UNIT – I
COAL BASED THERMAL POWER PLANT

1. **Write the type of Basic Boilers thermodynamic cycles and write the short notes of process of the Rankine cycle?**

In general, two important area of application for thermodynamics are:
1. Power generation
2. Heat pumps

Both are accomplished by systems that operate in thermodynamic cycles such as:

a. Power cycles:

Systems used to produce net power output and are often called engines.

b. Heat pump cycles:

The pumping systems used to create the heat effects are called heat pumps cycles.

Power generation cycles can further be categorized as (depending on the phase of the working fluid)

1. Gas Power cycles:

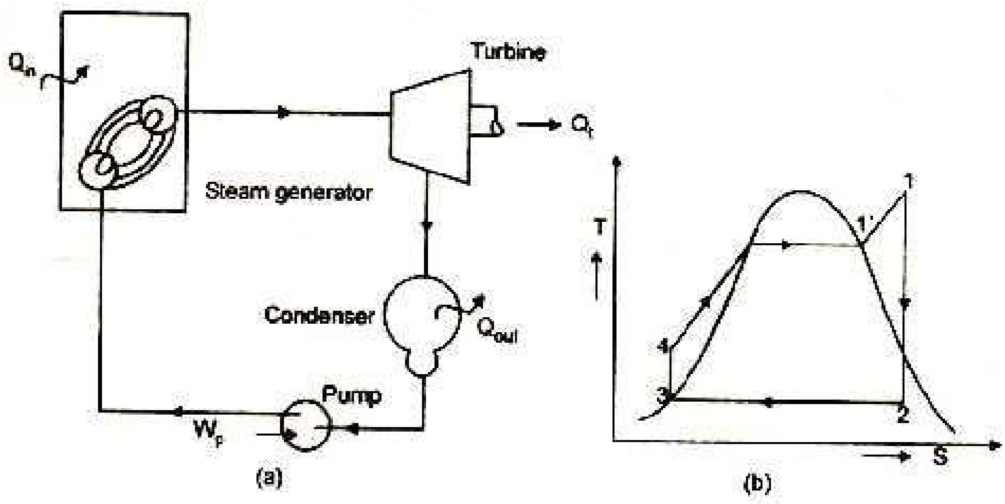
In this cycle working fluid remains in the gaseous phase throughout the entire process.

2. Vapour power cycles:

- In this case, the working fluid exists in the vapour phase during one part of the cycle and in the liquid phase during another part.
- Vapour power cycles can be categorized as
  a) Carnot cycle
  b) Rankine cycle (Steam Cycle)
  c) Reheat cycle
  d) Regenerative cycle
  e) Binary vapour cycle

<u>Steam cycles (Rankine cycle)</u>

- The Rankine cycle is a thermodynamic cycle.
- Rankine cycles describe the operation of steam heat engines commonly found in power generation plants.
- In such vapour plants, power is generated by alternatively vaporizing and condensing a working fluid
- The working fluid in a Rankine cycle follows a closed loop and is re-used constantly.
- Water vapour flowing from power plants is evaporating cooling water but not evaporates the working fluid.
- There are four processes in the Rankine cycle, each changing the state of the working fluid.



Schematic representation and T-S diagram of Rankine cycle.

Process 3-4

- First, the working fluid (water) is enter the pump at state 3 at saturated liquid.
- It is pumped (ideally isentropically) from low pressure to high (operating) pressure of boiler by a pump to the state 4.
- During this isentropic compression water temperature is slightly increased.
- Pumping requires a power input (either mechanical or electrical).
- The conservation of energy relation for pump is given as

$$W_{pump} = m\,(h_4 - h_3)$$

Process 4-1

- The high pressure compressed liquid enters a boiler at state 4 by an external source.
- It is heated at constant pressure to become a saturated vapour at state l′.
- Then the saturated vapour is superheated to state 1 through super heater.
- Common heat source for power plant systems are coal (or other chemical energy), natural gas or nuclear power.
- The conservation of energy relation for boiler is given as

$$Qin = m\,(h_1 - h_4)$$

Process 1 – 2:

- The superheated vapour enter the turbine at state 1 and expands through a turbine to generate power output.
- Ideally, this expansion is isentropic and this decreases the temperature and pressure of the vapour at state 2.
- The conservation of energy relation for turbine is given as

$$W_{turbine} = m\,(h_1 - h_2)$$

Process 2 – 3:

- The vapour then enters a condenser at state 2.
- At this state, steam is a saturated liquid- vapour mixture where it is cooled to

become a saturated liquid at state 3.

- This liquid then re- enters the pump and the cycle is repeated.
- The conservation of energy relation for condenser is given as

$$Q_{out} = m\ (h_2 - h_3)$$

The exposed Rankine cycle can also prevent vapour overheating, which reduces the amount of liquid condensed after the expansion in the turbine.

Variables:

Q_{in}- heat input rate (energy per unit time)
m= mass flow rate (mass per unit time)
W- Mechanical power used by or provided to the system (energy per unit time)
η - thermodynamic efficiency of process (power used for turbine per heat input)
h_1, h_2, h_3 and h_4 - Specific Enthalpy of fluid at specific points

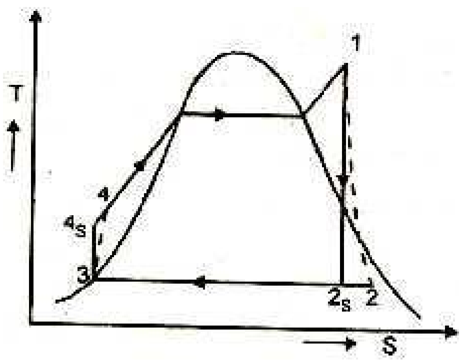
Efficiency Calculation:

The thermodynamic efficiency of the cycle as the ratio of net power output to heat input.

$$W_{net} = \left(W_{turbine} - W_{pump}\right) \text{ or } \left(Q_{in} - Q_{out}\right)$$

$$\eta = W_{net} / Q_{in}$$

Real Ranking Cycle (Non-ideal)



- In a real Rankine cycle, the compression by the pump and the expansion in the turbine are not isentropic.
- In other words, these processes are non-reversible and entropy is increased during the two process.
- This increases the power required by the pump and decreases the power generated by the turbine.
- It also makes calculations more involved and difficult.

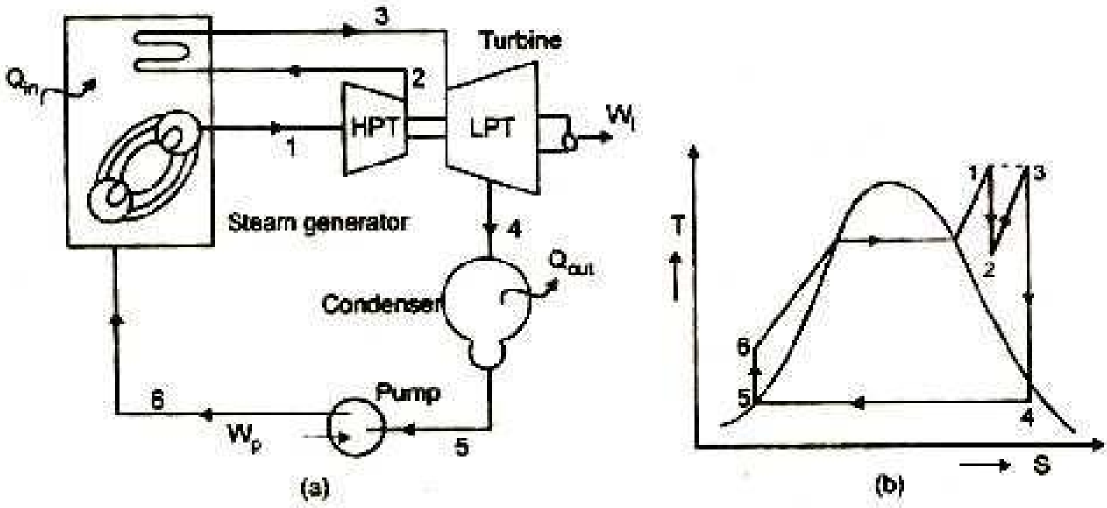
Improvisations of the Basic Rankine Cycle:

Two main variations of the basic Rankine cycle **to improve the efficiency** of the steam cycles are done by incorporating Reheater and Regenerator in the ranking cycle.

Rankine cycle with reheater:

- In this variation, two turbines work in series.
- The first accepts vapour from the boiler at high pressure.
- After the vapour has passed through the first turbine, it re-enters the boiler.

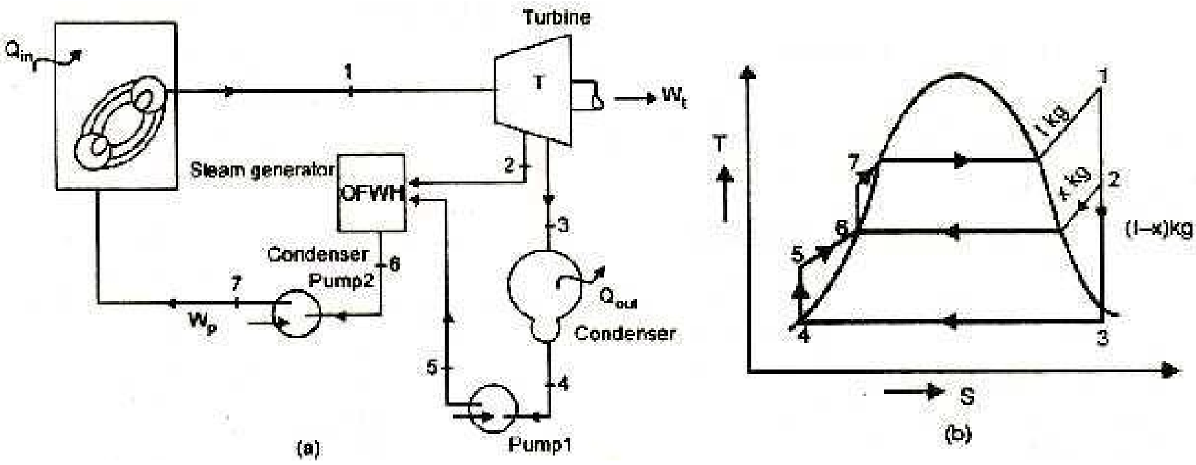
❖ It is reheated before passing through a second turbine and lowers the pressure turbine.
❖ This prevents the vapour from condensing during its expansion which can seriously damage the turbine blades.



Schematic diagram and T-S diagram of Rankine cycle with Reheater.

Ranking Cycle with Regenerator:

❖ In regenerative Ranking cycle, the working fluid is heated after coming from the condenser.
❖ The hot water from the condenser is heated upto the conversion of steam.
❖ Steam is tapped from the hot portion of the cycle and fed in to Open Feed Water Heater(OFWH).
❖ This increases the average temperature of heat addition which in turn increases the thermodynamics efficiency of the cycle.

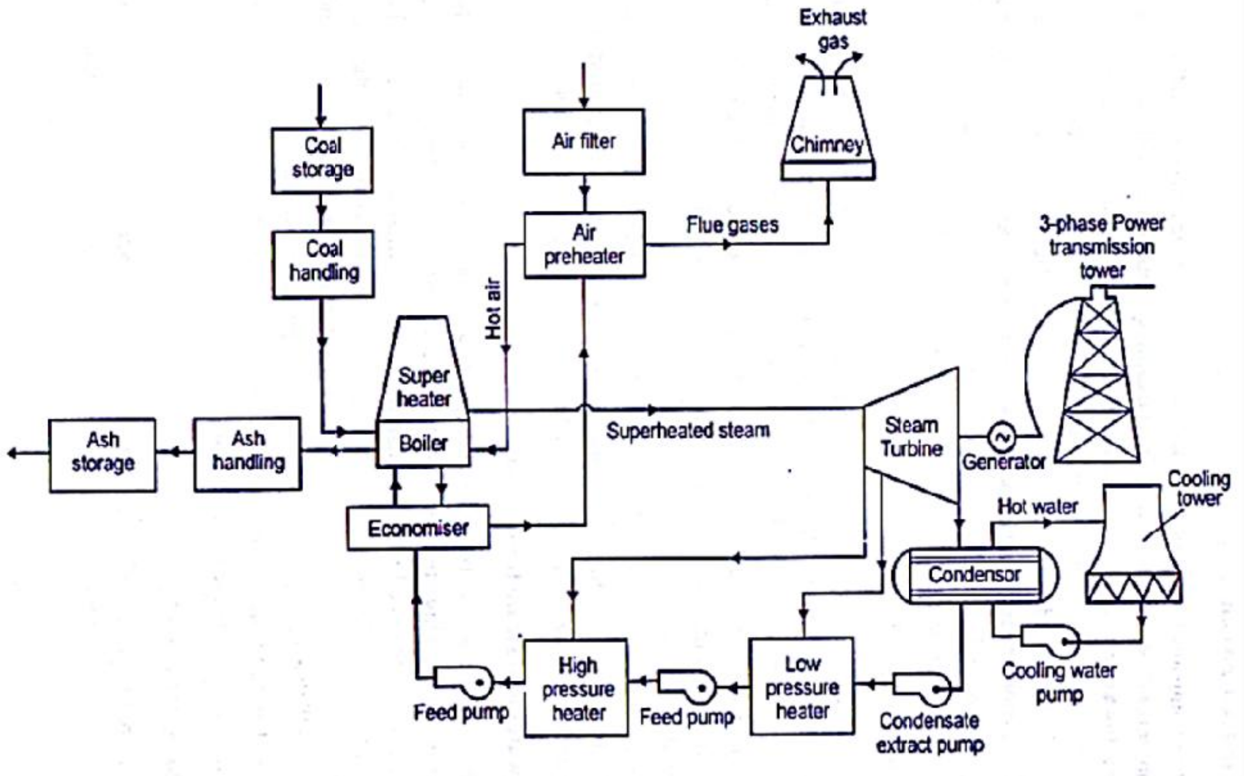


Schematic diagram and T-S diagram of Rankine cycle with Regenerator.

2. Draw and explain the working of thermal power plant?

<u>Introduction:</u>

- Steam is an important medium for producing mechanical energy. Steam is used to drive steam engines and steam turbines.
- Steam has the following advantages.
  - ❖ Steam can be raised quickly from water which is available in plenty.
  - ❖ It does not react with materials of the equipment used in power plants.
  - ❖ It is stable at temperatures required in the plant.



<u>Equipment of a Steam Power Plant:</u>

A steam power plant must have the following equipment.

1. A furnace for burning the fuel.
2. A steam generator or boiler for steam generation.
3. A power unit like a turbine to convert heat energy into mechanical energy.
4. A generator which converts mechanical energy into electrical energy.
5. Piping system to carry steam and water.

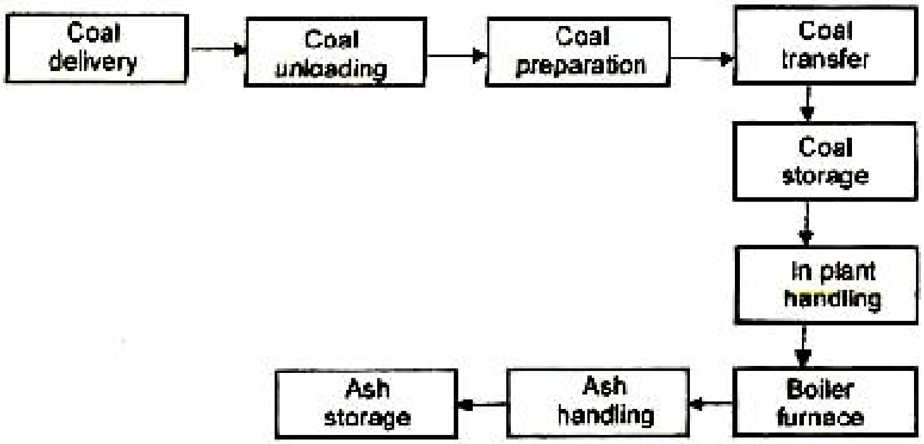
<u>Operation of Thermal power plant:</u>

The working of a steam power plant can be explained in four circuits.

1. Fuel (coal) and ash circuit
2. Air and flue gas circuit
3. Feed water and steam flow circuit
4. Cooling water flow circuit

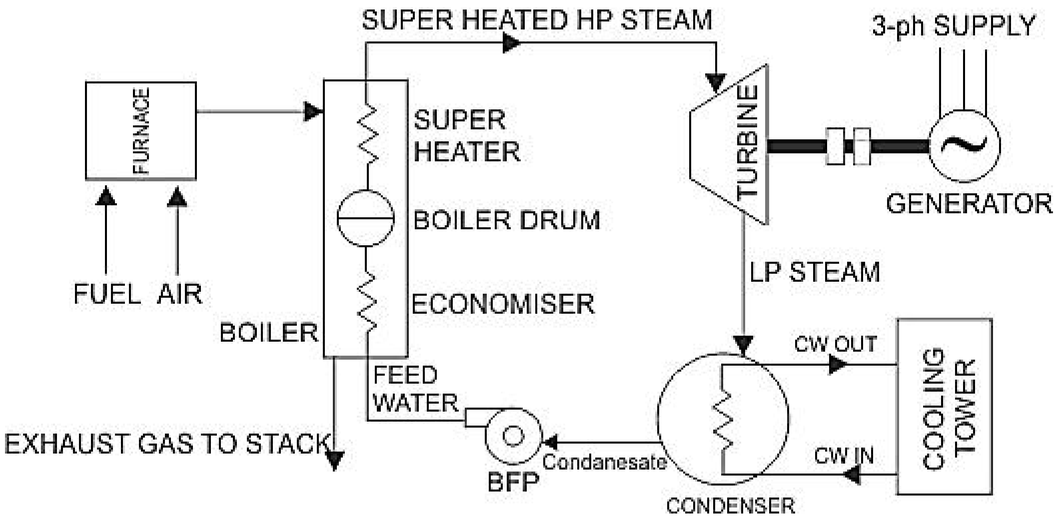
<u>Coal and Ash circuit:</u>

- ❖ The fuel and ash circuit includes coal delivery, preparation, coal handling, boiler furnace, ash handling and ash storage.



- ❖ The coal from coal mines is delivered by ships, rail or by trucks to the power station and unloaded the transporting vehicle. This process is called as Coal delivery and unloading
- ❖ This coal is sized by crushers or breakers so this process is called as coal preparation.
- ❖ The sized coal is then stored in coal storage (stock yard).
- ❖ From the stock yard, the coal is transferred to the boiler furnace by means of conveyors, elevators etc.
- ❖ The coal is burnt in the boiler furnace and ash is formed by burning of coal.
- ❖ Ash coming out of the furnace will be too hot, dusty and accompanied by some poisonous gases.
- ❖ The ash is transferred to ash storage. Usually, the ash is processed to reduce temperature corrosion and dust content.

Water and Steam circuit:

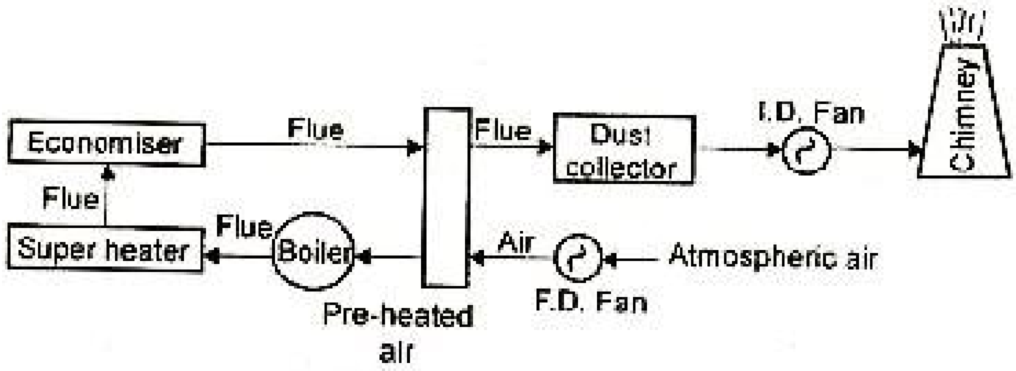


- ❖ It consists of feed pump, economizer, boiler drum, super heater, condenser, etc.
- ❖ Feed pump is used for passing the refined feed water is pumped to the economizer.
- ❖ This water is preheated by the flue gases in the economizer.
- ❖ This preheated water is then supplied to the boiler drum.
- ❖ Heat is transferred to the water by burning of coal and then water is converted into steam.

- The steam raised in boiler is passed through a super heater.
- It is superheated by the flue gases and then superheated steam is forced to rotate a turbine to do work.
- The turbine drives a coupled generator to produce electric power.
- The expanded (exhaust) steam is then passed through the condenser.
- In the condenser, the steam is condensed into water and re-circulated.

Air and Flue gas circuit:

- It consists of forced draught fan, air pre heater, boiler furnace, super heater, economizer, dust collector, induced draught fan, chimney etc.
- Air is taken from the atmosphere by the action of a forced draught fan(F.D fan).
- It is passed through an air pre-heater and this air is pre-heated by the flue gases in the pre-heater.
- This pre-heated air is supplied to the furnace to help the combustion of fuel.
- Due to combustion of fuel, hot gases (flue gases) are formed.

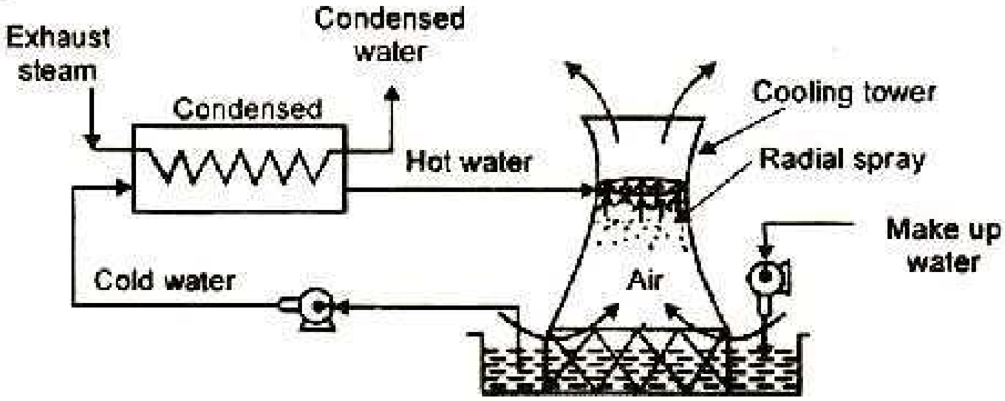


- The flue gases from the furnace pass over boiler tubes and super heater tubes. Then the flue gases pass through economizer to heat the feed water.
- After that, it passes through the air pre-heater to pre-heat the incoming air.
- It is then passed through a dust catching device (dust collector) for removing the ashes involved in the air.
- Finally, it is exhausted to the atmosphere through chimney.

Cooling water circuit:

- The circuit includes a pump, condenser and cooling tower.
- The exhaust steam from the turbine is condensed in condenser.
- In the condenser, cold water is circulated to condense the steam into water.
- The steam is condensed by losing its latent heat to the circulating cold water.
- Thus the circulating water is heated and this hot water is taken to a cooling tower.
- In cooling tower, the water is sprayed in the form of droplets through nozzles.
- The atmospheric air enters the cooling tower from the openings provided at the bottom of the tower.
- This air removes heat from hot water.
- Cooled water is collected in a pond and this water is again circulated through the pump, condenser and cooling tower.
- Thus the cycle is repeated again and again.

- Some amount of water may be lost during the circulation due to vaporization etc.



Merits (Advantages) of a Thermal Power Plant:

- The unit capacity of a thermal power plant is more. The cost of unit decreases with the increase in unit capacity.
- Life of the plant is more (25-30 years) as compared to diesel plant (2-5 years).
- Repair and maintenance cost is low when compared with diesel plant.
- Initial cost of the plant is less than nuclear plants.
- Suitable for varying load conditions.
- No harmful radioactive wastes are produced as in the case of nuclear plant.
- Unskilled operators can operate the plant.
- The power generation does not depend on water storage.
- There are no transmission losses since they are located near load centres.

Demerits of thermal power plant:

- Thermal plant are less efficient than diesel plants
- Starting up the plant and bringing into service takes more time.
- Cooling water required is more.
- Space required is more
- Storage required for the fuel is more
- Ash handling is a big problem.
- Not economical in areas which are remote from coal fields
- Fuel transportation, handling and storage charges are more

3. Explain in detail about some supercritical boilers used in steam power plant. (or) Describe some steam generators used in coal based thermal power plant.

In all modern power plants, high pressure boilers (> 100 bar) are universally used as they offer the following advantages.

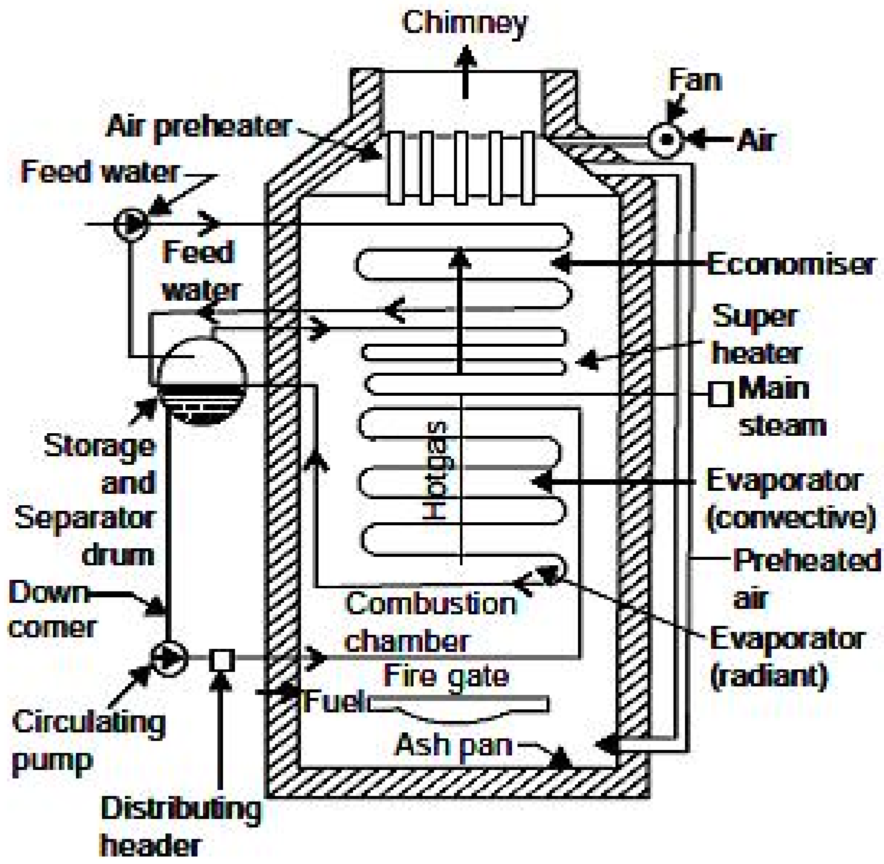
- ❖ The efficiency and the capacity of the plant can be increased as reduced quantity of steam is required for the same power generation if high pressure steam is used.
- ❖ The forced circulation of water through boiler tubes provides freedom in the arrangement of furnace and water walls, in addition to the reduction in the heat exchange area.
- ❖ The tendency of scale formation is reduced due to high velocity of water.
- ❖ The danger of overheating is reduced as all the parts are uniformly heated.
- ❖ The differential expansion is reduced due to uniform temperature and this reduces the possibility of gas and air leakages.

In order to obtain efficient operation and high capacity, forced circulation of water through boiler tubes is found helpful. Some special types of boilers operating at super critical pressures are called as super critical boilers.

LA MONT BOILER:

A forced circulation boiler was first introduced in 1925 by La Mont. The arrangement of water circulation and different components are shown in figure.

- ❖ The feed water from hot well is supplied to a storage and separating drum (boiler) through the economizer.
- ❖ Most of the sensible heat is supplied to the feed water passing through the economizer.
- ❖ A pump circulates the water at a rate 8 to 10 times the mass of steam evaporated.
- ❖ This water is circulated through the evaporator tubes and the part of the vapour is separated in the separator drum.
- ❖ The large quantity of water circulated (10 times that of evaporation) prevents the tubes from being overheated.
- ❖ The centrifugal pump delivers the water to the headers at a pressure of 2.5 bar above the drum pressure.
- ❖ The distribution headers distribute the water through the nozzle into the evaporator.
- ❖ The steam separated in the boiler is further passed through the super-heater.
- ❖ Secure a uniform flow of feed water through each of the parallel boiler circuits a choke is fitted entrance to each circuit.
- ❖ These boilers have been built to generate 45 to 50 tonnes of superheated steam at a pressure of 120 bar and temperature of 500°C.



La Mont Boiler

<u>**Important Components:**</u>

Steam separating drum – The feed water from the hot well is stored in the drum. The steam is separated from water in the drum and the steam is usually collected at the top of the drum.

Circulating pump – Water from the steam separating drum is drawn by a circulating pump and it circulates water through the evaporator tubes. Pump circulates water at a rate of 8-10 times the mass of steam evaporated. Forced circulation is necessary to prevent the overheating of tubes.

Distribution header – The distribution header distributes the water through the nozzle into the evaporator.

Radiant evaporator – Water from the drum first enters the radiant evaporator through the pump and header. The water is heated by the radiation heat from the combustion chamber. In radiant evaporator, the hot flue gases do not pass over the water tubes.

Convective evaporator – The mixture of water and steam coming out from the radiant evaporator enters the convective evaporator tubes. The hot flue gases passing over the evaporator tubes transfer a large portion of heat to the water by convection. Thus, water becomes steam and the steam enters to the steam separating drum.

Super heater – The steam from the steam separating drum enters the super heater tubes where it is superheated by the hot flue gases passing over them. The superheated steam then enters the steam turbine to develop power.

Economizer – The waste hot flue gases pass through the economizer where feed water is pre-heated. By pre-heating the feed water, the amount of fuel required to convert water into steam is reduced.

Air pre-heater - The hot flue gases then passes through the air pre-heater where the air required for combustion is pre-heated.

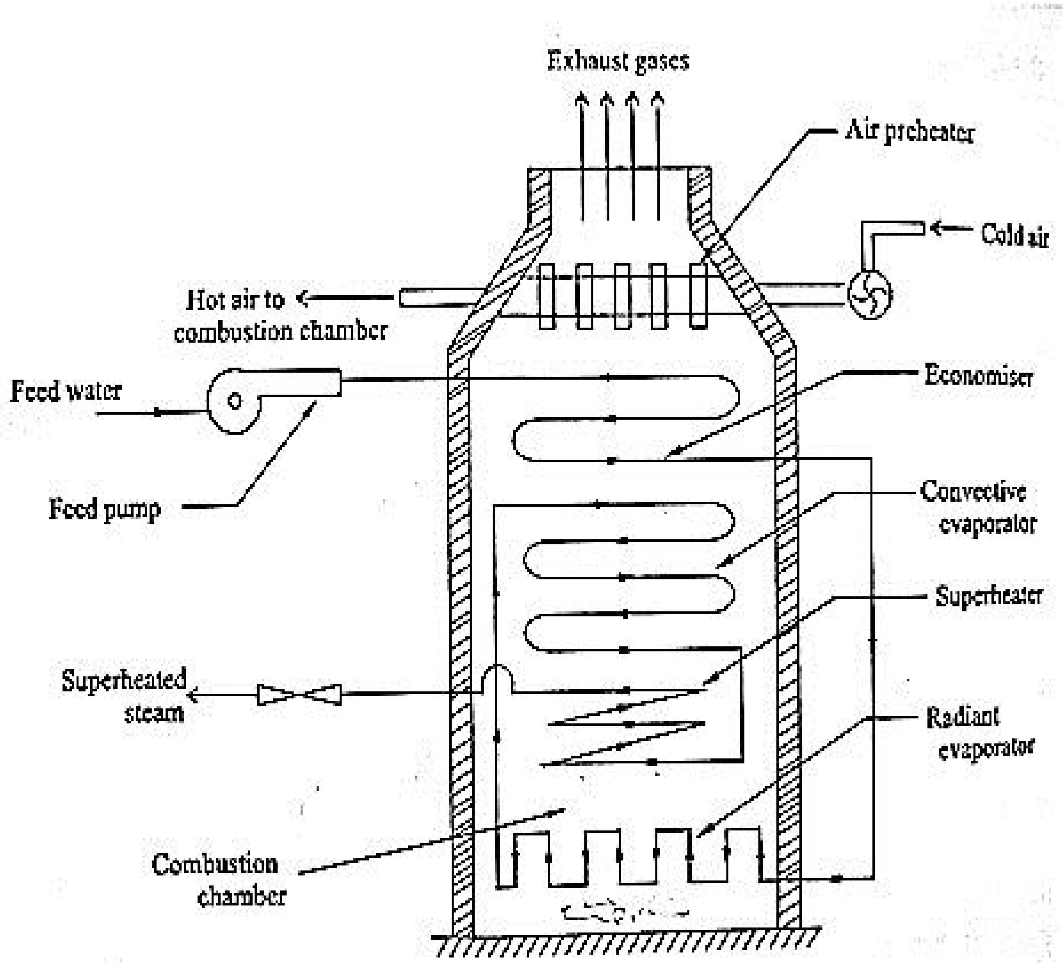
Advantages:

- ❖ La-Mont boilers can generate 45 to 50 tons of superheated steam at a pressure of 120 bar and temperature of 500°C.
- ❖ Drum is of small size.
- ❖ Tendency of scale formation is eliminated due to forced circulation of water.

Disadvantages:

- ❖ Bubbles are formed on the inside of the water tubes and this bubbles reduce the heat transfer rate.
- ❖ Initial and operating costs are high.
- ❖ Maintenance costs are very high.

BENSON BOILER:



- The main difficulty in La Mont boiler is the formation and attachment of bubbles on the inner surfaces of the heating tubes.
- The attached bubbles reduce the heat flow and steam generation as it offers higher thermal resistance compared to water film.
- Benson in 1922 argued that if the boiler pressure was raised to critical pressure (225 atm.) to reduce the formation of bubbles.
- The steam and water would have the same density and therefore the danger of bubble formation can be completed.
- Natural circulation boilers require expansion joints but these are not required for Benson boiler as the pipes are welded.
- The erection of Benson boiler is easier and quicker as all the parts are welded.

Important Components:

Economizer – The feed water from the well passes through the economizer where it is pre-heated by the pre-heat of exhaust hot flue gases.

Radiant evaporator – The feed water after circulation through the economizer flows through the radiant evaporator tubes. Water is heated up by the radiation heat from the combustion chamber. Here, part of the water is converted to steam directly.

Convective evaporator – The mixture of water and steam coming out from the radiant evaporator enters the convective evaporator tubes. The hot flue gases passing over the evaporator tubes transfer a large portion of heat to the water by convection. Thus, water becomes steam in the convective evaporator.

Super heater – The steam from the convective evaporator enters the superheater tubes where it is superheated by the hot flue gases passing over them. The superheated steam then enters the steam turbine to develop power.

Air pre-heater – The hot flue gases then passes through the air pre-heater where the air required for combustion is pre-heated.

Advantages:

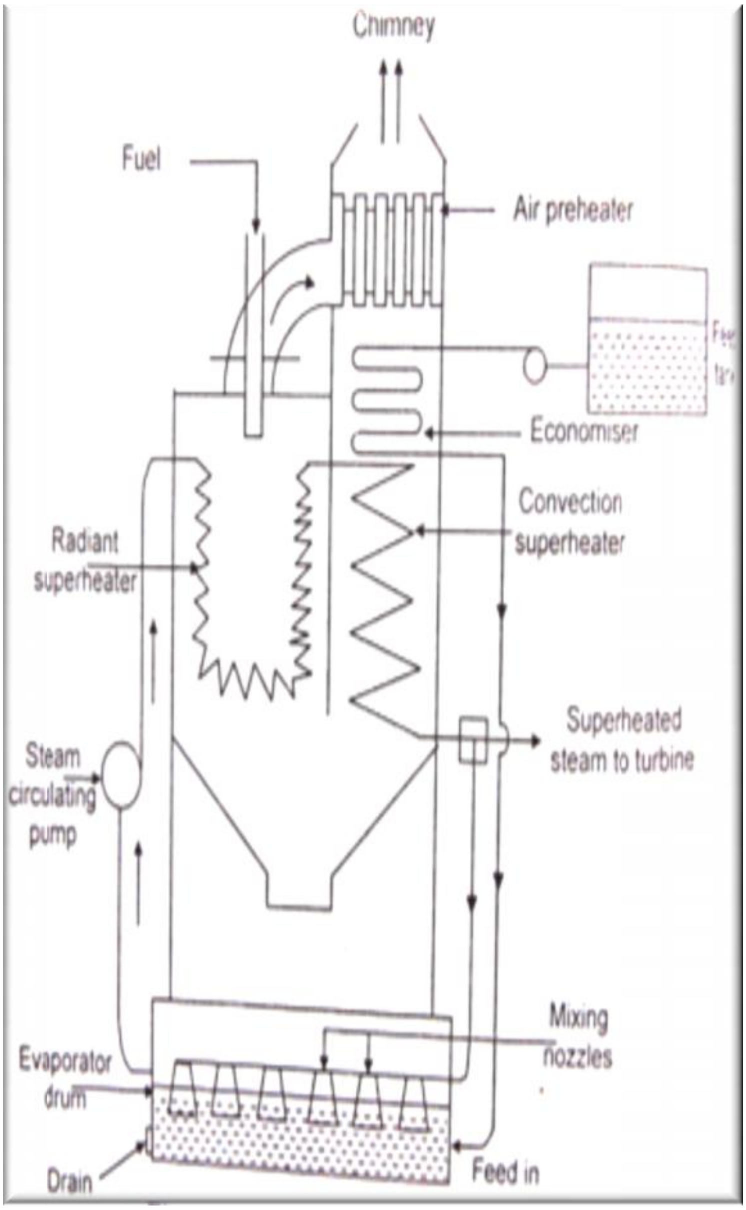
- As there is no drum, the total weight of Benson boiler is 20% less than other boilers.
- This reduces the cost of the boiler.
- Floor space requirements of Benson boiler are very less.
- Transportation of Benson boiler parts and its erection is very easy as there are no drums.
- Natural circulation boilers require expansion joints in pipes but the pipes in Benson boilers are welded.

Disadvantages:

- As the Benson boiler operates at high pressure and temperature, special alloy materials are required.
- Maintenance costs are very high.
- This is more efficient, resulting in slightly less fuel use.

LOEFFLER BOILER:

The major difficulty experienced in Benson boiler is the deposition of salt and sediment on the inner surfaces of the water tubes. The deposition reduced the heat transfer and ultimately the generating capacity. This further increased the danger of overheating the tubes due to salt deposition as it has high thermal resistance. The difficulty was solved in Loeffler boiler by preventing the flow of water into the boiler tubes.



- Most of the steam is generated outside from the feedwater using part of the superheated steam coming out from the boiler.
- The pressure feed pump draws the water through the economizer and delivers it into the evaporator drum.
- About 65% of the steam coming out of superheater is passed through the evaporator drum in order to evaporate the feed water coming from economizer.
- The steam circulating pump draws the saturated steam from the evaporator drum and is passed through the radiant superheater and then connective superheater.
- About 35% of the steam coming out from the superheater is supplied to the H.P. steam turbine.
- The steam coming out from H.P. turbine is passed through reheater before supplying to L.P. turbine.
- The amount of steam generated in the evaporator drum is equal to the steam tapped (65%) from the superheater.
- The nozzles which distribute the superheated steam through the water into the evaporator drum are of special design to avoid priming and noise.

This boiler can carry higher salt concentration than any other type and is more compact than indirectly heated boilers having natural circulation. These qualities fit it for land or sea transport power generation. Loeffler boilers with generating capacity of 94.5 tonnes/hr and operating at 140 bar.

SCHMIDT-HARTMANN BOILER:

The operation of the boiler is similar to an electric transformer. Two pressures are used to effect an interchange of energy.

- In the primary circuit, the steam at 100 bar is produced from distilled water. This steam is passed through a submerged heating coil which is located in an evaporator drum.
- The high pressure steam in this coil possesses sufficient thermal potential and steam at 60 bar with a heat transfer rate of 2.5 kW/m2-°C is generated in the evaporator drum.
- The steam produced in the evaporator drums from impure water is further passed through 'the superheater and then supplied to the prime-mover.
- The high pressure condensate formed in the submerged heating coil is circulated through a low pressure feed heater on its way to raise the feed water temperature to its saturation temperature. Therefore, only latent heat is supplied in the evaporator drum.
- Natural circulation is used in the primary circuit and this is sufficient to effect the desired rate of heat transfer and to overcome the thermo-siphon head of about 2 m to 10 m.

- ❖ In normal circumstances, the replenishment of distilled water in the primary circuit is not required as every care is taken in design and construction to prevent leakage.
- ❖ But as a safeguard against leakage, a pressure gauge and safety valve are fitted in the circuit.

Advantages:

- ❖ There is rare chance of overheating or burning the highly heated components of the primary circuit.
- ❖ The highly heated parts run very safe throughout the life of the boiler.
- ❖ The wide fluctuations of load are easily taken by this boiler due to high thermal and water capacity of the boiler.
- ❖ The absence of water risers in the drum, and moderate temperature difference across the heating coil allow evaporation to proceed without preparation.

VELOX-BOILER:

When the gas velocity exceeds the sound-velocity, the heat is transferred from the gas at a much higher rate than rates achieved with sub-sonic flow. The advantages of this concept are taken to effect the large heat transfer from a smaller surface area in this boiler.

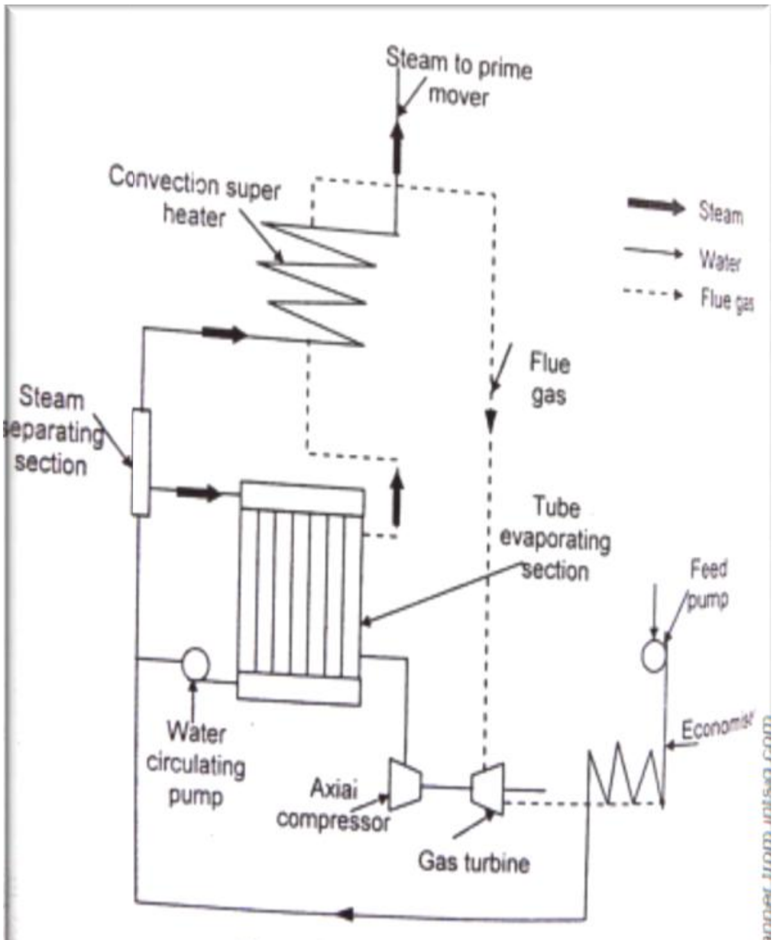


Figure 1.83 Velox boiler

- Air is compressed to 2.5 bar with the help of a compressor run by gas turbine before supplying to the combustion chamber to get the supersonic velocity of the gases passing through the combustion chamber and gas tubes and high heat release rates (40 MW/m3).
- The burned gases in the combustion chamber are passed through the annulus of the tubes.
- The heat is transferred from gases to water while passing through the annulus to generate the steam.
- The mixture of water and steam thus formed then passes into a separator which is so designed that the mixture enters with a spiral flow.
- The centrifugal force thus produced causes the heavier water particles to be thrown outward on the walls. This effect separates the steam from water.
- The separated steam is further passed to superheater and then supplied to the prime-mover.
- The water removed from steam in the separator is again passed into the water tubes with the help of a pump.
- The gases coming out from the annulus at the top are further passed over the superheater where its heat is used-for superheating the steam.
- The gases coming out of superheater are used to run a gas turbine as they carry sufficient kinetic energy. The power output of the gas turbine is used to run the air compressor.
- The exhaust gases coming out from the gas turbine are passed through the economizer to utilize the remaining heat of the gases.
- The extra power required to run the compressor is supplied with the help of electric motor.
- Feed water of 10 to 20 times the weight of steam generated is circulated through the tubes with the help of water circulating pump. This prevents the overheating of metal walls.
- The size of the velox boiler is limited to 100 tons per hour because 400 KW is required to run the air compressor at this output.
- The power developed by the gas turbine is not sufficient to run the compressor and therefore some power from external source must be supplied.

Advantages:

- Very high combustion rates are possible as 40 MJ/m3 of combustion chamber volume.
- Low excess air is required as the pressurized air is used and the problem of draught is simplified.
- It is very compact generating unit and has greater flexibility.
- It can be quickly started even though the separator has a storage capacity of about 10% of the maximum hourly output.

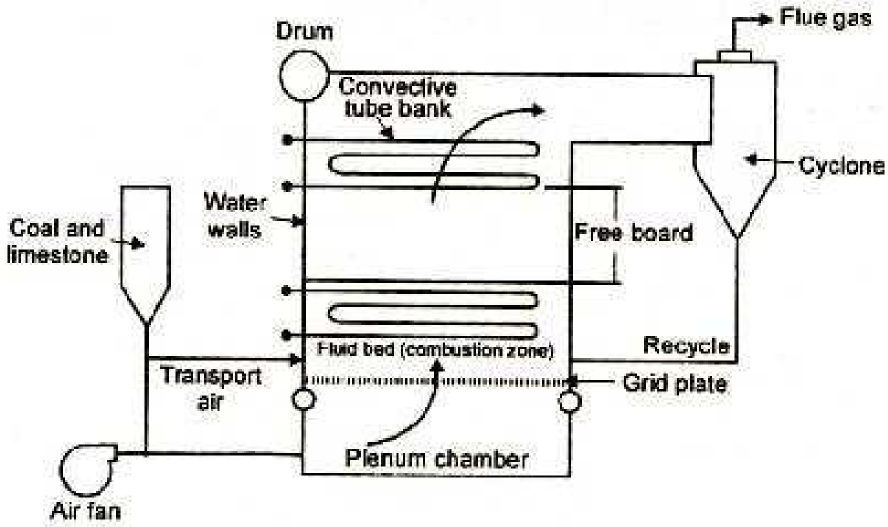
4. Draw and Explain the working principle of Fluidized Bed Combustion(FBC) Boiler. Also explain its types

Principle of Fluidized Bed Combustion Operation:

- ❖ A fluidized bed is composed of fuel and bed material contained within an atmospheric or pressurized vessel.
- ❖ The fuel materials used are coal, coke, biomass, etc.
- ❖ The bed material used are ash, sand or any sorbent.
- ❖ The bed becomes fluidized when air or other gas flows upward at a velocity sufficient to expand the bed.

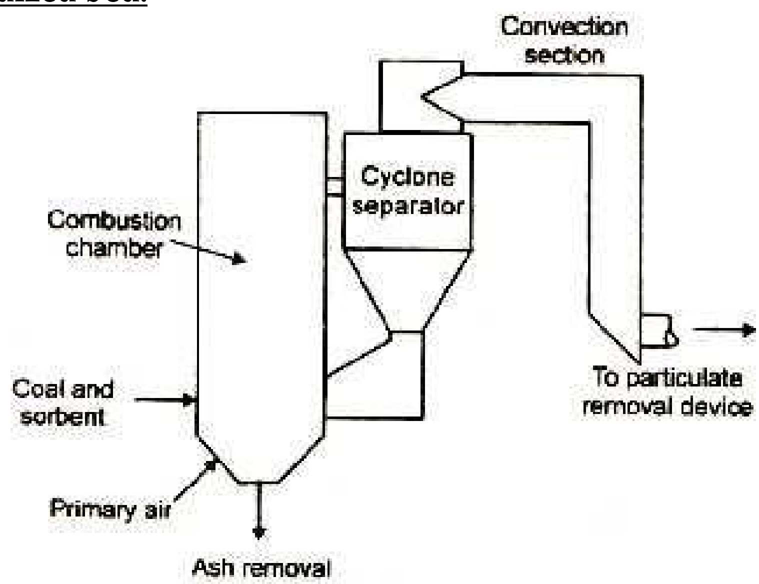
Bubbling Fluidized bed:

- ❖ At low velocities (0.9 to 3 m/s) relatively high density solids are maintained in the bed.
- ❖ At low velocities only a small fraction of the solids are drawn from the bed.
- ❖ The bed surface, well-defined for a BFB combustor becomes more diffuse and solids densities are reduced in the bed.
- ❖ A fluidized bed that is operated in this velocity range is referred to as a bubbling fluidized bed (BFB).



Atmospheric bubbling bed combustor

Circulating Fluidized bed:



- ❖ As the fluidizing velocity is increased, smaller particles are entrained in the gas stream and transported out of the bed.
- ❖ A fluidized bed that is operated at velocities in the range of 4 to 7 m/s is referred to as a circulated fluidized bed or CFB.

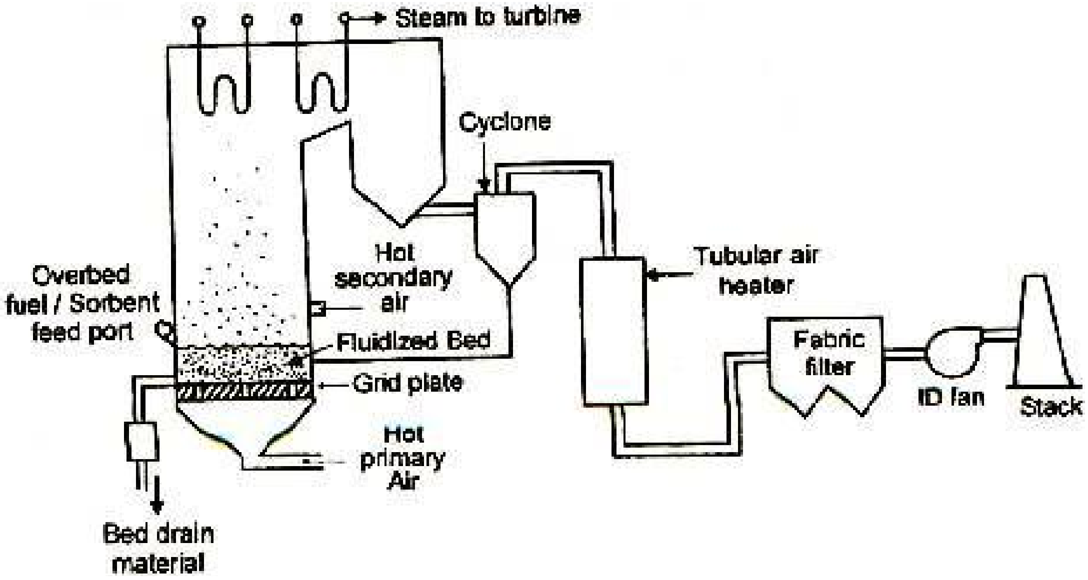
Circulating fluidized bed combustor.

Classification of Fluidized Bed Combustion:

1. Atmospheric fluidized Bed Combustion (AFBC)
    a. Bubbling fluidized bed combustors
    b. Circulating fluidized bed combustors
2. Pressurized Fluidized Bed Combustion (PFBC)

Atmospheric Fluidized Bed Combustion (AFBC)

Bubbling fluidized bed combustor:

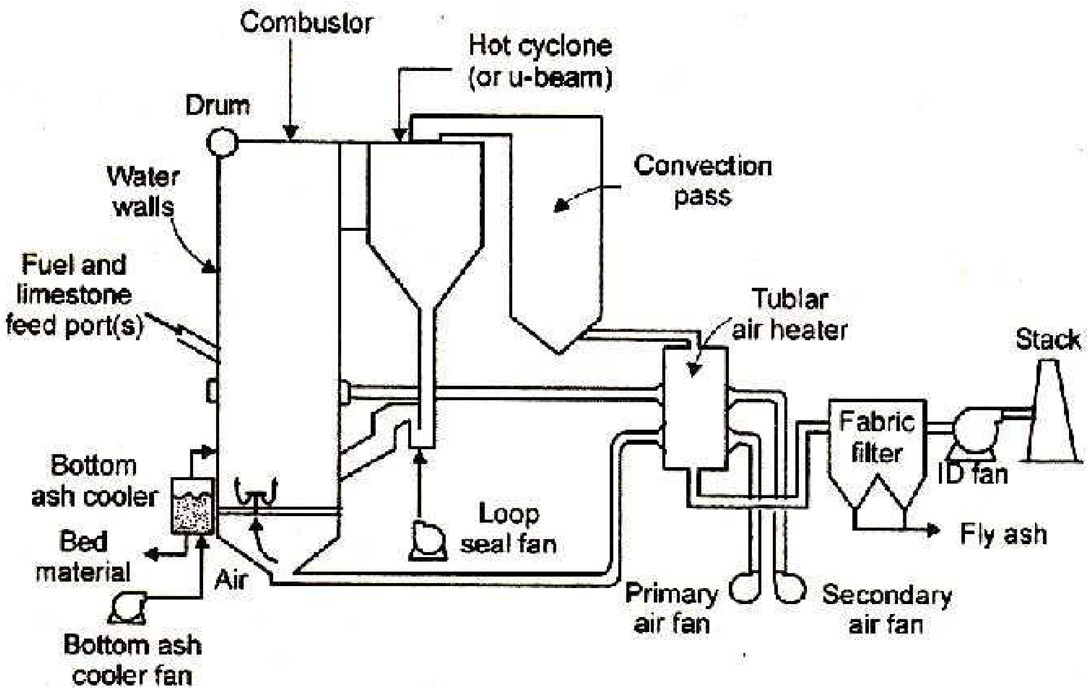


BFBC Arrangement

- ❖ Fuel and sorbent are introduced either above or below the fluidized bed.
- ❖ The bed consisting of about 97% limestone or inert material and 3% burning fuel.
- ❖ This bed is suspended by hot primary air entering the bottom of the combustion chamber.
- ❖ The bed temperature is controlled by heat transfer tubes immersed in the bed and by varying the quantity of coal in the bed.
- ❖ As the coal particle size decreases, as a result either combustion or erosion process takes place.
- ❖ The particles are elutriated from the bed and carried out to the combustor.
- ❖ A portion of the particles elutriated from the bed are collected by a cyclone and returned to the bed to improve combustion efficiency.
- ❖ Secondary air can be added above the bed to improve combustion efficiency and to lowering **NO_x** emissions.
- ❖ Recent designs BFB have regenerative type air heaters.

Circulating fluidized bed combustor:

- ❖ The bed consisting of about 97% limestone or inert material and 3% burning fuel.
- ❖ Hot primary air is introduced into the lower portion of the combustor where the heavy bed material is fluidized.
- ❖ The upper portion of the combustor contains the less dense material that is drawn from the bed.



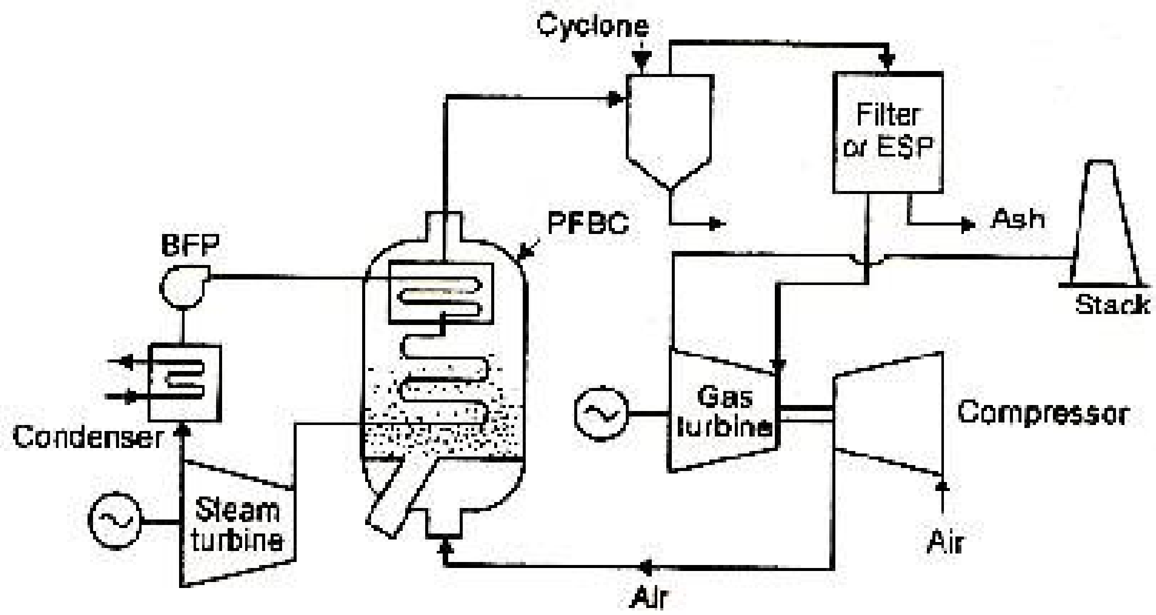
Atmospheric circulating bed combustor.

- ❖ Secondary air typically is introduced at higher levels in the combustor to ensure complete combustion and to reduce NOx emissions.
- ❖ The combustion gas generated in the combustor flows upward with a considerable portion of the solids.
- ❖ These solids particles are separated from the combustion gas in hot cyclone-type dust and are continuously returned to the combustion chamber by a recycle loop.
- ❖ The combustion chamber of a CFB consists of water walls to provide most of the evaporative boiler surface.
- ❖ The lower third of the combustor is strong to protect the water walls from erosion at high velocity bed region.
- ❖ Several CFB design offer external heat exchangers, which extract heat from the solids collected by the dust collectors before it is returned to the combustor.
- ❖ The external heat exchangers are used to provide additional evaporative heat transfer surface as well as superheat and reheat surface, depending on design.
- ❖ The flue gas, after removal of more than 99% of the drawn solids in the cyclone is passed to a convection pass.

- ❖ The convection pass designs are similar to unconventional coal-fueled units.
- ❖ The convection pass contain economizer, superheat, and reheat surface for better recycling process.

Pressurized Fluidized Bed Combustion:

- ❖ The PFBC unit is classified as either turbocharged or combined cycle units.
- ❖ In turbocharged arrangements (figure) combustion gas from the PEBC boiler is cooled to approximately 394 C and is used to drive a gas turbine.
- ❖ The gas turbine drives an air compressor, and there is little net gas turbine output.



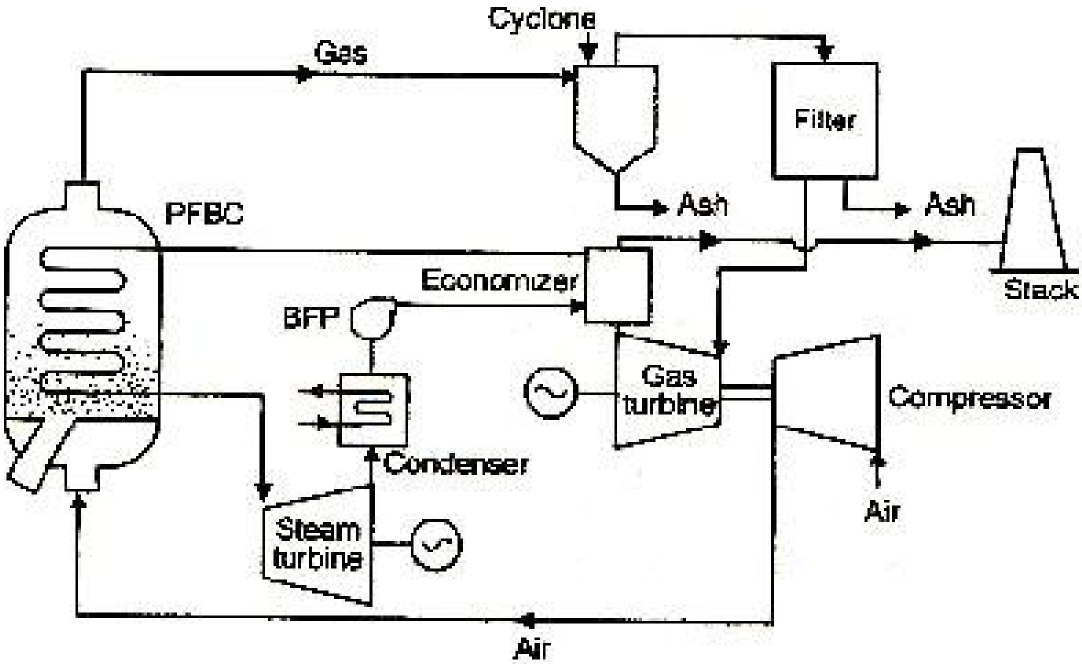
PFBC turbocharged arrangement

- ❖ Electricity is produced by a turbine generator driven by steam generated in the PFBC boiler.
- ❖ In the combined cycle arrangement 815°C to 871°C combustion gas from the PFBC boiler is used to drive the gas turbine.
- ❖ About 20% of the net plant electrical output is provided by the gas turbine.
- ❖ With this arrangement, thermal efficiency 2 to 3 percentage points higher than with the turbocharged cycle are feasible.

Advantages of fluidized bed combustion:

- ❖ SO_2 can be removed in the combustion process by adding limestone.
- ❖ Fluidized bed eliminates the need for an external desulfurization process.
- ❖ Fluidized bed boilers are inherently fuel flexible and can burn a variety of fuels.
- ❖ Combustion FBC units takes place at temperatures below the ash fusion temperature of most fuels.
- ❖ Because of the reduced combustion temperature, NO_x emissions are inherently

low.



PFBC combined cycle rearrangement

5. Explain the Working Principles of a Steam Turbine and also explain its types with the neat diagram.

- ❖ High pressure steam is fed to the turbine and passes along the machine axis through multiple rows of alternately fixed and moving blades.
- ❖ From the steam inlet port of the turbine towards the exhaust point, the blades and the turbine cavity are progressively larger to allow for the expansion of the steam.
- ❖ The stationary blades act as nozzles in which the steam expands and emerges at an increased speed but lower pressure (Bernoulli's conservation of energy principle – Kinetic energy increases as pressure energy falls).
- ❖ As the steam impacts on the moving blades it imparts some of its kinetic energy to the moving blades.
- ❖ The blades of steam turbines are designed to control
  - a) Speed of steam
  - b) Direction and pressure of the steam
  - c) Pressure of the steam
- ❖ There are two basic steam turbine types,
  - a) Impulse turbines
  - b) Reaction turbines

IMPULSE TURBINES:

Definition:

Impulse turbine is a turbine which changes the direction of flow of a high velocity fluid or gas jet. The resulting impulse spins the turbine and leaves the fluid flow with reduced kinetic energy.

Operation:

- ❖ The steam jets are directed at the turbine bucket shaped rotor blades.
- ❖ The pressure on the blades applied by the jets causes the rotor to rotate in quick manner.
- ❖ The velocity of the steam reduces because it conveys the kinetic energy to the blades.
- ❖ The blades in turn change the direction of flow of the steam however its pressure remains constant.
- ❖ It passes through the rotor blades since the cross section of the chamber between the blades is constant.
- ❖ Impulse turbines are therefore also known as constant pressure turbines.
- ❖ The next series of fixed blades reverses the direction of the steam before it passes to the second row of moving blades.

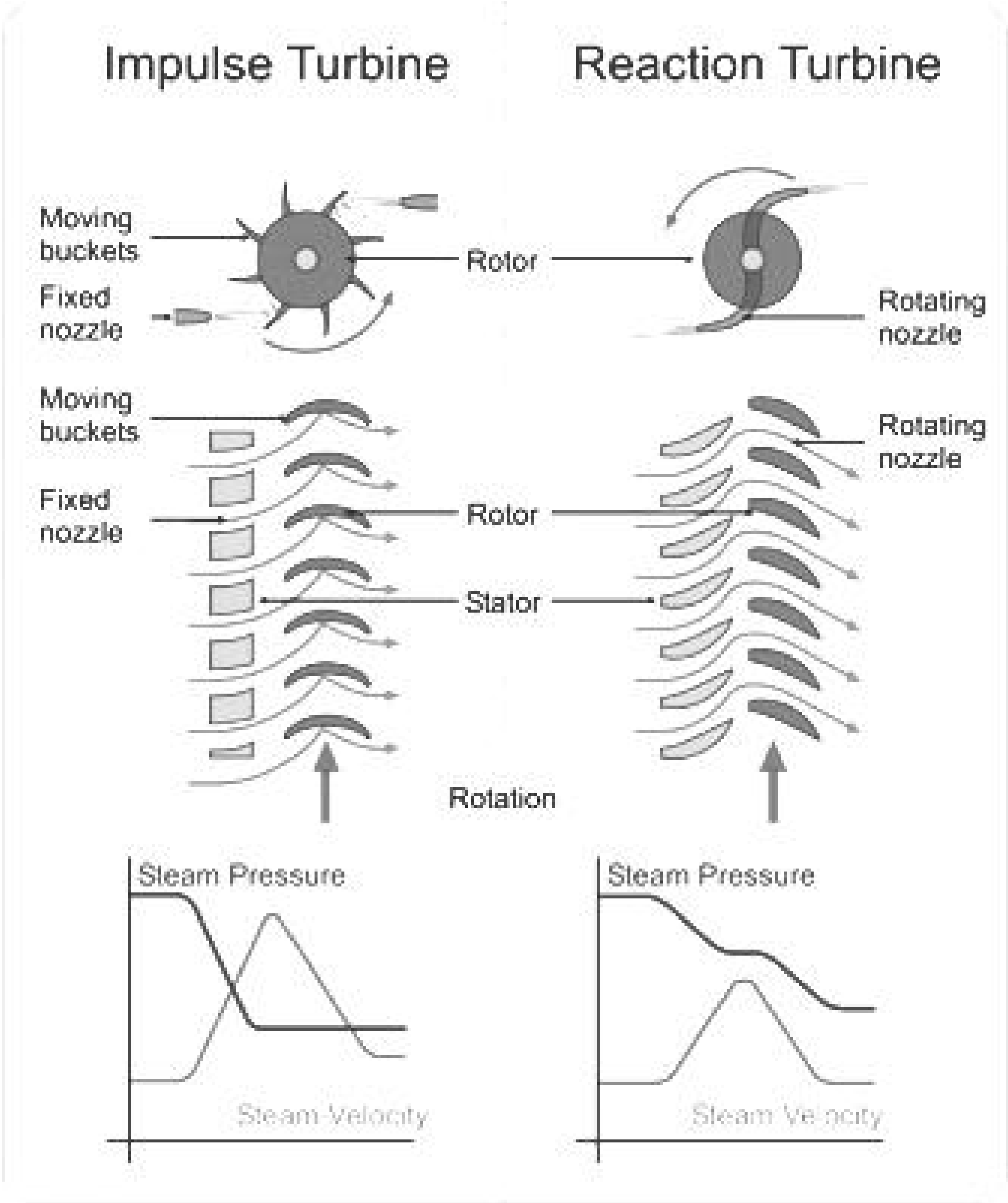
Advantages of Impulse turbine:

- ❖ Greater tolerance of sand and other particles in the water
- ❖ Better access to working parts
- ❖ No pressure seals around the shaft
- ❖ Easier to fabricate and maintain

Disadvantages of impulse turbine:

- ❖ They are unsuitable for low-head sites.
- ❖ It is operated under low specific speeds.

REACTION TURBINES:



Definition:

A turbine with rotating blades curved and arranged so as to develop torque from gradual decrease of steam pressure from inlet position to exhaust position is called as reaction turbine.

Operation:

- The rotor blades of the reaction turbine are shaped more like aero-foils.
- The blades are arranged such that the cross section of the chambers formed between the fixed blades diminishes from the inlet side towards the exhaust side of the blades.
- The chambers between the rotor blades essentially form nozzles.
- The steam passes through the chambers its velocity increases while at the same time its pressure decreases
- This process of pressure reduction is just as in the nozzles formed by the fixed blades.
- Thus the pressure decreases in both the fixed and moving blades.
- As the steam emerges in a jet from between the rotor blades, it creates a reactive force on the blades.
- This reactive force which in turn creates the turning moment on the turbine rotor. (Newton's Third Law - For every action there is an equal and opposite reaction)

Types of Reaction turbines:

- Radially inward flow turbines
- Outward flow turbines
- Axial flow turbines
- Mixed flow turbines

Advantages of reaction turbine:

- Capacity to use high pressure with high temperatures.
- Elevated capacity and weight ratio.
- Oil free exhaust system.
- High blade efficiency.
- High rotational speed.
- Lesser space is required when compared to impulse turbine.

Disadvantages of reaction turbine:

- Low speed application decrease gears are necessary.
- Effectiveness of small steam turbine is poor.
- Steam turbine cannot be prepared reversible.
- Recover less energy per stage.

6. What is meant by Condenser? And also explain its types for steam power plant.

Condensers are classified as follows:

a) Jet Condenser
   1. Low level counter flow jet condenser.
   2. High level (or) barometric jet condenser.
   3. Ejector condenser

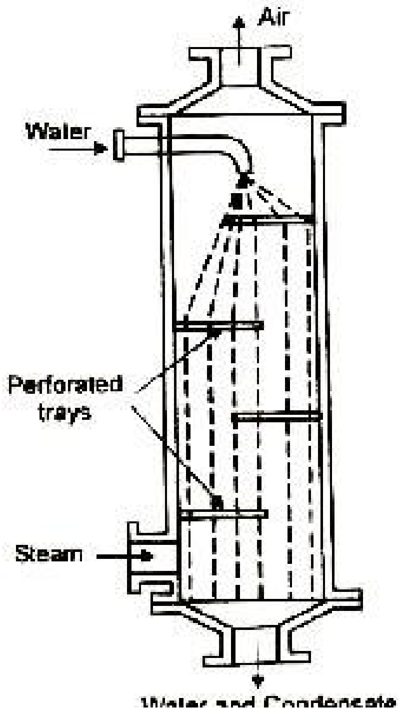
b) Surface Condenser
   1. Down flow condenser
   2. Central flow condenser
   3. Evaporative condenser

- In jet condensers, there is direct contact between the cooling water and the steam which is to be condensed.
- In surface condensers, there is no direct contact between the cooling water and the steam which is to be condensed.
- In parallel flow jet condensers, the flow of steam and cooling water are in the same direction.
- In counter flow jet condensers, the steam and cooling water flow in opposite directions.
- In low level jet condensers, the condensate is pumped by means of a condensate pump into the hot well.
- In high level jet condensers, the condensate falls to the hot well by the barometric leg provided in the condenser.
- In ejector condensers, a number of convergent nozzles are used.
- In down flow surface condensers, the condensed steam flows down from the condenser.
- In central flow surface condensers, the condensed steam moves towards the centre of condenser tubes.
- In single pass surface condensers, the cooling water flows in the condenser tubes only once.
- In multi pass surface condensers, the cooling water flows in the condenser tubes number of times.

7. Explain the working of Jet condensers with the help of its types? And what are merits & demerits?

- ❖ In a jet condenser, the steam to be condensed and the cooling water come in direct contact with the steam.
- ❖ The temperature of the condensate is the same as that of the cooling water leaving the condenser.
- ❖ For jet condensers the recovery of the condensate for reuse as boiler feed water is not possible.
- ❖ Depending upon the arrangement of the removal of condensate, the jet condensers are sub- divided into the following categories:
    - ✓ Low level counter flow jet condenser.
    - ✓ High level (or) barometric jet condenser.
    - ✓ Ejector condenser

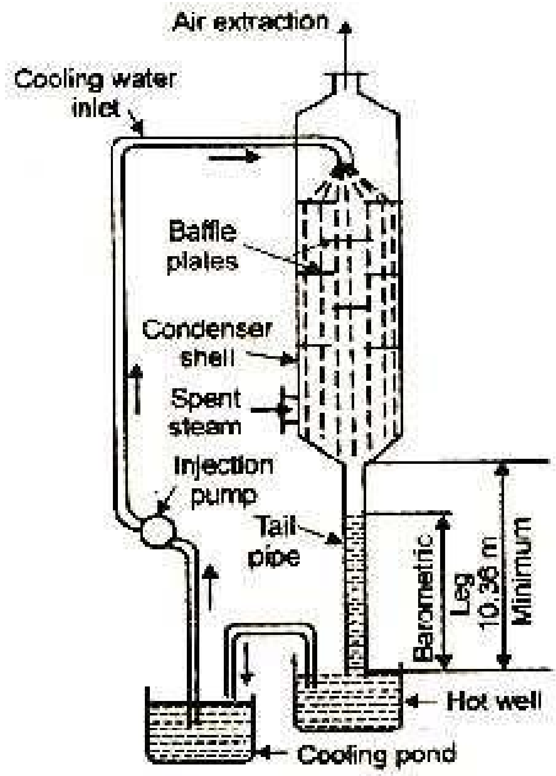
<u>Low level jet condenser:</u>



- ❖ In this condenser, the cooling water enters at the top and sprayed through jets.
- ❖ The steam enters at the bottom and mixes with the fine spray of cooling water.
- ❖ The condensate is removed by a separate pump.
- ❖ The air is removed by an air pump separately from the top.
- ❖ In a parallel flow type of this condenser, the cooling water and steam to be condensed move in the same direction. [i.e., from top to bottom].

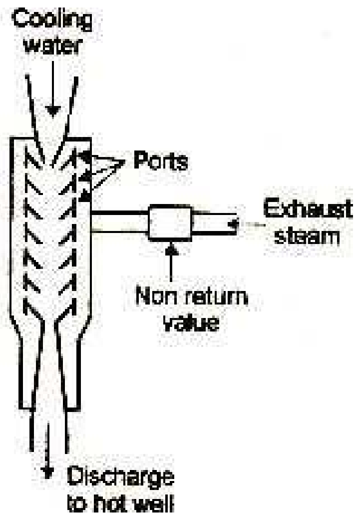
<u>High level jet condenser:</u>

- ❖ In this condenser, the cooling water enters at the top and sprayed through jets.
- ❖ The steam enters at the bottom and mixes with the fine spray of cooling water.
- ❖ This is similar to a low level condenser, except that the condenser shell is placed at a height of 10.36 m [barometric height] above the hot well.



- The column of water in the tail pipe forces the condensate into the hot well by gravity.
- Hence condensate extraction pump is not required.

<u>Ejector condenser:</u>



Ejector condenser

- In this condenser cooling water under a head of 5 to 6 m enters at the top of the condenser.
- It is passed through a series of convergent nozzles.
- There is a pressure drop at the throat of the nozzle.
- The reduction in pressure draws exhaust steam into the nozzle through a non-return valve.
- Steam is mixed with water and condensed.

- In the converging cones, pressure energy is partly converted into kinetic energy.
- In diverging cones, the kinetic energy is partly converted into pressure energy.
- The pressure obtained is higher than atmospheric pressure and this forces the condensate to the hot well.

Merits of jet condenser:

- Intimate mixing of steam and cooling water.
- Quantity of cooling water required is less.
- Simple equipment and cost is low.
- Less space is required.
- Cooling water pump is not needed in low level jet condenser.
- Condensate extraction pump is not required for high level and ejector condensers

Demerits of jet condenser:

- Condensate is wasted.
- The cooling water should be clean and free from harmful impurities.
- In low level jet condensers, the engine may be flooded, if condensate extraction pump fails

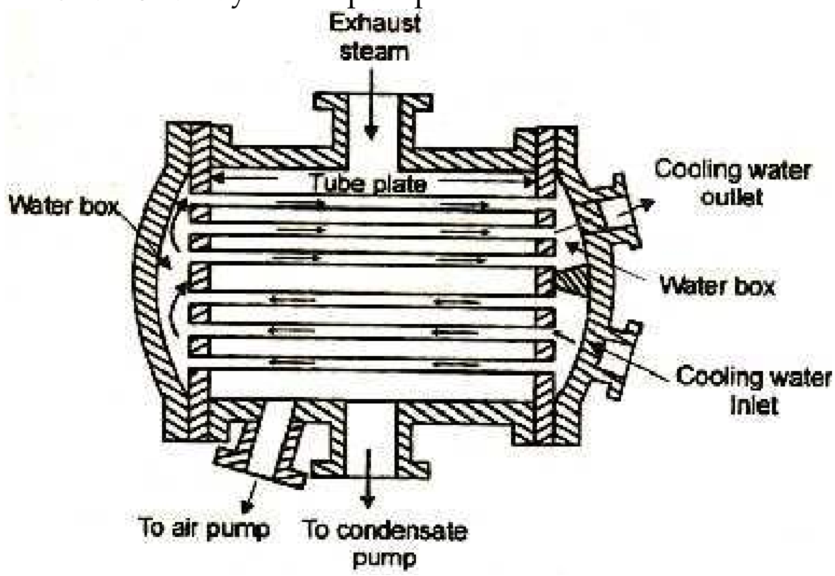
8. Explain the working of Surface condensers with the help of its types? With advantages and disadvantages?

Surface Condenser:

- In surface condensers there is no direct contact between the steam and cooling water and the condensate can be re-used in the boiler.
- In such a condenser even impure water can be used for cooling purpose.
- Although the capital cost and the space needed is more in surface condensers.
- But this expenditure is justified by the saving in running cost and increase in efficiency of plant achieved by using this condenser.

Operation of surface condenser:

- The exhaust steam from prime mover enters at top of the condenser and surrounds the condenser tubes through which cooling water is circulated under force.
- The steam gets condensed as it comes in contact with cold surface of the tubes.
- The cooling water flows in one direction through the first set of the tubes situated in the lower half of condenser.
- Then the water returns in the opposite direction through the second set of the condenser is discharged into the river or pond.
- The condensed steam is taken out from the condenser by a separate extraction pump and air is removed by an air pump.

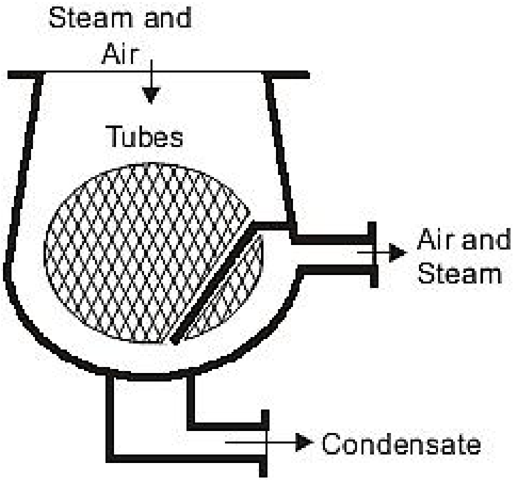


Surface condenser diagram

- Depending upon the position of condensate extraction pump, flow of condensate and arrangement of tubes the surface condensers may be classified as follows:

    1. Down flow condenser
    2. Central flow condenser
    3. Evaporative condenser

Down flow condenser:

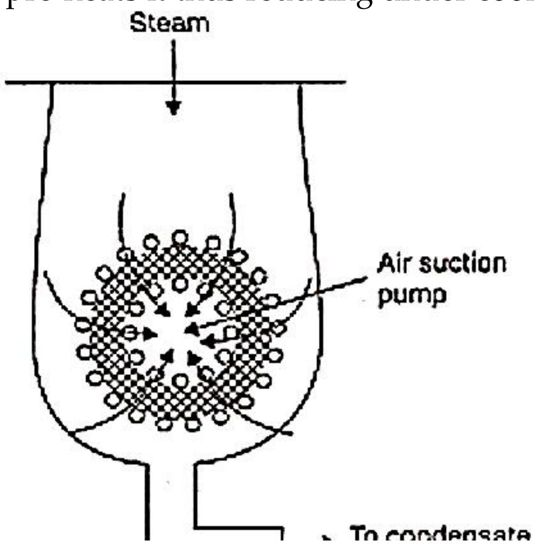


Sectional views of down flow condenser.

- ❖ Steam enters at the top and flows downward.
- ❖ The water flowing through the tubes in one direction in the lower half and comes out in the opposite direction in the upper half.
- ❖ The cooling water and exhaust steam do not come in direct contact with each other.
- ❖ This is generally used where large quantities of water are available.
- ❖ It is used for better quantity of feed water to the boiler must be used most economically.
- ❖ It consists of cast iron air- tight cylindrical shell closed at each end.
- ❖ A number of water tubes are fixed in the tube plates which are located between each cover head and shell.

Central flow condenser:

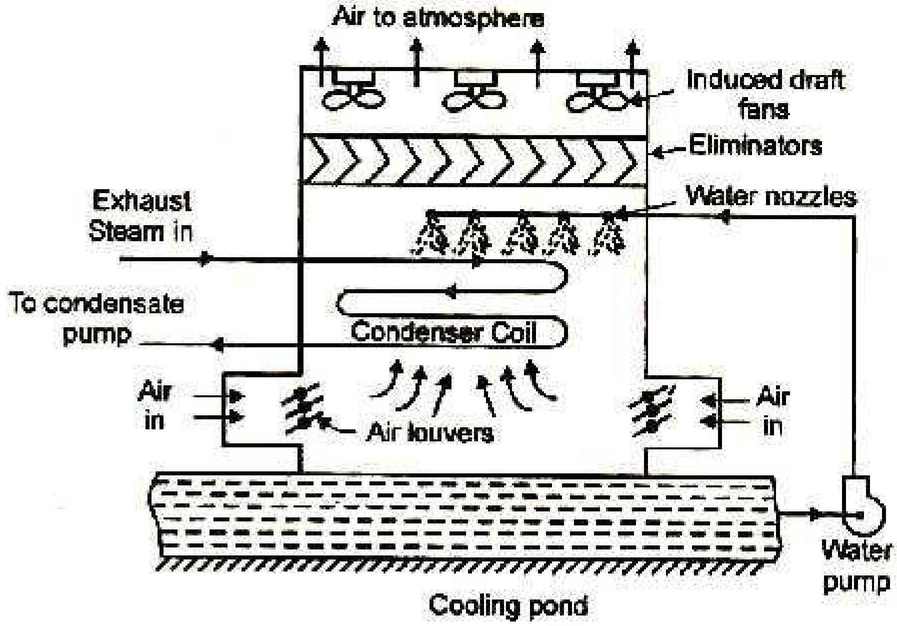
- ❖ In this condenser the steam passages are all around the periphery of the shell.
- ❖ Air is pumped away from the centre of the condenser.
- ❖ The condensate moves radially towards the centre of the next tube.
- ❖ Some of the exhaust steam which moving towards the centre meets the under cooled condensate and pre-heats it thus reducing under cooling.



Central flow condenser

Evaporative condenser:

- In this condenser steam to be condensed in passed through a series of tubes.
- The cooling water falls over these tubes in the form of spray using nozzles.
- Water is sprayed through the nozzles over the pipe carrying exhaust steam and forms a thin film over it.
- The air is drawn over the surface of the coil with the help of induced fan.
- The air passing over the coil carries the water from the surface of condenser coil in the form of vapour.
- The latent heat required for the evaporation of water vapour is taken from the water film formed on the condenser coil.
- This action reduces the temperature of the water film and helps for heat transfer from the steam to the water.
- This mode of heat transfer reduces 10% of cooling water requirement of the condenser.
- The water particles carried with air due to high velocity of air are removed with the help of eliminator.
- It does not require large quantity of water therefore needs a small capacity cooling water pump.



Evaporative condenser

Advantages of surface condenser:

- The condensate can be used as boiler feed water.
- Impure water can also be used as a cooling water.
- High vacuum (about 73.5 cm of Hg) can be obtained in the surface condenser.
- This increases the thermal efficiency of the plant.

Disadvantages of surface condenser:

- The capital cost is more.
- The maintenance cost and running cost of this condenser is high.
- It is bulky and required more space.

9. Draw and Explain the various steps involved in Coal(Fuel) handling?

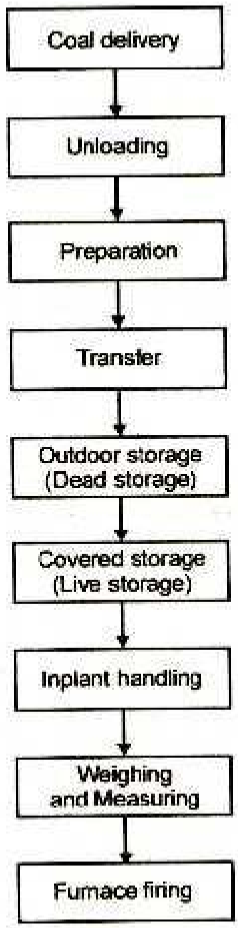
Fuel(Coal) Handling System:

The various steps involved in coal handling are as follows:

1. Coal delivery.
2. Unloading
3. Preparation
4. Transfer
5. Outdoor storage
6. Covered storage
7. In-plant handling
8. Weighing and measuring
9. Feeding the coal into furnace.

i) Coal delivery

- The coal from supply points is delivered by ships or boats to power stations situated near to sea or river.
- Coal is supplied by rail or trucks to the power stations which are situated away from sea or river.
- The transportation of coal by trucks is used if the railway facilities are not available.



ii) Coal Unloading

- The type of equipment to be used for unloading depends on how coal is received at the power station.
- If coal delivered by trucks, there is no need of unloading device as the trucks may dump the coal to the outdoor storage.
- Coal is easily handled and unloaded if the lift trucks with scoop are used.
- In case the coal is brought by railways wagons, ships or boats, the unloading may be done by **car shakes, rotary car dumpers, cranes, grab buckets and coal accelerators.**

iii) Preparation

- When the coal delivered is in the form of big lumps in more storage.
- It is not of proper size, the preparation (sizing) of coal can be achieved by **crushers, breakers, sizers, driers and magnetic separators.**

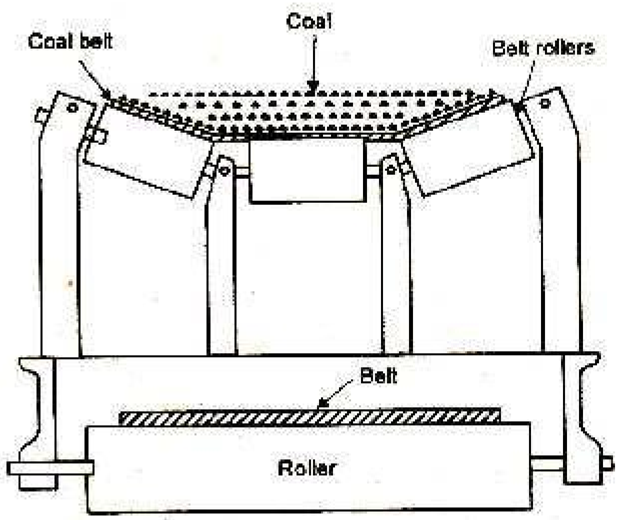
iv)Transfer

After preparation coal is transferred to the dead storage by means of :

1. Belt conveyors
2. Screw conveyors
3. Bucket elevators
4. Grab bucket elevators
5. Skip hoists
6. Flight conveyor

1. Belt Conveyor

- It consists of an endless belt moving over a pair of rollers.
- At some distance a supporting roller is provided at the centre.
- The belt is made up of rubber or canvas.
- Belt conveyor is suitable for the transfer of coal over long distances.
- It is used in medium and large power plants.

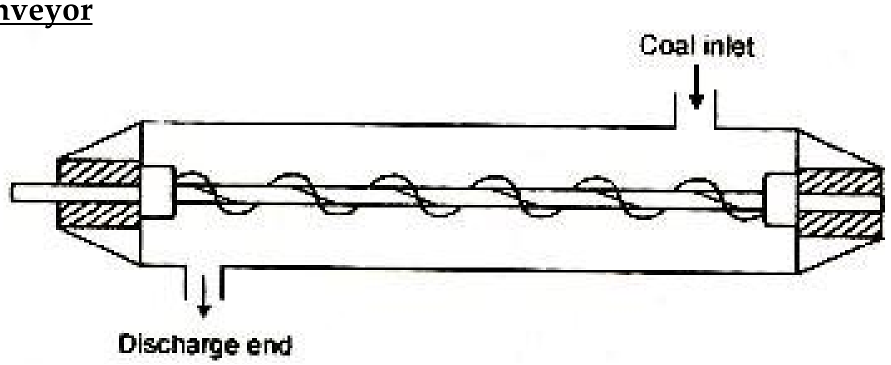


Belt Conveyor

Advantages of belt conveyor:

1. Its operation is smooth and clean
2. It requires less power as compared to other types of systems
3. Large quantities of coal can be discharged quickly and continuously.
4. Material can be transported on moderate inclines.

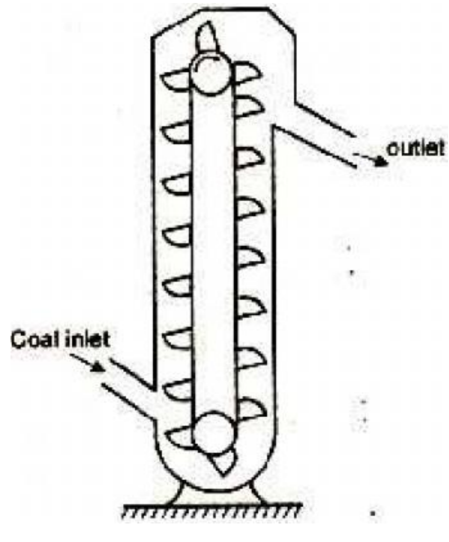
2. Screw Conveyor



- ❖ It consists of an endless helicoid screw fitted to a shaft.
- ❖ The screw while rotating in a trough transfers the coal from feeding end to the discharge end.
- ❖ This system is suitable, where coal is to be transferred over shorter distance and space limitations exist.
- ❖ Rotation of screw varies between 75-125 r.p.m

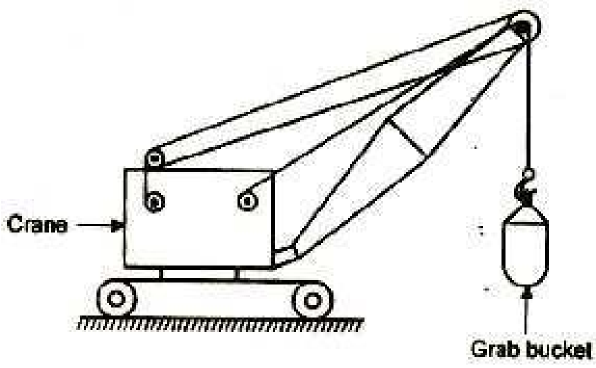
3. Bucket elevator

- ❖ It consists of buckets fixed to a chain.
- ❖ The chain moves over two wheels.
- ❖ The coal is carried by the bucket from bottom and discharged at the top.



Bucket elevator

4. Grab bucket elevator



Grab bucket elevator.

- It lifts and transfers coal on a single rail or track from one point to the other.
- The coal lifted by grab buckets is transferred to overhead bunker or storage.
- This system requires less power for operation and requires minimum maintenance.
- The grab bucket conveyor can be used with crane or tower.
- Although the initial cost of this system is high but operating cost is less.

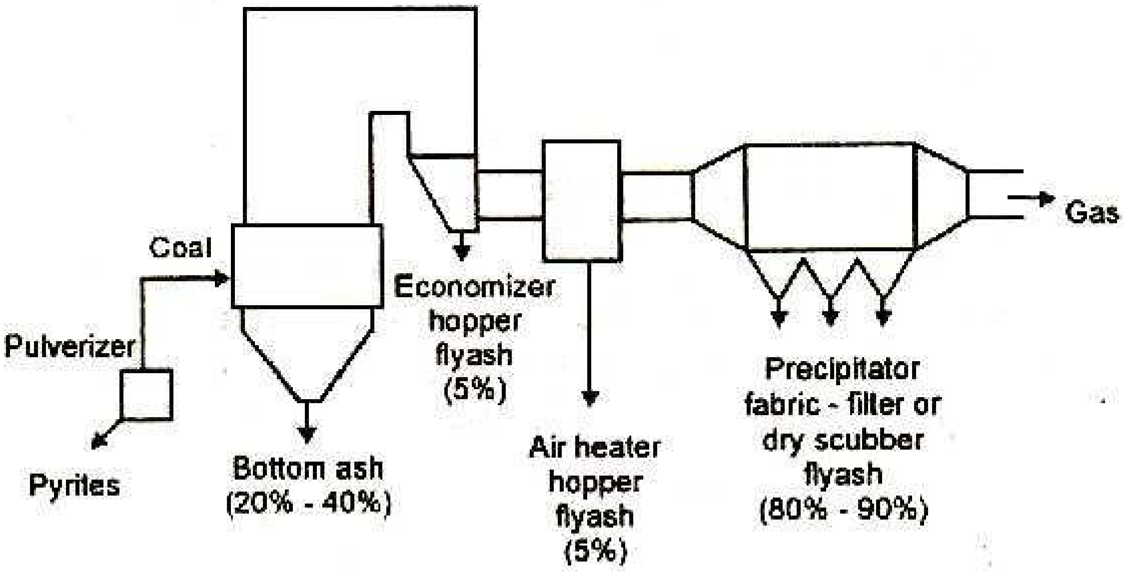
v) Storage of Coal

- Storage of coal gives protection against the interruption of coal supply.
- When there is delay in transportation of coal or due to strike in coal mines the stored coal is very useful.
- Also when the prices are low, the coal can be purchased and stored for future use.
- The amount of coal to be stored depends on the availability of space for storage, and transportation facilities.
- Storage of coal for longer periods is not economical and results in deterioration of the quality of coal.

10. Explain the Layout of Ash handling system.

Ash Handling System:

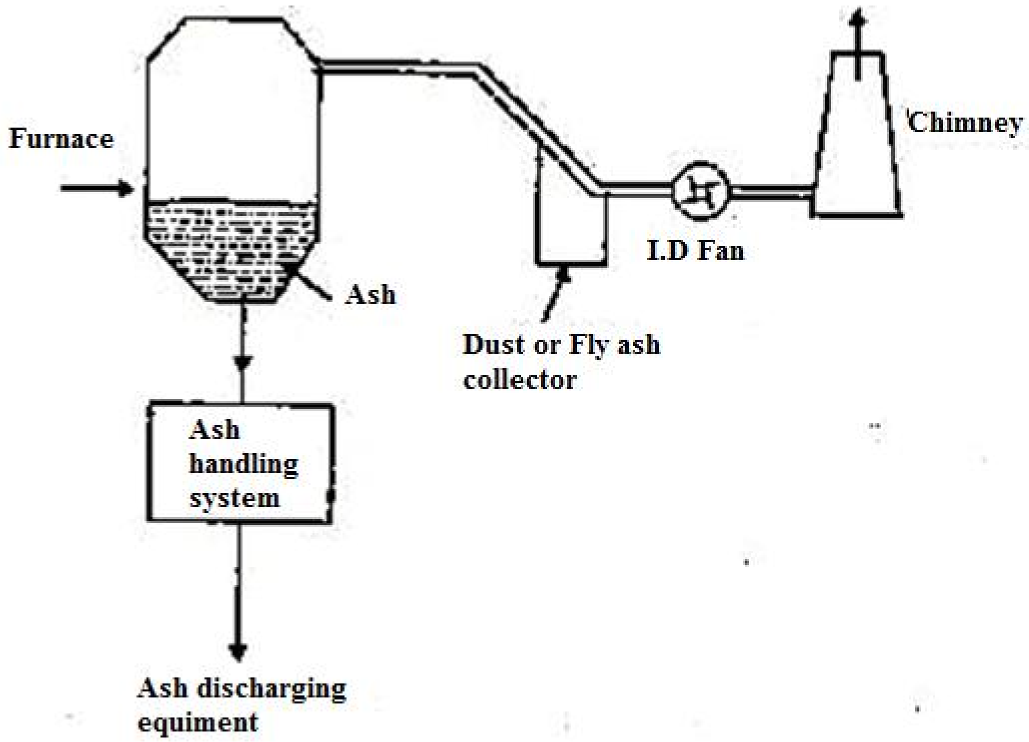
- Boilers burning coal and the large ash particles are collected under the furnace in a water-filled ash hopper.
- Fly ash is collected in dust collectors with either an electrostatic precipitator or a baghouse.
- A boiler generates approximately 80% fly ash and 20% bottom ash.
- Ash must be collected and transported from various points of the plants.
- Three major factors should be considered for ash disposal systems.
    1. Plant site
    2. Fuel source
    3. Environmental regulation
- Ash storage and disposal sites are guided by environmental regulations.
- The sluice conveyor system is the most widely used for bottom ash handling.
- The hydraulic vacuum conveyor is the most frequently used for fly ash systems.



Layout of ash collection and transportation

Ash Handling Equipment:

- Mechanical equipments are required for the disposal of ash.
- The commonly used ash discharge equipment is as follows:
    - i) Rail road cars
    - ii) Motor truck
    - iii) Barge
- The handling equipment should perform the following functions:
    1. Capital, operating and maintenance charges of the equipment should be low.
    2. It should be able to handle large quantities of ash.
    3. Ashes, dust etc. create troubles so the equipment should be able to handle them smoothly.
    4. The equipment should be non-corrosive and wear resistant.

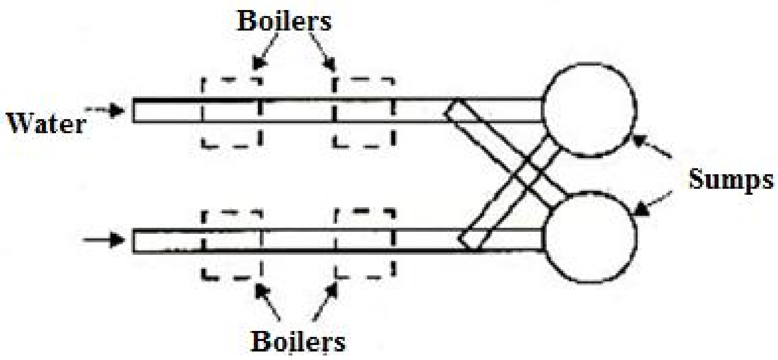


Ash handling equipment

Classification of Ash Handling System:

i) Hydraulic system
ii) Pneumatic system
iii) Mechanical system

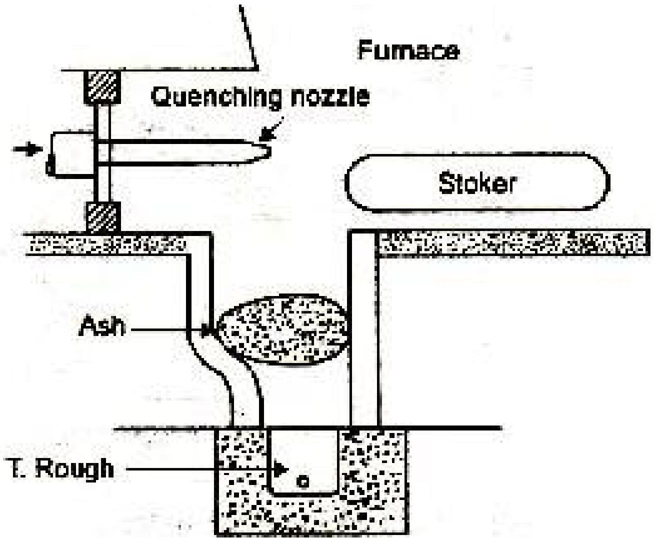
Hydraulic System:



Hydraulic system

- In this system, ash from the furnace falls into a system of water possessing high velocity and is carried to the sumps.
- It is generally used in large power plants.
- In this method water at sufficient pressure is used to take away the ash to sump. Where water and ash are separated and then ash is transferred to the dump site in wagons, rail cars to trucks.
- The loading of ash may be through a belt conveyor, grab buckets.
- If there is an ash basement with ash hopper the ash can fall directly in ash conveying system.

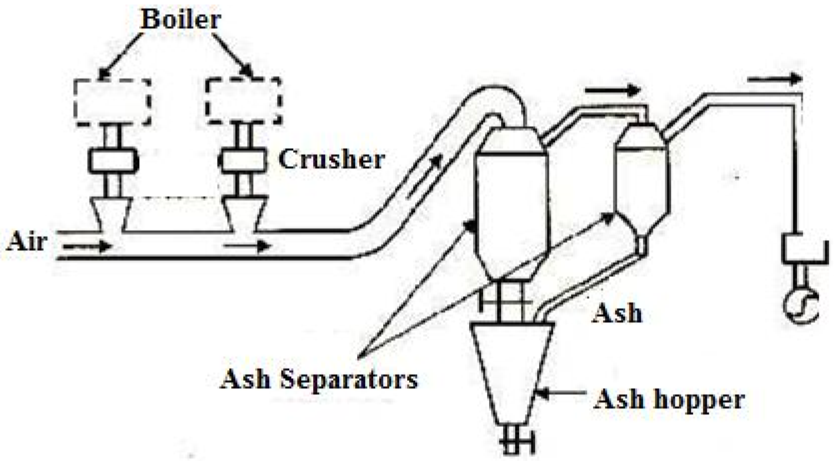
Water-Jetting System:



Water jetting

- In this method a low pressure jet of water coming out of quenching nozzle is used to cool the ash.
- The ash falls into rack and is then removed.

Pneumatic System:

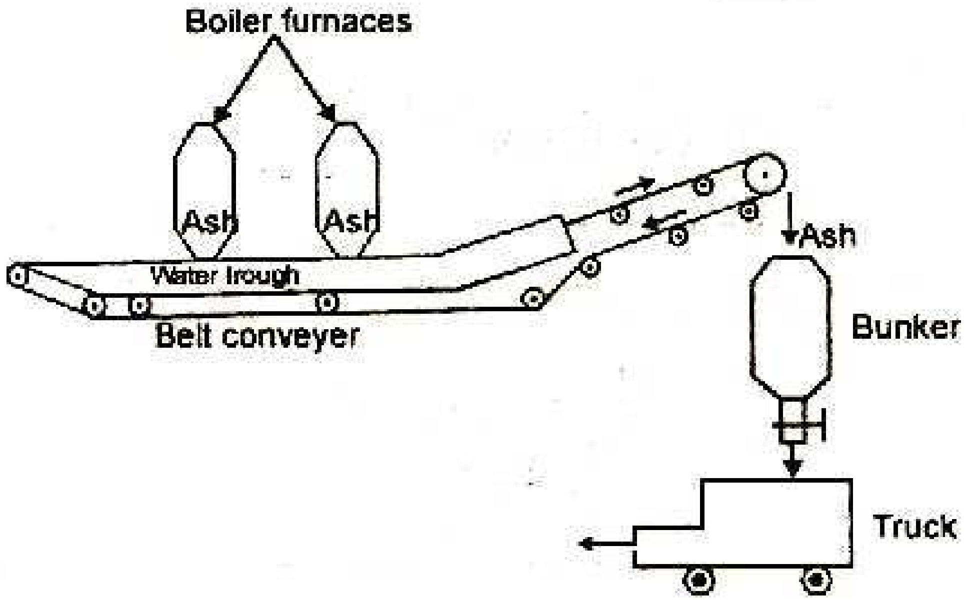


Pneumatic system

- In this system ash from the boiler furnace falls into a crusher.
- The larger ash particles are crushed to small sizes by using balls in the crusher.
- The ash is then carried by a high velocity air or steam to the point of delivery.
- Air leaving the ash separator is passed through filter to remove dust etc.
- So that the filter removes the dust particles and passes clean air which will protect the blades of the exhaust fan.

Mechanical system:

- In this system ash cooled by water seal falls on the belt conveyor.
- Then the deposited ash is carried out continuously to the bunker.
- The ash is then removed to the dumping site from the ash banker with the help of trucks.


Boiler furnaces
Ash
Ash
Water trough
Belt conveyer
Ash
Bunker
Truck

11. Define Draught and also explain the types of Draught.

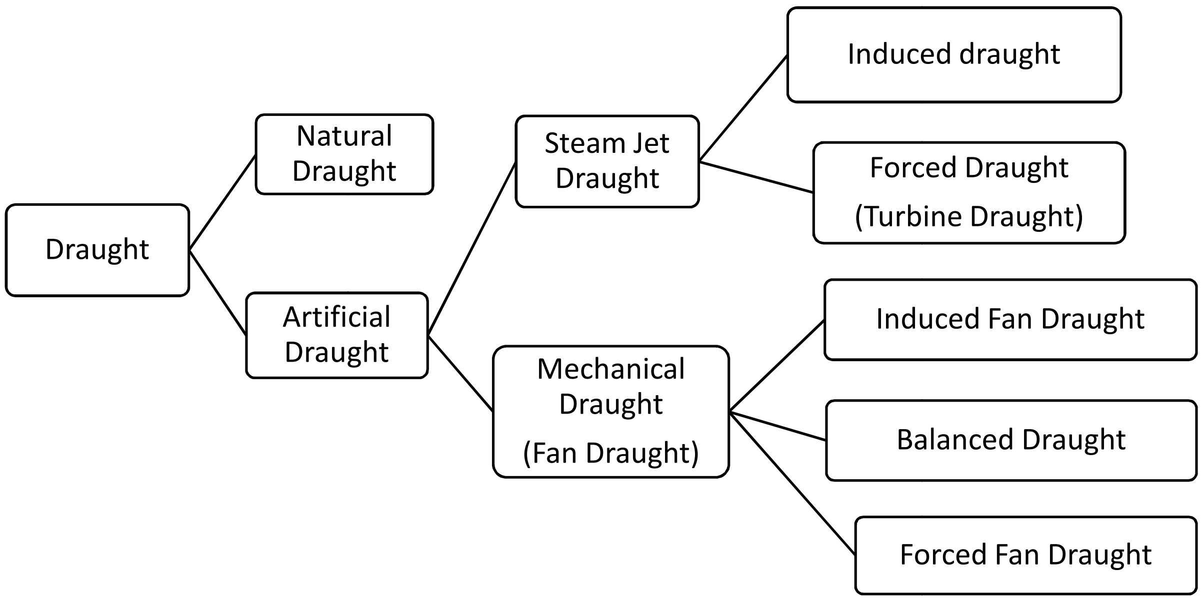
Draught:

- Draught is defined as the difference between absolute gas pressure at any point in a gas flow passage and the ambient (same elevation) atmospheric pressure.
- Draught is advantageous if Patm < Pgas and it is drawback if Patm > Pgas.
- Draught is achieved by small pressure difference which causes the flow of air or gas takes place.

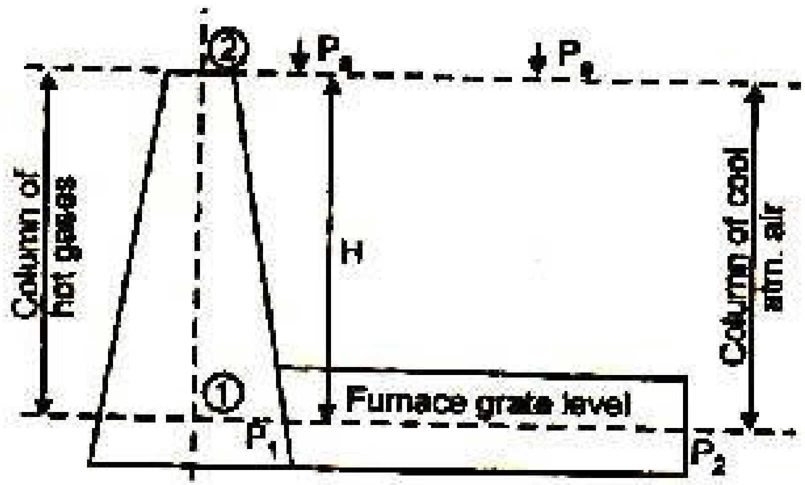
Purpose of draught:

- To supply required amount of air to the furnace for the combustion of fuel.
- The amount of fuel that can be burnt per square root of grate area depends upon the quantity of air circulated through fuel bed.
- To remove the gaseous products of combustion.

Classification of DRAUGHT:



Natural Draught:



Natural draught

Where H- Height of the Chimney (m)

p_a – Atmospheric pressure (N/m^2)

p_1 – Pressure acting on the grate from chimney side (N/m^2)

p_2 – Pressure acting on the grate from atmospheric (N/m^2)

- ❖ If only chimney is used to produce the draught, it is called natural draught.
- ❖ The chimney is a vertical tubular masonry structure or reinforced concrete.
- ❖ It is constructed for enclosing a column of exhaust gases to produce the draught(flow of air).
- ❖ It discharges the gases high enough to prevent air pollution.
- ❖ The draught is produced by this tall chimney due to temperature difference of hot gases in the chimney and cold external air outside the chimney.
- ❖ Due to this pressure difference (p), the atmospheric air flows through the furnace and the flue gases flow through the chimney.
- ❖ The pressure difference can be increased by increasing the height of the chimney or reducing the density of hot gases.

Merits of Natural Draught:

- ❖ No external power is required for creating the draught.
- ❖ Air pollution is prevented since the flue gases are discharged at a higher level
- ❖ Maintenance cost is practically nil since there are no mechanical parts.
- ❖ It has longer life.
- ❖ Capital cost is less than that of an artificial draught

Demerits of natural draught:

- ❖ Maximum pressure is required for small chimney.
- ❖ Heat cannot be extracted from the flue gases for economizer, superheater, etc.
- ❖ Overall efficiency of the plant is decreased since the fluid gases are discharged at higher temperatures.
- ❖ Not flexible under peak loads because height of a chimney is constant.
- ❖ Considerable amount of heat released by the fuel (about 20%) is lost due to flue gases.

Applications of natural draught:

Natural draught system is used only in small capacity boilers and it is not used in high capacity thermal plants.

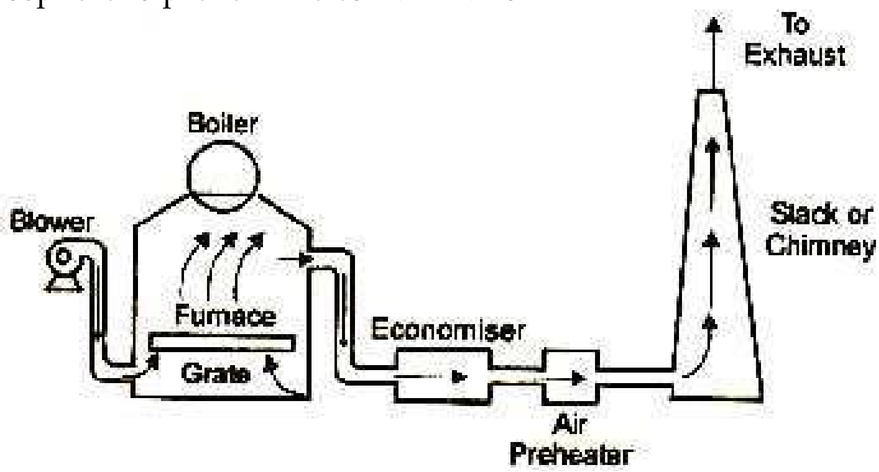
Artificial Draught:

- ❖ The draught produced by chimney is affected by the atmospheric conditions.
- ❖ Natural draught has no flexibility, poor efficiency and tall chimney is required.
- ❖ In modern power plants, the draught must be independence of atmospheric condition and it must have greater flexibility.
- ❖ The draught required in actual power plant is sufficiently high (300 mm of water) and to meet high draught requirements, some other system must be used known as artificial draught.
- ❖ The artificial draught is produced by a fan and it is known as fan (mechanical) draught.

❖ Mechanical draught is preferred for central power stations.

Forced Draught:

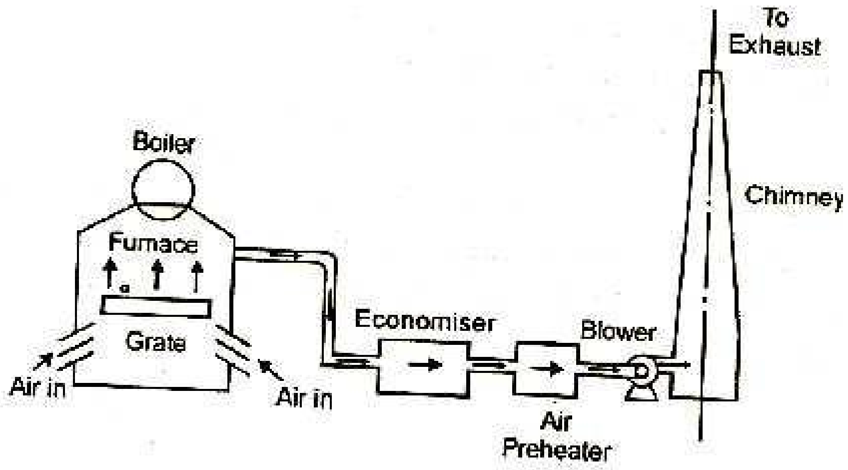
❖ In a forced draught system, a blower is installed near the base of the boiler.
❖ The air is forced to pass through the furnace, flues, economizer, air-preheater and to the stack.
❖ This draught system is also known as positive draught system because the pressure and air is forced to flow through the system.
❖ A stack or chimney is also used but its function is to discharge gases high in the atmosphere to prevent the contamination.



Forced draught

Induced Draught:

❖ In this system, the blower is located near the base of the chimney instead of near the furnace.
❖ The air is sucked in the system by reducing the pressure through the system below atmosphere.
❖ The induced draught fan sucks the burned gases from the furnace.
❖ The pressure inside the furnace is reduced below atmosphere and induces the atmospheric air to flow through the furnace.
❖ The action of the induced draught is similar to the action of the chimney.
❖ The draught produced is independent of the temperature of the hot gases.
❖ The gases may be discharged as cold as possible after recovering as much heat as possible in air-preheater and economizer.
❖ This draught is used generally when economizer and air-preheater are incorporated in the system.
❖ The chimney is also used in this system and its function is to discharge gases high in the atmosphere.
❖ The total draught produced in induced draught system is the sum of the draughts produced by the fan and chimney.



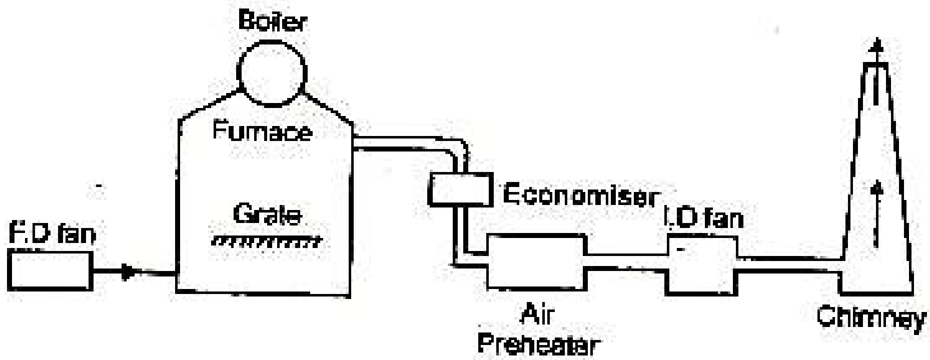
Induced draught

Balanced Draught:

❖ It is always preferable to use a combination of forced draught and induced draught instead of forced or induced draught alone.

❖ If the forced draught is used alone, then the furnace cannot be opened either for firing or inspection because the high pressure air inside the furnace will try to blow out suddenly and there is every chance of blowing out the fire completely and furnace stops.

❖ If the induced draught is used alone, then also furnace cannot be opened either for firing or inspection because the cold air will try to rush into the furnace as the pressure inside the furnace is below atmospheric pressure. This reduces the effective draught and dilutes the combustion.



Balanced draught

❖ To overcome both these difficulties, a balanced draught is always preferred.

❖ The balanced draught is a combination of forced and induced draught.

❖ The forced draught overcomes the resistance of the fuel bed therefore sufficient air is supplied to the fuel bed for proper and complete combustion.

❖ The induced draught fan removes the gases from the furnace maintaining the pressure in the furnace just below atmosphere.

❖ This helps to prevent the blow – off of flames when the doors are opened as the leakage of air is inwards.

❖ In balanced draught, the pressure inside the furnace is near atmospheric pressure.

❖ There is no danger of blowout or inrushing the air into the furnace when the doors are opened for inspection.

12 Explain in detail about the feed water treatment in steam power plant. (or) Describe the need of feed water treatment in coal based thermal power plant and also write the methods of feed water treatment.

For steam power plants water is one of the most important raw materials. In most of the cases, water used for steam power plants contains impurities which must be treated before use. All Natural waters-even rain, snow, bail, treated municipal supplies contain impurities in any one form.

Classification of Impurities in Water:

The impurities in water may be classified as follows:

1. Visible impurities:

(i) ***Microbiological growth:*** Presence of micro-organisms is always undesirable as they may produce ***clogging troubles***.

(ii) ***Turbidity and sediments***: *Turbidity* is the suspended insoluble matter whereas sediments are the coarse particles which settle down in stationary water, both are objectionable.

2. Dissolved gases :

(i) Carbon di-oxide
(ii) Oxygen
(iii) Nitrogen
(iv) Hydrogen sulphide
(v) Methane

3. Minerals and salts :

(i) Iron and manganese
(ii) Fluorides
(iii) Oxygen
(iv) Methane
(v) Sodium and potassium salt
(vi) Silica.

4. Mineral acids:

Their presence in water is always undesirable as it may result in the chemical reaction with the boiler material.

5. Hardness:

The salts of calcium and magnesium as bicarbonates, chlorides, sulphates, etc., are mainly responsible for the formation of a very hard surface which resists heat transfer and clogs the passages in pipes. Presence of these salts is known as **hardness**.

Troubles Caused by the Impurities in Water:

The impurities in water may cause one or more of the following troubles:

1. Scale formation
2. Corrosion
3. Carry over

4. Embrittlement.

Methods of Feed Water Treatment:

The different methods adopted to remove the various impurities are given below:

- Mechanical treatment:
  - ✓ Sedimentation
  - ✓ Coagulation
  - ✓ Filtration
  - ✓ Interior painting
- Thermal treatment
  - ✓ Deaeration
  - ✓ Distillation by evaporators
- Chemical treatment - Softening Process
- Demineralization
- Blow down

1. Mechanical treatment:

(i) Sedimentation:

- Sedimentation is a physical water treatment process using gravity to remove suspended solids from water.
- Solid particles drawn by the instability of moving water may be removed naturally by sedimentation in the feedwater of steam power plant.

(ii) Coagulation:

- Coagulation is the process of adding a chemical such as alum which produces positive charges to neutralize the negative charges on the small impure particles present in water.
- The coagulation process involves the addition of the chemical (e.g. alum – $\mathbf{Al_2(So_4)_3}$) and then a rapid mixing to dissolve the chemical and distribute it evenly throughout the water.
- Then the particles can stick together and forming larger particles which are more easily removed or filtered from the water.

(iii) Filtration:

- Filtration is the mechanical or physical operation which is used for the separation of solids from fluids by interposing a medium through which only the fluid can pass.
- Filtration is a technique used for two main purposes.
  - ✓ To remove solid impurities from a liquid.
  - ✓ To collect a desired solid from the solution from which it was precipitated or crystallized.
- Two general methods of filtration:
  - ✓ Gravity filtration

- ✓ Vacuum (or suction) filtration

(iv)Interior painting:

- ➢ The interior painting is needed for identifying the impurities present in water.
- ➢ This is used to detect which type of impurity is present inside the water.
- ➢ The impurities may affect either in physical or in chemical way such as corrosion.

2. Thermal treatment:

(i) Deaeration:

- ➢ The presence of oxygen, and other non-condensable gases, in the feedwater is a major cause of corrosion in the feedwater piping, boiler, and condensate handling equipment.
- ➢ Deaeration is the mechanical thermal process for the removal of dissolved gases from the boiler feedwater.
- ➢ The incoming feedwater must be heated to the full saturation temperature, corresponding to the steam pressure maintained inside the deaerator. This will lower the solubility of the dissolved gases to zero.

(ii) Distillation by evaporators:

- ➢ Distillation is a process of separating the component substances from a liquid mixture by selective evaporation and condensation.
- ➢ Distillation may result in essentially complete separation or it may be a partial separation that increases the concentration of selected components of the mixture.
- ➢ Distillation of feedwater can be carried out by evaporators.

3. Chemical treatment :

(i) Softening Process:

- ➢ When lime and soda ash are added, the hardness-causing minerals in the feedwater form nearly insoluble precipitates.
- ➢ Calcium hardness is precipitated as calcium carbonate ($CaCO_3$).
- ➢ Magnesium hardness is precipitated as magnesium hydroxide ($Mg(OH)_2$).
- ➢ These precipitates are then removed by conventional processes of coagulation, sedimentation, and filtration.

(i) Cold lime-soda softening process

(ii) Hot lime-soda softening process

(iii) Lime-phosphate softening process

(iv) Ion exchange process - The process may be sodium zeolite process or hydrogen zeolite process.

4. Demineralization:

- ➢ Demineralization is the process of removing all the salts dissolved in the water through a combination of strongly acidic cation exchangers and strongly basic anion exchangers.

- This process removes the unwanted minerals in the feedwater and creates the purified water without any chemical impurities.

5. **<u>Blow down :</u>**
   - Blow down is water intentionally wasted from a boiler to avoid concentration of impurities during continuing evaporation of steam.
   - The water is blown out of the boiler with some force by steam pressure within the boiler.
   - The amount of blow down depends on allowable solid concentration.

     % Blow down = $\frac{\textbf{Quantity of water blown down}}{\textbf{Quantity of feedwater admitted}}$
   - There are some blow down processes are:

     (i) Hot lime-soda and hot zeolite process

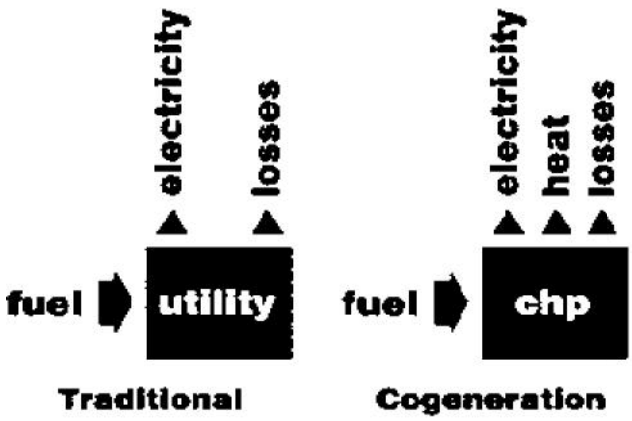
     (ii) Adding acid to control alkalinity and vice-versa.

13. **Explain in detail about Cogeneration system in power plants. (or) Describe in detail about the CHP power plants and also explain its types.**

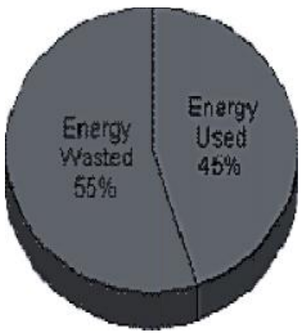
Introduction:

- Cogeneration is also called as combined heat and power or combine heat and power. Cogeneration works on concept of producing two different form of energy by using one single source of fuel.
- Out of these two forms one must be heat or thermal energy and other one is either electrical or mechanical energy.
- Cogeneration system is the most optimum, reliable, clean and efficient way of utilizing fuel.
- The fuel used may be natural gas, oil, diesel, propane, wood, coal etc.
- It works on very simple principle (i.e.) the fuel is used to generate electricity and this electricity produces heat and this heat is used to boil water to produce steam.
- In cogeneration plant the low pressure steam coming from turbine is not condense to form water but it is used for heating or cooling in building and factories.
- This low pressure steam from turbine has high thermal energy.
- The cogeneration plant has high efficiency of around 80 - 90 %. In India, the potential of power generation from cogeneration plant is more than 20,000 MW.
- The first commercial cogeneration plant was built and designed by Thomas Edison in New York in year 1882.

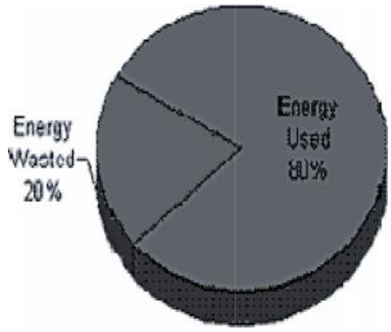
Comparison of conventional power plant and Cogeneration power plant:



- In traditional power plant, when we gave fuel as input we get electrical energy and losses as output.
- In case of cogeneration with fuel as input, the output is electrical energy, heat or thermal energy and losses.



Energy sceneric in convential power plant

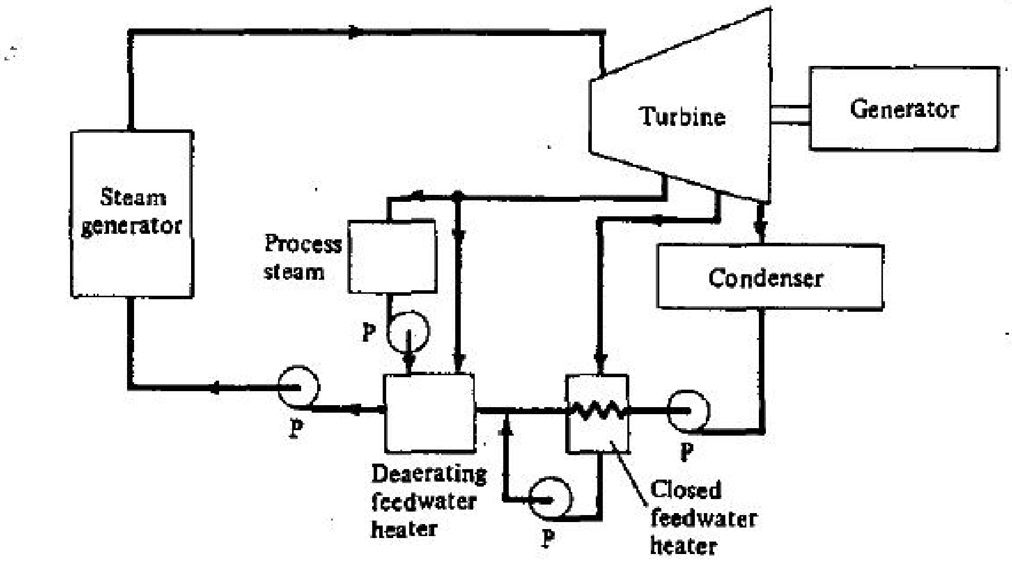


Energy sceneric in combined heat and power plant

- In conventional power plant with 100% energy input, only 45% of energy is used and rest 55% is wasted.
- With cogeneration plants, the total energy used is 80% and energy wasted is only 20%.
- It means with cogeneration the fuel utilization is more efficient and optimized and hence more economical.

Need for Cogeneration:

- Cogeneration helps to improve the efficiency of the plant.
- Cogeneration reduce air emissions of particulate matter, nitrous oxides, sulphur dioxide and carbon dioxide which leads to greenhouse effect.
- It reduces cost of production and improve productivity.
- Cogeneration system helps to save water consumption and water costs.
- Cogeneration system is more economical as compared to conventional power plant



Basic cogeneration plant with Extraction condensing turbine

Types of Cogeneration Power Plants:

- In a typical combined heat and power plant system there is a steam or gas turbine which takes steam and drives an alternator.
- A waste heat exchanger is also installed in cogeneration plant which recovers the excess heat or exhaust gas from the electric generator to in turn generate steam or hot water.
- There are basically two types of cogeneration power plants such as
    - ✓ Topping cycle power plant
    - ✓ Bottoming cycle power plant

Topping cycle power plant:

In this type of Combine Heat and Power plant electricity is generated first and then waste or exhaust steam is used to heating water or building. The most suitable electric-to-heat generation ratios vary from type to type. There are basically four types of topping cycles.

a) Combined-cycle topping CHP plant:

- In this type of plant the fuel is firstly burnt in a steam boiler.
- The steam so produced in a boiler is used to drive turbine and hence synchronous generator which in turn produces electrical energy.
- The exhaust from this turbine can be either used to provide usable heat, or can be send to a heat recovery system to generate steam.
- This generated steam may be further used to drive a secondary steam turbine.
- The steam turbine is either of the back-pressure type or an extraction-condensing type.
- The combined-cycle plant is most suitable only when the electric demand is high comparable to the heat demand.

b) Steam-turbine topping CHP Plant:

- In this the fuel is burned to produce steam which generates power.
- The exhaust steam is then used as low-pressure process steam to heat water for various purposes.
- Steam-electric power plant with steam extraction from a condensing turbine to generate electricity.
- This extraction condensing cogeneration plant is suitable over a wide range of ratios of electric-to-heat generation.

c) Water- turbine topping CHP Plant:

- In this type of CHP plant a jacket of cooling water is run through a heat recovery system.

- This cooling water is used to generate steam or hot water for space heating.
- Steam-electric power plant with a back-pressure turbine using water as a source for producing electricity.
- The back-pressure steam turbine plant is most suitable only when the electric demand is low compared with the heat demand.

d) <u>Gas turbine topping CHP plant:</u>

- In This topping plant a natural gas fired turbine is used to drives a synchronous generator to produce electricity.
- The exhaust gas is sent to a heat recovery boiler
- Gas-turbine power plant with a heat-recovery boiler which uses the gas turbine exhaust to generate steam.
- The gas turbine power plant is most suitable when the electric demand is almost nearer to the heat demand.

<u>Bottoming cycle power plant</u>:

- Bottoming cycle is exactly opposite to that of topping cycle power plant.
- In this type of CHP plant the excess heat from a manufacturing process is used to generate steam.
- This steam is used for generating electrical energy.
- In this type of cycle no extra fuel is required to produce electricity, as fuel is already burnt in production process.

<u>Configuration of Cogeneration Plants:</u>

- Gas turbine Combine heat power plants which uses the waste heat in the flue gas emerging out of gas turbines.
- Steam turbine Combine heat power plants that use the heating system as the jet steam condenser for the steam turbine.
- Molten-carbonate fuel cells have a hot exhaust, very suitable for heating.
- Combined cycle power plants adapted for Combine Heat and Power.

14. Explain in detail about Binary Vapour Cycle. (or) Write briefly about the Mercury-Steam binary vapour cycle with the T-s diagram.

Generally water is used a working fluid in vapour power cycle as it is found to be better than any other fluid, but it is far from being the ideal one. The binary cycle is an attempt to overcome some of the shortcomings of water and to approach the ideal working fluid by using two fluids.

The most important desirable characteristics of the working fluid suitable for vapour cycles are:

a .A high critical temperature and a safe maximum pressure.

b. Low- triple point temperature

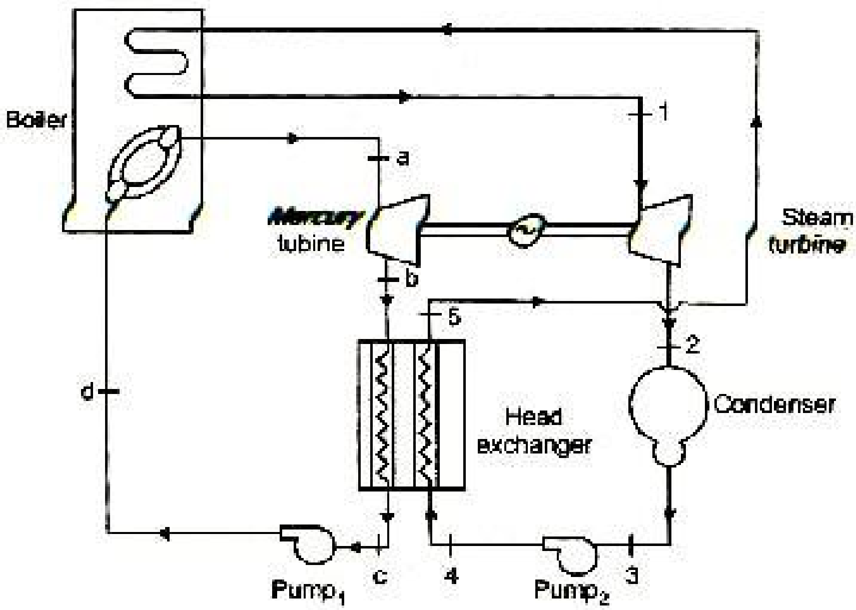
c. Condenser pressure is not too low.

d. high enthalpy of vaporization

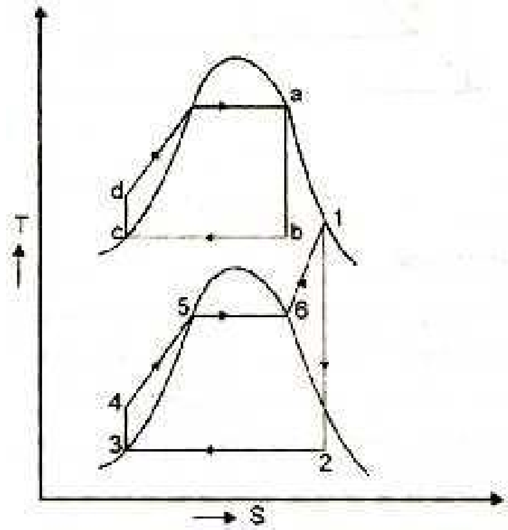
e. High thermal conductivity

Therefore it can be concluded that no single working fluids may have desirable requirements of working fluid. Different working fluids may have different attractive feature in them, but not all. In such cases two vapour cycles operating on two different working fluids are put together, one is high temperature region and the other in low temperature region and the arrangement is called binary vapour cycle.

The layout of mercury-steam binary vapour cycle is shown in figure. Along with the depiction of T-S diagram figure. Since mercury having high critical temperature (898°C) and low critical pressure (180 bar) which makes a suitable working fluid will act as high temperature cycle (toppling cycle) and steam cycle will act as low temperature cycle.



Mercury-steam binary vapour cycle



T-S diagram for Mercury-steam binary vapour cycle.

Here mercury vapour are generated in mercury boiler and sent for expansion in mercury turbine and expanded fluid leaves turbine to condenser. In condenser, the water is used for extracting heat from the mercury so as to condensate it. The amount water entering mercury condenser. The mercury condenser also act as steam boiler for super heating of heat liberated during condensation of mercury is too large to evaporate the water entering of seam an auxiliary boiler may be employed or superheating may be realized in the mercury boiler itself.

From the cycle,

The Network obtained, $W_{net} = W_{Hg} + W_{H2O} - \Sigma W_{pump}$

Since pump works are very small, it may be neglected

Work for mercury turbine, $W_{Hg} = m_{Hg}\,(h_a - h_b)$

Work for steam turbine, $W_{Steam} = m_{steam}\,(h_1 - h_2)$

Pump work, $W_{pump} = m_{Hg}\,(h_a - h_b) + m_{steam}\,(h_1 - h_2)$

Heat supplied to the cycle, $Q_{in} = m_{Hg}\left(h_a - h_d\right) + m_{steam}\left[\left(h_1 - h_6\right) + \left(h_5 - h_4\right)\right]$

Heat rejected, $Q_{out} = m_{steam}\,(h_2 - h_3)$

Efficiency of binary vapour cycle, $\eta_{bin\ vap} = \frac{Net\ Work\ done(Pump\ work)}{Heat\ Supplied}$

$$\eta_{bin\ vap} = \frac{W_{net}}{Q_{in}}$$

$$\eta_{bin\ vap} = \frac{W_{Hg} + W_{H2O} - pW_{pump}}{m_{Hg}\ h_a - h_d + m_{Steam}[\ h_1 - h_6 + h_5 - h_4\ ]}$$

$$\eta_{bin\ vap} = \frac{m_{Hg}\ h_a - h_b + m_{Steam}\ h_1 - h_2}{m_{Hg}\ h_a - h_d + m_{Steam}[\ h_1 - h_6 + h_5 - h_4\ ]}$$