Unit - I

Introduction to Energy sources & its conversion

→ Definition & unit of Energy and Power:

Energy : Capacity of doing work.
Unit : Joule or N-m.

Potential energy = $m \cdot g \cdot h$.
Kinetic energy = $\frac{1}{2} m v^2$.

Power : Rate of doing work.
Unit : Watt or J/sec.

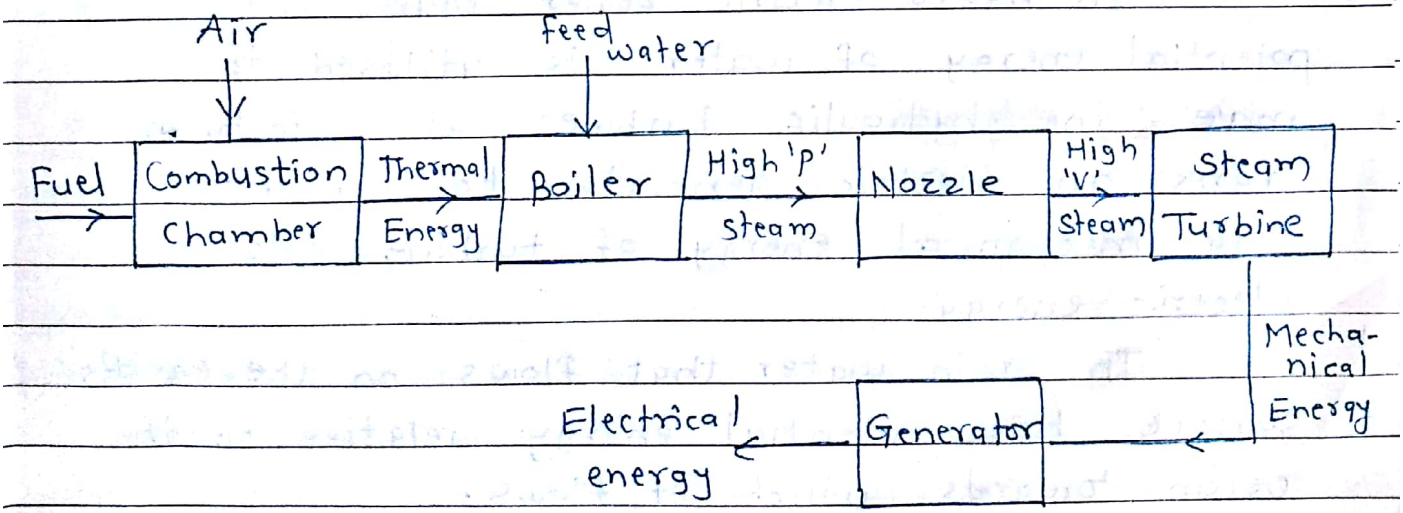
→ Categories of Energy sources :

Convential / Nonrenewable
e.g. coal, water, petroleum, natural gas.

Non-convential / renewable
e.g. solar, wind, ocean, tidal, geothermal energy.

→ Thermal energy :

Steam power plant :



In steam power plant, chemical energy of fuel is utilized to generate high pressure, high temperature steam in a boiler.

This steam is used in a turbine to produce mechanical power which is finally converted into electrical energy by an alternator.

Fuel used is coal, oil or natural gas.

Advantage of steam power plant:

Fuel is cheaper.
Less space required.
cost of electric power generation is less.

Disadvantage of steam power plant:

Oper & maintenance cost is high.
ash handling problem.
causes pollution.
less efficiency.

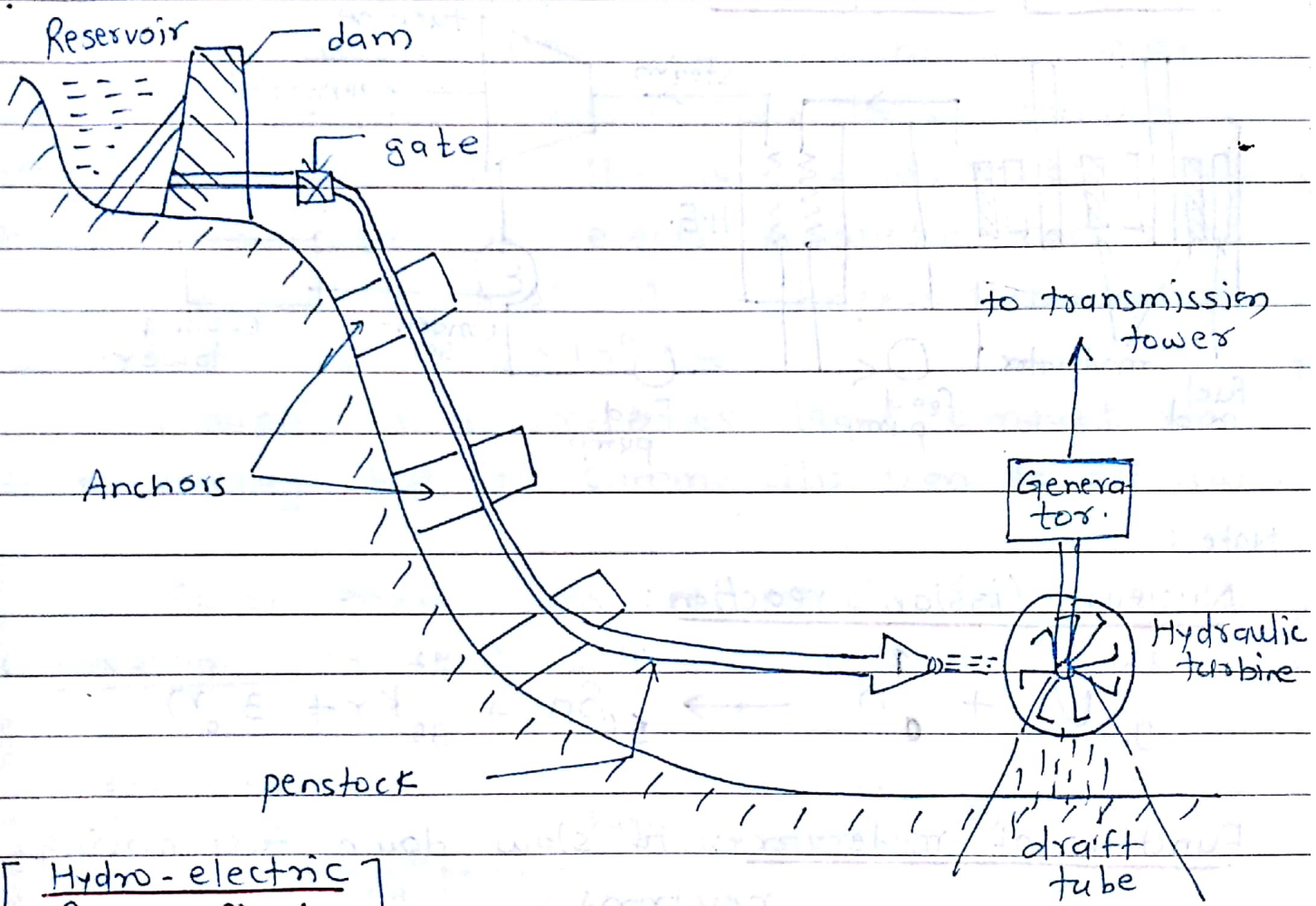
→ **Hydro-power energy:**

In hydro-electric power plant the potential energy of water is utilised to move the hydraulic turbines which in turn runs an electric generator to convert the mechanical energy of turbine into electric energy.

The rain water that flows on the earth's surface has potential energy relative to the ocean towards which it flows.

In hydro electric power plant, water is

collected & artificially stored by constructing dams across the flowing streams. This potential energy of water is converted into mechanical work & ultimately into electrical energy. Power developed by hydraulic turbine depends on the quantity of water & head of water available.



[Hydro-electric Power Plant]

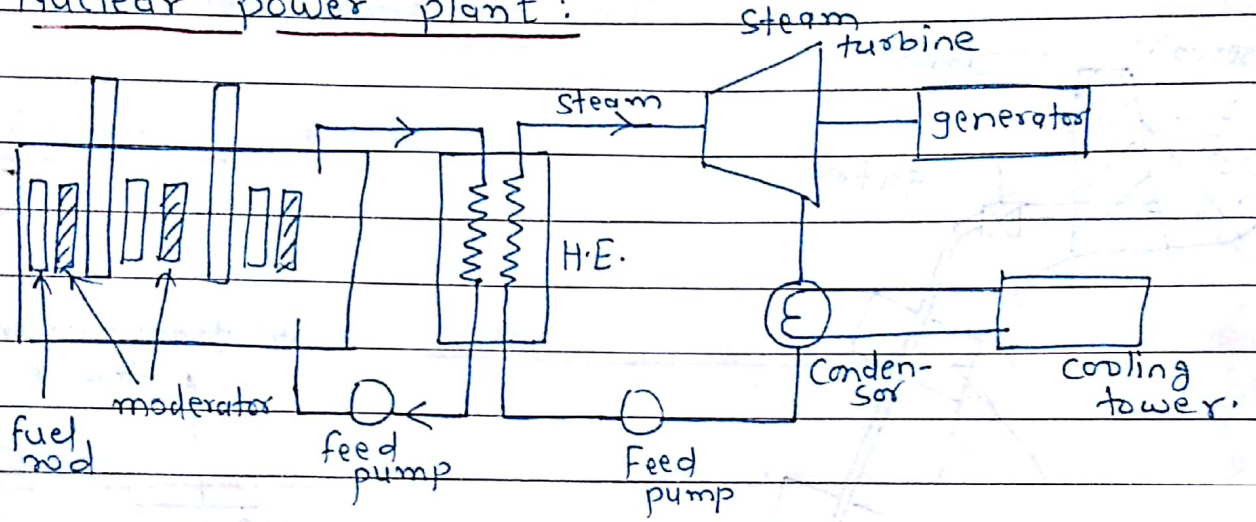
Advantages:
low operational cost
no ash disposal
non polluting.
efficient.

Disadvantage:
- depends on water
- set up cost high

→ **Nuclear energy**:

Energy produced by nuclear reactions by fission for raising steam. Steam is further utilised in a conventional steam power plant for running a steam turbine & an electric generator.

Nuclear power plant:



Note:

Nuclear fission reaction:

$$_{92}^{235}U + {}_{0}^{1}n \longrightarrow {}_{56}^{141}Ba + {}_{36}^{92}Kr + 3\,{}_{0}^{1}n$$

Function of moderator: to slow down fast moving neutrons.

Function of control rods: rate of heat energy released is controlled by cadmium / boron rods.

Advantages:

Large qty of energy is released by small amount of fuel.

fuel transporation avoided.

high performance.

less space reqd.

Disadvantages:

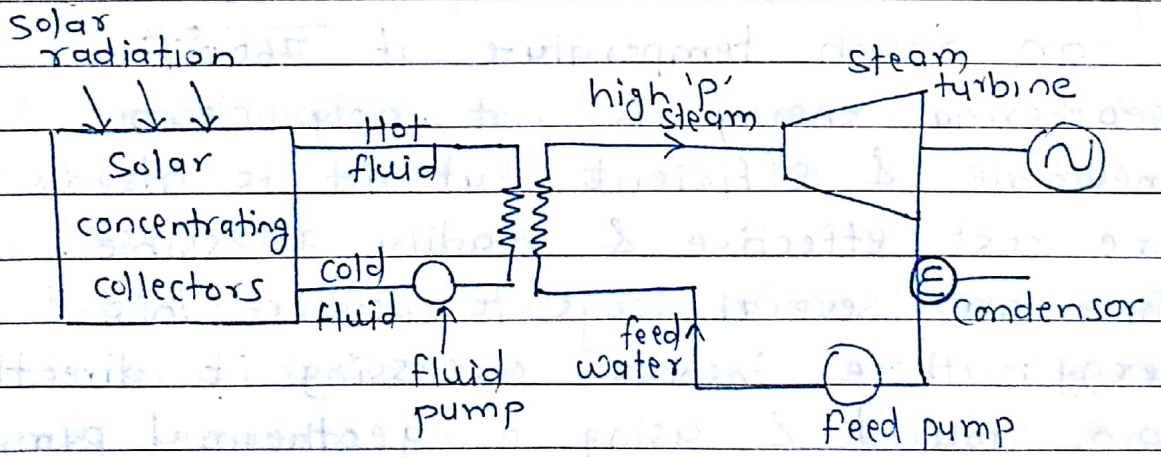
high capital cost.
needs trained man power.
problem of radioactive waste disposal.
high degree of safety req^{d}.

→ **Solar energy**:

Sun releases enormous amount of energy due to continuous fusion reactions taking place in the sun. The sun sends out this energy in form of electro magnetic radiations at rate of 3.7×10^{20} MW. Energy intercepted by earth is 1.85×10^{11} MW.

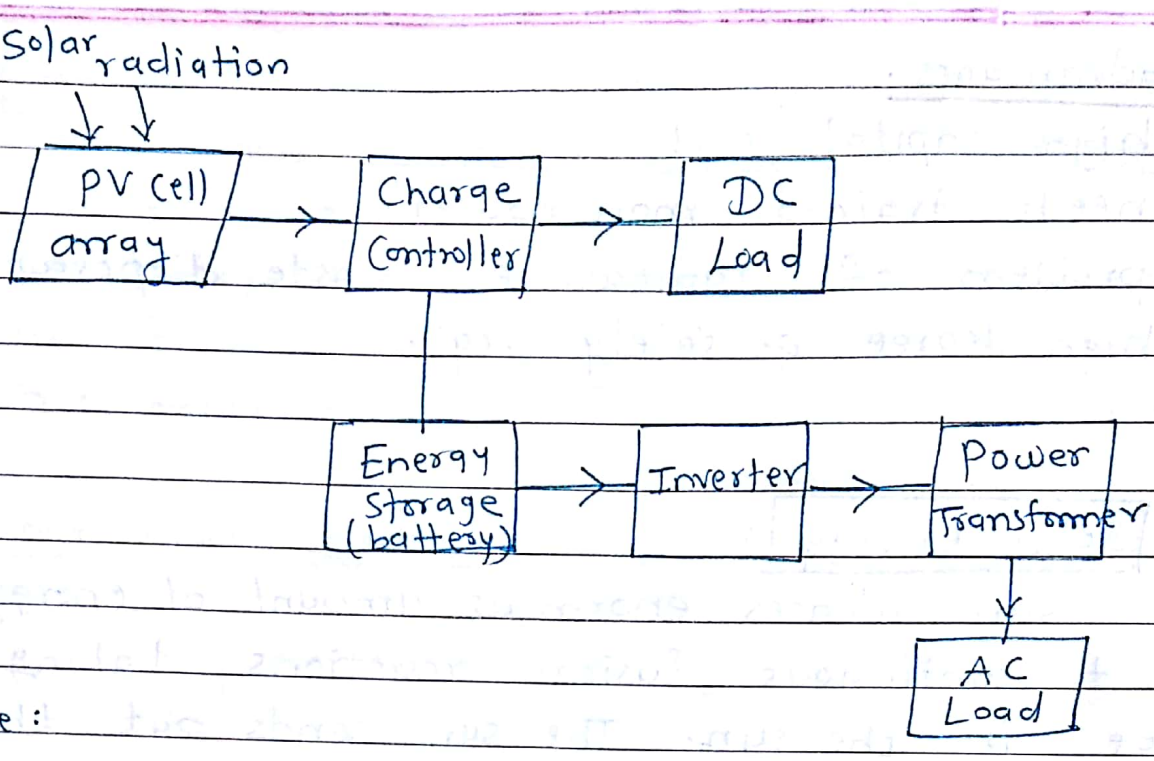
Though earth receives large amount of solar energy, but its commercilization is difficult.

Solar energy can be used for power generation as follows:



[Power generation using solar energy]

- Solar PV cells are used to convert solar energy directly into electrical energy. Since power output of one solar cell is about 3W (0.5V, 6A).



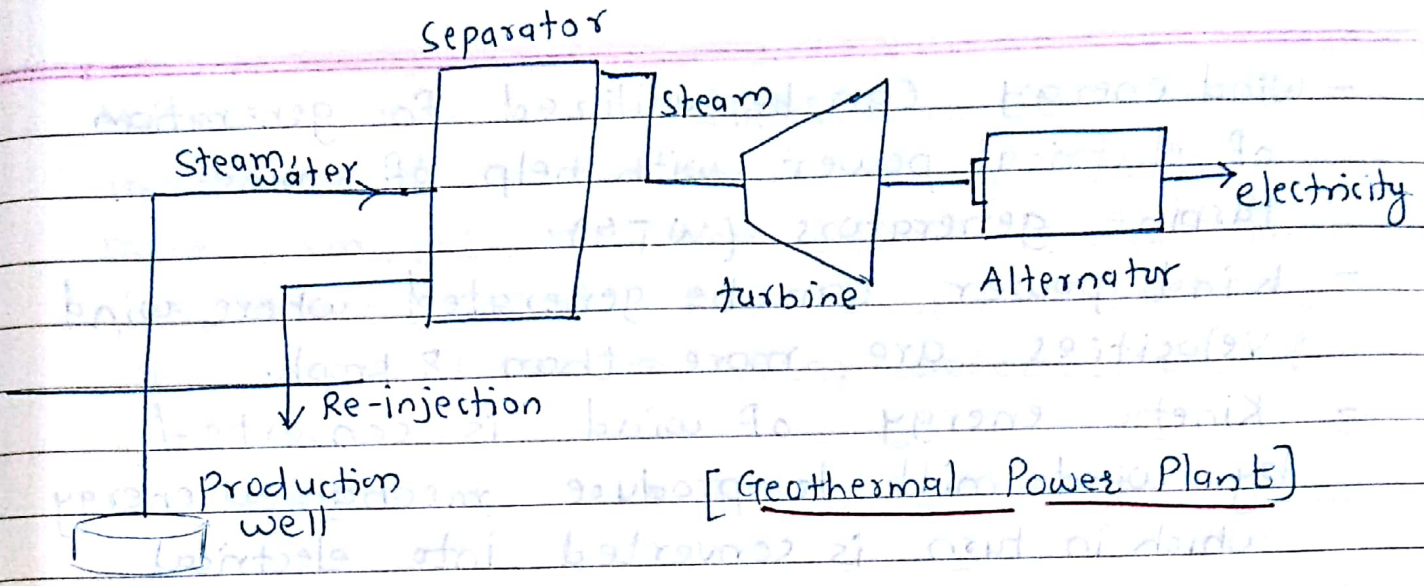
Note:

Function of charge controller: avoid back flow of current to PV cells.

Unit I
Systems in mechanical engineering

→ **Geothermal energy**

- It means energy from earth. It is the heat energy of steam & hot water heated by earth's core (4000 miles beneath) & can reach temperature of 7600°F.
- Geothermal energy is not only clean, renewable & efficient, but it is also more cost effective & readily accessible.
- There are several ways to acquire this energy; these include accessing it directly from ground & using a geothermal pump to heat & convert energy to electricity.
- Geothermal power plant generates electricity by piping hot water & steam through underground wells as shown.



[Geothermal Power Plant]

- A production well captures heat from within the earth's core that produces steam & water.
- Water is sent back into earth while steam spins turbines that produces electricity.

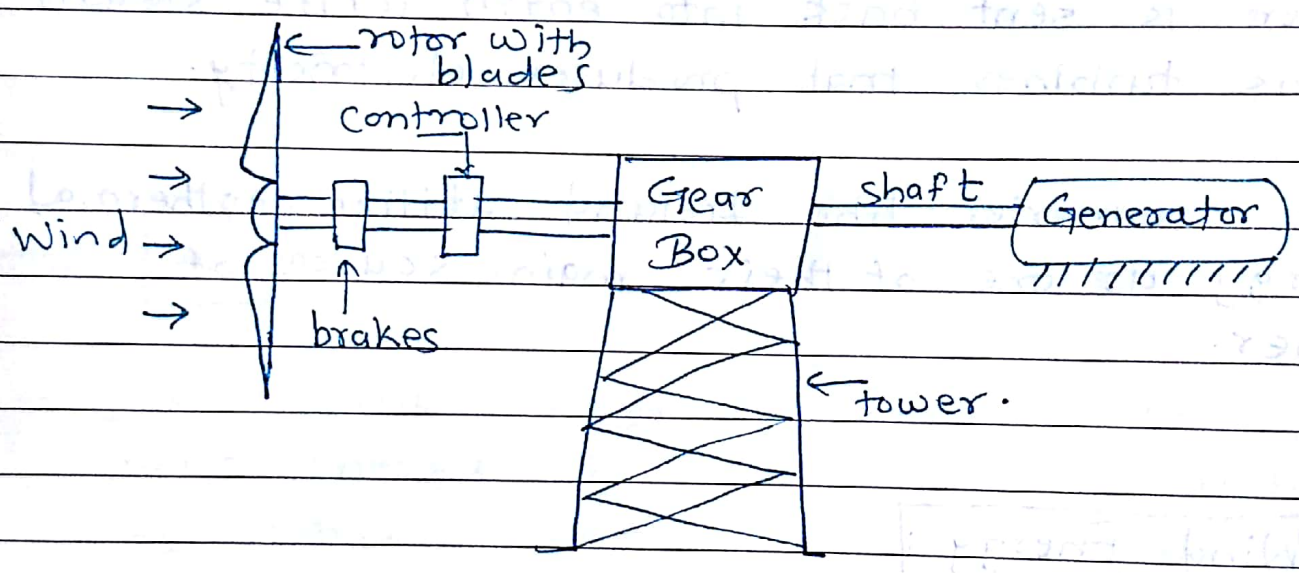
- Some countries like Iceland utilize geothermal energy as one of their main sources of power.

→ **Wind Energy:**

- A small portion of total solar radiations reaching on earth's surface cause winds due to following reason:

(i) Heating up of earth's surface due to absorption of solar radiations & cooling at night near hills / mountains.
(ii) Rotation of earth & its motion around sun.
(iii) Local winds caused due to differential heating.

- Wind energy can be utilized for generation of electrical power with help of wind turbine generators (WTG).
- Wind power can be generated where wind velocities are more than 8 kmph.
- Kinetic energy of wind is converted by wind mill to produce mechanical energy which in turn is converted into electrical power by means of generator.
- It is used to run water pump, charging of batteries etc.



- Wind power is clean, non polluting & un-exhaustible.
- Low m/t cost & low power generation cost.

→ **Hydrogen Energy :**

- It is a zero emission fuel when burned with oxygen. It can be used in fuel cells or internal combustion engines to power electric vehicles or electric devices.

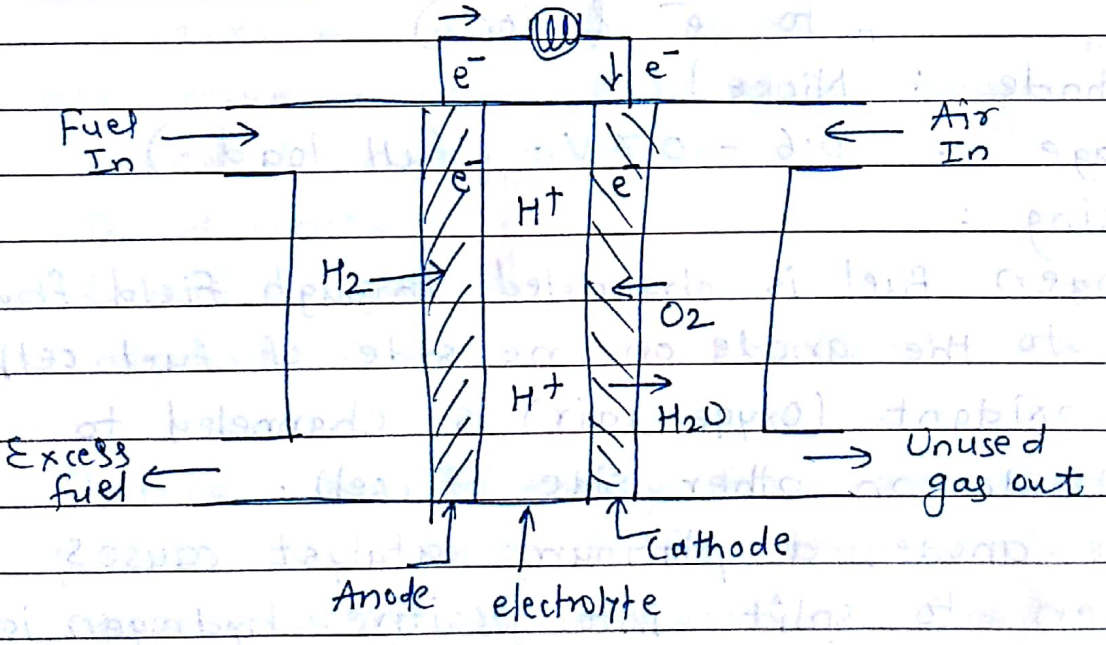
- Hydrogen gas is so light, it rises in the atmosphere & is therefore rarely Found in its pure form, H_2. In the flame of pure hydrogen gas, burning in air, hydrogen (H_2) reacts with oxygen (O_2) to form water (H_2O) & release energy.

$$2H_2 + O_2 \longrightarrow 2H_2O + \text{energy}$$

- C'mon production method includes electrolysis & steam methane reforming.

- Limitations:
  ↳ Hydrogen fuel is hazardous bcz of low ignition energy & high combustion energy of hydrogen.

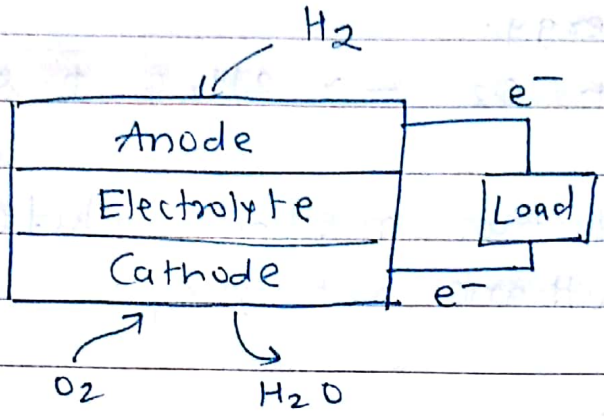
Hydrogen Fuel Cell:



- A fuel cell is an electrochemical cell that converts chemical energy of fuel & an oxidizing agent into electricity through pair of redox reaction.
- These are different from most batteries in requiring a continuous source of fuel & oxygen

to sustain chemical reaction, whereas in a battery chemical energy usually comes from metals & their ions & oxides.

- block diagram of fuel cell :



- electrolyte : potassium hydroxide / salt carbonate
- Fuel : hydrogen
- Anode : fine platinum powder (breaks into e^- & ions)
- Cathode : Nickel
- Voltage : 0·6 - 0·7 V. (full load)
- Working :

① Hydrogen fuel is channeled through field flow plates to the anode on one side of fuel cell, while oxidant (Oxygen/air) is channeled to the cathode on other side of cell.

② At the anode, a platinum catalyst causes hydrogen to split into positive hydrogen ions & negatively charged electrons.

③ Polymer electrolyte membrane allows only positively charged ions to pass through it to the cathode.
Negatively charged e^- must travel along an external circuit to cathode.

④ At cathode, electrons & positively charged hydrogen ions combine with oxygen to form water.

→ Application : power source in remote loc^{n} such as large parks, spacecraft, communication center.
- Toyota Mirai vehicle (automobile)
- fuel cell forklift
- submarines.

→ **Biomass Energy :**

- Biomass is plant / animal material used for energy production or in various industrial processess ~~ta~~ as raw material.
- Biomass is a renewable energy source bcz its supplies are not limited. We can always grow tree & crops & waste will always exist.
- We have 4 types of biomass today :
  wood & agri products
  Solid waste.
  Landfill gas & biogas
  alcohol fuels like biodiesel, ethanol.
- Plants absorb energy from the sun through process of photosynthesis. When biomass is burned, stored energy is released as heat. Some types of biomass can be converted into liquid fuels called biofuels (may power cars, trucks etc.)

- Advantages : Renewable.
  Carbon neutral
  Cost effective
  Abudant.

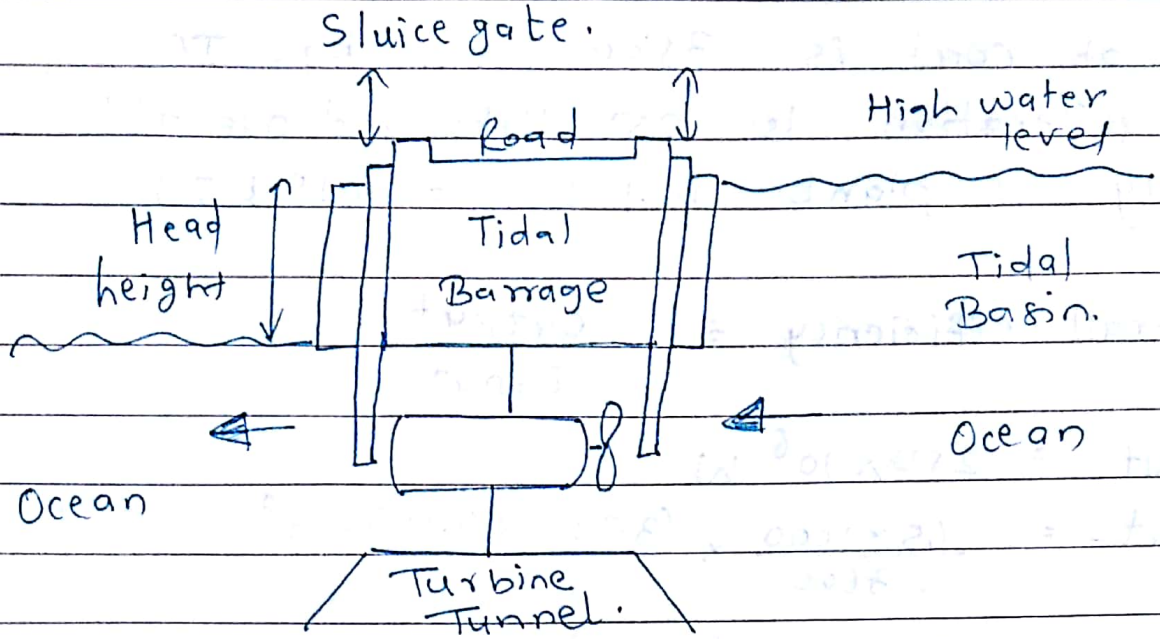
- Biomass Conversion: Thermal
  Chemical
  Biochemical.
  Electrochemical

→ **Tidal Energy :**

- Tidal energy or tidal power can be defined as the energy that is the result of the moon & sun's gravitational influence on the ocean.
- Hight differences between high & low tides create tidal currents in coastal areas & these currents can be strong enough to drive turbines.
- Tidal barrage power plant consists of three main parts : The first being the barrage itself, holding the water back during high tide.
- The second part is the sluice gate that let water through the third part, the turbine & generator, resulting in electricity generation.
- Sluice gates are left open during high tide & closed during low tides to create a water level differential, creating a potential difference that powers turbine when the water is released.

- Advantages of tidal energy :
  renewable
  green energy source.
  at low speed, large amount of energy
  tidal currents are predictable.

Tidal power plant :



→ **Grades of Energy :**

(i) weight grade (MJ/kg)

(ii) volume grade (MJ/m^3)

(iii) Area grade (MJ/hectare)

(iv) State grade : solid, liquid or gas.

Example 1 : A steam power plant has coal consumption of 165 Tonnes per hour. Calorific value of coal is 3500 Kcal/kg. If power generation is 250 MW; find overall efficiency of plant. (1 Kcal = 4.18 KJ)

Soln : Overall efficiency $= \frac{\text{Output}}{\text{Input}}$

$$\text{Output} = 250 \times 10^6 \text{ W}$$

$$\text{Input} = \frac{165 \times 1000}{3600} \times (3500 \times 4.18) \times 10^3$$

$$\eta = \frac{250 \times 1000 \text{ (KJ/s)}}{(165 \times 1000/3600)(3500 \times 4.18)}$$

$$= 0.3728$$

$$= 37.28\%$$

Example 2 : A small generating plant of 100 KW capacity uses gas of a calorific value of 4000 KJ/m^3. The volume of gas required per hour when plant is running at full load condition is 450 m^3/hr. Find input power & overall efficiency.

Soln : Output : 100 MW $= 100 \times 10^6$ W.

Input : $4000 \times 10^3 \frac{J}{m^3} \times 450 \frac{m^3}{hr}$

$$= \frac{4000 \times 10^3 \times 450}{3600} \text{ J/sec.}$$

$\eta = \frac{O/P}{I/P} =$

Example 3 : A steam power plant has coal consumption of 16200 kg/hr with calorific value of coal as 17793.9 kJ/kg. If speed of steam turbine is 1000 rpm & generated torque is 477464.82 N-m. Find i/p power, o/p power & efficiency.

Soln : I/p power = $\frac{16200 \text{ kg}}{3600 \text{ sec}} \times 17793.9 \times 10^3 \frac{\text{J}}{\text{kg}}$

= W

O/P power = $\frac{2\pi NT}{60} = \frac{2\pi \times 1000 \times 477464.82}{60}$ J/sec

$\therefore \eta = \frac{\text{O/P}}{\text{i/P}} =$

Example 4 : Steam power plant has coal consumption of 16300 kg/hr with calorific value of coal as 17793.9 kJ/kg. If speed of steam turbine is 1100 rpm, radial distance is 1.5 m & generated force is 318309.88 N. Find generated torque, i/p power, o/p power & efficiency.

Soln : Generated torque (T) = F × R

i/p power = $\frac{16300 \text{ kg}}{3600 \text{ sec}} \times 17793.9 \times 10^3 \frac{\text{J}}{\text{kg}}$

O/p power = $\frac{2\pi N \cdot T}{60}$

$\therefore \eta = \frac{\text{O/P}}{\text{i/P}}$

Example 5 :

Det' power in the wind if wind speed is 20 m/s & blade length is 50m. $\rho_{air} = 1.23\ kg/m^3$

Soln : $P = \frac{\pi}{2} \cdot r^2 \cdot v^3 \cdot \rho \cdot \eta$

(r: radius, v: speed, ρ: density, η: efficiency factor (40%))

$\therefore P = \frac{\pi}{2} \times (50)^2 \times (20)^3 \times 1.23 \times 0.40$

$= 15079644\ W.$

$\approx 15\ MW.$

Practice Problem: ① In thermal power plant work done by steam turbine is 900 J/kg. Work consumed by pump is 50 J/kg. Heat supplied by boiler to system is 2800 J/kg Find (i) net work done (ii) η

② $W_T = 1\ KJ/kg$, $H.S. = 2.2\ KJ/kg$; $\eta = 38\%$. , $W_p = ?$ (164)

③ $H.S. = 2900\ KJ/kg$, $W_T = 900\ J/kg$, $W_p = 100\ J/kg$. $\eta_{old} = ?$
$\eta_{new} = \eta_{old} + 3\%$. ; H.S. & W_T : same, $(W_p)_{new} = ?$

④ $W_T = 1200\ J/kg$, $H.S. = 4000\ J/kg$, W_p : neglected $\eta_1 = ?$
if $W_p = 75\ J/kg$; $\eta_2 = ?$

Construction, working of centrifugal pump, reciprocating compressor, pelton turbine & basic wind mill.

Pelton Turbine

→ Hydraulic machines which convert the hydraulic energy into mechanical energy are called as turbines.

→ Water turbine consists of wheel called as runner or rotor having no. of specially designed vanes / blades.
Water with large amount of hydraulic energy strikes the runner & causes it to rotate.

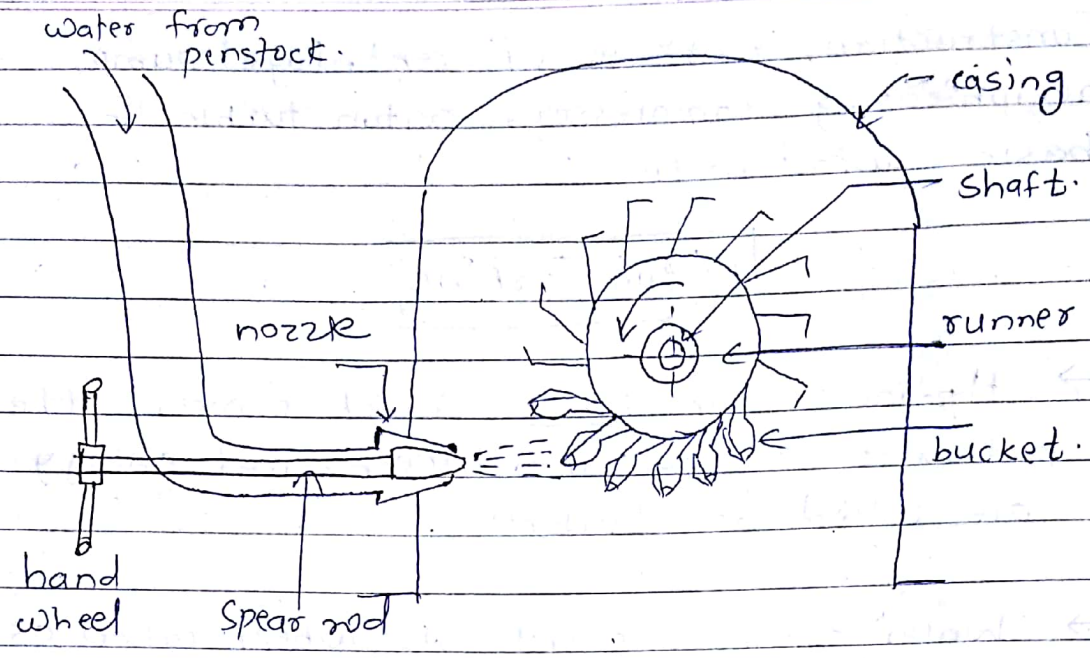
→ Thus mechanical energy is supplied to generator coupled to a runner, generates electrical energy.

→ Classification of hydraulic turbine:

1. Acc. to action of water flowing through the turbine runner: a) Impulse turbine
   b) Reaction turbine.

2. Acc. to dirⁿ of flow of water in turbine
   a) Tangential flow
   b) Radial flow
   c) Axial flow
   d) Mixed flow.

3. Acc. to head & qty of water required.
   a) high head
   b) medium head
   c) low head.

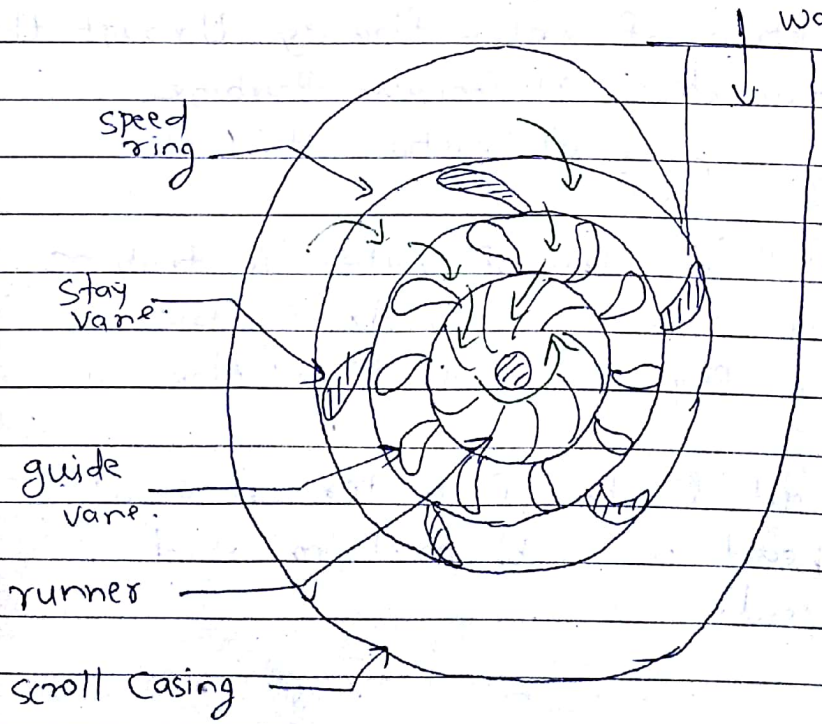


[Pelton wheel]

→ Impulse Turbine:

all the available energy of water is converted into kinetic energy by passing it through nozzle. This high velocity is impinged on a series of buckets of runner causing it to revolve.

Casing is provided on runner to prevent splashing & to guide water discharged from buckets to tail race.

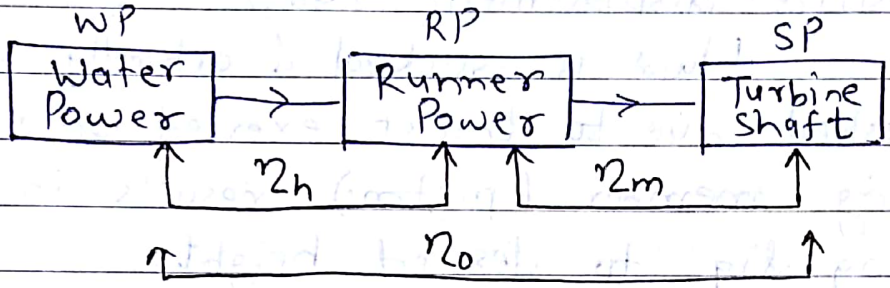


[Fransic Turbine]

→ Reaction Turbine :

Only part of available energy of water is converted into kinetic energy & some part is in potential energy. Pressure difference bet^n inlet & outlet of runner is called reaction pressure & turbine is called 'reaction turbine.'

★ Numerical :



A pelton wheel works under water power of 1.3 MW. Hydraulic efficiency of turbine is 95%. Find runner power developed. If mech. eff. is 90%. Find overall efficiency & shaft power of turbine.

Soln : WP = 1.3 MW = 1.3×10^6 W. RP = ? η_o = ?

η_h = 95%. η_m = 90%. SP = ?

$$\eta_h = \frac{RP}{WP} \times 100 = 95 = \frac{RP}{1.3 \times 10^6} \times 100$$

$\therefore$ RP = 1.23 MW.

$$\eta_o = \eta_m \times \eta_o = 85.5\%$$

$$\eta_o = \frac{SP}{WP} \times 100$$

$\therefore$ SP = 1.11 MW

Centrifugal Pump

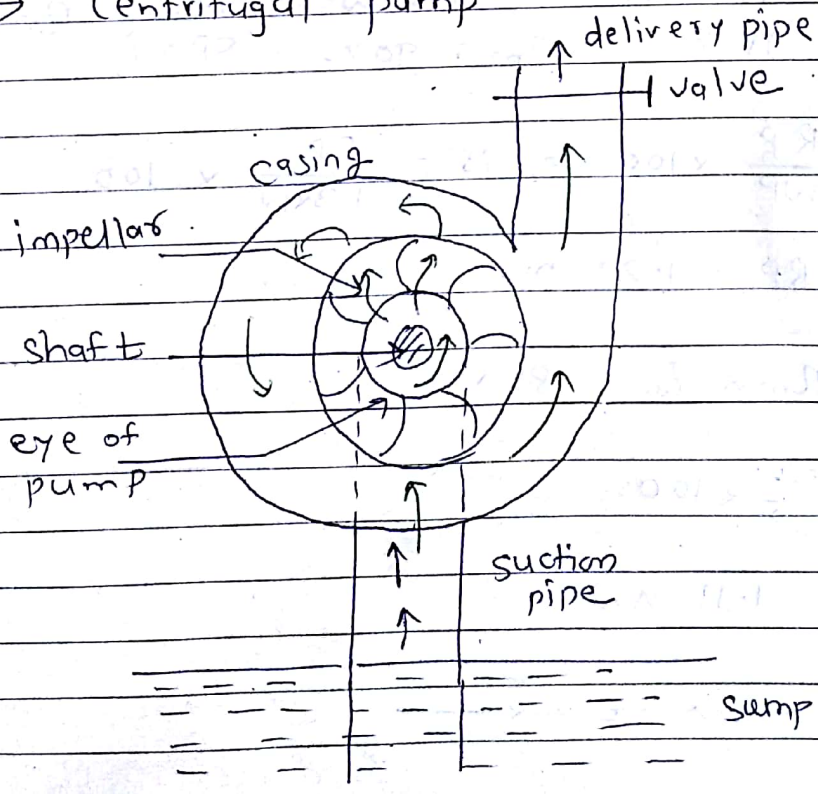
→ Pump is a mechanical device which when connected in pipeline converts mech. energy supplied to it into hydraulic energy & transfer it to liquid.

→ Classification of pump :

1. Positive displacement pump :
Fluid is sucked & actually displaced or pushed due to thrust exerted on it by moving member (piston), results in lifting liq. to desired height.

2. Rotodynamic / dynamic pressure pump :
Pumps have rotating element (impellar) through which as liquid passes its angular momentum changes hence pressure energy of water is increased.

→ Centrifugal pump :

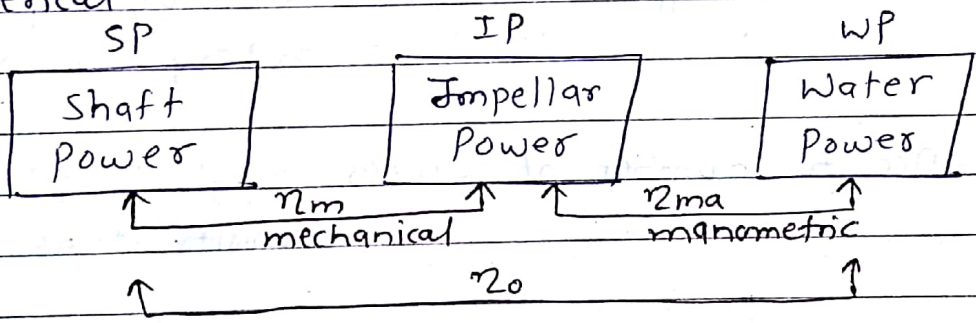


Main parts are : impellar
casing
suction pipe
delivery pipe.

Imp. point :
(i) impellar : rotating part
(ii) casing : area goes on increasing thereby velocity of flow decreases & pressure increases.
(iii) Suction pipe : strainer / filter.

Appln : domestic water supply
boiler feed appln.
power plants etc.

Numerical :



In centrifugal pump, work done by impellar is 346 KW & manometric efficiency is 60%. Find power delivered by pump. If mech. eff. is 75%, find input power of pump shaft

Soln : IP = 346 KW, $\eta_{ma} = 60\%$.
$\eta_m = 75\%$. WP = ? SP = ?

$$\eta_{ma} = \frac{WP}{IP} \times 100 =$$

WP = 207 KW

$$\eta_m = \frac{IP}{SP} \times 100$$

$\therefore$ SP = 4.61 KW.

Compressor

↳ A device or machine providing air at high pressure is called as air compressor.

→ Appl^n of compressed air:
- to operate pneumatic drills.
- cleaning of workshop & automobile.
- For spray painting.
- paper, print industry.

↳ Classification of air compressor:

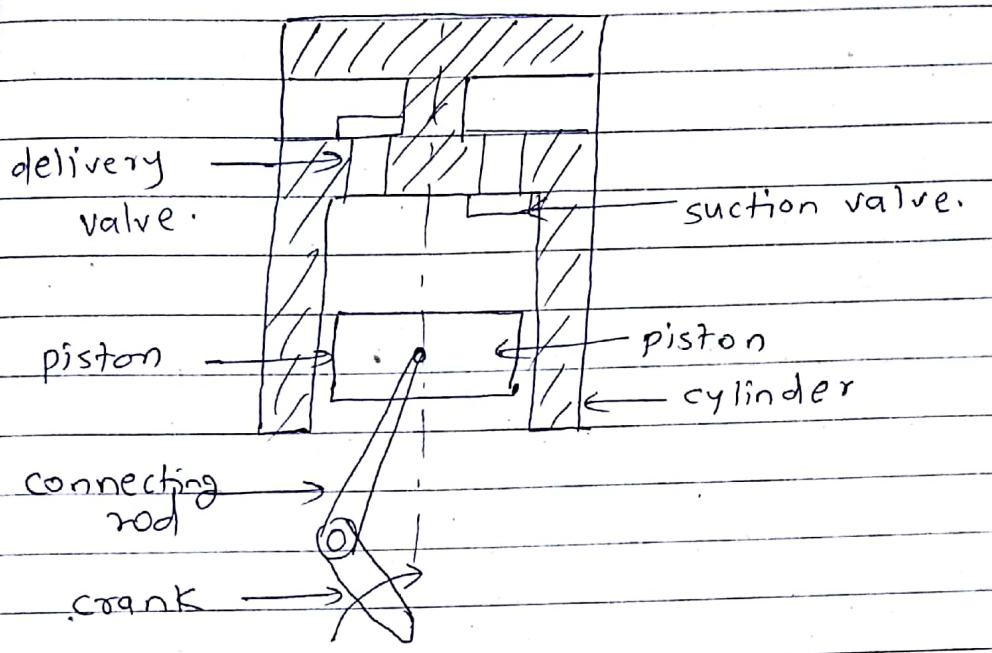
1. Acc. to type of motion: reciprocating air compr
   rotary air compr.

2. Acc. to number of stages: single stage
   multi stage.

3. Acc. to working position of piston:
   single acting compressor
   double acting compressor

→ Reciprocating Compressor:
- crank is connected to prime mover.
- Suction stroke: piston moves downwards due to which pressure in cylinder falls below atmospheric & inlet valve opens & air is sucked.
- Delivery stroke: Piston moves upwards with compression of air in cylinder.

At that time both inlet & delivery valves are closed.



[Reciprocating air compressor]

Numerical :

Indicated power : 5.8 KW.

Brake power : 6.25 KW.

work supplied actual : 6.2 KW

Polytropic work : 6 KW.

Isothermal work : 5.5 KW.

Cal: isothermal efficiency, mech. efficiency & polytropic efficiency.

$$\eta_{iso} = \frac{(WD)_i}{(WD)_a} \times 100 = \frac{5.5}{6.2} \times 100 = 88\%.$$

$$\eta_m = \left(\frac{IP}{BP}\right) \times 100 = \left(\frac{5.8}{6.25}\right) \times 100 = 92.5\%.$$

$$\eta_p = \frac{WD_i}{WD_a} \times 100 = \frac{6}{6.2} \times 100 = 96\%.$$

—x—o—x—