $p2$ and temperature $T2$. As the steam is exhausted it becomes wetter and cooled from 2 to 3.

4. **Operation (3-4).** In this operation the wet steam at '3' is compressed isentropically till the steam regains its original state of temperature $T1$ and pressure $p1$. Thus cycle is completed.



Carnot cycle on T-s and p-V diagrams.

Net work done = Heat supplied – heat rejected

$$= T_1 (s_2 - s_3) - T_2 (s_2 - s_3)$$

$$= (T_1 - T_2)(s_2 - s_3).$$

$$\text{Carnot cycle } \eta = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{(T_1 - T_2)(s_2 - s_3)}{T_1 (s_2 - s_3)} = \frac{T_1 - T_2}{T_1}$$

Limitations of Carnot Cycle

1. It is difficult to compress a wet vapour isentropically to the saturated state as required by the process 3-4.

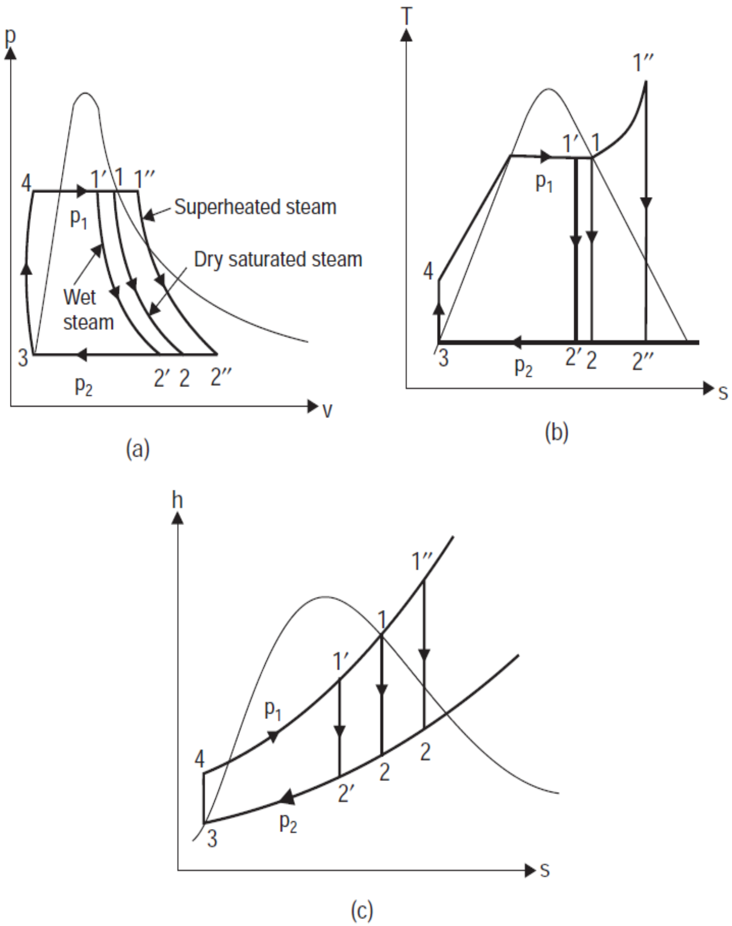
2. It is difficult to control the quality of the condensate coming out of the condenser so that the state '3' is exactly obtained.

3. The efficiency of the Carnot cycle is greatly affected by the temperature $T1$ at which heat is transferred to the working fluid. Since the critical temperature for steam is only 374°C, therefore, if the cycle is to be operated in the *wet region*, the maximum possible temperature is severely limited.

4. The cycle is still more difficult to operate in practice with superheated steam due to the necessity of supplying the superheat at constant temperature instead of constant pressure (as it is customary).

RANKINE CYCLE

VAPOUR POWER CYCLES

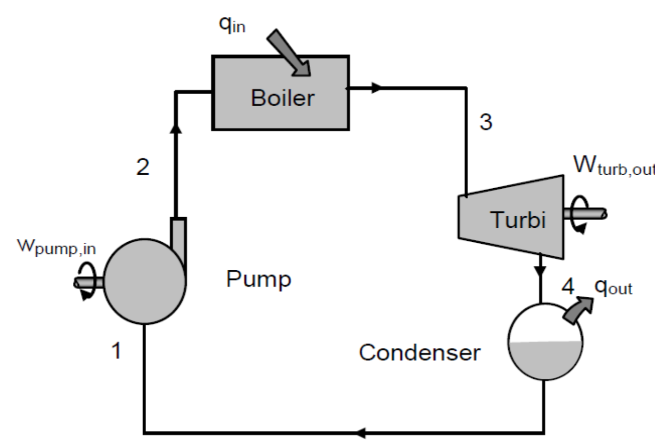


Process 1-2 : Reversible adiabatic expansion in the turbine

Process 2-3 : Constant-pressure transfer of heat in the condenser.

Process 3-4 : Reversible adiabatic pumping process in the feed pump.

Process 4-1 : Constant-pressure transfer of heat in the boiler.



Working of Rankine cycle

Steam power plant basically works on the Rankine cycle in which steam and water is working fluid.

In the boiler steam is generated from water by burning of coal. The Steam which is expanded in a turbine, which produces mechanical power. The output power of turbine is utilized to run the generator. The steam after expansion in turbine is usually condensed in a condenser. The condensed steam (Water) is again feed to the boiler and cycle is repeated.

Considering 1 kg of fluid :

Applying steady flow energy equation (S.F.E.E.) to boiler, turbine, condenser and pump :

(i) For boiler (as control volume)

$$Q_1 = h_1 - h_4$$

(*ii*) **For turbine** (as control volume)

$$W_T = h_1 - h_2$$

(*iii*) **For condenser**

$$Q_2 = h_2 - h_3$$

(*iv*) **For the feed pump**

$$W_P = h_4 - h_3$$

Efficiency of Rankine cycle

$$\eta_{Rankine} = \frac{W_{net}}{Q_1}$$

$$= \frac{h_1 - h_2}{h_1 - h_4}$$

Increase the Efficiency of the Rankine cycle

- Superheating the steam to high temperatures (Increases T_{high}*(mean)*.

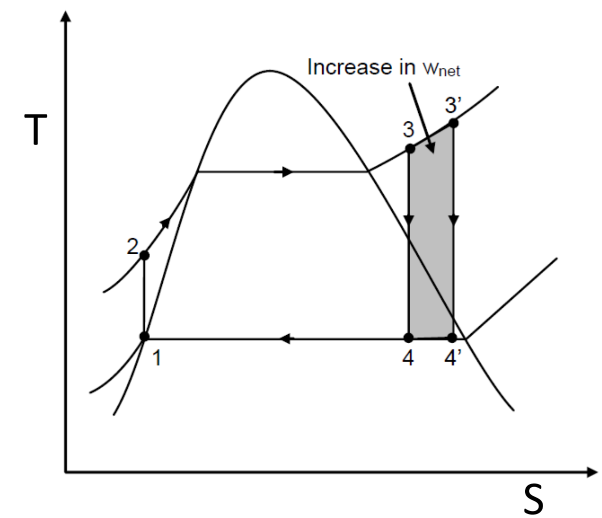
- Increasing the boiler pressure (Increases T_{high}*(mean)*.
- Reheating

Increasing the Boiler Pressure: The mean temperature during the heat addition process is to increase the operating pressure of the boiler, which automatically raises the temperature at which boiling take place. Increase the thermal efficiency of the cycle .

- ❖ Increase in turbine work
- ❖ Increase in mean temperature of heat addition
- ❖ Decrease in heat rejection
- ❖ Increase in efficiency
- ❖ Decrease in dryness fraction at exit of turbine

Superheating the steam: The average temperature at which heat is added to the steam can be increased without increasing the boiler pressure by superheating the steam to high temperatures. Superheating the steam to higher temperatures has very desirable effect : It decreases the moisture content of the steam at the turbine exit . The temperature to which steam can be superheated is limited by metallurgical consideration .

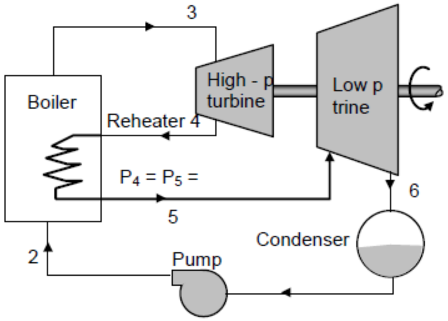
- ❖Increase in turbine work
- ❖Increase in mean temperature of heat addition
- ❖Increase in heat rejection
- ❖Increase in efficiency
- ❖Increase in dryness fraction at exit of turbine
- ❖Increase in heat supply

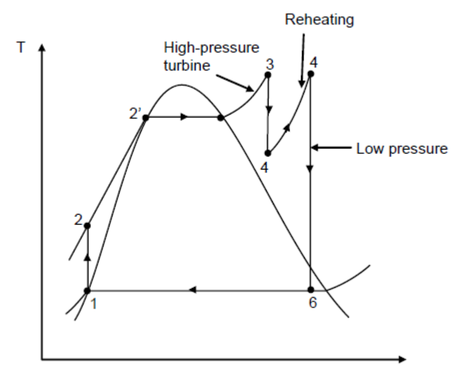


✓ Steam is heated by flue gases

Reheating : The efficiency of the Rankine cycle can increase by expanding the steam in the turbine in two stages, and reheating it in between. Reheating is a practical solution to the excessive moisture problem in turbines, and it is commonly used in modern steam power plants.

In first stage (the high-pressure turbine), steam is expanded isentropically to an intermediate pressure and sent back to the boiler where it is reheated at constant pressure, usually to the inlet temperature of the first turbine stage. Steam then expands isentropically in the second stage (low-pressure turbine) to the condenser pressure.



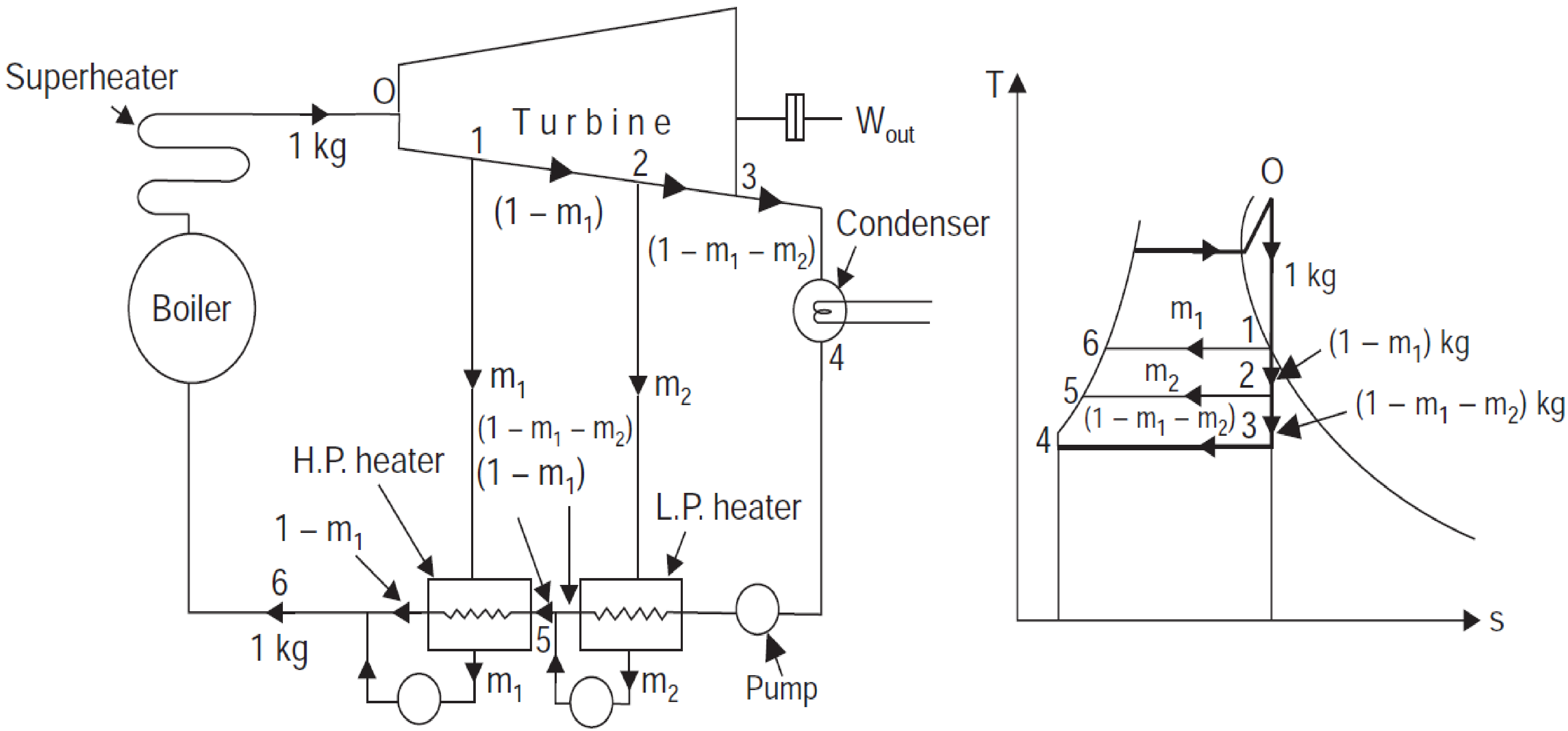


(b)

Regenerative Rankine Cycle

In the Rankine cycle it is observed that the condensate which is fairly at low temperature has an irreversible mixing with hot boiler water and this results in decrease of cycle efficiency. Methods are, therefore, adopted to heat the feed water from the hot well of condenser irreversibly by interchange of heat within the system and thus improving the cycle efficiency. This heating method is called regenerative feed heat and the cycle is called regenerative cycle.

The principle of regeneration can be practically utilised by extracting steam from the turbine at several locations and supplying it to the regenerative heaters. The resulting cycle is known as regenerative or bleeding cycle



Regenerative cycle.

Let, m_1 = kg of high pressure (H.P.) steam per kg of steam flow,

m_2 = kg of low pressure (L.P.) steam extracted per kg of steam flow, and

$(1 - m_2 - m_2)$ = kg of steam entering condenser per kg of steam flow.

Neglecting pump work :

The heat supplied externally in the cycle

$$= (h_0 - h_{f_6})$$

Isentropic work done $= m_1 (h_0 - h_1) + m_2 (h_0 - h_2) + (1 - m_1 - m_2)(h_0 - h_3)$

The thermal efficiency of regenerative cycle is

$$\eta_{\text{thermal}} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{m_1 (h_0 - h_1) + m_2 (h_0 - h_2) + (1 - m_1 - m_2)(h_0 - h_3)}{(h_0 - h_{f_6})}$$

Advantages of Regenerative cycle over Simple Rankine cycle

1. The heating process in the boiler tends to become reversible.
2. The thermal stresses set up in the boiler are minimized. This is due to the fact that temperature ranges in the boiler are reduced.
3. The thermal efficiency is improved because the average temperature of heat addition to the cycle is increased.
4. Heat rate is reduced.
5. The blade height is less due to the reduced amount of steam passed through the low pressure stages.
6. Due to many extractions there is an improvement in the turbine drainage and it reduces erosion due to moisture.
7. A small size condenser is required.

Disadvantages :

1. The plant becomes more complicated.
2. Because of addition of heaters greater maintenance is required.
3. For given power a large capacity boiler is required.
4. The heaters are costly and the gain in thermal efficiency is not much in comparison to the heavier costs.

Layout of **Steam Power Plant**

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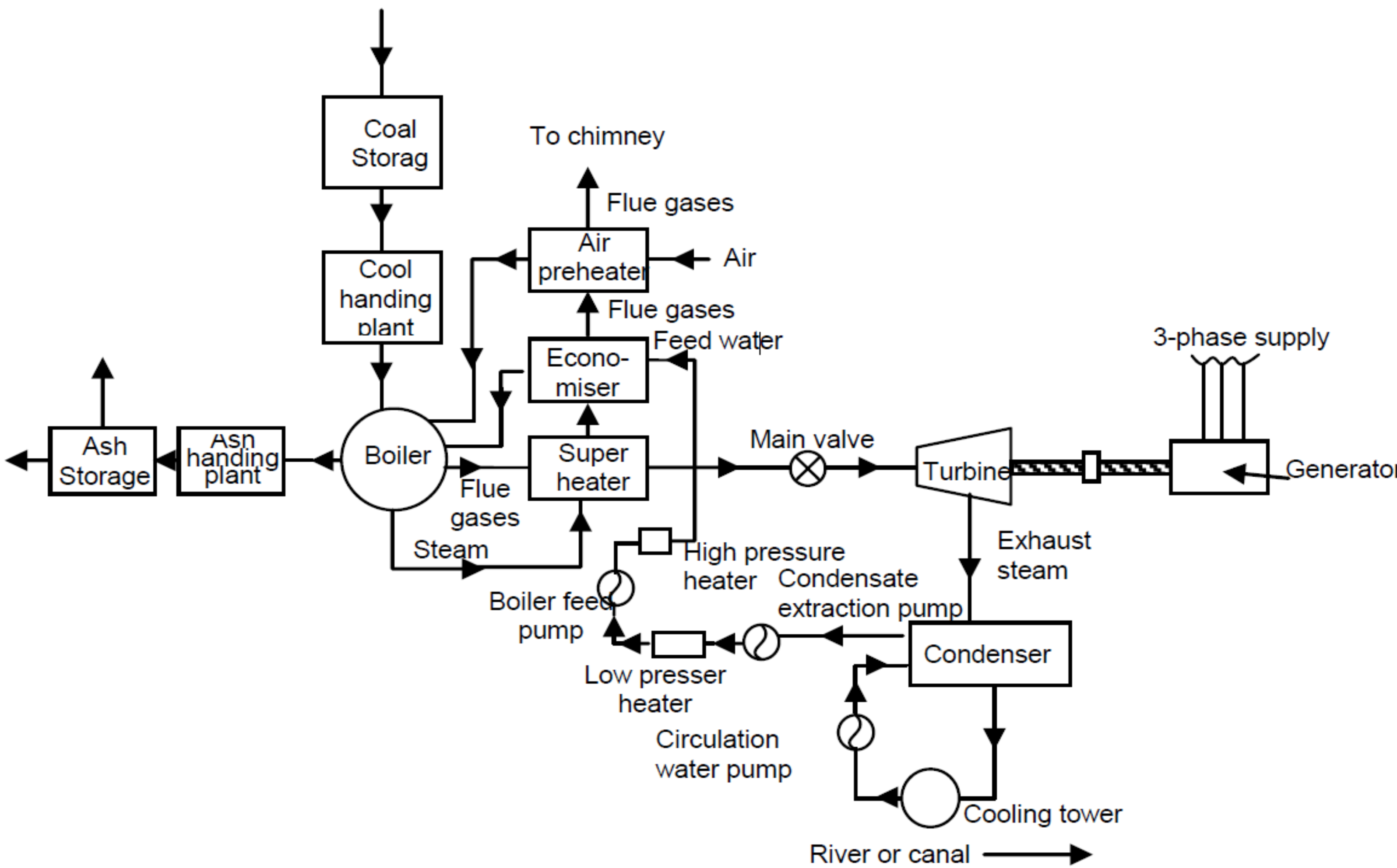
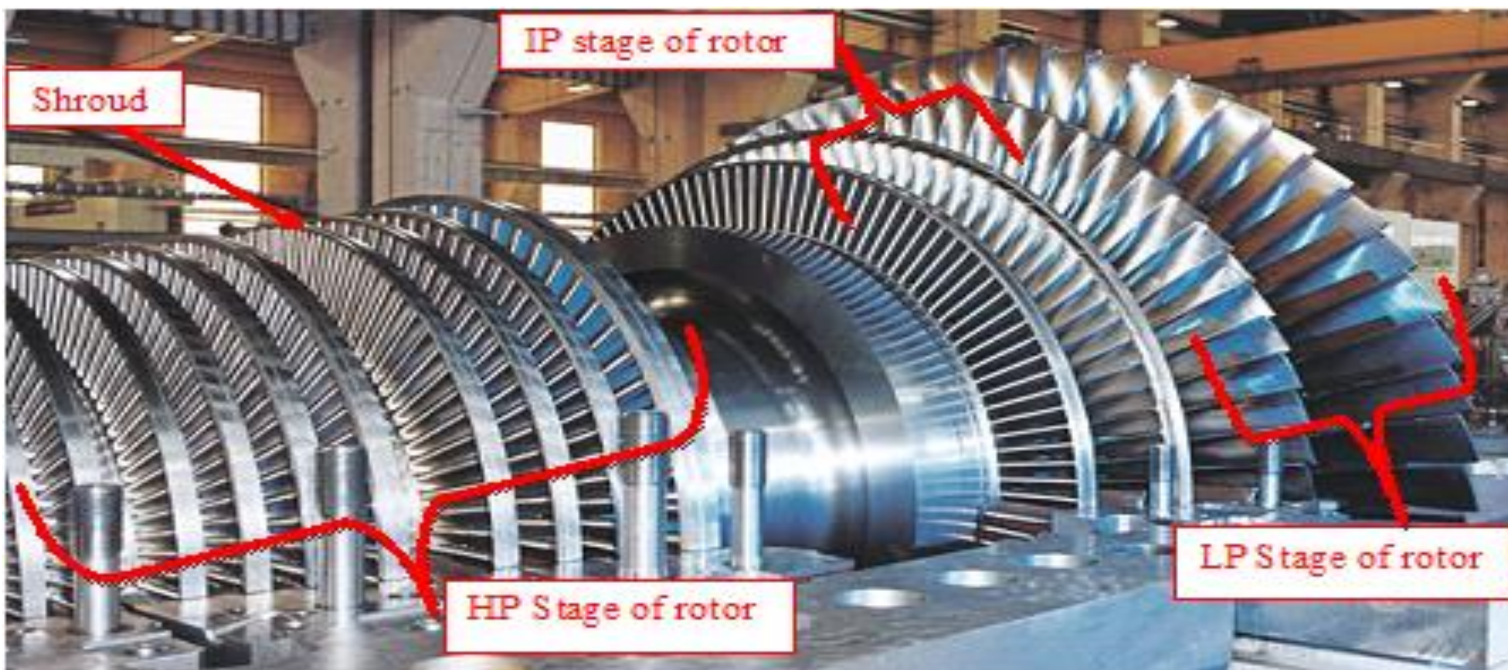
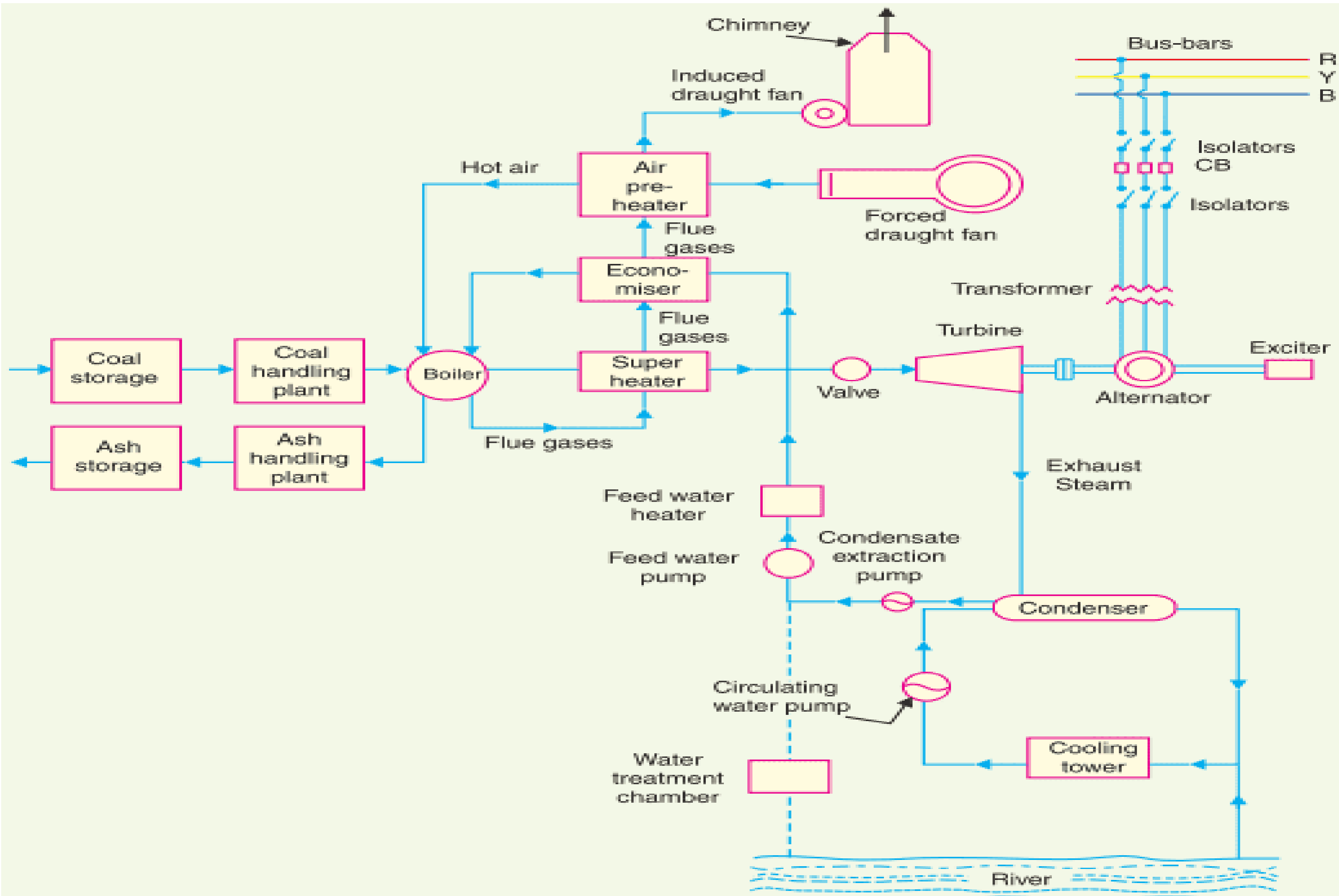



IP stage of rotor
Shroud
LP Stage of rotor
HP Stage of rotor



Chimney
Induced draught fan
Bus-bars
R
Y
B
Isolators
CB
Isolators
Hot air
Air pre-heater
Forced draught fan
Flue gases
Econo-miser
Transformer
Flue gases
Turbine
Exciter
Coal storage
Coal handling plant
Boiler
Super heater
Valve
Alternator
Ash storage
Ash handling plant
Flue gases
Exhaust Steam
Feed water heater
Condensate extraction pump
Feed water pump
Condenser
Circulating water pump
Cooling tower
Water treatment chamber
River

Essentials of Steam Power Plant Equipment

A modern steam power plant comprises of the following components :

1. Boiler
(i) Superheater (ii) Reheater
(iii) Economiser (iv) Air-heater.
2. Steam turbine
3. Generator
4. Condenser
5. Cooling towers
6. Circulating water pump
7. Boiler feed pump
8. Wagon tippler
9. Crusher house
10. Coal mill
11. Induced draught fans
12. Ash precipitators
13. Boiler chimney
14. Forced draught fans
15. Water treatment plant
16. Control room
17. Switch yard.

Selection of site for thermal power plant

- Nearness to the load centre
- Water resources
- Availability of Coal
- Land Requirement
- Transportation Facilities
- Labour supplies
- Ash Disposal
- Distance from populated area

Nearness to the load center

The power plant should be as near as possible to the load centre to the centre of load. So that the transmission cost and losses are minimum.

Water resources

For the construction and operating of power plant large volumes of water are required for the following reasons

(i) To raise the steam in boiler.
(ii) For cooling purpose such as in condensers
(iii) As a carrying medium such as disposal of ash.
(iv) For drinking purposes.

Availability of Coal: Huge amount of coal is required for raising the steam. The steam power plants should be located near the coal mines to avoid the transport of coal & ash.

Land Requirement:
The land is required not only for setting up the plant but for other purposes also such as staff colony, coal storage, ash disposal etc.
Eg: For 2000MW plant, the land requirement may be of the order of 200-250 acres. As the cost of the land adds up to the final cost of the plant, it should be available at a reasonable price. Land should be available for future extension.

Transportation Facilities:

The facilities must be available for transportation of heavy equipment and fuels e.g near railway station.

Labour supplies: Skilled and unskilled laborers should be available at reasonable rates near the site of the plant.

Ash Disposal: Ash is the main waste product of the steam power plant and with low grade coal, it may be 3.5 tones per day , some suitable means for disposal of ash should be though of. It may be purchased by building contractors, or it can be used for brick making near the plant site. If the site is near the coal mine it can be dumped into the disused mines. In case of site located near a river,sea or lake ash can be dumped into it.

Distance from populated area: The continuous burning of coal at the power station Produces smoke, fumes and ash which pollute the surrounding area. Such a pollution due to smoke is dangerous for the people living around the area. Hence, the site of a plant should be at a considerable distance from the populated area.

The layout of a modern steam power plant comprises of the following four circuits :

1. Coal and ash circuit.
2. Air and gas circuit.
3. Feed water and steam flow circuit.
4. Cooling water circuit.

Coal and Ash Circuit. Coal arrives at the storage yard and after necessary handling, passes on to the furnaces.

Ash resulting from combustion of coal collects at the back of the boiler and is removed to the ash storage yard through *ash handling equipment*.

Air and Gas Circuit. Air is taken in from atmosphere through the action of a forced . Passes on to the furnace through the *air preheater*, where it has been heated by the heat of flue gases which pass to the chimney *via* the preheater. The flue gases after passing around boiler tubes and superheater ,economiser, and finally through the air preheater before being exhausted to the atmosphere.

Feed Water and Steam Flow Circuit. Condensate is first heated in a closed feed water heater through extracted steam from the lowest pressure extraction point of the turbine. It then passes through the *deaerator* and a few
more water heaters before going into the boiler through *economiser*.
In the boiler drum and tubes, water circulates due to the difference between the density of water in the lower temperature and the higher temperature sections of the boiler. Wet steam from the drum is further heated up in the superheater for being supplied to the prime mover.

Functions of some important parts

1. ***Boiler.*** Water is converted into wet steam.
2. ***Superheater.*** It converts wet steam into superheated steam.
3. ***Turbine.*** Steam at high pressure expands in the turbine and drives the generator.
4. ***Condenser.*** It condenses steam used by the steam turbine. The condensed steam (known as *condensate*) is used as a feed water.
5. ***Cooling tower.*** It cools the condenser circulating water. Condenser cooling water absorbs heat from steam. This heat is discharged to atmosphere in cooling water.
6. ***Condenser circulating water pump.*** It circulates water through the condenser and the cooling tower.
7. ***Feed water pump.*** It pumps water in the water tubes of boiler against boiler steam pressure.
8. ***Economiser.*** In economiser heat in flue gases is partially used to heat incoming feed water.
9. ***Air preheater.*** In air preheater heat in flue gases (the products of combustion) is partially used to heat incoming air.

BOILER

A boiler (or steam generator) is a closed vessel in which water, under pressure , is converted into steam. The heat is transferred to the boiler by all three modes of heat transfer i.e. conduction ,convection and radiation.

Types of boilers

(i) fire tube boiler and (ii) water tube boiler

(iii)Horizontal, vertical or inclined

(iv) Externally fired and internally fired

Boiler Terms

Shell The shell of a boiler consists of one or more steel plates bent into a cylindrical form and riveted or welded together. The shell ends are closed with the end plates.

Setting The primary function of setting is to confine heat to the boiler and form a passage for gases. It is made of brickwork and may form the wall of the furnace and the combustion chamber.

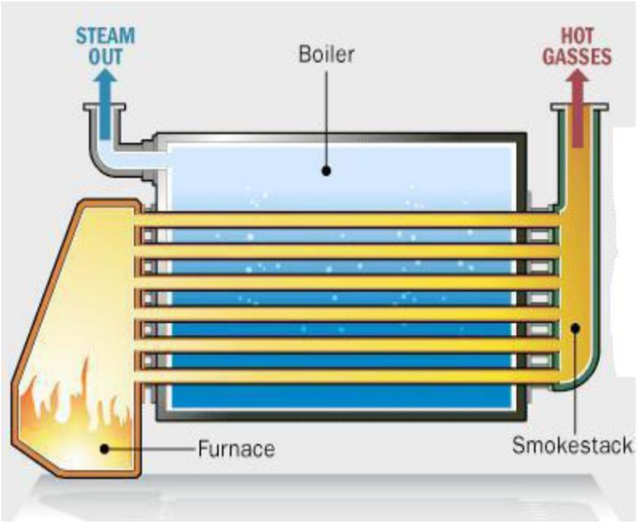
Grate It is the platform in the furnace upon which fuel is burnt and it is made of cast iron bars. The bars are so arranged that air may pass on to the fuel for combustion. The area of the grate on which the fire rests in a coal or wood fired boiler is called grate surface

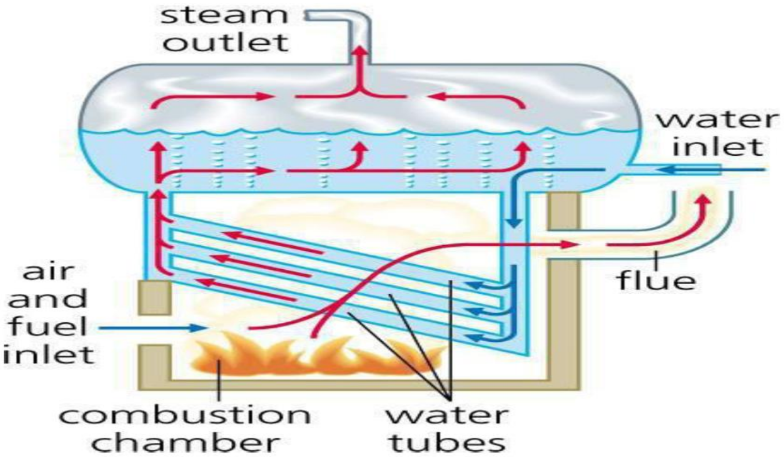
Mountings The items such as stop valve, safety valves, water level gauges, fusible plug, blow-off cock, pressure gauges, water level indicator etc. are termed as mountings and a boiler cannot work safely without them.

Accessories The items such as super heaters, economisers, feed pumps etc. are termed as accessories and they form integral part of the boiler. They increase the efficiency of the boiler.

Scale A deposit of medium to extreme hardness occurring on water heating surfaces of a boiler because of an undesirable condition in the boiler water.

Blowing off The removal of the mud and other impurities of water from the lowest part of the boiler (where they usually settle) is termed as blowing off .

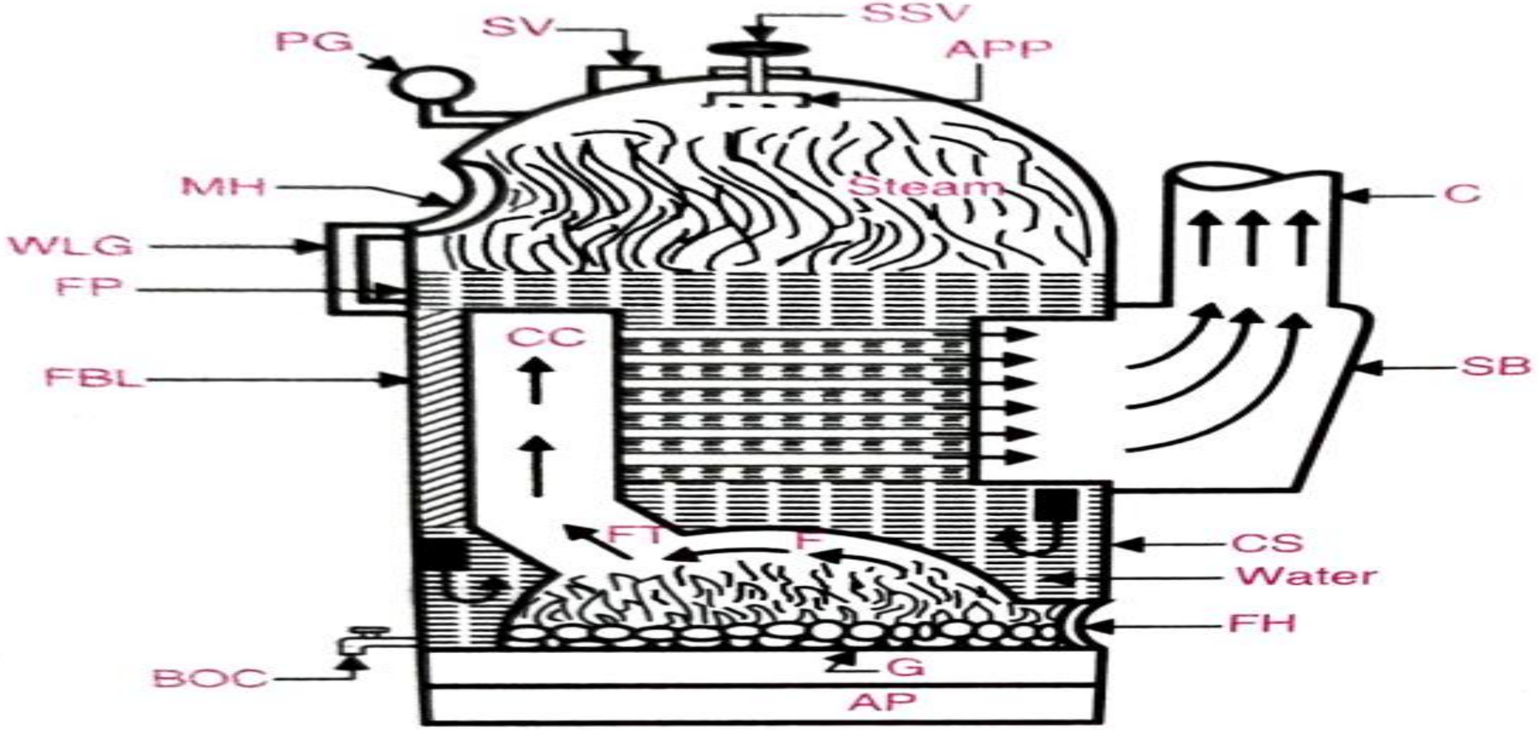




Fire Tube Boiler

Water tube boiler

Cochran boiler

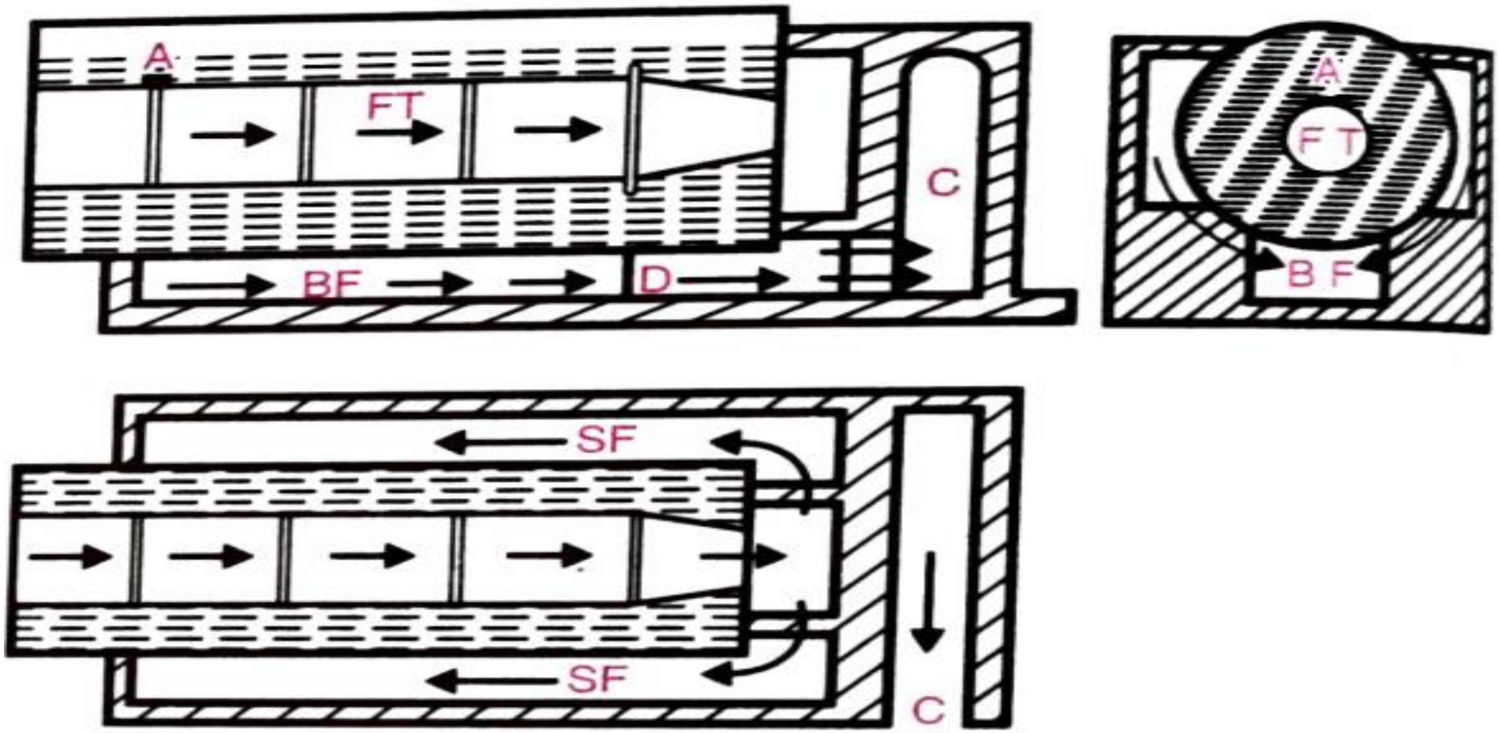


CS = Cylindrical shell
CC = Combustion chamber
FBL = Fir brick lining
F = Furnace (dome shaped)
G = Grate
AP = Ash pit
SV = Safety valve
MH = Man hole
WLG = Water level gauge
FT = Flue tube
SB = Smoke box
C = Chimney
FH = Fire hole
BOC = Blow-off cock
SSV = Steam stop valve
APP = Antipriming pipe
PG = Pressure gauge

Specifications

1	**Shell diameter**	**2.75 m**
2	Height	5.79 m
3	Working pressure	6.5 bar (max. pressure = 15 bar)
4	Steam capacity	3500 kg/h (max. capacity = 4000 kg/h)
5	Efficiency	70 to 75% (depending on the fuel used)

Cornish boiler

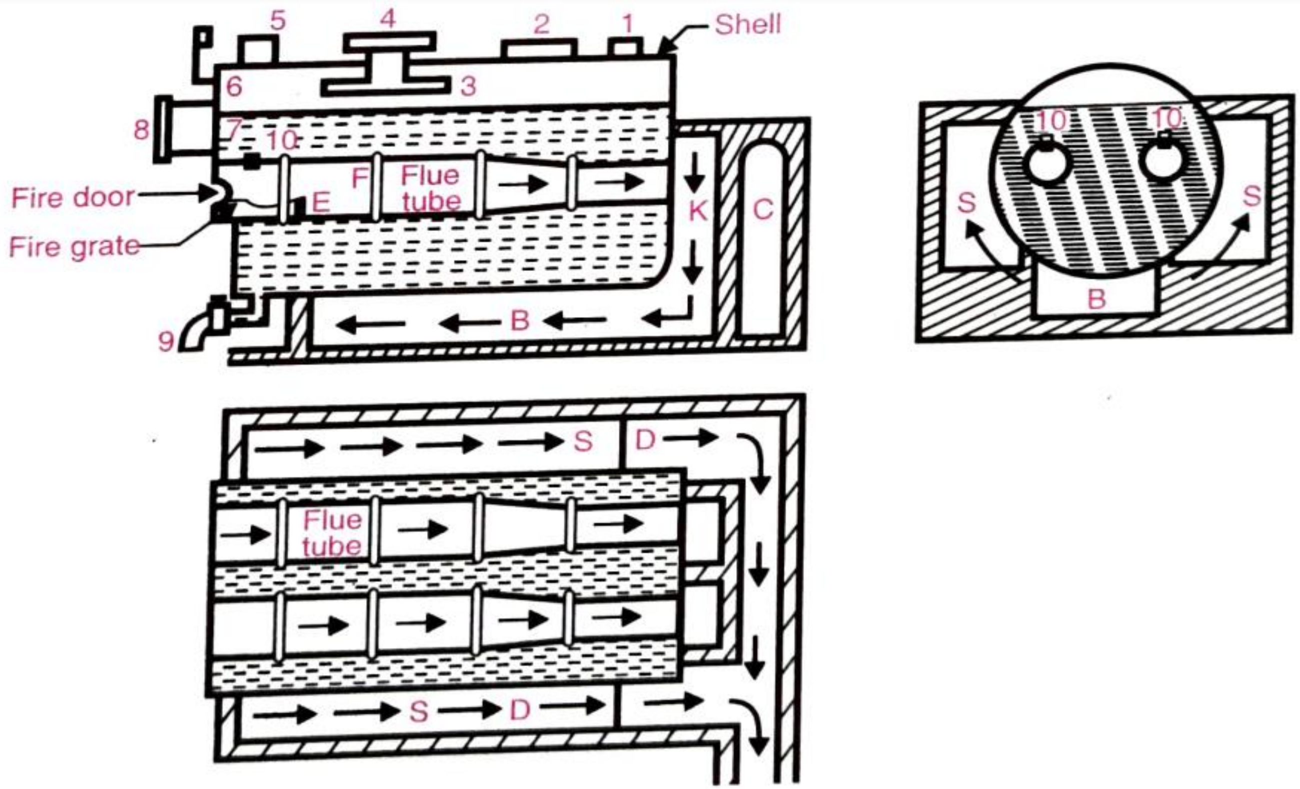


A = Fusible plug
BF = Bottom flue
D = Damper
FT = Flue tube
SF = Side flue
C = Passage to chimney

Specifications

1	**No. of flue tubes**	**1**
2	Diameter of the shell	1.25 to 1.75 m
3	Length of the shell	4 to 7 m
4	Pressure of the steam	10.5 bar
5	Steam capacity	6500 kg/h

Lancashire boiler



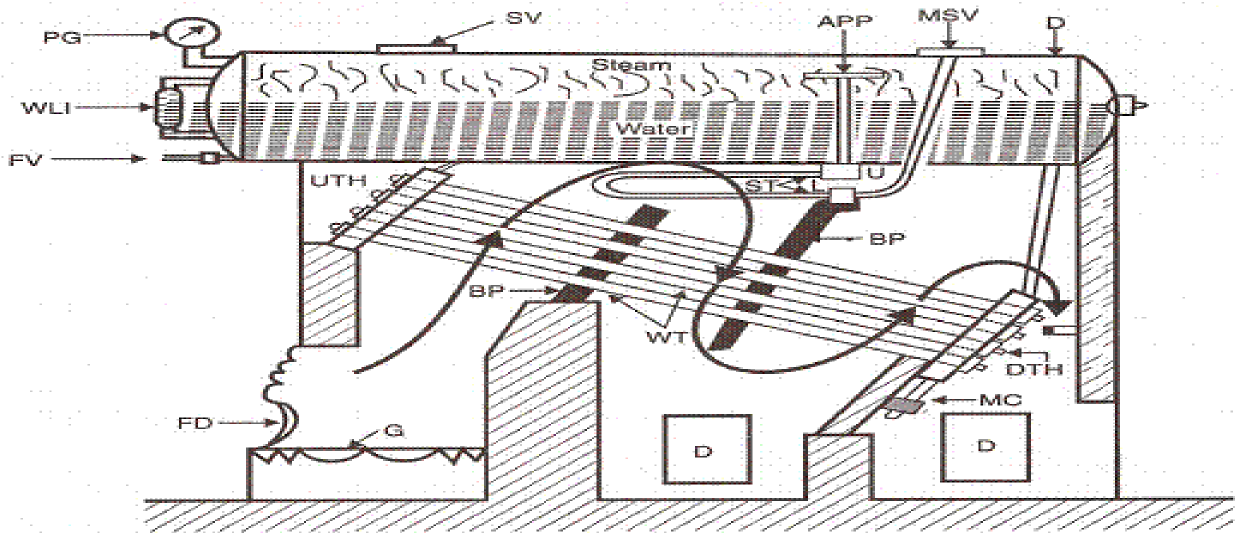
B = Bottom flue
C = Chimney
D = Dampers
E = Fire-bridge
F = Flue tube
K = Main flue
S = Side flue

1. High steam low water safety valve
2. Manhole
3. Antipriming pipe
4. Steam stope valve
5. Safety valve
6. Pressure gauge
7. Feed check valve
8. Water gauge
9. Blow down cock
10. Fusible plug

Specifications

1	**Diameter of the shell**	**2 to 3 m**
2	Length of the shell	7 to 9 m
3	Maximum working pressure	16 bar
4	Steam capacity	9000 kg/h
5	Efficiency	50 to 70%

Babcock and wilcox water tube boiler



D = Drum	*PG* = Pressure gauge
DTH = Down take header	*ST* = Superheater tubes
WT = Water tubes	*SV* = Safety valve
BP = Baffle plates	*MSV* = Main stop valve
D = Doors	*APP* = Antipriming pipe
G = Grate	*L* = Lower junction box
FD = Fire door	*U* = Upper junction box
MC = Mud collector	*FV* = Feed valve
WLI = Water level indicator	

Specifications

1	Diameter of the drum	2 to 1.83 m
2	Length	6.096 to 9.144 m
3	Size of the water tubes	7.62 to 10.16 cm
4	Size of superheater tubes	3.84 to 5.71 cm
5	Efficiency	50 to 70%
6	Working pressure	40 bar (max.)
7	Steaming capacity	40000 kg/h (max.)
8	Efficiency	60 to 80%