ME8792 Power Plant Engineering

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:

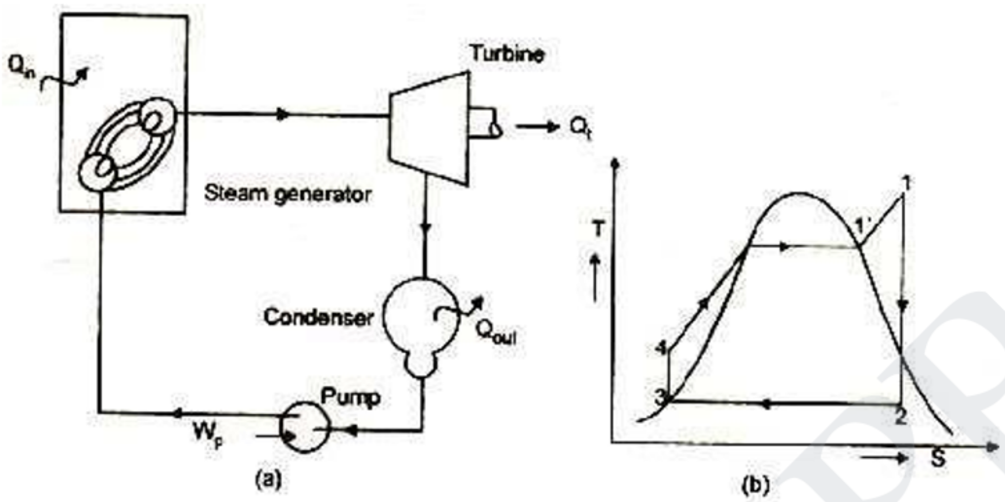
In this cycle working fluid remains in the gaseous phase throughout the entire process.

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 1'.
- 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

$$Q_{in} = m\,(h_1 - h_4)$$

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

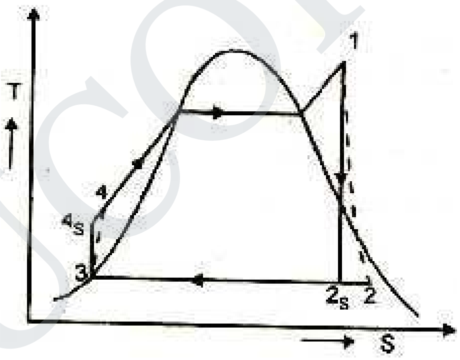
Efficiency Calculation:

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.

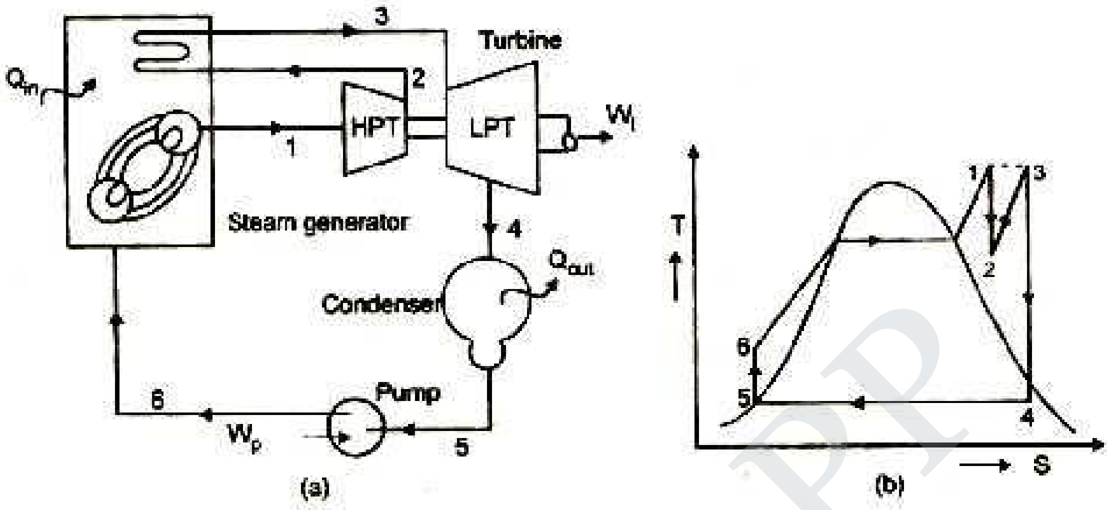
Improvisations of the Basic Rankine Cycle:

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.

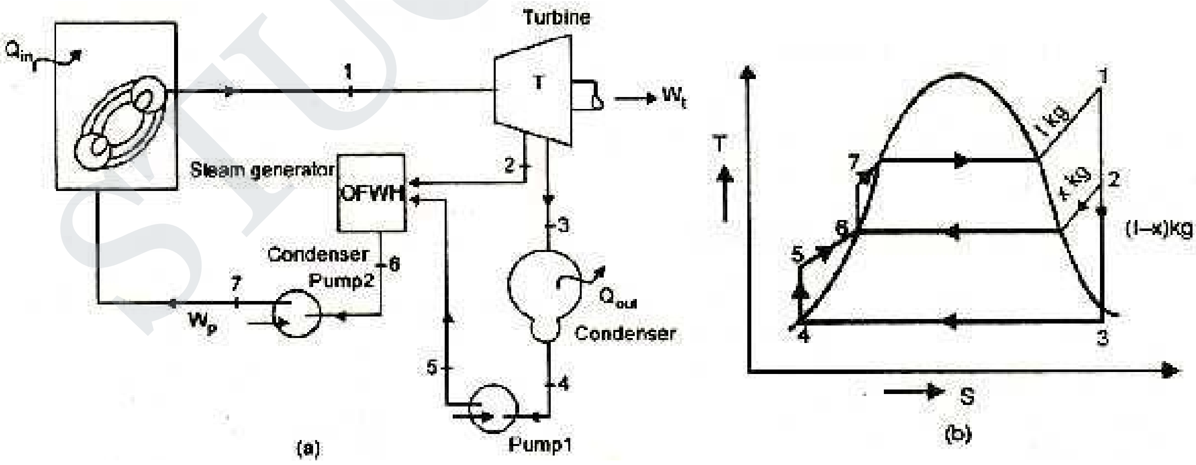
- ❖ It is reheated before passing through a second turbine and lowers the pressure turbine.
- ❖ This prevents the vapour from condensing during its expansion which can seriously damage the turbine blades.



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.

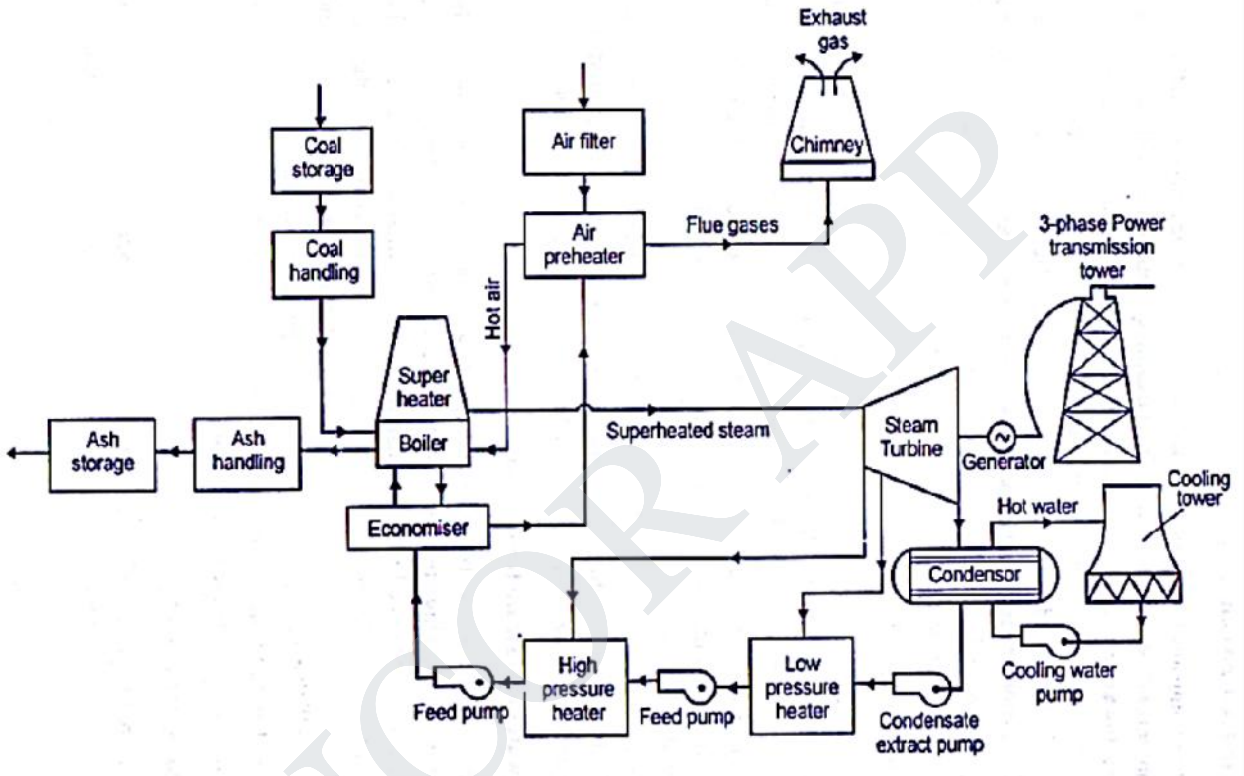


Schematic diagram and T-S diagram of Rankine cycle with Regenerator.

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

Introduction:

- 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.



Equipment of a Steam Power Plant:

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.

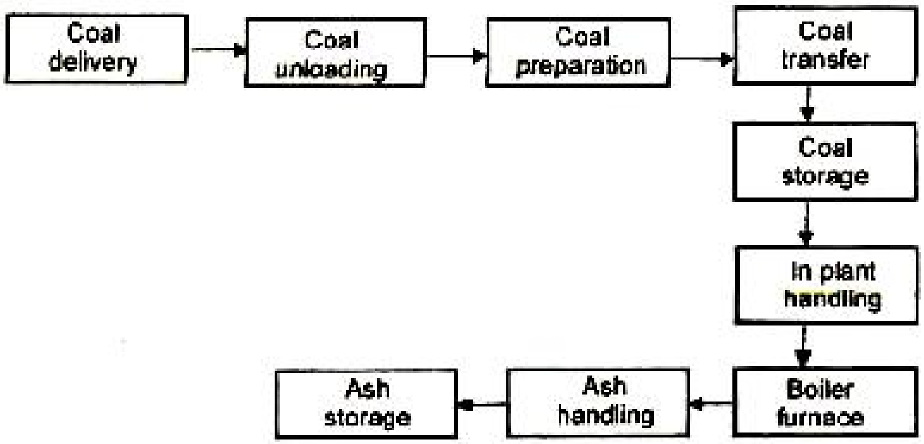
Operation of Thermal power plant:

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

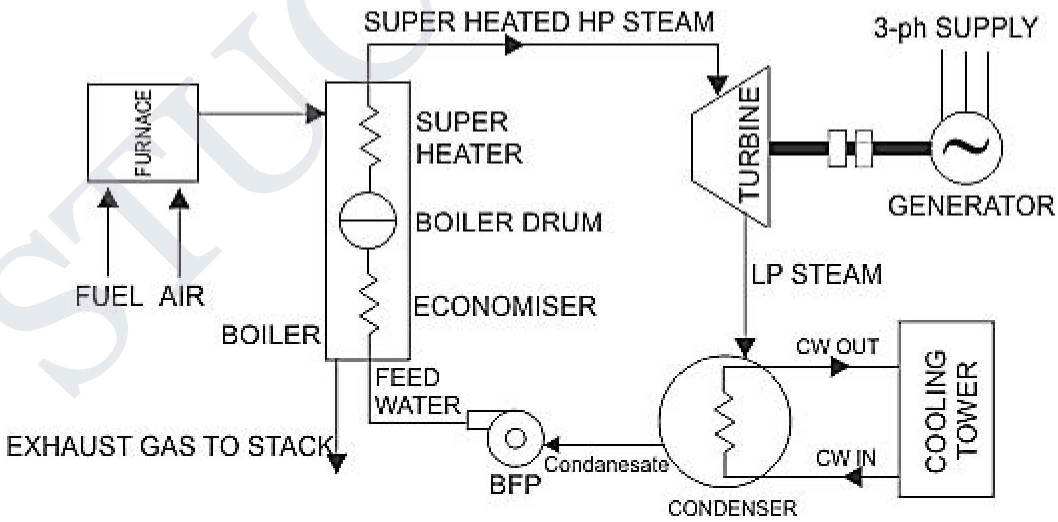
Coal and Ash circuit:

- ❖ 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:

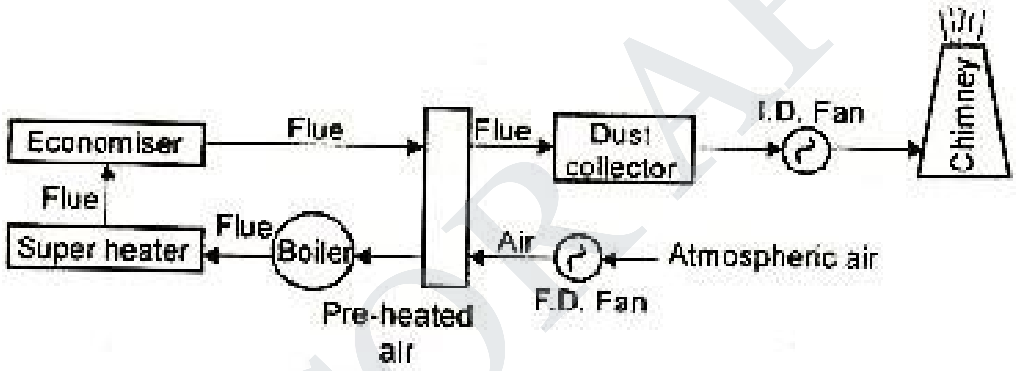


- It consists of feed pump, economizer, boiler drum, super heater, condenser, etc.
- Feed pump is used for passing the refined feed water is pumped to the economizer.
- This water is preheated by the flue gases in the economizer.
- This preheated water is then supplied to the boiler drum.
- Heat is transferred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

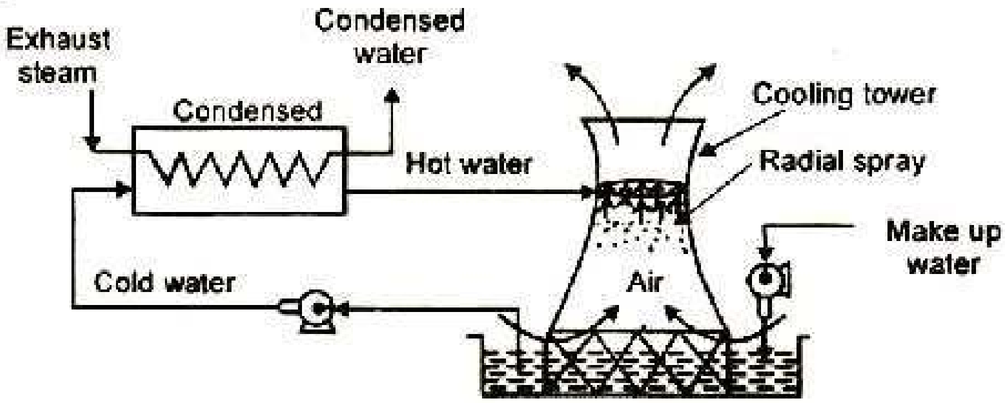


- The flue gases from the furnace pass over boiler tubes and super heater tubes. Then the flue gases pass through economizer to heat the feed water.
- After that, it passes through the air pre-heater to pre-heat the incoming air.
- It is then passed through a dust catching device (dust collector) for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

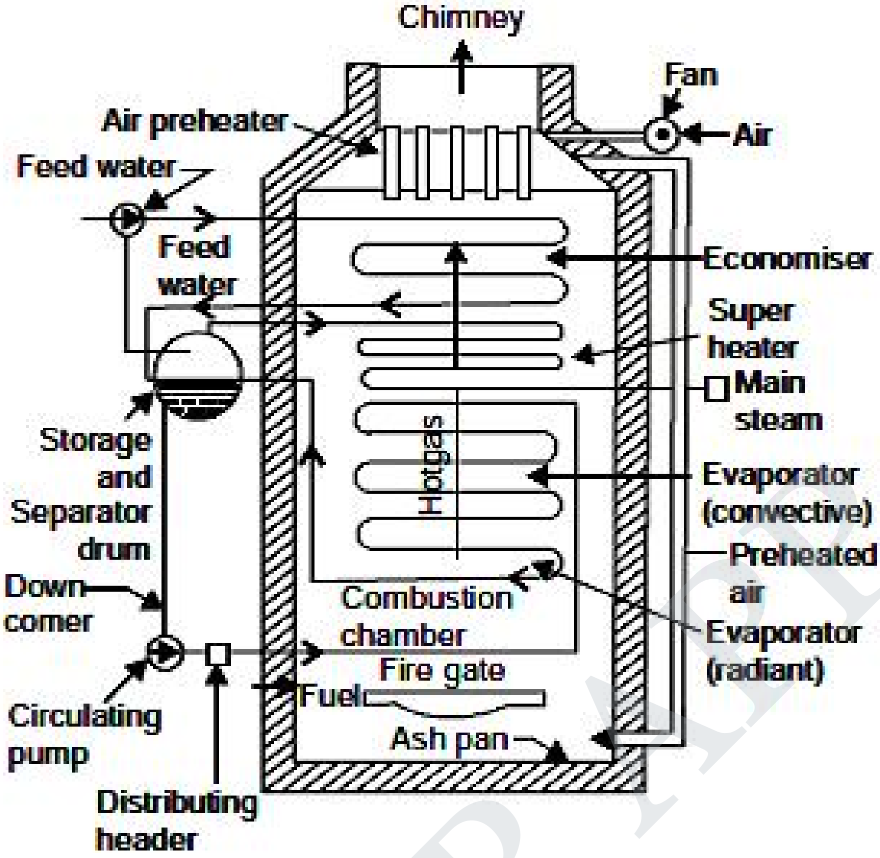
- The efficiency and the capacity of the plant can be increased as reduced quantity of steam is required for the same power generation if high pressure steam is used.
- The forced circulation of water through boiler tubes provides freedom in the arrangement of furnace and water walls, in addition to 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

__Important Components:__

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.

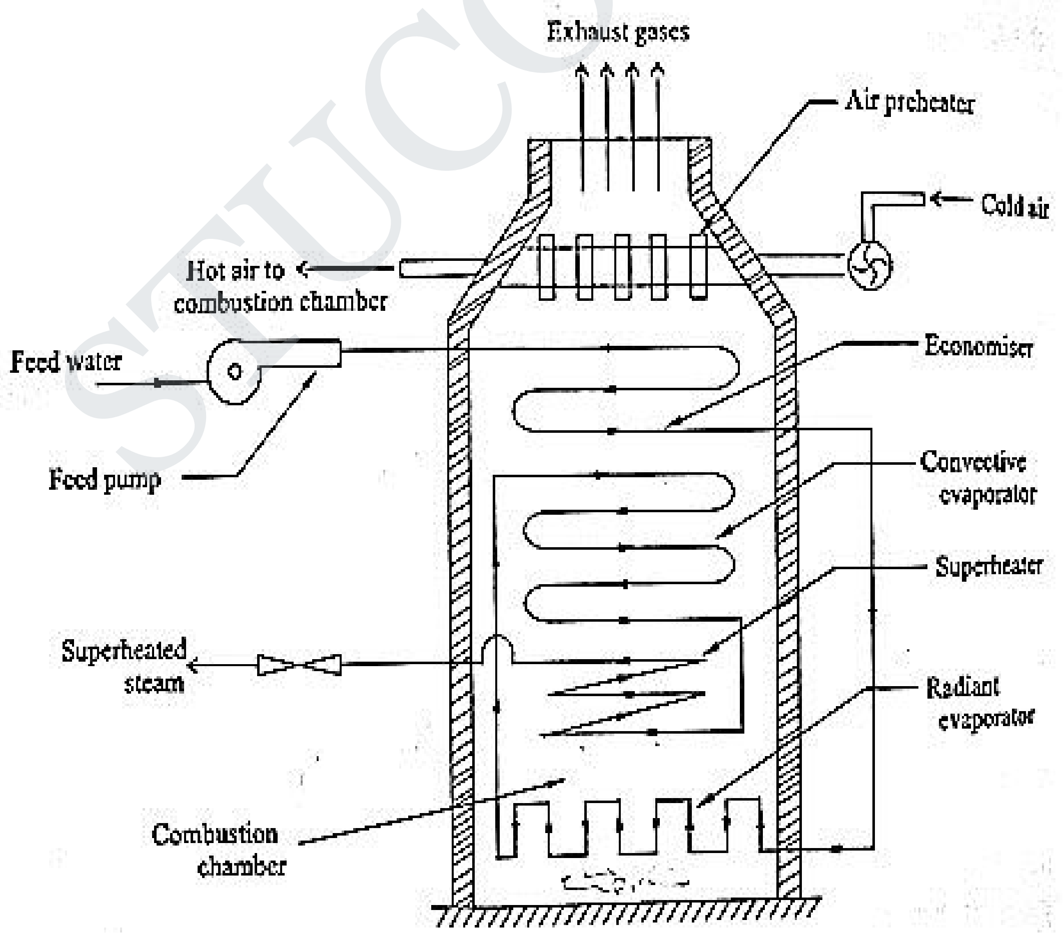
Advantages:

- 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:

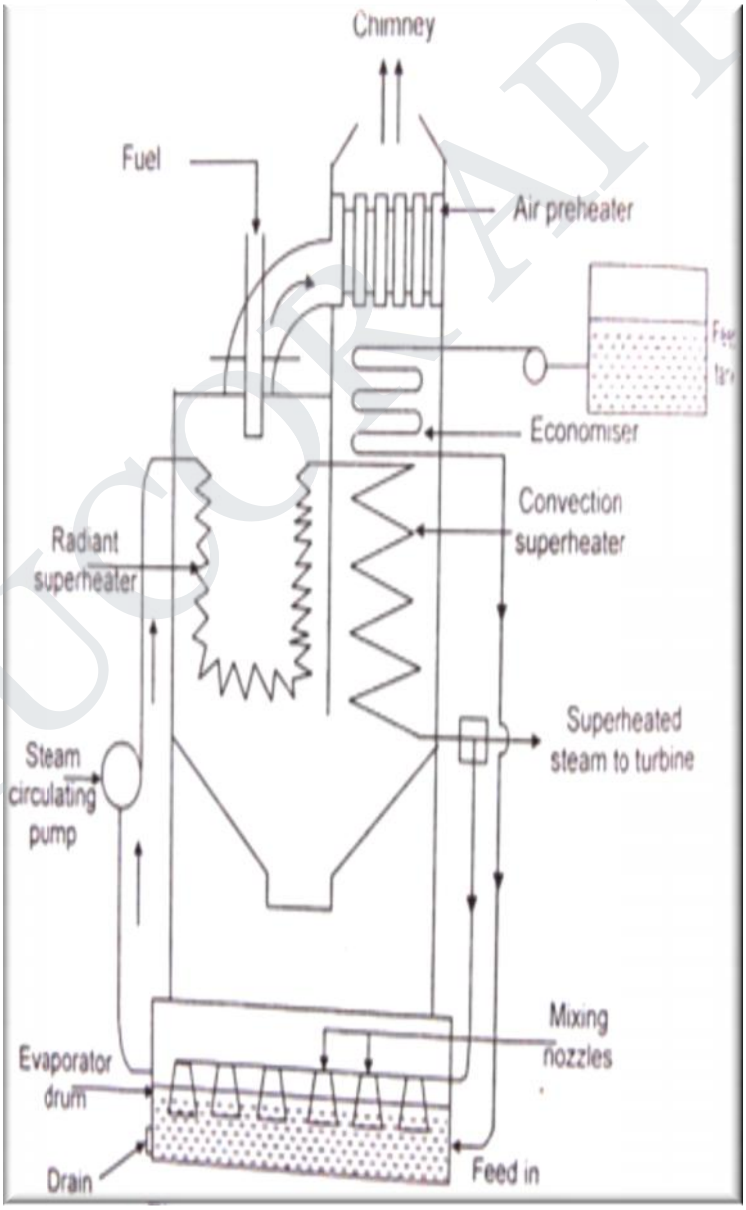
- As there is no drum, the total weight of Benson boiler is 20% less than other boilers.
- This reduces the cost of the boiler.
- Floor space requirements of Benson boiler are very less.
- Transportation of Benson boiler parts and its erection is very easy as there are no drums.
- Natural circulation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

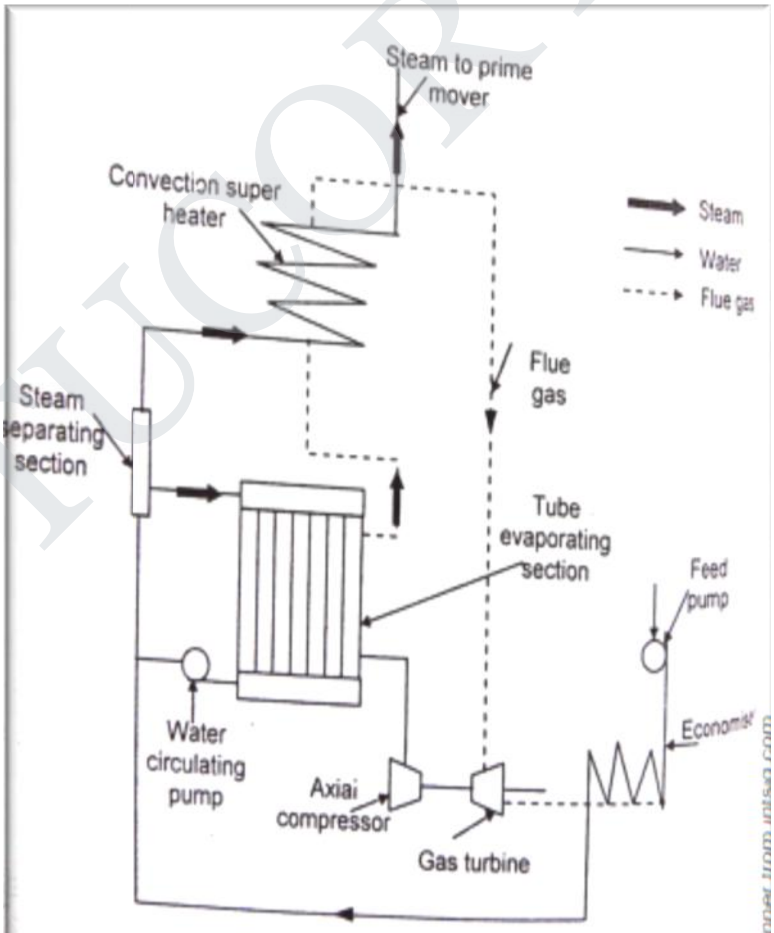


Figure 1.83 Velox boiler

- 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.

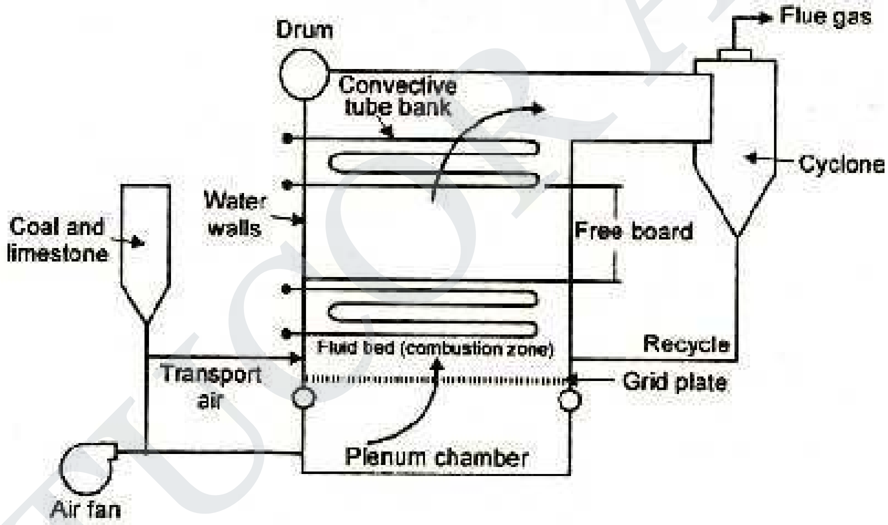
4. Draw and Explain the working principle of Fluidized Bed Combustion(FBC) Boiler. Also explain its types

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.

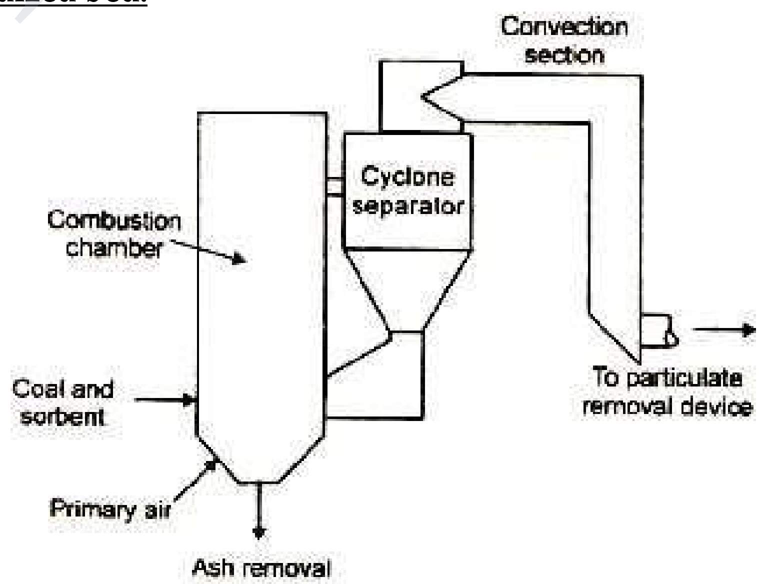
Bubbling Fluidized bed:

- 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.

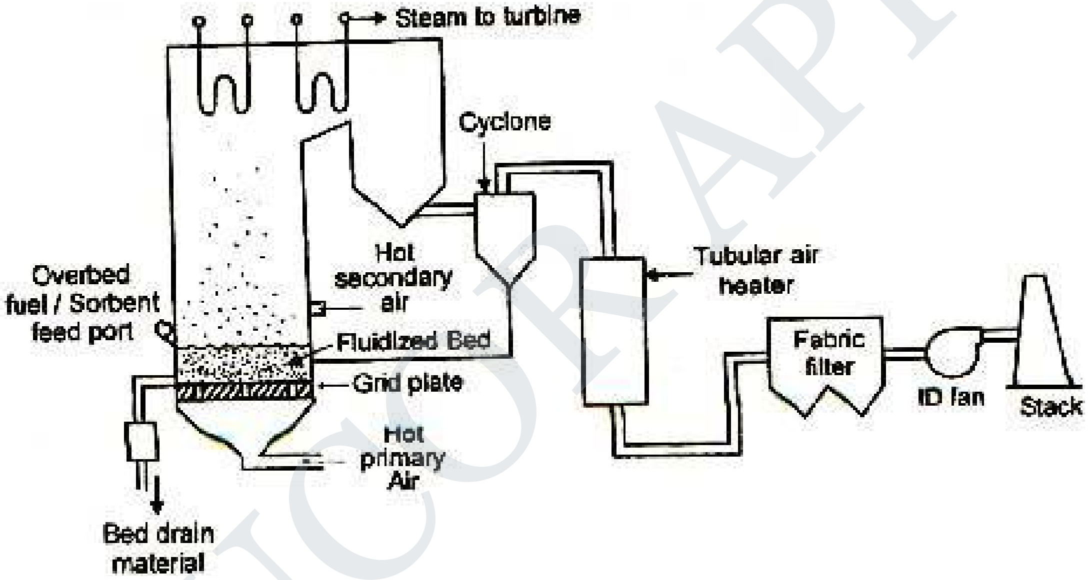
Circulating fluidized bed combustor.

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:

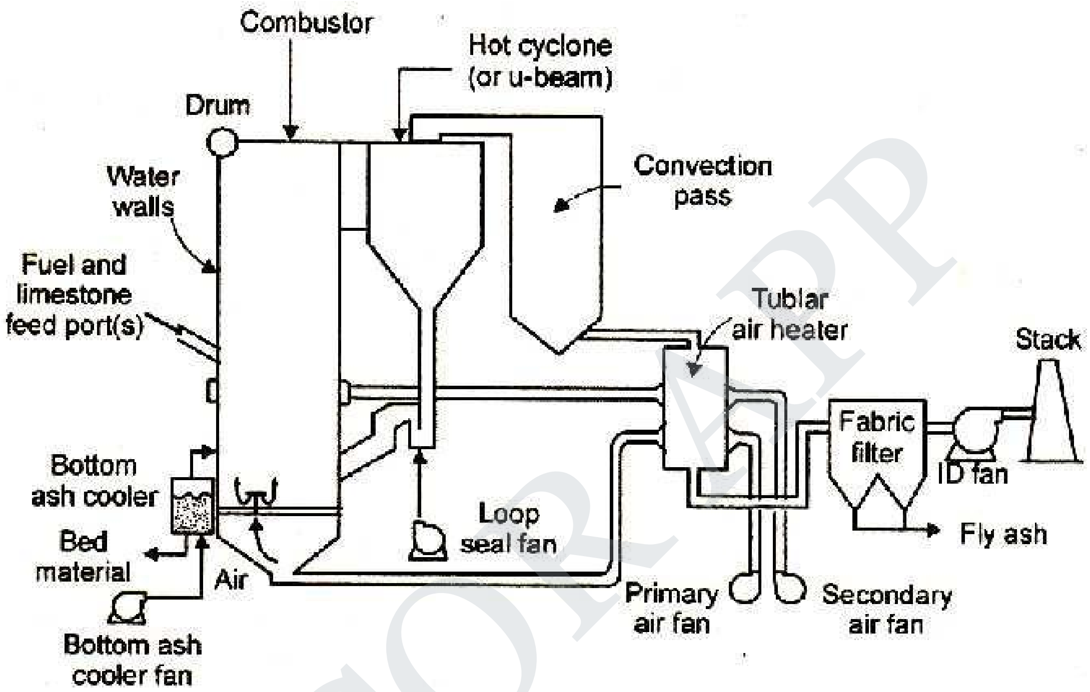


BFBC Arrangement

- ❖ 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.



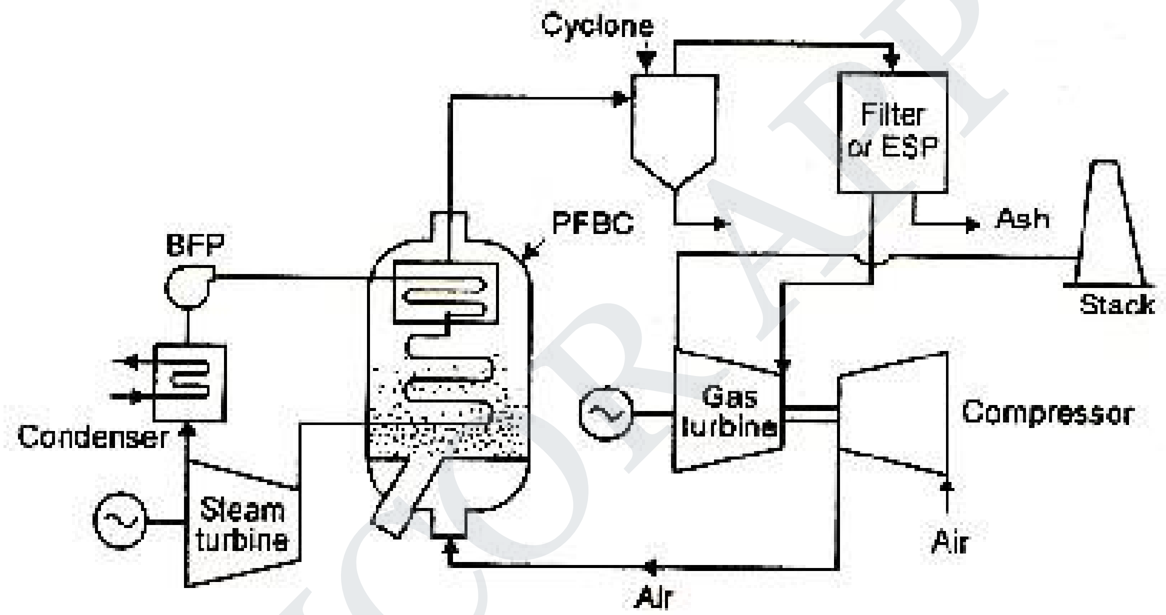
Atmospheric circulating bed combustor.

- ❖ 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.



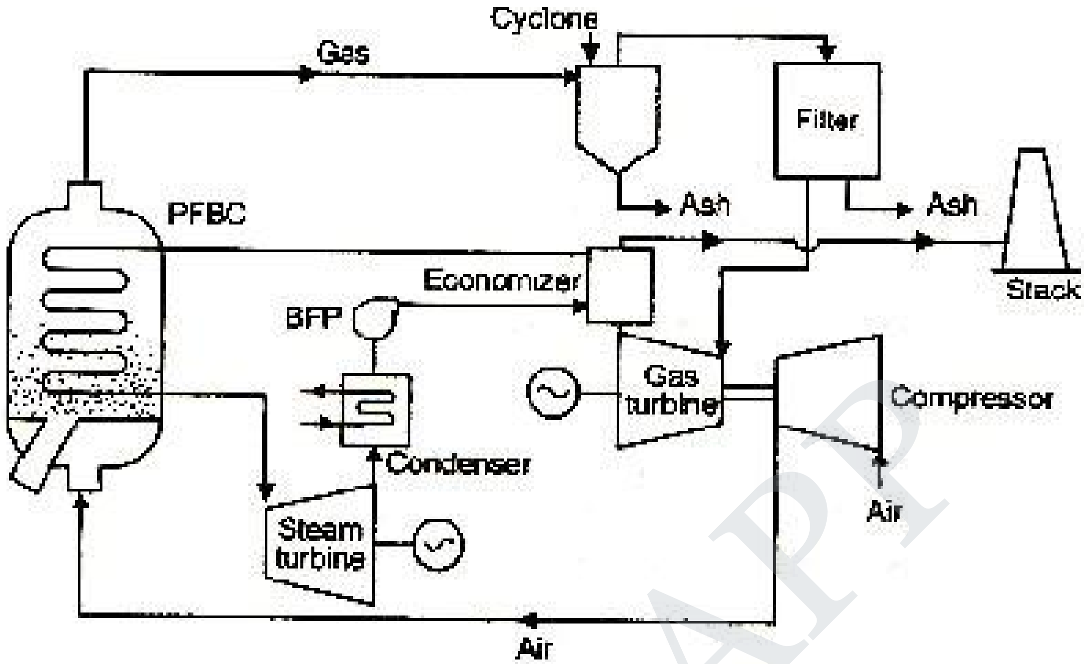
PFBC turbocharged arrangement

- ❖ 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.

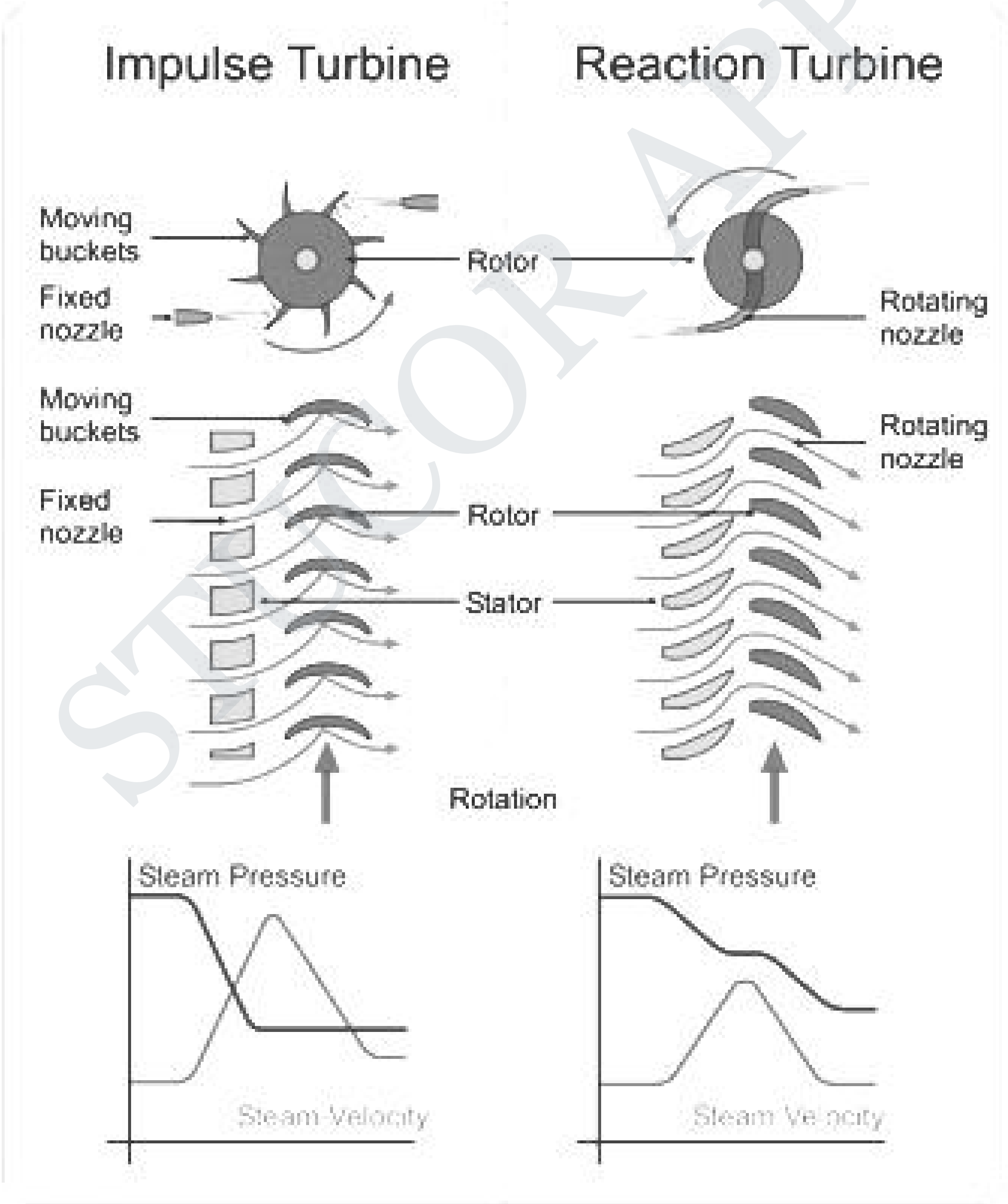
Advantages of Impulse turbine:

- 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

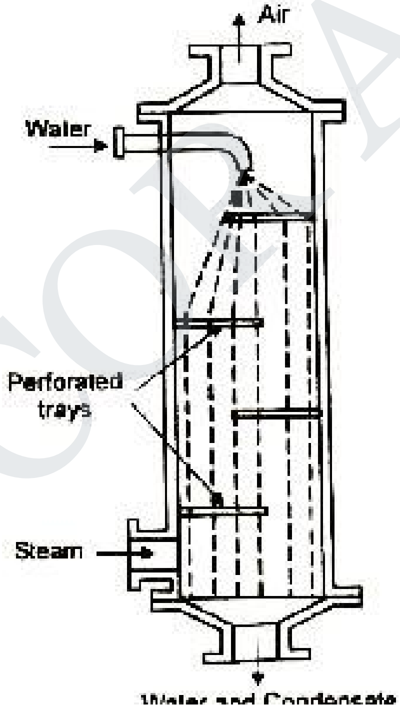
b) Surface Condenser
   1. Down flow condenser
   2. Central flow condenser
   3. Evaporative condenser

- 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

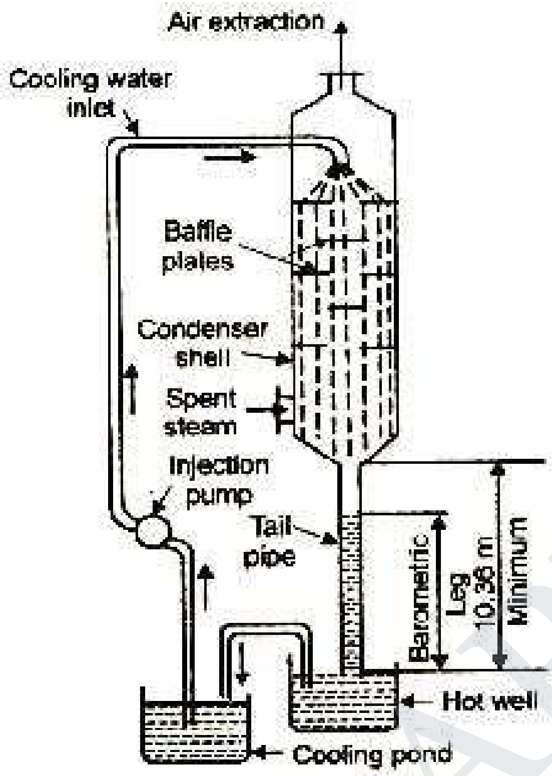
<u>Low level jet condenser:</u>



- 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].

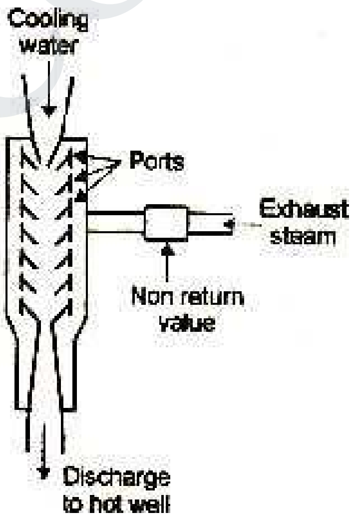
<u>High level jet condenser:</u>

- 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.

Ejector condenser:



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

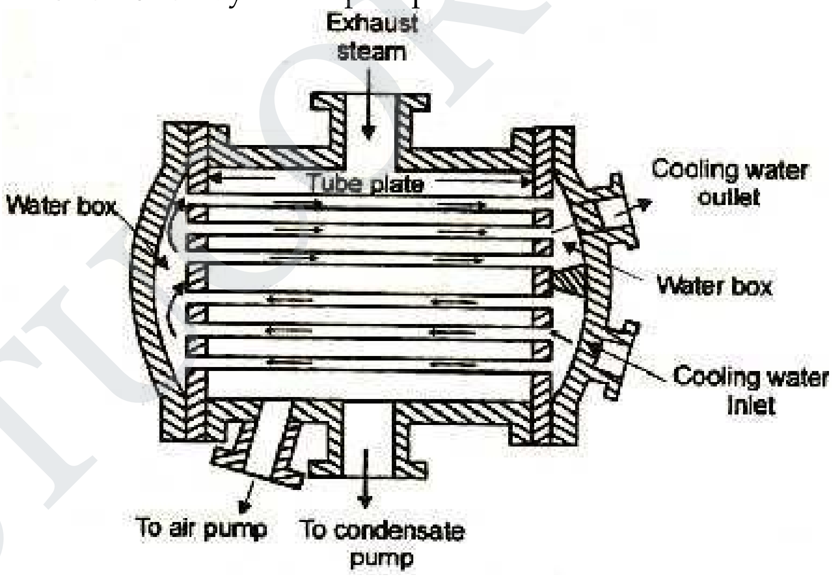
8. Explain the working of Surface condensers with the help of its types? With advantages and disadvantages?

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.

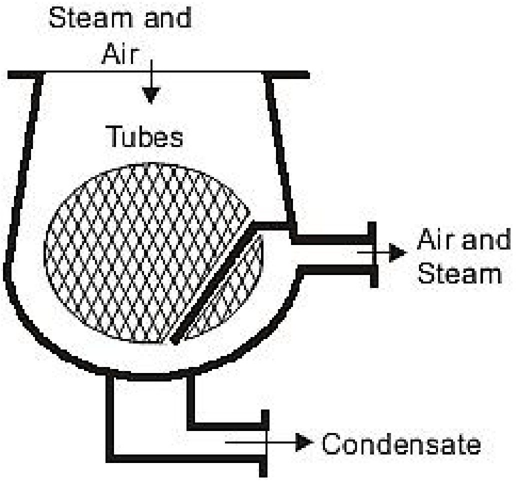


Surface condenser diagram

- 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:

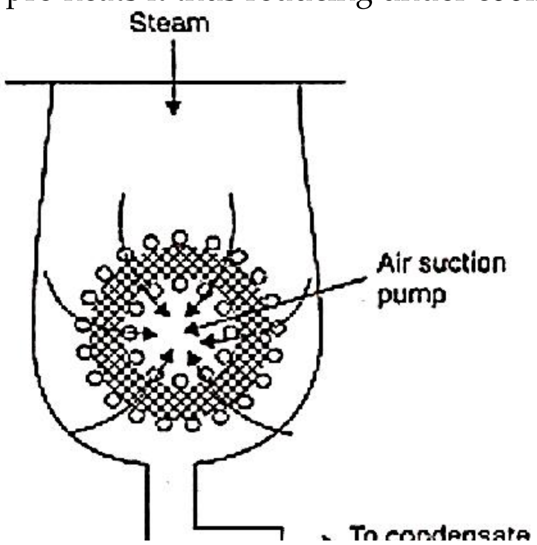


Sectional views of down flow condenser.

- 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:

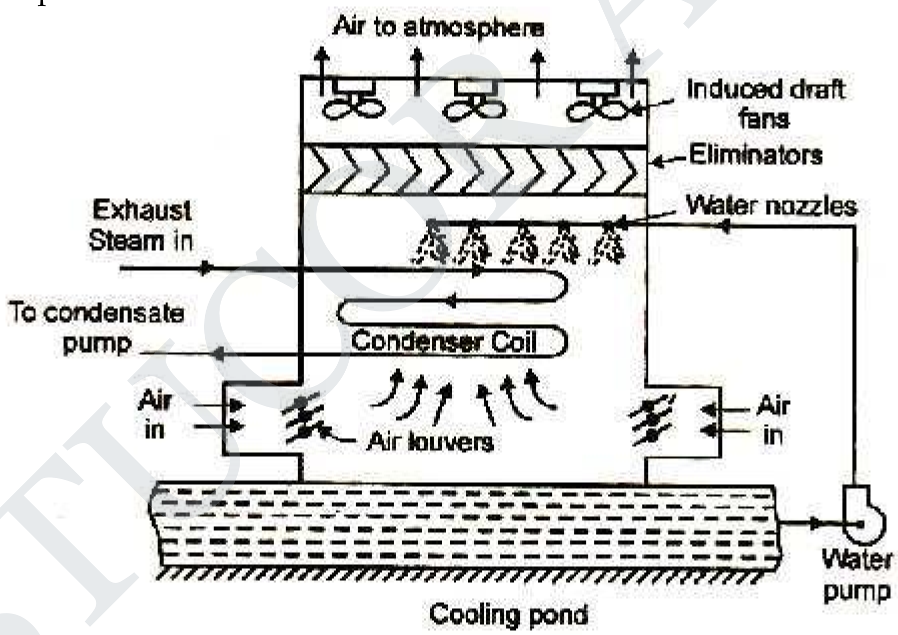
- In this condenser the steam passages are all around the periphery of the shell.
- Air is pumped away from the centre of the condenser.
- The condensate moves radially towards the centre of the next tube.
- Some of the exhaust steam which moving towards the centre meets the under cooled condensate and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

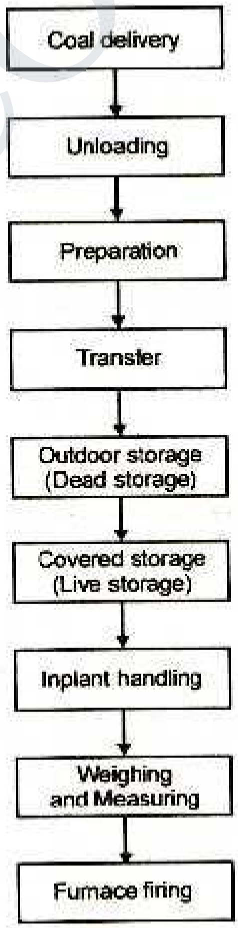
Fuel(Coal) Handling System:

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.**

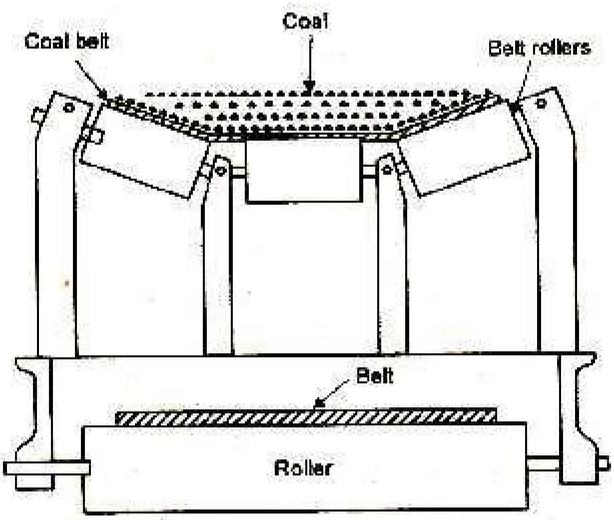
iv)Transfer

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.

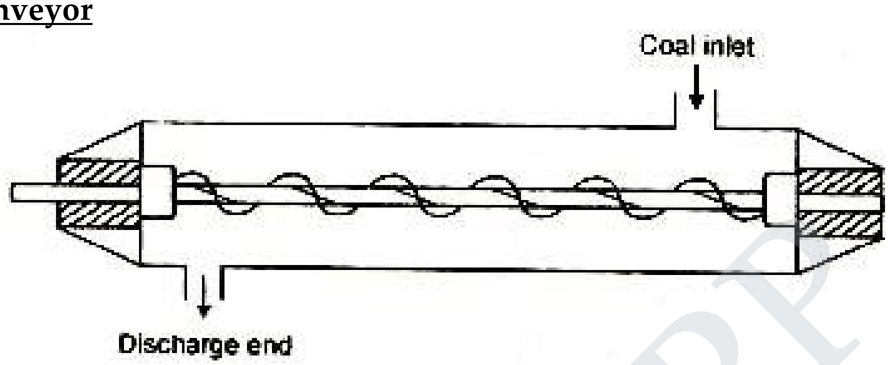


Belt Conveyor

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.

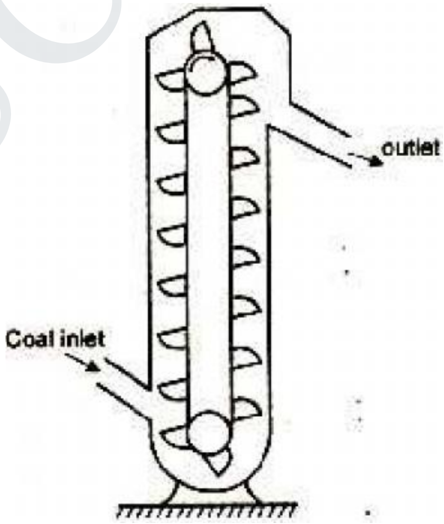
2. Screw Conveyor



- 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

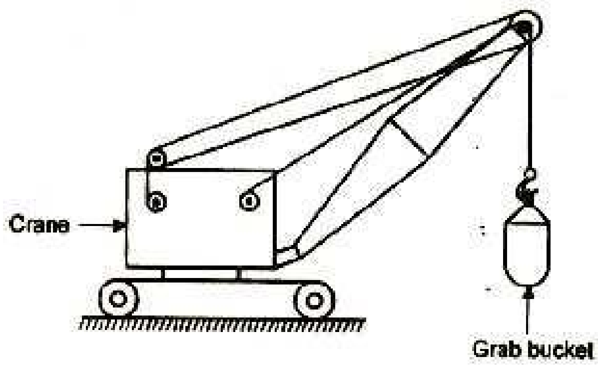
3. Bucket elevator

- 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

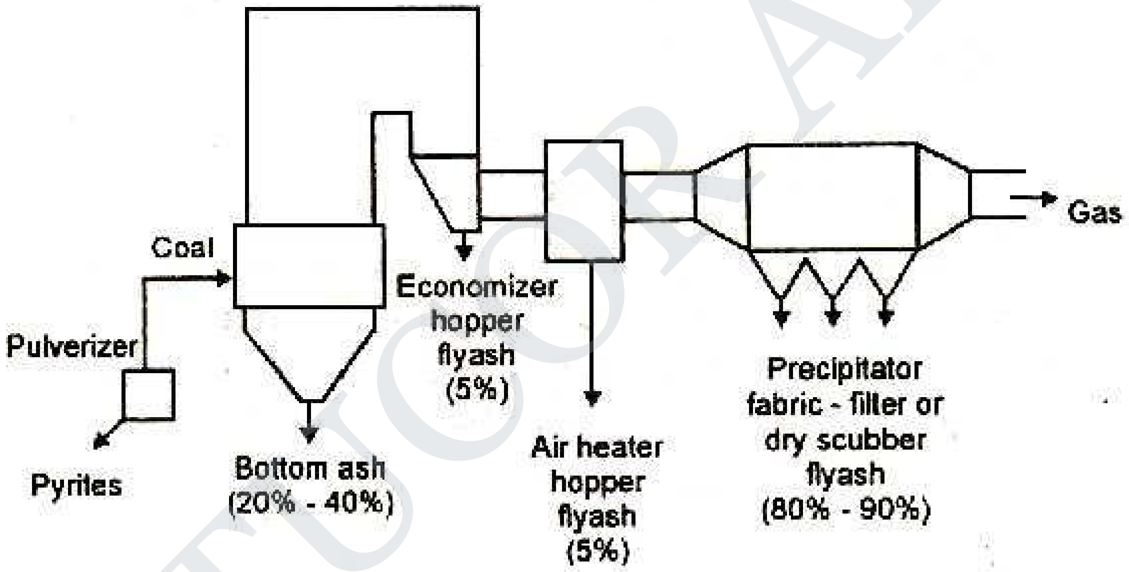
- Storage of coal gives protection against the interruption of coal supply.
- When there is delay in transportation of coal or due to strike in coal mines the stored coal is very useful.
- Also when the prices are low, the coal can be purchased and stored for future use.
- The amount of coal to be stored 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.

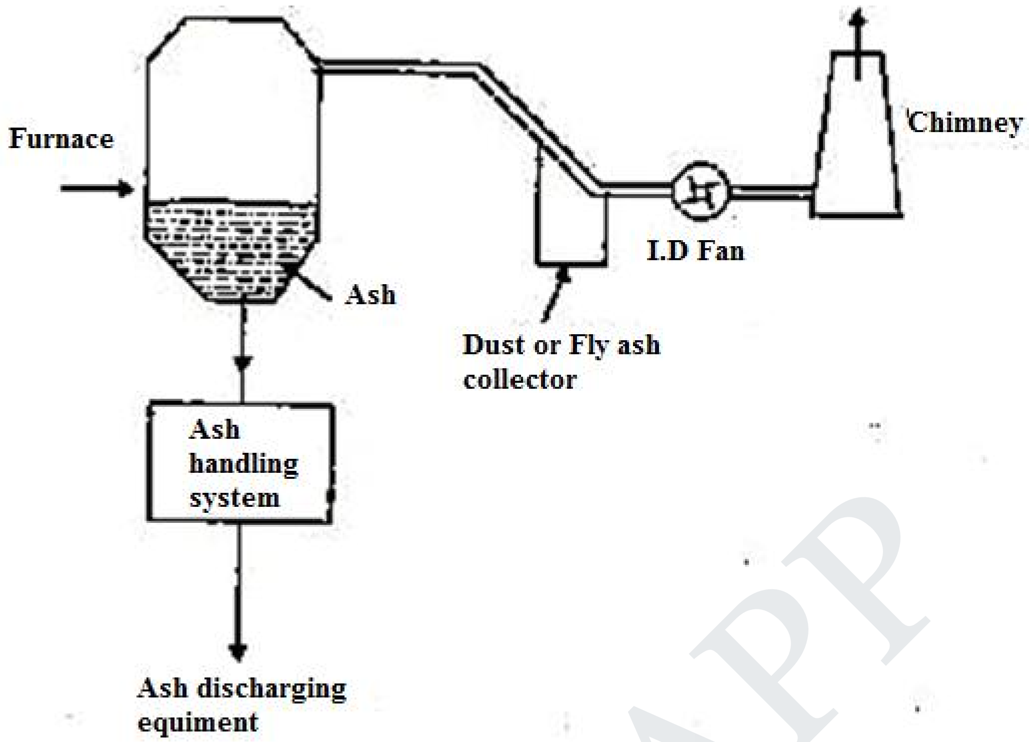


Layout of ash collection and transportation

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.

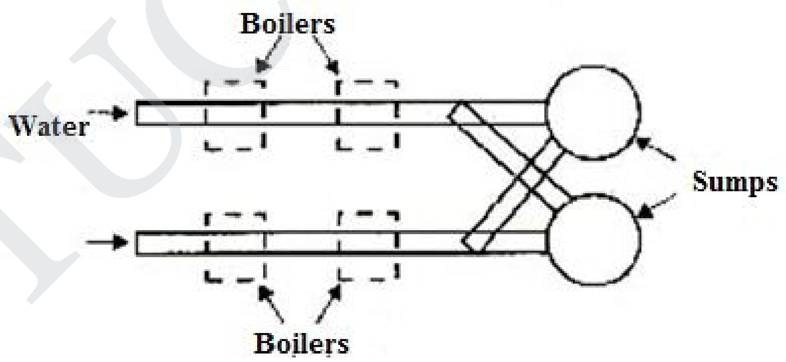


Ash handling equipment

Classification of Ash Handling System:

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

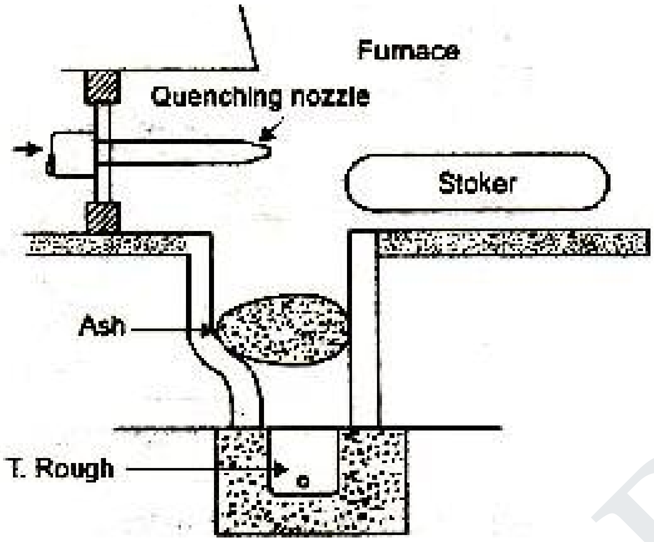
Hydraulic System:



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.

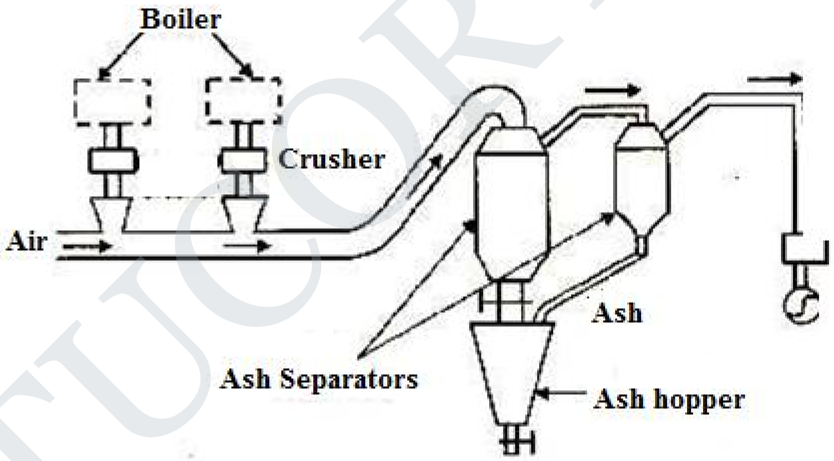
Water-Jetting System:



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:

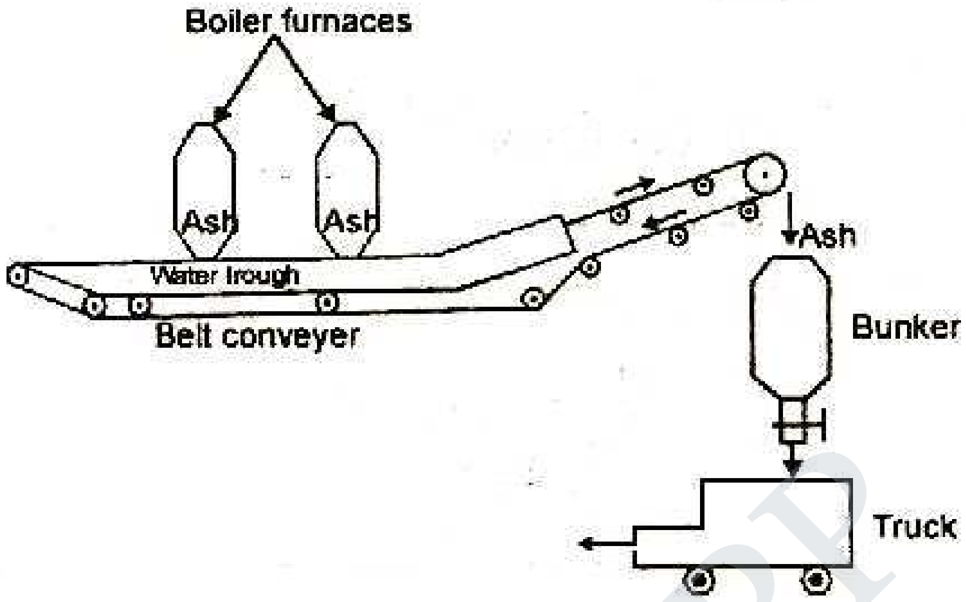


Pneumatic system

- 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.

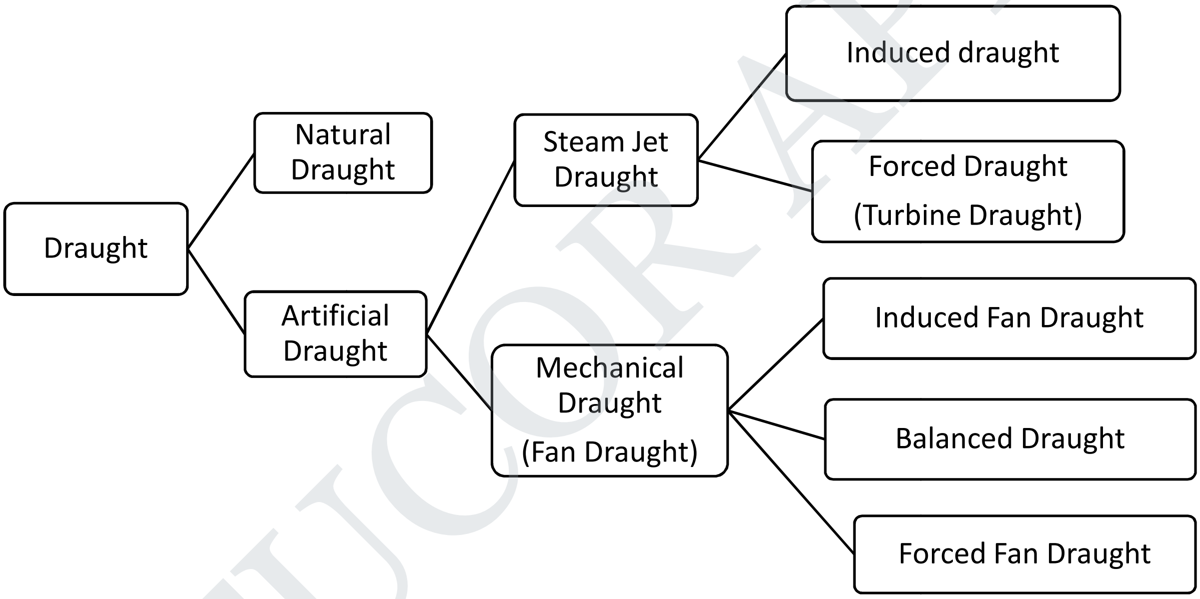
Draught:

- 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.

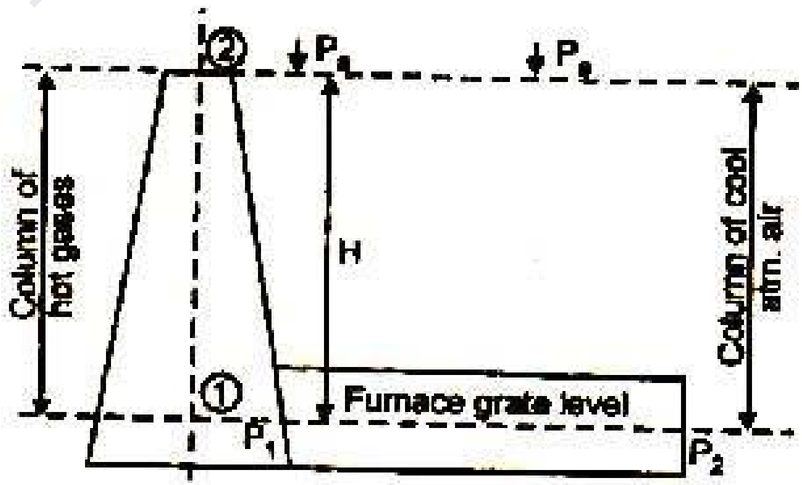
Purpose of draught:

- 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.

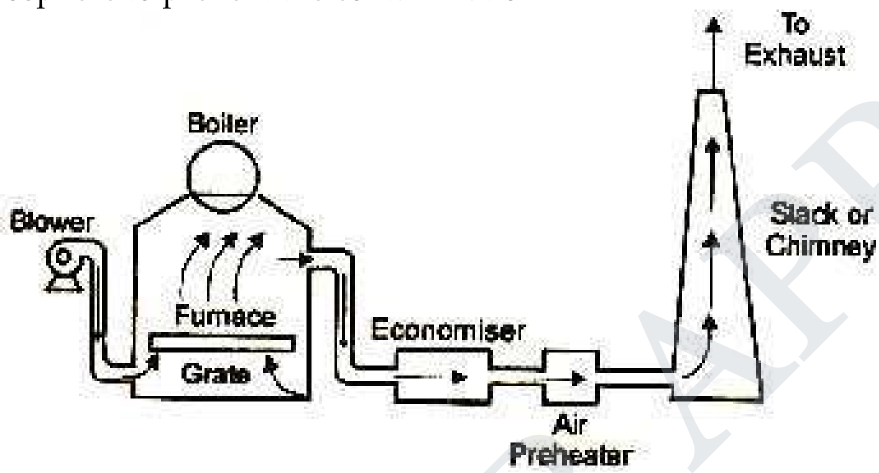
Artificial Draught:

- 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:

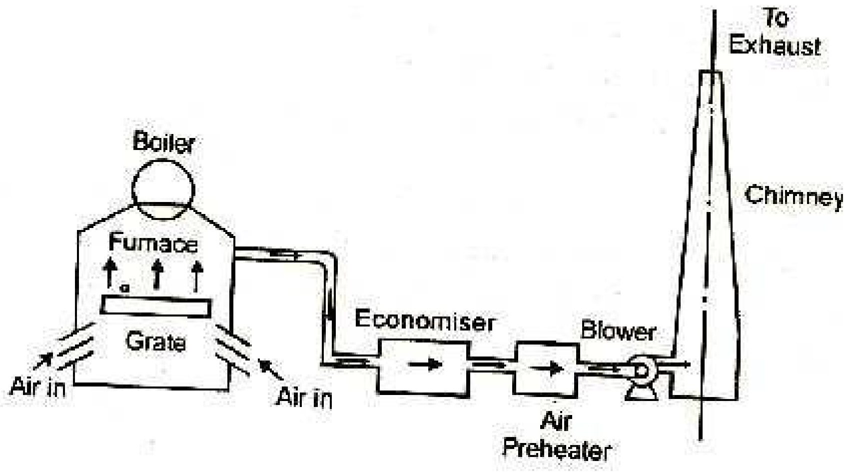
- In a forced draught system, a blower is installed near the base of the boiler.
- The air is forced to pass through the furnace, flues, economizer, air-preheater and to the stack.
- This draught system is also known as positive draught system because the pressure and air is forced to flow through the 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:

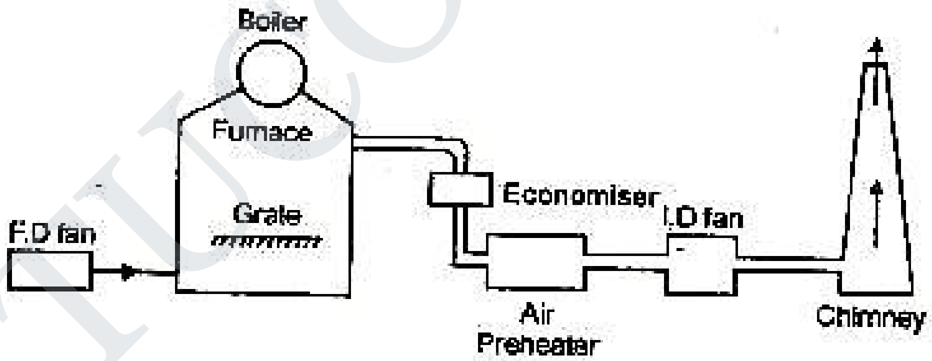
- In this system, the blower is located near the base of the chimney instead of near the furnace.
- The air is sucked in the system by reducing the pressure through the system below atmosphere.
- The induced draught fan sucks the burned gases from the furnace.
- The pressure inside the furnace is reduced 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 – **$Al_2(So_4)_3$**) 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. **Blow down :**

- 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 = $\frac{\textit{Quantity of water blown down}}{\textit{Quantity of feedwater admitted}}$

- There are some blow down processes are:

  (i) Hot lime-soda and hot zeolite process

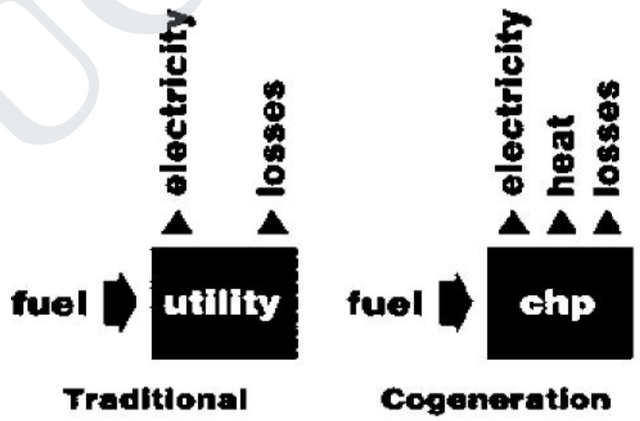
  (ii) Adding acid to control alkalinity and vice-versa.

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

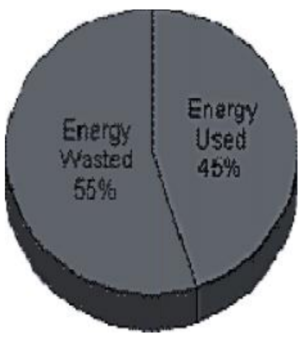
Introduction:

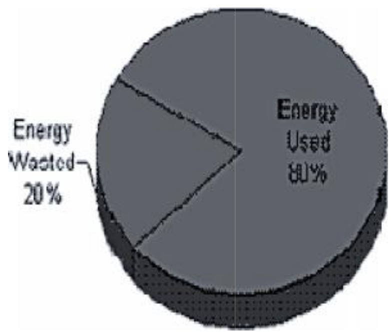
- Cogeneration is also called as combined heat and power or combine heat and power. Cogeneration works on concept of producing two different form of energy by using one single source of fuel.
- Out of these two forms one must be heat or thermal energy and other one is either electrical or mechanical 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.



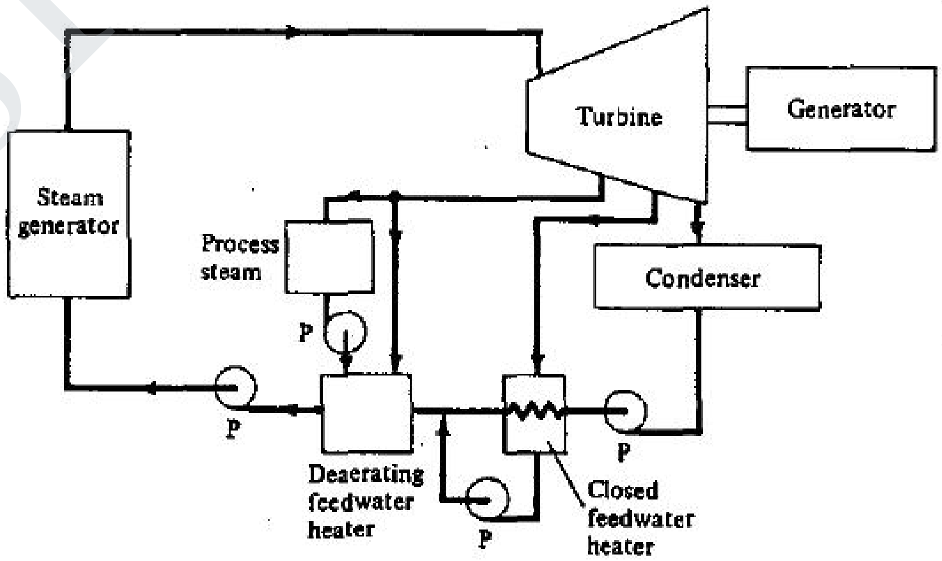


Energy sceneric in convential power plant Energy sceneric in combined heat and power plant

- 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.

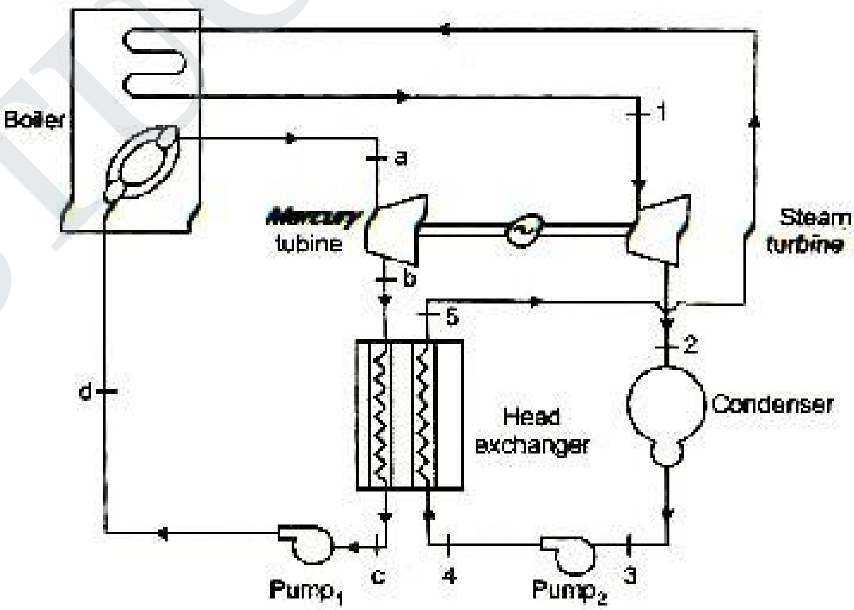
Generally water is used a working fluid in vapour power cycle as it is found to be better than any other fluid, but it is far from being the ideal one. The binary cycle is an attempt to overcome some of the shortcomings of water and to approach the ideal working fluid by using two fluids.

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

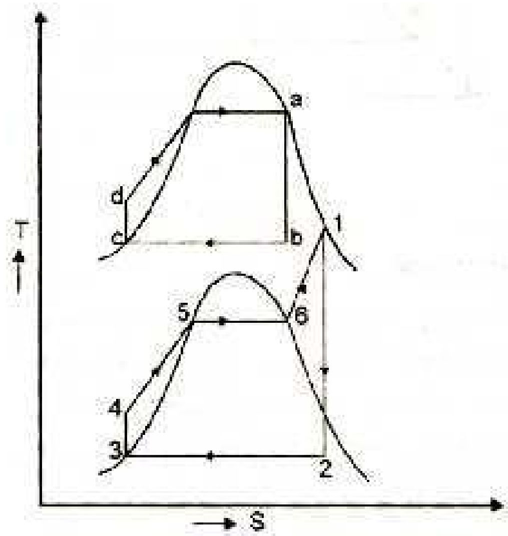
a .A high critical temperature and a safe maximum pressure.
b. Low- triple point temperature
c. Condenser pressure is not too low.
d. high enthalpy of vaporization
e. High thermal conductivity

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, $\eta_{bin\ vap} = \dfrac{Net\ Work\ done (Pump\ work)}{Heat\ Supplied}$

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

$$\eta_{bin\ vap} = \frac{W_{Hg} + W_{H20} - \Sigma W_{pump}}{m_{Hg}\ h_a - h_d + m_{Steam}[\ h_1 - h_6 + h_5 - h_4\ ]}$$

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

UNIT – III

NUCLEAR POWER PLANTS

1. Write a short notes on basics of Nuclear Engineering.

<u>**STRUCTURE OF AN ATOM:**</u>

- In 1803 John Dalton, attempting to explain the laws of chemical combination, propose his simple but incomplete atomic hypothesis. He postulated that all elements consists of indivisible minute particles of matter and atoms were different for different elements and preserved their identity in chemical reactions.
- In 1811 Amadeo Avo-gadro introduced the molecular theory based on the molecule, a particle of matter composed of a finite number of atoms. It is now known that the atoms are themselves composed of sub particles, common among atoms of all elements.
- An atom consists of a relatively heavy, positively charged nucleus and a number of much lighter negatively charged electrons that exist in various orbits around the nucleus. The nucleus, in turn, consists of sub particles, called nucleons.
- Nucleons at primarily of two kinds: the neutrons which are electrically neutral and the proton which are positively charged.
- The electric charge on the proton is equal in magnitude but opposite in sign to that on the electron.
- The atom as a whole is electrically neutral the number of protons equals the number of electrons in orbit. One atom may be transformed into another by losing or acquiring some of the above sub particles.
- The masses of the three primary atomic sub particles are

  Neutron mass *mn* = 1.008665 amu

  Proton mass *mP* = 1.007277 amu

  Electron mass *me* = 0.0005486 amu.

  amu = *atomic mass unit* = 1.66 × 10–27 kg, or 3.66 × 10–2 lb.
- These three particles are the primary building blocks of all atoms. Atoms differ in their mass because they contain varying numbers of them.

<u>**ISOTOPES:**</u>

- The number of protons have similar chemical and physical characteristics and differ mainly in their masses. They are called *isotopes*. For example, deuterium frequently called *heavy hydrogen* and it is an isotope of hydrogen.

<u>**ATOMIC NUMBER AND MASS NUMBER:**</u>

- The number of protons in the nucleus is called the atomic number. *It is denoted as Z*.
- The total number of nucleons in the nucleus is called the mass *number A*.

VALENCE ELECTRON AND VALENCE SHELL:

- Electrons that orbit in the outermost shell of an atom are called *valence electron*.
- The outermost shell is called the *valence shell*. Thus, hydrogen has one valence electron and its K shell is the valence shell, etc.

CRITICAL MASS:

- There is a threshold mass of a radioactive isotope at which the flux density of radioactive particles will sustain a chain reaction. If this reaction is uncontrolled the result is an atomic bomb explosion.

Types of Radiation	Atomic Weight	Charge
Alpha radiation (Helium nucleus)	4	+2
Beta radiation (Electron)	~0	– 1
Neutron	1	0
Gamma ray	~0	0

ALPHA PARTICLES(α particles):

- Alpha is quickly absorbed by matter because the particles have a large probability of collision with nuclei. Sources external to the human body cause radiation absorption within the thickness of the skin.
- Radiation from airborne particles in the lung are absorbed by surface membranes lining the lung.
- Alpha emitters ingested with food cause radiation absorption by the lining of the gut. The risk of genetic damage to adult organisms is very small because absorption takes place in surface cells.

BETA PARTICLES(β particles):

- Beta particles penetrate to the deepest parts of the body and can cause genetic damage and disrupt the function of cells anywhere in the body. Building walls and earthwork provide substantial shielding.

GAMMA PARTICLES(γ particles):

- Gamma has the greatest penetration due to their small cross-section.
- Gamma particles can pass through ordinary materials. Effective shielding requires blankets of lead. Gamma radiation is a danger to all cells in the body.

HALF LIFE(T):

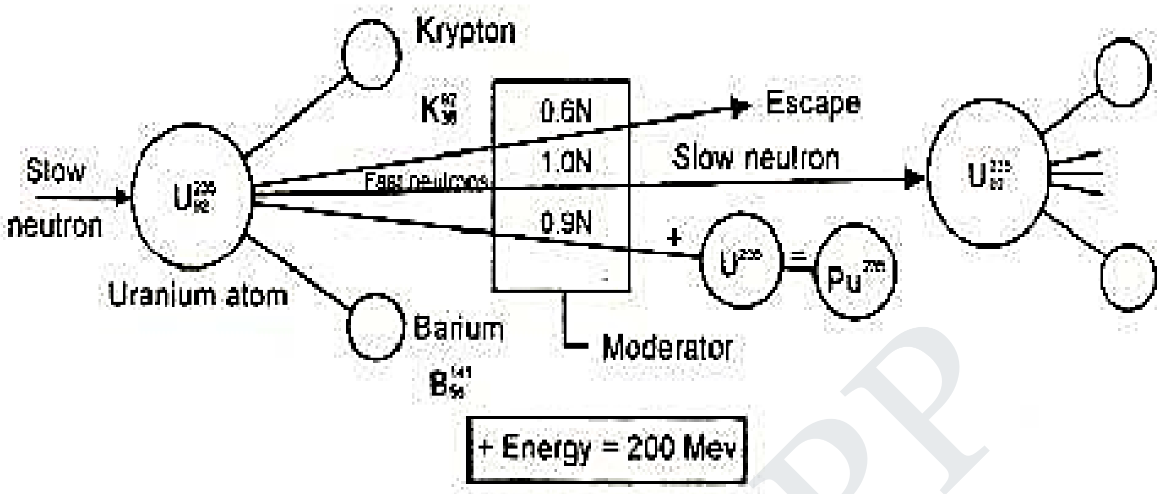
Time taken for half the atomic nuclei to spontaneously split is called as Half-life. The amount of nuclei decays exponentially

$$N = N_o \exp(-t/T)$$

N = Amount of radioactive material, t = Elapsed time

N_o = Initial amount

Fission energy:



Nuclear fission

- Nuclear energy is divided from splitting (or) fissioning of the nucleus of fissionable material like Uranium U-235.
- Uranium has several isotopes (Isotopes are atoms of the same element having different atomic masses) such as U-234, U-235 and U-238.
- Of the several isotopes, U-235 is the most unstable isotope, which is easily fissionable and hence used as fuel in an atomic reactor.

When a neutron enters the nucleus of an unstable U-235, the nucleus splits into two equal fragments (Krypton and Barium) and also releases 2.5 fast moving neutrons with a velocity of 1.5×10^7 m/sec and along with this produces a large amount of energy, nearly 200 million electro-volts. This is called nuclear fission.

Chain reaction:

- The neutrons released during fission are very fast and can be made to initiate the fission of other nuclei of U-235, thus causing a chain reaction.
- When a large number of fission occurs, enormous amount of heat is generated, which is used to produce steam.
- The chain reaction under controlled conditions can release extremely large amount of energy causing "atomic explosion"

- Energy released in chain reaction, according to Einstein law is

$$E = mc^2$$

Where, E = Energy liberated (J)

m= Mass (kg)

c = Velocity of light (3×10^8 m/sec).

Out of 2.5 neutrons released in fission of each nucleus of U-235, one neutron is used to sustain the chain reaction about 0.9 neutron is captured by U-238 which gets converted into fissionable material Pu-239 and about 0.6 neutron is partially absorbed by control rod materials, coolant and moderator.

If thorium is used in the reactor core, it gets converted to fissionable material U-233.

Thorium 232 + Neutron → Uranium-233

Pr-239 and U-233 so produced are fissionable materials are called secondary fuels. They can be used as nuclear fuels. U-238 and Th-232 are called fertile materials.

<u>Fusion energy:</u>

Energy is produced in the sun and stars by continuous fusion reactions in which four nuclei of hydrogen fuse in a series of reactions involving other particles that continually appear and disappear in the course of the reaction, such as He^3, nitrogen, carbon, and other nuclei, but culminating in one nucleus of helium of two positrons.

$$4\,{}_1H \rightarrow {}_2He + 2\,{}_{+1}e$$

To cause fusion, it is necessary to accelerate the positively charged nuclei to high kinetic energies, in order to overcome electrical repulsive forces, by raising their temperature to hundreds of millions of degrees resulting in plasma. The plasma must be prevented from contacting the walls of the container, and must be confined for a period of time (of the order of a second) at a minimum density. Fusion reactions are called thermonuclear because very high temperatures are required to trigger and sustain them. Table lists the possible fusion reactions and the energies produced by them. n, p, D, and T are the symbols for the neutron, proton, deuterium (H2), and tritium (H3), respectively.

Number	**Fusion reaction**		**Energy per reaction MeV**
	Reactants	**Products**	
1	D + D	T + p D	4
2	+ D	He^3 + n T	3.2
3	+ D	He^4 + n	17.6
4	He^3 + D	He^4 + p	18.3

Many problems have to be solved before an artificially made fusion reactor becomes a reality.

2. Draw and explain block diagram of Nuclear power plant and write few advantages and disadvantage. (or) Explain the layout of Nuclear power plant with their component functions.

The Main components of nuclear power plants are:

i) Nuclear Reactor
ii) Steam generator
iii) Turbine
iv) Coolant pump and Feed pump
v) Generator(for converting mechanical energy into electrical energy)

i) Nuclear reactor:

- Nuclear reactor is a device designed to maintain a chain reaction producing a steady flow of neutrons generated by the fission of heavy nuclei.
- Heat is produced in the reactor due to nuclear fission of the fuel U235.
- The heat liberated in the reactor is taken up by the coolant circulating through the core.

Need of Shielding in Reactor:

The important sub components present in nuclear reactor are:

- ✓ Moderator
- ✓ Reflector
- ✓ Shielding
- ✓ Cladding
- ✓ Control rods
- ✓ Coolant

A) Moderator:

- In any nuclear chain reaction, the neutrons produced are fast moving neutrons.
- These are less effective for further fission reaction with U235 and they try to escape from the reactor.
- To reduce the speed of these neutrons must be reduced if their effectiveness is carrying out fission is to be increased.
- This is done by making these neutrons collide with lighter nuclei of other materials.
- Each collision causes loss of energy and thus the speed of neutrons is reduced. Such a material is called a 'Moderator'.
- The neutrons thus slowed down are easily captured by the fuel element at the chain reaction proceeds slowly.

B) Reflectors:

- Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials.

- The remaining neutrons will try to escape from the reactor and will be lost.
- Such losses are minimized by surrounding the reactor core with a material called a reflector which will reflect the neutrons back to the core.
- They improve the neutron economy. (Examples: Graphite, Beryllium)

C) Shielding:

- The radiations due to nuclear fission in the reactor are very harmful to human life.
- It requires strong control to ensure that this radioactivity is not released into the atmosphere to avoid atmospheric pollution.
- A thick concrete shielding and a pressure vessel are provided to prevent the escape of these radiations to atmosphere.
- Tin, lead or steel is used as shielding material.

D) Cladding:

- In order to prevent the contamination of the coolant by fission products, the fuel element is covered with a protective coating. This is known as cladding.

E) Control rods:

- Control rods are used to control the reaction to prevent it from becoming violent.
- They control the reaction by absorbing neutrons.
- These rods are made of boron or cadmium.
- Whenever the reaction needs to be stopped, the rods are fully inserted and placed against their seats and when the reaction is to be started the rods are pulled out.

F) Coolant:

- The main purpose of the coolant in the reactor is to transfer the heat produced inside the reactor.
- The same heat carried by the coolant is used in the heat exchanger for further utilization in the power generation.

Some of the desirable properties of good coolant are listed below

- It must not absorb the neutrons.
- It must have high chemical and radiation stability
- It must be non-corrosive.
- It must have high boiling point (if liquid) and low melting point (if solid)
- It must be non-oxidizing and non-toxic.

The above-mentioned properties are essential to keep the reactor core in safe condition as well as for the better functioning of the content.

- It must have high density
- It must have low viscosity
- It must have high conductivity

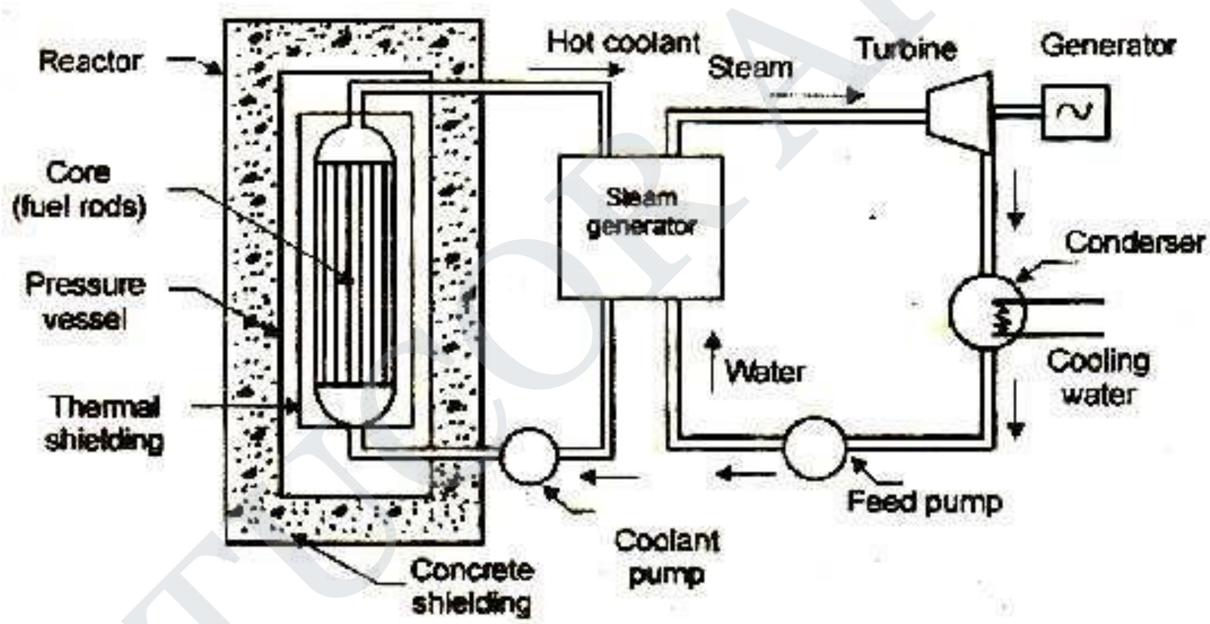
- It must have high specific heat.

These properties are essential for better heat transfer and low pumping power.

- The water, heavy water, gas (He, CO_2), a metal in liquid form (Na) and an organic liquid are used as coolants.
- The coolant not only carries large amounts of heat from the core but also keeps the fuel assemblies at a safe temperature to avoid their melting and destruction.

ii) Steam generator:

- The steam generator is fed with feed water which is converted into steam by the heat of the hot coolant.
- The purpose of the coolant is to transfer the heat generated in the reactor core and use it for steam generation.
- Ordinary water or heavy water is a common coolant.



Layout of Nuclear Power Plant

iii) Turbine and Generator:

- The steam produced in the steam generator is passed to the turbine and work is done by the expansion of steam in the turbine.
- The turbine rotates the generator and produces an electrical energy by its principle.

iv) Coolant pump and Feed pump:

- The steam from the turbine flows to the condenser where cooling water is circulated.
- Coolant pump and feed pump are provided to maintain the flow of coolant and feed water respectively.

Advantages of nuclear power plant:

- It can be easily adopted where water and coal resources are not available.
- The nuclear power plant requires very small quantity of fuel. Hence fuel transportation cost is less.
- Space requirement is less compared to other power plants of equal capacity.
- It is not affected by adverse weather conditions.
- Fuel storage facilities are not needed as in the case of the thermal power plant.
- Nuclear power plants will converse the fossils fuels (coal, petroleum) for other energy needs.
- Number of workmen required at nuclear plant is far less than thermal plant.
- It does not require large quantity of water.

Disadvantages of nuclear power plant:

- Radioactive wastes, if not disposed of carefully, have adverse effect on the health of workmen and the population surrounding the plant.
- It is not suitable for varying load condition.
- It requires well-trained personnel.
- It requires high initial cost compared to hydro or thermal power plants.

3. Explain in detail about Boiler Water Reactor. (or) Describe the construction and operation of BWR. (or) Explain any one type of light water nuclear reactor.

Introduction:

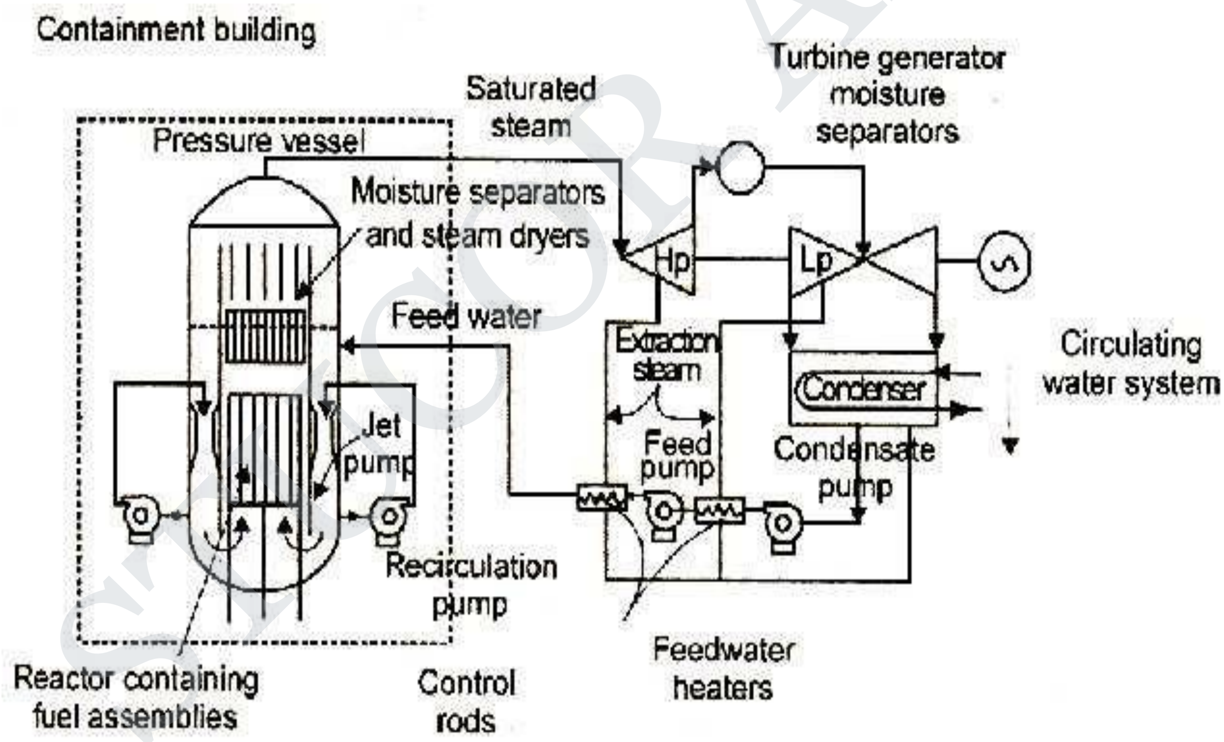
- The **Boiling Water Reactor** (**BWR**) is a type of light water nuclear reactor used for the generation of electrical power.
- It is the second most common type of electricity generating nuclear reactor after the pressurized water reactor (PWR).
- The purposes of the reactor vessel assembly are to:
  - ✓ House the reactor core
  - ✓ Serve as part of the reactor coolant pressure boundary
  - ✓ Support and align the fuel and control rods
  - ✓ Provide a flow path for circulation of coolant across the fuel
  - ✓ Remove moisture from the steam exiting the core, and
  - ✓ Provide a refloodable volume for a loss of coolant accident

Construction of BWR:

- The BWR reactor core consists of a large number of fuel rods housed in fuel assemblies in a nearly cylindrical arrangement.
- Each fuel assembly contains an 8×8 or 9×9 square array of 64 or 81 fuel rods (typically two of the fuel rods contain water rather than fuel) surrounded by a square Zircaloy channel box to ensure no coolant cross flow in the core.

- The fuel rods are similar to the PWR rods, although larger in diameter. Each fuel rod is a zirconium alloy- clad tube containing pellets of slightly enriched uranium dioxide (2% to 5% U-235) stacked end-to- end.
- The reactor is controlled by control rods housed in a cross-shaped, or cruciform, arrangement called a control element.
- The control elements enter from the bottom of the reactor and move in spaces between the fuel assemblies.
- The BWR reactor core is housed in a pressure vessel that is larger than that of a PWR.
- A typical BWR pressure vessel, which also houses the reactor core, moisture separators, and steam dryers, has a diameter of 6.4 m, with a height of 22 m.
- Since a BWR operators at a nominal pressure of 6.9 MPa, its pressure vessel is thinner that of a PWR.

Schematic Diagram:



Schematic diagram for boiling water reactor.

Operation (Working) of BWR:

- The fuel Uranium-235 is used as a fuel in the reactor to produce nuclear fission chain reaction.
- Light water which acts as the coolant and moderator.

- The coolant passes through the core where boiling takes place in the upper part of the core.
- The heat produced by the nuclear fission reaction is taken by the coolant into the steam generator.
- The steam generator(Boiler) transfers the hot water and some of the water is vapourized into the steam.
- The wet steam then passes through a bank of moisture separators and steam dryers in the upper part of the pressure vessel.
- The water that is not vaporized to steam is recirculated through the core with the entering feed water using two recirculation pumps coupled to jet pumps.
- The steam leaving the top of the pressure vessel is at saturated conditions of 7.2 MPa and 278◎C.
- The steam then expands through a turbine coupled to an electrical generator.
- After condensing of steam into liquid in the condenser, the liquid is returned to the reactors as feedwater.
- Prior to entering the reactor, the feedwater is preheated in several stages of feedwater heaters.
- The balance of plant systems (Example: Turbine generator, feedwater heaters) are similar for both PWR and BWRs.

<u>Advantages of BWR:</u>

- Heat exchanger circuit is eliminated and consequently there is gain in thermal efficiency and gain in cost.
- There is use of a lower pressure vessel for the reactor which further reduces cost and simplifies containment problems.
- The metal temperature remains low for given output conditions.
- The cycle for BWR is more efficient than PWR for given containment pressure, the outlet temperature of steam is appreciably higher in BWR.
- The pressure inside the pressure vessel is not high so thicker vessel is not required.

<u>Disadvantages of BWR:</u>

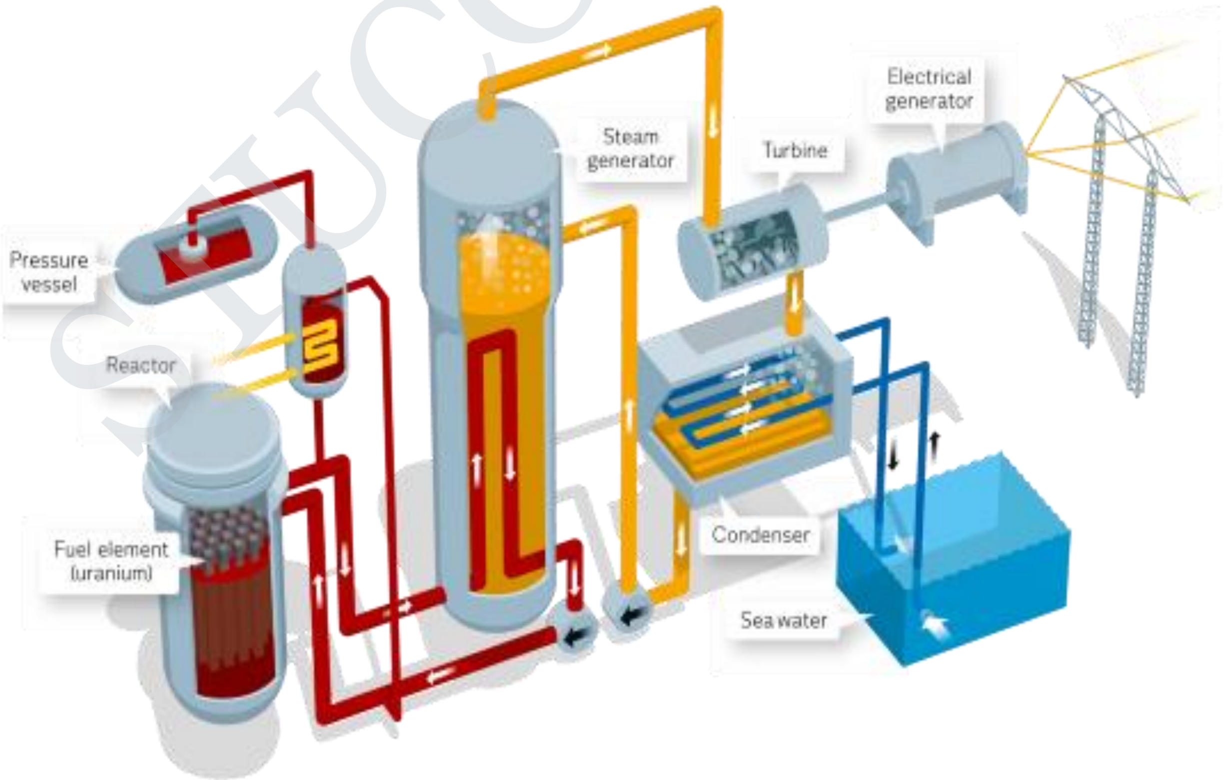
- Possibility of radioactive contamination in the turbine mechanism should there be any failure of fuel elements.
- More safety precautions are needed which are costly.
- Wastage of steam resulting in lowering of thermal efficiency on part load operation.
- Boiling limits power density only 3 to 5% by mass can be converted to steam per pass through the boiler.
- The possibility of "burn out" of fuel is more in this reactor than PWR as boiling of water on the surface of the fuel is allowed.

4. Explain in detail about Pressurized Water Reactor with its advantages and disadvantages. (or) Describe the construction and operation of PWR. (or) Explain any one type of light water nuclear reactor.

PWR Reactor Design(Construction):

Coolant:

- Light water is used as the primary coolant in a PWR.
- It enters the bottom of the reactor core at about 275 °C (530 °F) and is heated as it flows upwards through the reactor core to a temperature of about 315 °C (600 °F).
- The water remains liquid with the high temperature due to the high pressure in the primary coolant loop around 155 bar (15.5 MPa at 153 atm)
- Pressure in the primary circuit is maintained by a pressurizer, a separate vessel that is connected to the primary circuit and partially filled with water which is heated to the saturation temperature.
- To achieve a pressure of 155 bar, the pressurizer temperature is maintained at 345 40°C, which gives a sub-cooling margin of 30 °C.
- The coolant is pumped around the primary circuit by powerful pumps, which can consume upto 6 MW each.
- After picking up heat as it passes through the reactor core, the primary coolant transfers heat in a steam generator to water and evaporating the secondary coolant to saturated steam.



Schematic diagram for Pressurized Water Reactor

Moderator:

- Pressurized water reactors require the fast fission neutrons to be slowed down (a process called moderation or thermalization) in order to interact with the nuclear fuel and sustain the chain reaction.
- In PWRs the coolant water is used as a moderator by letting the neutrons undergo multiple collisions with light hydrogen atoms in the water, losing speed in the process.
- This "moderating" of neutrons will happen more often when the water is denser (more collisions will occur).
- The use of water as a moderator is an important safety feature of PWRs, as an increase in temperature may cause the water to turn to steam.
- Therefore, if reactivity increases beyond normal, the reduced moderation of neutrons will cause the chain reaction to slow down, producing less heat and makes PWR reactors very stable.

Fuel:

- After enrichment the uranium dioxide (UO_2) powder is fired in a high-temperature, sintering furnace to create hard, ceramic pellets of enriched uranium dioxide.
- The cylindrical pellets are then clad in a corrosion-resistant zirconium metal alloy Zircaloy which are backfilled with helium to aid heat conduction and detect leakages.
- Zircaloy is chosen because of its mechanical properties and its low absorption cross section.
- The finished fuel rods are grouped in fuel assemblies called fuel bundles that are used to build the core of the reactor.
- A typical PWR has fuel assemblies of 200 to 300 rods each and a large reactor is about 150–250 such assemblies with 80–100 tonnes of uranium in all.
- Generally, the fuel bundles consist of fuel rods bundled 14 × 14 to 17 × 17.
- A PWR produces on the order of 900 to 1,500 MWe.
- PWR fuel bundles are about 4 meters in length.
- Refueling for most commercial PWRs is on an 18–24 month cycle.

Control Rods:

- Boron and control rods are used to maintain primary system temperature at the desired point.
- Boron readily absorbs neutrons and increasing or decreasing its concentration in the reactor coolant.

- An entire control system involving high pressure pumps is required to remove water from the high pressure primary loop and re-inject the water back in with differing concentrations of boric acid.
- The reactor control rods, inserted through the reactor vessel head directly into the fuel bundles, are moved for the following reasons:
  - ✓ To start up the reactor.
  - ✓ To shut down the primary nuclear reactions in the reactor.
  - ✓ To accommodate short term transients such as changes to load on the turbine.
- The control rods can also be used:
  - ✓ To compensate for nuclear poison inventory.
  - ✓ To compensate for nuclear fuel depletion.

<u>Operation (Working) of PWR:</u>

- The reactor have reactor vessel which contains water as coolant and uranium as Moderator.
- When the uranium atoms are splitting to produce nuclear fission chain reaction.
- The nuclear fission reaction produces fast moving neutrons and also some energy in the form of heat.
- Due to heat from nuclear reaction, the water is heated to 325°C.
- The high pressure inside the reactor is regulated by a pressure vessel, preventing the boiling of water.
- The hot water from the reactor is transferred to the steam generator which is a large heat exchanger.
- Steam is produced because the pressure is lower and steam is subsequently fed into the turbine.
- The pressure from the steam causes the turbine blades to rotate and the turbine operates a generator which generates electricity.
- The steam is then conveyed to a condenser which consists of a large number of small pipes.
- Sea water is pumped through pipes and condenses the steam into water again.
- The sea water is pumped back out to the sea again and is then around 10°C warmer than when it entered the condenser.
- The condensed water is pumped back from the steam generator into the reactor to be heated again.
- The water in the reactor thus circulates in a closed cycle so neither the steam generator water nor the cooled sea water comes into contact with the water in the reactor.

Advantages of PWR:

- PWR reactors are very stable due to their tendency to produce less power as temperatures increase.
- PWR turbine cycle loop is separate from the primary loop, so the water in the secondary loop is not contaminated by radioactive materials.
- When power is lost, the control rods immediately stop the primary nuclear reaction. The control rods are held by electromagnets and fall by gravity when current is lost.
- PWR technology is favoured by navy, the compact reactors fit well in nuclear submarines and other nuclear ships.

Disadvantages of PWR:

- The PWR design requires high strength piping and a heavy pressure vessel and hence increases construction cost.
- Additional high pressure components such as reactor coolant pumps, pressurizer, steam generators, etc. are also needed.
- Additional components increases the capital cost and complexity of a PWR power plant.
- The high temperature water coolant with boric acid can cause radioactive corrosion products to circulate in the primary coolant loop. This limits the lifetime of the reactor
- The requirement to enrich the uranium fuel for PWRs also presents a serious explosion risk.
- Water acts as a neutron moderator, it is not possible to build a fast neutron reactor with a PWR design.

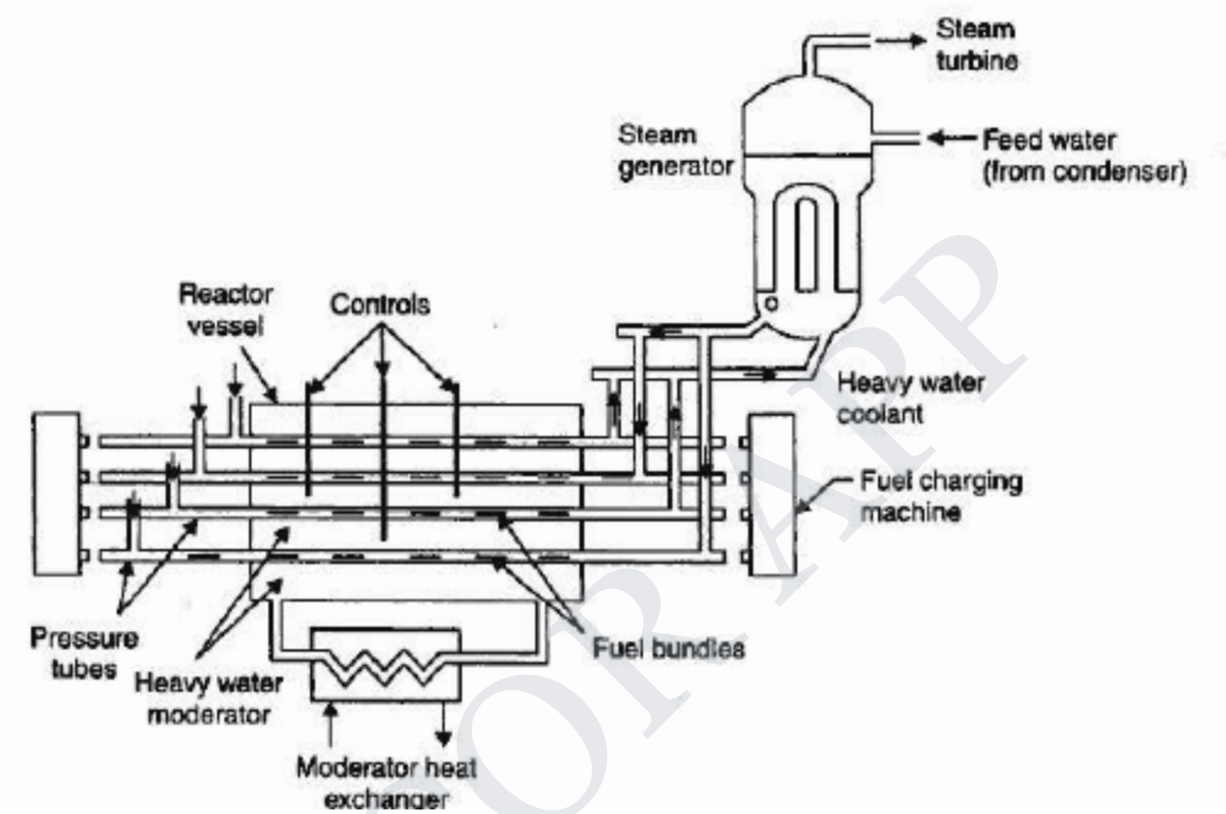
5. Explain in detail about CANada Deuterium Uranium Reactor with its advantages and disadvantages. (or) Describe the construction and operation of CANDU Reactor. (or) Explain the most preferable nuclear reactor used in Canada.

CANDU Reactor Components:

Reactor vessel and core:

- The reactor vessel is a steel cylinder with a horizontal axis; the length and diameter of a typical cylinder being 6 m and 8 m respectively.
- The vessel is penetrated by some 380 horizontal channels called pressure tubes because they are designed to withstand a high internal pressure.
- The channels contain the fuel elements and the pressurized coolant flows along the channels and around the fuel elements to remove the best generated by fission.
- Coolant flows in the opposite directions in adjacent channels.

- The high pressure (10 MPa) and high temperature (3700 C) coolant leaving the reactor core enters the steam generator.
- About 5% of fission heat is generated by fast neutrons escaping into the moderator, and this is removed by circulation through a separate heat exchanger.



Schematic diagram of CANDU Reactor

Fuel system:

- In a CANDU reactor the fuel is normal (i.e., unenriched) uranium oxide as small cylinder pellets.
- The pellets are packed in a corrosion resistance zirconium alloy tube, nearly 0.5 long and 1.3 cm diameter, to form a fuel rod.
- The relatively short rods are combined in bundles of 37 rods and 12 bundles are placed end to end in each pressure tube.
- The total mass of fuel in the core is about 97,000 kg.
- The CANDU reactor is unusual in that refueling is conducted while the reactor is operating.

Control and protection system:

- There are the various types of vertical control system incorporated in the CANDU reactor:
- A number of strong neutron absorber rods of cadmium which are used mainly for reactor shut-down and start-up.

- In addition to above there are other less strongly, absorbing rods to control power variations during reactor operation and to produce an approximately uniform heat (power) distribution throughout the core.
- In an emergency situation, the shut-down rods would immediately drop into the core, if necessary by the injection of a gadolinium nitrate solution into the moderator.

Steam system:

- The respective ends of the pressure tubes are all connected into inlet and outlet headers.
- The high temperature coolant leaving the reactor passes out the outlet header to a steam generator of the conventional inverted U-tube and is then pumped back into the reactor by way of the inlet header.
- Steam is generated at a temperature of about 265°C.
- There are two coolant outlet (and two inlet) headers, one at each end of the reactor vessel corresponding to the opposite directions of coolant flow through the core.
- Each inlet (and outlet header is connected to a separate steam generator and pump loop.
- A single pressurizer maintains an essentially constant coolant system pressure.
- The reactor vessel and the steam generator system are enclosed by a concrete containment structure.
- A water spray in the containment would condense the steam and reduce the pressure that would result from a large break in the coolant circuit.

Operation of CANDU reactor:

- The fuel Uranium-235 is used as a fuel in the reactor to produce nuclear fission chain reaction.
- The reactor have reactor vessel which contains heavy water as coolant and uranium as Moderator.
- When the uranium atoms are splitting to produce nuclear fission chain reaction.
- The nuclear fission reaction produces fast moving neutrons and also some energy in the form of heat.
- The heavy water which acts as a moderator slow down the fast moving neutrons and pull back the neutrons for the next nuclear fission reaction.
- Due to heat from nuclear reaction, the heavy water is heated to some high temperature.
- The hot water from the reactor is transferred to the steam generator which is a large heat exchanger.
- Steam is produced because the pressure is lower and steam is subsequently fed into the turbine.
- The pressure from the steam causes the turbine blades to rotate and the turbine operates a generator which generates electricity.

- The steam is then conveyed to a condenser which consists of a large number of small pipes.
- Sea water is pumped through the pipes and condenses the steam into water again.
- The sea water is pumped back out to the sea again and is then around 10°C warmer than when it entered the condenser.
- The condensed water is pumped back from the steam generator into the reactor to be heated again.

Advantages of CANDU reactor:

- Heavy water is used as moderator, which has higher multiplication factor and low fuel consumption.
- Enriched fuel is not required.
- The cost of the vessel is low as it does not withstand a high pressure.
- Less time is needed (as compared to PWR and BWR) to construct the reactor.
- The moderator can be kept at low temperature which increases its effectiveness in slowing down neutrons.

Disadvantages of CANDU reactor:

- It requires a very high standard of design, manufacture and maintenance.
- The cost of heavy water is very high.
- There are leakage problems.
- The size of the reactor is extremely large as power density is low as compared with PWR and BWR.

6. Draw and explain the Fast Breeder Reactor? (or) Describe the FBR with its coolant.

Introduction:

- A breeder reactor is a nuclear reactor capable of generating more fissile material than it consumes. These devices are able to breed (or create) more fissile fuel than they use from fertile material such as uranium-238 or thorium-232.
- Breeders were at first found attractive because their fuel economy was better than light water reactors,
- But the interest is declined after 1960s as more uranium reserves were found and new methods of uranium enrichment with reduced fuel costs.

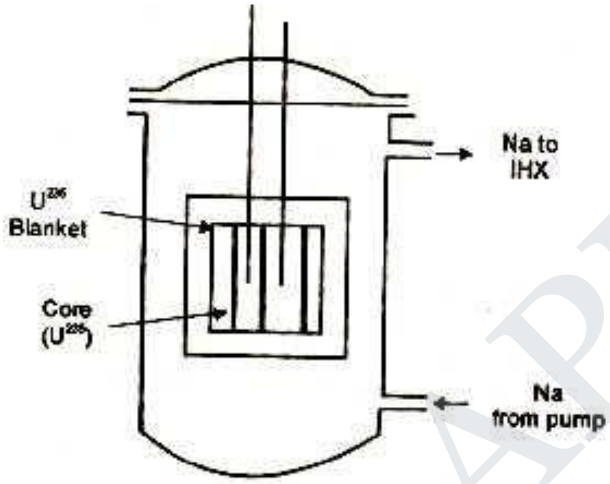
Types of Breeder Reactor:

A) Thermal Breeder:

- Thermal breeder reactor use thermal spectrum (moderated) neutrons to breed fissile uranium-233 from thorium (thorium fuel cycle).
- Due to the behavior of the various nuclear fuels, a thermal breeder is thought commercially feasible only with thorium fuel, which avoids the buildup of the heavier transuranics.

B) Fast Breeder Reactor:

- Fast breeder reactor (FBR) uses fast neutrons to breed fissile plutonium and possibly higher transuranics from fertile uranium-238.
- The fast spectrum is flexible enough that it can also breed fissile uranium-233 from thorium, if desired.
- It is mostly preferable because of fuel utilized is abundant in nature compared to thermal breeder used fuel.



Fast breeder reactor arrangement

Fast Breeder Reactor Design:

- In this reactor the core containing U235 is surrounded by a blanket (a layer of fertile material placed outside the core) of fertile material U238.
- Fast breeder reactor has no moderator to control the speed of chain reaction.
- The fast moving neutrons liberated due to fission of U-235 are absorbed by U-238 which gets converted into fissionable material Pu-239 which is capable of sustaining chain reaction.
- This reactor is important because it breeds fissionable material from fertile material U238 available in large quantities.
- Like sodium graphite nuclear reactor this reactor also uses two liquid metal coolant circuits.
- Liquid sodium is used as primary coolant when circulated through the tubes of intermediate heat exchange transfers its heat to secondary coolant sodium potassium alloy.
- The secondary coolant while flowing through the tubes of steam generator transfers its heat to feed water.
- Fast breeder reactors are better than conventional reactors both from the point of view of safety and thermal efficiency.
- The fast breeder reactor becomes inescapable in view of the massive reserves of thorium and the finite limits of its uranium resources.

Coolant for Fast Breeder reactor:

The commonly used coolants for fast breeder reactors are as follows:

i) Liquid metal (Na or Na-K)
ii) Helium (He)
iii) Carbon dioxide(CO_2)

Sodium has the following advantages:

- It has very low absorption cross-sectional area.
- It possesses good heat transfer properties at high temperature and low pressure.
- It does not react on any of the structural materials used in primary circuits.

Operation of Breeder reactor:

- In this reactor the core containing the fuel as Uranium-235(U-235) is surrounded by a layer of fertile material Uranium-238(U-238).
- Sodium is used as coolant to transfer the heat from reactor to an intermediate heat exchanger(IHX).
- When nuclear fission reaction of U-235 takes place, the fast moving neutrons are liberated and also some energy is generated in the form of heat.
- The fast moving neutrons are absorbed by U-238 which gets converted into fissionable material Plutonium-239(Pu-239)
- When Pu-239 combines with the neutrons, it is capable of producing further nuclear chain reaction.
- The heat generated by the nuclear reaction is absorbed by the coolant(sodium).
- Sodium is boiled quickly due to its low boiling point and and the hot sodium is supplied to Heat exchanger.
- In the heat exchanger, the heat of sodium is transferred to the cool water present in the same heat exchanger.
- After the heat transfer, the cool sodium metal can be fed back into the reactor core through the feedpump.
- Some of the hot water in heat exchanger is vapourized into steam and steam is subsequently fed into the turbine.
- The pressurized steam causes the turbine blades to rotate and the turbine operates a generator which generates electricity.
- The steam is then conveyed to a condenser and condenses the steam into water again.
- The condensed water is pumped back from the steam generator into the reactor to be heated again.

Advantages of breeder reactor:

- A breeder reactor creates 30% more fuel than it consumes.
- Breeder reactors can even use the uranium waste from uranium processing plants.
- It reuses fuel for the expenses for mining, milling, and processing of uranium ore are minimized.

- This technology does not contribute to air pollution, except during the mining and processing of uranium ore.
- Breeder reactors can use a small core, which is important to sustain chain reactions.
- It can generate much more energy than traditional coal power plants.

Disadvantages of breeder reactor:

- Breeder reactors use highly enriched fuels which causes the danger of critical accidents.
- Breeder reactors are always working at a very high temperature and a fast pace.
- Low efficiency due to fissile material such as Plutonium.
- It requires liquified sodium or potassium metal as a coolant,
- The construction and operation is very costly.
- These reactors are complex to operate.

7. Explain in detail about Gas Cooled Reactor with its advantages and disadvantages. (or) Describe the construction and operation of GCR. (or) Explain the operation of nuclear reactor which uses carbon-dioxide as coolant.

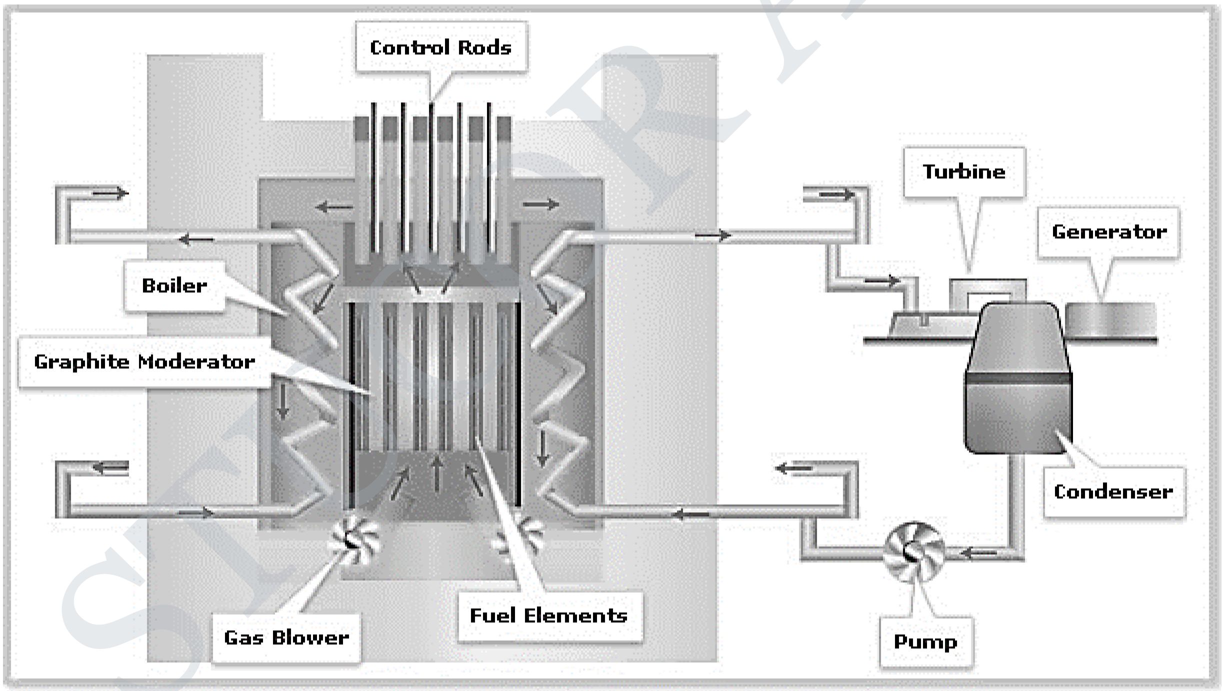
Introduction:

- The Gas Cooled Reactor was one of the original design reactor which uses the moderator is graphite and an Inert gas as coolant (e.g. helium or carbon dioxide).
- The advantage of the design is that the coolant can be heated to higher temperatures than water.
- As a result higher plant efficiency (40% or more) could be obtained compared to the water cooled design (33-34%).
- The older reactor design uses carbon dioxide gas circulating through the core (at a pressure of 1.6 MPa or 230 pounds) per square inch to remove the heat from the fuel elements.
- The fuel consists of natural uranium metal clad with an alloy of magnesium known as Magnox (thus the name for the reactor type).
- The newer Advanced Gas Cooled (AGR) Reactors use a slightly enriched uranium dioxide clad with stainless steel as moderator and Carbon dioxide gas is the coolant.

Operation (Working) of Gas Cooled Reactor:

- The reactor core consists of fuel element which is natural uranium metal and it is cladded by Magnox(an alloy of magnesium).
- Carbon-di-oxide is used as a coolant and graphite is used as moderator.
- When the uranium atoms are splitting to produce nuclear fission chain reaction.
- The nuclear fission reaction produces fast moving neutrons and also some energy in the form of heat.

- Carbon dioxide gas passed through the fuel channels absorbs the fission heat and also reduces the speed of neutrons.
- The hot carbon-di-oxide gas from the reactor is transferred to the Heat exchanger(steam generator).
- In the heat exchanger, the heat of CO_2 gas is transferred to the cool water present in the same heat exchanger.
- After heat transfer, the CO_2 gas is fed back into the reactor core through feedpump.
- Some of the hot water is vapourized into steam in the heat exchanger and steam is subsequently fed into the turbine.
- The pressurized steam causes the turbine blades to rotate and the turbine operates a generator which generates electricity.
- The steam is then conveyed to a condenser and condenses the steam into water.
- The condensed water is pumped back from the steam generator into the reactor to be heated again.



Schematic diagram for Gas Cooled Reactor based Power Plant

Gas Cooled reactor design:

Reactor core:

- The reactor moderator consists of a 16 sided stack of Graphite bricks.
- The graphite acts as moderator as well as provide necessary channels for fuel assembly, control rods and coolant flow.
- The shielding around the core is necessary to protect the surrounding steel work and boilers from neutrons.

- The shielding is provided by using more thickness of graphite moderator and also higher thickness steel is used for boiler design.
- The upper neutron shield consists of graphite and steel bricks.
- The lower shield is made up of graphite bricks which is placed on steel plates.
- For control the chain reaction of the neutrons with the fuel, control rods are inserted into the core.
- Under emergency conditions, nitrogen may be injected between the fuel assemblies to absorb neutrons.

Fuel:

- In a Gas Cooled Reactor design, the unit operates on fast neutrons and there is no moderator is needed to slow neutrons down.
- Apart from nuclear fuel such as uranium, other fuels can also be used.
- The most common is thorium, which absorbs a fast neutron and decays into Uranium 233.
- Gas Cooled Reactor designs have breeding properties because they can use fuel that is unsuitable in light water reactor designs and breed fuel.
- Because of these properties, once the initial loading of fuel has been applied into the reactor, the unit can go years without needing fuel.
- If these reactors are used for breeding, it is economical to remove the fuel and separate the generated fuel for future use.

Coolant:

- The gas used can be many different types, including carbon dioxide or helium.
- It must be composed of elements with low neutron capture cross sections to prevent induced radioactivity.
- The use of gas also removes the possibility of phase transition–induced explosions, such as in water-cooled reactor flashes to steam upon overheating or depressurization.
- The use of gas also allows for higher operating temperatures than are possible with other coolants increasing thermal efficiency,
- The gas coolant allows other non-mechanical applications of the energy such as the production of hydrogen fuel.

Advantages of Gas Cooled Reactor:

- If CO_2 is used as the cooling gas, it eliminates the possibility of explosion which is always present in water cooled reactors
- There is no need for cladding the metallic fuel which leads to simple fuel processing techniques.

- In this reactor design, the coolant can be heated to higher temperatures than water to achieve higher thermal efficiency.
- This reactor design is not susceptible to some types of accidents possible with water cooled reactors.

Disadvantages of Gas Cooled Reactor:

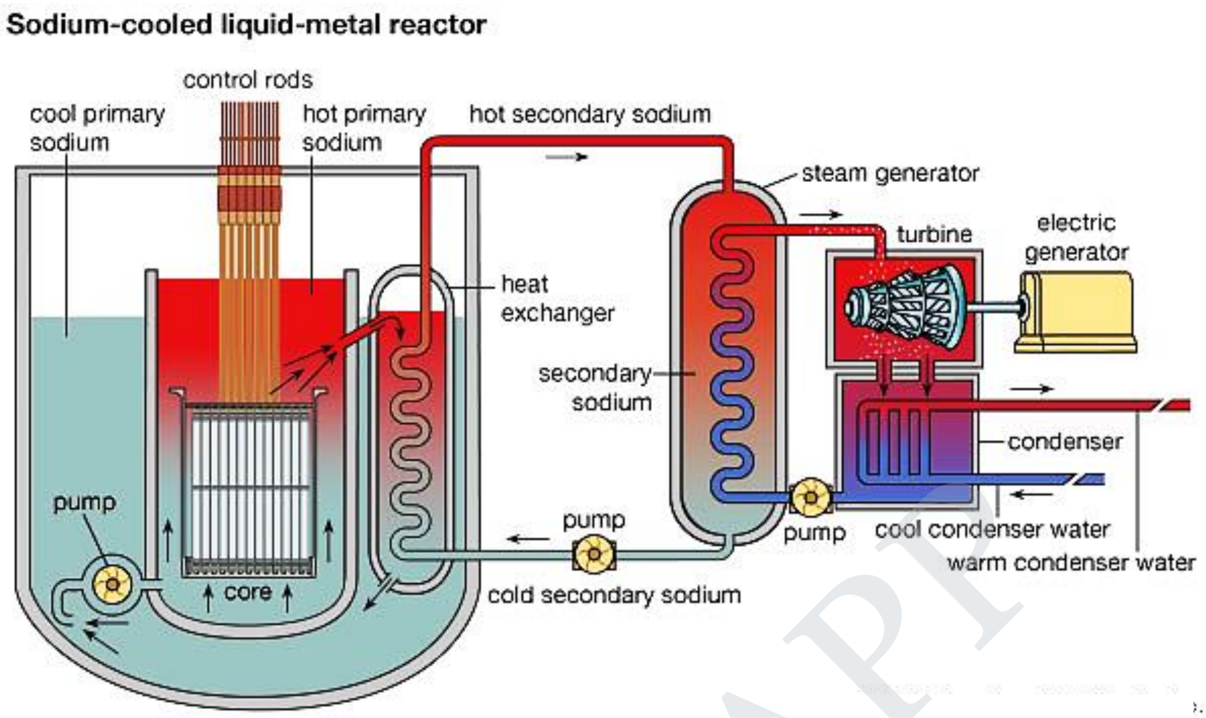
- The main drawback of these plants is there low power density
- This reactor design requires large size of the reactor for relatively smaller power requirements.
- When Helium is used as coolant, its low neutron absorbing capacity makes it unsuitable for load control.

8. Explain in detail about Liquid Metal Cooled Reactor with its advantages and disadvantages. (or) Describe the construction and operation of LMCR. (or) Explain the operation of nuclear reactor which uses Liquid Metal as coolant.

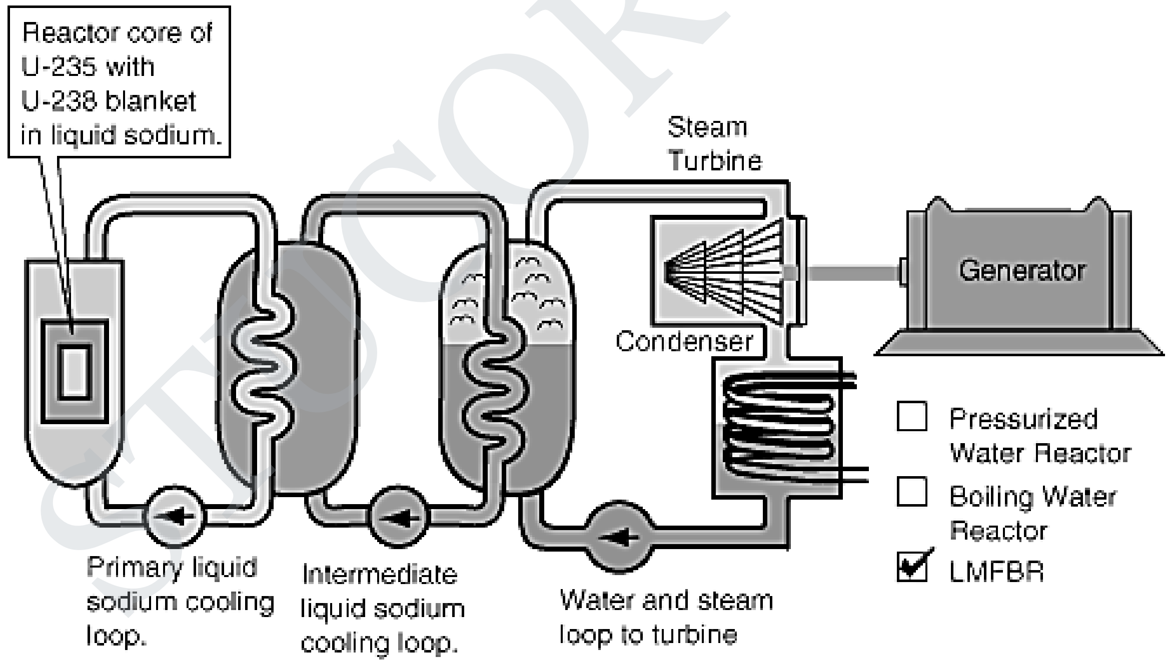
Liquid Metal Cooled Reactor:

Introduction:

- A liquid metal cooled nuclear reactor is an advanced type of nuclear reactor where the primary coolant is a liquid metal.
- The alternate names for liquid metal cooled reactor such as Liquid metal Fast Reactor or LMFR
- Liquid metal cooled reactors were first adapted for nuclear submarine use and also studied for power generation applications.
- Because the metal coolants have much higher density than the water used in most reactor design.
- The metal coolants remove heat more rapidly and allow much higher power density.
- This property of metal coolant is attractive in situations where small size and less weight is required like on ships and submarines.
- To improve cooling with water, most reactor designs are highly pressurized to raise the boiling point which presents safety and maintenance issues that liquid metal designs lack.
- Additionally, the high temperature of the liquid metal can be used to produce vapour at higher temperature than in a water cooled reactor leading to a higher thermodynamic efficiency



Schematic diagram of Pool type Liquid Metal Cooled Reactor Power Plant



Schematic diagram of Loop type Liquid Metal Cooled Reactor Power Plant

Liquid Metal Cooled Reactor Design:

- All liquid metal cooled reactors are fast neutron reactors, and most fast neutron reactors have been liquid metal cooled fast breeder reactors.

- The liquid metals used typically need good heat transfer characteristics. Some of the liquid metals used in nuclear reactor are:
  - ✓ Mercury
  - ✓ Sodium
  - ✓ Sodium Potassium
  - ✓ Lead
  - ✓ Tin
- Fast neutron reactor cores tend to generate a lot of heat in a small space when compared to other reactors.
- A low neutron absorption is desirable in any reactor coolant, but especially important for a fast reactor.
- The slower neutrons are more easily absorbed, the coolant should ideally have a low moderation of neutrons.
- It is also important that the coolant does not cause excessive corrosion of the structural materials and so it's melting and boiling points are suitable for the reactor operating temperature.
- Ideally the coolant should never boil as that would make it more likely to leak out of the system, resulting in a loss-of-coolant accident.
- Conversely, if the coolant can be prevented from boiling this allows the pressure in the cooling system to remain at neutral levels, and this dramatically reduces the probability of an accident.

Coolant Properties:

- If the pressurized water could be used for a fast reactor, it tends to slow down neutrons and absorb them.
- This limits the amount of water that can be allowed to flow through the reactor core, and since fast reactors have a high power density
- Water boiling point is also much lower than most metals so that the cooling system be kept at high pressure to effectively cool the core.

Liquid metal coolants		
Coolant	**Melting point**	**Boiling point**
Sodium	97.72 °C, (207.9 °F)	883 °C, (1621 °F)
NaK	−11 °C, (12 °F)	785 °C, (1445 °F)
Mercury	−38.83 °C, (−37.89 °F)	356.73 °C (674.11 °F)
Lead	327.46 °C, (621.43 °F)	1749 °C, (3180 °F)
Lead-bismuth eutectic	123.5 °C, (254.3 °F)	1670 °C, (3038 °F)
Tin	231.9 °C, (449.5 °F)	2602 °C, (4716 °F)

Operation of Liquid Metal cooled Reactor:

- The reactor have reactor vessel which contains sodium liquid metal as coolant and uranium as Fuel.
- When the uranium atoms are splitting to produce nuclear fission chain reaction.
- The nuclear fission reaction produces fast moving neutrons and also some energy in the form of heat.
- Due to heat from nuclear reaction, the sodium is heated in the reactor vessel quickly due to its low boiling point.
- The hot sodium from the reactor is transferred to the Heat exchanger(steam generator).
- In the heat exchanger, the heat of sodium is transferred to the cool water present in the same heat exchanger.
- After the heat transfer, the cool sodium metal can be fed back into the reactor core through the feedpump.
- Some of the hot water is vapourized into steam and steam is subsequently fed into the turbine.
- The pressurized steam causes the turbine blades to rotate and the turbine operates a generator which generates electricity.
- The steam is then conveyed to a condenser and condenses the steam into water again.
- The condensed water is pumped back from the steam generator into the reactor to be heated again.

Advantages of Liquid metal cooled reactor:

- This reactor design has a high fuel burn-up ratio.
- This reactors design does not corrode steel reactor vessel. The reactor design is very compact.
- It has a high power output for its size.
- Liquid metal-cooled reactors are not pressurized leading to simpler piping systems.
  The liquid metal coolant cannot turn to steam unlike water during a meltdown and making a steam explosion impossible.
- Some changes of this design can be used as breeder reactors.

Disadvantages of Liquid metal cooled reactor:

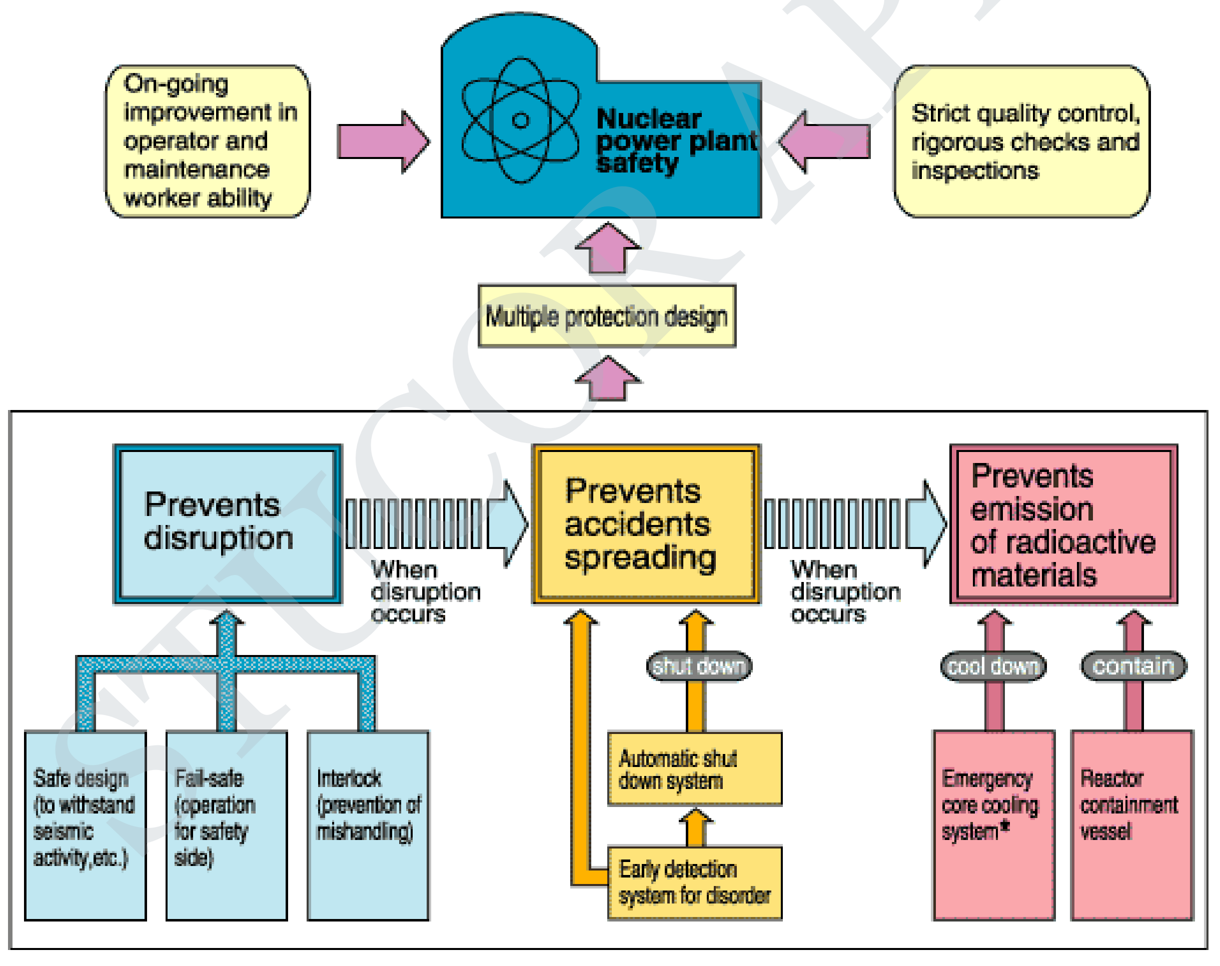
- The high temperature of the reactor could make the complex design.
- Sodium as coolant reacts violently with water and air.
- Cost is very high

9. Describe the need of safety measures in nuclear power plant and also explain in detail about the safety measures of nuclear power plant.

Need of safety measures:

- Nuclear power plants requires multiple safety measures which are designed on the assumption that they must ensure the safety of the neighboring communities.
- The safety measures should not have no adverse impacts on their health.
- Nuclear power plants are designed to prevent abnormal incidents from occurring.
- Even if abnormal incidents do occur, nuclear plants are also designed to prevent the potential spreading of abnormal incidents and leakage of radioactive materials around the surrounding environment.

Safety Features of Nuclear Plant Design



* Emergency Core Cooling System (ECCS): When an accident occurs, huge amounts of water will be automatically poured into a nuclear reactor to cool down nuclear fuel.

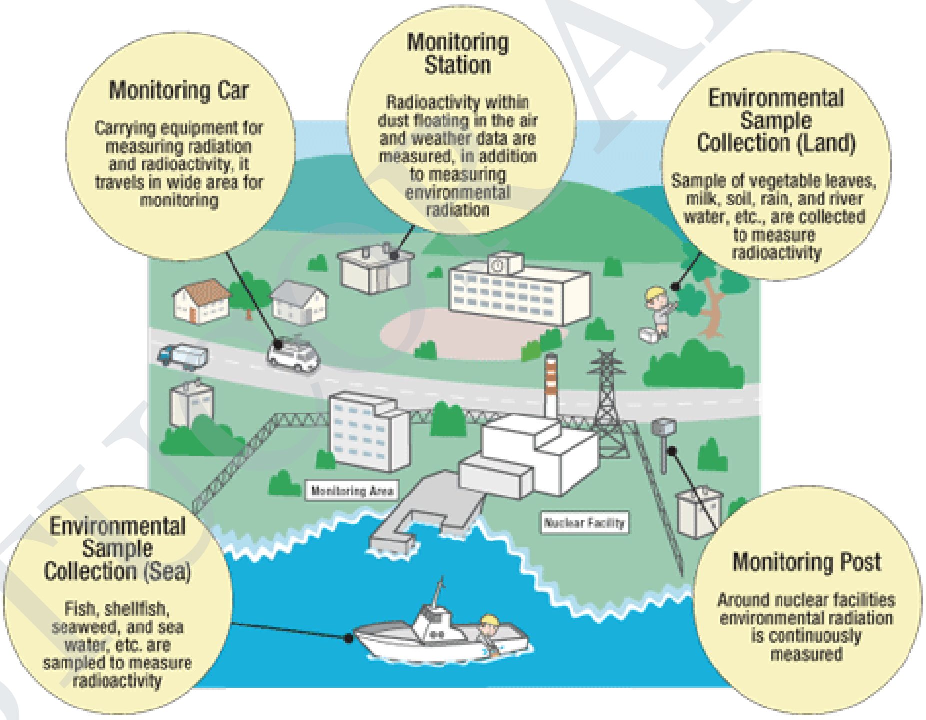
Environmental Radiation Monitoring measures:

- Nuclear operators monitor environmental radiation around their facility and radioactivity in environmental samples in order to confirm that there is no harmful effect on the surrounding environment.

- Local governments as well as utilities independently measure radiation dose in the air by radiation monitoring systems around nuclear power plants.
- In addition, they periodically collect seawater, soil and agricultural as well as sea products to measure and analyze them for radioactive material content and to ensure that power plants have no adverse impact on the surrounding environment.

- Measures to be put into action in order to ensure safety during unusual events can be summarized in the following three points:
  - ✓ To shut down operating reactors
  - ✓ To cool down reactors so as to remove heat from nuclear fuel
  - ✓ To neutralize the radioactive materials during such accidents

Environmental Radiation Monitoring around Nuclear Facilities



Aseismic Measures:

- Several safety measures against earthquakes are taken at all stages of design, construction of nuclear power plants.
  - ✓ Thorough Installation
  - ✓ Seismic design considering even an extremely rare earthquake
  - ✓ Detailed Analytical Evaluation
  - ✓ Confirmation of safety of bearing ground and surrounding slopes

Aseismic Measures Taken by Nuclear Power Plants

【8 key safety points】

Stages	Measures	Details
Assuring safety at the design stage	① Thorough investigation	Perform a detailed survey of active faults and past earthquakes at the site and its surrounding areas as well as the geology and geological structure of the site.
	② Seismic design considering even an extremely rare earthquake	Assure the seismic design to prevent safety-significant components and systems from losing their functions against ground motions both in the horizontal and vertical direction which are assumed to occur during the plant service life, even though the possibility is extremely low.
	③ Detailed analytical evaluation	Perform detailed analyses of possible complicated jolts to important buildings and components when a postulated earthquake hits the site using reliable computational codes to verify the seismic safety.
	④ Confirmation of safety of bearing ground and surrounding slopes	Perform tests and analyses to verify if the ground, on which the facilities important for seismic safety are to be built, has sufficient bearing resistance against earthquakes and confirm that assumed events accompanying an earthquake, such as the collapse of surrounding slopes, would not significantly influence the safety of reactor facilities.
	⑤ Confirmation of safety against tsunami	Performing detailed numerical simulations of a tsunami which is assumed to accompany an earthquake to confirm that it would not significantly influence the safety of the facilities.
Assuring safety at the construction and operation stages	⑥ Construction of a nuclear power plant on ground with sufficient bearing resistance	Build a nuclear power plant on ground that has a low amplitude of earthquake ground motion, sufficient bearing resistance, and no possibility of sliding or adverse subsidence.
	⑦ Automatic shutdown function	Install a system which can automatically shut the reactor immediately after jolts exceeding a certain level are detected.
	⑧ Demonstration of earthquake resistance and understanding of seismic limits using a shaking table and exciter	Demonstrate the earthquake resistance of nuclear facilities, understand the design margin and verify the validity of computational codes used in the maintenance and analysis of equipment functions by applying earthquake loads exceeding the design limit to the actual unit or a specimen equivalent to the actual unit by using a shaking table or exciter.

- ✓ Confirmation of safety of any other natural disaster such as storm, tsunami, etc.
- ✓ Construction of nuclear power plant on ground with bearing resistance
- ✓ Automatic shutdown function of reactor during accidents
- ✓ Demonstration of earthquake resistance and analyzing the seismic limits by shaking tables and exciter.

UNIT – IV
POWER FROM RENEWABLE ENERGY

1. Draw the Layout diagram of Hydro Power Plant and also explain the components and working of Hydro power plant?

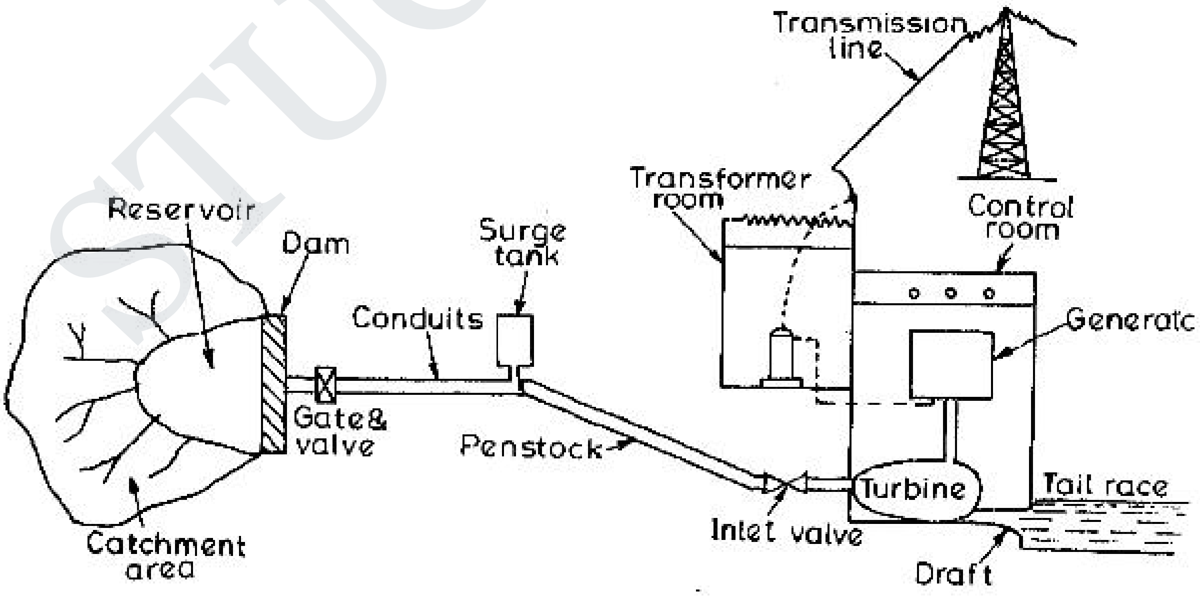
Introduction:

Hydro-electric power plant utilizes the potential energy of water stored in a dam built across the river. The potential energy of water is used to run water turbine to which the electric generator is coupled. The mechanical energy available at the shaft of the turbine is converted into electrical energy means of the generator.

Elements of Hydro Power Plant:

The schematic representation of a hydro-electric power plant is shown in figure.

- Catchment area
- Water reservoir
- Dam and the intake
- Inlet water ways
- Penstock and Surge Tanks
- Power house and its equipment
- Forebay and Spillways
- Draft Tube and Tail race



Catchment area:

- The area behind the dam, which collects rain water and drains into a stream or river is called catchment area.
- Water collected from catchment area is stored in a reservoir behind the dam.

Water reservoir:

- The water reservoir is the large area to store huge amount of water for the future irrigation purpose.
- The purpose of the reservoir is to store the water during rainy season and supply it during dry season.
- Water surface in the storage reservoir is known as head race level or simply head race.
- A reservoir can be either natural or artificial.
- A natural reservoir is a lake in high mountains and an artificial reservoir is made by constructing a dam across the river.
- Water held in upstream at the reservoir is called **storage** whereas water behind the dam at the plant is called **pondage**.

Dam:

- A dam is a structure of masonry earth and/or rock fill built across a river.
- It has two functions:
  - a) To provide the head of water
  - b) To create storage or pondage
- The basic requirements of a dam are economy and safety.
- The dam foundation must provide for dam stability under different forces and supports its weight.
- The foundation should be sufficiently impervious to prevent leakage of water under the dam.
- Concrete and masonry dams are quite popular and are made as:
  - c) Solid gravity dam
  - d) Buttress dam
  - e) Arched dam

Water Intake:

- The intake house includes the work head which are the structure at the inlet of canals, tunnels or waterfalls.
- There are booms, screens or trash racks and channels for by passing the foreign particles and gate valves for controlling the water flow.
- Gates discharge excess water during flood duration.
- Gates are of different types such as **radial gates, sluice gates, wheeled gates, plain sliding gates, crest gates, rolling or drum gates, etc.**
- The various types of valves used are **needle valve and butterfly valves**.

Inlet water ways:

- Inlet water ways are the passages through which water is conveyed from the dam to the power house.
- It includes canal, penstock or tunnel, flume, forebay and also surge tank.

- Tunnel is made by cutting the mountains where canal or pipe line cannot be used due to slope regions.
- Tunneling provides a direct and short route for the water passages.

Penstocks:

- Water may be conveyed to turbines through open canals or closed pressure pipes called penstocks made of reinforced concrete or steel.
- It is desirable that the penstock should be slopping towards the power house.
- Penstocks usually are not covered and placed as exposed pipes which facilitates easy maintenance and repair.
- When there is danger from slides of snow, rock, earth etc. covered penstocks are used.
- The thickness of the penstock increases as working pressure or head of the water increases.
- Long penstocks are manufactured in sections and joined together by welding, the welded joints give less friction loss.

Surge Tanks:

- Surge tank is an additional storage space near the power unit which is usually provided in high head or medium head plants
- The surge tank provides additional water when the load on the turbine increases.
- When the load on the generator decreases, the gates allowing water to the turbines are suddenly closed, this cause sudden rise of pressure in the penstock above normal due to reduced load on generator is known as water hammer.
- Surge tank relieves water hammer pressures when the penstock under conditions of sudden changes in condition of water flow.
- The surge tank has the following functions:
    - To regulate the flow of water through the penstock,
    - To relieve water hammer pressures
    - To improve performance of the machines by providing better speed regulation.

Forebay:

- The water carried by the power canals is distributed to various penstocks leading to the turbine through the temporary storage path is called as Forebay also known as head pond.
- Water is temporarily stored in the forebay, this water is supplied when the load is suddenly increased.
- The forebay also acts as a sort of regulating reservoir.

Spillways:

- These structures provide for discharge of the surplus water from the storage reservoir into the river.
- Spillway is considered a safety device for a dam, which has the ability to discharge major floods without damage to the dam.
- There are several designs of spillways such as simple spillway, side channel spillway, siphon spillway, etc.

Power House:

- The power house is a building in which the turbines, alternators and the auxiliary plant are housed.
- Here conversion of energy of water to electrical energy takes place.
- Some of the main equipments provided in a power house:
    - ✓ Turbines coupled with generators
    - ✓ Turbine governors
    - ✓ Gate valves
    - ✓ Water circulating pumps and Flow measuring devices
    - ✓ Transformers and Reactors
    - ✓ Switch board equipment and instruments
    - ✓ Oil circuit breakers
    - ✓ Cranes
    - ✓ Shops and offices
- The turbines which are in common use are Pelton turbine, Francis turbine, Kaplan turbine and Propeller turbines.

Tail Race:

- Tail race is a passage for discharging the water leaving the turbine into the river.
- In certain cases, the water from the tail race can be pumped back into the original reservoir.
- The water held in the tail race is called as tail race water level.

Draft Tube:

- The draft tube is an essential part of reaction turbine installation.
- It is a diverging passage from the point of runner exit down to the tail race.
- Thus a draft tube has two main functions:
    - ✓ It permits the establishment of negative head below the runner and so makes it possible to set the turbine above the tail race level, where it is more easily accessible and yet does not cause a sacrifice in head.

✓ Its diverging passage converts a large portion of the velocity energy rejected from the runner into useful pressure head, thereby increasing the efficiency of the turbine.

2. What is the classification of Hydro Power plant? Explain in detail. (or) Explain the types of Hydro-Power plant with its proper layout.

Introduction:

- In hydro-plants, water is collected behind the dam through reservoir.
- Water reservoir may be classified as either storage or pondage according to the amount of water flow.
- The function of the storage is to hold excess river flow during the rainy season to increase the low rates of flow during dry seasons.
- With pondage, the water level always fluctuates during operations:
  - ✓ It rises at the time of storing water
  - ✓ It falls at the time of drawing water
  - ✓ It remains constant when the load is constant.

Classification of Hydro-power Plant:

The hydro-power plants can be classified as below:

- Storage plant
  - a) High head plants
  - b) Low head plants
  - c) Medium head plants
- Run-of-river power plants
  - a) With pondage
  - b) Without pondage
- Pumped storage power Plants.

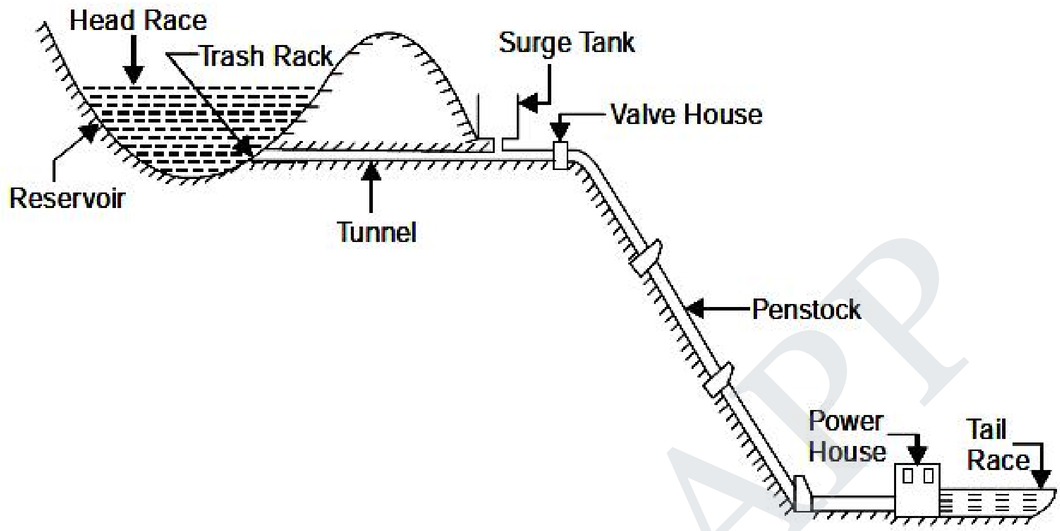
STORAGE PLANTS:

- These plants are usually base load plants.
- The power plant can be classified on the basis of head in the following manner:
  - (a) High head plants: **About 100 m and above**
  - (b) Medium head plants: **About 30 to 100 m**
  - (c) Low head plants: **Upto about 50 m**

High Head Plants:

- The water from the reservoir can be taken to a smaller storage known as a forebay by means of tunnels.

- The function of the forebay is to distribute the water to penstocks leading to turbines. The incoming flow to the forebay is so regulated that the level in the forebay remains nearly constant.
- The turbines will get constant water flow from forebay based on load condition.



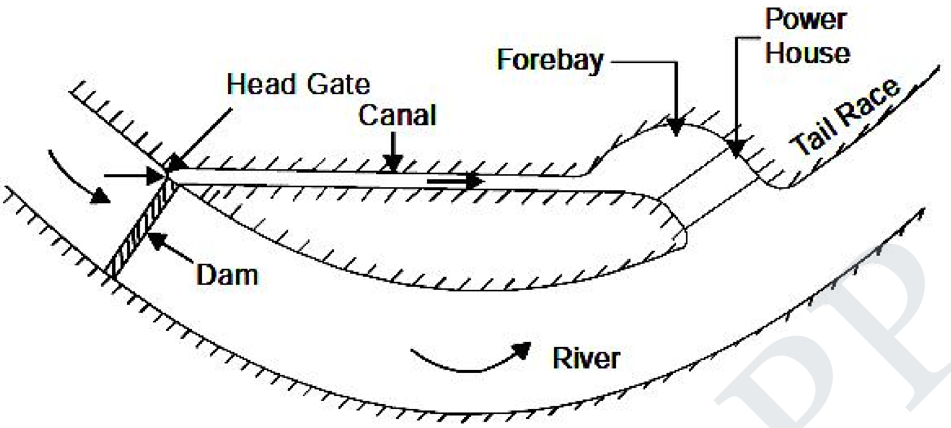
Schematic layout of High head plant

- Trash racks are fitted at the inlets of the tunnels to prevent the foreign matter from going into the tunnels.
- When the construction of forebay is not possible, vertical constructions known as `surge tanks' are built.
- The surge tanks are provided before the valve house and after the tunnel from the head works.
- The function of the surge tank is to prevent a sudden pressure rise in the penstock when the load on the turbines decreases and the inlet valves to the turbines are suddenly closed.
- In the valve house, the butterfly valves or the sluice type valves control the water flow in the penstocks and these valves are electrically driven.
- Gate valves are also there in the power house to control the water flow through the turbines.
- Finally, the water is discharged to the tail race.

Low Head Power Plants:

- These power plants are also known as Canal power plants.
- A dam is built on the river and the water is diverted into a canal.
- At the mouth of the canal, head gates are fitted to control the flow in the canal.
- The canal water is passed into a forebay which is allowed to flow through turbines.
- Screens or Trash-racks are designed in the final stage of forebay to prevent foreign particles into the turbines.
- After this process, the water is again discharged into the river through a tail race.

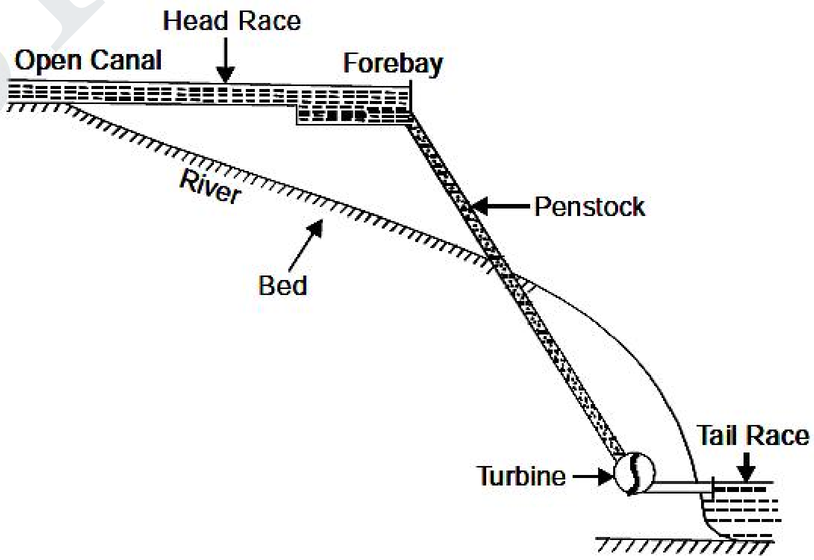
- If there is any excess water due to increased flow in the river or due to decrease of load on the plant, it will flow over the top of the dam and handled down into the river.
- For cleaning and repair of the canal and the forebay, the head gate is closed and the drain gate is opened so that whole of the water is drawn into river.



Low Head hydro power plant

Medium Head Plants:

- If the head of water available is more than 50 metres, then the water from the forebay is conveyed to the turbines through pen-stocks. Such a plant will then be named as a medium head plant.
- In these plants, some amount of the river water is diverted into the canal without the help of dam across the river.
- The canal water is passed into a forebay which is allowed to flow through turbines by means of penstock.
- Screens or Trash-racks are designed in the final stage of forebay to prevent foreign particles into the turbines.
- After this process, the water is again discharged into the river through a tail race.



Medium Head hydro power plant

RUN-OF-RIVER POWER PLANTS:

Run-Off power can be classified as

- ✓ Plants without pondage
- ✓ Plants with pondage.

a) Plants without pondage:

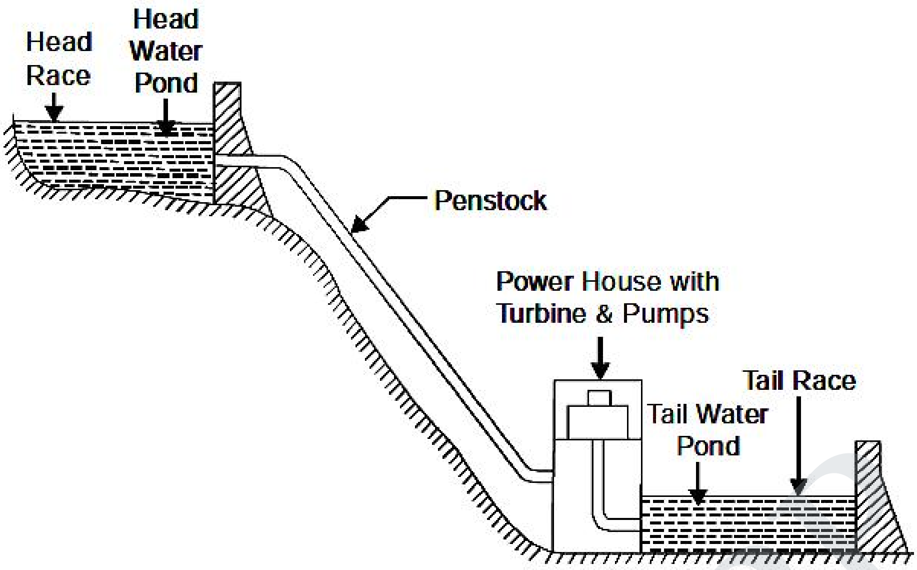
- ➢ A run-off river plant without pondage has no control over river flow and uses the water as it comes.
- ➢ These plants usually supply peak load.
- ➢ During floods, the tail water level may become excessive and so the plant is inoperative.

b) Plants without pondage:

- ➢ A run-of-river plant with pondage may supply base load or peak load power.
- ➢ At high water flow, the plant may be worked under base loaded conditions
- ➢ At low and medium water flow, the plant may be worked under peak loaded conditions

PUMPED STORAGE POWER PLANTS:

- ➢ These plants supply the peak load for the base load power plants and pump all or a portion of their own water supply.
- ➢ The usual construction would be a tail water pond and a head water pond connected through a penstock.
- ➢ The generating pumping plant is at the lower end.
- ➢ During off peak hours, some of the surplus electric energy is being generated by the base load plant.
- ➢ This energy is utilized to pump the water from tail water pond into the head water pond and this energy will be stored there.
- ➢ During times of peak load, this energy will be released by allowing the water to flow from the head water pond through the water turbine of the pumped storage plant.



- Pumped storage plant is nothing but a hydraulic accumulator system and is shown in figure.
- These plants can have either vertical shaft arrangement or horizontal shaft arrangement.
- The latest pumped storage plant uses a Francis turbine which is just the reverse of centrifugal pump.
- When the water flows through it from the head water pond it will act as a turbine and rotate the generator.
- When rotated in the reverse direction by means of an electric motor, it will act as a pump to shunt the water from the tail water pond to the head water pond.
- The efficiency of such a plant is never 100 percent because of some water may evaporate from the head water pond

Advantages of pumped storage plants:

- Peak load capacity of the plant at comparatively low capital cost.
- Due to rated load on the plant, the operating efficiency of the plant is high.
- There is an improvement in the load factor of the plant.
- Load on the hydro-electric plant remains uniform.
- The hydro-electric plant becomes partly independent of the stream flow conditions.

3. Draw and explain the construction and working principle of Pelton turbine.

Introduction:

- Pelton turbine is a commonly used impulse type turbine.
- It is named after an American engineer Lester.A.Pelton who developed this turbine.

- The Pelton wheel is suitable for very high heads and it requires a lesser quantity of water.
- It consists of a runner, buckets, a nozzle, a guide mechanism, a hydraulic brake and casing.

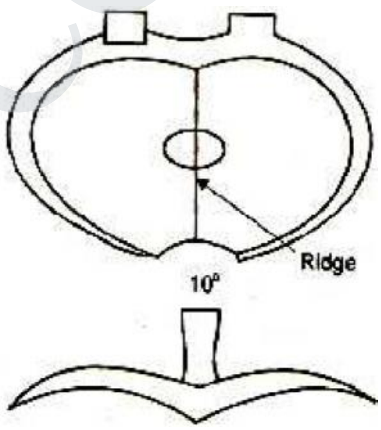
Construction:

Pelton turbine consists of:

A) Runner and buckets
B) Nozzle and guide mechanism
C) Hydraulic brake
D) Casing

a) Runner and Buckets:

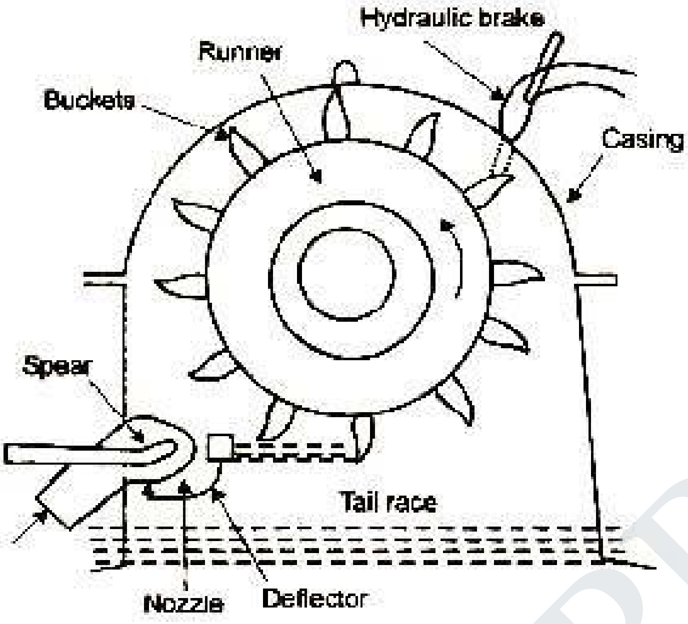
- The runner is a circular disc and consists of a number of semi-ellipsoidal buckets evenly spaced around its periphery.
- The buckets are divided into two hemi-spherical cups by a sharp edged ridge known as a splitter.
- Generally, the buckets are bolted to the periphery of the runner.
- In some cases, the buckets and the wheel are cast integral as one piece in some cases.
- For low heads, the bucket is made of case iron and for high heads, they are made of bronze or stainless steel to withstand heavy impact.



Bucket of pelton wheel

b) Nozzle and Guide mechanism:

- A nozzle is fitted to the end of the penstock near the turbine.
- The nozzle is provided with a conical needle or spear to regulate the quantity of water coming out of the nozzle, thereby control the speed of the runner.
- The spear may be operated manually by a hand wheel or automatically by a governing mechanism.



Pelton Turbine

c) **Hydraulic brake:**

- When the turbine has to be brought to rest by closing the inlet valve of the turbine, the runner generally takes a very long time to come to rest due to its inertia.
- To bring it quickly, a small brake nozzle is provided.
- This nozzle is opened and it directs a jet of water at the back of the buckets.
- This acts as a mechanical brake to bring revolving runner quickly to rest.

d) **Casing:**

- The casing is made up of cast-Iron or fabricated steel plates.
- It is provided for the following purposes:
  - ✓ To prevent splashing of water
  - ✓ To lead the water to the tail race
  - ✓ To act as a safeguard against any accidents

Working principle:

- The water is conveyed to the power house from the head race through penstocks.
- The nozzle is fitted to the end of the penstock (power house end) delivers a high velocity water jet into the bucket.
- One or more jets of water are arranged to interfere on the buckets tangentially.
- The impact of water jet on the bucket causes the wheel to rotate, thus producing mechanical work.

- An electric generator is coupled to the runner shaft and mechanical energy is converted into electrical power.
- After leaving the turbine wheel, water falls into the tail race.
- The Pelton wheel is located above the tail race so that, the buckets do not splash the tail race water.

4. Draw and explain the construction and working principle of Francis turbine.

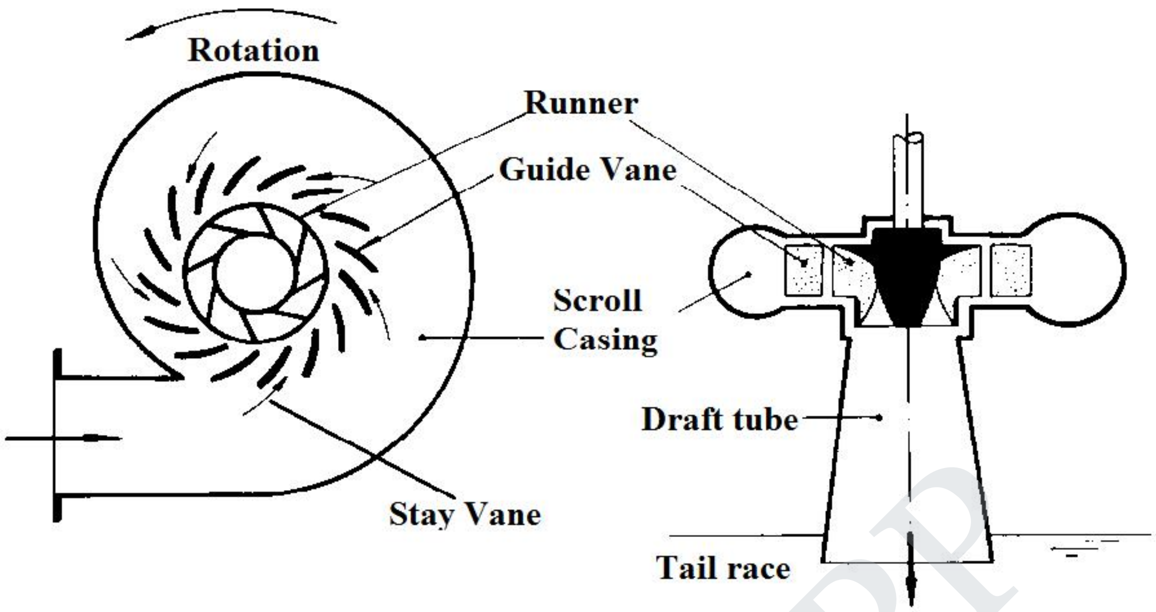
Reaction turbine:

- Reaction turbines operate under pressure of water.
- Only a part of the total head of water is converted into a kinetic energy before it reaches the runner.
- The water completely fills all the passages in the runner (turbine runs full) and flows through the vanes.
- When flowing through the vanes, both the pressure and velocity change. The water leaves the turbine to the tail race at a reduced pressure and velocity.

- Reaction turbines may be:
  a) Radially inward flow turbines
  b) Outward flow turbines
  c) Axial flow turbines
  d) Mixed flow turbines.

Francis Turbine Introduction:

- Francis turbine is one type of Reaction Turbine.
- The modern Francis turbine is a mixed flow type of reaction turbine.
- In this turbine, water enters the runner towards the centre in a radial direction and leaves the runner axially(parallel).
- It operates under medium heads and requires a moderate quantity of water.



(a) Cross sectional view of Scroll casing (b) Francis Turbine

Construction:

Francis turbine consists of:

A) Scroll casing
B) Stay ring(Stay vane)
C) Guide mechanism(Guide vane)
D) Runner
E) Draft tube

a) **Scroll Casing:**

- Water from the penstock is received by a scroll casing.
- The scroll casing (also called spiral casting) surrounds the guide wheel and runner.
- The cross-sectional area of the casing decreases uniformly to distribute the water around the guide ring uniformly.
- The casing is made of welded steel plates or cast steel.

b) **Speed ring or Stay ring:**

- The speed ring or stay ring consists of two rings held together by a series of fixed vanes called stay vanes.
- This ring directs water from the scroll casing to the guide vanes.
- It also transfers the loads (caused by the water pressure, weight of turbine and the weight of the generator) to the foundation.
- It is made of cast iron, cast steel or fabricated plate steel.

c) **Guide mechanism(Guide vane):**

- The guide blades (wicket gates) are fitted between two rings in the form of a wheel known as a guide wheel.

- The guide vanes guide the water to enter tangentially (radially) to the runner blades.
- Each guide vane is pivoted and it can be rotated about its pivot by a system of levers and links.
- This rotation of guide vanes alters the width of the water passage between them.
- The guide vanes are generally made of case steel or stainless steel.

d) Runner:

- The runner consists of series of curved vanes.
- The vanes (16 to 24) are evenly arranged around the circumference in the space between two plates.
- The vanes are properly shaped to receive the water without a shock.
- The runner is set to the shaft which may be vertical or horizontal.
- The runner is made of cast iron for small turbines and it is made of cast steel or stainless steel for large turbines.

e) Draft tube:

- This is a pipe or passage which leads the water exhausted from the turbine into the tail race.
- Its cross-section increases gradually towards the outlet.
- The bottom enlarged end is submerged in a tail race water level.
- It is made of cast steel, welded plate steel or concrete.

Working principle:

- The water from the reservoir is carried to the turbine through penstocks and enters the scroll casing.
- The casing distributes water evenly around the circumference of the turbine runner.
- From the scroll casing, the water passes through the stay ring and this ring directs water to the guide vanes.
- The air foil shape of the guide vanes allows the water to flow smoothly without a shock.
- The water enters the runner with a low velocity and considerable pressure.
- As the water flows through the runner, the direction of flow of waters changed from axial to radial.
- The pressure energy is gradually converted into kinetic energy and the runner is rotated at high speed.
- This high speed produces torque that is transmitted to the generator which is coupled to the runner shaft.

- After passing through the runner water enters the tail race through a draft tube.

5. Draw and explain the construction and working principle of Kaplan turbine?

Introduction:

- The Kaplan turbine works on the principle of reaction turbine.
- It is an axial flow reaction turbine.
- It is suitable for relatively low water head regions.
- It requires a large quantity of water to develop high power.
- It operates in an entirely closed conduct from the head race to the tail race.
- The basic difference between Kaplan turbine and Francis turbine is the **runner blade arrangement**.

Construction:

The main components of a Kaplan turbine are given as:

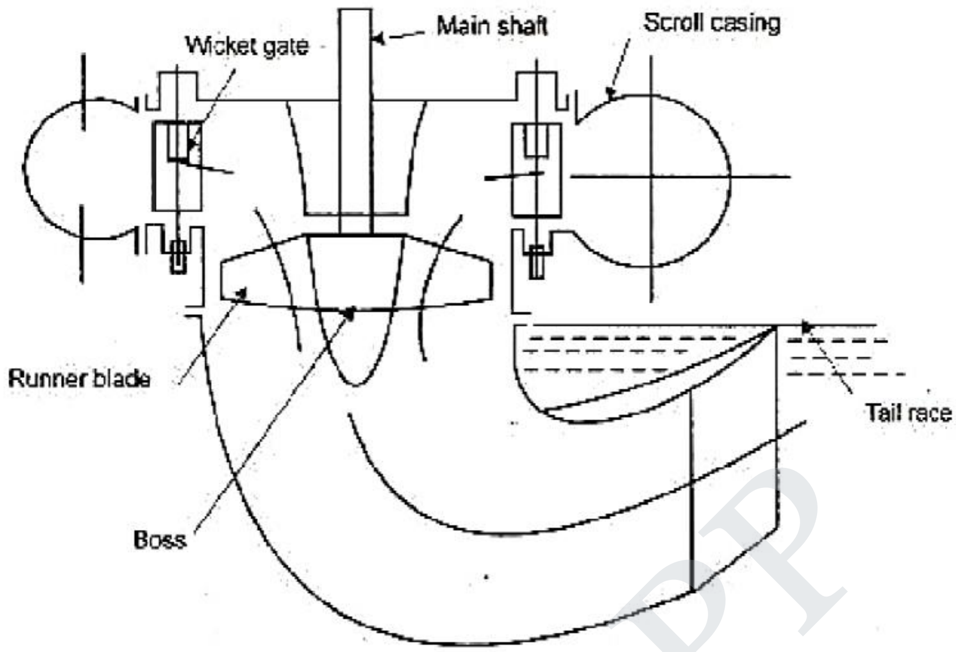
A) Scroll casing
B) Stay ring(Stay vane)
C) Guide mechanism(Guide vane)
D) Runner
E) Draft tube

a) Scroll Casing:

- Water from the penstock is received by a scroll casing.
- The scroll casing (also called spiral casting) surrounds the guide wheel and runner.
- The cross-sectional area of the casing decreases uniformly to distribute the water around the guide ring uniformly.
- The casing is made of welded steel plates or cast steel.

b) Speed ring or Stay ring:

- The speed ring or stay ring consists of two rings held together by a series of fixed vanes called stay vanes.
- This ring directs water from the scroll casing to the guide vanes.
- It also transfers the loads (caused by the water pressure, weight of turbine and the weight of the generator) to the foundation.
- It is made of cast iron, cast steel or fabricated plate steel.



Schematic diagram of Kaplan turbine

c) **Guide mechanism(Guide vane):**

- The guide blades (wicket gates) are fitted between two rings in the form of a wheel known as a guide wheel.
- The guide vanes guide the water to enter tangentially(radially) to the runner blades.
- Each guide vane is pivoted and it can be rotated about its pivot by a system of levers and links.
- This rotation of guide vanes alters the width of the water passage between them.
- The guide vanes are generally made of case steel or stainless steel.

d) **Runner:**

- The runner has 4 to 6 blades attached to a hub or boss.
- It resembles like a ship propeller and hence a Kaplan turbine is a type of propeller turbine.
- The blades are so shaped that water flows axially through the runner.
- The blades of the runner can also be adjusted to any desired angle and the area of flow passage can be varied.
- Both the guide vane angle and runner blade angle may be varied thus results in higher efficiency.
- Even at partial load, when a lower quantity of water is flowing through the turbine high efficiency can be obtained.

e) **Draft tube:**

- This is a pipe or passage which leads the water exhausted from the turbine into the tail race.
- Its cross-section increases gradually towards the outlet.
- The bottom enlarged end is submerged in a tail race water level.
- It is made of cast steel, welded plate steel or concrete.

Working principle:

- The water from the scroll casing flows over the guide vanes.
- It is deflected through 900 between guide vanes and runner.
- The blades are shaped such that water flows axially in the runner and the water flows axially into the runner.
- The force exerted on the blades causes the runner shaft to rotate.
- This rotation is transmitted to the generator which is coupled to the runner shaft.
- The generator produces an electrical power due to rotation(mechanical energy) given by the turbine.
- After passing through the runner, the water enters the tail race through a draft tube.

6. Draw and explain the Wind-Electric Generating power plant.

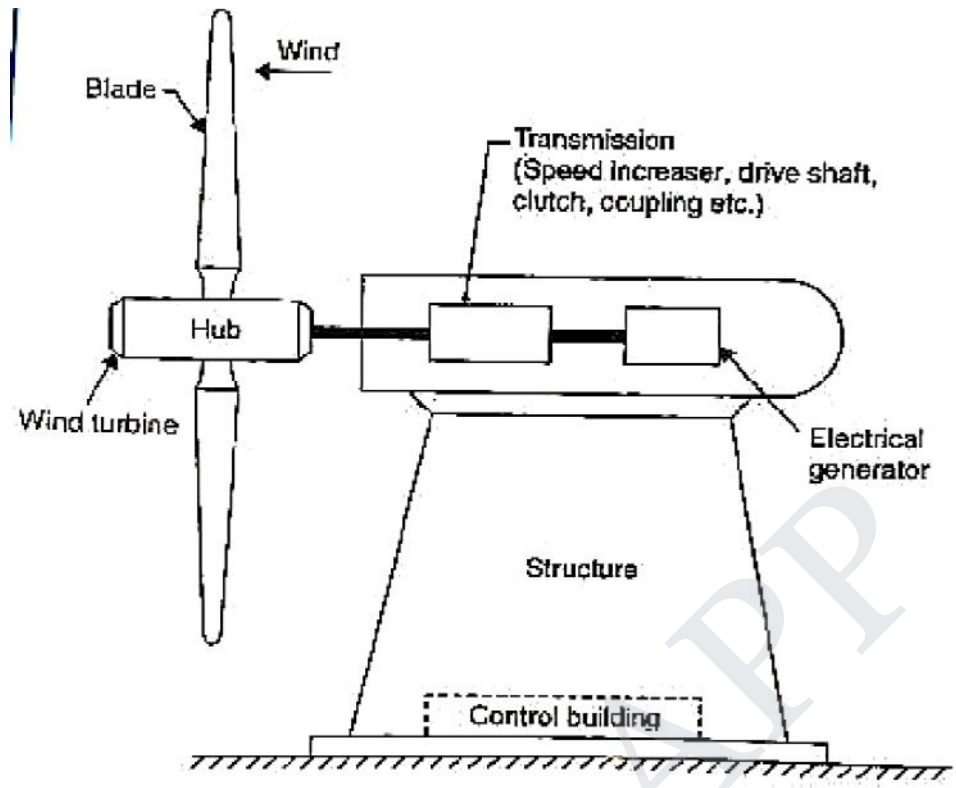
Introduction to wind:

- Wind energy is the potential source of energy.
- Winds are the motion of air caused by uneven heating of the earth surface by the sun and rotation of the earth.
- It generates due to various global phenomena such as air-temperature difference associated with different rates of solar heating.
- The strong winds are created by sharp temperature difference between the land and the sea.
- Wind resources in India are tremendous and so wind power plants are mainly located near the sea coasts.
- Wind machines are also called as an Aero-generators.

Construction of Wind Power plant:

Wind power plant consists of the following essential components:

a) Wind turbine or rotor
b) Wind mill head – it houses speed increaser, drive shaft, coupling, etc.
c) Electric generator
d) Tower



Wind-Electric power plant layout

a) **Wind turbine (or) wind Rotor:**

- The wind turbine is a rotating part which consists of center shaft and rotor blades.
- There are two types of forces operating on the blades of wind turbine such as circumferential force and axial force.
- The Circumferential forces in the direction of wheel rotation that provide the torque.
- The axial forces in the direction of the wind stream that provide an axial push that must be neutralized by proper mechanical design.
- The wind turbine may be located either unwind or downwind of the power.
- In unwind rotors, the wind encounters the turbine blades before reaching the tower.
- In downwind rotors, the wind encounters the tower before reaching the turbine blades.

b) **Wind mill head:**

- Wind mill head is facilitated by mounting it on the top of the supporting structure on suitable bearings.
- The wind mill head performs the following functions:
    - ✓ It supports the rotor housing and the rotor bearings.
    - ✓ It also houses any control mechanism like changing the pitch of the blades for safety devices.
    - ✓ It changes the position of tail vane to set the rotor in wind direction.

c) Electric Generator:

- The generator is coupled with the wind turbine shaft.
- When the turbine rotates, it also rotates the generator shaft by means of mechanical force.
- By the generator principle, the mechanical force is converted into an electrical energy.

d) Tower:

- Tower is the supporting structure which is designed to withstand the wind load.
- Its type and height is related to cost and transmission system incorporated.
- Horizontal axis wind turbines are mounted on towers so as to be above the level of instability and other ground related effects.

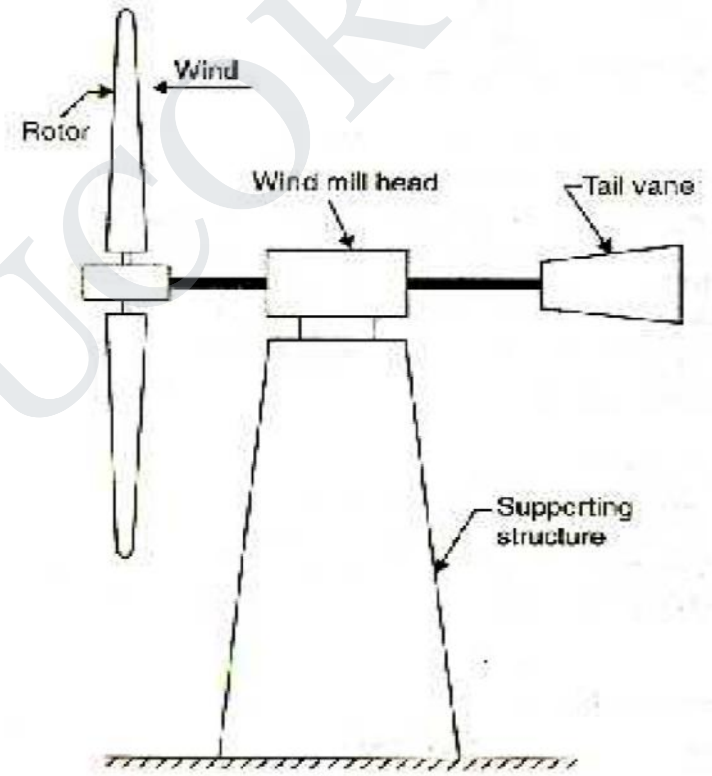
Types of Wind Machines:

Wind machines (aero-generators) are generally classified as follows:

a) Horizontal axis wind machines.

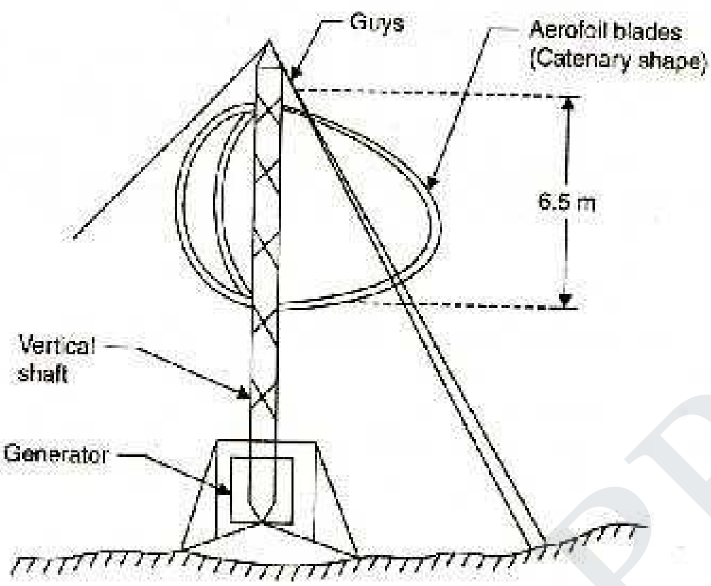
b) Vertical axis wind machines.

Horizontal axis wind machines:



- The common wind turbine with horizontal axis is simple in principle.
- Especially a large one that would produce electric power economically but the design of a complete system is complex.
- It is of primary importance that the components like rotor, transmission, generator and tower should not only be as efficient as possible but they must also function effectively in combination.

Vertical axis wind machines:



- One of the main advantages of vertical axis rotors is that they do not have to be turned into the wind stream as the wind direction changes.
- Because their operation is independent of wind direction, vertical axis machine are called **Panemones**.

7. Explain the construction and working principle of Tidal power plants.

Introduction:

- Tide or wave is periodic rise and fall of water level of the sea.
- Tides occur due to the attraction of sea water by the moon.
- Tides contain large amount of potential energy which is used for power generation.
- When the water is above the mean sea level, it is called flood tide or High tide.
- When the water level is below the mean level it is called ebb tide or Low tide.

Principle:

Tidal energy is a form of hydropower that converts the energy of tides into useful forms of power such as electricity. This conversion is achieved by means of turbine coupled with an electric generator.

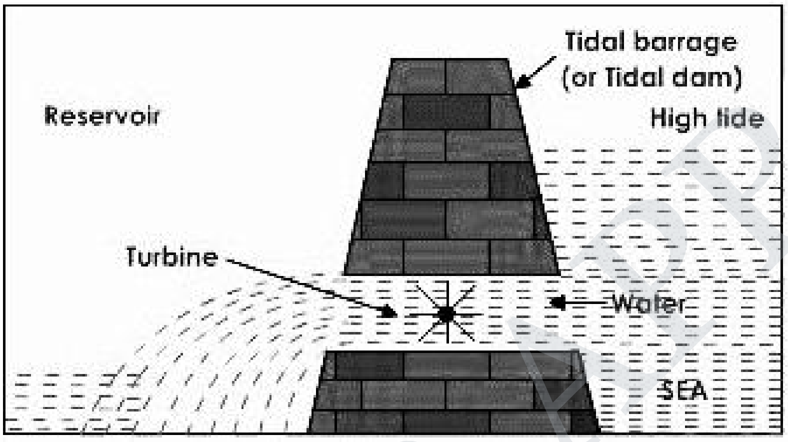
Construction:

- A dam is constructed in the sea for separating the water reservoir (water basin) from the sea
- The dam consists of power house which holds Turbine and electric generator for Power generation.
- The ocean tides rise and fall depends on the attraction of sea with the moon.
- During high tide, water from the sea can be stored in the water reservoir.

- During low tide, the stored water from the water reservoir is flowed into the sea which rotates turbine in the dam.
- A difference in water level is obtained between the basin and sea and the arrangement of the system is shown in figure.

Working:

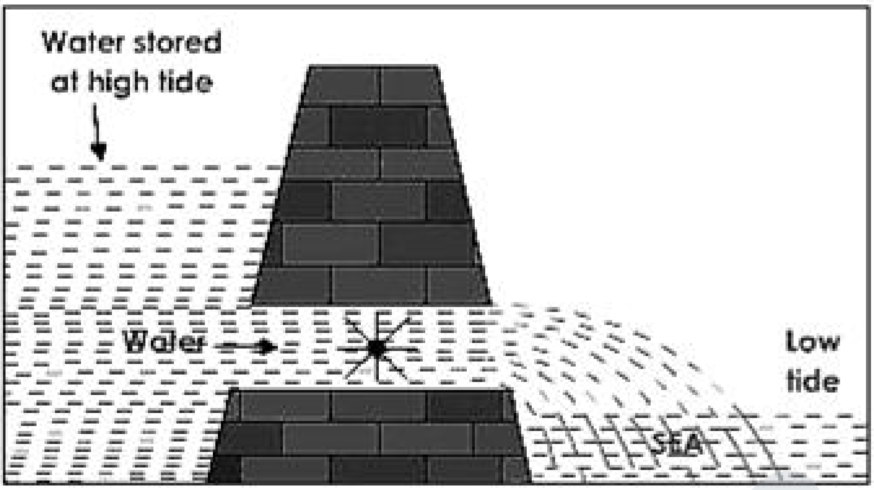
High tide duration:



High Tide: water from Sea to Reservoir

- During high tide period, the height of tide is above that of water level in the reservoir.
- So the water flows from the sea into the water reservoir through the water turbine.
- During the water flow from sea to reservoir, the turbine unit in the dam rotates due to speed of the water flow.
- When the turbine rotates, the generator coupled with turbine shaft is also rotates due to mechanical force on the turbine shaft.
- Then the generator produces electrical energy(power) from the mechanical energy given by the turbine.

Low tide duration:



ow Tide: water from Reservoir to Sea

- During low tide period, the height of tide is below that of water level in the reservoir.
- So the water flows from the water reservoir into the sea through the water turbine.
- During the water flow from reservoir to sea, the turbine unit in the dam rotates due to speed of the water flow.
- When the turbine rotates, the generator coupled with turbine shaft is also rotates due to mechanical force on the turbine shaft.
- Then the generator produces electrical energy(power) from the mechanical energy given by the turbine

The generation of power stops only when the sea level and the tidal basin level are equal. For the generation of power economically using this source of energy requires some minimum tide height and suitable site. Kislaya power plant of 250 MW capacity in Russia and Rance power plant in France are the only examples of this type of power plant.

Classification of Tidal power plant:

The tidal power plants are generally classified on the basis of the number of basins used for the power generation. The classification of Tidal power Plants are:

- Single basin - one way cycle
- Single basin - two way cycle
- Single basin - two way cycle with pump storage
- Double basin type
- Double basin with pump storage

Advantages of tidal power plants:

- It is free from pollution as it does not use any fuel.

- It is superior to hydro-power plant as it is totally independent of rain.
- It improves the possibility of fish farming in the tidal basins

Disadvantages:

- Tidal power plants can be developed only if natural sites are available on the bay.
- Transmission cost and transmission losses are high due to long distance from cities.
- The supply of power is not continuous as it depends upon the timing of tides.
- Utilization of tidal energy on small scale is not economical.

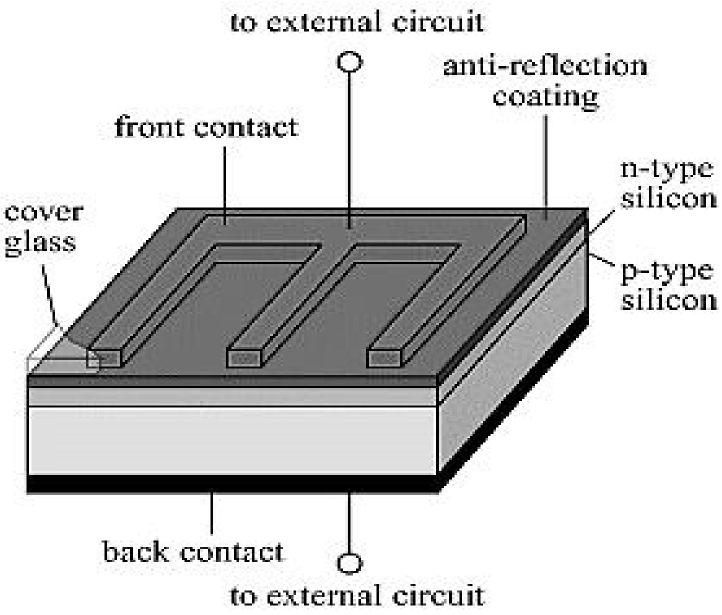
8. Explain the construction and working of solar photovoltaic cell with the neat diagram. (or) Explain the construction and working of PV cell with the neat diagram.

Introduction:

- A solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into electricity.
- It works on the principle of by the photovoltaic effect.
- It is a form of photoelectric cell which is a device whose electrical characteristics such as current, voltage, or resistance, vary when exposed to light.
- Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.
- Solar cells are being photovoltaic irrespective of whether the source is sunlight or an artificial light.

Basic principle of PV cell:

Photovoltaic effect is the process in which two dissimilar materials are in close contact produce an electrical voltage when it is exposed to light or other radiant energy. It is a physical and chemical phenomenon.



Construction of PV cell:

- Solar cells are always made up of crystalline silicon which is a semiconductor material.
- Solar cell consists of n-type semiconductor (emitter) layer and p-type semiconductor layer (base).
- The two layers of different semiconductors are joined to form a connection called as p-n junction.
- The surface is coated with anti-refection coating to avoid the loss of incident light energy due to reflection.
- There is a transparent gum layer over the anti-reflection coating to absorb the solar radiations.
- The front and back contact is used to transfer the produced electric field to the external circuit.
- The photovoltaic cell requires 3 basic characteristics:
    - ✓ The absorption of light for generating either electron hole pair or excitons.
    - ✓ The separation of charge carriers of opposite types.
    - ✓ The separate extraction of those carriers to an external circuit.

Operation of Photovoltaic cell:

- When light falls on the photovoltaic cell, the absorption of photons from the solar radiations occurs.
- By the absorption of photons, the free electrons in n-type is excited and tries to acquire holes in p-type silicon.
- The electron and holes are diffuse across the p-n junction and there is a formation of electron-hole pair.
- As electron continuous to diffuse, more electrons build on n-type side and positive charge build on p-type side.
- The accumulation of similar charged particles near p-n junction creates the region called the depletion region.

- This weak region cannot allow the formation of an electron hole pair near to p-n junction.
- When the PN junction is connected with external circuit by using front and back contact in the photovoltaic cell.
- The free electrons flow through an electrical circuit to acquire holes in p-type silicon and process an electric field.
- The electric field in the circuit operates a load connected in the external circuit by means of flow of current.

Types of Photovoltaic Solar Cell:

There are 4 types of PV cells according to their manufacturing technology:

a.)Single or Mono-Crystalline Cell:

Mono-crystalline cells which are made of pure silicon surface and a thin structure are known to have high efficiency. Examples: Si (Silicon) and Gallium Arsenide (GaAS).

b.) Polycrystalline PV cell:

It has a crystalline structure. It has a manufacturing technology in the form of a thin film. Efficiency is not more than 10%. Examples: Cadmium telluride (CdTe) or Copper indium di-selenide (CIS).

c.) Amorphous silicon PV cell:

It has a non-crystalline structure. Rate of efficiency is not very high. It is used in small devices such as calculators and digital dictionaries.

d.) Hybrid Solar Cell:

Organic and chemical substances are used together in its structure. Even though it has quite a high rate of energy efficiency, it is not yet used in industries.

Advantages of photovoltaic cells:

- It is clean and non-polluting
- Solar cells do not produce noise and they are totally silent operation.
- They require very little maintenance
- They are renewable sources of energy which can be used almost anywhere
- They have long life time
- There are no fuel costs or fuel supply problems

Limitations of photovoltaic cells:

- Soar power cannot be obtained in night time.
- Solar panels are very expensive.
- Energy has not be stored in batteries.
- Air pollution and weather can affect the production of electricity.

Applications of photovoltaic cells:

- Rural electrification Hybrid system

- Water pumping
- Communication stations
- Street lighting

9. Explain the construction and working principle of Solar thermal power plant?

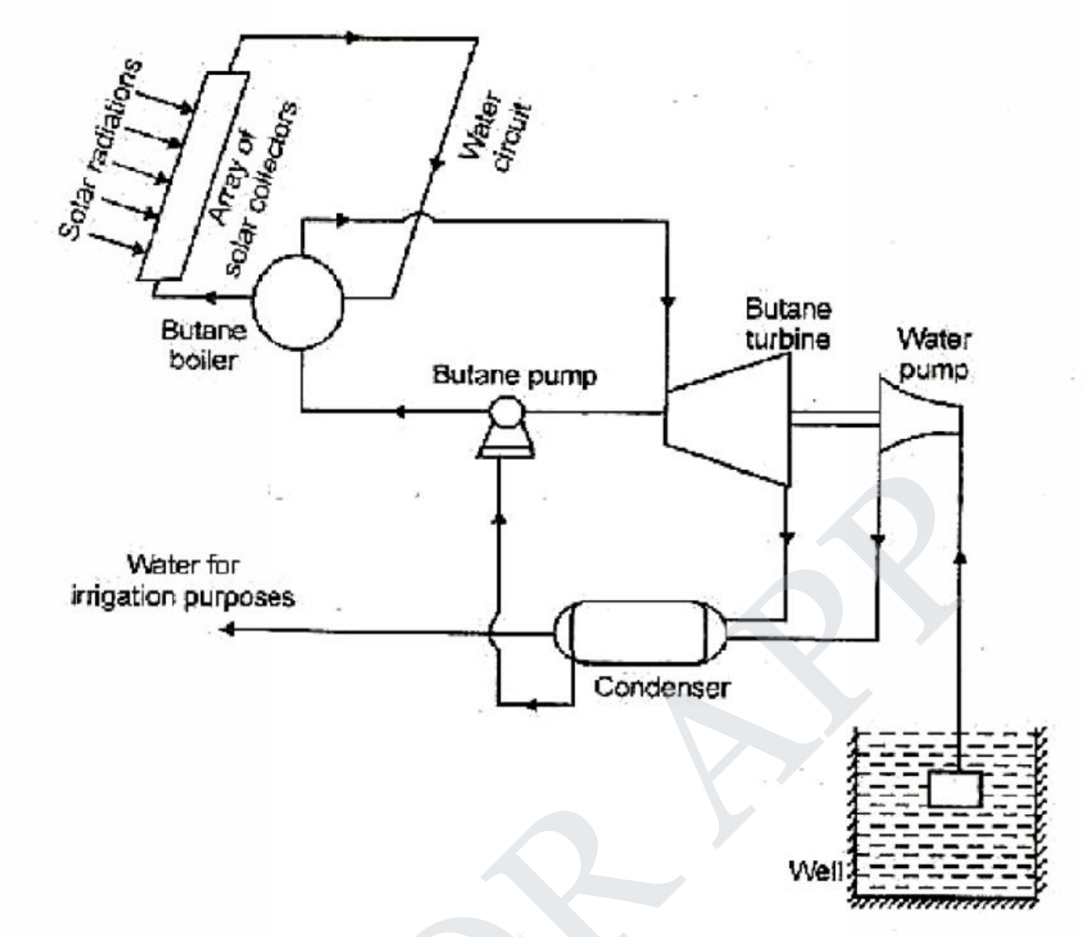
Introduction:

- Solar thermal technology is not the same as solar panel or photovoltaic technology. Solar thermal electric energy generation concentrates the light from the sun to create heat.
- The heat is used to run a heat engine, which turns a generator to make electricity. The working fluid that is heated by the concentrated sunlight can be a liquid or a gas.
- Different working fluids include water, oil, salts, air, nitrogen, helium, etc.
- Different engine types include steam engines, gas turbines, etc.
- All of these engines can be quite efficient and are capable of producing 10 to 100 megawatts of power

Construction of solar thermal Power plant:

Solar thermal power plant consists of the following essential components:

a) Solar collectors
   - ✓ Flat plate collector
   - ✓ Cylindrical parabolic concentrator collector
   - ✓ Solar tower system
b) Butane boiler
c) Turbine
d) Generator



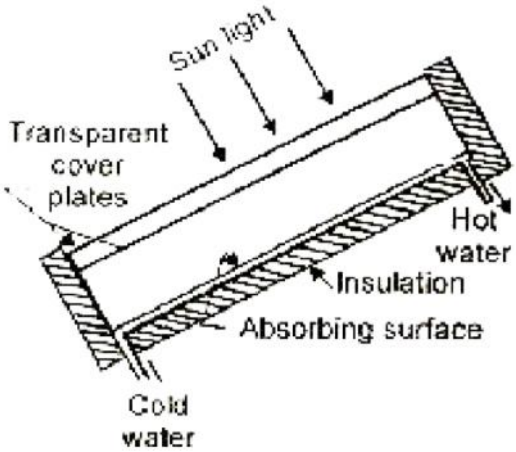
Layout of Solar thermal power plant

A) <u>Solar collectors:</u>

- Solar collector is an equipment which receives the solar radiation from the sun.
- It gains heat from the radiation and transferred the heat to the water in the absorber tube.
- There are two different types of solar collectors:
  - ✓ Flat plate collector
  - ✓ Cylindrical parabolic concentrator collector
  - ✓ Solar tower system

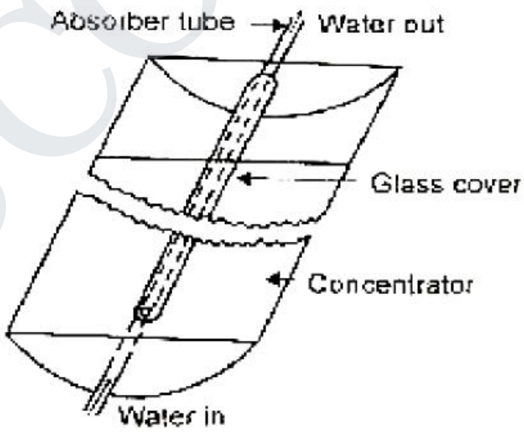
<u>Flat plate collector:</u>

- In a flat plate collector, the radiation energy of the sun falls on a flat surface coated with black paint having high absorbing capacity.
- It is placed facing the direction of the sun.



- The materials used for the plate may be copper, steel or aluminium.
- Copper tubes is provided in thermal contact with the plate.
- Heat is transferred from the absorbed plate to water which is circulated in the copper tubes.
- Thermal insulation is provided behind the absorber plate to prevent heat losses from the rear surface.
- Insulating material is generally fibre glass or mineral wool.
- The front cover is made up of glass and it is transparent to the incoming solar radiations.

Cylindrical parabolic concentrator collector:



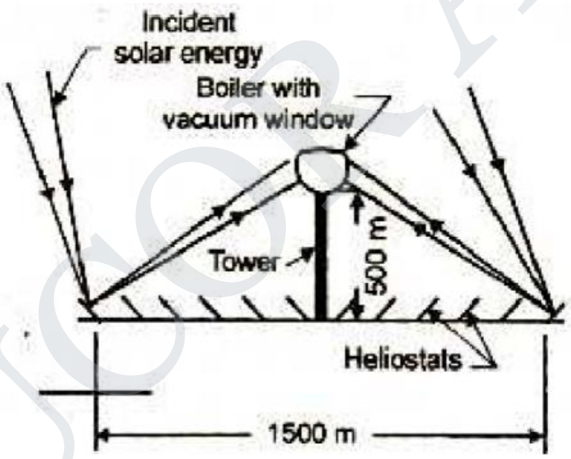
Cylindrical parabolic concentrator collector

- Concentrator collectors are of reflecting type utilizing mirrors.
- The reflecting surface may be parabolic mirror.
- The solar energy falling on the collector surface is reflected and focused along a line where the absorber tube is located.
- As large quantity of energy falling on the collector surface is collected over a small surface.
- Heat is transferred from the absorbed tube to water which is circulated in the copper tubes.

- The temperature of the absorber fluid is very much higher than in flat plate collector.
- This type of collectors are designed to heat water to medium and high temperature ranges.

Solar Tower system:

- The tower concept consists of an array of plane mirrors or heliostats.
- The plane mirrors are individually controlled to reflect radiations from the sun into a boiler
- The boiler is placed on a 500 metres supporting structure named as Tower. Steam in generated in the boiler, which may attain a temperature upto 2000 K.
- Then the steam is used to rotate the turbine which inturn rotates the generator
- Electricity is generated by passing steam through the turbine coupled to a generator.



Tower concept for power generation

B) **Butane boiler:**

- The vessel used for heating is normally called as Boiler.
- For solar power plant, the butane gas is used as burning fuel because of its low boiling point.
- Boiling point of butane is about 500C.
- The water heated in solar collector to 800 C is used for boiling butane at high pressure in the butane boiler.

C) Turbine and Generator:

- A turbine is a mechanical device which converts the kinetic energy at blades into rotating energy in the shaft.
- The butane vapour generated at high pressure in the boiler is used to run the vapour turbine

- The rotation of turbine also drives the electrical generator due to coupling between turbine and generator.
- By the generator principle, this rotational energy is converted into an electrical energy.
- The vapour coming out of the turbine at low pressure is condensed in a condenser using water.
- The condensed liquid butane is fed back to the butane boiler using feed pump.

Advantages of solar thermal power plant:

- Solar energy is a very large inexhaustible and renewable source of energy
- It is environmentally very clean and hence pollution-free.
- It is a dependable energy source without new requirements of a highly technical design.
- It is the best alternative for the rapid depletion of fossil fuels.

Disadvantages of solar thermal power plant:

- Very large collecting area are required.
- Capital cost is more for the solar plant.
- Solar energy is not available at night or during rainy days.

Applications of Solar thermal power plant:

- Solar engines for pumping
- Solar water heaters
- Solar cookers
- Solar driers
- Solar furnaces
- Solar power generation

10. Explain the construction and working principle of geothermal power plant? (or) Explain the layout of Power plant which uses geothermal energy as source.

Introduction:

- Geothermal energy is energy that is an intensive heat continuously flows outward from deep within the Earth.
- Word "geothermal" has its roots in two Greek words, "geo" means Earth and "thermal" means heat.
- This energy is mainly generated from Earth's core since temperature of Earth's center is reaching temperatures above 6000 degrees Celsius which is even hot enough to melt a rock.

Principle:

The heat energy is extracted from the deep of the earth is converted into electrical energy by means of Thermal process.

Construction of Geothermal plant:

Geothermal power plant consists of the following essential components:

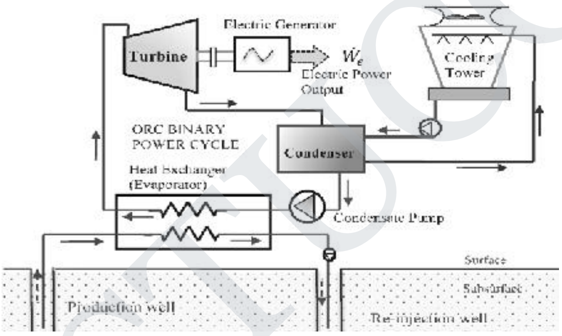
a) Steam well
b) Heat Exchanger
c) Turbine
d) Generator
e) Condenser

Steam well(Production well and Re-injection well):

- Pipes are embedded for pouring cooled water at the places of subsurface of an earth with high temperature called steam wells.
- By sending water through embedded pipes, the water is converted into hot water due to high temperature.
- The hot water is extracted from the subsurface of earth by using another wall named as Production well.

Heat exchanger(Evaporator):

- Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other.
- The steam heat is transferred to cooled water in the heat exchanger for power generation process
-



Turbine:

- A turbine is a turbo-machine with at least one moving part called a rotor assembly,

- The rotor may be shaft or drum which are provided with rotating blades .
- Moving fluid acts on the blades so that they move and communicate rotational energy to the rotor.
- The steam from the heat exchanger is passed through the turbine which in turn rotates the turbine.

Generator:

- Generator is an electrical machine which converts the mechanical energy into an electrical energy.
- The generator starts rotating due to coupling between turbine and generator and produces an electricity.

Condenser:

- Condenser is a device used to shrink a substance from its gaseous to its liquid state by cooling it.
- The exhaust steam from the turbine is condensed, so the steam is converted into water.
- The condensed water is pumped into the earth to absorb the ground heat again and to get converted into steam.

Working:

- The cold water is injected to subsurface of the earth by using Injection well.
- The water is converted into hot water due to high temperature at the subsurface of earth.
- From the production well the hot water is extracted, the hot water is converted into steam at the surface of earth.
- The steam is then circulated to the heat exchangers.
- The steam heat is transferred to the cooled water in the heat exchanger and then the water is converted into super-heated steam.
- The super-heated steam is used to drive the turbine.
- The turbine rotates the electric generator which is already coupled with the turbine shaft.
- The generator converts the mechanical force into an electrical power(electricity).
- At the same time, the steam coming out from the turbine reaches the condenser.
- The condenser converts steam into hot water and it is cooled down through the cooling towers.
- The cooled water is again injected into the subsurface of the earth to get the heat again for the next power generation process.

Advantages of Geothermal Power Plant:

- Geothermal energy is a renewable energy resource.
- It is non-polluting and environment friendly.
- There is no wastage or generation of by-products.
- Geothermal energy can be used directly.
- Maintenance cost of geothermal power plants is very less.
- Geothermal power plants requires less space.
- Unlike solar plants, it is not dependent on the weather conditions.

Disadvantages of Geothermal Power Plant:

- Geothermal power plants are far from cities and difficult to consume power.
- Total power generation of this source is too small.
- There is always a danger of eruption of volcano.
- Installation cost of steam power plant is very high.
- It may release some harmful, poisonous gases that can escape through the holes drilled during construction.

11. Explain in detail about the Biogas power plant with its construction and operation. (or) Describe the bio-conversion processes involved in the biomass energy applications.

BIO-CONVERSION PROCESS

There are mainly three aerobic and anaerobic bio-conversion process for the biomass energy applications: There are:

(i) Bio-products:

The conversion of biomass into chemicals for making products that are made from petroleum-based products.

(ii) Biofuels:

The conversion of biomass into liquid fuels for transportation is called as Biofuel. For transportation, the common types of biofuels are Ethanol, Biodiesel and Methanol.

(iii) Bio-power:

Burning biomass directly or indirectly converted into a gaseous fuel or oil to generate electricity. There are six major types of bio-power systems:

- Fermentation
- Direct fired system
- Co-firing system
- Gasification system
- Pyrolysis
- Small modular system

Biogas Introduction:

- Biogas is a good renewable energy resource.
- Biogas refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen.
- It can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste.
- The constituents involved in biogas are given as:

Gas	%
Methane (CH_4)	55 – 70
Carbon dioxide (CO_2)	30 – 45
Hydrogen sulphide (H_2S)	1 – 2
Hydrogen (H_2)	1 – 2
Ammonia (NH_3)	1 – 2
Carbon monoxide (CO)	trace
Nitrogen (N_2)	trace
Oxygen (O_2)	trace

Properties of Biogas:

- Comparatively simple and can be produced easily.
- Burns without smoke and without leaving ash as residues.
- Household wastes and bio-wastes can be disposed in suitable manner.
- Reduces the use of wood and to a certain extent prevents deforestation.
- The slurry from the biogas plant is used as fertilizer.

Basic principle of Biogas energy:

- The process of organic degradation without oxygen is called as Fermentation.
- It is the process of degradation of the organic substances using the micro-organisms also known as anaerobe (or) anaerobic digestion. It converts the solid biomass into a gas called Biogas.

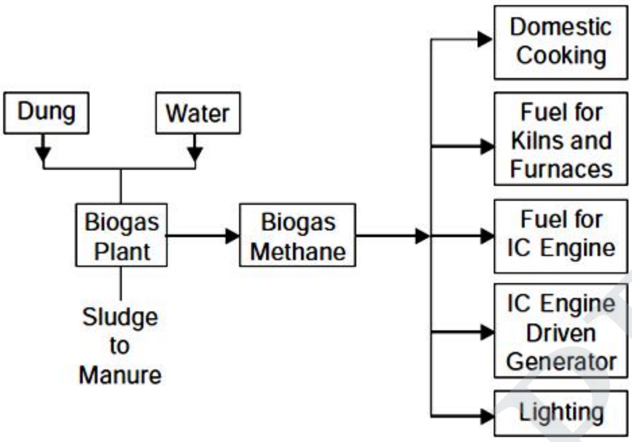
Raw materials for Biogas plant:

The biomass used as a raw material can be classified into the following categories:

Wastes	***Cultivated and Harvested***
Agricultural wastes	Agricultural energy crops
Rural animal wastes	Aquatic crops
Wastes from Poultry	Forest crops
Urban waste (garbage)	
Aquatic wastes	
Forest wastes	
Coconut husk waste	
Industrial wastes	

Parts of Biogas plant:

- The tank where biomass undergoes decomposition (digester)
- The tank where biomass is mixed with water (mixing tank)
- The tank where slurry of biomass is collected (out flow tank)
- Arrangement to store gas.



Energy route for Biogas power plant

Classification of Biogas plant:

Biogas plants are classified into following main types:

- Continuous type or batch type
    a) Single stage continuous type Biogas plant
    b) Two state continuous type Biogas plant
- Dome type
    a) Fixed dome type
    b) Floating gas type (or) Drum type

Continuous type (or) Batch type Biogas plant:

- Continuous type biogas plant delivers the biogas continuously and is fed with the biomass regularly.
- It delivers gas intermittently and dis-continuously.
- It may have several digesters which are operated in a sequential manner to obtain the biogas continuously.
- It have longer digestion time.
- It needs initial seeding to start the anaerobic fermentation.
- It needs larger volume of the digester and hence initial cost is higher.
- Operation and maintenance is more complex for batch type biogas plant.

(A) Single stage continuous type Biogas plant:

- In such a plant acid formation and methane formation are carried out in the same chamber without barrier.
- Such plants are simple, economical, easy to operate and control.
- These plants are generally preferred for small and medium size biogas plants.

- Single stage plants have lesser rate of gas production than the two stage plant.

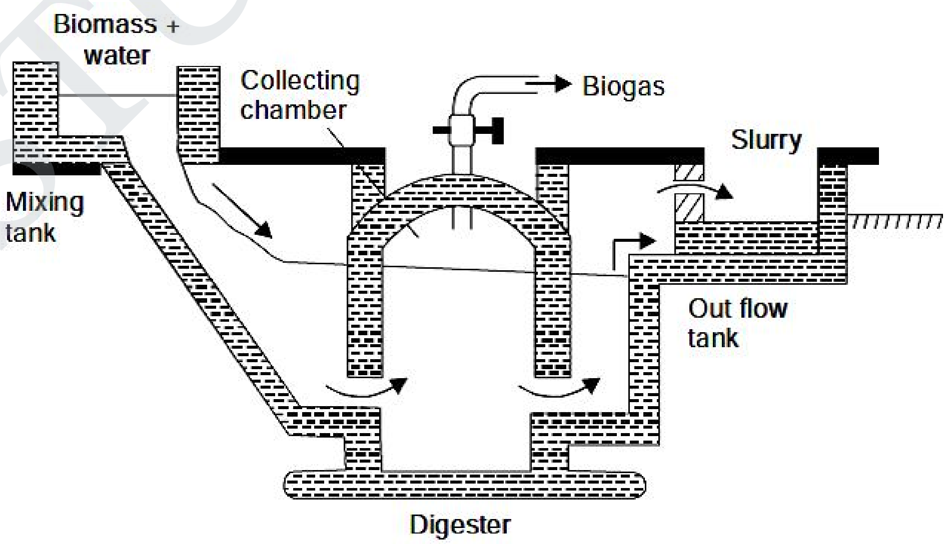
(B) Two state continuous type Biogas plant:

- In such a plant the acid formation and methane formation take place in separate chambers.
- The plant produces more biogas in the given time than the single stage plant.
- The process is complex and the plant is costlier, difficult to operate and maintain.
- Two stage plant is preferred for larger biogas plant systems.

<u>Dome type Biogas plant:</u>

(a) <u>Fixed dome type:</u>

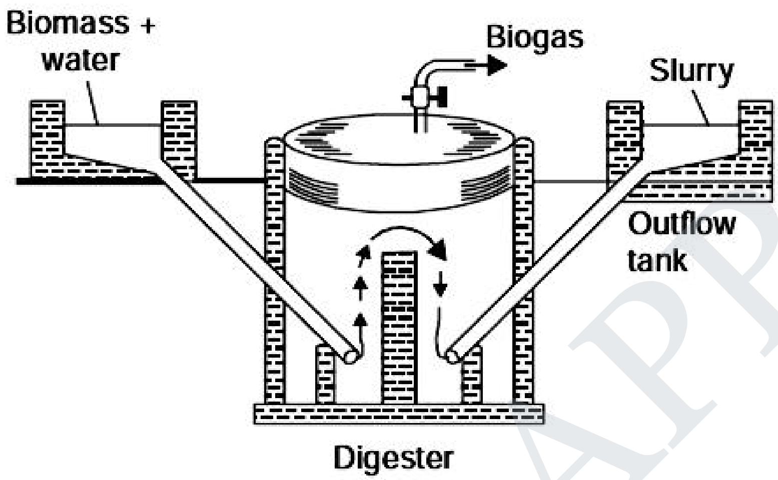
- In the fixed dome type digester biogas plant, the digester and gas-collector (gas dome) are enclosed in the same chamber.
- The digester is conveniently built at or below ground level in comparatively cooler zone.
- The pressure inside the digester increases as the biogas is liberated.
- The biogas gets collected in the upper portion of the digester in a dome shaped cavity.
- The outlet pipe is provided at the top of the fixed dome.
- Alternatively the gas collector (gas holder) is a separately installed chamber.
- The digester tank and gas collector chamber are separated by a water seal tank.
- An additional displacement chamber may be provided for providing space to the displacement slurry in the digester due to gas pressure in the upper dome.
- The excess slurry in the digester gets accommodated in the displacement chamber.



(b) <u>Floating Gas Holder Type:</u>

- In this design a dome made floats above the slurry in the disaster.
- The disaster tank is of cylindrical masonry construction.

- The floating dome is of fabricated steel construction.
- The dome guide shaft provides the axial guide to the floating dome and the gas is collected in it.
- The gas generated in the slurry gets collected in the dome and the dome rises.
- The water seal tank provides separation between the gas in the dome and the outlet gas.



- In this type, the cylinder rises up as the gas fills the tank and the storage capacity increases.
- Residue of biomass (slurry) can be used as good manure.

<u>Advantages of Biogas plant:</u>

- Provides a non-polluting and renewable source of energy.
- Efficient way of energy conversion.
- Wastes from this plant are used as fertilizers.
- Provides a source for decentralized power generation.
- Leads to employment generation in the rural areas.
- Household wastes and bio-wastes can be disposed in useful manner.
- The technology is cheaper and much simpler than those for other bio-fuels, and it is ideal for small scale application.
- Biogas plants significantly lower the greenhouse effects on the earth's atmosphere.

<u>Disadvantages of Biogas plant:</u>

- The process is not very attractive economically as compared to other biofuels.
- It is very difficult to enhance the efficiency of biogas systems.
- Biogas contains some gases as impurities which are corrosive to engine metal parts.
- Not feasible to locate at all the locations.

Applications of Biogas plant:

- Biogas is used as a fuel
- Slurry from plant is used as Fertilizers
- Additive fuel in vehicles to reduce toxic emissions
- Biogas is used for an electric power generation

12. Write a short notes of Fuel cell with Schematic diagram?

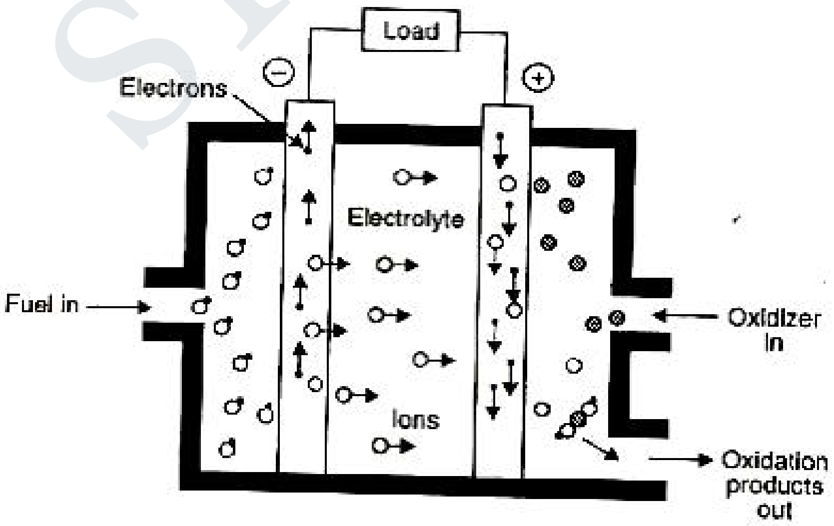
Introduction:

- A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent.
- Of the available fuels, hydrogen gas is mostly used as fuel.
- Cells consuming coal, oil or natural gas would be economically much more useful for large scale applications.
- Some of the possible reactions for different fuels are:

Fuel used	Output in Volts	Chemical reaction	Oxidation product
Hydrogen/oxygen	1.23 V	$2H_2 + O_2 \rightarrow 2H_2O$	Water
Hydrazine	1.56 V	$N_2H_4 + O_2 \rightarrow 2H_2O + N_2$	Water and Nitrogen
Carbon (coal)	1.02 V	$C + O_2 \rightarrow CO_2$	Carbon-di-oxide
Methane	1.05 V	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	Water and carbon-di-oxide

Principle:

The chemical energy of a conventional fuel is converted directly and efficiently into low value of direct-current electrical energy by the oxidation process.



Schematic diagram of a fuel cell

Working:

- A fuel cell is often described as primary battery.
- The fuel is supplied from external to the anode of the fuel cell as needed.
- The oxidizer is supplied from external to the cathode of the fuel cell as needed.
- The fuel gas diffuses through the anode and is oxidized, thus releasing electrons to the external circuit.
- The oxidizer diffuses through the cathode is combined with the Hydrogen ions from the anode and produces some oxidation products.
- The transfer of electrons from anode to cathode gives supply to the small load connected in the fuel cell.
- The flow of electrons through the load has the value of low voltage from 1.0 to 2.0 volt.

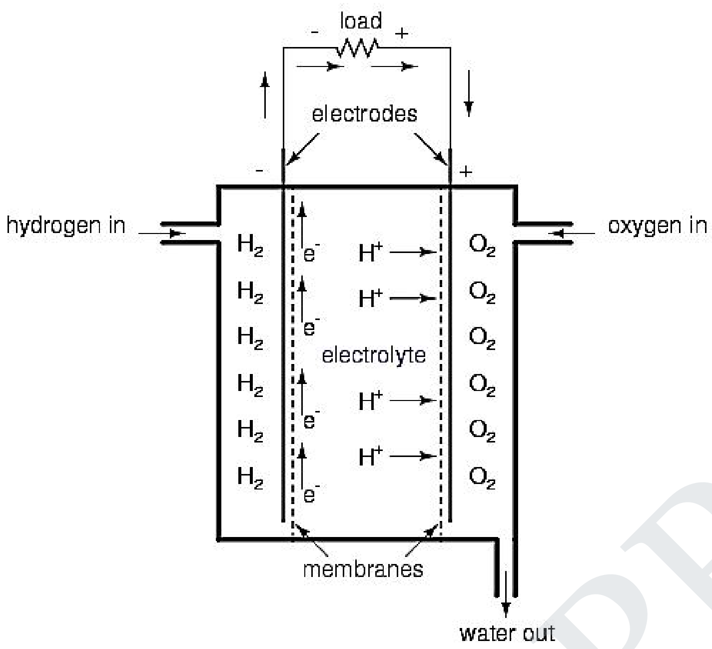
Contruction:

Hydrogen-oxygen cell :

- The hydrogen-oxygen fuel cell has three chambers separated by two porous electrodes, the anode and the cathode.
- The middle chamber between the electrodes is filled with a strong solution of potassium hydroxide as electrolyte.
- The surfaces of the electrodes are chemically treated to repel the electrolyte, so that there is minimum leakage of potassium hydroxide into the outer chambers.
- The gases diffuse through the electrodes, undergoing reactions are show below:

Electrolyte:	$4KOH \rightarrow 4K^{+} + (OH)^{-}$
Anode:	$2H_2 + 4\,(OH)^{-} \rightarrow 4H_2O + 4e^{-}$
Cathode:	$O_2 + 2H_2O + 4e^{-} \rightarrow 4\,(OH)^{-}$
Cell reaction:	$2H_2 + O_2 \rightarrow 2H_2O$

- The water formed is drawn off from the side.
- The electrolyte provides the (OH)- ions needed for the reaction and remains unchanged at the end, since these ions are regenerated.



- The electrons liberated at the anode find their way to the cathode through the external circuit.
- This transfer is equivalent to the flow of a current from the cathode to the anode.
- Such cells when properly designed and operated have an open circuit voltage of about 1.1 volt. Unfortunately, their life is limited since the water formed continuously dilutes the electrolyte.
- Fuel efficiencies as high as 60%-70% may be obtained.

Advantages of Fuel cell:

- A fuel cell is less complicated than a conventional gas or diesel engine.
- It is not involved to high temperatures for power generation.
- No Corrosion problems which are found in other engines.
- The output product of fuel cell is harmless to an environment.
- Fuel cell is free from pollution.

Disadvantages of Fuel cell:

- High costs compared to other energy systems technology
- Operation requires disposable fuel supply
- Fuel used in fuel cell is highly flammable such as Hydrogen.
- Transfer of hydrogen fuel is too difficult

13. Comparison between Impulse turbine and Reaction turbine

Sl. No.	Impulse turbine	Reaction turbine
1.	**Head:** The machine is suitable for high installation. (H=100 + 200 m).	The machines can be used for medium heads(H=50 to 500 m) and low heads (less than 50 m)

2.	**Nature of input energy to the runner:** The nozzle converts the entire hydraulic energy into kinetic energy before water strikes the runner.	The head is usually inadequate to produce high velocity jet. Hence water is supplied to the runner in the forms of both pressure and kinetic energy.
3.	**Method of energy transfer:** The buckets of the runner are so shaped that they extract almost all the kinetic energy of the jet.	The wicket gates accelerate the flow a little and direct the water to runner vanes to which energies of water are transferred.
4.	**Operating pressure:** The turbine works under atmospheric pressure. Which is the difference between the inlet and exit points of the runner.	The runner works is a closed system under the action of reaction pressure.
5.	**Admission of water to the wheel:** Only a few buckets comprising a part of the wheel are exposed to the water jet.	The entire circumference of the wheel receives water and all passages between the runner blades are always full of water.
6.	**Discharge:** They are essential low discharge turbines.	Since power is a product of head and weight of the rate of flow, these turbines consume large quantities of water in order to develop a reasonable power under a relatively low head.
7.	**Speed of operation:** The speed are invariably high.	Although the specific speeds of these turbines is high, their actual running speeds are comparatively low.
8.	**Size :** These are generally small size.	The turbines sizes is much larger than impulse wheels, in order to accommodate heavy discharge.
9.	**Casing:** It prevents splashing of water. It has no hydraulic function to serve.	The spiral casing has an important role to play; it distributes water under the available pressure uniformly around the periphery of the runner.
10.	**Turbine setting:** The head between the wheel and race is lost.	The draft tube ensures that the head of water below tail race level is not lost.
11.	**Maximum efficiency:** The highest efficiency (=88%) is less than that of reaction turbine.	The maximum efficiency (=95%) of design output is higher than that of impulse wheels.
12.	**Part load operation:** From about 20% to 100% of design output, the efficiency remains nearly the same. Hence the machine is ideal for generating small loads over long periods of time.	With the exception of a Kaplan turbine, all reaction turbines give poor part load performance i.e., appreciably low efficiency at less than design output.

13.	**Cavitation:** These machine are not susceptible to cavitation.	Runner blades and draft tube invariably undergo cavitation on damage.
14.	**Civil engineering works:** Civil works like excavation and concreting are much simpler and economical.	Civil works are more expensive on account of spiral casing and draft tube.

14. Discuss in detail about nuclear waste management.

Nuclear Waste Management:

- Nuclear power is characterized by the very large amount of energy available from a very small amount of fuel.
- The amount of waste is correspondingly very small.
- However, much of the waste is radioactive and therefore must be carefully managed as hazardous waste.
- Radioactive wastes comprise a variety of materials requiring different types of management to protect people and the environment.
- They are normally classified as low-level, medium-level or high-level wastes, according to the amount and types of radioactivity in them.
- For each kind of radiation, the higher the intensity of radioactivity in a given amount of material, the shorter the half lives involved.

Three general principles are employed in the management of radioactive wastes:

i. Concentrate-and-contain.
ii. Dilute-and-disperse.
iii. Delay-and-decay.

- The first two are also used in the management of non-radioactive wastes. The waste is either concentrated and then isolated, or it is diluted to acceptable levels and then discharged to the environment.
- Delay-and-decay however is unique to radioactive waste management; it means that the waste is stored and its radioactivity is allowed to decrease naturally through decay of the radioisotopes in it.

Types of radioactive waste

i. Low-level waste:

- It is generated from hospitals, laboratories and industry, as well as the nuclear fuel cycle.
- It comprises paper, rags, tools, clothing, filters etc. which contain small amounts of mostly short-lived radioactivity.
- Usually it is buried in shallow landfill sites.
- To reduce its volume, it is often compacted in a closed container before disposal.
- Worldwide it comprises 90% of the volume but only 1% of the radioactivity of all radwaste.

ii. Intermediate-level waste:

- It contains higher amounts of radioactivity and may require special shielding.
- It typically comprises resins, chemical sludges and reactor components, as well as

contaminated materials from reactor decommissioning.

- It may be solidified in concrete or bitumen for disposal.
- Generally short-lived waste (mainly from reactors) is buried, but long-lived waste (from reprocessing nuclear fuel) is disposed of deep underground.
- Worldwide it makes up 7% of the volume and has 4% of the radioactivity of all radwaste

iii. High-level waste:

- It may be the used fuel itself, or the principal waste separated from reprocessing this.
- While only 3% of the volume of all radwaste, it holds 95% of the radioactivity.
- It contains the highly-radioactive fission products and some heavy elements with long-lived radioactivity.
- It generates a considerable amount of heat and requires cooling, as well as special shielding during handling and transport.

a. Reprocessing

- If the used fuel is later reprocessed, it is dissolved and separated chemically into uranium, plutonium and high-level waste solutions.
- About 97% of the used fuel can be recycled leaving only 3% as high-level waste.
- The recyclable portion is mostly uranium depleted to less than 1% U-235, with some plutonium, which is most valuable.
- Arising from a year's operation of a typical 1000 MWe nuclear reactor, about 230 kilograms of plutonium (1% of the spent fuel) is separated in for recycle.
- This can be used in fresh mixed oxide (MOX) fuel (but not weapons, due its composition).
- The separated high-level wastes – about 3% of the typical reactor's used fuel – amounts to 700 kg per year and it needs to be isolated from the environment for a very long time.

b. Immobilising separated high-level waste

- Solidification processes have been developed in several countries over the past fifty years. Liquid high-level wastes are evaporated to solids, mixed with glass-forming materials, melted and poured into robust stainless steel canisters which are then sealed by welding.
- This block contains material chemically identical to high-level waste from reprocessing.
- A piece this size would contain the total high-level waste arising from nuclear electricity generation for one person throughout a normal lifetime.

c. Waste disposal

- Final disposal of high-level waste is delayed for 40-50 years to allow its radioactivity to decay, after which less than one-thousandth of its initial radioactivity remains, and it is much easier to handle.
- Hence canisters of vitrified waste, or used fuel assemblies, are stored under water in special ponds, or in dry concrete structures or casks, for at least this length of time.
- The ultimate disposal of vitrified wastes, is burial in stable geological formations

some 500 metres deep.

- Several countries are investigating sites that would be technically and publicly acceptable, and in Sweden and Finland construction is proceeding in 1.9 billion year-old granites.

UNIT – V

ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER PLANTS

1. Explain in detail the Power Tariff used for energy consumption. (or) Describe the Power Tariff types with its advantages and Disadvantages.

TARIFF DEFINITION:

The rate at which electrical energy is supplied to a consumer is known as tariff.

- Cost of Producing Electricity depends upon the magnitude of Electricity consumed by load.
- Tariff fixation has to be given to different types of consumers (*e.g.*, industrial, domestic and commercial).
- Tariff fixing for different consumers is more complicated.

Objectives of tariff.

Electrical energy is sold at such a rate so that it not only returns the cost but also earns reasonable profit. Tariff should include the following objectives:

- Recovery of cost of producing electrical energy at the power station.
- Recovery of cost on the capital investment in transmission and distribution systems.
- Recovery of cost of operation and maintenance of supply of electrical energy
- A suitable profit on the capital investment.

Characteristics of a Tariff:

(i) Proper return:

- The total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit.
- This will enable the electric supply company to ensure continuous and reliable service to the consumers.

(ii) Fairness:

- The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy.
- A big consumer should be charged at a lower rate than a small consumer with fixed charges and thus reducing overall production cost of electrical energy.

- A consumer whose load conditions do not deviate much from the non-variable load should be charged at a lower rate than big consumers with variable load.

(iii) Simplicity:

- The tariff should be simple so that an ordinary consumer can easily understand it.
- A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) Reasonable profit:

- The profit element in the tariff should be reasonable.
- An electric supply company is a public utility company and generally enjoys the benefits of monopoly.
- The investment is relatively safe due to non-competition in the market and the profit is to be restricted to 8% or so per annum.

(v) Attractive:

- The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy.
- Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

Types of Tariff:

There are several types of tariff.

1. Simple Tariff
2. Flat rate Tariff
3. Block rate Tariff
4. Two part Tariff
5. Maximum demand tariff
6. Power Factor Tariff
7. Three part Tariff

1. Simple tariff:

When there is a fixed rate per unit of energy consumed, it is called a **simple tariff** or **uniform rate tariff.**

Advantages of Simple Tariff:

- In simple tariff, the cost does not vary with increase or decrease in number of units consumed.
- The consumption of electrical energy at the consumer terminals is recorded by means of an energy meter.

- This is the simplest of all tariffs and is easily understood by the consumers.

Disadvantages of Simple Tariff:

- Every consumer has to pay equally for the fixed charges irrespective of load variation.
- The cost per unit delivered is high.
- (iii) It does not encourage the use of electricity.

2. **Flat rate tariff:**

When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.

- In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.
- The different classes of consumers are made taking into account their diversity and load factors.

Advantages of Flat rate tariff:

- This tariff is more benefit to different types of consumers
- Flat rate tariff is quite simple in calculations.

Disadvantages of Flat rate tariff:

- Separate meters are required for lighting load, power load etc.
- The application of such a tariff is expensive and complicated.
- A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed.

3. **Block rate tariff.**

When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff.

- The energy consumption is divided into blocks and the price per unit is fixed in each block.
- The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy.
- For example, the first 30 units may be charged at the rate of 60 paise per unit; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

Advantages of Block rate Tariff:

- The consumer gets an incentive to consume more electrical energy.
- This increases the load factor of the system and hence the cost of generation is reduced.

Disadvantages of Block rate Tariff:

- It lacks a measure of the consumer demand.
- This type of tariff is being used for majority of residential and small commercial consumers.

4. Two-part tariff:

When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a **two-part tariff**.

- In two-part tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges.
- The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.
- Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e.

$$\text{Total charges} = \text{Rs}\ (b \times kW + c \times kWh)$$

where, b = charge per kW of maximum demand

c = charge per kWh of energy consumed

- This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages of two part Tariff:

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer.
- It is independent of the units consumed.

Disadvantages two part Tariff:

- The consumer has to pay the fixed charges irrespective of energy consumed
- There is always error in assessing the maximum demand of the consumer.

5. Maximum demand tariff.

It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.

Advantages of Maximum demand tariff:

- The maximum demand is assessed merely on the basis of the rateable value.

- This type of tariff is mostly applied to big consumers.

Disadvantages of Maximum demand tariff:

- It is not suitable for a small consumer.
- Separate maximum demand meter is required.

6. Power factor tariff:

The tariff in which power factor of the consumer load is taken into consideration is known as **power factor tariff**.

- A low power factor increases the rating of station equipment and line losses.
- A consumer having low power factor must be penalized.

The following are the important types of power factor tariff:

(i) kVA maximum demand tariff :

- It is a modified form of two-part tariff.
- In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW.
- A low power factor consumer has to contribute more towards the fixed charges.

(ii) Sliding scale tariff :

- This is also known as average power factor tariff.
- In this case, an average power factor, say 0·8 lagging, is taken as the reference.
- If the power factor of the consumer falls below this factor, suitable additional charges are made.
- If the power factor is above the reference, a discount is allowed to the consumer.

(iii) kW and kVAR tariff:

- In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately.
- A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

7. Three-part tariff:

When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a **three-part tariff**.

$$\text{Total charge} = \text{Rs}\ (a + b \times \text{kW} + c \times \text{kWh})$$

Where, a = fixed charge made during each billing period.
b = charge per kW of maximum demand,
c = charge per kWh of energy consumed.

- It may be seen that by adding fixed charge to two-part tariff, it becomes three-part tariff.

- The principal objection of this type of tariff is that the charges are split into three components.
- This type of tariff is generally applied to big consumers.

2. Define the load distribution parameters involved in the power system economics. (or) Explain the load distribution parameters related to power distribution system.

Energy:

Energy is defined as the power consumption in the particular period of time.

- It is expressed in Kilo-Watt Hour(kWh)
- Mechanical work done over a period of time is also a form of energy like heat.

Work done:

Work done is defined as the distance travelled by the applied force.

- Its unit is Newton metre (or)Joules.
- Electrical work is the product of voltage difference and the current flows in the conductor.
- Electrical work = Power = Volt x Amp = watt = Joule/sec

Installed capacity:

Installed capacity is the designed power generation capacity of a plant.

- It is expressed in terms of energy generated per unit time (MWh).

Power:

It is the rate of work or work done per unit time.

- It is generally expressed as Joules/second or MW.
- The basic unit is watt (Joules per second).

Heat rate:

Heat rate is the amount of energy (kJ) that the fuel must supply to produce unit amount of electrical energy (kWh).

- It is expressed as kJ/kWh or kilo Calories/KWh.
- This represents the overall efficiency of a power plant.

Turbine Heat rate:

Turbine heat rate is the amount of heat steam must deliver to produce unit of heat.

- It is expressed in Kilo-Watt Hour(kWh).

Thermal efficiency:

Thermal efficiency is the amount of heat carried by the steam per unit amount of heat delivered through the fuel.

Combustion efficiency:

Combustion efficiency is defined as the ratio of the amount of energy or heat released by the fuel to the energy contained in the burnt fuel.

Availability:

- Availability is the fraction of the time a plant is available for generation.
- A plant may be partially available due to lack of operation of some components of the plant. It is called partial availability.

Outage:

Outage is another term for shut down of the plant either for planned maintenance (Planned outage) or due to unforeseen break down (forced outage).

Base Load:

The unvarying load which occurs almost the whole day on the station is called as Base load.

Peak Load:

The various peak demands of load over and above the base load of the station is known as Peak Load.

- It is also known as Peak demand

Connected load:

The sum of the continuous ratings of all the equipments connected to the power system is called connected load.

Maximum load:

Maximum load is the greatest demand on the given period during a given period.

- It is also known as Maximum demand.

Average Load:

The average of all the loads occurring at the various instants on the generating station is called **average load**. Or

The total electrical energy delivered in a given period divided by the time period is called as **average load**.

$$\text{Average load} = \frac{\textbf{kWh energy supplied in a period}}{\textbf{\textit{Time period}}}$$

$$\text{Daily average load} = \frac{\textbf{kWh energy supplied in day}}{\textbf{24}}$$

$$\text{Monthly average load} = \frac{\textbf{kWh energy supplied in day}}{\textbf{24 X 30}}$$

Variable load:

The load on a power plant varies from time to time due to uncertain demands of the consumers is known as Variable load.

Effects of variable load:

- *Need of an additional equipment*
- *Increase in production cost*

Interconnected load:

The connection of two or more loads in parallel condition is known as an interconnected load.

Advantages:

- Exchange of peak loads
- Use of older plants
- Ensures an economical operation
- Increases diversity factor
- Reduces plant reserve capacity
- Increases reliability of supply.

Base load Plant:

Base load plant is a type of plant which supplies to a constant load demand in more efficient manner.

- Such plants run 100% of the time.
- Examples: Nuclear and Coal fired plants.

Peak Load Plant:

Peal load plant is a type of plant which supplies to both constant load demand as well as maximum demand.

- These plants helps over short term (15%) demand peak.
- Gas turbine, hydro plant can be used.

Interconnected grid system:

The connection of several generating stations are connected in parallel is known as an interconnected grid system.

Load Factor:

Load factor is defined as the ratio of an Average load to the Maximum load.

$$\text{Load Factor} = \frac{\textbf{Average load}}{\textbf{Maximum load}}$$

Diversity Factor:

Diversity factor is defined as the ratio of sum of individual maximum demands to the maximum demand on the power plant.

$$\text{Diversity factor} = \frac{\textit{Sum of individual maximum demands}}{\textit{Maximum demand on the power plant}}$$

Utilization factor:

Utilization factor is defined as the ratio of Maximum load to the Rated capacity of the plant.

$$\text{Utilization factor} = \frac{\textbf{Maximum load}}{\textbf{Rated capacity of plant}}$$

Plant use factor:

Plant use factor is defined as the ratio of kWh generated output to the product of rated capacity of plant and the number of hours for which the plant was in operation.

$$\text{Plant use factor} = \frac{\textbf{kWh generated output}}{\textbf{Rated capacity of plant X Number of Hours in use}}$$

Capacity factor:

Capacity factor is defined as the ratio of Average load to the Rated capacity of the plant. It is also called as **Plant capacity factor.**

$$\text{Capacity Factor} = \frac{\textbf{Average load}}{\textbf{Rated capacity of plant}} = \frac{\textbf{Total energy output in a period}}{\textbf{Rated capacity of plant}}$$

Demand factor:

Demand factor is defined as the ratio of Maximum demand on the station to the total load connected to the plant.

$$\text{Demand factor} = \frac{\textbf{Maximum demand}}{\textbf{Total connected load}}$$

Reserve Factor:

Reserve factor is defined as the ratio of Load factor to the capacity factor.

$$\text{Reserve factor} = \frac{\textbf{Load factor}}{\textbf{Capacity factor}}$$

Plant Reserve capacity:

Plant reserve capacity is defined as the difference between the Rated capacity of the plant ant the Maximum demand on the plant.

Reserve capacity = Rated capacity of the plant – Maximum demand on the plant

Coincidence Factor:

Coincidence factor is defined as the ratio of Capacity factor to the Load factor.

$$\text{Coincidence factor} = \frac{\mathbf{1}}{\mathbf{Reserve\ factor}} = \frac{\mathbf{Capacity\ factor}}{\mathbf{Load\ factor}}$$

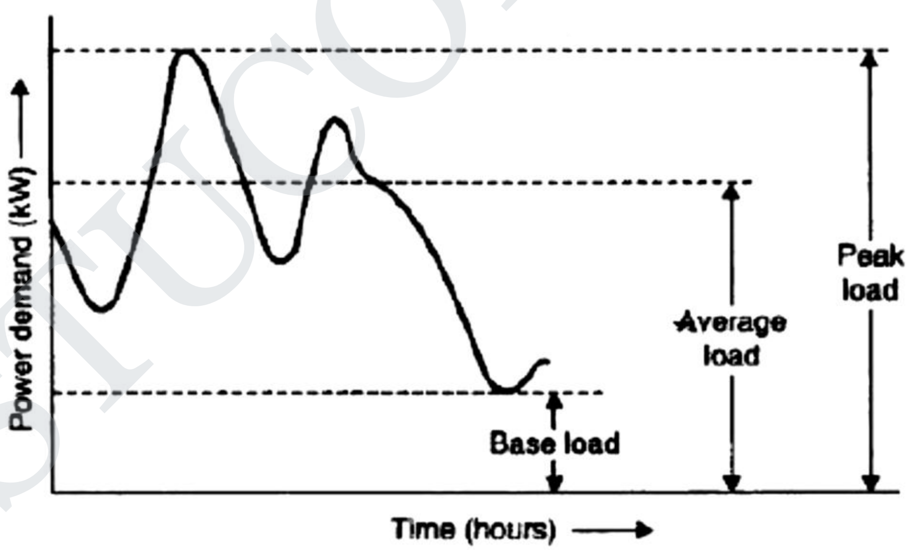
3. Explain Load curve and load duration curve with its significance. Explain the graphical representation of variable load during different time period. (or) Draw and explain the parameters related to load curve and Load duration curve.

A) <u>Load curve:</u>

- The curve showing the variation of the load on the power station with respect to time is known as **Load curve**.
- The load on a power station is never constant because it varies time to time.

<u>Types of load curve:</u>

- The load variations during the whole day is plotted against the time is called as **Daily load curve.**
- The load variations during the whole month is plotted against the time is called as **Monthly load curve**. This can be obtained from the daily load curve of that month.
- The load variations during the whole year is plotted against the time is called as **Yearly load curve**. This can be obtained from the monthly load curve of that particular Year.



Graphical representation of Load (Load curve)

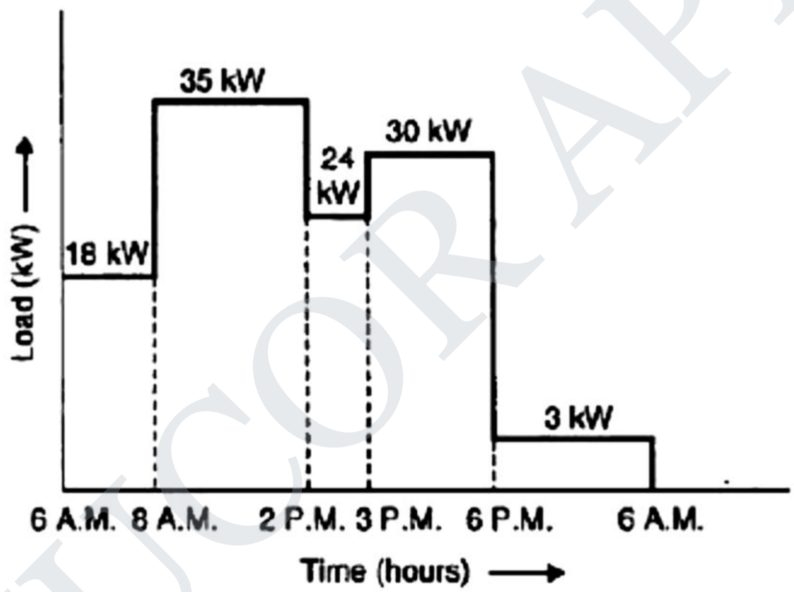
<u>Significance of load curve:</u>

- The area under the load curve represents the energy generated in the period considered.
- The area under the curve divided by the total number of hours gives the average load on the power station.

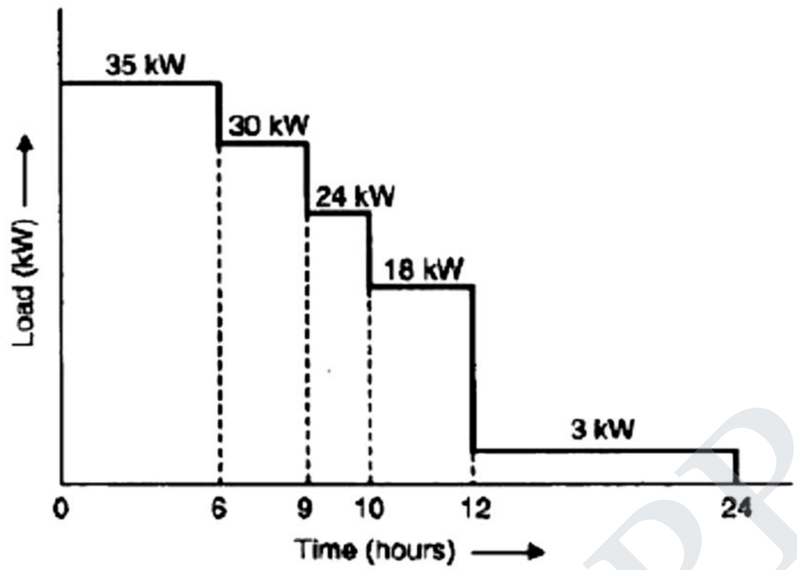
- The peak load indicated by the load curve is the graph represents the maximum demand of the power station.
- Load curve helps in selecting the size and number of generating units of the power station.
- Load curves give full information about the incoming load.
- Load curve helps in deciding the operation schedule of the station.
- Load curves also help to estimate the generating cost.

B) <u>Load duration curve:</u>

When the load elements of load curve are arranged in order of descending magnitude, the curve thus obtained is called a load duration curve.



Daily load Curve



Load duration curve

Significance of Load Duration curve:

- The area under the load duration curve and the corresponding chronological load curve is equal.
- Load duration curve represents total energy delivered by the generating station with optimized operating units.
- Load duration curve gives a clear analysis of generating power economically.
- Proper selection of base load power plants and peak load power plants becomes easier.

C) Important definitions for Load Curve:

Base Load:

The unvarying load which occurs almost the whole day on the station is called as Base load.

Peak Load:

The various peak demands of load over and above the base load of the station is known as Peak Load.

- It is also known as Peak demand

Connected load:

The sum of the continuous ratings of all the equipment connected to the power system is called connected load.

Maximum load:

Maximum load is the greatest demand on the given period during a given period.

- It is also known as Maximum demand.

Average Load:

The total electrical energy delivered in a given period divided by the time period is called as **average load**.

$$\text{Average load} = \frac{\textbf{kWh energy supplied in a period}}{\textit{Time period}}$$

Load Factor:

Load factor is defined as the ratio of an Average load to the Maximum load.

$$\text{Load Factor} = \frac{\textbf{Average load}}{\textbf{Maximum load}}$$

Diversity Factor:

Diversity factor is defined as the ratio of sum of individual maximum demands to the maximum demand on the power plant.

$$\text{Diversity factor} = \frac{\textit{Sum of individual maximum demands}}{\textit{Maximum demand on the power plant}}$$

Utilization factor:

Utilization factor is defined as the ratio of Maximum load to the Rated capacity of the plant.

$$\text{Utilization factor} = \frac{\textbf{Maximum load}}{\textbf{Rated capacity of plant}}$$

Plant use factor:

Plant use factor is defined as the ratio of kWh generated output to the product of rated capacity of plant and the number of hours for which the plant was in operation.

$$\text{Plant use factor} = \frac{\textbf{kWh generated output}}{\textbf{Rated capacity of plant X Number of Hours in use}}$$

Capacity factor:

Capacity factor is defined as the ratio of Average load to the Rated capacity of the plant. It is also called as **Plant capacity factor.**

$$\text{Capacity Factor} = \frac{\textbf{Average load}}{\textbf{Rated capacity of plant}}$$

$$\text{Capacity Factor} = \frac{\textbf{Total energy output in a period}}{\textbf{Rated capacity of plant}}$$

Demand factor:

Demand factor is defined as the ratio of Maximum demand on the station to the total load connected to the plant.

$$\text{Demand factor} = \frac{\textbf{Maximum demand}}{\textbf{Total connected load}}$$

Reserve Factor:

Reserve factor is defined as the ratio of Load factor to the capacity factor.

$$\text{Reserve factor} = \frac{\textbf{Load factor}}{\textbf{Capacity factor}}$$

Plant Reserve capacity:

Plant reserve capacity is defined as the difference between the Rated capacity of the plant ant the Maximum demand on the plant.

Reserve capacity = Rated capacity of the plant – Maximum demand on the plant

Coincidence Factor:

Coincidence factor is defined as the ratio of Capacity factor to the Load factor.

$$\text{Coincidence factor} = \frac{\mathbf{1}}{\textbf{Reserve factor}} = \frac{\textbf{Capacity factor}}{\textbf{Load factor}}$$

Cold reserve:

Cold reserve is that reserve generating capacity which is not in operation but can be made available for service.

Hot reserve:

Hot reserve is that reserve generating capacity which is in operation but not in service.

Spinning reserve:

Spinning reserve is that reserve generating capacity which is connected to the bus and is ready to take the load.

D) Types of loads:

- **Residential load**: This type of load includes domestic lights, power needed for domestic appliances such as radios, television, water heaters, refrigerators, electric cookers and small motors for pumping water.
- **Commercial load:** It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants etc. This load occurs for some hours during the day time.
- **Industrial load:** It consists of load demand of various industries. The magnitude of this type of load depends on the type of industry.
- **Municipal load:** It consists of street lighting, power required for water supply and drainage purposes. This pumping process occurs at the night time only.
- **Irrigation load**: This type of load includes electrical power needed for pumps driven by electric motors to supply water to fields. This type of load is supplied for night 12 Hours.
- **Traction load:** It includes trams, cars, trolley, buses and railways. This type of load has wide variation depends on time.

4. Explain the factors to be considered for site selection of power plant. (or) Describe the site selection factors considered for different power plant construction and operation.

In general, both the construction and operation of a power plant requires the existence of some conditions such as water resources and stable soil type. Some factors such as population centers and protected areas will be affected by either the construction or operation of the plants.

Factors for power plant site selection:

Area size:

- Before any other consideration, the minimum area size required for the construction of power plant should be selected.

Transportation network:

- Reduced transportation is needed from the availability of fuel
- Easy and enough access to transportation network is required in both power plant construction and operation periods.

Gas pipe network:

- Area to the gas pipes reduces the required expenses on the space required.
- If underground pipes are used there is no need of

Power transmission network:

- To transfer the generated electricity to the consumers in reduced cost.
- The plant should be connected to electrical transmission system with profitable manner.
- The plant should be located nearer to the electric network to distribute power.

Geology and soil type:

- The power plant should be built in an area with alternate soil and rock layers
- This combination of soil can withstand the weight and vibrations of the power plant.

Earthquake and geological faults:

- Even weak and small earthquakes can damage many parts of a power plant intensively.
- Therefore the site should be away enough from the faults and previous earthquake areas.

Topography (Slope Areas):

- Changing of a sloping area into a flat site for the construction of the power plant needs extra budget.
- Therefore, the parameters of elevation and slope should be considered.

Rivers and floodways:

- The power plant should have a reasonable distance from permanent and seasonal rivers and floodways.

Water resources:

- For the construction and operating of power plant more volume of water are required. This could be supplied from either rivers or underground water resources.
- Enough water supplies in defined area can be a factor in the site selection.

Environmental resources:

- Operation of a power plant has important impacts on environment.
- Priority will be given to the locations that are far enough from national parks, wildlife, protected areas, etc.

Population centers:

- The waste from the power plant has adverse effects on the environment and population.
- The site should have an enough distance from population centers.

Need for power:

- In general, the site should be near the areas that there is more need for generation capacity.
- More power near the power plant is to decrease the amount of power loss and transmission expenses.

Climate:

- The productivity of a power plant depends on parameters such as temperature, humidity, wind direction and speed.
- The environmental conditions should be always taken into site selection criteria.

Land cover:

- Some land cover types such as forests, agricultural land, etc. are sensitive to the pollutions caused by a power plant.
- The effect of the power plant on such land cover types surrounding it should be considered.
- Proper waste disposal systems are to be designed in addition to construction of power plant.

Distance from airports:

- The power plant has high towers and chimneys and large volumes of gas.
- For security reasons, they should be away from airports.

Archeological and historical sites:

- The vibrations of power plant should not affect the historical building because they are fragile and at same time very valuable.
- The site should have an enough distance from historical building areas.

5. **Write the advantages and disadvantages of various power plants.**

Thermal Power Plant:

Advantages of Thermal Power Plant:

- They can respond to rapid1y changing loads without difficulty.
- A portion of the steam generated can be used as a process steam in different industries.
- Can be located very conveniently near the load centre.
- As these plants can be set up near the industry transmission costs are reduced.
- Steam engines and turbines can work under 25 per cent of overload continuously.
- Fuel used is cheaper.
- Less space is required in comparison with that for hydro-electric plants.
- Cheaper in production cost in comparison with that of diesel power stations.
- Cheaper in initial cost in comparison with that of diesel power stations.

Disadvantages of thermal power plant:

- Maintenance and operating costs are high.
- The cost of plant increases with increase in temperature and pressure.
- Long time required for erection and putting into action.
- A large quantity of water is required.
- Great difficulty experienced in coal handling.

- The plant efficiency decreases rapidly below about 75 per cent load.
- Presence of troubles due to smoke and heat in the plant.

Diesel turbine Power Plant:

Advantages of Diesel Power plant:

- The advantages of diesel power plants are listed below.
- Very simple design also simple installation.
- Limited cooling water requirement.
- Standby losses are less as compared to other Power plants.
- Low fuel cost.
- Quickly started and put on load.
- Smaller storage is needed for the fuel.
- Layout of power plant is quite simple.
- There is no problem of ash handling.
- Less supervision required.
- For small capacity, diesel power plant is more efficient as compared to steam power plant.
- They can respond to varying loads without any difficulty.

Disadvantage of Diesel Power Plant:

- High Maintenance and operating cost.
- Fuel cost is more, since in India diesel is costly.
- The plant cost per kW is comparatively more.
- The life of diesel power plant is small due to high maintenance.
- Noise is a serious problem in diesel power plant.
- Diesel power plant cannot be constructed for large scale.

Gas turbine Power plant:

Advantages of Gas turbine Power plant:

- It is smaller in size and weight as compared to an equivalent steam power plant.
- The initial cost and operating cost of the plant is lower than an equivalent steam power plant.
- The plant requires less water as compared to a condensing steam power plant.
- The plant can be started quickly and can be put on load in a very short time.
- There are no standby losses in the gas turbine power plant
- The maintenance of the plant is easier and maintenance cost is low.
- The lubrication of the plant is easy.
- The plant does not require heavy foundations and building.

- There is great simplification of the plant over a steam plant due to the absence of boilers with their feed water evaporator and condensing system.

Disadvantages of Gas turbine power plant:

- Major part of the work developed in the turbine is used to derive the compressor.
- Network output of the plant is low.
- Temperature of the products of combustion becomes too high
- Service becomes complicated even at moderate pressures.

Nuclear Power Plant:

Advantages of Nuclear Power Plant:

- Nuclear reactor have long life.
- Breeder reactors create more usable fuel than they use.
- A nuclear aircraft carrier can circle the globe continuously for 30 years on its original fuel.
- Reprocessing of nuclear material creates the nuclear fuel for hundreds of years.
- Nuclear power plant can be located almost anywhere far away from the cities.
- Very low greenhouse gas emissions due to shielding of reactor.
- Nuclear power plants requires less space.
- Nuclear power plants already exist and are available worldwide.
- More nuclear power can be produced in large quantities over short periods of time.
- The contribution of nuclear power to global warming is relatively little.

Disadvantages of Nuclear Power Plant:

- Nuclear disaster changes the living land to Non- living land for more number of years.
- Nuclear research has created large contamination problems.
- Nuclear plants are more expensive to build and maintain.
- Lack of nuclear fuels needed for nuclear power plants.
- Nuclear plant workers may be exposed to high levels of radiation causes diseases.
- Breakdown of nuclear reactor are costly to replace.
  High risk power supply is needed for nuclear power plant.
- Nuclear meltdown can release massive amounts of radiation.
  Nuclear energy can create more problems than they solve.
- These plants also consume large amounts of water.
- Initial cost of nuclear power plant is higher as compared to hydro or steam power plant.
- Nuclear power plants are not well suited for varying load conditions.
- Maintenance cost of the plant is high.
- It requires trained personnel to handle nuclear power plants.

Hydro-electric Power plant:

Advantages of Hydro-electric Power plant:

- The plant is highly reliable
- Maintenance and operation charges are very low.
- The plant can be run up and synchronized in a few minutes.
- The load can be varied quickly
- The rapidly changing load demand can be met without any difficulty.
- The plant has no stand-by losses.
- No fuel charges.
- The efficiency of the plant does not change with age.
- The cost of generation of electricity varies little with the passage of time.

Disadvantages of Hydro-electric Power plant:

- The capital cost of the plant is very high.
- The hydro-electric plant takes much longer in design and execution.
- These plants are usually located in hilly areas far away from the load center.
- Transformation and transmission costs are very high.
- The output of a hydro-electric plant is never constant due to vagaries of monsoons and their dependence on the rate of water flow in a river.

Magneto-Hydro Dynamite Power Generation:

Advantages of MHD Generation:

- Here only working fluid is circulated, and there are no moving mechanical parts.
- Mechanical losses are very low and makes the operation more dependable.
- The temperature of working fluid is maintained the walls of MHD.
- It has the ability to reach full power level almost directly.
- The cost of MHD generators is much lower than conventional generators.
- MHD has very high efficiency.

6. Write the comparison of capital and operating cost for various power plants. (or) Explain in detail about the capital and operating cost of different power plants from the basics of Power plant economics.

A power plant should provide a reliable supply of electricity at minimum cost to the consumer is generally called as Power plant Economics.

The cost per kilo-Watt hour(kWh) is determined by three different costs:

1. Fixed cost
2. Variable cost (Operation and Maintenance cost)
3. Fuel cost·

Fixed cost(FC) or Capital cost:

- Fixed cost is the installation cost which mainly includes interest, depreciation, insurance, taxes.
- This cost is depending on the capital invested on the plant construction including the cost of the land.

Variable cost:

- Variable cost is the combination of Operating and Maintenance cost of the power plant.
- Operation cost includes the cost of wages for workers and servicing of equipment.
- Maintenance cost includes the cost of repairs including spare parts, water, lubricating oil, chemicals and miscellaneous expenses.

Fuel cost:

Fuel cost is the cost which depends on the amount of electricity generated in kWh of electricity sent out per year.

Total annual cost of power plant:

The total annual cost (C_i) in a power plant can be calculated from

$$C_I = \left(\frac{I+D+T}{100}\right) C_c + (W + R + M) + Cr$$

Where, I = interest in %; D = Depreciation in %; Taxes and insurance in %;
Cc = Construction cost; W = Cost of wages and salaries; R = Repair cost;
M = Miscellaneous cost ; Cr = fuel cost.

- In order to calculate the electric power cost to a consumer, the power outage cost (which includes transmission cost, distribution cost, administrative expenses, and return or profit on the investment).is also considered in addition to the production cost.
- A measure for the reliability of a power plant is the forced outage rate is defined by the annual ratio.

$$\text{Forced outage rate} = \frac{\textbf{Forced outage hours}}{\textbf{Service hours+ Forced outage hours}}$$

- In general, central station generators has a tradeoff between capital and operating costs.

- Those types of plants that have higher capital costs tend to have lower operating costs.
- Further, generators which run on fossil fuels tend to have operating costs that are extremely sensitive to changes in the underlying fuel price.

- Typical capital and operating costs for different power plants

Type of Power plant	**Capital Cost ($/kW)**	**Operating Cost ($/kWh)**
Coal-fired combustion turbine	$500 — $1,000	0.20 — 0.04
Natural gas combustion turbine	$400 — $800	0.04 — 0.10
Coal gasification combined-cycle (IGCC)	$1,000 — $1,500	0.04 — 0.08
Natural gas combined-cycle	$600 — $1,200	0.04 — 0.10
Wind turbine (includes offshore wind)	$1,200 — $5,000	Less than 0.01
Nuclear	$1,200 — $5,000	0.02 — 0.05
Photovoltaic Solar	$4,500 and up	Less than 0.01
Hydroelectric	$1,200 — $5,000	Less than 0.01

- Depends on capital and operating cost, the direct comparison of overall costs of different power plants is not possible.

- Power plant installation cost is based on a measure called the "Levelized Cost of Energy"(LCOE).

- LCOE is the measure of cost which is the average price per unit of output needed for the plant to break even over its operating lifetime.

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where,

LCOE = Levelized cost of electricity

I_t = Investment expenditures in the year *t*

M_t = Operations and maintenance expenditures in the year *t*

F_t = Fuel expenditures in the year *t*

E_t = Electricity generation in the year *t*

r = Discount rate

n = Life of the system

- Irrespective of technology, all generators share the following characteristics which influence the plant operations:

  Ramp rate: This variable influences how quickly the plant can increase or decrease power output in percentage of capacity per unit time.

  Ramp time: The amount of time taken from the moment a generator is turned on for providing energy to the grid at its lower operating limit.

  Capacity: The maximum output of a plant in megawatt.

  Lower Operating Limit (LOL): The minimum amount of power(in MW) is generated in a plant once it is turned on.

  Minimum Run Time: The shortest amount of time required for a plant to generate minimum amount of electricity once it is turned on.

  No-Load Cost: The no-load cost is the fixed cost of operation without any power generation in the power plant.
  Start-up and Shut-down Costs:

  These are the costs involved in turning the plant on and off, in Dollars/MWh.

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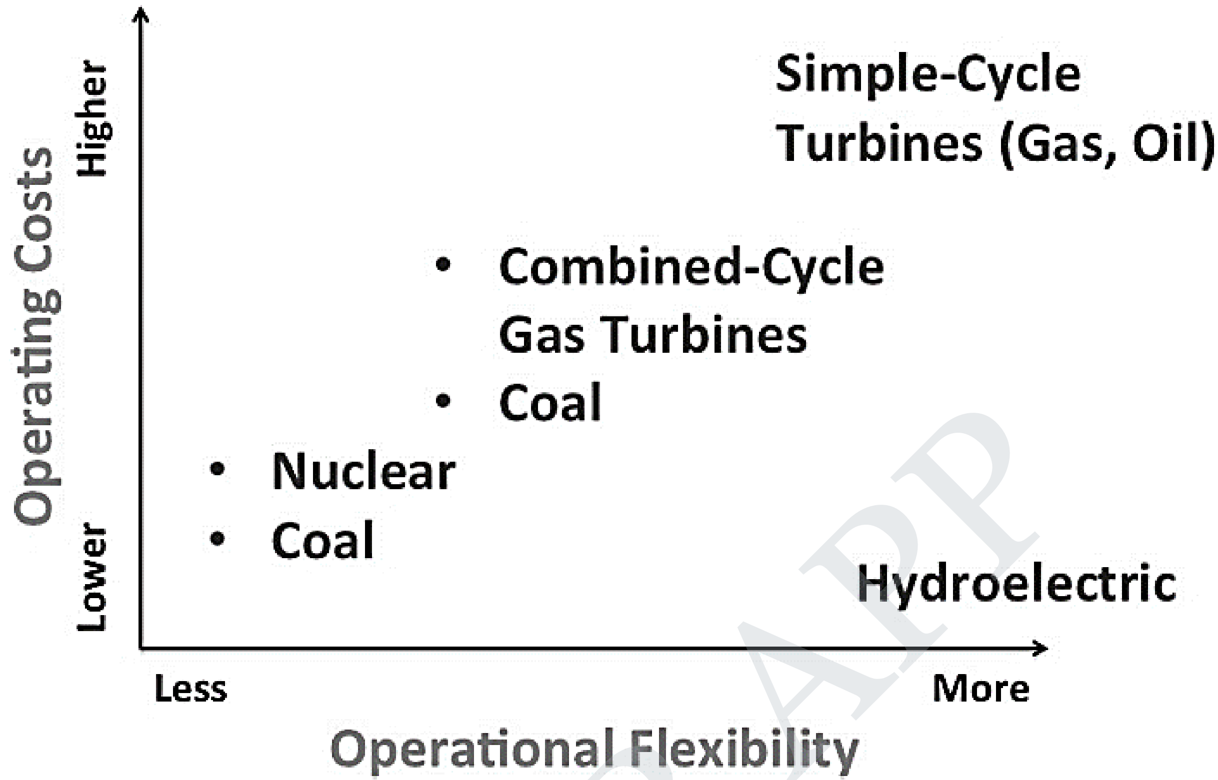

Comparison of operating cost and operational flexibility for different power plant

- The cost structure for transmission and distribution is different than for power generation.
- There is basically no fuel cost involved with operating transmission and distribution wires (and their associated balance-of-systems, like substations).

Typical Ramp and Run times for power plants.		
Type of Power plant	**Ramp Time**	**Minimum Run Time**
Simple-cycle combustion turbine	minutes to hours	minutes
Combined-cycle combustion turbine	hours	hours to days
Nuclear	days	weeks to months
Wind Power plant	minutes	none
Hydro-electric power plant	minutes	none