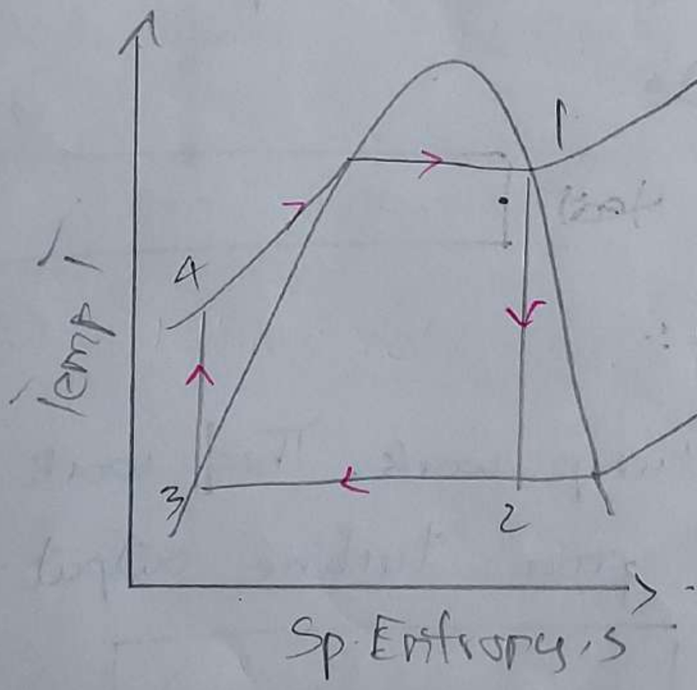
UNIT - I

COAL BASED THERMAL POWER PLANTS

Rankine Cycle :

→ A rankine vapour cycle is based on a modified carnot cycle to overcome its limitations.

→ It consists of four steady flow processes as in Fig.



Process 1-2 :

The steam is reversibly and adiabatically expanded in the future. So, turbine work input

$$W_e = m(h_1 - h_2)$$

Process 2-3 :-

→ Constant pressure heat rejection in the condenser.

→ The cooling water extracts the latent heat of condensation from the exit steam exhausted to the condenser. The condensation is complete.

→ The entire vapour is converted into a condensate.

Heat rejection $= m(h_2 - h_3)$

Process 3-4 :-

Pump work. This work must be apportioned from turbine output.

$$W_p = m(h_4 - h_3)$$

Net work output $W_{net} = W_e - W_p$

$$\eta = \frac{W_{net}}{Q_{add}}$$

$$= \frac{W_t - W_p}{Q_{add}}$$

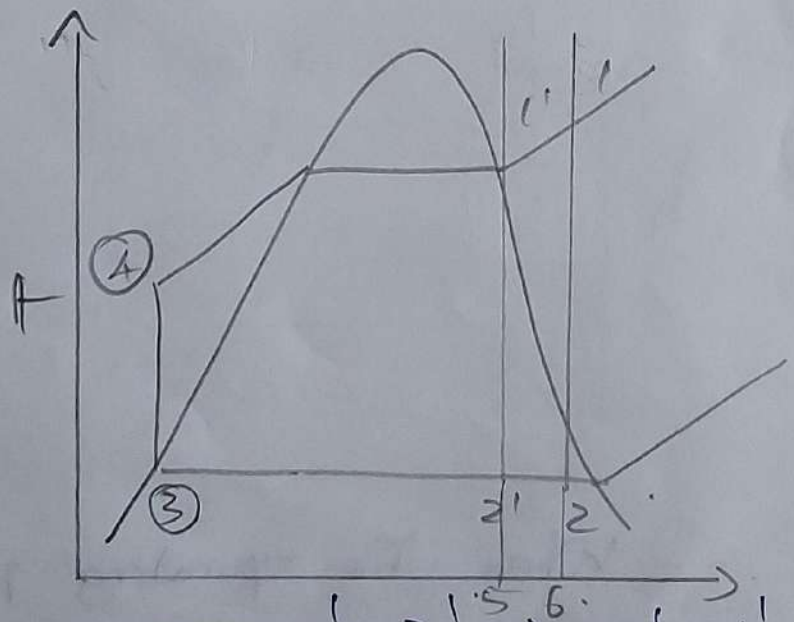
$$\eta = \frac{m(h_1 - h_2) - m(h_4 - h_3)}{m(h_1 - h_4)}$$

Rankine Cycle - Improvisation:

Effect of increasing pressure:

The steam pressure at exit is increased from p to while maintaining a constant superheated steam temperature ie $T_1 = T_1$

$\Delta W_{output};\ p$ = area 1-2-3-4-1



= area 1'-2'-3-4'-1'

$\Delta W_{output};\ p \simeq \Delta W_{output},\ p'$

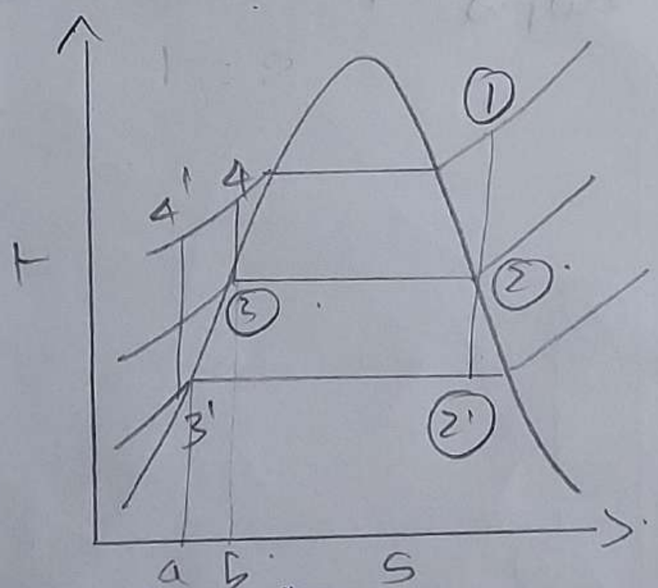
→ However, the heat rejection area is reduced due to the higher pressure steam utilization. area (2 - -5 - 6)

→ This increases the efficiency of cycle.

$$\eta = 1 - \frac{Q_{rejection}}{Q_{addition}}$$

Effect of reducing Constant Pressure:-

→ If the consider pressure is reduced the net work is increased by area 2-2-2'-3'-4'-4-3-2.

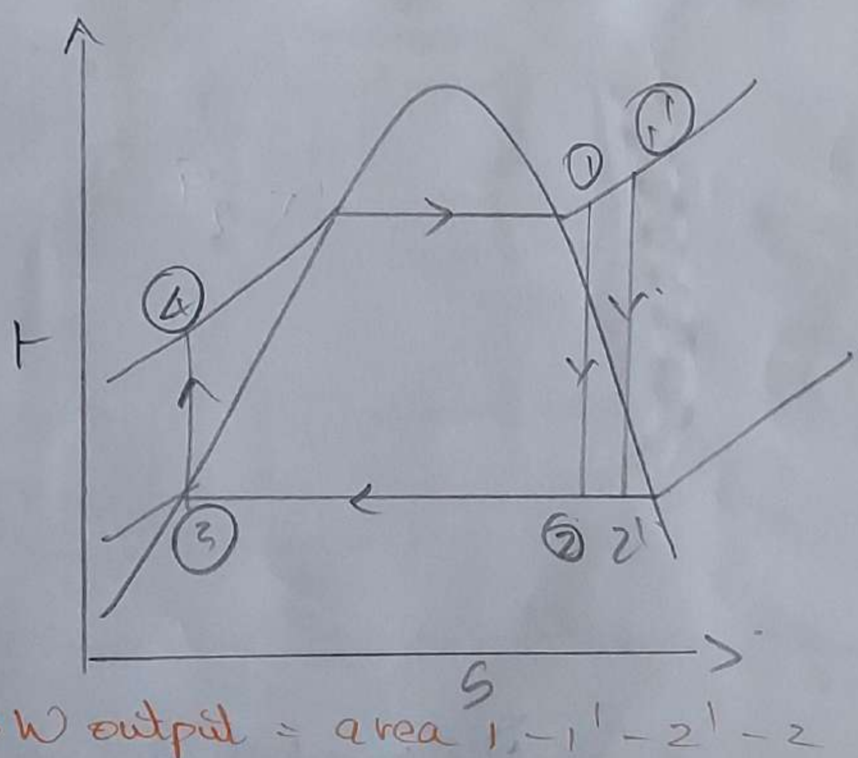


→ When the operating pressure of the condenser is decreased, the heat added area automatically increases and at the same time

Q rej also decreases with the net effect.

Rankine Cycle with Superheated Steam:

If the heating of the working fluid is continued beyond the dry saturation point ie well into superheated regime before feeding it to the turbine, ie ; state insted of state 1 the amount of heat added increase bringing about an incipient increase in work output.



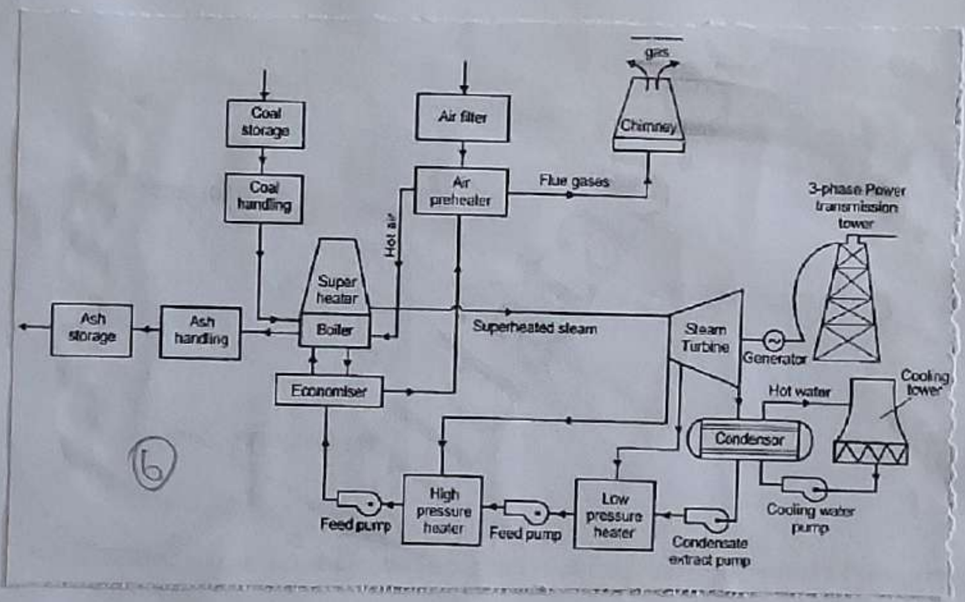
ΔW output = area $1 - 1' - 2' - 2$

So, superheating be get a higher cycle efficiency.

Layout of modern coal power plant :-

→ The development of Thermal plants becomes a necessity and advantageous one as about 60% of total power developed in India is by Thermal power plant only.

→ The schematic representation of modern coal power plant is shown below.



→ It mainly consists of following four main circuits.

* Coal and ash circuit.
* Air and flue gas circuit.

* Feed water and steam flow circuit.
* Cooling water circuit.

* Coal and ash Circuit:

→ Coal from storage yard is transferred to the boiler furnace through coal handling system.

→ Ash produced due to combustion of coal in the furnace is removed to ash storage yard through ash handling system.

* Air and Flue gas Circuit:

→ Air needed for combustion is drawn from atmosphere through the air filter to air preheater.

→ The preheated air is then supplied to the furnace of boiler through draught fans.

→ The flue gases are the exhausted to the atmosphere through economizer, air preheater and dust collector.

* Feed water and steam flow Circuit :-

→ The work obtained by steam expansion is utilized to develop mechanical power in the turbine.

→ The condensate leaving condenser is first heated in low pressure heater and then in high pressure heater by using the steam tapped from various extraction points of turbine.

* Cooling water Circuit :-

→ Water circulating through condenser may be taken from upper side of river.

→ Abundant quantity of water is required for condensing the steam in the condenser.

Working principle :-

→ First steam is generated in boiler by utilizing chemical energy released due to combustion.

→ The turbine is coupled to electric alternator or generator which converts mechanical into electric energy.

→ Thus electric power is produced in steam power plants.

Advantages:

* Low cost
* Low time requirement
* Fuel used is quite cheap.
* Low space requirement.
* Low initial cost.

Disadvantages:

* Exhaustion of fossil fuel.
* Efficiency decrement due to time.
* Low life.
* Air pollution.
* High cost of power generation.
* Cannot be used at peak load.

SUPER CRITICAL BOILERS

→ Supercritical boilers requires only economizer and super heater.

→ Supercritical boilers are employed when the capacity of the plant is above 300 MW.

→ The types of supercritical boilers are, as follows.

* Lamont boiler.
* Loeffler boiler.
* Benson boiler.
* Velox boiler.

* Lamont boiler:

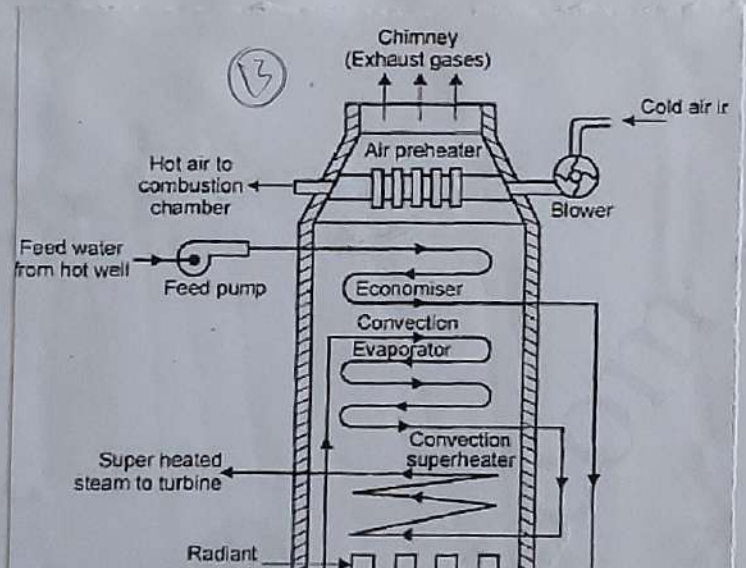
→ Initially drum receives feed water through economizer from the well using feed pump.

→ Circulating pump draws water from drum and delivers it to evaporator through distributor head that contains small orifices at pressure above drum pressure.

* Benson Boiler :

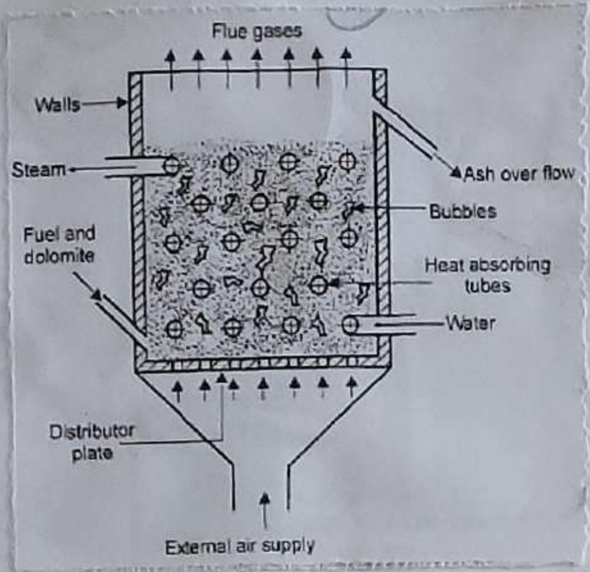
→ Water from hot well passes through feed pump and economizer to the radiant evaporator where part of the water is converted into steam.

→ The feedwater passes through the economizer to the water cooled walls of the furnace.



→ The water receives heat by radiation and the temperature increases to nearly critical temperature.

FBC Boilers :-



→ When a gas is passed through a packed bed of finely divided solid particles, it experiences a pressure drop across the bed.

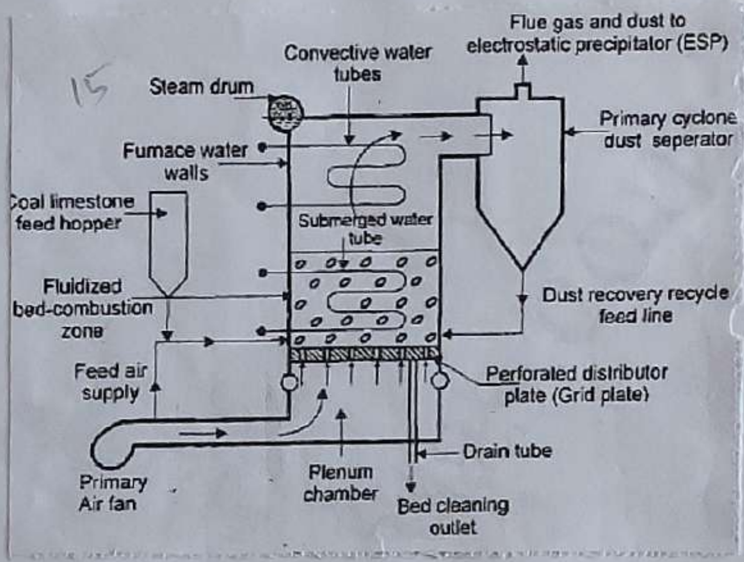
→ When the velocity of gas is increased further, at a stage the particles get suspended in the gas stream and the new packed bed becomes a fluidized bed.

→ Burning of a fuel in such a state is known as fluidized bed combustion.

Types of FBC:

* Bubbling Fluidized Bed Boilers.
* Circulating Fluidized Bed Boilers.

Bubbling Fluidized Bed Boilers: (BFB)



* BFB boilers are designed to allow a wide range of fuels to be burned, seperately or in combination.

* The ability to utilize various fuel sources and types provides owners with the flexibility to take advantage of oppertunity fuels

Advantages:

→ Several features combine to provide low maintenance costs, high availability and long term reliability.

→ An open bottom permits easy removal of oversized of foreign material.

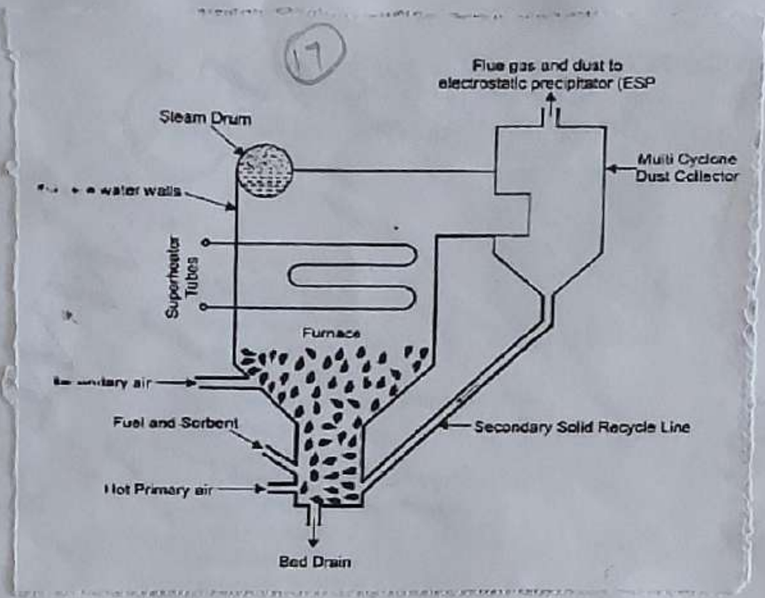
→ A water cooled, gas tight lower furnace eliminates the potential for gas leaks caused from refractory damage.

→ Bottom supported hoppers remove load from the boiler, reduce captial requirements, and reduce potential mechanical stresses between water cooled and non cooled components.

Capacity:

* Bottom supported: Upto 2,25,000 lb/h.
* Top supported: From 2,25,000 to 10,00,000 lb/h.

Circulating Fluidized Bed Boilers :-



→ Generally, CFBC consists of a boiler and a high temperature cyclone.

→ The intra furnace gas velocity is as high as 4 to 8 m/s.

→ A coarse fluidizing medium and char in flue gas are collected by high temperature cyclone and recycled to the boiler.

→ Recycling maintains the bed height and increases the denitration efficiency.

→ To increase the thermal efficiency, a pre heater for the fluidizing air and combustion air, and a boiler feed water heater are installed.

→ Most of the boiler technologies are manufactured overseas, mainly from Foster Wheeler, Lurgi, Steinmuller, ALSTOM and Babcock & Wilcox.

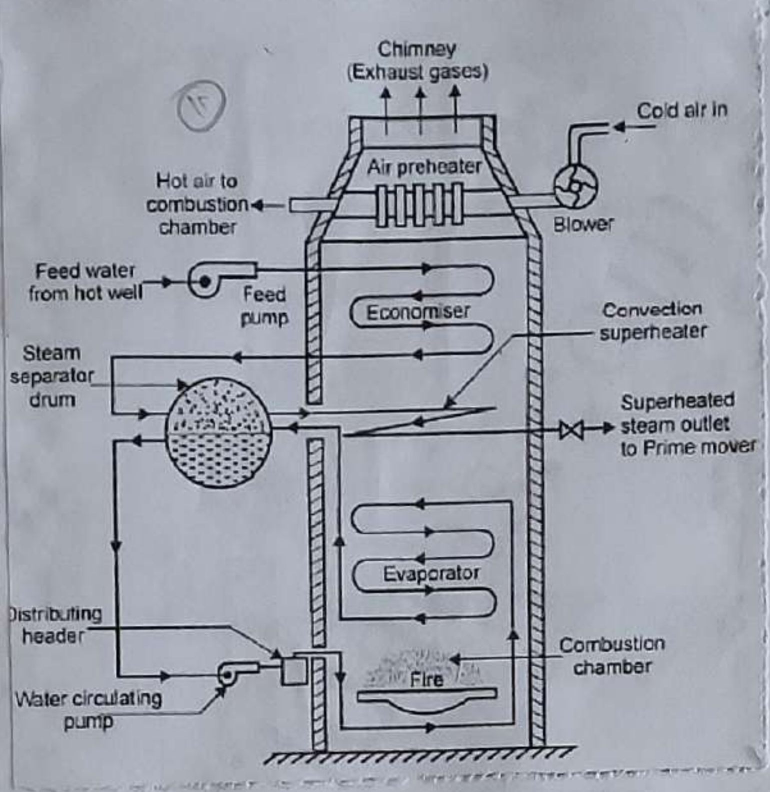
TURBINES :-

→ Steam turbine is a device which is used to convert kinetic energy to mechanical energy.

→ The steam turbine depends completely on the dynamic action of steam.

→ According to Newton's second law of motion, the force is proportional to rate of change of momentum.

Force = mass × velocity.



→ The superheated steam leaves the boiler and enters into the prime mover through steam outlet to perform work.

→ Air preheater is used for preheating the air required for efficient combustion in combustion chamber using waste hot flue gases.

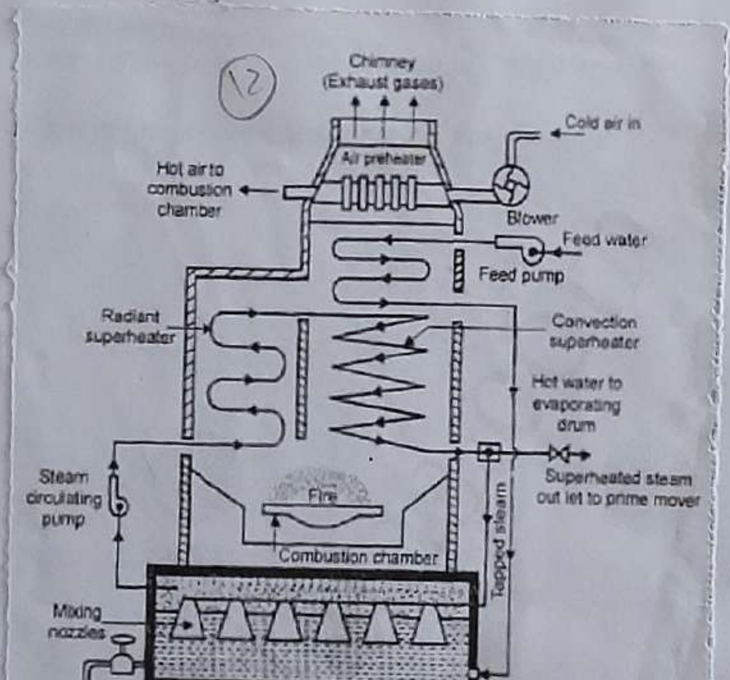
→ The capacity of this boiler is about 40 to 50 tonnes per hour of superheated steam at a pressure of 130 bar at 540°C.

* Loeffler Boiler:-

→ The high pressure feed pump feed water and supplies to economizer.

→ In economizer heat is exchanged from hot exhaust gases to feed water.

→ Hot water then enters the evaporating drum situated outside the boiler where the water is converted to saturated steam.



→ Mixing nozzles are provided in evaporating drum for evaporating feed water.

→ The capacity of boiler is about 100 tonnes per hour of super heated steam.

→ High velocity steam impinges on curved blades and its direction of flow is changed.

→ It causes a changes in momentum and thus, the force developed drives the turbine shaft.

→ The steam turbines has been used as a prime mover in all steam power plants.

→ Now a days, a single steam turbine of 1000 MW capacity is built in many countries.

Classification of Steam Turbines :-

1. On the basis of method of steam expansion
   * Impulse Turbine
   * Reaction Turbine
   * Combination of impulse and reaction
2. On the basis of number of stages.
   * Single Stage Turbines.
   * Multi Stage turbines

3. On the basis of steam flow directions

* Axial Turbine
* Radial Turbine
* Tangential Turbine.
* Mixed flow Turbine.

4. On the basis of pressure of steam.

* Low Pressure Turbine
* Medium Pressure Turbine
* High Pressure Turbine.

Comparision between impulse and reaction turbine.

Impulse	Reaction.
* Consists of nozzles and moving blades.	* Fixed and moving blades.
* It has constant blade channel area.	* It has varying blade channel area.
* Pressure drop occurs in nozzles.	* Pressure drop occurs in fixed and moving blades.
* Power developed is less	* Power developed is high.

Advantages :

* It requires less space.
* Simple in mechanism.
* It is quiet and smooth in operation.
* Its over load capacity is large.
* The power generated at uniform rate, therefore the flywheel is not needed.
* It can be designed for much higher speed.
* Efficiency is high.

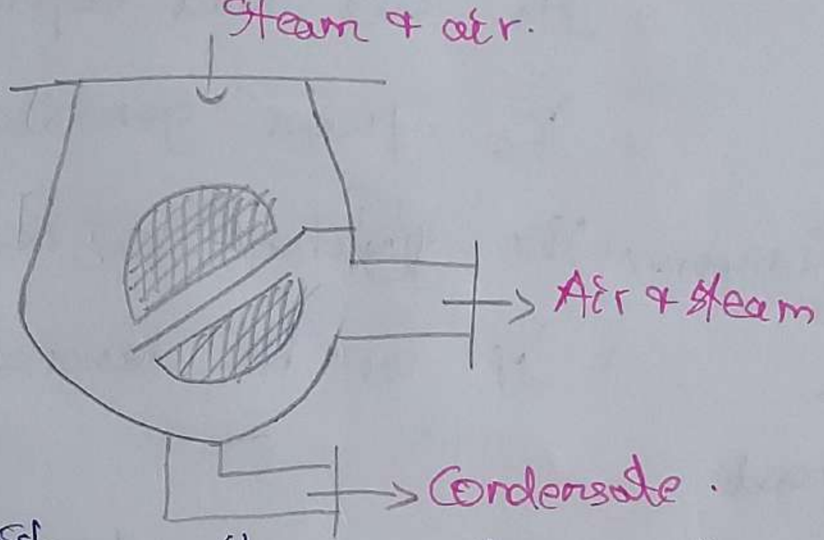
CONDENSORS :

→ Condenser is a closed vessel in which steam is condensed by abstracting the heat and where the pressure is maintained below atmospheric pressure.

→ The various types of condenser are as follows.

* Down flow condenser
* Central flow condenser.
* Evaporation condenser.

* Down Flow Condenser:

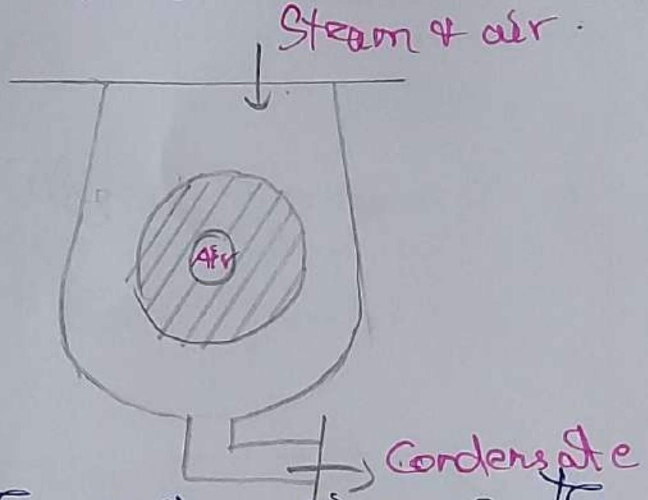


→ Steam enters on top of the condenser vessel and it comes down over cooling water pipes.

→ Also the partial pressure of steam decreases from top to bottom of steam condenser.

→ The air exit is scheduled from the down steam of condensate by means of baffle plate and thus air is extracted with only a comparatively small amount of vapour.

* Central Flow Condenser:



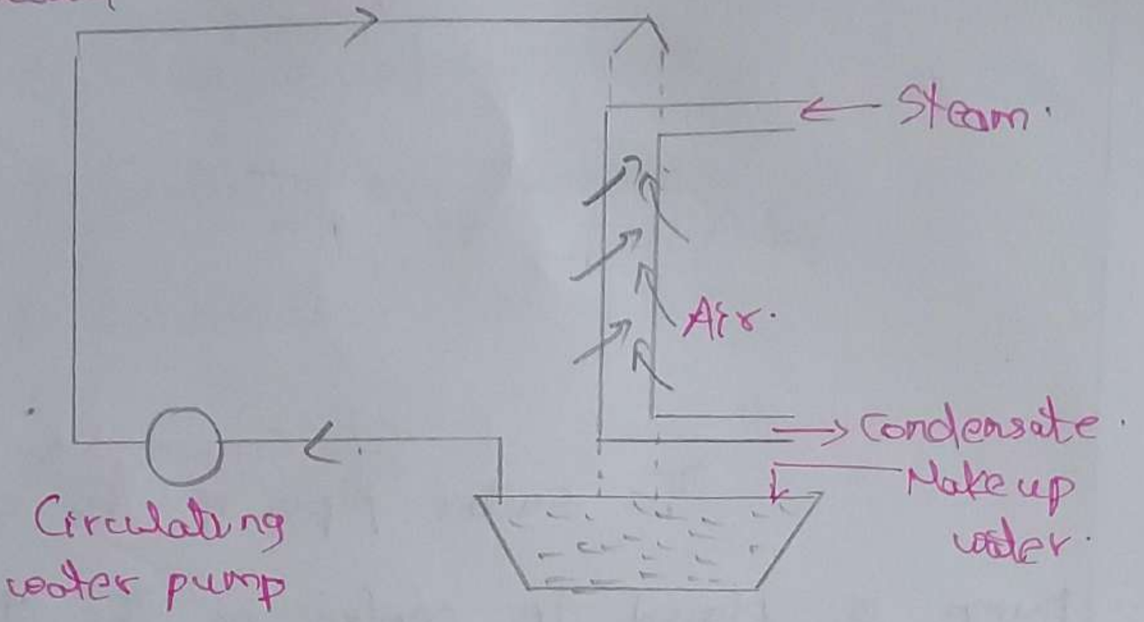
→ The suction pipe of the air extraction pump is placed in centre of the tubes nest, This causes the condensate to flow radially towards the centre.

→ The condensate leaves at the bottom where the condensate extraction pump is located.

→ The air is withdrawn from the center of the nest of tubes.

→ This method is an improvement on the down flow type as the steam is directed radially inward by a volute casting around the tube nest it has thus access to the whole periphery of the tubes.

* Evaporation Condenser:



→ As a water cooled condenser, evaporative cooling of condensers first transfer of heat into the water, and then form the water outdoors.

→ Evaporative condenser, however, combines the functions of a cooling tower and condenser are located in one package.

STEAM AND HEAT RATE:

* Steam Rate:

→ It is defined as the ratio of amount of steam (kg) or steam flow in kg/hr required to produce unit shaft power output (1 kW).

→ It is a measure of the capacity of a steam power plant.

$$\text{Steam rate} = \frac{3600}{W_{net}} \left(\frac{kg}{kW\text{-}hr} \right)$$

where W_{net} is in kJ/kg.

→ Higher steam rate requires more steam consumption for particular amount of power. Hence lower steam rate is desirable for power plant.

$$SSC = \frac{\text{Mass of steam } (m) \text{ in kg/hr}}{\text{Power output in kW}}$$

$$= \frac{m\ (kg/hr)}{m\ (kg/sec) \times W_{net}\ (kJ/kg)}$$

$$= \frac{3600}{W_{net}\ (kJ/kg)}$$

* Heat Rate:

→ It is the rate of heat input (Q_1) in kJ/hr required to produce unit power of 1 kW.

→ It is expressed as kJ/kW-hr.

$$\text{Heat rate} = \frac{3600 \times Q_1}{W_{net}} \left(\frac{kJ}{kW\text{-}hr}\right)$$

$$= \frac{\text{Heat supplied} \times 3600}{\text{Heat supplied} - \text{Heat rejected}} \ kJ/kW\text{-}hr.$$

$$= \frac{3600}{\text{Thermal efficiency}(\eta)} \ kJ/kW\text{-}hr.$$

$$= \frac{\text{Thermal Energy (input)}}{\text{Electrical Energy (output)}}.$$

$$= \frac{\text{mass of fuel (kg/hr)} \times \text{Calorific value (kJ/kg)}}{\text{Power output (kW)}}.$$

→ It indicates the amount of fuel required to generate one unit of electricity.

SUBSYSTEMS OF THERMAL POWER PLANTS:-

Fuel Handling System:-

Coal delivery.
↓
Unloading
↓
Preparation.
↓
Transfer.
↓
Outdoor storage.
↓
Inplant handling.
↓
Weighting and Measuring.
↓
Furnace.

i) Coal Delivery:-

Coal from supply point is delivered by ships or boats to power stations situated near to sea or river whereas coal is supplied by rail or trucks to power stations.

ii) Unloading:-

→ The type of equipment to be used for unloading the coal received at the power station depends on how coal is received at the power station.

→ Rotary car dumpers although costly are quite efficient for unloading closed wagons.

iii) Preparation:-

→ when the coal delivered is in the form of big lumps and it is not of proper size, The preparation of coal can be achieved by crushers, sizers etc.

iv) Transfer:-

After preparation coal is transferred to dead storage by means of following system.

* Belt Conveyors
* Screw Conveyors
* Bucket Conveyors
* Grab bucket elevators
* Skip Hoists.
* Flight Conveyors.

Ash Handling:

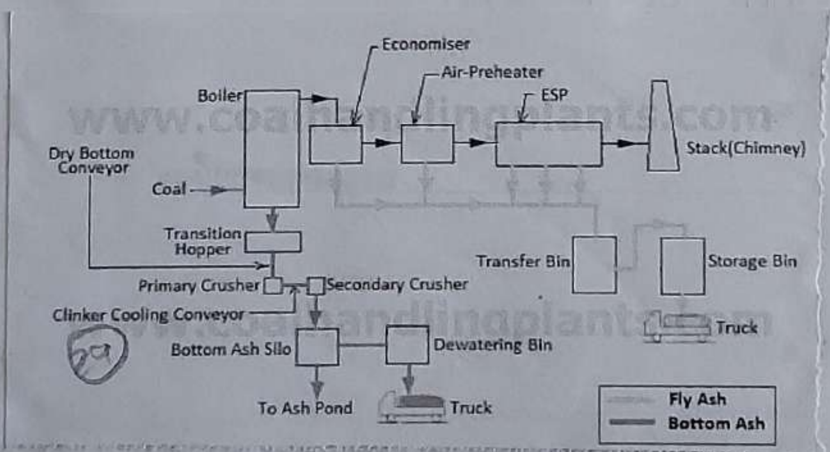
→ In thermal power plants, coal is used as a fuel for generating electricity.

→ After burning of coal, 40% of total cost consumption is converted into ash which need to be properly disposed off from thermal power plant.

Types of Ashes:

* Bottom ash.
* Fly ash.

Working of Ash Handling System:



Fly ash handling System:

→ Fly ash is captured and removed

from flue gases by economizer, air preheater and electrostatic precipitator located at outlet of the furnace and before the induced draft.

→ The fly ash is pneumatically transported from collection hopper of economizer, air-preheater and to storage silo for subsequent tracks.

Bottom ash Handling System:

→ It is collected in bottom hopper located under the furnace boiler.

→ Due to coarse in nature it is treated through clinkers and grinders to normalize the bottom ash size.

Ash slurry disposal system:

→ Ash received from bottom ash is mixed with water in bottom ash silo.

→ Slurry formed due to mixing of water and ash is transported to ash disposal area using high concentration ash slurry disposal system, lean ash slurry disposal system.

DRAUGHT SYSTEM :

→ Because of the emission of large amount of flue gases and other materials environment is polluted, Thus to decrease the environmental pollution some techniques and equipments are used.

→ Generally Electrostatic precipitators and Draught system is used by coal gas plants to decrease the environment pollution.

→ The types of draught systems are as follows.

* Natural draught
* Artificial draught

* Natural draught :

→ This system of producing the draught is useful for small capacity boilers and it does not play much important role in present high capacity thermal power plant.

→ A chimney is a vertical structure of masonry ; brick built for the purpose of enclosing a column of hot gases to produce the draught and discharge the gases high enough which will prevent an air pollution the draught produced by the chimney.

Artificial Draught :-

Artificial draught can be further classified as.

* Forced draught
* Induced draught.
* Balanced draught.

* Forced Draught :

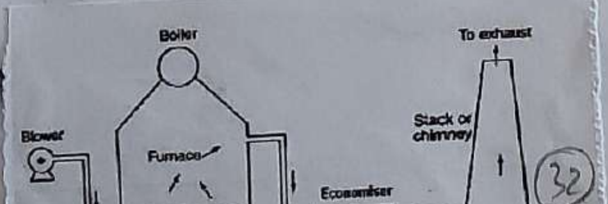


Figure L.99 Forced draught

→ This draught system is known as positive draught or forced draught system because the pressure of air throughout the system is above atmospheric pressure and air is forced to flow throughout the system.

→ A stack or chimney is also used in this system but its function is to discharge gases high in the atmosphere to prevent the contamination.

* Induced draught:

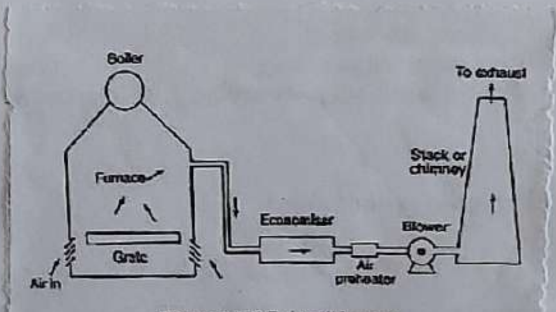


Figure 1.100 Induced draught

→ This draught system is used generally when economizer and air preheater are incorporated in the system.

→ The fan should be located at

such a place that the gas temperature handled by the fan is lowest.

→ The chimney is also used in this system and its function is similar as mentioned in forced draught but total produced in induced draught is sum of the draught produced by chimney.

* Balanced draught.

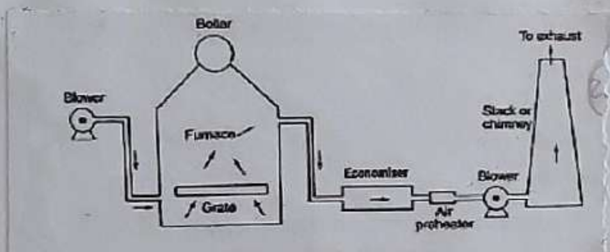


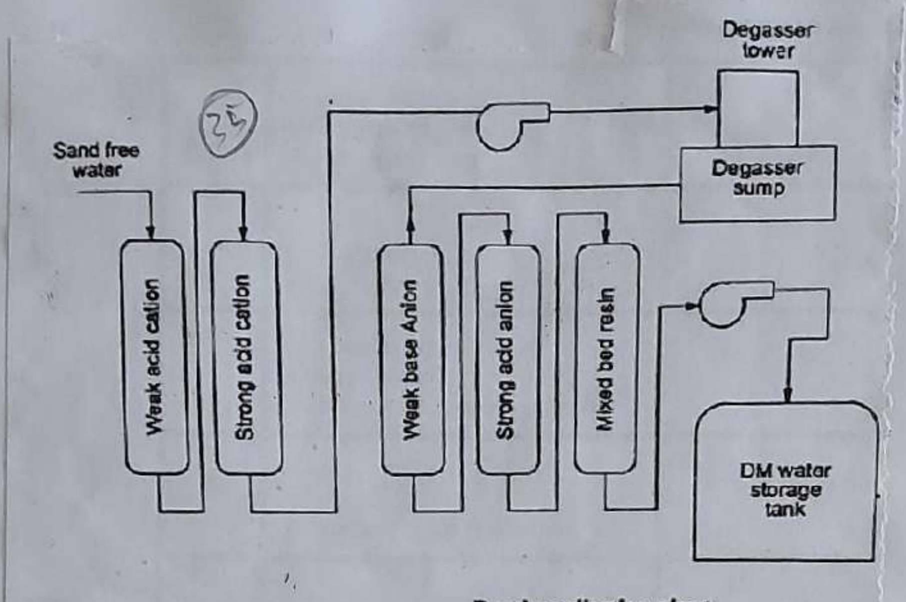
Figure 1.101 Balanced draught

→ Balanced draught is the combination of forced and induced draught.

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

→ The pressure of air above the grate is just below the atmosphere.

FEED WATER TREATMENT :



Demineralization plant

→ Boiler water treatment is used to control alkalinity, prevent scaling, correct PH and to control conductivity.

→ The boiler water needs to be alkaline and not acidic, so that it does not ruin the tubes.

→ There can be too much conductivity in the feed water when there are too many dissolved solids.

→ The main objectives to treat and condition boiler water is to exchange heat without scaling, produce steam.

→ The treatment of boiler water can be put into two parts.

* Internal treatment.
* External treatment

→ The internal treatment is for boiler feed water and external treatment is for make up feed water and to condensate part of the system.

→ Internal treatment protects against feed water hardness by preventing precipitating of scale on the boiler tubes.

→ This treatment also protects against concentrations of dissolved and suspended solids in the feed water without priming or foaming.

→ These treatment chemicals also help with the alkalinity of feed water making it more of a base to help protect against boiler corrosion.

→ The correct alkalinity is protected by adding phosphates.

→ These phosphates precipitate the solids to the bottom of the boiler drum.

→ At the bottom of the boiler drum there is a bottom blow to remove these solids.

→ These chemicals also include anti-scaling agents, oxygen scavengers, and anti foam agents.

→ Sludge can also be treated by two approaches.

* Coagulation
* Dispersion

→ When there is a high amount of sludge to form large particles in order to just use the bottom blow to remove them from the feed water.

BINARY CYCLES:-

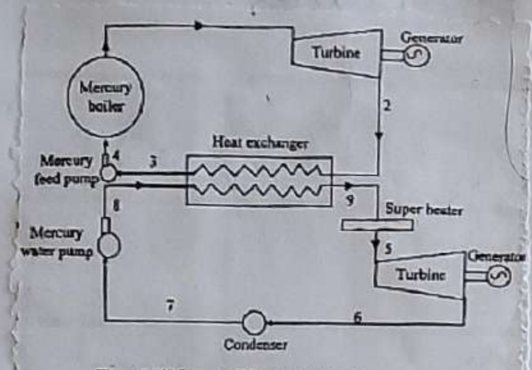
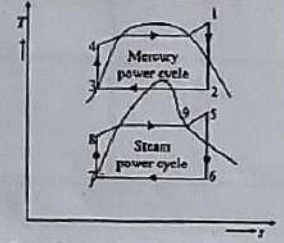


Figure 1.113 Layout of binary vapour cycle



→ A binary vapour cycle is defined in Thermodynamics as a power cycle that is a combination of two cycles, one in a high temp region and other in low region.

→ A binary cycle power plant is a type of geothermal power plant that allows cooler geothermal reservoirs to be used than is necessary for dry steam and flash steam plants.

→ As of 2010, flash steam plants are

The most common type of geothermal power generation plants in operation today, which use water at temperature greater than 182°C.

→ With binary cycle geothermal power plants, pumps are used to pump hot water from a geothermal well, through a heat exchanger, and the cooled water is returned to underground reservoir.

→ A second working or binary fluid with a low boiling point, typically a butane or petane hydrocarbon, is pumped at fairly high pressure through the heat exchanger, where it is vaporized and then directed through a turbine.

→ The vapor exiting the turbine is then condensed by cold air radiators or cold water and cycled back through heat exchanger.

→ Binary vapour cycle is defined in thermodynamic as a power cycle.

COGENERATION SYSTEM:

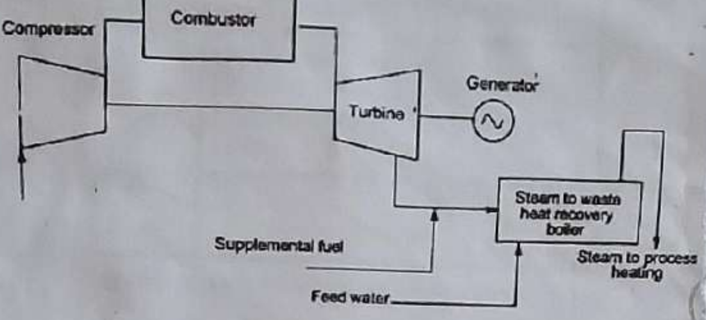


Figure 1.116 Gas turbine topping CHP plant

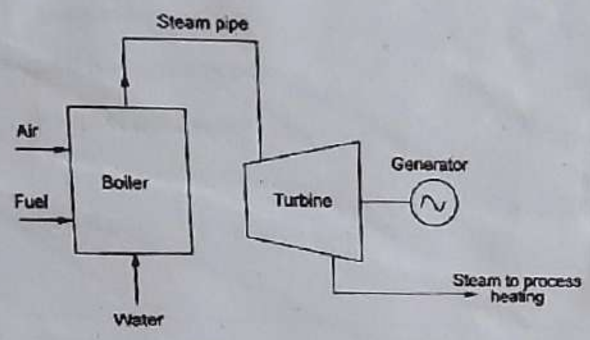


Figure 1.117 Steam-turbine topping CHP Plant

→ Combined heat and power plants recover otherwise wasted thermal energy for heating at moderate temperatures (100 - 180°C, 212 - 356°F) can also be used.

→ Cogeneration system is the use of a heat engine or power station to generate electricity and useful heat at the same time.

→ Cogeneration can also be applied to the power systems generating simultaneously electricity, heat and industrial chemicals.

Eg: Syngas or pure hydrogen.

→ Cogeneration system recover otherwise waste thermal energy for heating.

→ This is also called combined heat and power district heating.

→ Small CHP plants are an example of decentralized energy.

→ By product heat at moderate temperatures can also be used in absorption refregirators for cooling.

→ The supply of high temperature heat first drives a gas or steam turbine powered generator.

→ Combined cooling, heat and power systems can attain higher overall efficiencies than cogeneration or traditional power plants.

→ Trigeneration differs from cogeneration in that the waste heat is used for both heating and cooling, typically in absorption refregirator.

→ Cogeneration was practised in some of the earliest installations of electrical generation.

→ Before central stations distributed power, industries generating their own power used exhaust steam for process heating.

→ Large office and apartment building hotels and stores commonly generated their own power and used waste steam for building heat.

→ Due to high cost of early purchased power, these CHP operations continued for many years after utility electricity became available.

UNIT - II

DIESEL, GAS TURBINE AND COMBINED CYCLE POWER PLANTS

OTTO CYCLE:

→ An otto cycle is an idealized cycle that describes the functioning of a typical spark ignition piston engine.

→ In case of the otto cycle, the effect will be to produce enough net work from the system so as to propel an automobile and it's occupants in environment.

→ The otto cycle is constructed from.

Top and bottom of the loop:

A pair of quasi-parallel and isentropic processes.

Left and right sides of the loop:

A pair of parallel isochoric process (constant volume).

→ The isentropic process or expansion implies that there will be no inefficiency and there be no transfer of heat into or out of the system.

→ Hence the cylinder, and piston are assumed impermeable to heat during that time.

→ Work is performed on the system during the lower isentropic compression process.

→ Heat flows into Otto cycle through the left pressurizing process and some of it flows back out through the right depressurizing process.

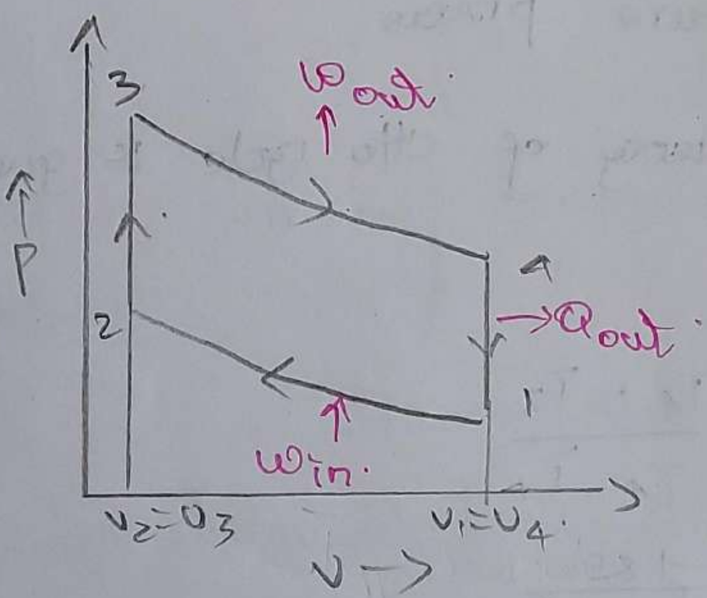
→ The process are described by

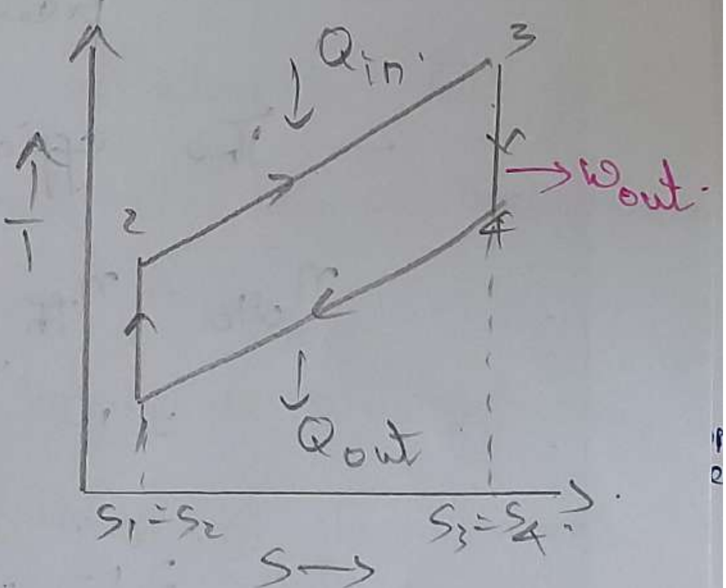
Process 0-1 :- A mass of air is drawn into piston at constant pressure.

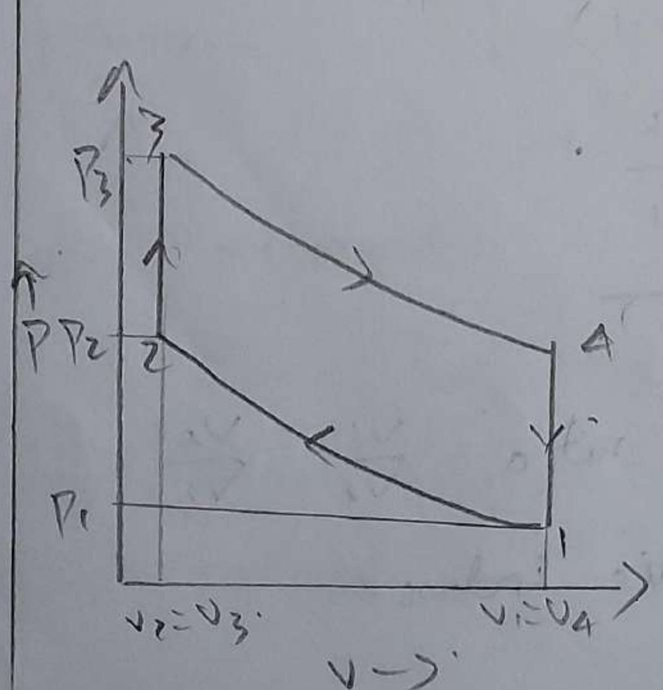
Process 1-2 :- An adiabatic compression of the charge as piston moves from BDC to TDC.

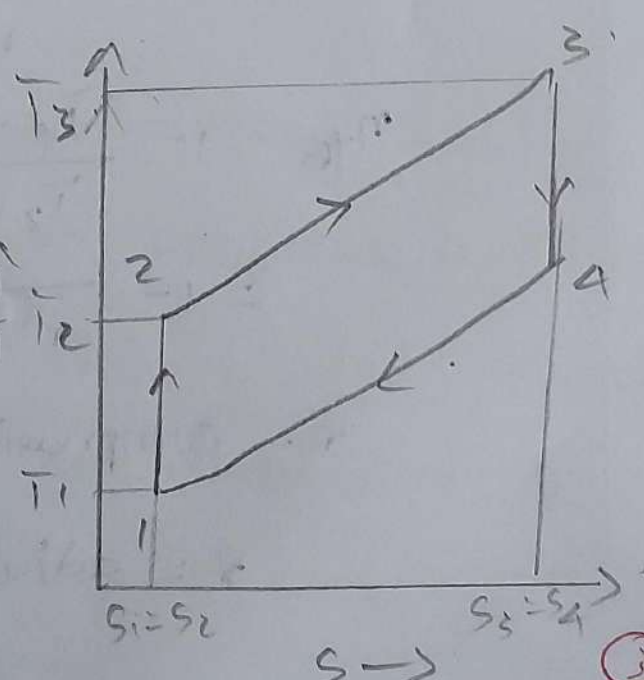
Process 2-3 : * Constant Volume heat transfer to the working gas from an external source while the piston is set is at top dead centre.

* The process is intended to represent the ignition of fuel air mixture and rapid burning.









Process 3-4 : Adiabatic expansion.

Process 4-1 : Completes the cycle by a constant volume process in which heat is rejected from air while the piston is at bottom dead centre.

Process 1-0 : The mass of air is released to the atmosphere in a constant pressure process.

→ The efficiency of otto cycle is given by

$$\eta_{otto} = \eta_{th}$$

$$= 1 - \frac{T_4 - T_3}{T_2 - T_1}$$

$$= 1 - \frac{1}{r^{(\gamma - 1)}}$$

$$\eta_{th} = 1 - \frac{T_4 - T_3}{T_2 - T_1}.$$

$$= 1 - \frac{1}{r^{(\gamma - 1)}}$$

r = compression ratio = $\frac{V_1}{V_2} = \frac{V_4}{V_3}$.

γ = adiabatic index.

DIESEL CYCLE:

→ Diesel cycle was invented by Rudolph Diesel in the year 1893.

→ He put forward an idea by which we can attain higher thermal efficiency with a high compression ratio.

→ All diesel engine works on this cycle.

→ Diesel is used as fuel in this cycle as it can be compressed at higher compression ratio.

→ It is also known as constant pressure cycle because heat is added in it at constant pressure.

→ It has high thermal efficiency and compression ratio as compared to otto cycle.

→ The engine that is put forward by Rudolph consists of an enclosed air in the cylinder.

→ The cylinder walls are perfectly non conductors of heat, but the bottom is a perfect conductor of heat.

→ It has a hot body, cold body and insulating cap, which are alternately brought in contact with the cylinder.

→ The ideal diesel cycle consists of 4 processes, two isentropic, one constant pressure and one constant volume.

→ The four processes are as follows

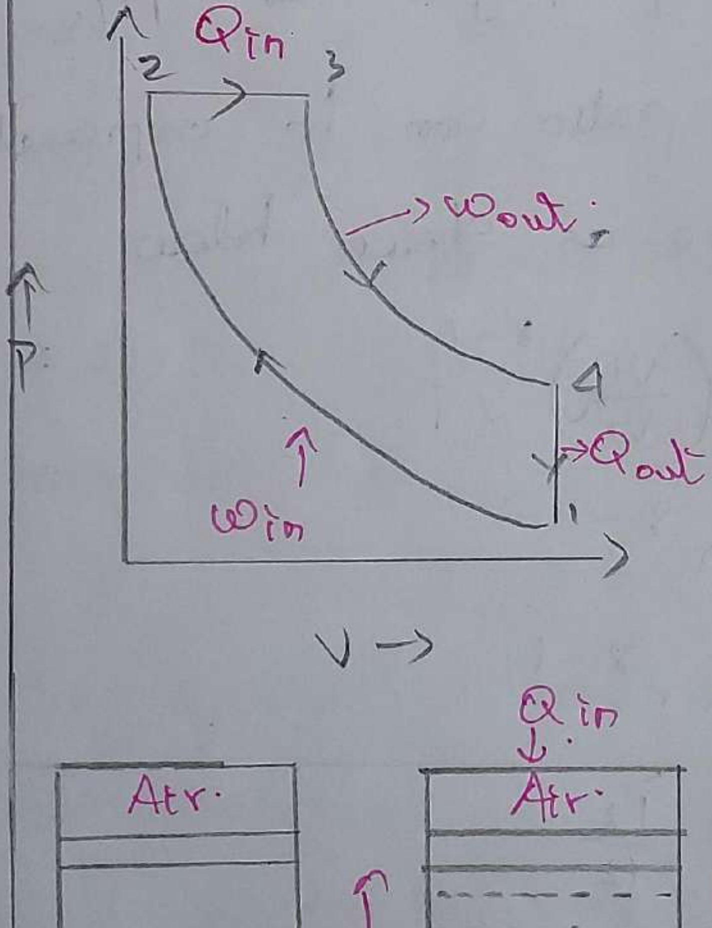
* Isentropic Compression
* Constant Pressure Heat addition
* Isentropic Expansion.
* Constant Volume Heat rejection.

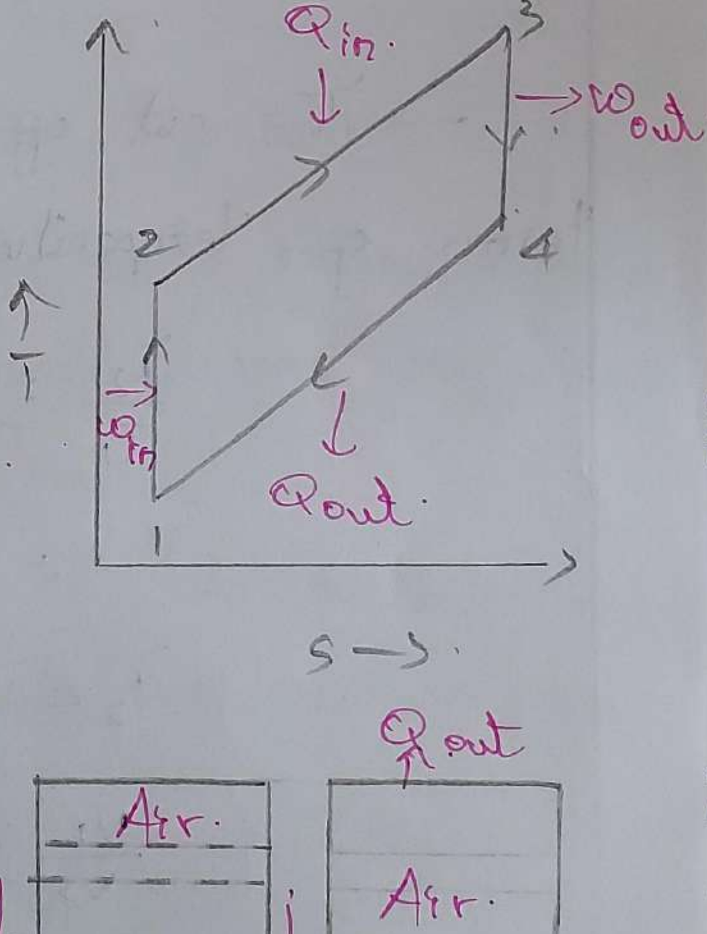
→ Compared to otto cycle which assumes an instantaneous heat addition, heat is partly at constant volume and constant pressure.

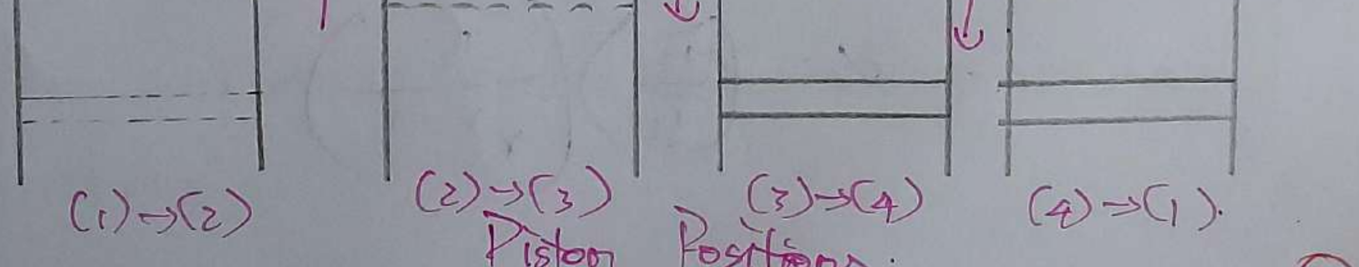
→ Therefore the advantage is that more time is available for the fuel to combust completely.

→ On the other hand, the use of a dual cycle is slightly more complex.

→ The thermal efficiency lies between Otto and Diesel Cycle.







Piston Positions.

$$\eta_{Th} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\alpha^{\gamma}-1}{\gamma(\alpha-1)}\right]$$

where

η_{Th} is Thermal efficiency.

α is cut off ratio V_3/V_2.

r is the compression ratio $\frac{V_1}{V_2}$.

γ is ratio of specific heat C_p/C_v.

→ The cut off ratio can be expressed in terms of temperature as shown below.

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$= r^{\gamma-1}$$

$$T_2 = T_1 r^{\gamma-1}.$$

$$\frac{V_3}{V_2} = \frac{T_3}{T_2}.$$

$$\alpha = \left(\frac{T_3}{T_1}\right)\left(\frac{1}{r^{\gamma-1}}\right)$$

DUAL CYCLE:

→ The dual combustion cycle is a Thermal cycle That is a combination of Otto Cycle and Diesel Cycle first introduced by Russian German engineer Gustav Trinkler.

→ Heat is added partly at constant volume and partly at constant pressure, The advantage of which is more time is available for The fuel to completely combust.

→ Because of lagging characteristics of fuel this cycle is invariably used for Diesel and hot spot ignition engines.

→ It consists of two adiabatic and two constant volume and one constant pressure processes.

→ It consists of two adiabatic and two constant volume and one constant pressure processes.

→ Efficiency lies between otto and diesel cycle.

→ The dual cycle consists of the following operations.

Process 1-2 : Isentropic Compression.

Process 2-3 : Heat addition at constant volume.

Process 3-4 : Heat addition at constant pressure.

Process 4-5 : Isentropic expansion.

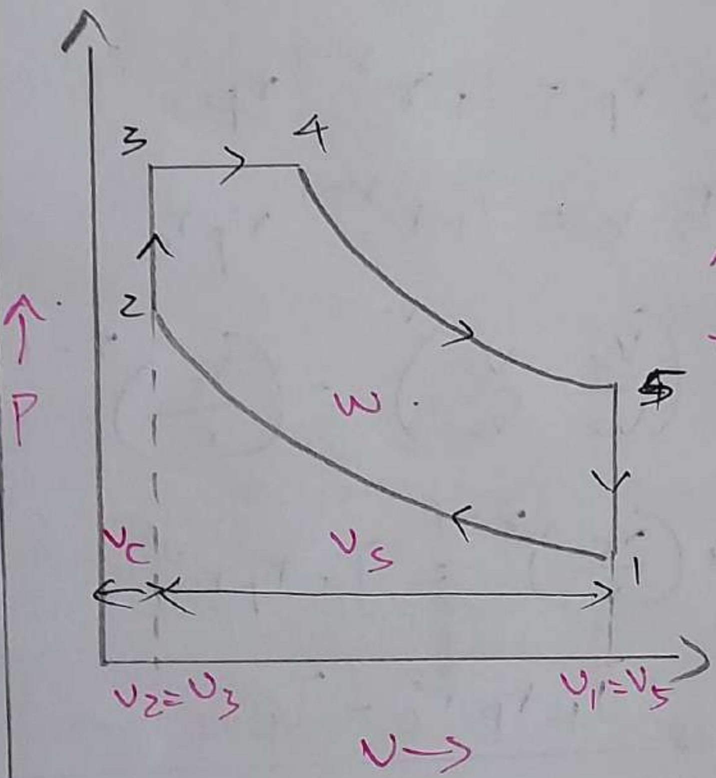
Process 5-1 : Heat rejection at constant volume.

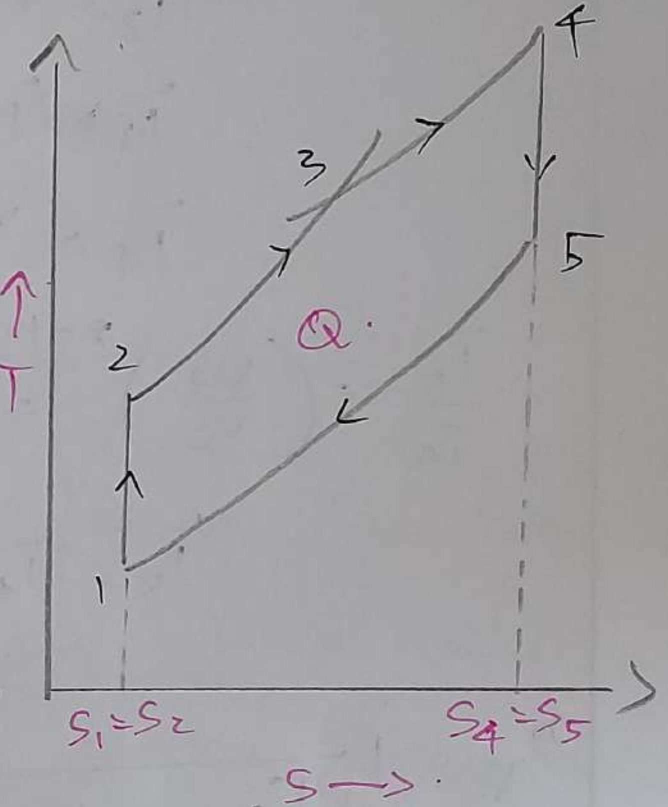
→ During the dual cycle, The piston works on the gas between states 1 and 2.

→ The gas works on the piston between stages 2 and 3. and 2 & 3.

→ The difference between workdone by gas and work done is the networks produced by the cycle and it corresponds to area enclosed by cycle curve.

→ The work produced by the cycle times the rate of the cycle is equal to the power produced by Diesel engine.





Heat supplied $= mC_v(T_3 - T_2) + mC_p(T_4 - T_3)$

Heat rejected $= mC_v(T_5 - T_1)$

Net work done $= mC_v(T_3 - T_2) + mC_p(T_4 - T_3) - mC_v(T_5 - T_1)$.

$$\eta_{th} = \frac{mC_v(T_3 - T_2) + mC_p(T_4 - T_3) - mC_v(T_5 - T_1)}{mC_v(T_3 - T_2) + mC_p(T_4 - T_3)}$$

$$\eta_{th} = 1 - \frac{T_5 - T_1}{(T_3 - T_2) + \gamma(T_4 - T_3)}$$

Let $P_3/P_2 = r_p$; $\frac{V_4}{V_3} = r_c$; $\frac{V_1}{V_2} = r$.

$$T_2 = T_1 r^{\gamma-1}$$

$$T_3 = T_2 r_p = T_1 r^{\gamma-1} r_p$$

$$T_4 = T_3 r_c = T_1 r^{\gamma-1} r_p r_c$$

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{V_4}{V_2} \cdot \frac{V_2}{V_5}\right)^{\gamma-1} = \left(\frac{r_c}{r}\right)^{\gamma-1}$$

$$T_5 = T_4 \left(\frac{r_c}{r}\right)^{\gamma-1} = T_1 r_p r_c^{\gamma}$$

$$\eta_{th} = 1 - \frac{T_1 r_p r_c^{\gamma} - T_1}{\left[(T_1 r^{\gamma-1} r_p - T_1 r^{\gamma-1}) + \gamma(T_1 r^{\gamma-1} r_p r_c - T_1 r^{\gamma-1} r_p)\right]}$$

$$= 1 - \frac{(r_p r_c^{\gamma} - 1)}{\left[(r_p r^{\gamma-1} - r^{\gamma-1}) + \gamma(r_p r_c r^{\gamma-1} - r_p r^{\gamma-1})\right]}$$

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{r_p r_c^{\gamma} - 1}{(r_p - 1) + \gamma r_p (r_c - 1)}\right]$$

BRAYTON CYCLE:-

→ Brayton cycle is the ideal cycle for gas turbine engines.

→ There are two types of Brayton cycle which are as follows.

* Open gas turbine Cycle
* Closed gas turbine Cycle.

→ The difference between These two cycles is That during open gas cycle a combustion takes place and exhaust gas are Thrown out, while in closed gas cycle the combustion process is replaced by heat addition process. The exhaust gases are also utilized so as to increase the temperature of air enters the compressor.

Working:

→ First, fresh air at ambient condition is taken into compressor and here the air temperature and pressure are raised, resulting of the compression process.

→ Second, high pressure air draws into the combustion chamber and mixes with the fuel.

→ Here the combustion process occurs at constant temperature.

→ Third, the resulting high temperature gases enters the turbine to generate power.

→ In this operation, the hot gases are expand to the atmospheric pressure.

→ Finally the exhaust gases leaving the turbine are discharged.

→ In the closed gas turbine, although the compression and expansion process have in common, combustion chamber is replaced by a heat exchanger in which increases the compresed air temperature.

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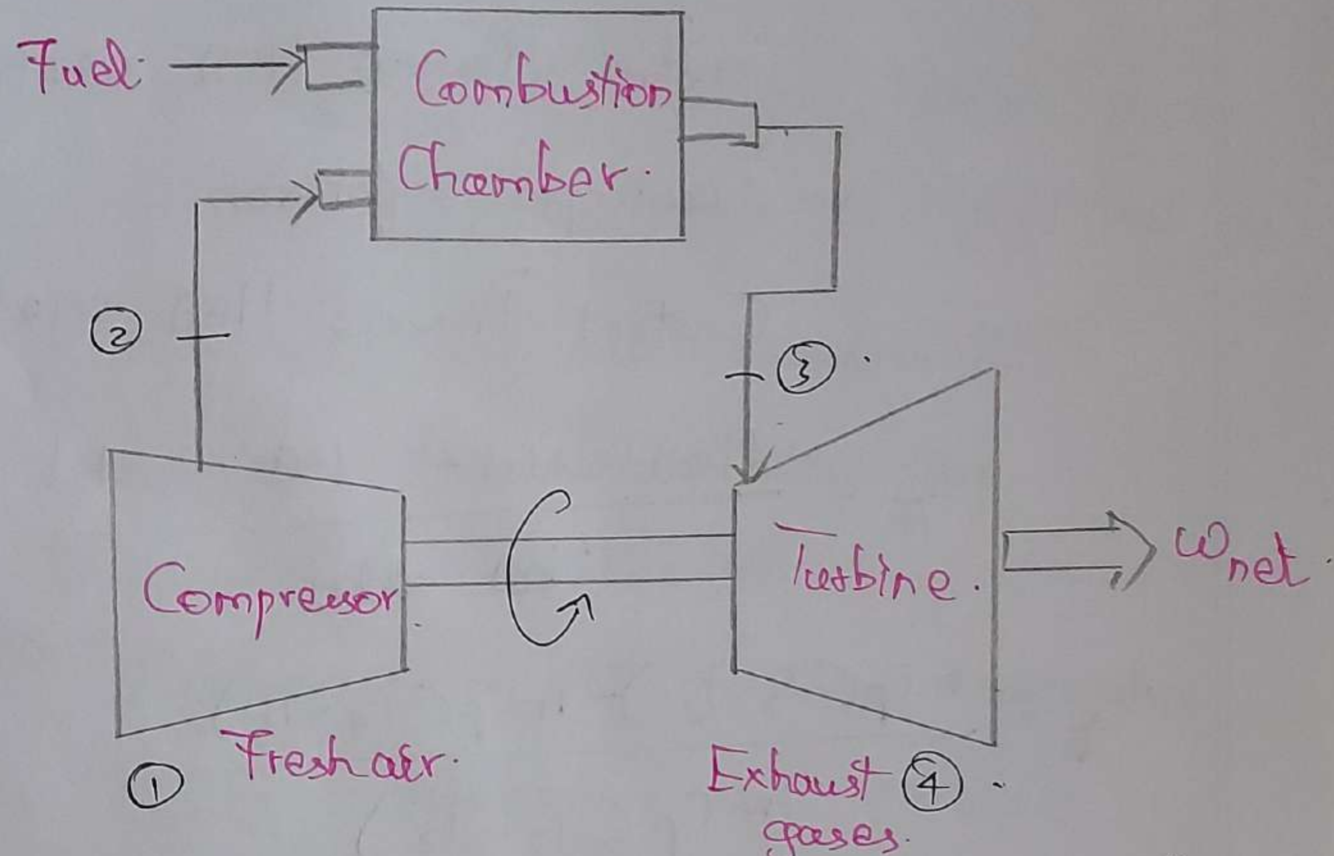
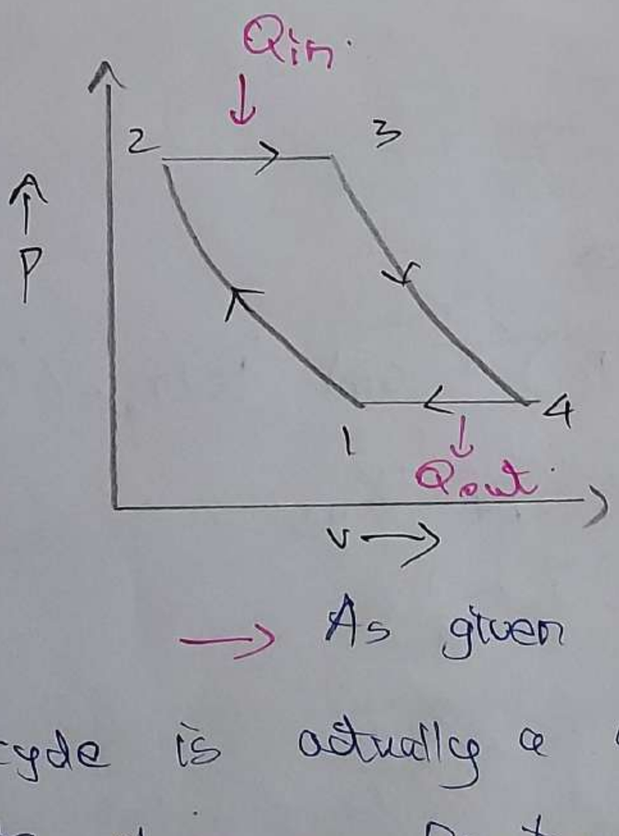
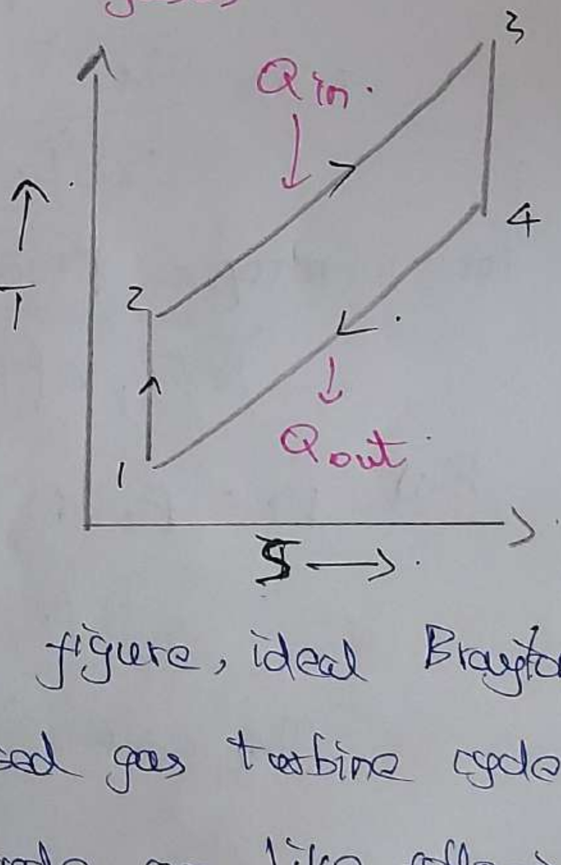






→ As given in figure, ideal Brayton cycle is actually a closed gas turbine cycle, The steps of Brayton cycle are like following.

→ The steps are going to get discussed in following session.

Process 1-2: Isentropic compression.

Process 2-3: Constant Pressure Heat addition

Process 3-4: Isentropic expansion

Process 4-1: Constant Pressure Heat rejection.

$$\eta_{Th} = \frac{\text{Heat added} - \text{Heat rejected}}{\text{Heat added}}$$

$$\eta_{Th} = \frac{mC_p(T_3 - T_2) - mC_p(T_4 - T_1)}{mC_p(T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For isentropic processes

$$T_2/T_1 = (P_2/P_1)^{\frac{\gamma-1}{\gamma}} \text{ and } T_3/T_4 = (P_3/P_4)^{\frac{\gamma-1}{\gamma}}$$

But $P_2 = P_3$ & $P_1 = P_4$ Thus.

$$T_2/T_1 = T_3/T_4.$$

$$\eta_{Th} = 1 - \frac{T_4}{T_3} = 1 - \frac{T_1}{T_2}.$$

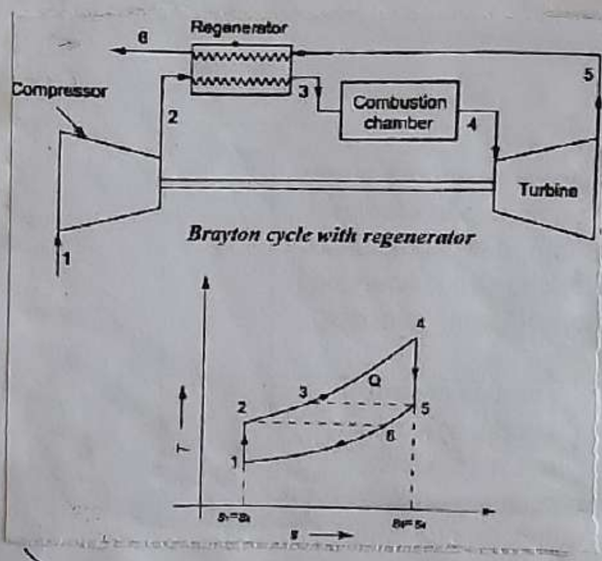
$$\eta_{Th} = 1 - \frac{1}{r_p^{\frac{\gamma-1}{\gamma}}}$$

ANALYSIS AND OPTIMIZATION

→ The efficiency of gas turbine power plant can be improved in four ways such as

* Brayton cycle with regeneration
* Brayton cycle with intercooling
* Brayton cycle with reheating
* Brayton cycle with combine regeneration, intercooling and reheating.

*Brayton Cycle with regeneration:



Brayton cycle with regenerator

→ Regenerator preheats the air using the exhaust.

→ Thermal efficiency increases.

* Work not altered.

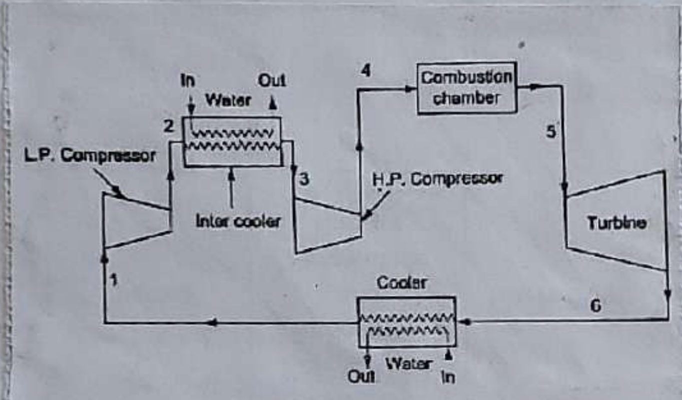
* Heat added reduced.

$$Q_{in} = \dot{m}(h_3 - h_x).$$

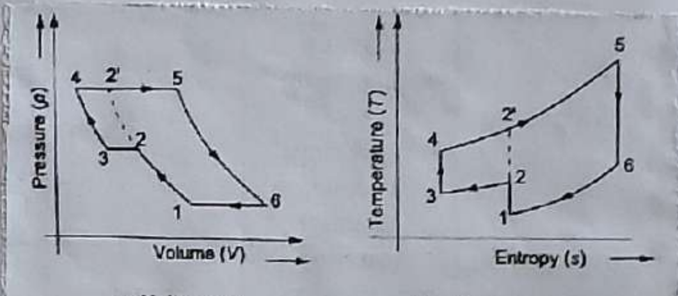
→ Regenerator effectiveness.

* Maximum Theoretical value of T_x is T_4.

* Brayton Cycle with intercooling:



Brayton cycle with intercooler



p-V diagram   T-s diagram

→ Multistage compression with intercooling decreases input work.

→ The work required to compress a gas between two specified pressures can be decreased by carrying out the compression process in stages and cooling the gas in between.

→ This keeps the specific volume as low as possible.

COMPONENTS OF DIESEL AND GAS POWER PLANT :

→ Diesel power plant is used to generate electrical energy for small scale production and at the load end.

→ When the grid power is not available the diesel engine is used to supply load in emergency condition.

→ The various components of diesel power plant are shown below.

* Diesel Engine
* Air intake system
* Exhaust system
* Cooling water system
* Fuel supply system
* Lubrication system
* Diesel engine starting system

→ The brief description of each components are shown below.

* Engine :-

→ Diesel engine is the main component of diesel power plant.

→ There are two types of diesel engine

* Two stroke engine
* Four stroke engine.

→ Four stroke engines are more preferred over two stroke engines for the application of small scale generation and DG sets.

$$\text{Capacity of Plant} = \frac{(\text{Connected Load} \times \text{Demand Factor})}{(\text{Diversity Factor})}$$

* Air intake System :-

→ Large diesel engine power plant requires air in the range of 4-8 m^3/kwh.

→ In natural air, lots of dust particles are available which may damage the cylinders of engine.

* Exhaust System:-

→ While combustion of diesel, gase are produced.

→ The exhaust system are designed in such a way that they will remove gases without losing pressure.

→ If pressure releases, it requires more work to do to exhaust gases.

* Cooling Water System:-

→ The IC Engine works by burning fue with air and the percentage utilization of energy is as below.

* 30 - 37% - useful work.
* 30 - 35% - carried by exhaust gases.
* 0 - 12% - lost by radiation
* 22 - 30% - Heat energy flows.

* Fuel Supply System:-

→ In a diesel power plant, as the name suggests, diesel is used as a fuel.

* Depending upon the capacity of engine, the fuel must be filtered.

* Provide return path to unused fuel.

* Lubricating System:

→ The Lubrication system prevents direct contact between two metals and will reduce the wear and tear in moving parts.

* Piston and Cylinder.
* Main crankshaft bearings.
* Cam, camshaft & bearings.
* Ends of bearings.

* Diesel Engine starting System:

→ There are several methods introduced to start a diesel engine. some of them are follows.

* Hand or kick starting
* Electrical starting.
* Hot bulb ignition.
* Compressed air.

COMBINED CYCLE POWER PLANTS:

→ Combined Cycle Power Plant or combined cycle gas turbine, a gas turbine generator generates electricity and waste heat is used to make steam to generate additional electricity.

→ The gas turbine is one of the most efficient one for the conversion of gas fuels to mechanical power or electricity.

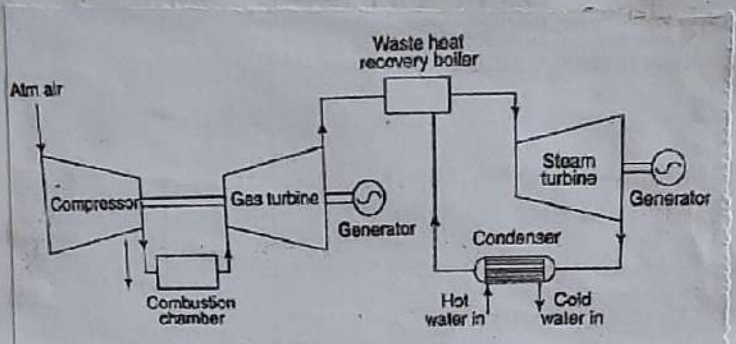
→ The use of distilled liquid fuels, usually diesel, is also common as alternate fuels

→ More recently, as simple cycle efficiencies have improved and as natural gas prices have fallen, gas turbines have been more widely adopted for base load power generation especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam used to produce additional electricity.

→ There are two types of combined cycle power plant.

* Gas Turbine - Steam Turbine Plant.
* Gas Turbine - Diesel Power Plant

* Gas Turbine - Steam Turbine Plant.

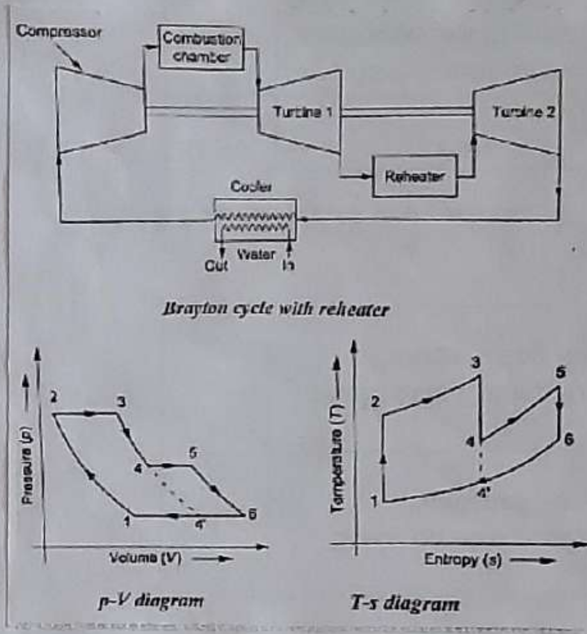


Combined gas turbine-steam turbine power plant

→ Combined Cycle power generation improves the general thermal efficiency of the plant by recovering this high temperature exhaust gas.

→ Many combined cycle power generation plants adopt a waste heat recovery cycle in which exhaust gas from gas turbine is led to the waste recovery boiler to generate steam using recovered heat to drive steam turbine.

* Brayton cycle with reheating:-



Brayton cycle with reheater

p-V diagram *T-s diagram*

→ Reheating keeps the specific volume of working fluid as high as possible during an expansion process, thus maximizing work output.

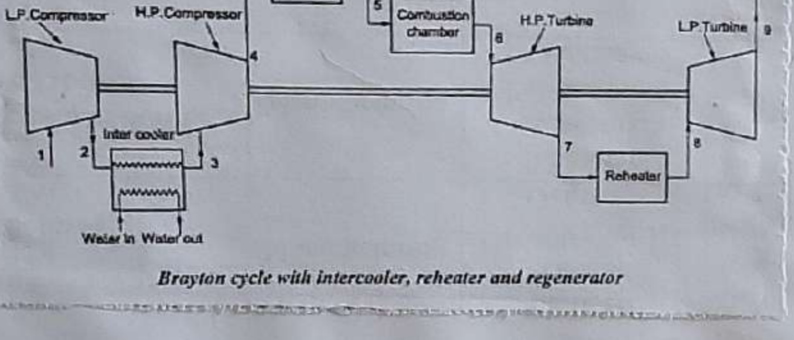
→ Reheating increases work while limiting temperature.

* Brayton cycle with combined work:-

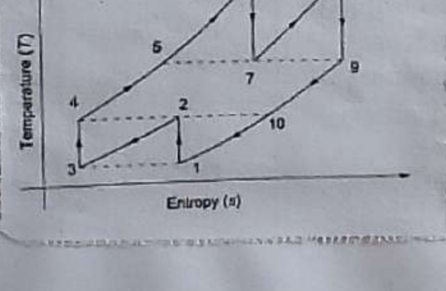
→ Reheat and intercooling are complementary to heat generation.

→ By themselves, they would not necessar increases the thermal efficiency, however, when intercooling or reheat is used in conjuction with heat regeneration, a significant increase in thermal efficiency can be achieved, and the net work output is also increased.

→ This requires a gas turbine with two stages of compression and two turbine stages.



Brayton cycle with intercooler, reheater and regenerator



→ The thermal efficiency can be improved by increasing pressure ratio, heat regeneration, reheat.

Advantages:

* High thermal Efficiency

→ In comparison with thermal efficiency of about 40% in steam power generation, combined cycle power generation feature a thermal efficiency of atleast 60%.

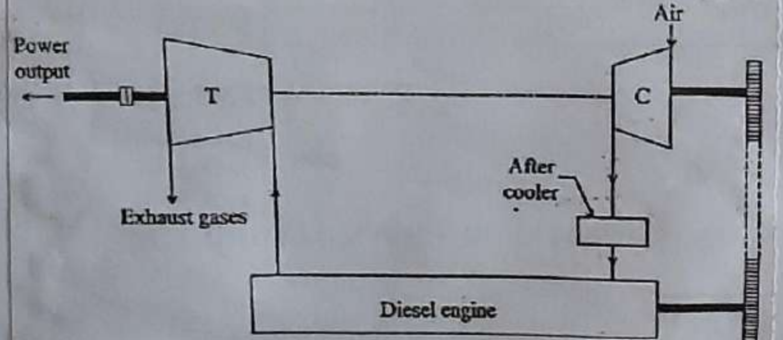
* Environmentally friendly.

→ CO_2 is released in smaller quantities into the atmosphere.

→ NO_x and SO_x are released in smaller quantities into atmosphere.

→ High temperature wastewater is discharged in smaller quantities into the sea.

* Gas turbine - Diesel power plant.



→ Combined diesel and gas is a type of propulsion system for ships that need a maximum speed that is considerably faster than their cruise speed particularly warships like modern frigates and corvettes.

→ Sometimes the engine arrangement of diesel engine and gas turbine with each system using its own shafts and propellers is also called CODAG.

→ Such installation avoid the use of a complicated switching gearbox, but have some disadvantages compared to real CODAG system.

Advantages:

* Efficiency is high.
* Suitable for rapid start and shutdown.
* High ratio of power output to occupy ground space.

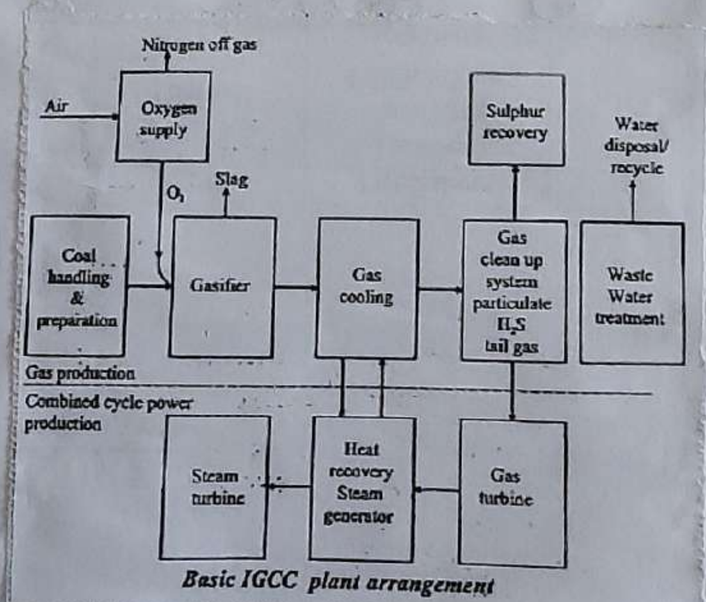
INTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS

→ An integrated gasification combined cycle is a technology that uses a high pressure gasifier to turn coal and other carbon based fuels into pressurized gas synthesis gas.

→ It can then remove impurities from syngas prior to power generation cycle.

→ Some of these pollutants such as sulfur can be turned into reusable byproducts through the claus process.

→ This results in lower emissions of SO_2, particulates, mercury, and in some cases CO_2



Basic IGCC plant arrangement

→ With additional process equipment, a water gas shift reaction can increase gasification efficiency and reduce CO emission by converting it to CO_2.

→ The resulting CO_2 from the shift reaction can be seperated, compressed and stored through sequestration.

→ Excess heat from the primary combustion and syngas fired generation is then passed to steam cycle.

→ This process results in improved thermodynamic efficiency compared to conventional pulverized coal combustion.

→ The gasification process can produce syngas from a wide variety of carbon containing feedstocks, such as high sulfur coal, heavy petroleum residues and biomass.

→ The plant is called integrated because of the following reasons.

* The syngas produced in gasification section is used as fuel for gas turbine in combined cycle.

* The steam produced by syngas coolers in gasification section is used by the steam turbine in combined cycle.

→ In a normal combined cycle so called "waste heat" from gas turbine exhaust is used in a Heat Recovery Steam Generator (HRSG) to make steam for steam turbine cycle.

→ An IGCC plant improves the overall process efficiency by adding the higher temperature steam produced by the gasification process to the steam turbine cycle.

→ IGCC plants are advantageous in comparison to conventional coal power plants due to their high thermal efficiency, low non carbon greenhouse gas emissions, and capability to process low grade coal.

UNIT - III

NUCLEAR POWER PLANTS

(1) Basics of Nuclear Engineering :

* Nuclear power is a clean and efficient way to make steam which turns turbine to produce electricity.

* Nuclear power plants use low enriched uranium fuel to produce electricity through a process called fission - The process of splitting of uranium atoms in nuclear reactor.

* Uranium fuel consists of small, hard ceramic pellets that are packed into a long, vertical tubes.

* Bundles of this fuel are inserted into the reactor.

* A single uranium pellet, slightly larger than a pencil eraser, contains the same

energy as a ton of coal, 3 barrels of oil or 17,000 cubic feet of natural gas.

* Each uranium fuel pellet provides up to five years of heat for power generation.

* And because Uranium is one of the world's most abundant metals, it can provide fuel for the world's commercial nuclear plant for generations to come.

* Nuclear power offers many benefits for the environment as well.

* Power plants burn any materials, so They produce no combustion by products.

* Additionally, because they dont produce greenhouse gases, nuclear power plant helps protect air quality and mitigate climate change.

* When it comes to efficiency and reliability no other electricity source can match

nuclear energy.

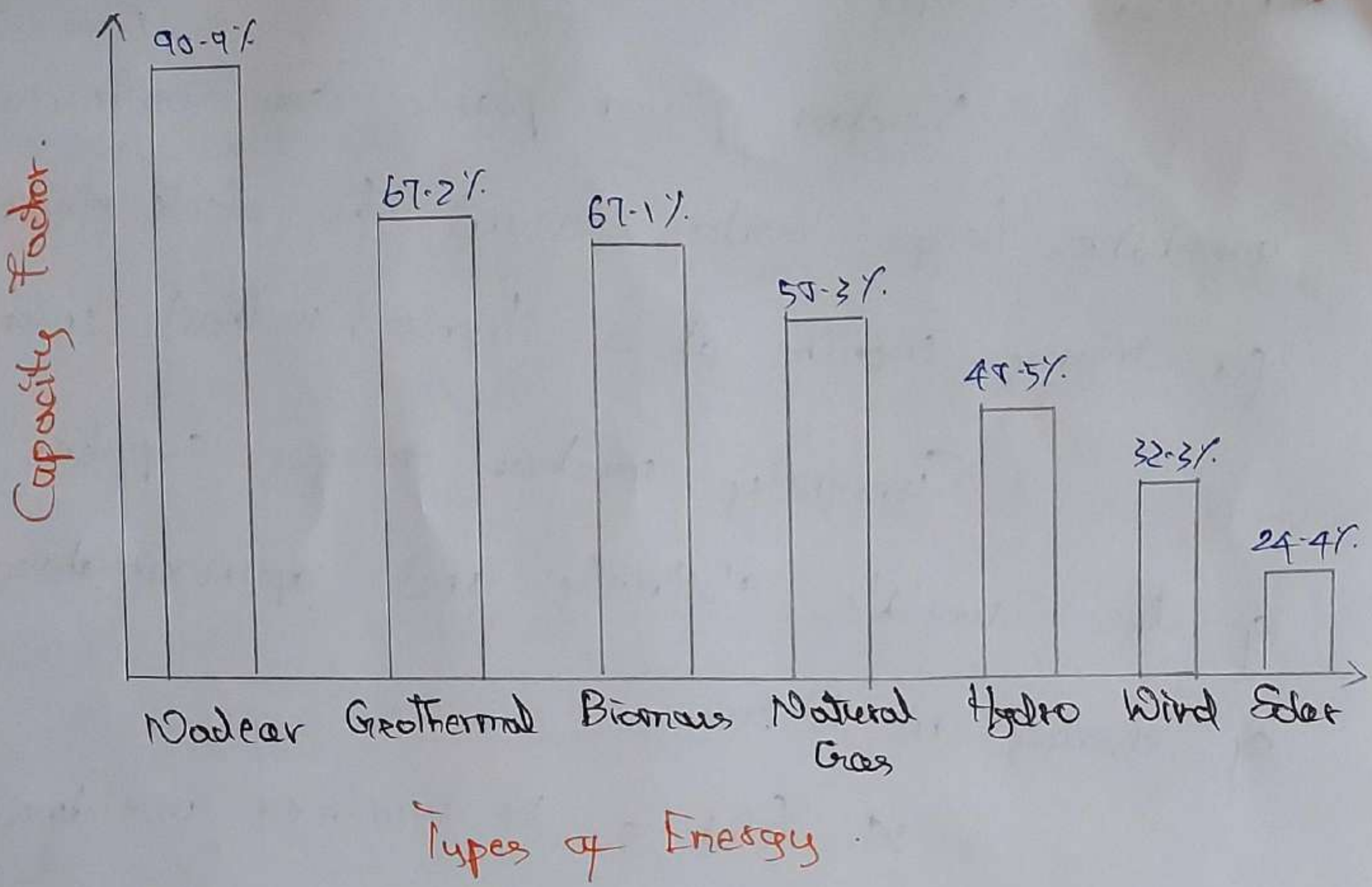
* Nuclear power plants can continuously generate large-scale, around the clock electricity for many months at a time, without interruption.

* Currently nuclear energy supplies 10% of the world's electricity and approximately 20% of energy in U.S.

* A total of 32 countries worldwide are operating 440 nuclear reactors for electricity generation.

* For decades, GE and Hitachi have been at the forefront of nuclear technology, setting the industry benchmark for reactor design and construction and helping utility customers operates their plants safely and reliably.

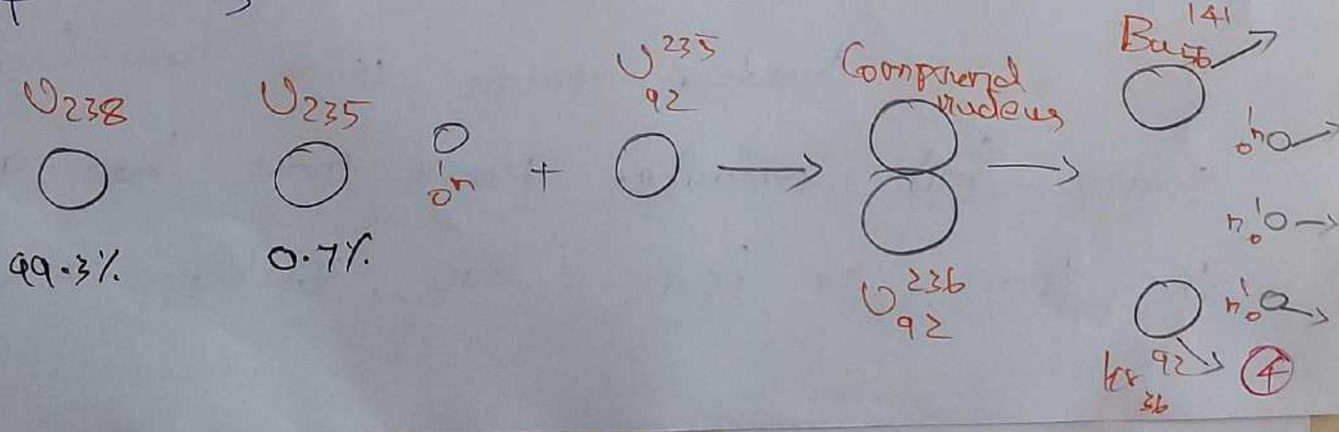
* Nuclear energy is a base load energy source that generates power more than 90% of the time, 24 hours a day, 365 days a year.



* Nuclear energy is a vital component of a clean energy strategy.

* Currently nuclear generation avoids the emission of over two billion tonnes of carbon dioxide each year.

* A reaction in which an atomic nucleus of heavy elements notably uranium and plutonium



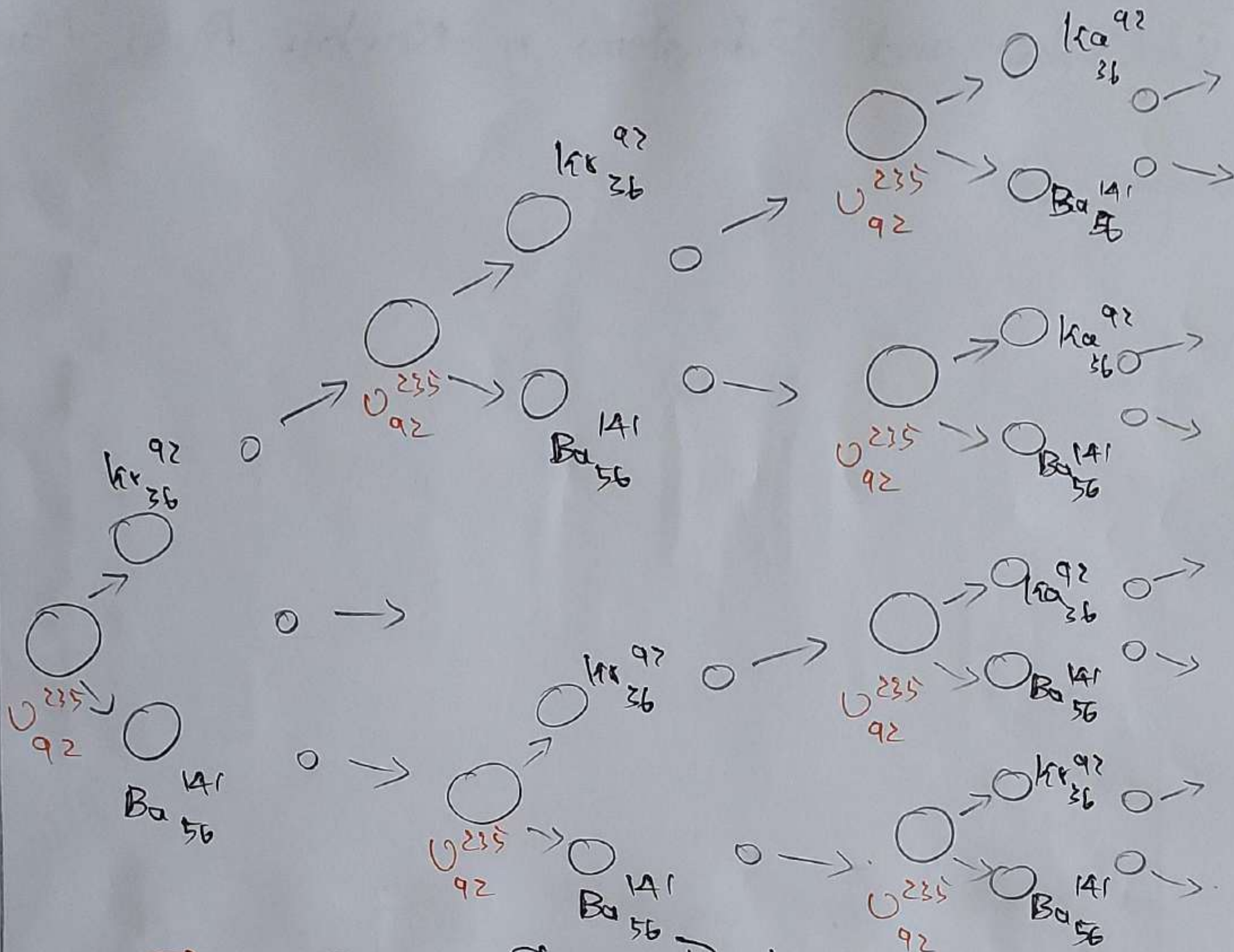
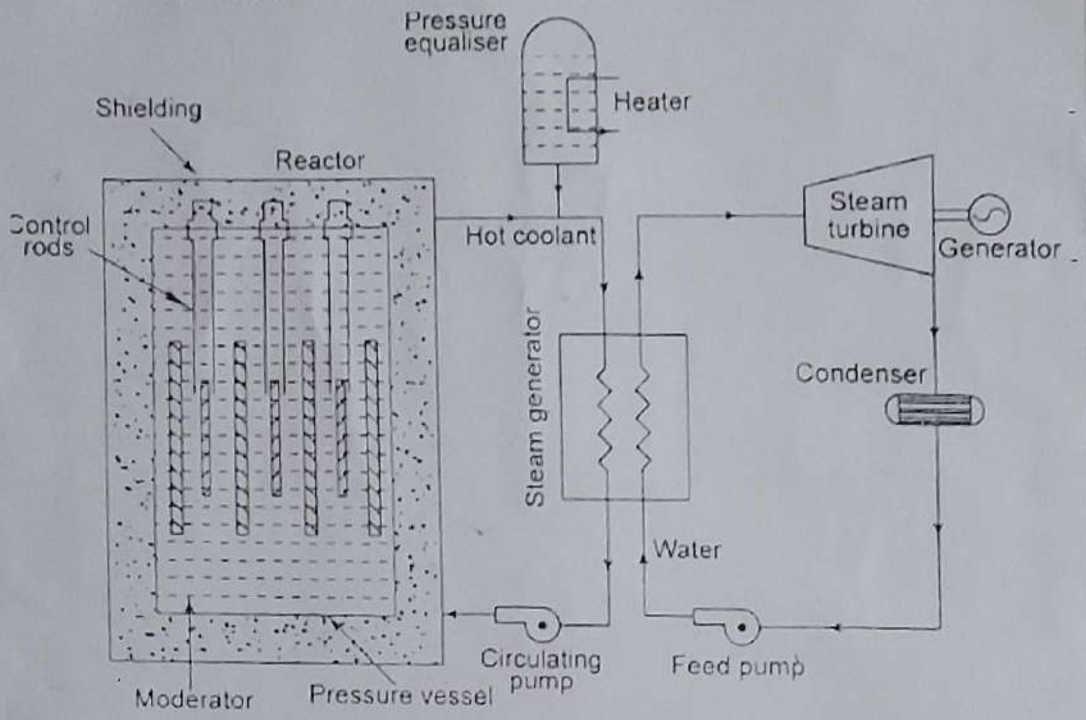


Fig: Fission Chain Reaction.

* Nuclear Fuel Cycle consists of sequence of steps in which uranium ore is minded, milled, enriched and fabricated into nuclear fuel and then irradiated in a reactor for several years.

* Nuclear fuel is highly engineered manufactured product.

② Layout and Subsystems of Nuclear Power Plants.



* The nuclear reactor consists of the following principal parts.

- → Reactor Core.
- → Moderator
- → Control rods
- → Reflector
- → Cooling System.
- → Reactor vessel.
- → Biological shielding

→ Reactor Core:

* It consists of nuclear fuel, neutron moderator and space for coolant.

* Reactor core has a shape approximately a right circular cylinder with diameters ranging from 0.5 m to 15 m.

* The fuel elements are made of plates or rods of Uranium metal.

* Fuel is shaped and located in such a way that the heat produced within the reactor is uniform.

→ Moderator:

* Process of slowing down the neutrons from high velocity without capturing them is known as moderation.

* Moderator is a material which is used to slow down the neutrons from high velocities without capturing them.

→ Control rods :-

* The function of control rod are as follows.

→ To control fission rate.
→ To start the chain reaction
→ To shut down the reactor
→ To maintain chain reaction
→ To prevent melting of fuel rods.

→ Reflector :

* Reflector material is placed around the core to reflect some of the neutrons back that they leak out from the core surface.

* The reflected neutrons cause more fission and they improve the neutrons economy of the reactor.

* Reflector is made of the same material as moderator.

→ Cooling System:

→ It should have low melting point

→ It should have high boiling point.

→ It should have low viscosity

→ It should be non toxicity.

→ It should have high density.

→ Reactor Vessel:

→ Reactor vessel encloses the reactor core, moderator, reflector, shield and control rods.

→ It is a strong walled container to withstand high pressure.

→ Biological Shielding:

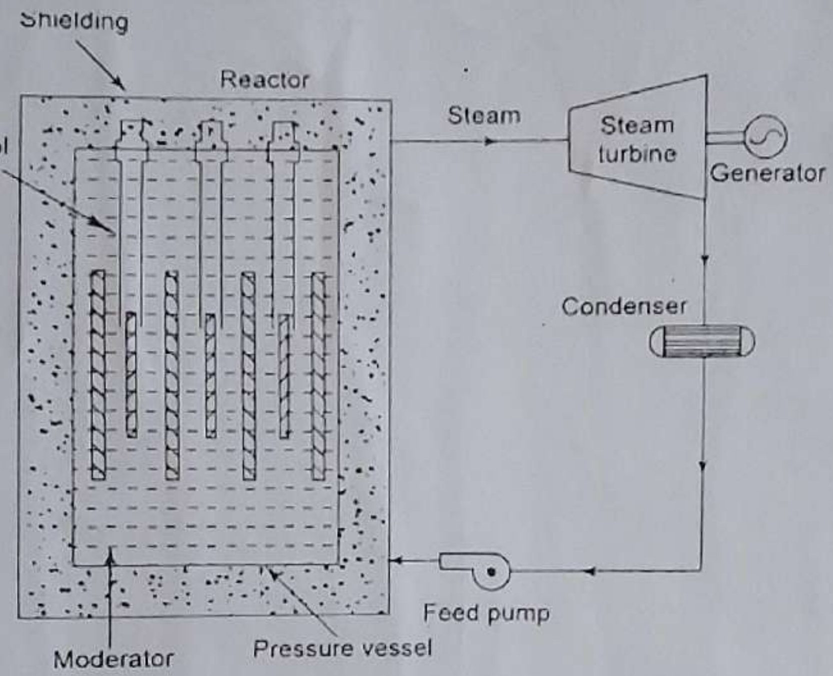
Good shielding material should have the following properties.

→ Should absorb α, β & γ rays.

→ Should have uniform density.

→ Should be fire resistant.

(3) Boiling water Reactor (BWR).



Boiling water reactor (BWR)

→ The arrangement of BWR is simple when compared to pressurized water reactor.

→ In this reactor, Uranium is used as a fuel and water is used as a moderator, coolant and reflector in PWR.

→ The only difference between PWR and BWR is, in BWR steam is generated in the reactor itself insted of a seperate steam generator.

→ water enters the reactor at the bottom

→ This water is heated by the heat released due to this fission of fuel and it gets converted into steam.

→ The steam which leaves the top of the reactor is passed through the turbine and it gets expanded.

→ Exhaust steam from the turbine passes through the condenser and it gets condensed.

→ The condensed water is again recirculated again by using a feed pump.

Advantages:

* Some intermediate heat exchange equipment is eliminated.
* Overall thermal efficiency is high.
* Water is cheap.

* Conversion rate may be high.
* Ordinary leakage can be tolerated.
* Fission products are contained.
* Core is compact
* Negative temperature coefficient.

Disadvantages:

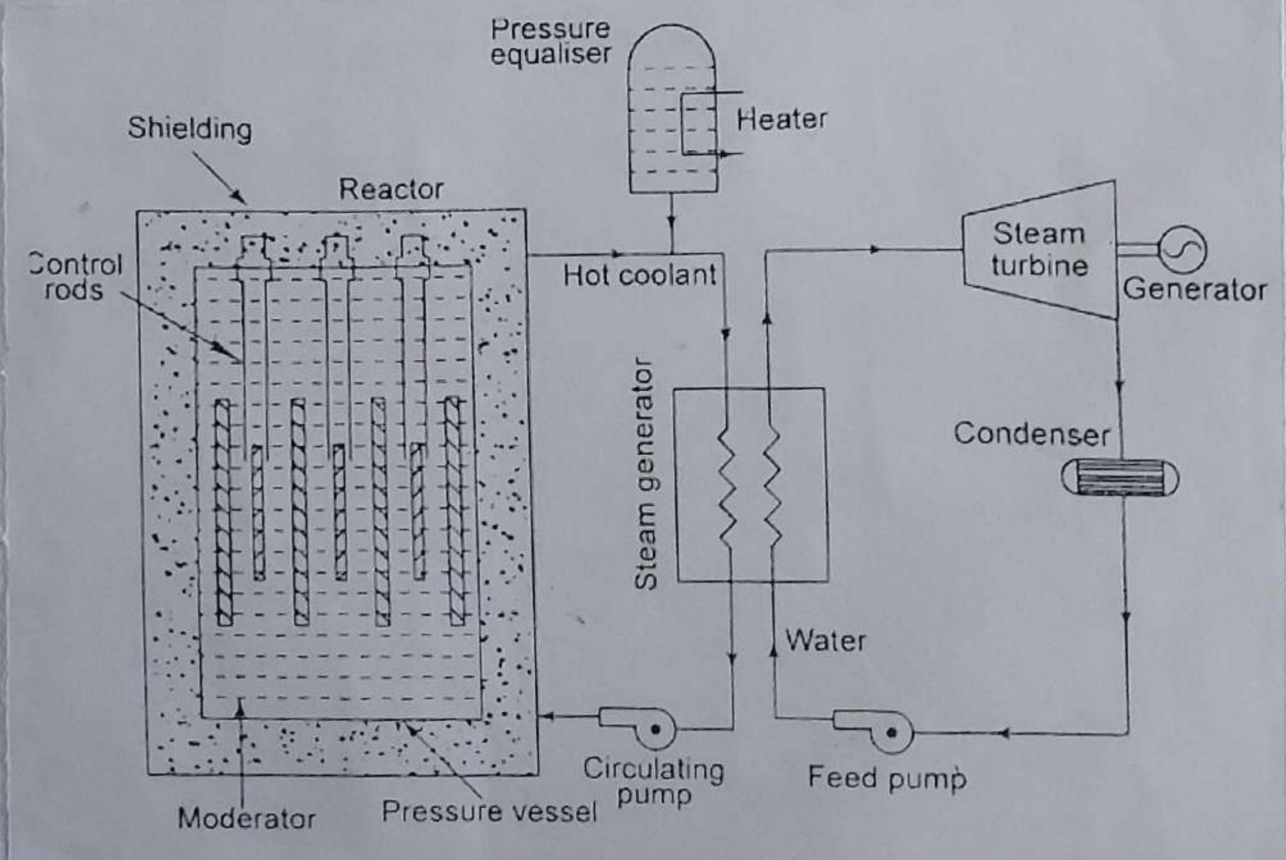
* Fuel must be atleast slightly enriched
* Fuel handling necessities complex equipment.
* Condenser leak may cause a serious trouble.
* Reactor must be shut down to unload and reload curve.
* Water flashes to steam during rupture of primary system.
* Power fluctuations demand cannot be met.

(4) Pressurized Water Reactor (PWR)

→ PWR is a light water cooled and moderated reactor having an unusual core design using both natural and highly enriched fuel.

→ The main components of reactor are as follows.

* Reactor
* Pressurizer
* Heat Exchanger



Pressurised water reactor

→ The coolant in primary circuit is pumped to reactor core.

→ The coolant absorbs the heat energy which is liberated during nuclear fission process in reactor core.

→ The hot coolant is passed through the heat exchanger where the coolant transfer the heat energy to feed water and steam is generated.

→ The pressure in primary circuit should be high so that the boiling of water takes place at high pressure.

→ It enables the water to carry more heat from the reactor.

→ The pressuring tank keeps the water at about 14 MN/m² so that it will not boil.

→ To reduce the pressure, water spray is used to condense the steam.

Advantages:-

→ Reactor is compact and high power density.

→ Number of control rod required is less.

→ Easily available natural uranium is used as a fuel.

→ Steam is not contaminated by radiation.

→ Allows in reducing the fuel cost extracting more energy per unit weight of fuel.

Disadvantages:-

→ Capital cost is high.

→ Fuel element fabrication is expensive.

→ Thermal efficiency is low.

→ Necessary to shut down the reactor for fuel charging.

→ More corrosion due to high pressure.

(5) CANDU (Cardain Deuterium Uranium) Reactor

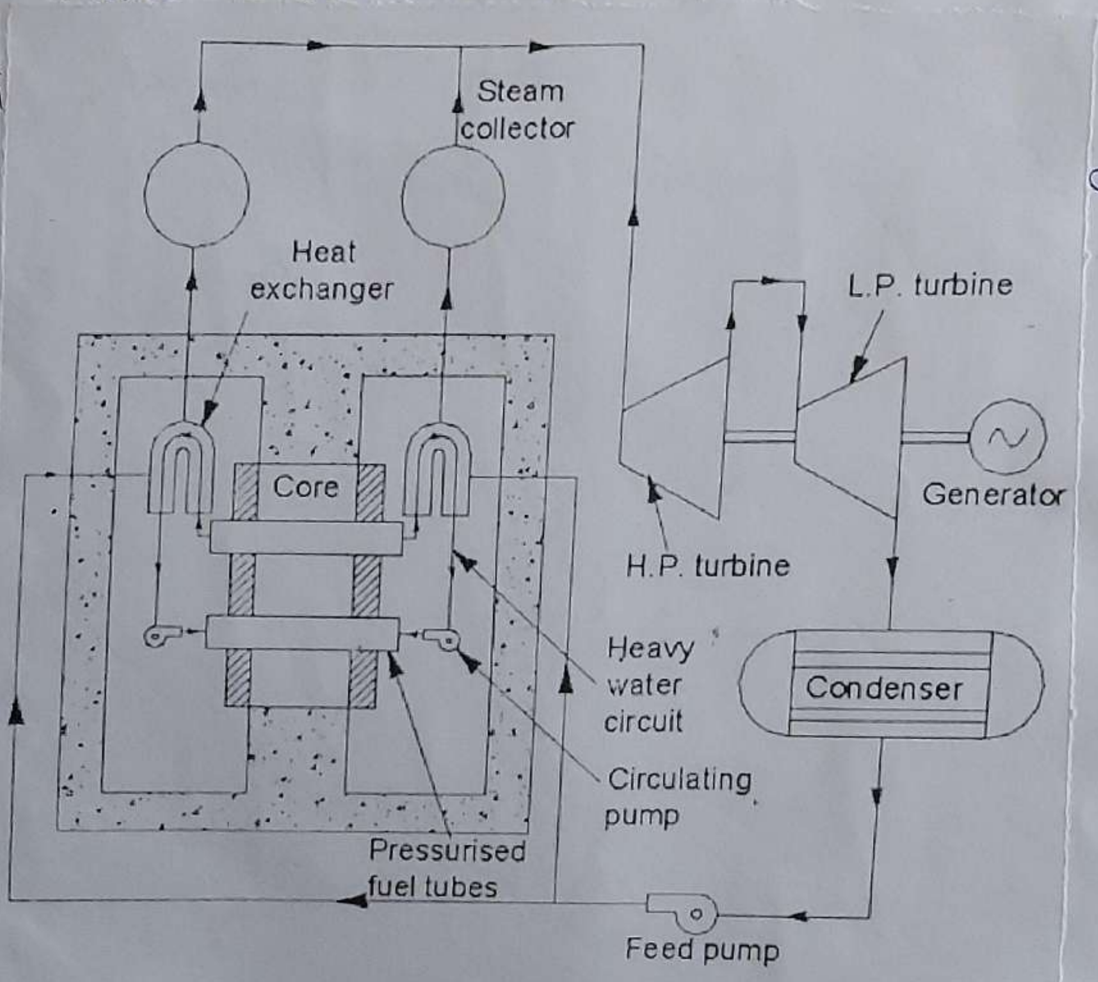
→ CANDU reactor is also called as heavy water cooled and moderated type reactor.

→ In this reactor heavy water is used as moderator and coolant as well as neutron reflector.

→ These reactors are more economical for those countries which do not produce coal

as fuel

in



CANDU reactor

→ The coolant is passed through the pressurized fuel tubes and it is heated up by a nuclear fission.

→ This hot coolant is passed through the heat exchanger where the heat is transferred to feed water and steam is produced.

→ By varying the moderator level the reactor can be easily controlled and hence, control rods are not necessary.

→ In this reactor the steam is generated at a temperature of about 265°C.

→ The reactor vessel and the steam generator system are enclosed by a concrete container structure.

→ For rapid shutdown purposes, the moderator can be dumped through a large area into a tank provided below the reactor.

Advantages:

→ No need of enriched fuel.

→ Reactor cost is less

→ No need of control rods.

→ Construction period of plant is shorter.

→ Heavy water is used as moderator, which increases its effectiveness and it provides low fuel consumption.

Disadvantages:

→ Heavy water is costly.

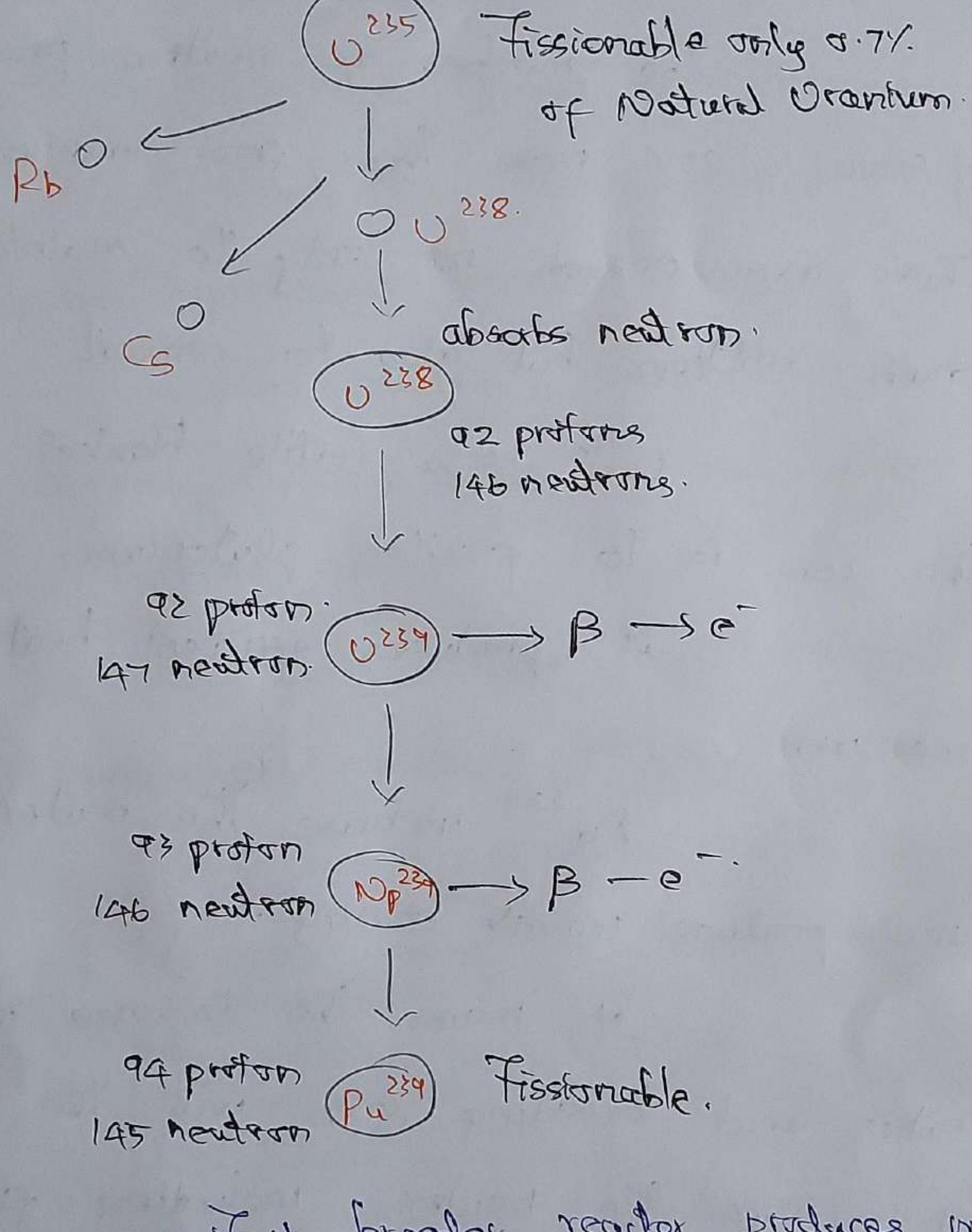
→ Leakage of water is a major problem.

→ Power density is low (9.7 kW/lit)

→ Very high standards are required for the design, manufacture and inspection.

→ High maintenance.

(6) Fast Breeder Reactor:



→ Fast breeder reactor produces more fissionable fuel than they use.

→ A fast breeder reactor uses plutonium or relatively higher enriched uranium as its basic fuel since it fission sufficiently with fast neutrons

→ The number of neutron produced per fission is 25% more than from uranium and there are enough not only to maintain the chain reaction but also to convert.

→ U^{238} is a fertile blanket around the core is to fissile plutonium.

→ It produces efficient heat transfer medium.

→ Pu^{239} increase the neutron energy and produce 155 keV energy.

→ It means the increase in breeding ratio and breeding gain with the average energy of the neutrons including fission reaction.

→ Fast Breeder Test reactor is used at Indira Gandhi Centre for Atomic for 45 MW.

7) Gas Cooled Fast Breeder Reactor :-

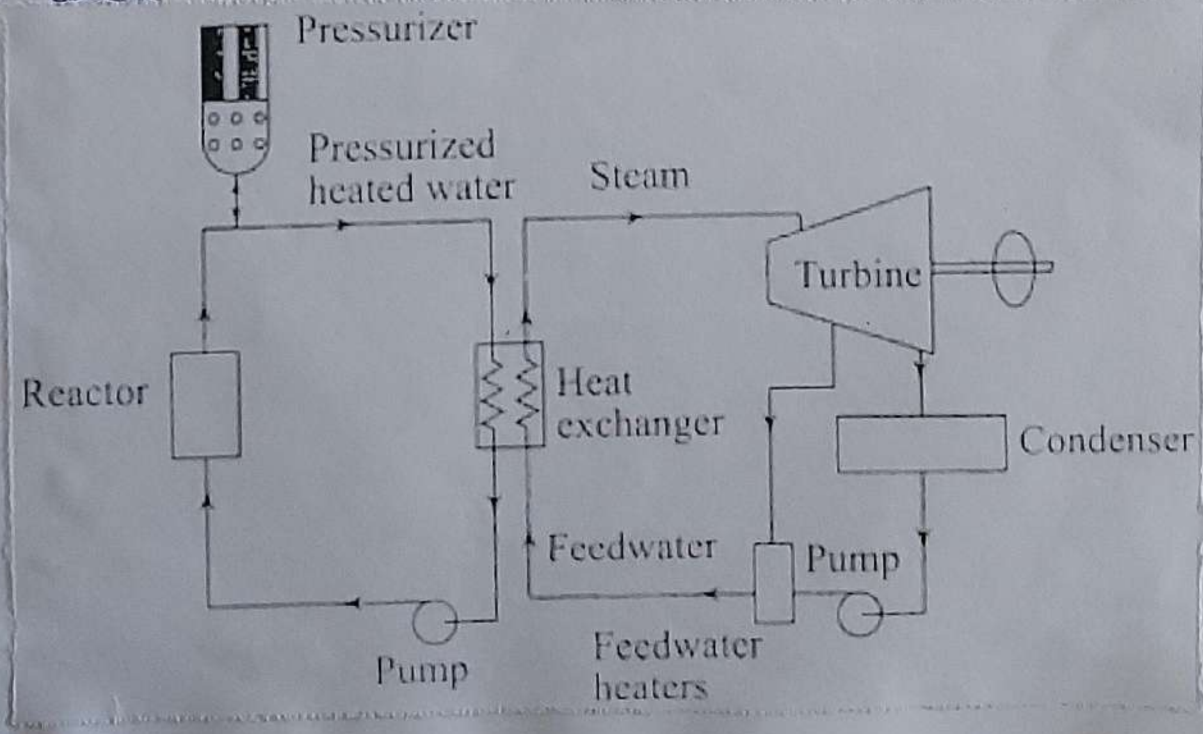
→ The reactor is high temperature of 850°C suitable for power generation.

→ Reactor is Thermochemical hydrogen production on other process heating.

→ For electricity generation gas will be directly drive either a gas turbine or steam turbine cycle.

→ Fuel include the depleted uranium and any other fissile or fertile materials.

→ In This reactor carbon dioxide gas is used to carry away the heat produced.



→ First gas cooled reactor with CO_2 used in Britain with fuel of natural uranium clad with alloy of magnesium called magnox and pressure maintained at 16 bar.

→ Gas enters the reactor at the bottom.

→ This gas is heated by the heat released by the fission of fuel and it leaves the reactor at the top and it flows to a heat exchanger.

→ In heat exchanger, hot gas transfers its heat to water which get converted into steam.

→ This steam is passed through the turbine and expanded to produce mechanical work.

→ Gas is recycled with the help of gas blowers.

→ Coolant does not react with fuel.

→ Graphite remain stable under irradiation at high temperature.

→ No possibility of explosion since CO_2 as coolant negative temperature coefficient.

→ Cost of heavy water is high.

→ Leakage of gas is problem while using helium gas.

→ Fuel loading is more elaborated and costly.

Advantages:

* No corrosion.
* Coolant is cheap.
* Ordinary leakage can be tolerated.

Disadvantages:

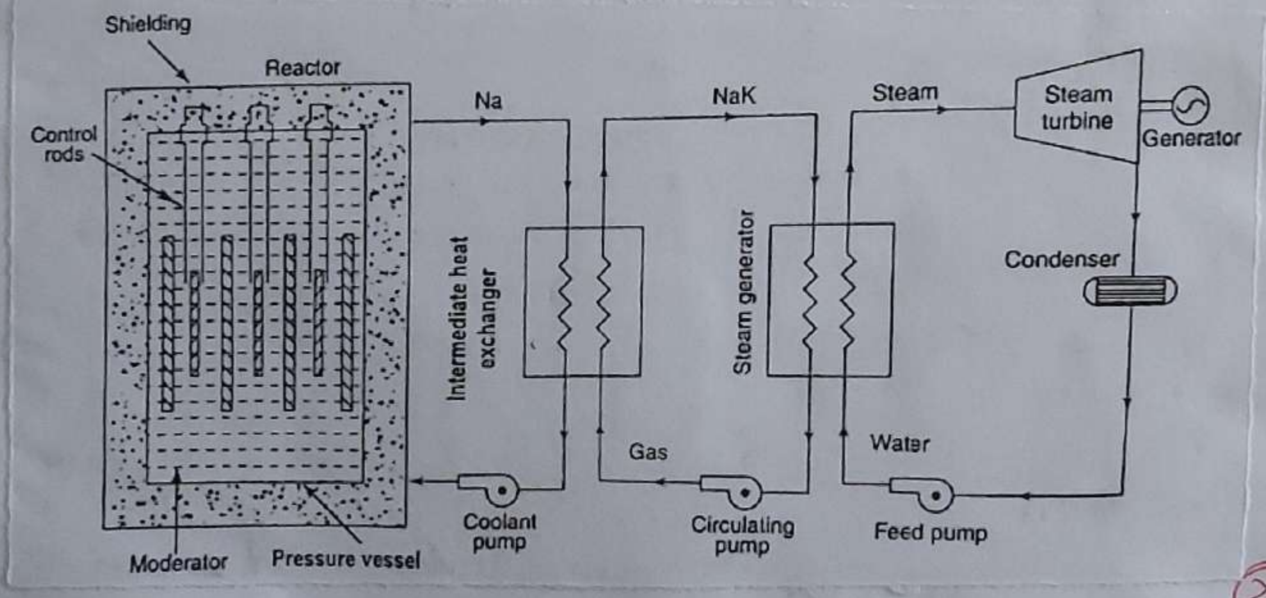
* Heat transfer efficiency is low.
* Coolant must be pressurized.
* CO_2 dissociates above 255 °C.

(8) Liquid Metal Cooled Reactors: (LMCR)

→ LMCR is an advanced type of nuclear reactor where primary coolant is a liquid metal.

→ Liquid metals such as mercury, sodium and sodium potassium, Lead and Tin are normally used liquid metals.

→ Since the liquid metal coolants have much higher density than the water or heavy water used in most reactor designs they remove heat more rapidly and allow much higher power density.



→ The high temperature of liquid metal can be used to produce vapour at higher temperature than in a water cooled reactor, leading to a higher thermodynamic efficiency.

→ Sodium is an excellent heat transfer material and can operate at high pressure density.

→ So LMCR core can be comparatively small.

→ Sodium has very high boiling point, reactor coolant loops can be operated at high temperature.

→ Sodium is not corrosive to many structural materials.

→ Sodium has higher melting point than room temperature.

Advantages:

* No moderator is required.
* High breeding is possible.
* Gives more power density.
* Higher efficiency.
* Better fuel utilization.
* Absorption of neutron is low.
* Sodium doesn't react with Uranium and Thorium.
* Electromagnetic pumps can be used with fair efficiency.

Disadvantages:

* Requires high enriched fuel.
* Specific power is low.
* Fuel handling is very difficult.
* Neutron flux is high.
* High Thermal stress.

(9) Safety Measures for Nuclear Power Plants:

→ The fundamental safety objective is to protect people and environment from harmful effects of Ionizing the radiation.

Safety in Design:

→ In nuclear reactor energy is generated by fission due to uranium or plutonium nuclei in a continuous chain reaction.

→ Safety function are as follows.

* Control of fission reaction.
* Cooling of reactor core.
* Containment of the radioactive fission.

* Control rods.

→ Control rods are used in nuclear reactors to control the fission rate of uranium and plutonium.

→ They are chemical elements such as

boron, silver, iridium and cadmium.

→ They are capable of absorbing many neutrons without themselves fissioning.

→ Control rods are raised or lower in reactor to regulate the power.

→ For shutting down the reactor, the control rods are completely inserted to the reactor. This is called as Primary shut down system.

→ Additional secondary shutdown system is adopted for control of reactor.

* Core Cooling Maintenance.

→ Two or more coolants are provided.

→ Because heat is produced during fission and even shut down condition small heat is produced.

→ To further improve reliability

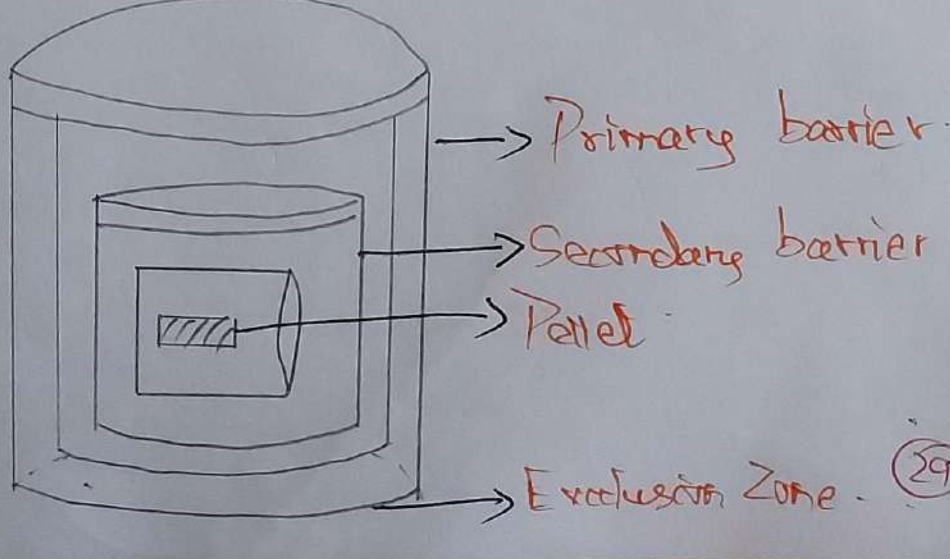
coolant pumps are provided with back up power supply from diesel generators and battery banks which supply power during grid failure.

→ Emergency Core Cooling system is used even if there is a leak in the cooling circuits.

* Containment of Radioactivity

→ Radioactive material is produced in the core of reactor when fission occurs.

→ However to prevent radioactive release to environment, under transient or accident condition atleast three barriers provided



First Barrier - Fuel clad within which fuel is enclosed.

Second Barrier - Leak tight Coolant Circuit.

Third Barrier - Containment building around Coolant Circuit.

→ With all three barriers radioactive material under an accident condition is neglected.

→ No permanent residence is allowed within 1.5 km from reactor.

UNIT - 4

POWER FROM RENEWABLE ENERGY

① Mini Hydel Power Plants:

→ Hydropower (or) water power is one of the most established renewable sources for electricity generation from stored water at a given height.

→ Kinetic energy in falling water from a height is converted into mechanical energy by hydraulic turbine.

Types:

→ Depending on Capacity

* Micro hydel plant ⇒ Less than 100 kW.
* Mini hydel plant ⇒ 100 kW to 1 MW.
* Small hydel plant ⇒ 1 MW to 10 MW.

→ Depending on head.

* Ultra low head plant ⇒ Below 3 m.
* Low head plant ⇒ Below 30 m.

* Medium Head plant => 30 m to 75 m.
* High Load plant => Above 75 m.

→ Depending on usage.

* Independent scheme => Primary purpose.
* Subordinate scheme => Primary purpose.
* Drinking or irrigation => Secondary purpose.

Advantages:

→ Wave condition are predictable, therefore energy can be predicted.

→ No need of Large Land.

→ Pollution free.

Disadvantages:

→ Low lifetime, difficult maintenance, high cost.

→ Must withstand natural calamities.

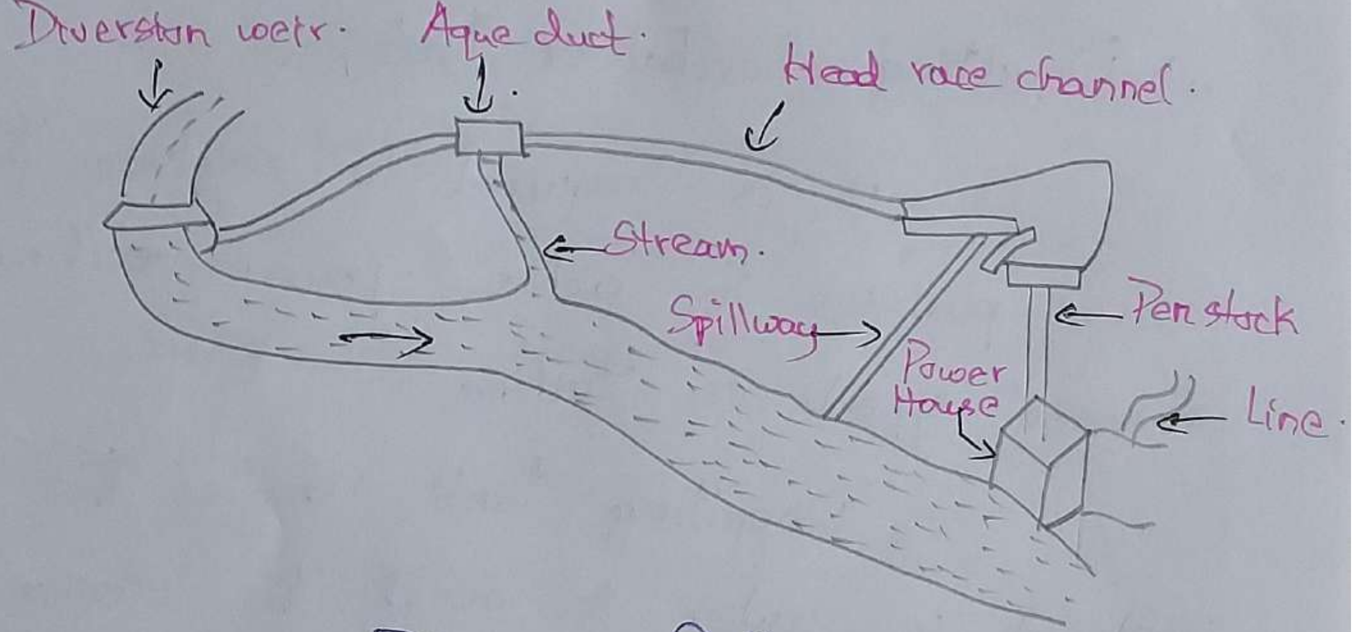
→ Harnessing power from wave energy is difficult.

→ Irregularity in wave energy.

→ Depending on construction.

* Storage plant
* Run off the river plant.

Components of Hydel Power Plant:



* Diversion System.
* Desilting chamber or tank.
* Water conductor system.
* Forebay / Balancing reservoir.
* Surge tank.
* Penstock
* Spillway.
* Power house
* Tail race.

i) Diversion System:

→ It is a solid structure used to divert the required flow from river bed to intake structure.

ii) Desilting chamber or tank:

→ It is required to exclude the coarse particles to achieve power without abrasion effects on turbine.

→ Desilting tank removes the coarse material in water to avoid the errosion of turbine blade.

iii) Water Conductor System:

→ It should be designed to have minimum loss of head.

→ Commonly trapezoidal section is used for channel section of water conductor system.

iv) Forebay / Balancing Reservoir:

→ Forebay helps to provide a minimum head over penstock.

v) Surge Tank:

→ It is necessary for water conductor length of more than 5 time the head on machine.

vi) Penstock:

→ Penstock pipes used of mild steel to feed water to the turbine.

→ Bell mouth entry is preferred to ensure in reduction of head loss.

vii) Spillway:

→ It does not allow water level to rise and flood the area.

→ Channel or pipe is used for spillway.

viii) Power House:

→ Power house posses turbine, generator control pannels etc.

→ Constructed by reinforced concrete.

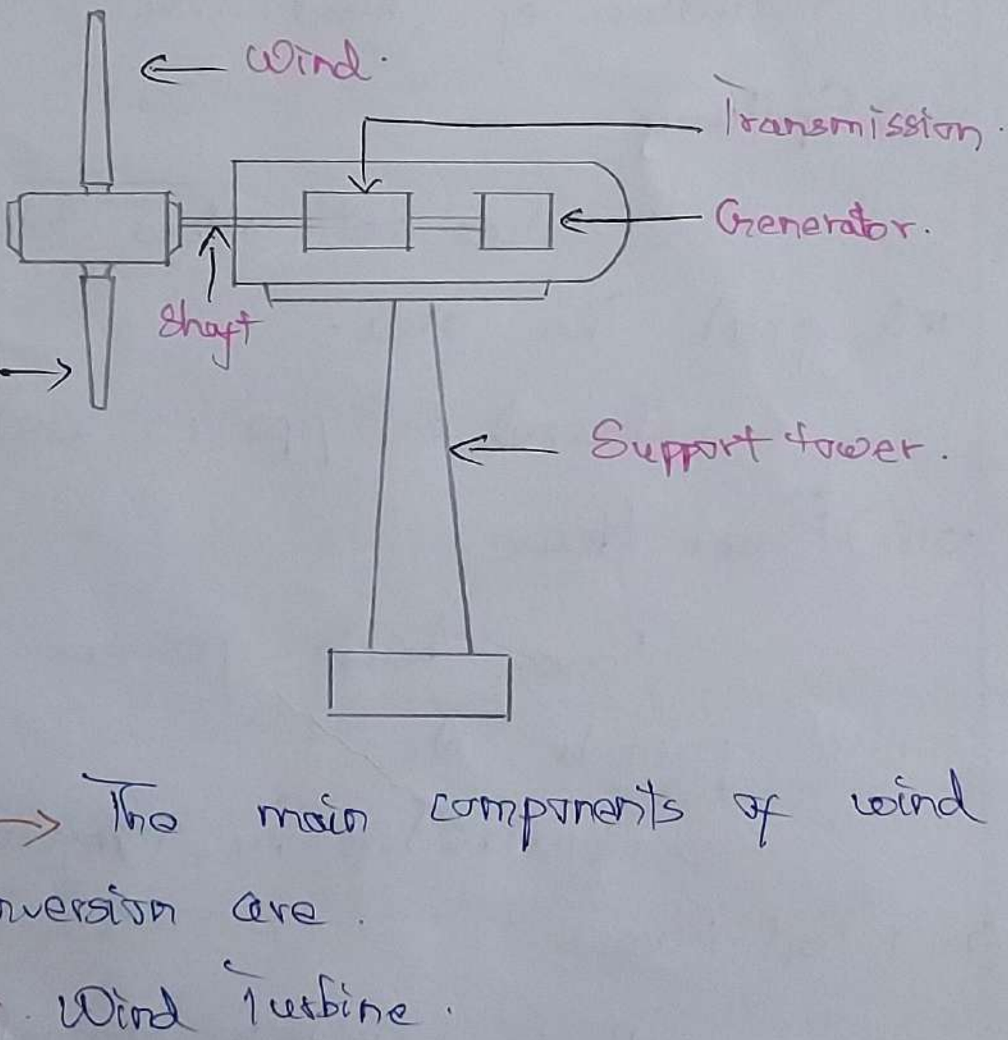
ix) Tail Race:

→ It is a water channel which is used for turbine outlet to river.

(2) Horizontal Wind Mill (or) Components of Wind Energy Conversion :-

→ Horizontal axis wind turbine has the horizontal axis of rotation with respect to ground.

→ HAWT or propeller type turbines are more common and highly developed than vertical axis type.



→ The main components of wind energy conversion are.

* Wind Turbine.
  Nacelle
  Rotor
  Hub & Shaft

* Transmission System.
* Electric generator.
* Yaw Control Systems.
* Storage.
* Energy converters.
* Tower to support.

* **Wind Turbine**:

→ It is the main component of energy conversion systems.

→ Blades rotated by wind produce mechanical energy to electrical energy.

Nacelle:

→ It includes gearbox, low & high speed shaft, generator controller & brake.

Rotor:

→ Hub & blades together compose rotor.

Hub & Shaft:

→ Rotor connected to shaft & hub assembly.

* Transmission System:

→ Mechanical power generated by rotor is transmitted to electric generator by transmission system.

→ Purpose of gearbox is to increase the speed of rotor from 20 rpm to 50 rpm and also from 1000 rpm to 1500 rpm.

* Electric Generator:

→ Two options for generator in wind turbine are asynchronous or synchronous generator.

→ Asynchronous generator need reactive power from the grid systems.

→ But synchronous generator do not require reactive power hence used for turbine.

* Yaw Control Systems.

→ It is used to turn nacelle according to wind direction.

→ It continuously orient the rotor in wind direction.

* Storage:

→ Used to store energy when there is excess power developed and to discharge when there is lack of power.

→ Most common storage device is Lead acid battery.

* Energy Convertor:

→ Usually electricity produced from wind energy is direct current.

→ So it should be converted to Alternating current using inverter before supplying to grid.

* Towers:

→ Towers are used to support and withstand wind loads and gravity loads.

→ Range of tower is from 12 m to 37 m for small wind application and from 30 m to 75 m for other wind turbines.

3 # Tidal Energy

→ Tidal energy is a form of energy obtained with every tide.

→ The periodic rise & fall of sea water level carried by the action of sun & moon on water of earth is called tide.

→ The rise & fall of tidal water is maximum near seashore & river mouths.

→ Basic principle of tidal cycle operation is the difference in water surface elevation at high tide & low tide.

→ The difference in potential energy during high tide & low tide is converted into tidal energy.

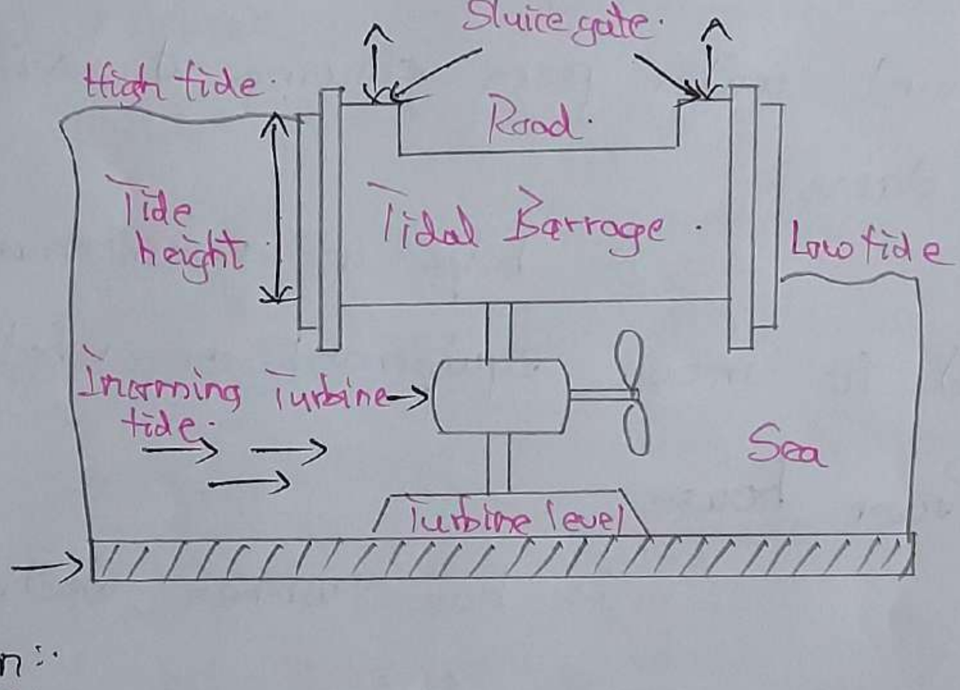
→ This differential head is utilized for operating a hydraulic turbine which is coupled to generator.

→ Following are the components of Tidal Power Plant.

Components of Tidal Power Plant:

Main components of Tidal Power Plant are

* Dam
* Sluice Ways.
* Embankments.
* Power House.



* Dam:

→ Dams are used to store water at high tides, which makes use of potential energy.

→ The potential energy possessed by difference in height between high & low tides.

* Sluice ways:

→ Sluice ways allows water to enter into tidal basics during high tide.

→ Vertical lift gates and flap gates are used as sluice ways.

* Embarkments:

→ They are made of concrete to prevent water from flowing at certain parts of dams.

→ It helps in maintenance work & used to move equipment or vehicles over it.

* Power house:

→ It has turbines, electric generators and other equipments.

→ Large turbines are used to apply di for low head availability.

→ Water with high potential energy flows through turbine to run generators.

Potential or Status in Tidal Plants:-

→ Gulf of Cambay & Gulf of Kutch in Gujarat have maximum tidal range of 11 m & 8 m respectively.

→ Ganges delta in Sundarbans is approximately 5 m in average tidal range.

→ Central Electricity Authority carried out cost estimation and feasibility study for 900 MW Kutch project in 1986.

→ In 1993, the execution of project with an estimate of INR 1184 crore.

→ In early nineties, National Hydro power generation Ltd reported that Kutch project is not economically viable.

→ 100 tidal plants has been installed in India due to high cost of electricity generation.

Advantages:

→ Tidal power is renewable & sustainable energy source.

→ No pollution.

→ Large area of valuable land not required.

→ Independent of rain which fluctuates year to year.

→ Tidal power is showing energy density four times greater than air energy.

Disadvantages:

→ Due to variation in tidal range, output is not uniform.

→ Corrosion risk is high due to sea water.

→ Difficult to construct in sea.

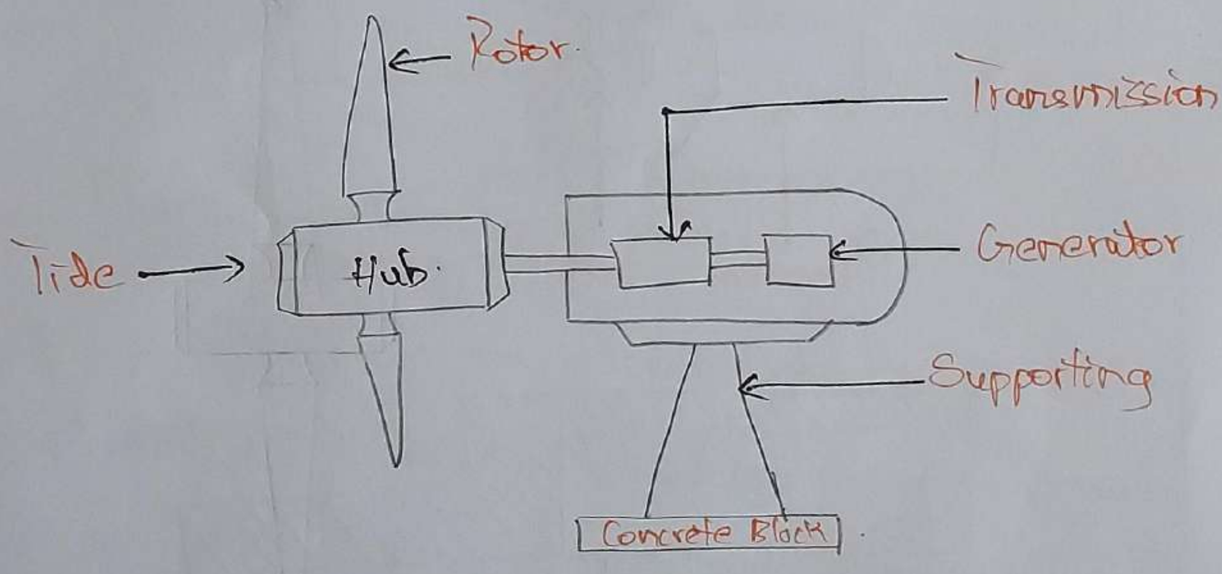
→ Compared to other energy sources, tidal power is costly.

4. Types of Tidal Stream Generators:-

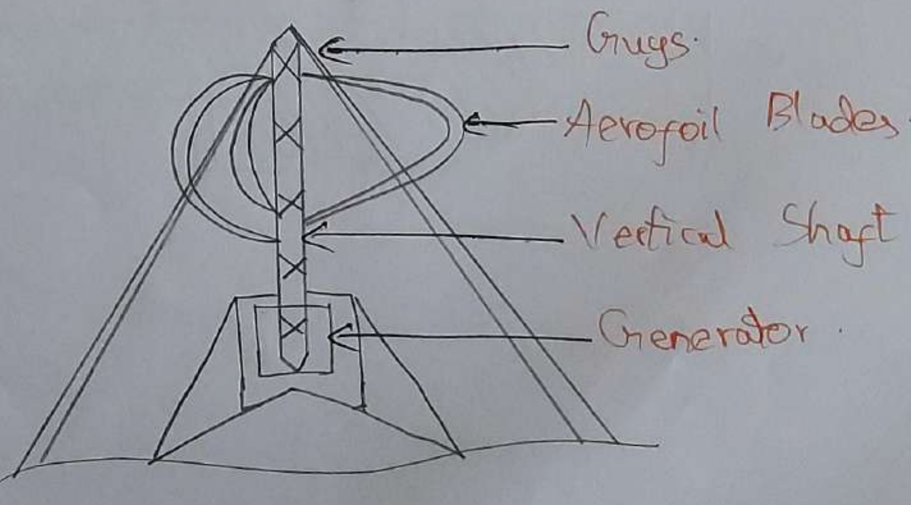
→ Two major types of tidal stream generators are.

* Horizontal axis Tidal Turbine
* Vertical Axis Tidal Turbine.

* Horizontal Axis Tidal Turbine.

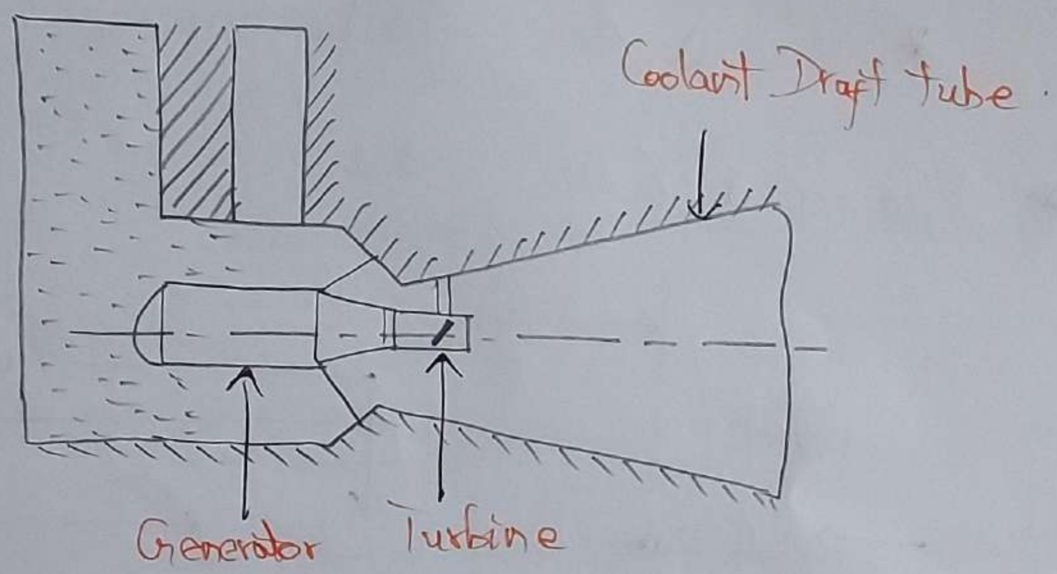


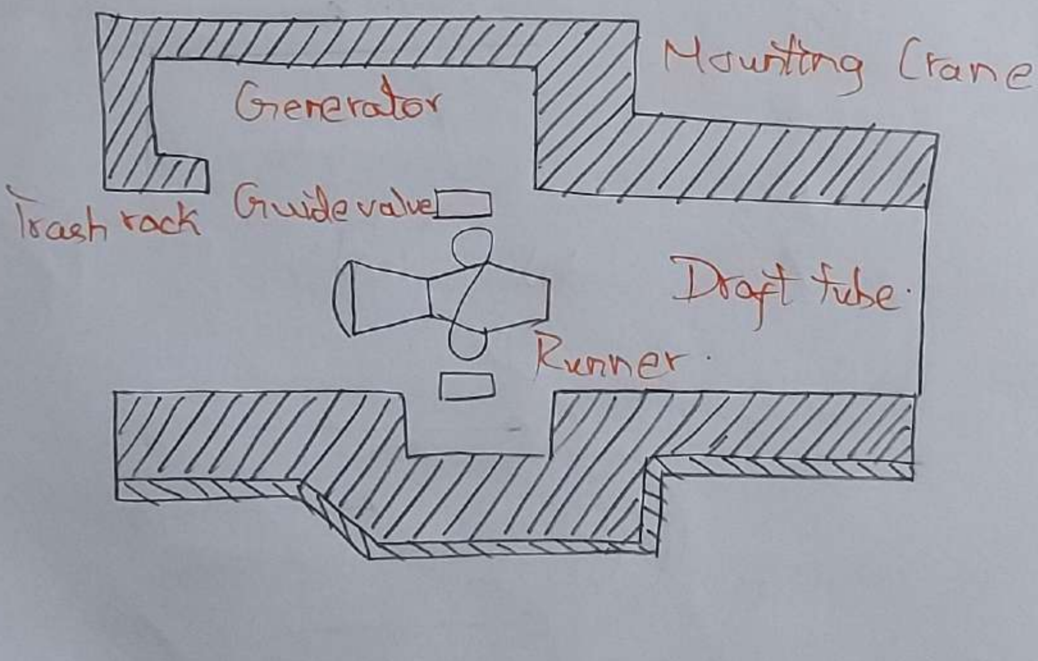
* Vertical Axis Tidal Turbine.



Types of Tidal Turbines:-

* Bulb Turbine.
* Rim Turbine.
* Tubular Turbine.





Wave Energy:-

→ Wave energy is the energy of interchanging potential and kinetic energy in the wave.

→ To extract the stored energy in waves, wave energy conversion devices are used in which two or more bodies move relative to each other.

Wave Energy Conversion Devices:-

→ Technologies developed to generate energy from waves called hydrokinetic energy conversion devices are generally categorized as wave energy.

→ Wave Profile Devices - It turns oscillating height of oceans surface into mechanical energy.

→ Oscillating Water Columns - It converts wave energy into air pressure.

(6) Solar Photovoltaic Energy Conversion:-

→ In solar energy conversion, the solar photovoltaic system convert solar light energy into electrical energy.

→ Basic conversion device is known as Photovoltaic cell or solar cell.

→ Photovoltaic effect is defined as the generation of electromotive force as a result of absorption of ionizing radiation.

→ Solar cell - A single converter cell generally a photovoltaic cell.

→ Module - Combination of multiple interconnected solar cells.

→ Panel - Collection of modules physically and electrically grouped together.

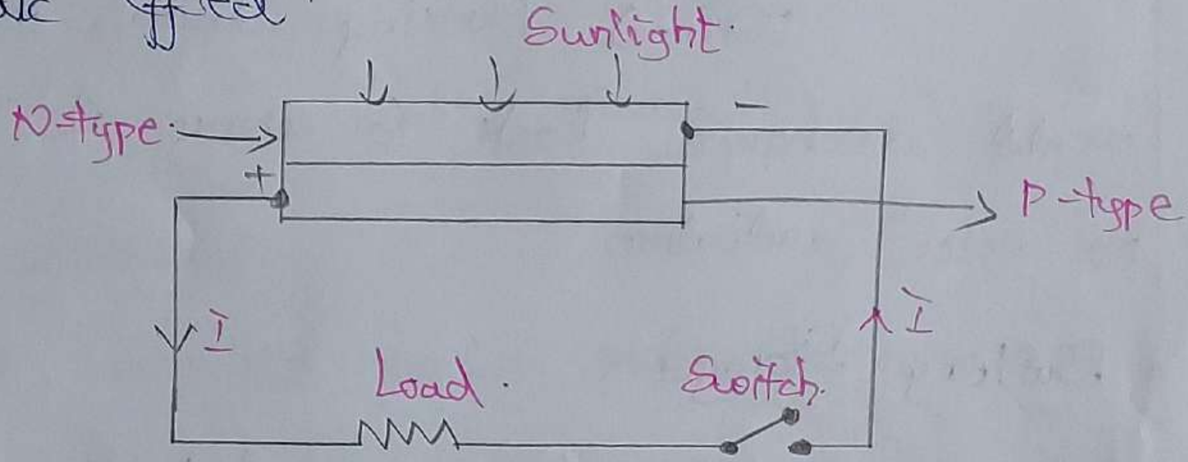
→ Array - Collection of Solar panels.

→ Most solar panels have 30 to 36 cells connected in series.

Photovoltaic Effect:

→ When solar cell is illuminated by solar radiation, the electron-hole pairs generated and it is acted upon by internal electric fields thereby resulting in photocurrent.

→ This phenomenon is called photo-voltaic effect.



Solar PV Power Generation System:

→ Basic components of solar PV power generation system are.

* Solar array.
* Blocking Diode.
* Battery Storage.
* Inverter.
* Switches

* **Solar Array:**

→ It is the collection of solar cells which converts solar energy to DC power.

* **Blocking Diodes:**

→ It lets array generated power flow only towards battery or grid.

→ without blocking diode, the battery would discharge back to array at time of no solar radiation.

* **Battery Storage:**

→ Used to store electricity produced from array.

* **Inverter:**

→ Converts to DC power to AC power to match the output grid.

→ It has suitable output setup transformer and power correction circuits.

* Switches and Circuit Breakers

→ Used to connect and disconnect the power flow from solar array setup to output setup.

* Overall PV cell current

$$I = I_D - I_L$$

I_D - Diode Current

I_L - Light Induced Current

Advantages:

→ No moving parts & hence no wear.

→ No pollution and highly reliable.

→ Less maintenance.

→ Long effective life.

Disadvantages:

→ Expensive.

→ Efficiency is low.

→ Toxic chemicals used for PV cell production.

(7) Flat Plate Solar Collectors:-

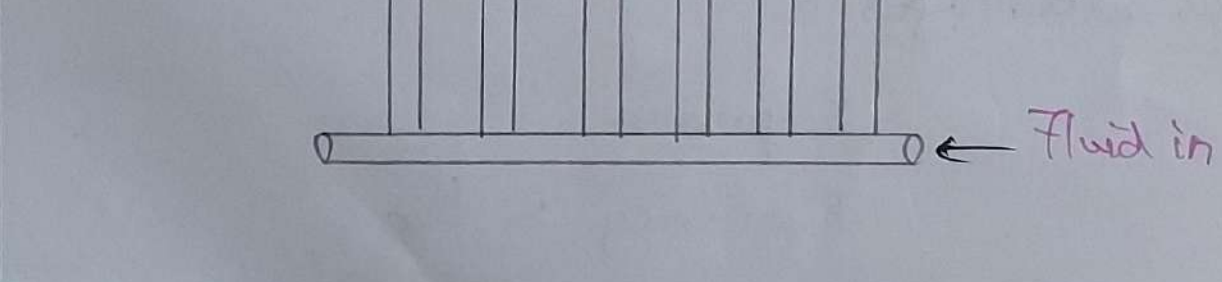
→ The types of Flat Plate Solar Collectors are as follows.

* Liquid Heating Collectors.
* Air Heating Collectors

*Liquid Heating Collectors:-

→ It is used for heating water using solar radiation.

→ Construction and position details of simple flat plate collector is shown below.



Working:-

→ Direct and Diffuse solar radiation

incident on flat plate collector.

→ Radiation enters glass cover and incident on absorber plate.

→ Use of two glasses is to avoid loss due to contact with air and absorber plate.

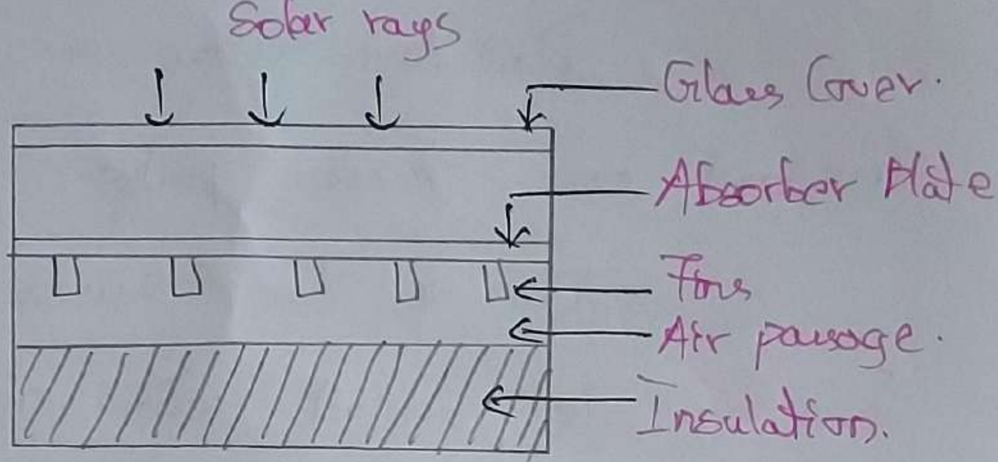
→ Absorber plate temperature increases and transfers the heat to tubes.

→ Tubes temperature increases and makes the water inside the tube to hot condition.

→ Water flows as cold at inlet and passing tubes which resulted in higher temperature as hot water at outlet.

→ Installation at bottom of tube is used to avoid the escape of heat from tube to atmosphere.

Solar Air Heater:



Components & Working:

→ Construction is similar to water heater setup with only difference is absence of water tubes.

→ Solar radiation enters glass cover and incident on absorber plate.

→ Instead of tubes, this air heater has fins at the bottom of absorber plate.

→ Air passes below the absorber plate and absorbs heat from fins & plates.

→ Fins increases heat transfer from absorber plate.

→ Insulation avoids the escape of heat

flow from air to the atmosphere.

Advantages:-

→ Simple construction of easy maintenance.

→ Corrosion is eliminated.

→ Leakage of air is less.

→ No need of antifreezing solution.

Disadvantages:-

→ Need of electric power to blow air is necessary.

→ Heat transfer between air and absorber plate is poor.

→ Less Thermal energy storage.

Application:-

→ Heating greenhouse building.

→ Drying agricultural products.

→ In heat engine.

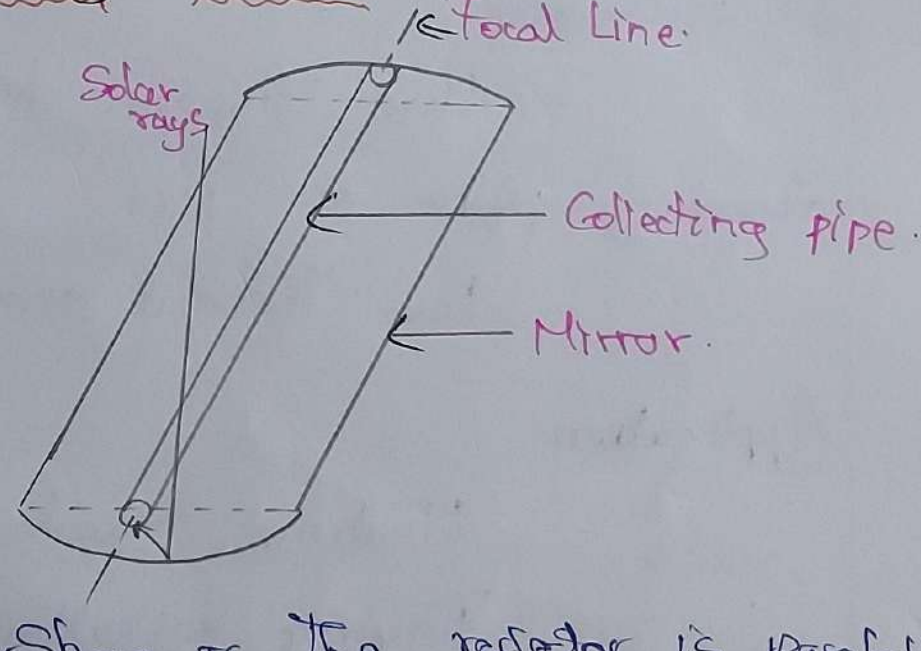
→ Air conditioning buildings.

(8) Solar Concentration Collectors:-

→ The types of solar concentration collectors are as follows.

* Parabolic Trough Collector.
* Parabolic Dish Collector.
* Mirror Strip Reflector.
* Fresnel Lens Collector.
* Flate Plate Collector
* Compound Parabolic Concentrator.

* Parabolic Trough Collector:-



→ Shape of the reflector is parabolic in this type.

→ A collecting pipe is placed at the centre of parabolic reflector.

→ Collecting pipe contains any type of fluid (oil, water, salt).

→ When the direct or beam radiation falls on the parabolic mirror, it get reflected and focused on glass envelope.

→ Concentration ratio of about 5 to 30 could be obtained in this type.

→ Hot fluid is finally delivered at outlet pipe.

* Parabolic Dish Collector:-

→ Dish shaped concentrator - 6.6 m dia.

→ 200 curved mirror segments on parabolic surface.

→ Receiver - Tank Zirconium - Copper alloy with black chrome coating.

→ Hot water flows in and out through inferior pipe.

→ Dish moves automatically.

* Mirror Strip Reflector:

→ A number of plane or slightly curved mirrors strips are mounted on parabolic base.

→ Angle of individual mirrors is arranged in a direction, so that solar radiation reflected towards a same focal line.

→ Based on suns direction the angle of mirrors could be adjusted to maintain same focal line.

→ At focus point the collecting pipe with heat transport fluid passes.

* Frensel Lens Collector:

→ It has refracting type focusing collector.

→ For attaining max efficiency, Frensel lens are alligned continuously with sun in two directions both along & perpendicular.

→ Main difference in this setup is, solar radiation focused on pipe from top to bottom.

→ Lens - 4.7 m length, 0.95 m width made of acrylic plastic.

* Flat Plate Collector:

→ It has flat plate facing south with mirrors at north & south poles.

→ Mirrors reflect to tot radiation in addition to beams radiation.

→ These mirrors are called booster mirrors.

→ Maximum concentration value is less than four.

→ For a single collector, booster mirrors are used on all four stages.

→ Efficiency can be increased by changing mirror angles based on climate changes in a year.

* Compound Parabolic Concentrator :-

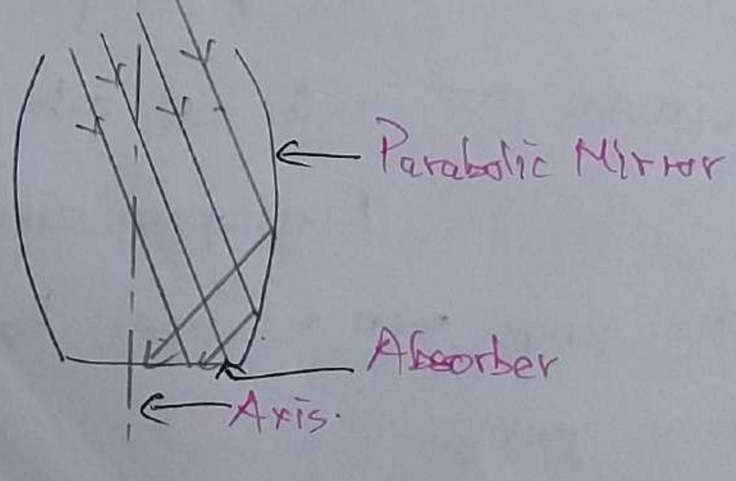
→ It is non focusing type but radiation from many directions reflected towards bottom of trough.

→ Due to this setup, diffuse radiation also absorbed on small area.

→ It has two parabolic mirrors facing in opposite direction.

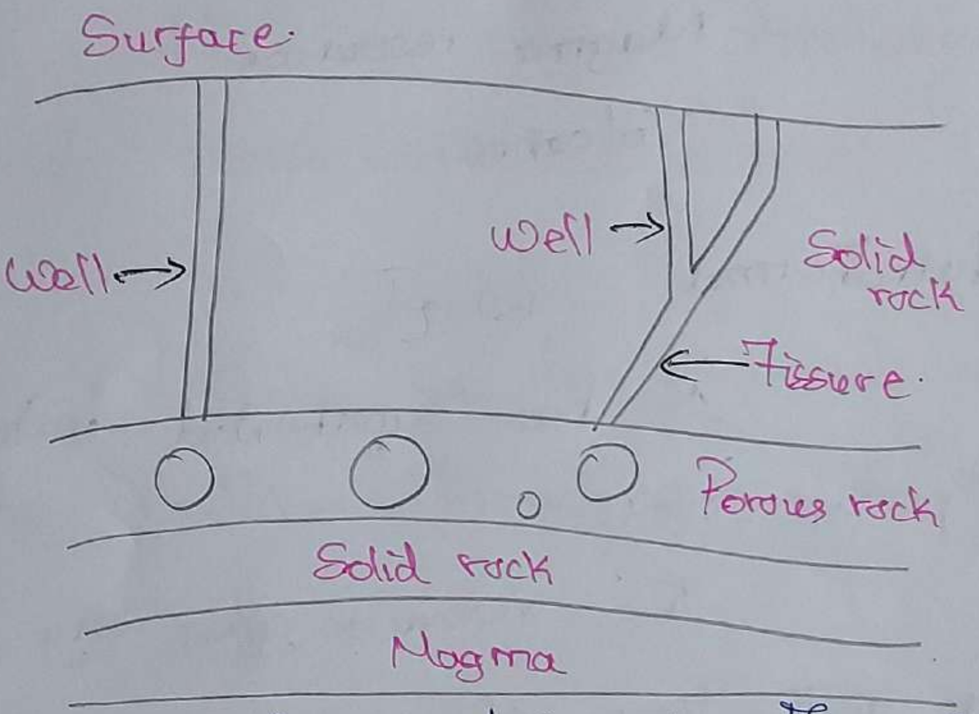
→ An advantage of this type is that it provides good concentration on in east west direction without adjustment for sun tracking.

→ Although the concentration is less than focusing type.



⑨ Geothermal Energy Resources:-

→ Thermal energy contained in the interior of earth is called geothermal energy.



→ Magma lying in the earths core transfer heat to solid rocks.

→ This heat transfers from solid rock to porous rocks.

→ Wells dig through solid rock, through which water is allowed to absorb heat from porous rock.

→ This hot water produces energy.

UNIT - V

ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER PLANTS

1) Types of Tariff:

→ The different types of tariffs are

* Flat demand tariff
* Straightline Meter tariff
* Step meter rate
* Block meter tariff
* Two part tariff
* Three part tariff.

→ The general form of Tariff can be stated as follows.

$$z = ax + by + c$$

z - Total amount.

x - Max demand in kW.

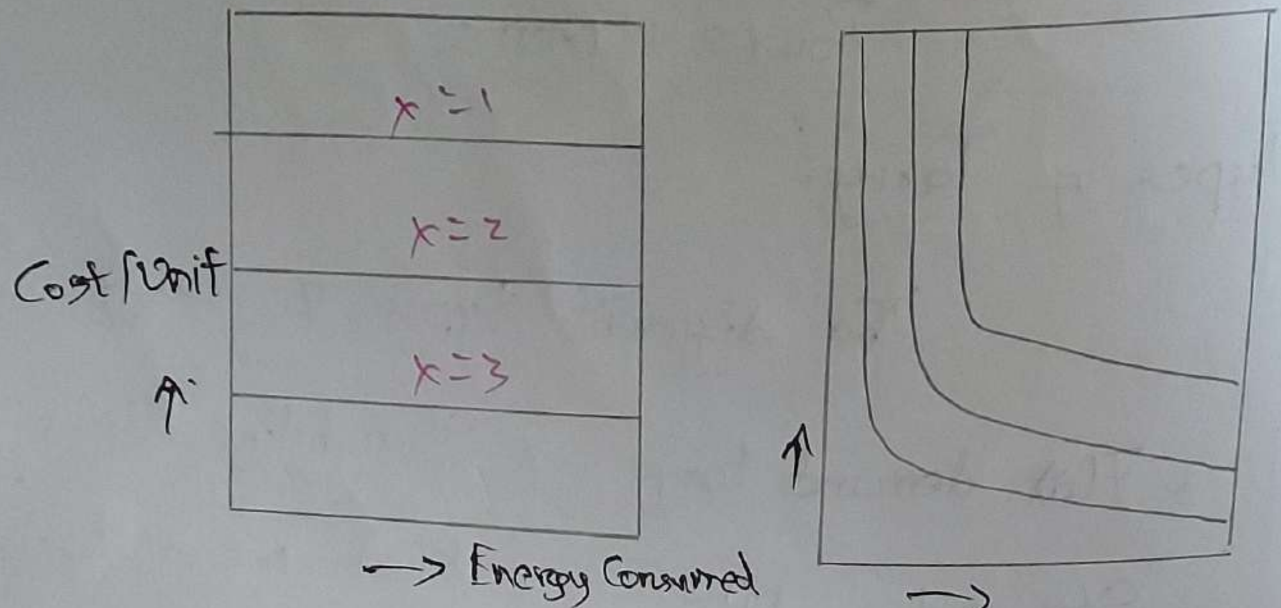
y - Energy consumed in kW hr.

a - Rate per kW

b - Energy rate / kW hr.

c - constant amount.

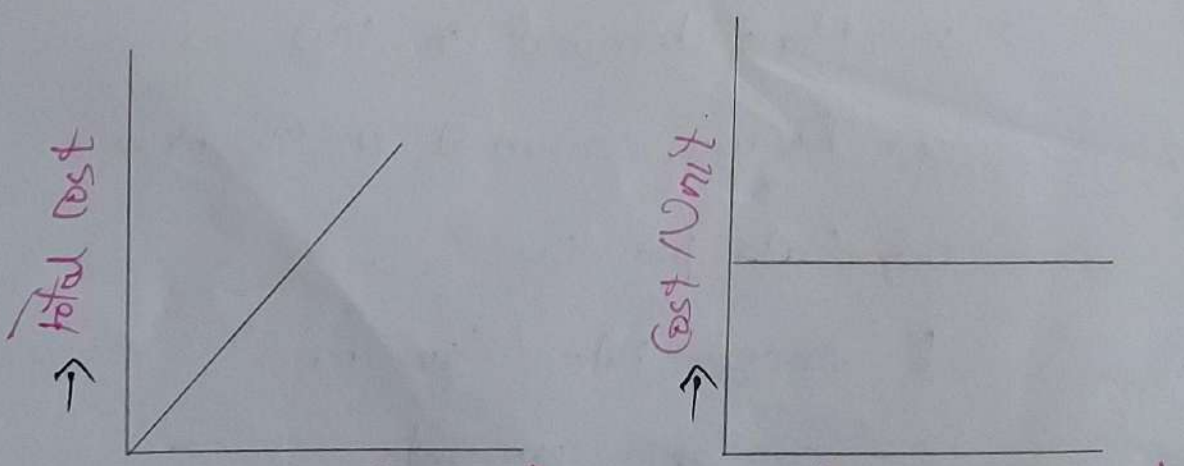
* Flat Demand rate



→ It is based on number of lamps installed and a fixed number of hours of use per month or per year.

→ This energy rate expresses the certain charge per unit of demand of consumer.

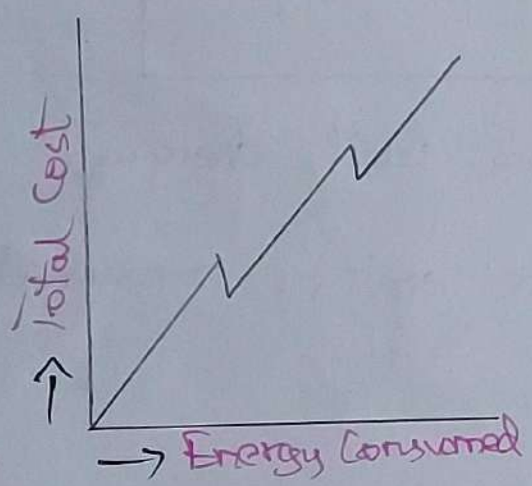
* Straight Line meter rate

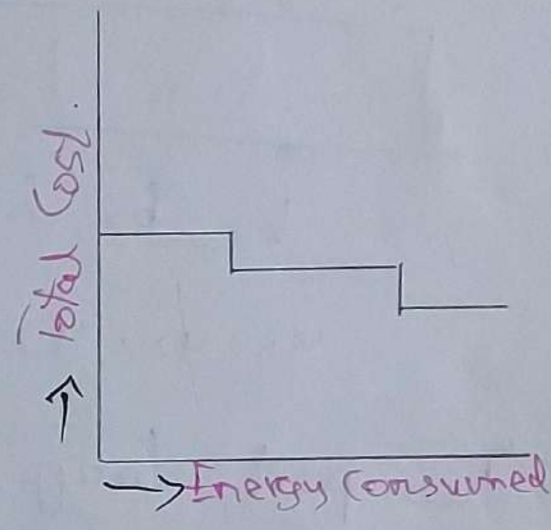


→ The tariff can be made according to the consumption energy and it is recorded by kw - hr meter.

→ This amount is direction proportional to the consumption of consumer.

* Step meter rate





→ In this tariff the charges can be reduced when the energy consumption is increased.

→ It is expressed as.

$z = by$ if $0 \le y \le A$

$z = b_1 y_1$ if $0 \le y_1 \le B$

$z = b_2 y_2$ if $0 \le y_2 \le C$.

* Lock meter rate:

→ In this tariff, a certain amount per unit (kW) is charged for all or my part of the block of each unit and for succeeding blocks of energy the corresponding unit charges decreases.

$$x = b_1 y_1 + b_2 y_2 + b_3 y_3 + \cdots$$

b_1, b_2, b_3 are unit charges.

y_1, y_2, y_3 are energy consumed.

* Two part tariff.

→ In this tariff the total amount of bill is based on maximum demand and energy consumed.

→ It is expressed as two meter.

→ One is energy meter and another one is required to measure maximum demand.

(2) Load Distribution Parameters:

→ The electrical power system consists of generating units where primary energy is converted into electric power, transmission and distribution networks that transport this power and consumers equipment where power is produced.

→ Various types of loads are described below.

* Residential Load
* Commercial Load
* Industrial Load
* Municipal Load
* Irrigation Load.
* Traction Load

→ Below section represents detailed description about the above loads.

* Residential Load

→ This type of load includes domestic lights and power needed for domestic appliances such as washing machine, television, electric cookers, water heaters, refregirators, mixer, grinders etc.

* Commercial Load

→ It includes lighting for shops, advertisements and electric appliances used in shops, hotels, restaurants etc.

* Industrial Load:

→ It consists of Load demand for various industries.

* Municipal Load:

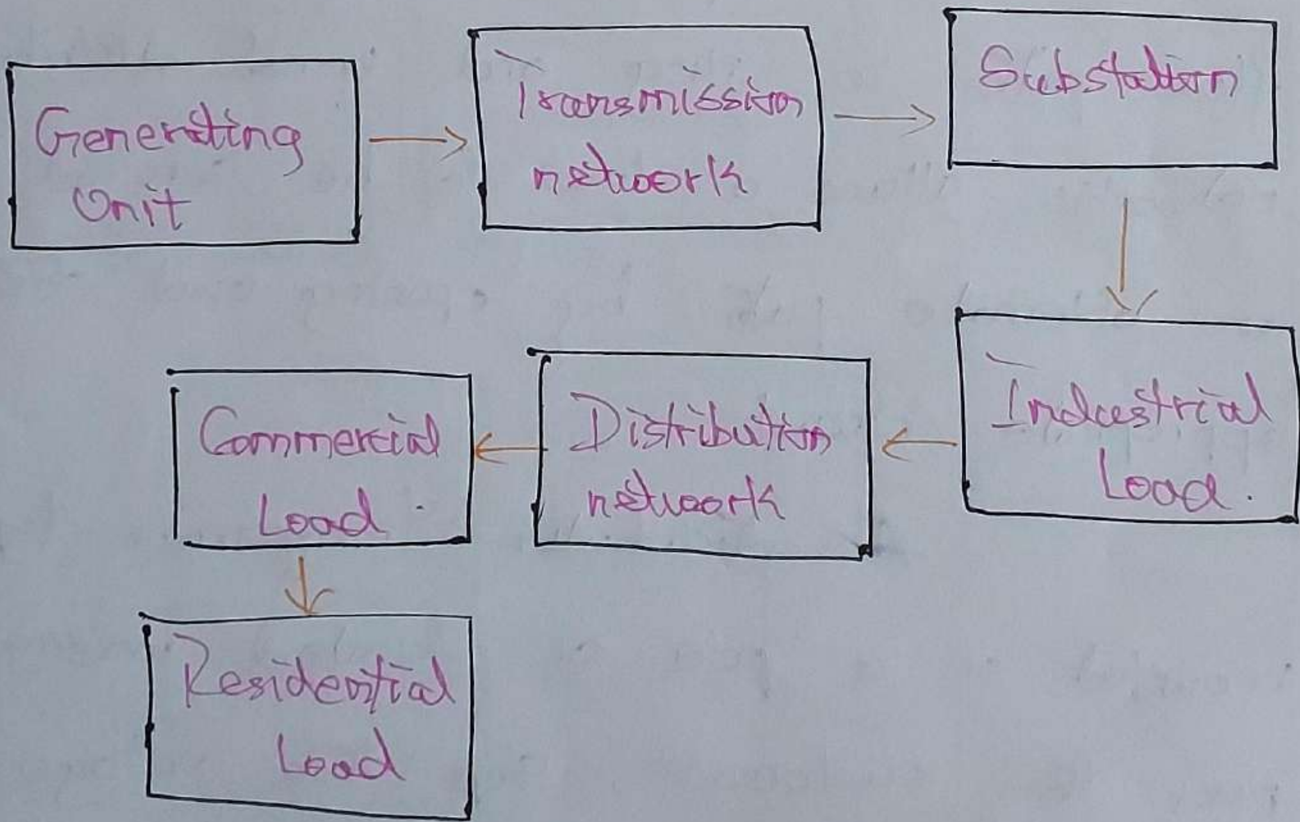
→ It consists of power required for street lights, water supply etc.

* Irrigation Load:

→ It includes electrical power required for street lights, water supply and drainage purposes.

* Traction Load

→ It consists of power required for tram cars, trolley, buses and railways.



→ Distribution network usually have a radial topology, referred to as a "star network". with only one power flow path between the distribution substation and a particular load.

→ Distribution networks sometimes have a ring topology, with two power flow paths between the distribution substation and the load.

→ The presence of multiple power flow paths in ring and mesh distribution networks allows a load to be serviced through an alternate path by opening and closing appropriate circuit.

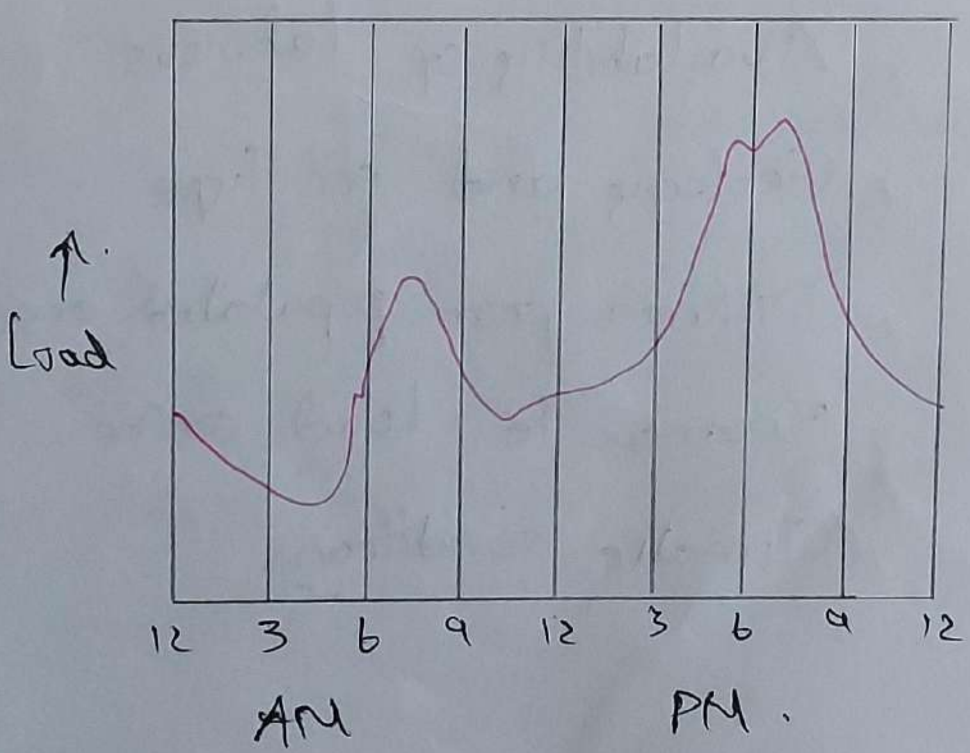
→ A distribution transformer typically mounted on a pole or located underground near the customer, steps this voltage down to the secondary distribution level which is safe enough for use by general customers.

Load Curve:

→ It is a graphical representation which shows power demands for every instant during a certain time period.

→ It is drawn between load in kw and time in hours.

→ If it is plotted for one hour it is called hourly load curve and if the time is considered of 24 hours, Then it is called daily load curve.



③ Comparison of Site Selection Criteria:

→ Selecting a proper site for a thermal power plant is vital for its long term efficiency.

→ Many factors have to be considered regarding suitable location of a plant.

* Availability of Coal
* Transportation facilities
* Availability of Land
* Supply of water.
* Availability of Labours
* Geology and soil type.
* Distance from populated area
* Nearness to Load centre.
* Climatic conditions

* **Availability of Coal:**

→ As the power plant consumes large amount of coal, enough quantity must be available either in vicinity or it should be easily and economically viable to transport the coal to power plant.

→ Proximity to sea route and rail transport are the major criteria.

* **Transportation facilities.**

→ A typical power plant with 1000 MW capacity approximately consumes more than 10,000 tons of coal per day.

→ Hence the necessity for continuous supply and storage capability of coal in power station by rail, by sea and road must be ensured.

* **Availability of Land:**

→ Ash is the main byproduct of combustion and as the amount of coal used is large, proportionately Thousands of tons and ash are generated per day.

→ Ash as it comes out from the boiler is hot and is very corrosive in nature.

→ Disposing of such huge quantities of ash requires a large amount of empty space where it can be safely dumped.

* **Supply of Water**

→ Different quantities of water are required for running the power plant

→ However care should be taken to ensure that site is at a reasonable distance from seasonal rivers.

* Availability of Labours

→ Apart from these major requirements availability of skilled labour is also essential in the plant locality, as the semi and unskilled labour requirements are very high.

→ Proper transportation facility is very vital for the arrangement of labours.

* Geology and soil type

→ Power plant should be built on a land that is not prone to vibrations generated by rotating equipments.

→ Also the site should be away enough from the faults and earth quake prone areas as weak and small earthquakes can damage many parts of power plant which leads to dangerous situation.

(4) Cost of Electrical Energy:

→ The cost of electrical energy generated consists of fixed cost, running cost, customer charges and investors profit.

→ The cost of electrical energy is classified as follows.

Fixed Cost:

→ Fixed cost are those cost which remains same for a given capacity.

→ It does not vary with output.

→ This includes.

* Capital Cost of power plant.
* Capital cost of primary distribution
* Other capital cost

* Capital Cost

→ The capital cost of thermal power plant does not change much, but it charges more for hydraulic power plant because the cost of depends upon foundation required, land etc.

- Cost of Electrical Energy
  - Fixed Cost
    - Capital Cost of Power Plant
      - Land Cost
      - Building Cost
      - Equipment Cost
      - Installation Cost
      - Planning Cost
    - Capital Cost of Primary distribution
      - * Substation Cost
      - * Transmission line cost
    - Other Capital Cost
      - Interest
      - Tax
      - Insurance
      - Maintenance
      - Depreciation
  - Operating Cost
  - Customer Charges
  - Investor Profit

→ Different methods used to calculate depreciation cost of power plant are

* Straight Line method
* Sinking Fund method
* Diminish of value method

* Straight Line Method

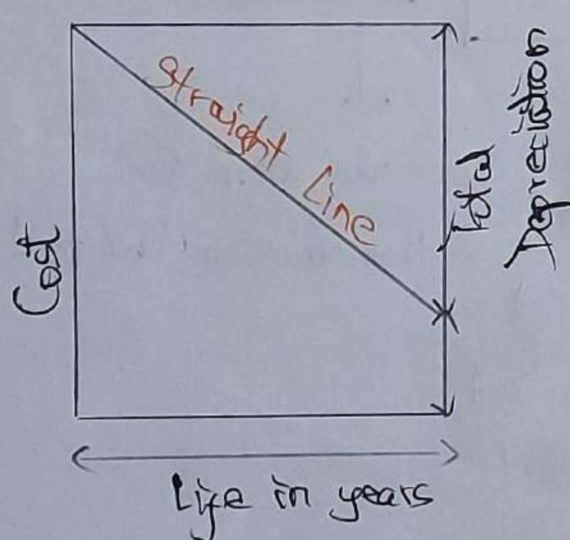
→ This method assumes that the loss of value of equipment is directly proportional to its age.

n = Life in years.

r = Annual rate of interest.

A = Depreciation amount / year.

C = Initial investment.



s = Salvage value

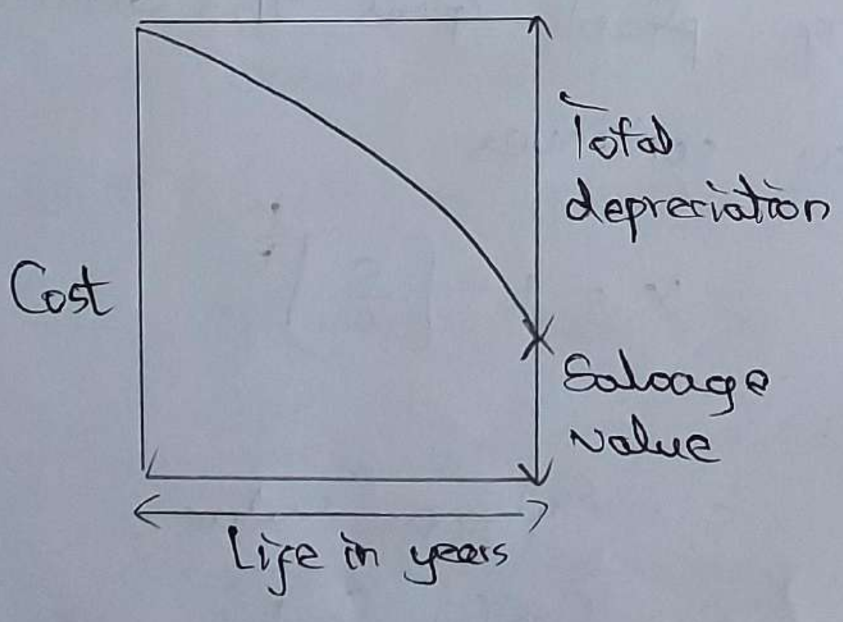
$$A = \frac{C - S}{n}$$

* Sinking Fund Method

→ This method consists of providing depreciation by means of fixed periodic charges which aggregated with compound interest over the life of equipment.

→ The rate of interest is also constant through out the life of machine

$$A = C - S\left[\frac{r}{(1+r)^n - 1}\right]$$



C = capital cost.

S = salvage value

r = rate of interest.

* Diminishing Value Method

→ The amount is set aside per year decreases as the life of plant increases.

→ This is also called reducing balance method.

→ The diminishing value of plant is much greater in the early years and lesser in latter years.

→ Under this method the book value of plant goes on decreasing as its existence continues.

$$x = 1 - \left[\frac{s}{c}\right]^{\frac{1}{n}}$$

where

s = Salvage value.

C = Capital Cost.

n = number of years

Operating Cost :

→ Operating cost are varies with respect to output of the plant.

→ This includes cost of fuel, operating labour, maintenance cost, material for regular maintenance etc.

Cost of Fuel and Oil

→ The cost of fuel and oil proportional the output generated.

→ Consumption of fuel is also varies with load on power plant.

→ At full load the fuel consumption is minimum because the prime mover works at maximum efficiency.

Cost of water :

→ This cost of material and water

also proportional to output of plant.

Customer Charges:

→ This cost is depends upon the quantity of customers.

→ This includes the capital cost of secondary distribution system cost of inspection, maintenance of distribution lines, the cost of labor required for meter reading and cost of publicity.

Investor's Profit:

→ The investor expects some profit on his investment.

→ The profit rate varies according to business condition.

→ The cost power generation can be reduced.

(5) Pollution Control Methods :-

→ The environment around the thermal power plant depends on the following factor

* Fuel combustion process
* Type of fuel used
* Flue gas device used
* Dust collecting

→ The emission of CO and SO_2 to the atmosphere depends on following factor.

* Excess air supplied for burning.
* Combustion process.
* Stabilisation of flame.
* Diameter of furnace chamber.

→ The maximum permissible concentration of SO_2 at ground level are 0.05 to 0.08 ppm for 24 hours & 0.12 - 0.2 ppm for 1 hour.

* Control of CO_2

→ CO_2 is an unavoidable part of the combustion process.

→ Some control measures for reducing CO_2 emission are as follows.

* Economically available cleanest fuel should be used.

* When burning coal, more care should be given to high heat content, low ash & low sulfur coal.

* Coal washing should be done to reduce the ash content especially for high ash coal.

* The selection of best technology is to choose the fuel to balance the environmental and economic benefits.

* Control of SO_2

→ The prevention of SO_2 emission into the atmosphere is very important as it is harmful.

→ There are two basic approaches to the problem.

* Removal of sulphur compound from fuel before burning and.
* Removal of SO_2 from flue gas.
* There are three methods used to clean SO_2 from flue gas.

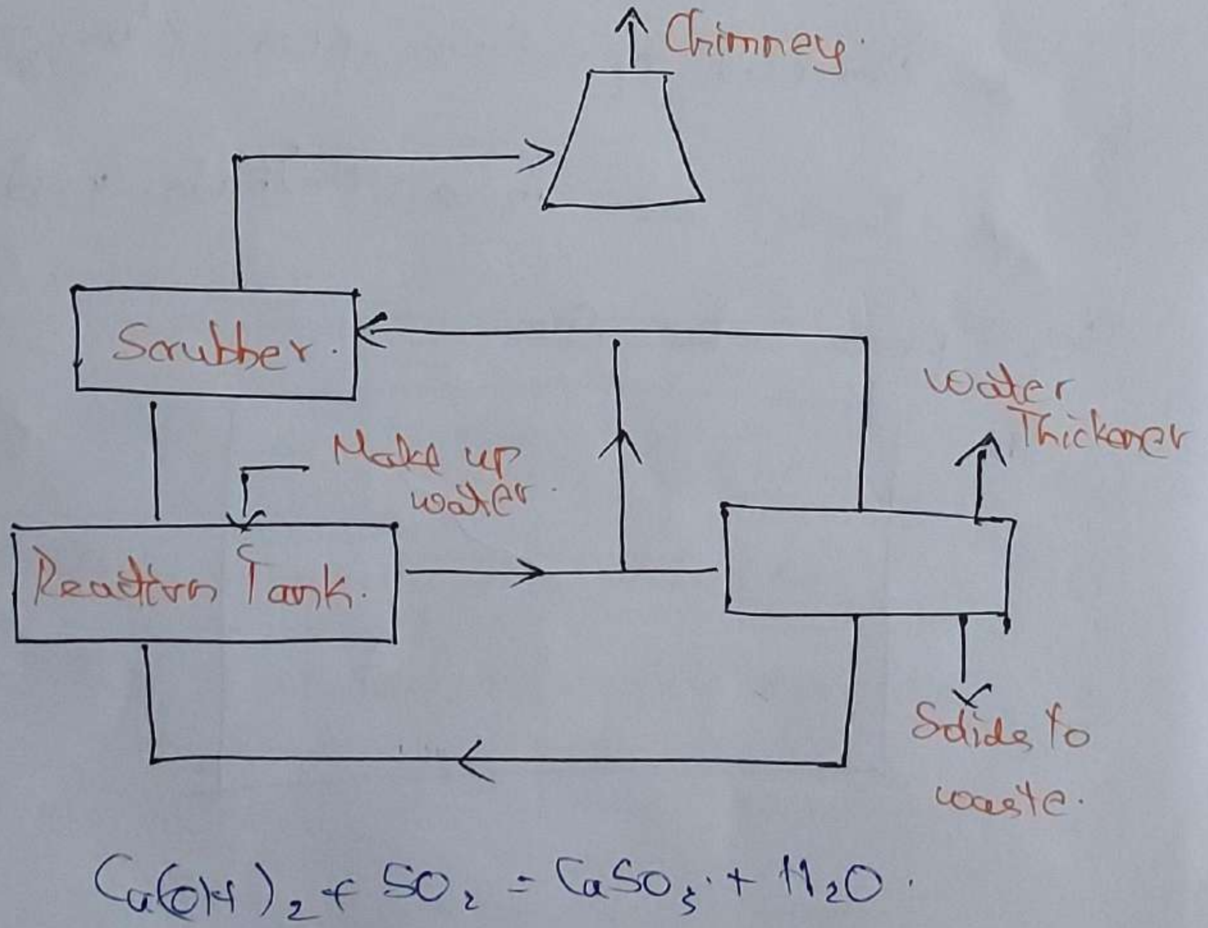
→ Wet Scrubbing
→ Catalytic oxidation
→ Solid absorbent

* Wet Scrubbing

→ The system uses lime stone in the form of aqueous slurry.

→ The slurry is bought in contact with flue gas which absorbs SO_2.

→ Exhaust SO_2 is absorbed and it is chemically reacted with water & limestone from products and sent from scrubber to tank.



$Ca(OH)_2 + SO_2 = CaSO_3 + H_2O$

$CaCO_3 + SO_2 = CaSO_3 + CO_2$

⑥ Waste Disposal Options for Coal and Nuclear Power Plants

→ Radioactive wastes are stored so as to avoid any chance of radiation exposure to people.

→ The radioactive of the wastes decays with time, providing a strong incentive to store high level wastes for about 50 years.

→ Storage of used fuel is normally under water for atleast five years and then often in dry storage.

→ Disposal of low level wastes is straight froward and can be undertaken safely almost anywhere.

→ The commonly accepted disposal

options are.

* Near surface disposal
* Deep geological disposal

* Near Surface Disposal :-

→ The International atomic Energy Agency (IAEA) definition of this option is the disposal of waste, with or without engineered barriers in.

→ Near surface disposal facilities at ground level.

→ These facilities are on or below the surface where the protective covering is of the order of a few metres thick.

→ waste containers are placed in constructed vaults and when full the vaults are backfilled.

→ Eventually they will be covered and capped with an impermeable layer and topsoil.

→ These facilities may incorporate some form of drainage and possibly a gas venting system.

→ The term near surface disposal replaces the term shallow land and ground disposal, but these older terms are still sometimes used when referring to this option.

→ These facilities will be affected by long term climatic changes and this effect must be taken into account when considering safety such as changes could cause disruption of these facilities.

→ This type of facility is therefore

typically used for LLW and ILW with a radionuclide content of short half life.

Deep geological Disposal:

→ The long timescales over which some of the waste remains radioactive led to the idea of deep geological disposal in underground repositories in stable geological formations.

→ Isolation is provided by a combination of engineered and natural barriers and no obligations to actively maintain the facility is passed on to future generations.

→ This is often termed a multi barrier concept, with the waste packaging, the engineered repository and geology all providing barriers to prevent radio nucludes.

Disposal options for coal combustion waste

→ There are three possible regulatory outcomes regarding management of coal combustion wastes.

* Hazardous
* Non Hazardous
* Special nonhazardous

On island Hazardous Waste Disposal Options

→ If the EPA determines CCT wastes to be hazardous, those waste would be managed according to the requirements of RCRA subtitle C.

→ Strict rules apply whether the wastes are disposed of on site or off site.

→ Because Hawaii has no hazardous waste disposal facilities.

Off Island Nonhazardous Waste Disposal:

→ The same three disposal options for hazardous waste. eg. shipment to the U.S mainland, shipment to other countries, and ocean disposal, exist for nonhazardous waste disposal, but the issues differ and the costs are lower.

Specialized Non hazardous Waste Disposal

→ It is possible that coal combustion wastes could be regulated at the federal level under a special category of nonhazardous industrial wastes that is neither hazardous as defined under RCRA subtitle C nor nonhazardous as currently provided for under RCRA subtitle D.

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