

Difference b/n Renewable & Non-Renewable Sources.

Renewable Resources

- (1) These are the resources which can be used again & again throughout its life.
- (2) These resources are present in unlimited quantity.
- (3) They are the energy resources which can't be exhausted.
- (4) It is environmental friendly.
- (5) The amount of carbon emission released by renewable resources is low.
- (6) The cost of these resources is low.
- (7) These resources are pollution free.
- (8) The maintenance cost of the renewable resources is very high.

Non-Renewable Resources

- (1) These are the resources which cannot be used again & again.
- (2) These resources are present in limited quantity only.
- (3) They are the energy resources which can be exhausted.
- (4) It is not environmental friendly.
- (5) The amount of carbon emission released by non-renewable resources is high.
- (6) The cost of these resources is high.
- (7) These resources are not pollution free.
- (8) The maintenance cost of the non-renewable resources is very low.

(9) It requires large land area for the installation of the power plant.

(10) It is sustainable.

(11) Can be reused & recycled.

(12) Ex:- wind, solar, hydel, Geothermal etc.

(13) No harm done to the environment due to its use.

(9) It requires less land area for the installation of the power plant.

(10) It is exhaustible.

(11) Cannot be reused & recycled.

(12) Ex:- coal, nuclear energy, fossil fuel, natural gas etc.

(13) Huge harm done to the environment because of the harmful emissions.

(14)

→ Sun is the basic source of energy for Earth.

→ Brightness of the sun varies from its centre to its edge, however, for engineering calculations, it is assumed to be uniform over the entire solar disc.

→ The sun generates an enormous amount of energy approximately 1.1×10^{20} kw-hours every second.

UNIT- I

(2)

Solar Energy

Energy radiated by the sun in the form of Electromagnetic waves reaches the earth's surface is called "Solar Radiation".

Solar energy - Received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as heat & Electricity which can be utilized by man.

The distance b/n the sun & earth varies a little through the year. Because of this variation, the extra terrestrial flux also varies. The earth is closest to the sun in the summer & farthest away in the winter.

This variation in distance produces - a nearly sinusoidal variation in the intensity of solar radiation ' I ' that reaches the earth. This can be approximated by the equation

$$\frac{I}{I_{sc}} = 1 + 0.033 \cos \frac{360(n-2)}{365}$$

$$\approx 1 + 0.033 \cos \frac{360 \times n}{365}$$

where ' n ' is the day of the year

$I \rightarrow$ intensity of solar radiation that reaches the earth.

Extra terrestrial radiation refers to solar radiation that has not yet entered the Earth's atmosphere. (outside the earth atmosphere).

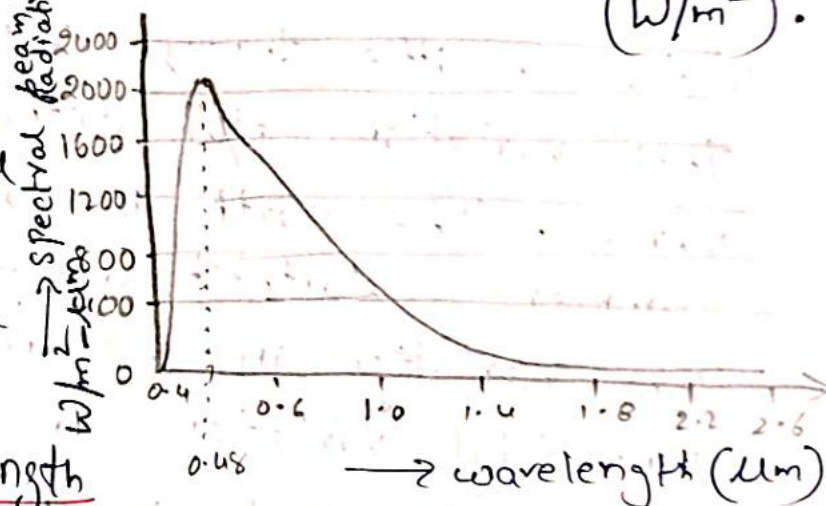
→ The intensity of extraterrestrial radiation is influenced by the Earth's elliptical orbit & the time of year.

→ Extraterrestrial radiation is not affected by atmospheric conditions like clouds, dust or gases.

→ The intensity of extraterrestrial radiation is often measured in Watts per square meter (W/m^2).

Fig shows the spectral distribution of extraterrestrial solar radiation.

And its maximum value is 2074 W/m^2 - μm occurs at a wavelength of $0.48 \mu\text{m}$.



The percentage radiation obtained upto a certain wavelength is given in the table below.

Wavelength (μm)	0 - 0.38	0.38 - 0.78	0.78 - 40
Approximate energy (W/m^2)	95	640	618
Approximate percentage of total energy	7%	47.3%	45.7%

(3)

Terrestrial Solar Radiation: - solar radiation at the Earth's surface is called Terrestrial solar radiation.

Solar radiation received at the earth's surface is entirely different due to the various reasons.

The solar radiation that penetrates the earth's ~~surface~~ atmosphere & reaches the surface differs in both amount & character from the radiation at the top of the atmosphere.

Solar radiation passes through earth atmosphere are subjected to atmospheric absorption & scattering.

In the first place, part of the radiation is reflected back into the space, especially by clouds.

Later, the solar radiation entering the atmosphere is partly ^{ially} absorbed by molecules in the air.

solar energy reaching the top of the earth's ~~surface~~ atmosphere consists

- (i) 8% ^{short wavelength} ultraviolet radiation (< 0.39 micrometer)
- (ii) 46% of visible light (0.39 to $0.78 \mu m$)
- (iii) 46% of long wavelength (more than $0.78 \mu m$) Infrared radiation

ie., short wavelength ultraviolet radiation absorbed by oxygen & ozone (O_3).

Long wavelength Infrared radiation absorbed by water vapour & carbon dioxide (CO_2).

In addition, part of the solar radiation is scattered (its direction has been changed) by air molecules, dust particles, water droplets in clouds.

Beam Radiation:- Solar radiation reaches the ground directly from the sun is called "direct radiation" or "Beam radiation".

(means that has not been absorbed or scattered).

Diffuse radiation:- Diffuse radiation is that solar radiation received from the sun after its direction has been changed by reflection & scattering by the atmosphere.

Because of the solar radiation is scattered in all directions in the atmosphere, diffuse radiation comes to the earth from all parts of the sky.

Total solar radiation at any point on the earth's surface is the sum of direct & diffuse radiation.

$$\begin{aligned} \text{Total radiation} &= \text{Beam radiation} + \text{Diffuse radiation} \\ \text{Global } I_T &= I_b + I_d \end{aligned}$$

solar constant: - The sun is a large sphere (4) of very hot gases, the heat being generated by various kinds of fusion reactions.

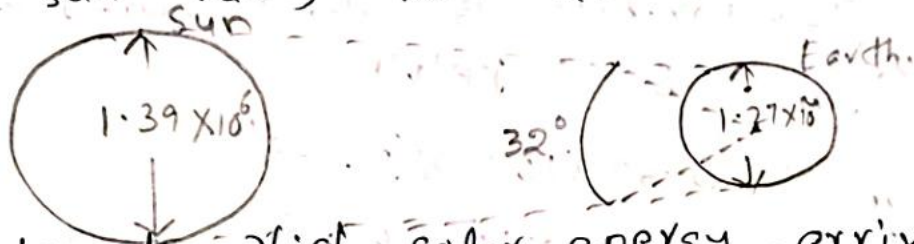
Sun diameter $\rightarrow 1.39 \times 10^6$ km

Earth diameter $\rightarrow 1.27 \times 10^4$ km

Distance b/n sun & earth $\rightarrow 1.5 \times 10^8$ km.

Although the sun is large, it subtends an angle of only 32° at the earth's surface. This is because it is also at a very large distance.

Thus the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its centre to its edge.



The rate at which solar energy arrives at the top of the atmosphere is called the solar constant I_{sc} . This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction, at the mean distance of the earth from the sun. Because of the sun's solar radi distance & activity vary throughout the year, the rate of arrival of solar radiation varies accordingly. That's why the Solar constant is an average from which the actual values vary upto about 3% in either direction.

The NASA standard value for the solar constant expressed in three common units is as follows.

- (1) 1.353 kw per square meter (or) 1353 watt per square meter.
- (2) 116.5 calories per sq. cm per hour (or) 1165 Kcal per sq. m per hour.
- (3) 429.2 Btu per sq. ft per hour.

From Stefan Boltzmann law

Solar constant calculation

Radiant Energy emitted per unit area by sun

$$E_{\text{sun}} = \sigma T^4 \quad \text{where } T \rightarrow \text{Temp. of hot body}$$

$\sigma \rightarrow \text{Stefan Boltzmann Constant}$

considering Temperature of sun's surface as

$$T_{\text{sun}} = 5777 \text{ kelvin}$$

$$E_{\text{sun}} = 5.67 \times 10^{-8} \times (5777)^4$$

$$E_{\text{sun}} = 6.31 \times 10^7 \text{ W/m}^2$$

$$E_{\text{sun}}^{\text{total}} = E_{\text{sun}} \times A_{\text{total}}^{\text{Total area of the sun.}}$$

Considering sun. to be a sphere, $\therefore$ Surface area of a sun.

$$E_{\text{sun}}^{\text{total}} = 6.31 \times 10^7 \times 4\pi \left(\frac{1.393 \times 10^9}{2} \right)^2$$

$$A = 4\pi R^2$$

$$D_{\text{sun}} = 1.393 \times 10^9 \text{ m}$$

$$E_{\text{sun}}^{\text{total}} = 3.85 \times 10^{26} \text{ Watts.}$$

Total Radiant energy from the sun at the earth

$$a) E_{\text{earth}}^{\text{Sun}} = \frac{E_{\text{sun}}^{\text{total}}}{4\pi R_{\text{earth}}^2}$$

Here $R \rightarrow$ Mean distance b/n the earth & sun.

$$E_{\text{earth}}^{\text{Sun}} = 1.369 \text{ kw/m}^2$$

$$R = 1.496 \times 10^{11} \text{ m}$$

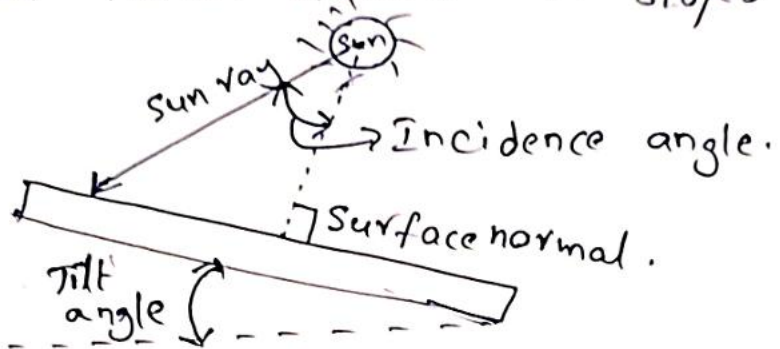
(5)

Tilted surface:- A tilted surface is a surface that is inclined at an angle relative to a horizontal or vertical plane.

In simpler terms, it is a surface that is not flat or level, but rather slanted or sloped.

Tilt angle

The angle at which the surface is tilted relative to the horizontal.



The concept of tilt surfaces is important in various fields, including solar energy where tilt angle of solar panels affects their efficiency.

Solar Radiation on Tilted surfaces:- The amount of solar energy radiated on a given surface on the ground depends on the orientation of the surface with reference to the sun. When the surface is far to the sun's rays, it receives the maximum amount of solar radiation, whereas the tilted surface will receive smaller amount of solar radiation.

→ Tilting the surface changes the angle of incidence, reducing the amount of radiation received.

Angle of Incidence:- The angle at which sunlight strikes the surface directly impacts the intensity of solar radiation received. When the angle is 90° , the intensity is high.

sun at zenith :- This is the position of the sun directly over head. (6)

Air Mass (m) :- It is the ratio of the path of the sun's rays through the atmosphere to the length of path when the sun is at the zenith.

$m = 1$ when the sun is at zenith or at sea level

$m = 2$ when zenith angle is 60° (θ_z the angle subtended by the zenith & the line of sight to the sun.)

$m = 0$, just above the earth's atmosphere.

Attenuation of Beam Radiation :- The variation of in solar radiation reaching the earth than received at the outside of the atmosphere is due to absorption & scattering in atmosphere.

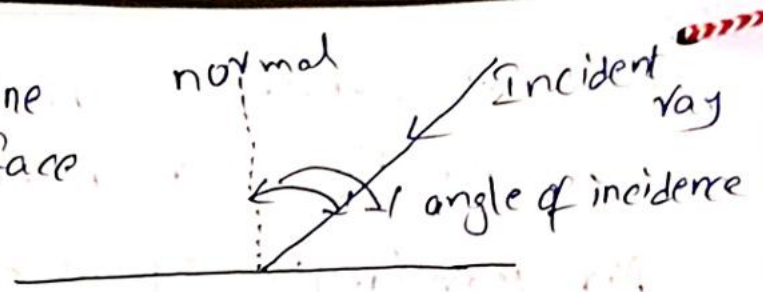
Equator :- The equator is the circle of latitude that divides Earth into the northern & southern hemisphere.

Incidence angle :- the angle formed b/n the normal & the incident ray at the point of incidence is incoming ray & the line tan to the surface at the point where the ray hits.

(or)

This is the angle formed b/n the incident ray & the normal line.

Normal line :- This is a line that is perp to the surface at the point where the incident ray hits.

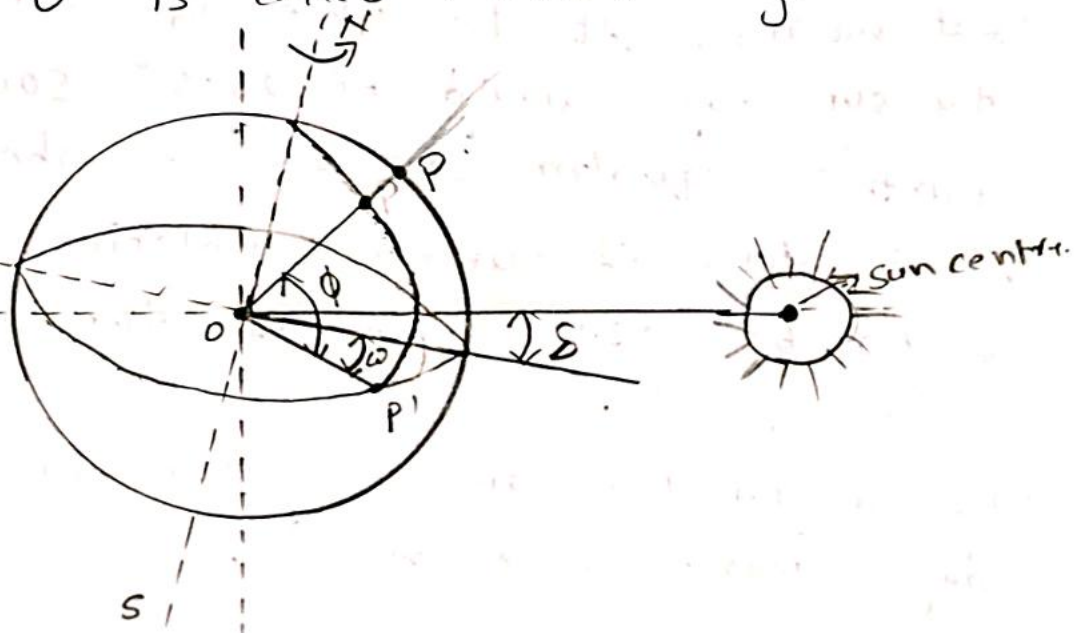


Angle of incidence determines how concentrated or diffuse the solar energy is on a surface. A smaller angle of incidence (sun is more directly overhead) means more concentrated energy.

7

ϕ = latitude angle
 δ = declination angle
 ω = hour angle
 γ_s = solar Azimuth angle
 α = altitude angle (inclination angle)
 θ_z = zenith angle.

If θ is the angle b/n an incident beam radiation I & the normal to the plane surface, then the equivalent flux or radiation intensity falling normal to the surface is given by $I \cos \theta$. θ is called incident angle.



Latitude (ϕ): - The latitude ' ϕ ' of a point or location is the angle made by the radial line joining to the location centre of the earth with the projection of the line on the equatorial plane.

As shown in the fig., it is the angle b/n the line OP & the projection of OP on the equatorial plane. Point 'P' represents the location on the earth surface & 'O' represents the centre of the earth.

Declination angle (δ): - It is the angle b/n a line extending from the centre of the sun to the centre of the earth & the projection of this line upon the earth's equatorial plane.

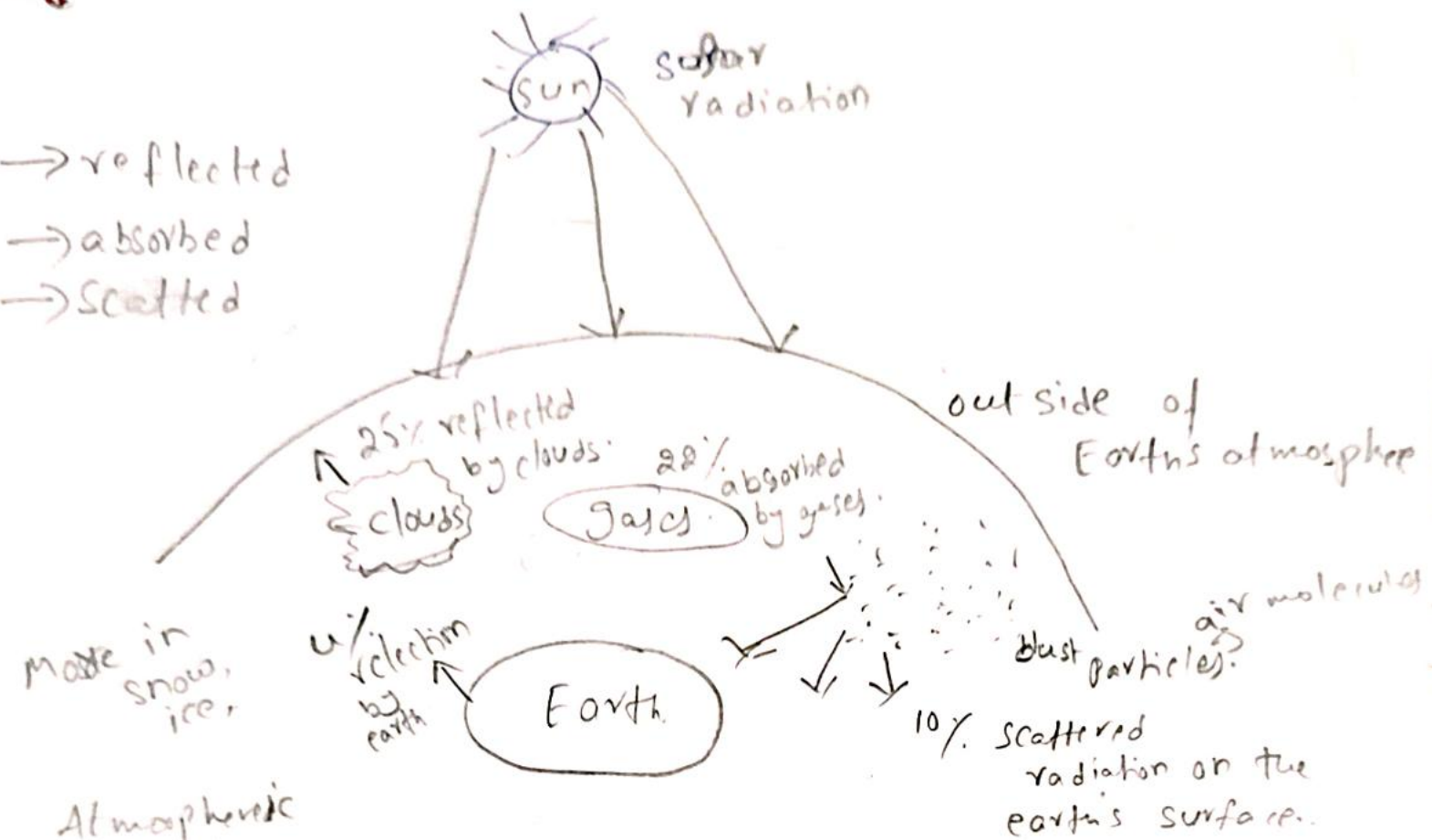
The Declination angle vary from a max. value of $\delta = 23.5^\circ$ on June 22 to a min. value of $\delta = -23.5^\circ$ on Dec 22.

That means, At the time of winter solstice, the sun rays would be 23.5° south of the earth's equator ($\delta = -23.5^\circ$). where as

At the time of summer solstice, the sun rays would be 23.5° north of the earth's equator ($\delta = 23.5^\circ$).

The declination angle is zero on two equinoxes days (March 22 & Sep 22).

- reflected
- absorbed
- scattered



Atmospheric Gases
 CO₂
 Methane
 Nitrous oxide
 Water vapour

25% reflected
 22% absorbed

 47%

Remaining 53% including scattered radiation received by earth's surface.

$$53\% - 4\% \rightarrow 49\%$$

Solar radiation reaches the earth's surface depends on no. of factors.

- what is the cloudiness
- what is the composition of atmospheric gases particularly water vapour content.
- what is the amount of pollutant, dust particles

Abscissa

437

438

440

447

450

452

450

468

1E 441

424

431

452

433

434

440

The hour angle ' ω ' is equivalent to 15° per hour. It is measured from noon based on the local solar time (LST), being ~~positive~~ negative in the afternoon & ~~negative~~ positive in the morning.

(or)

It is the angle representing the position of the sun w.r. to clock hour ω with reference to sun position at 12 Noon.

The declination angle in degrees for any given day may be calculated from the approximate equation

$$\delta \text{ (in degrees)} = 23.45 \sin \left[\frac{360}{365} (284 + n) \right]$$

where 'n' is the day of the year.

Ex: June 21, 1988 is the 173th (31 + 29 + 31 + 30 + 31 + 21) day of 1988 i.e., $n = 173$.

Hour angle (ω):- It is the angle measured in the earth's equatorial plane, b/n the projection of OP & the projection of a line from the centre of the sun to the centre of the earth.

The hour angle ω is the angle through which the earth must turn to bring the meridian of a point directly in line with the sun's rays.

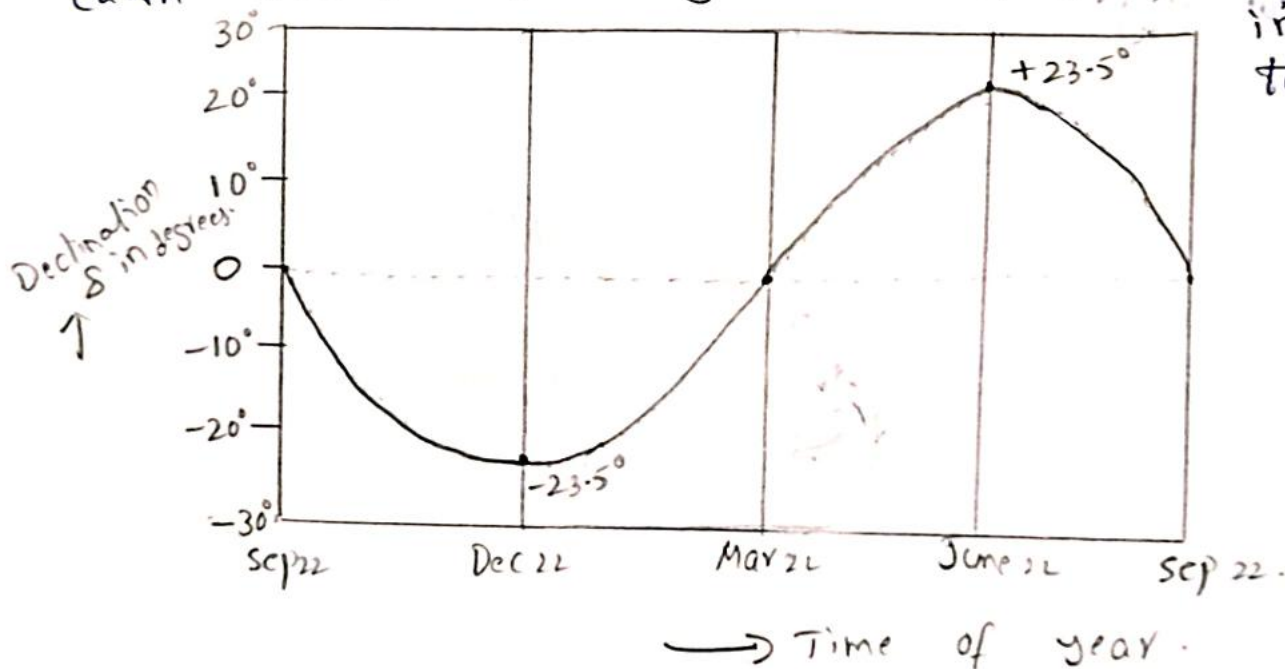
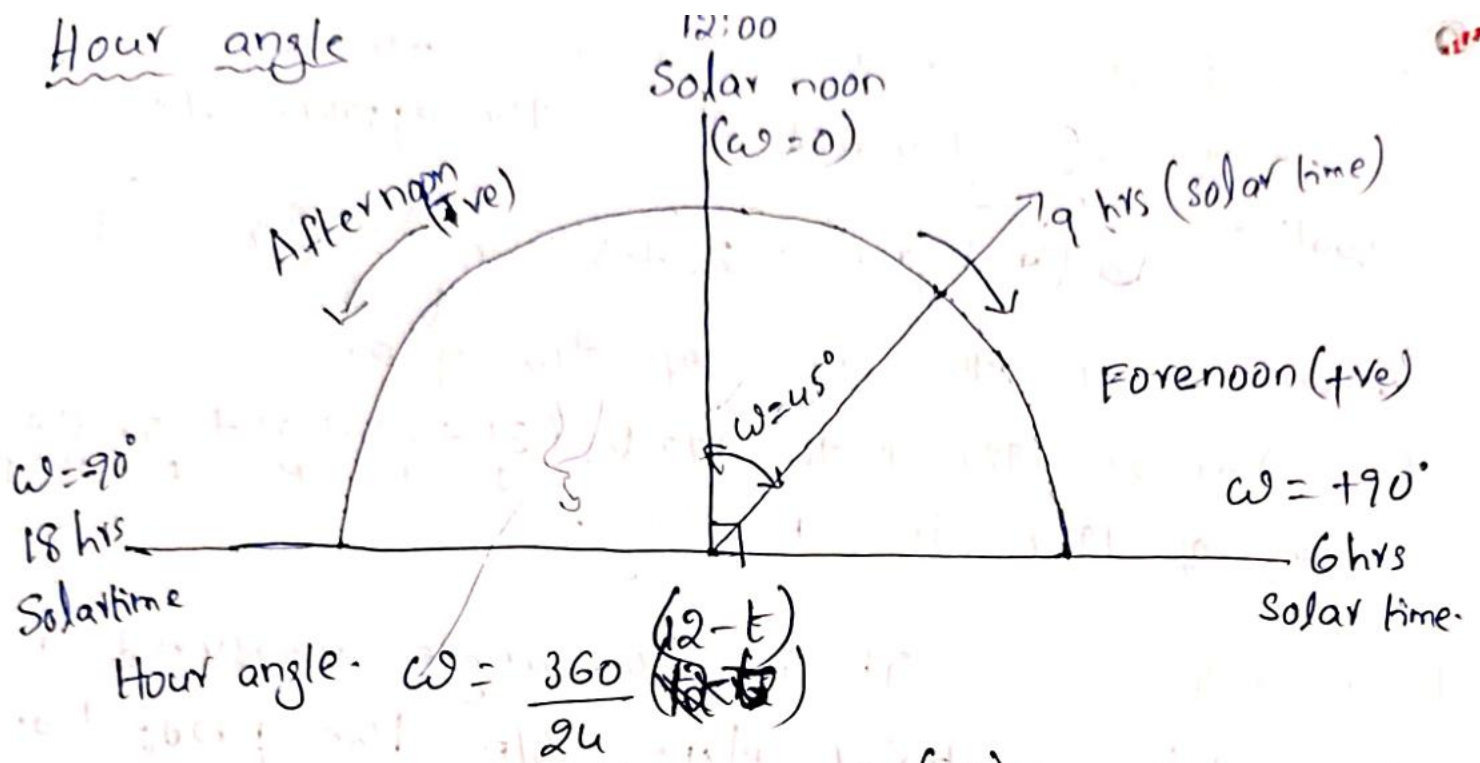
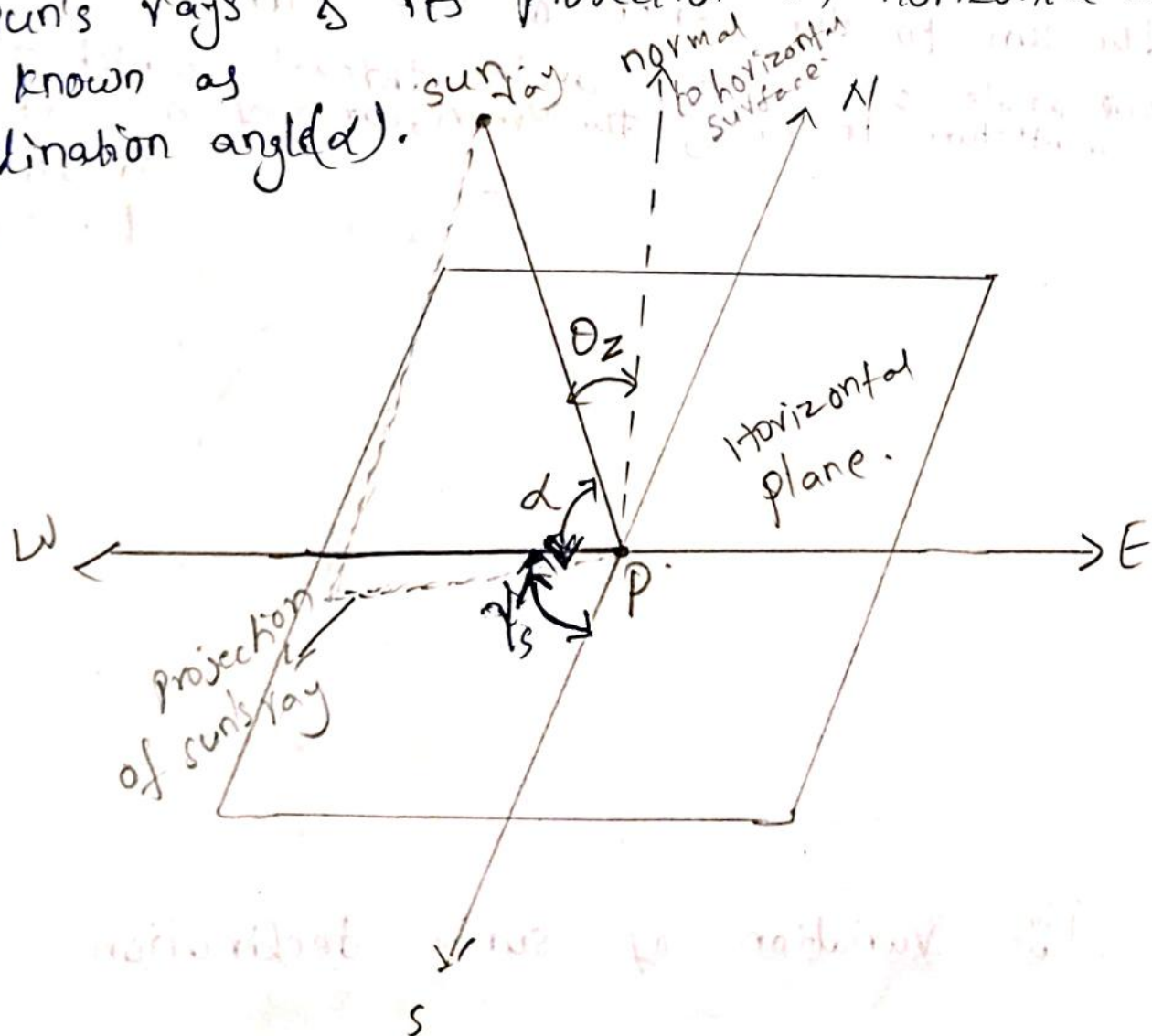


Fig:- Variation of sun's declination.

Hour angle



Altitude (or) Inclination Angle (α):- The angle b/w sun's rays & its projection on horizontal surface is known as Inclination angle (α).



Zenith angle (θ_z):- It is the angle b/n sun's rays & ^{line} perpendicular to the horizontal plane i.e. the angle b/n the beam from the sun & the vertical.

$$\theta_z = \frac{\pi}{2} - \alpha$$

Also it is the complementary angle of sun's ~~latitude~~ altitude angle.

Solar Azimuth angle (γ_s):- The angle on a horizontal plane, b/n the line due south & the projection of sun's ray on the horizontal plane is known as solar Azimuth angle (γ_s).

It is considered as positive when it is measured from south towards west. $\swarrow$ +ve $\searrow$ S

Altitude angle (α), zenith angle (θ_z) & solar Azimuth angle γ_s can be expressed in terms of ϕ (latitude angle), δ (declination angle) & ω (hour angle) which are also called basic angles.

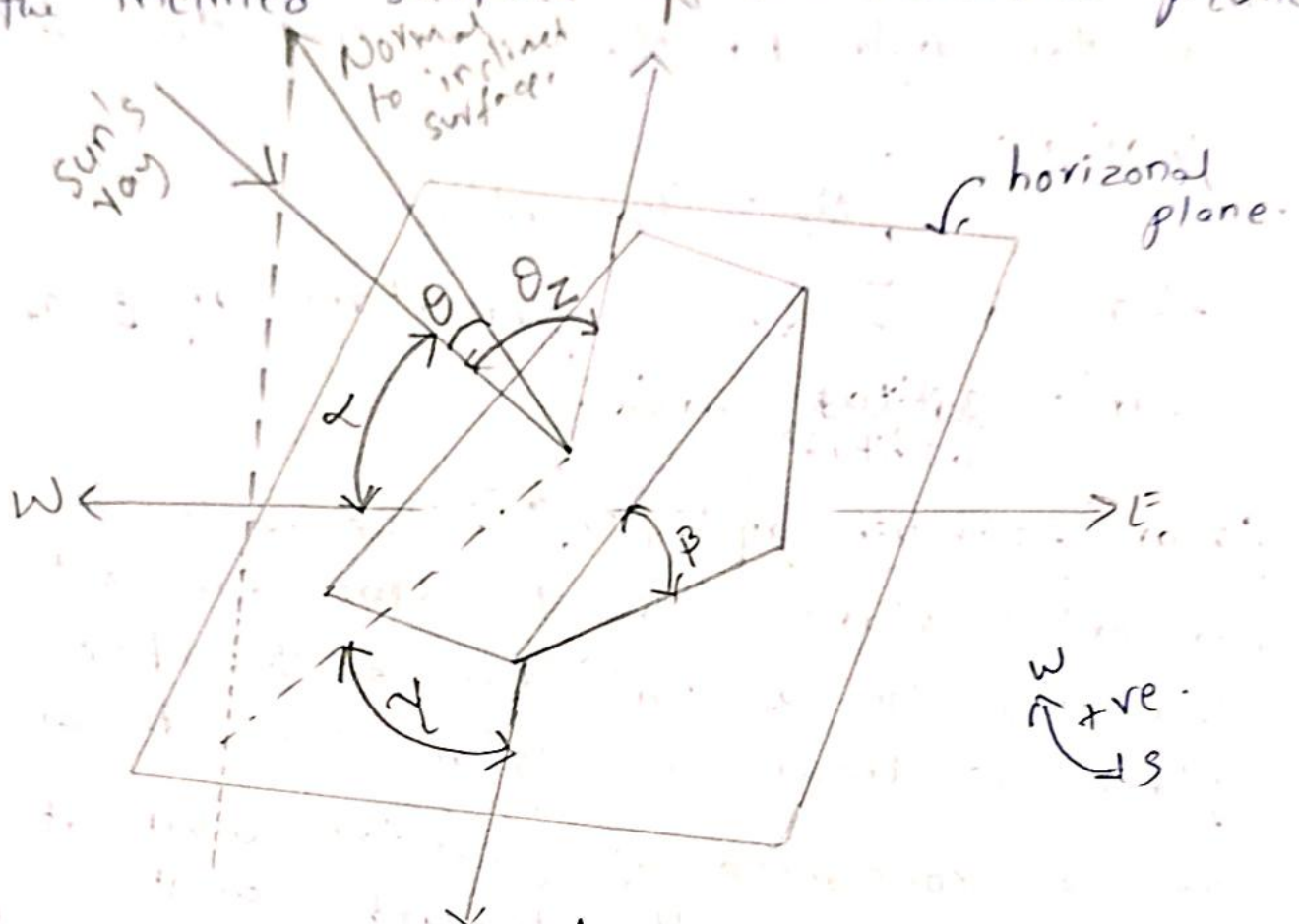
The expressions are

$$\cos \theta_z = \cos \phi \cos \omega \cos \delta + \sin \phi \sin \delta$$

$$\cos \gamma_s = \sec \alpha (\cos \phi \sin \delta - \cos \delta \sin \phi \cos \omega)$$

$$\sin \gamma_s = \sec \alpha \cos \delta \sin \omega$$

slope (or) Tilted angle (β) :- It is the angle b/n the inclined surface & the horizontal plane.



For Horizontal surface, $\beta = 0$

zenith angle $\theta_z = \text{Angle of incidence } \theta$.

Surface Azimuth angle (γ) :- It is the angle in the horizontal plane, b/n the line due to South & the horizontal projection of the normal to the inclined plane surface.

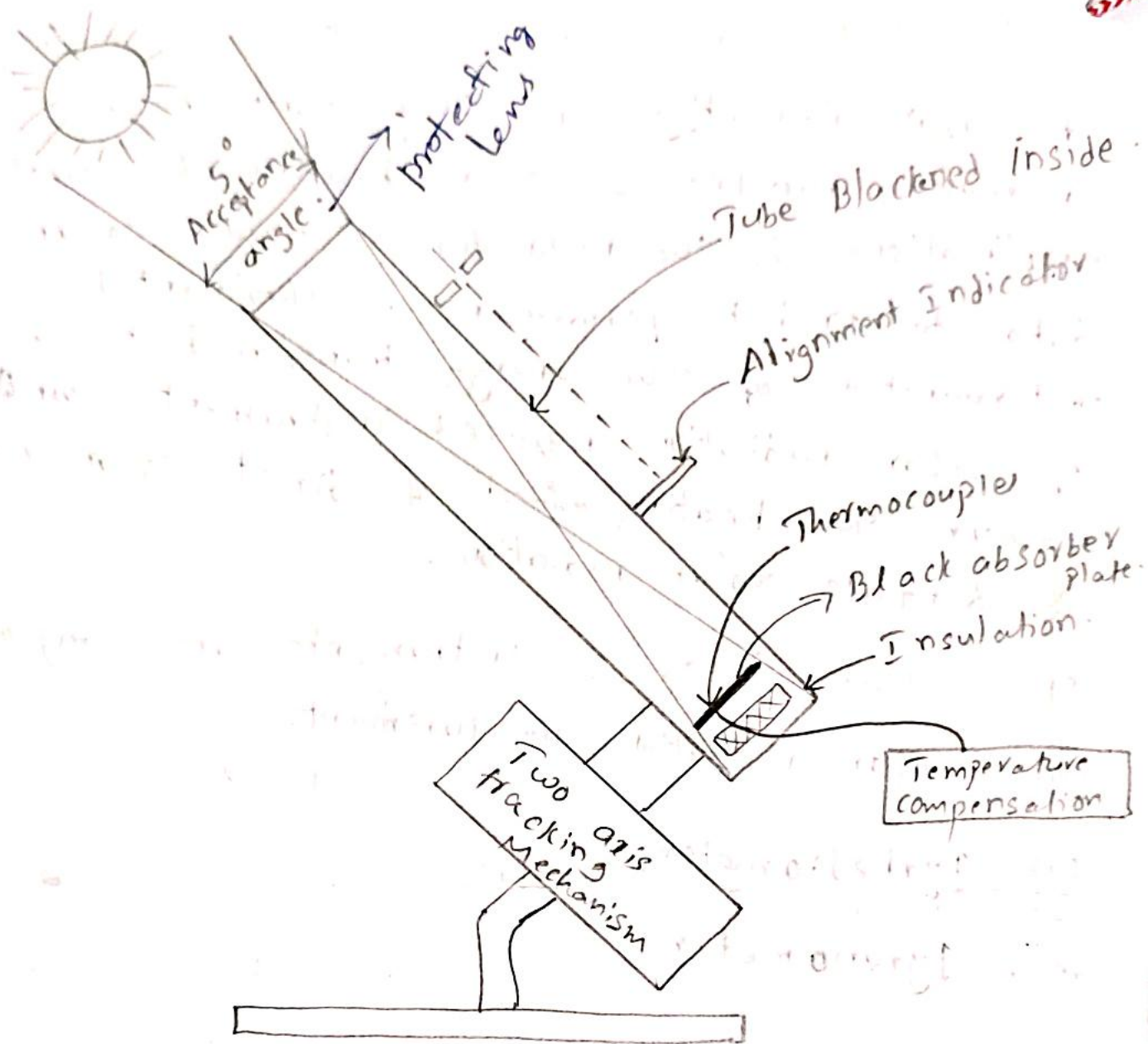
Measurement of solar radiation! - Measurements of solar radiation are important because of the increasing number of solar heating & cooling applications, & the need for accurate solar irradiation data to predict performance. Experimental determination of the energy transferred to a surface by solar radiation required instruments which will measure the heating effect of direct solar radiation & diffuse solar radiation.

Two basic types of instruments are employed for solar radiation measurements.

(1) Pyrheliometer

(2) Pyranometer

(1) Pyrheliometer: - A pyrheliometer is an instrument which measures beam radiation falling on a surface normal to the sun's rays. In this pyrheliometer, a sensor disc is located at the base of a tube ~~this tube~~ ^{whose axis} is aligned with the direction of the sun's rays with the help of a two axis tracking mechanism & Alignment indicator.

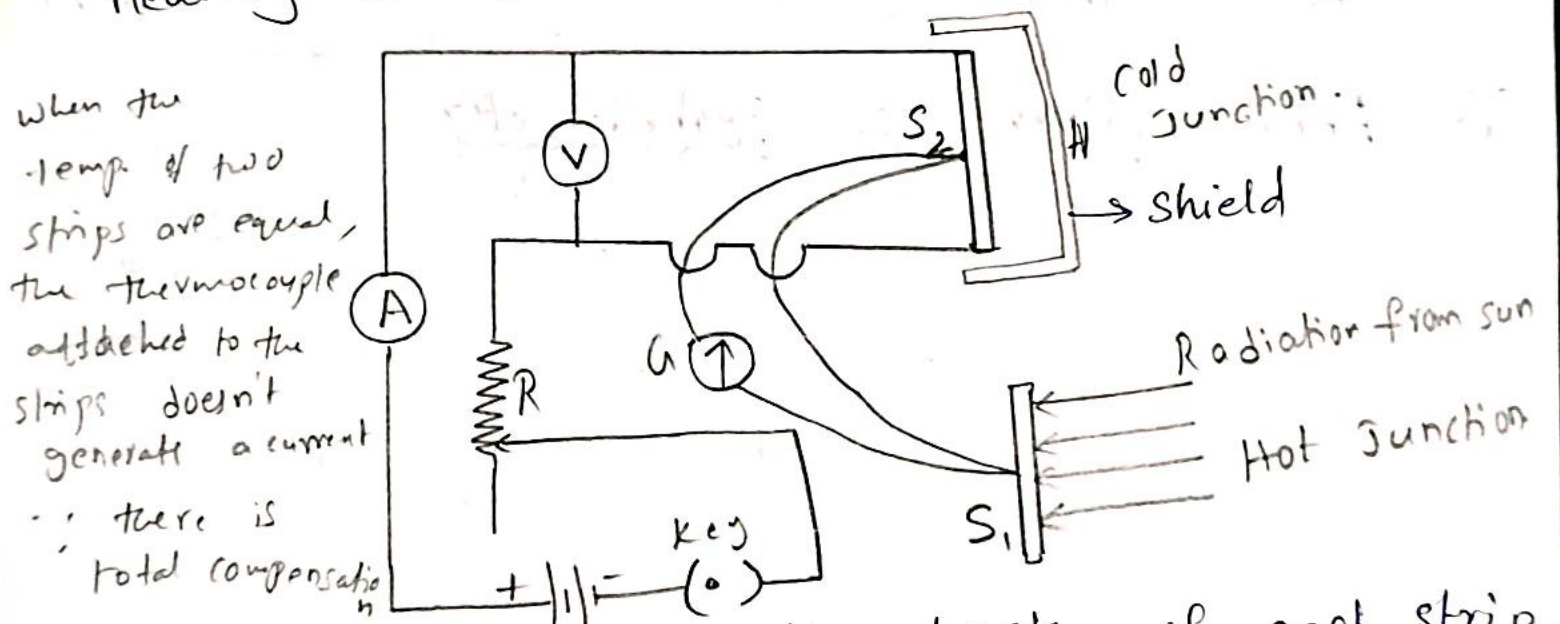


To measure the direct solar radiation, the receiving surface must be normal to direct solar rays i.e., a line joining the sun & receiver.

Three pyrheliometers have been in use to measure normal incident beam radiation.

- (i) the Angstrom pyrheliometer
- (ii) the Abbot silver disc pyrheliometer
- (iii) Eppley pyrheliometer.

(i) Angstrom pyrheliometer: - In this pyrheliometer, a thin blackened shaded magnanin strip is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation. It is shown in fig below. Under steady state conditions (both strips at identical temp) the energy used for heating is equal to the absorbed solar energy.



The thermocouples on the back of each strip, connected in opposition through a sensitive galvanometer (or other null detector), are used to test for the equality of temp. The energy 'H' of direct radiation is calculated by the formula,

$$H_{DN} = Ki^2$$

where H_{DN} = Direct solar radiation incident on an area normal to sun's rays.

i = heating current in amperes.

k $\rightarrow$ Dimension & instrument constant.
depending upon resistance

$$i = \frac{R}{W\alpha}$$

where R is the resistance per unit length of the absorbing strip, Ω/cm

W $\rightarrow$ Mean width of the absorbing strip,

α $\rightarrow$ absorbing coefficient of the absorbing strip.

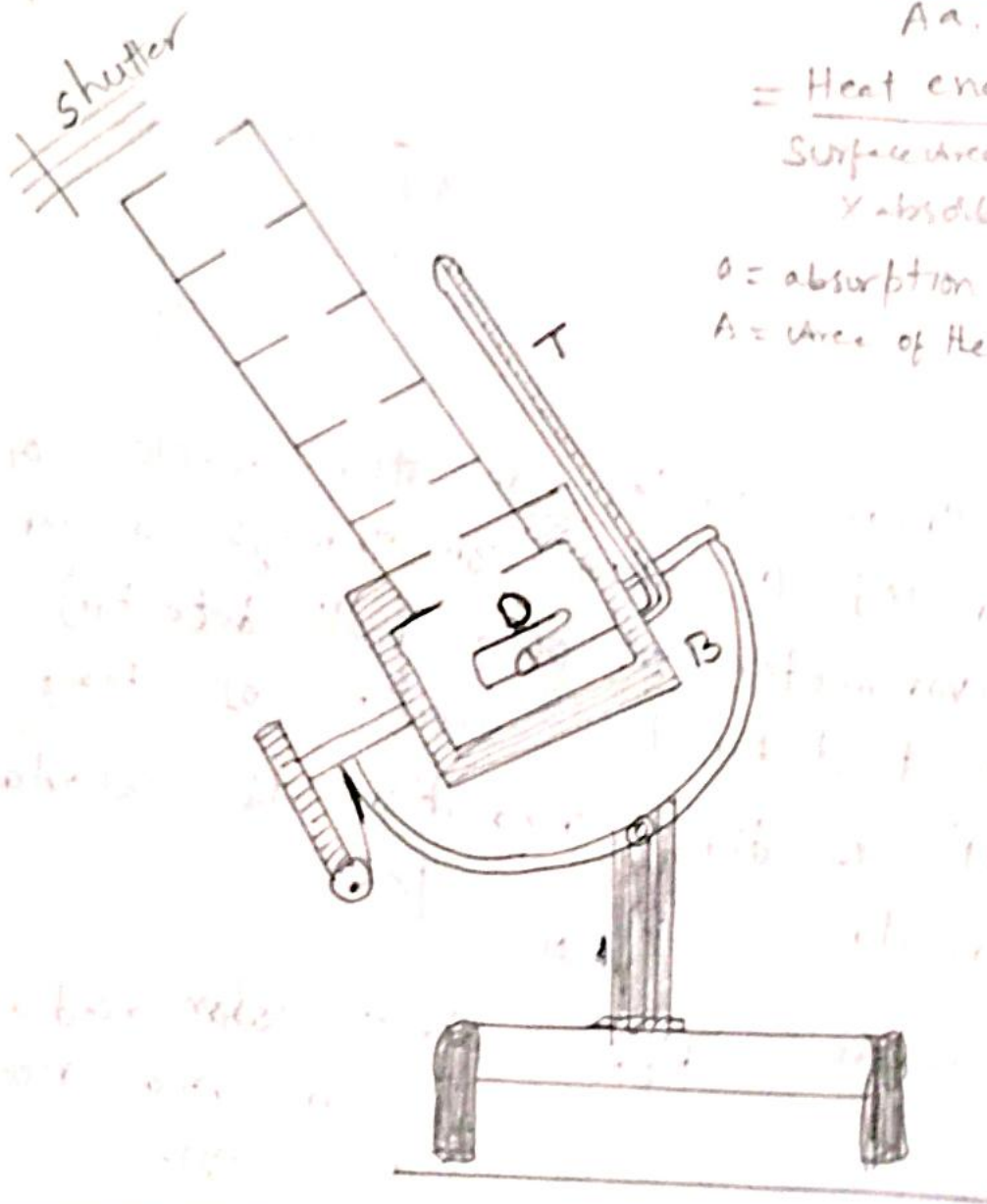
(ii) Abbot silver disc Pyrheliometer

$$S = \frac{VIt}{Aat}$$

$$S = \frac{V.I}{Aa}$$

= $\frac{\text{Heat energy}}{\text{Surface area} \times \text{time} \times \text{absorbed radiant}}$

a = absorption coeff.
 A = area of the plate



- It consists of essentially of a blackened silver disc positioned at the lower end of a tube with diaphragms to limit the whole aperture to 5.7° .
- A Mercury in glass thermometer is used to measure the temperature at the disc.
- A shutter made of three polished metal leaves is provided at the upper end of the tube to allow the solar radiation to fall on the disc at regular intervals & the corresponding changes in temperature of the disc are measured.
- The thermometer stem is bent through 90° so that it lies along the tube to minimize its exposure to the sun.

A thermopile is basically a series arrangement of thermocouples used to develop a much greater voltage than is possible using only one.

(iii) Eppley pyrheliometer :- The Eppley pyrheliometer measures the length of time that the surface receives sunlight & the sunshine's intensity also. It consists of two concentric silver rings of equal area, one blackened & the other whitened, connected to a thermopile. i.e., one side of the thermopile is exposed to the incoming solar radiation, while the other side is shielded. This creates a temp. d/f b/n the two rings.

→ The temp. d/f b/n the exposed & shielded sides of the thermopile generates a voltage o/p that is proportional to the intensity of the solar radiation.

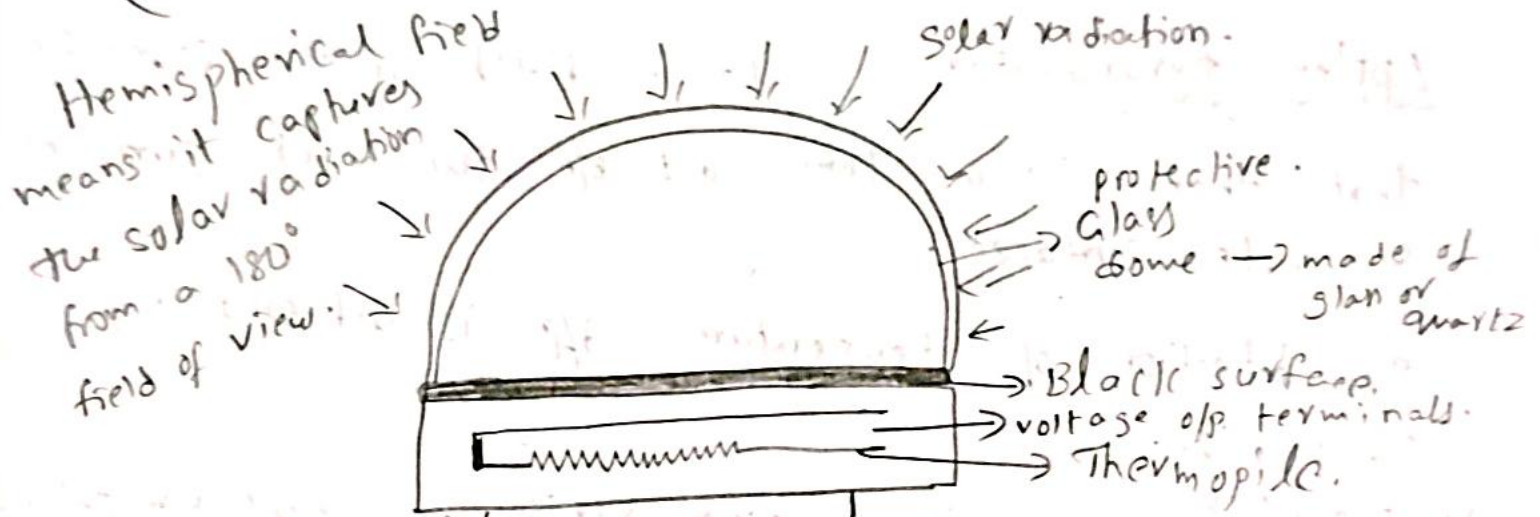
Construction:- It consists of two concentric silver rings of equal area connected to a thermopile with 15 junctions mounted at the base of a brass tube.

→ The limiting diaphragms of the tube subtend an angle of $5-7^\circ$.

→ A Thermopile is basically a series arrangement of thermocouples used to develop a much more voltage than its possible using only one.

→ The tube is filled with dry air & sealed with crystal quartz window which is removable.

Pyranometer: - A device measures the global solar radiation ^{over a hemispherical field of view} is called a pyranometer.
(It measures both direct & diffuse solar radiation)



Glass dome protects the internal components from environmental factors while allowing solar radiation to pass through.

In most pyranometers, the sun's radiation is allowed to fall on a black surface to which the hot junctions of a thermopile are attached. The cold junctions of the thermopile are located in such a way that they don't receive the radiation. As a result, an emf proportional to the solar radiation is generated. This emf is usually in the range of 0 to 10 mV can be used read, recorded or integrated over a period of time with regular

They are many types of Pyranometers,
mostly used are (i) Eppley Pyranometer
(ii) Yellot ^{Solorimeter} ~~Pyranometer~~:

(i) Eppley Pyranometer :- It is based on the principle that there is a temp. diff b/n the black surfaces & white surfaces.

→ The detection of temperature diff is achieved by Thermopile.

In older types
→ It uses concentric silver rings of 0.25 mm thick, appropriate coated black & white with either 10 or 50 thermo couple junctions to detect the temp- difference b/n coated ring.

→ Later models use wedges arranged in a circular pattern, with alternate black & white coatings.

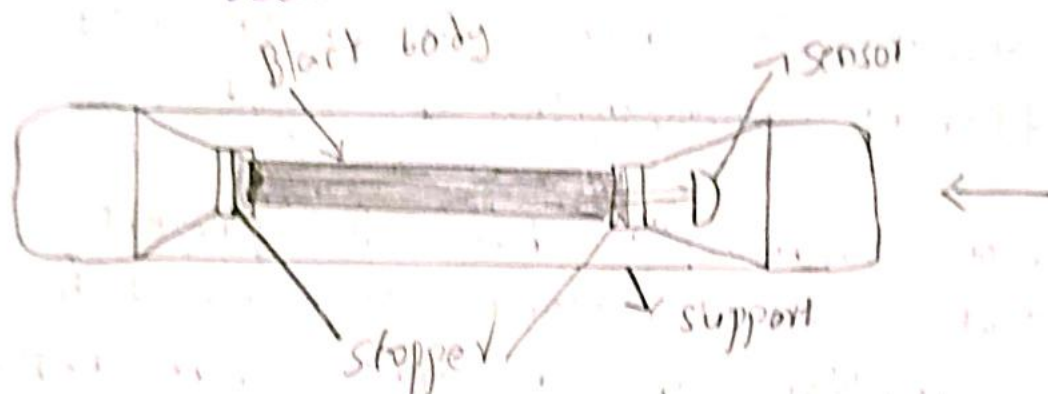
→ The wedges or disks are placed in a hemispherical glass over.

→ Eppley pyranometer is calibrated in a horizontal position.

→ calibration of these instruments will vary to some degree if the instrument is inclined to measure radiation on other than a horizontal surface.



(ii) Yellot solarimeter:



A Yellot solarimeter is a type of pyranometer that uses a photovoltaic solar cell made of Silicon as a sensor to measure solar radiation.

→ The Yellot solarimeter converts light energy into Electrical energy.

ie, The electrical energy is proportional to the amount of solar radiation it receives.

→ It is designed to measure the total solar radiation (both direct & diffuse) falling on a surface.

→ The instrument's o/p needs to be calibrated because the silicon cells spectral response (how it reacts to different wavelengths of light) is not perfectly linear.

→ That's why the instrument's calibration process depends on the spectral distribution of the incoming ^{solar} radiation.
(or)
Incident

[spectral distribution of solar energy describes how the sun's energy is distributed across different wavelengths of light].

The silicon solar cells have the property that their light current (approximately equal to I_{sc}) is a function of incident solar radiation.

$$\text{Spectral distribution (or) response} = \frac{\text{current generated by the solar cell}}{\text{Power incident on the solar cell}} = A/W.$$

- Sensor is placed on airtightly covered with a semicircle of polished glass
- This type of device not recommended by world metrology organization). Its readings based on wavelength of solar radiation

Sunshine Recorder: The duration of sunshine in a day is measured by means of a sunshine recorder.

The sun's rays are focused by a glass sphere to point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere.

Whenever there is a bright sunshine, the image formed is intense enough to burn a spot on the card strip. Through the day the sun moves across the sky, the image moves along the strip, creating a ^(focused spot of light) continuous burn mark.

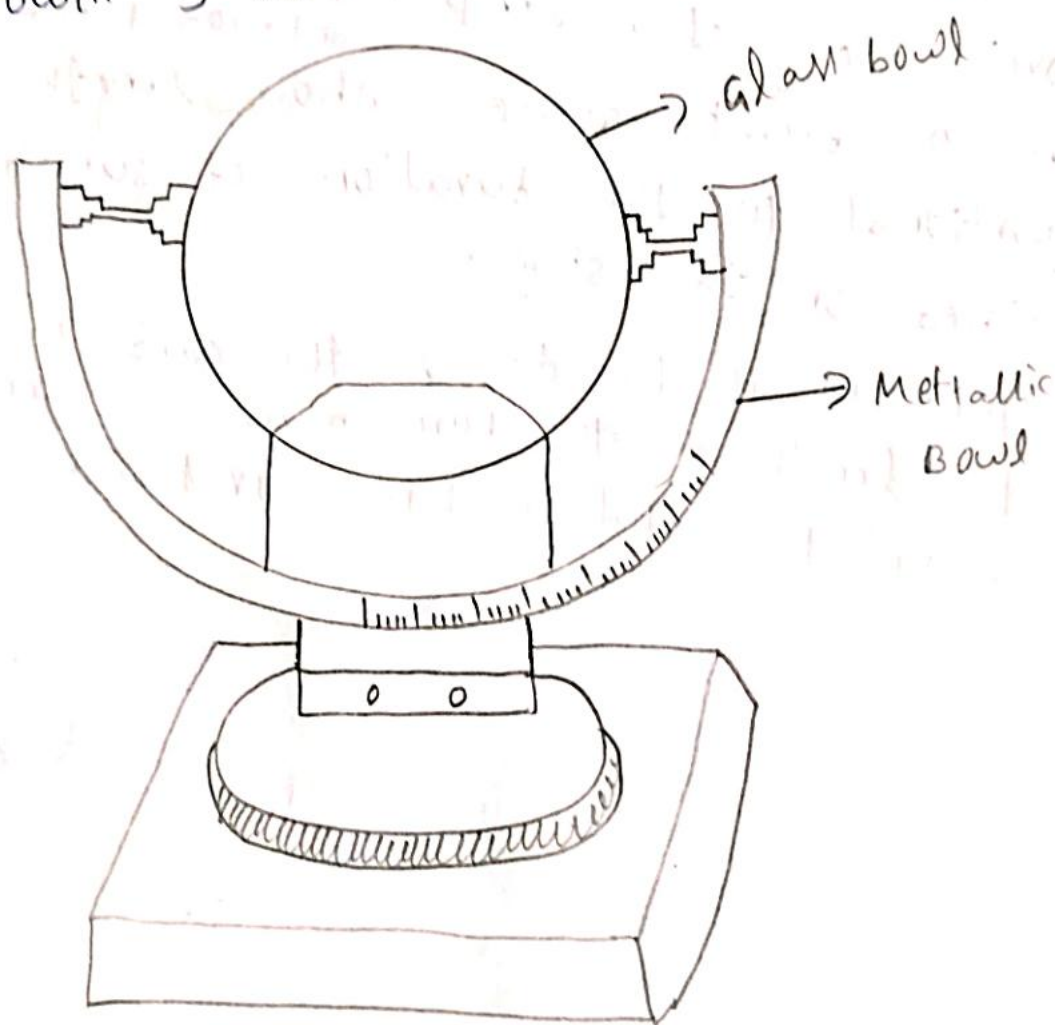
Thus a burnt space whose length is proportional to the duration of sunshine is obtained on the strip.

At the end of the day, the card is removed, & the length of the burn mark is measured to determine the total sunshine duration.

A sunshine recorder measures the duration of bright sunshine at a location.

→ The most common type, the Campbell-Stokes recorder, uses a glass sphere to focus sunlight onto a specially designed card, creating a burn mark that indicates sunshine duration.

→ Sunshine recorder provide data on the amount of direct sunlight received, which is crucial for understanding weather patterns, crop growth & solar energy potential.



Sunrise, Sunset & Day length.

Sunrise is when the sun appears to emerge above the eastern horizon, making the start of daylight.

Sunset is when the sun disappears below the western horizon, marking the end of daylight.

Day length is also known as the length of the day, is the time b/n sunrise & sunset.

(i.e. duration of day light is the day length).

This duration varies throughout the year due to the Earth's axial tilt & its orbit around the Sun.

[Example during summer the days are longer.
& during winter " " " Shorter.]

This is very essential requirement to know about the period during which sun's energy availability.

w.k.r for horizontal surfaces, slope $\beta = 0$.

& $\theta = \theta_z$ i.e. incident angle = Zenith angle.

$$\cos \theta_z = \cos \phi \cos \omega \cos \delta + \sin \phi \sin \delta$$

The hour angle corresponding to sunrise or sunset on a horizontal surface can be found using the ^{above} following equation & substituting $\theta = \theta_z = 90^\circ$.

$$\cos \phi_0 = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega$$

$$0 = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega$$

$$\cos \omega = -\frac{\sin \phi \sin \delta}{\cos \phi \cos \delta}$$

$$\cos \omega = -\tan \phi \tan \delta$$

$$\boxed{\omega = \cos^{-1}(-\tan \phi \tan \delta)} \text{ in degrees.}$$

As 15° corresponds to 1 hour, then the corresponding day length in hrs is given by

$$t_d = \frac{2}{15} \omega$$

$$\boxed{t_d = \frac{2}{15} \cos^{-1}(-\tan \phi \tan \delta)} \text{ in hours.}$$

It is clear from the equation that the day length depends upon the latitude angle (ϕ) & declination angle (δ).

The hour angle corresponding to sunrise or sunset on an inclined surface will be lesser than the value corresponding to horizontal surface.

Then $\omega = \cos^{-1}(-\tan(\phi - \beta) \tan \delta)$ & the corresponding day length (in hours) is given by.

$$\boxed{t_d = \frac{2}{15} \cos^{-1}[-\tan(\phi - \beta) \tan \delta]}$$

Local solar time :- Local solar time is a time system where noon defined as a moment the sun reaches its highest point in the sky for a specific location. This time varies from place to place due to Earth's rotation & elliptical orbit around the sun.

$$LST = LT + 4 (L_{site} - L_{STM}) + EOT$$

LST $\Rightarrow$ Local solar time

LT $\Rightarrow$ Local time

4 $\rightarrow$ Earth rotate 1 degree longitude every 4 minutes

L_{site} $\rightarrow$ Longitude of the site

L_{STM} $\rightarrow$ Local standard time Meridian

EOT $\rightarrow$ Equation of time.

Solar Energy Collectors :- A solar collector is a device for collecting solar radiation & transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors. They are 2 types.

- (1) Non concentrating or flat plate type solar collector
- (2) concentrating type solar collector.

The solar energy collector, with its associated absorber, is the essential component of any system for the conversion of solar radiation energy into more usable form (heat or electricity).

collector area $\rightarrow$ the area that intercepts the solar radiation.

absorber area $\rightarrow$ the area absorbing the radiation.

In the non-concentration type, the collector area is the same as the absorber area.

On the other hand, in concentrating collectors, the area intercepting the solar radiation is greater, sometimes hundred of times greater than the absorber area.

$\rightarrow$ By means of concentrating collectors, much higher temperatures can be obtained than with the non-concentrating type.

Solar collectors absorb the solar radiation & convert to thermal energy (heat). This heat is extracted by flowing fluid in the tube of the collectors for further utilization in different applications. In simple solar collector is a device for collecting solar radiation & it also transfers the energy to a fluid passing through it.

Flat plate collectors are particularly convenient where the temperatures below 90°C are adequate.

- They are made in rectangular panels, from about 1.7 to 2.9 sq m in area.
- Flat plate collectors can collect & absorb both direct & diffuse solar radiation.
- Flat plate collectors may be divided into two main classifications based on the type of heat transfer fluid used.

(i) Liquid heating collectors

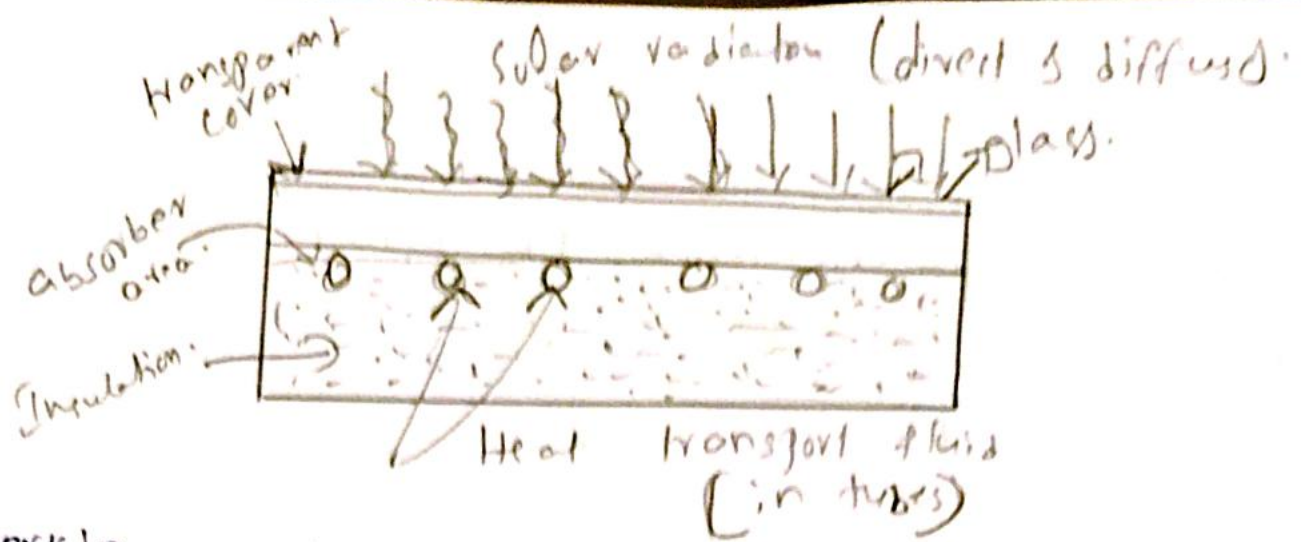
(ii) Solar air heaters.

The d/f b/n the two types is the design of passage for the heat for the transfer fluid.

Solar Energy Collectors

The majority of flat plate collector have five main components as follows.

- (i) A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.
[Glass easily transmits short wave radiation, but it is a very poor transmitter of long wave radiation.
once the sun's energy has passed through the glass windows & has been absorbed by some material inside, the heat will not be reradiated back outside. ∴ Glass act as a heat trap.]
- (ii) Tubes, fins, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.
- (iii) The absorber plate, normally metallic or with a black surface, although a wide variety of other materials can be used with air heaters.
- (iv) Insulation, which should be provided at the back & sides to minimise the heat losses.
- (v) The container which enclose the other components & protects them from the weather.



Working: - Solar radiation both direct & diffuse passes through the transparent cover.

- The radiation strikes the dark coloured absorber plate, which heats up.
- The heat from the absorber plate is transferred to the heat transfer fluid flowing through the tubes.
- The heated fluid is then circulated to a storage tank or used directly for heating applications.

Applications

- used in water heating & space heating systems
- used to heat water on large scales
- used in solar cookers
- " " solar drying process
- " " distillation

Factors affecting the performance of Flat plate collectors.

Several factors influence the performance of flat plate solar collectors including

- solar radiation
- selective surface properties
- No. of cover plates
- spacing b/n the absorber plate & cover
- tilt angle.

These factors affect the amount of solar energy absorbed, the rate of heat transfer & overall η of the collector.

(1) Incident solar Radiation :- Higher solar radiation (more sunlight) leads to increased heat absorption by the collector thus improving its performance.

If more energy available for heating the working fluid, resulting in higher outlet temp. & overall η .

(2) Selective surface :- Selective surfaces ensure that a large portion of the incident solar energy is absorbed by the collector plate (high absorptivity & low emissivity), which is then transferred to the working fluid.

(3) No. of cover plates : - Each glass cover acts as a barrier to heat transfer.

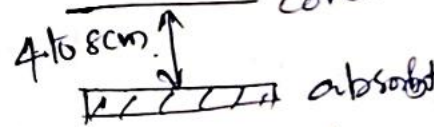
Therefore multiple glass cover plates reduce amount of solar radiation reaching the absorber.

Typically one or two cover plates are used to balance heat loss reduction & solar radiation transmission.

(4) spacing b/n cover & absorber : -

Increasing spacing b/n the absorber plate & the cover plate reduces heat loss & enhancing η .

A larger air gap allows for more air flow, which can increase heat transfer to the cover but also increases radiation losses if the gap is too large.



Careful design of the spacing is necessary to optimize heat transfer & minimize losses.

(5) collector Tilt angle : - Tilt angle significantly affects the amount of solar radiation intercepted by the collector throughout the day & year.

Tilt angles should be adjusted based on the latitude of the location & the seasonal variations in solar angles.

For optimal performance, the collector should be tilted at an angle roughly equal to the latitude of the location.

Other factors

- Absorber plate material & thickness: - Different materials & thicknesses affect the heat absorption & conduction.
- Wind speed: Higher wind speeds increase convective heat loss.
- Inlet & outlet Temperatures: These affect heat transfer & η .
- Volumetric flow rate: Affects the rate at which heat is carried away from the collector.
- Dust & dirt: Accumulation of dust on the cover can reduce solar radiation transmission.
- Atmospheric conditions: changes in atmospheric conditions such as temp. & humidity ~~in~~ affects the performance of flat plate collectors.

By carefully considering these factors & optimizing the design & operation of flat-plate collectors, it's possible to maximize their thermal performance & efficiency.

Concentrating or focussing type of collectors :-

Focussing type of collector is a device to collect solar radiation with high intensity on the energy absorbing surface.

Such collectors generally use optical system in the form of reflectors or refractors.

Concentrating or focussing collectors may be considered in two general categories.

- (1) Line focussing → Line is a collector pipe
(2) point focussing → point is a small volume through which the heat transport fluid flows.

Central receiver collector.

Main types of concentrating collectors are

- (i) parabolic trough collector
- (ii) Mirror strip reflector
- (iii) Fresnel lens collector
- (iv) Flat plate collector with adjustable mirrors
- (v) compound parabolic concentrator.

Parabolic Trough collector :- A parabolic trough collector is a type of solar thermal technology that uses a curved, mirrored trough to focus sunlight onto a receiver tube, heating a fluid that can be used to generate electricity or for other industrial processes.

Key components

- (1) parabolic reflector
- (2) Receiver tube
- (3) Heat transfer fluid
- (4) Tracking system.

Working :- Solar radiation coming from the particular direction is collected over the area of the reflecting surface & is concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic cross section, the solar radiation is focused along a line.

- A tube placed along the focal line of the parabola, containing a heat transfer fluid (like synthetic oil, molten salt or pressurized water).
- The heated fluid then carries the thermal energy to a heat exchanger, where it can be used to generate steam for electricity production.

→ A mechanism that allows the collector to rotate & track the sun's movement across the sky, ensuring optimal sunlight concentration on the receiver tube.

Adv :- parabolic trough collectors have been made of highly polished aluminium, & silvered glass or of a thin film of aluminized plastic on a firm base.

→ parabolic troughs can reach high temperatures (up to 400°C or more), making them suitable for electricity generation & other high temp. applications.

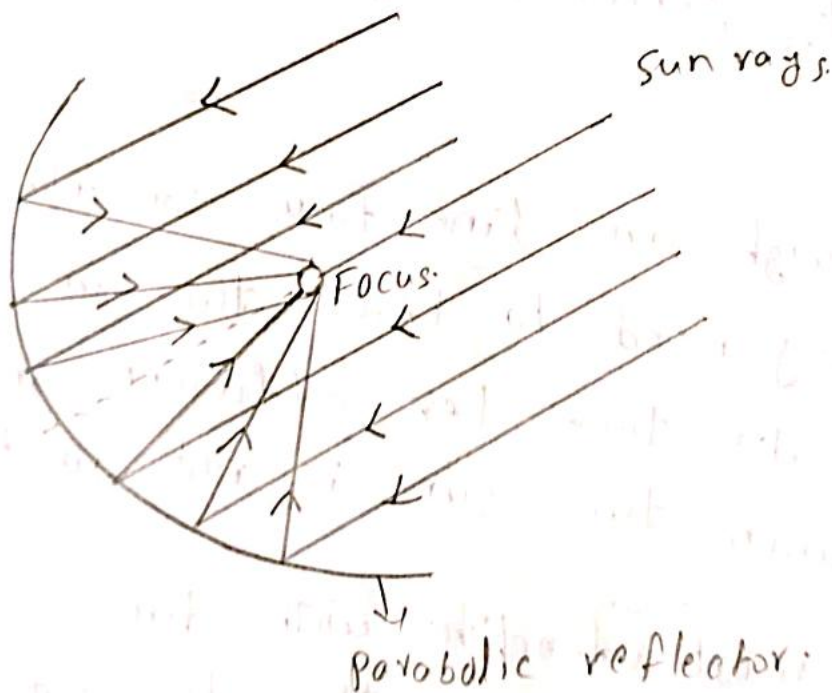
Dis adv

parabolic troughs are line focus concentrators, meaning they need to track the sun along one axis. This can make them less efficient on cloudy days or when the sun is not directly aligned.

→ They are most effective with direct sunlight & less " " with diffused " " .

Working

- The curved, trough shaped reflector ~~arrange~~ of mirrors, concentrates the sunlight onto a focal line. Here a ^{receiver} tube ^{is placed} placed along the focal line of the parabola.
- The concentrated sunlight heats the heat transfer fluid flowing through the receiver tube.
- The heated fluid then carries the thermal energy to a heat exchanger, where it can be used to generate steam for electricity production.



Mirror Strip Reflector :- It is another kind of focusing collector, a no. of plane or slightly curved mirror strips are mounted on a flat base.

→ The angles of the individual mirrors are such that they reflect solar radiation from a specific direction onto the same focal line.

→ The angles of the mirrors must be adjusted to allow for changes in the sun's elevation, while the focal line (for collector pipe) remains in a fixed position.

→ Alternatively, as mentioned for parabolic trough collectors, the mirror strips may be fixed & the collector pipe moved continuously so as to remain on the focal line.

→ Mirror strip reflectors are also known as ^{Linear} Fresnel lens reflector (LFR) because instead of refracting light these are reflecting light.

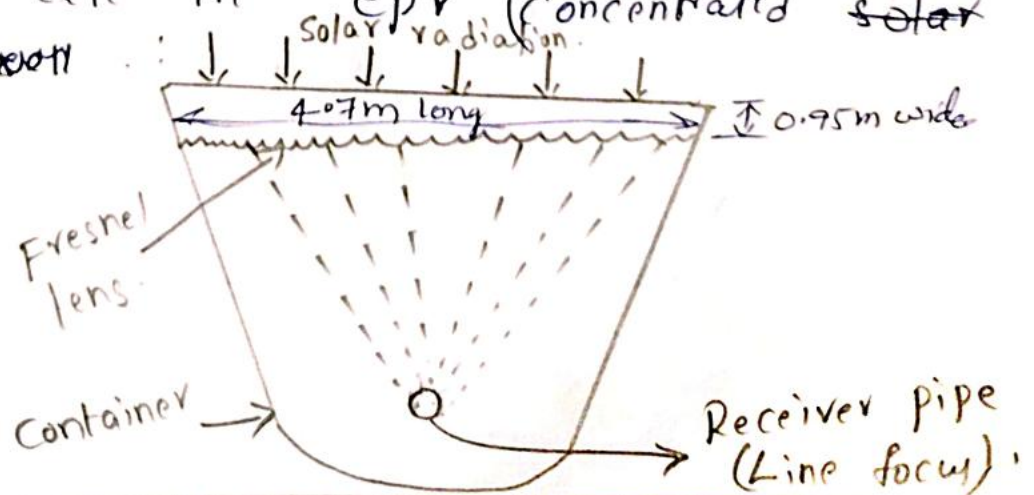


Fresnel Lens collector :- In addition to the reflecting collector type of Fresnel lens collector, a refraction type of focussing collectors has been developed. It utilizes the focussing effect of Fresnel Lens as shown in fig.

A Fresnel lens collector uses a special type of lens called a Fresnel lens to focus sunlight.
→ These Lenses are light weight, relatively inexpensive, can concentrate sunlight onto a smaller area.

Working :- Fresnel Lens is made up of concentric grooves or prisms.

These grooves refract light in a similar way to a traditional lens but require much less material.
→ The Fresnel lens focuses incoming sunlight onto a smaller receiver, such as a pipe containing a heat transfer fluid in CSP (Concentrated Solar Power) systems or a photovoltaic cell in CPV (Concentrated solar photovoltaics).



Difference b/n Flat plate collector & concentrating collectors

Flat plate collector

- (1) collector area is same as the absorber area.
- (2) Suitable only for the low temp. (below 100°C)
- (3) Not suitable for generation of steam & hence not suitable for power generation.
- (4) collects beam & diffuse radiation.
- (5) Maintenance cost is low.
- (6) Efficiency is less
- (7) Less energy output
- (8) more material for construction

concentrating collector

collector area is more than absorber area.

Suitable for high temp. upto 500°C .

Suitable for power generation.

collects only beam radiation.

Maintenance cost is high.

Efficiency is more

Higher energy output with a small surface area

Less material for construction

Advantages & Disadvantages of concentrating collectors.

Advantages

- Reflecting surface is simpler & needs less material.
- solar energy is concentrated over a small area thus produce more heat.
- Due to less area for heat loss, the working fluid can attain higher temp.
- More efficient & can be used for electric power generation.

Dis

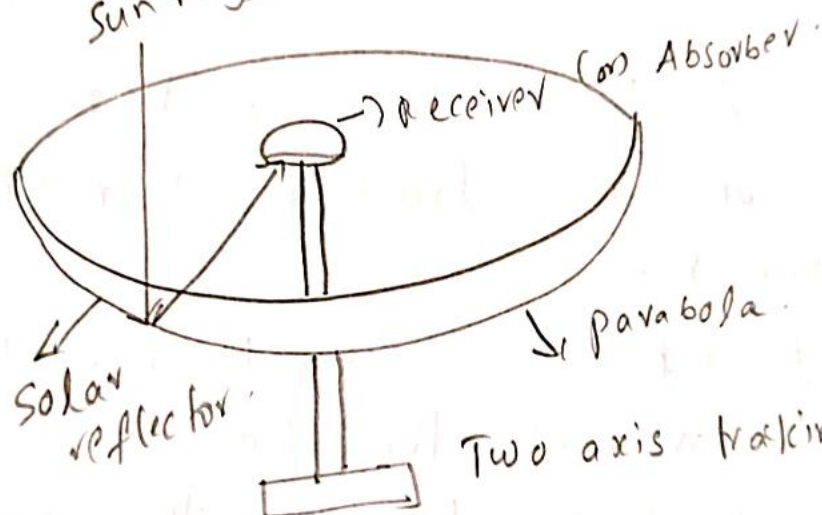
- Initial cost is high.
- Need costly orienting system for reflector to track the sun.
- only direct radiation is collected in case of focusing type collectors.

Point Focusing collector

Paraboloidal Type :- A paraboloidal dish collector brings solar radiation to a focus at a point actually a small central volume.

→ A dish 6.6 m in diameter has been made from about 200 curved mirror segments forming a paraboloidal surface.

→ The absorber, located at the focus, is a cavity made of a zirconium-copper alloy with a black chrome selective coating.



→ The heat-transport fluid flows into & out of the absorber cavity through pipes bonded to the interior.

→ The dish can be turned automatically about two axes (up down & left-right) so that the sun is always kept in a line with the focus & the base of the paraboloidal dish.

Thus the sun can be fully tracked at essentially all times.

Central tower solar energy collectors

It is also known as a solar power tower is a type of concentrating solar power system.

- It uses a field of mirrors called heliostats to focus sunlight onto a receiver located at the top of a tall tower.
- This concentrated solar energy heats a working fluid, which is then used to generate steam & drive a turbine producing electricity.

Heliostats :- A large field of two axis tracking mirrors known as heliostats, surrounds the central tower.

- These heliostats are computer controlled to trace the sun's movement throughout the day, constantly redirecting sunlight towards the receiver on the tower.

Central tower & receiver :- A tall tower stands at the centre of the heliostat field.

- At the top of the tower there is a receiver which absorbs the concentrated solar radiation.
- The receiver contains heat transfer fluid that is heated by the concentrated sunlight.

Electricity generation :- The heated fluid in the receiver is used to produce steam.

→ This steam then drives a turbine, which is connected to a generator that produces Electricity.

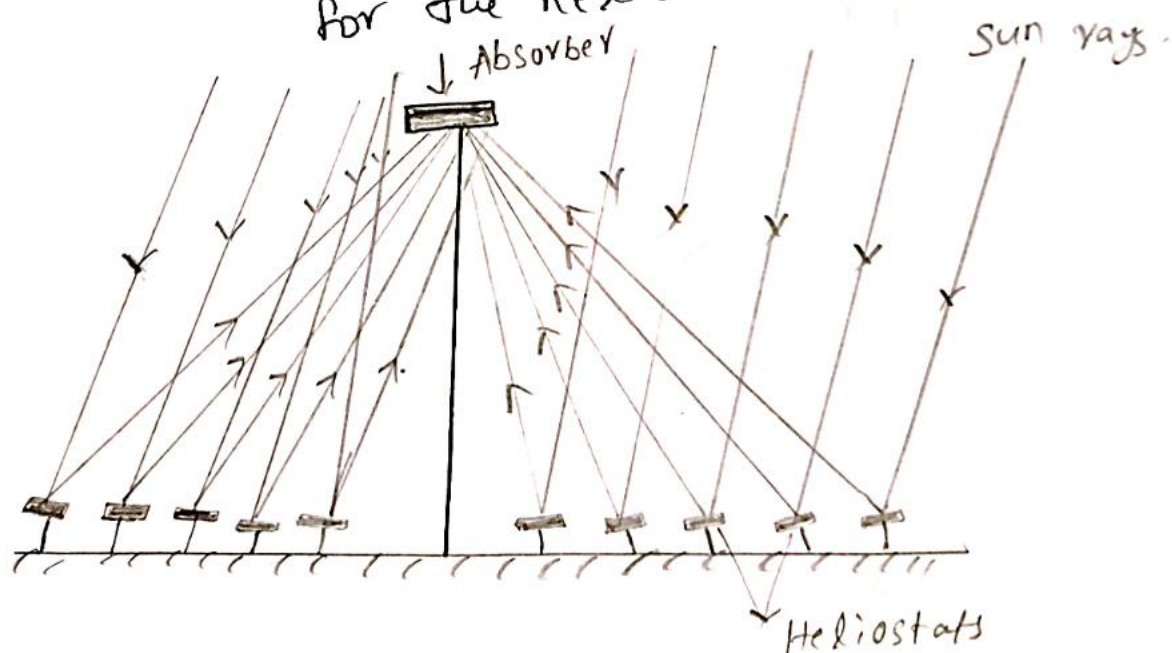
Adv :- → High temperatures

→ Thermal energy storage → This system allows for electricity generation even when the sun is not shining.

Disadv :- → complexity & cost

↓
Large no. of heliostats & the need for tracking systems can make solar tower plants more complex & expensive than the other types of solar power plants.

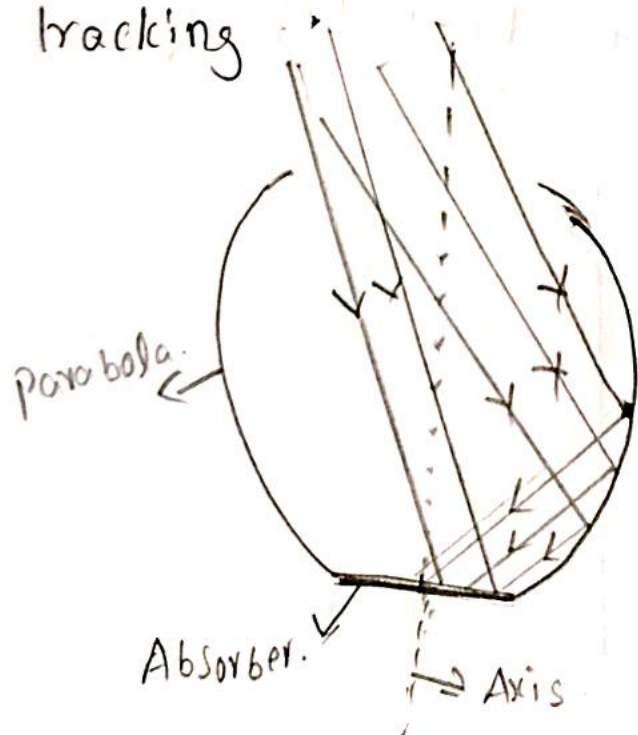
→ Land use :- They require a large area of land for the heliostat field.



Compound parabolic concentrator (CPC): - The CPC (or Winston collector) is a trough like arrangement of two facing parabolic mirrors. Unlike a single parabolic trough reflector, the CPC is non focusing, but solar radiation from many directions is reflected toward the bottom of the trough.

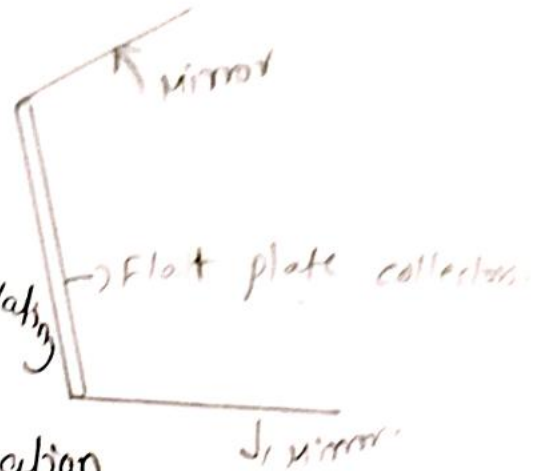
Because of this characteristic, a large proportion of solar radiation, including diffuse radiation, entering the trough opening is collected or concentrated on a small area.

⇒ Another advantage of CPC is that it provides good concentration of solar energy in an east-west direction without adjustment for sun tracking.

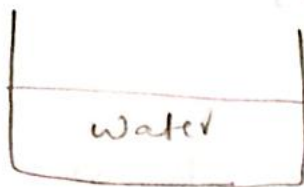


Flat plate collectors with adjustable mirrors

A flat plate solar collector with adjustable mirrors is a system that enhances the energy collection of a flat plate collector by incorporating adjustable mirrors to reflect additional solar radiation on to the absorber surface.



- This design allows for increased energy capture, particularly ~~during~~ when the sun's angle of incidence is not optimal for the flat plate collector alone.
- The mirrors are positioned to reflect additional solar radiation onto the absorber plate, effectively increasing the amount of solar radiation captured.
- The mirrors can be adjusted manually or automatically (through tracking system) to optimize their position based on the sun's angle & time of day.

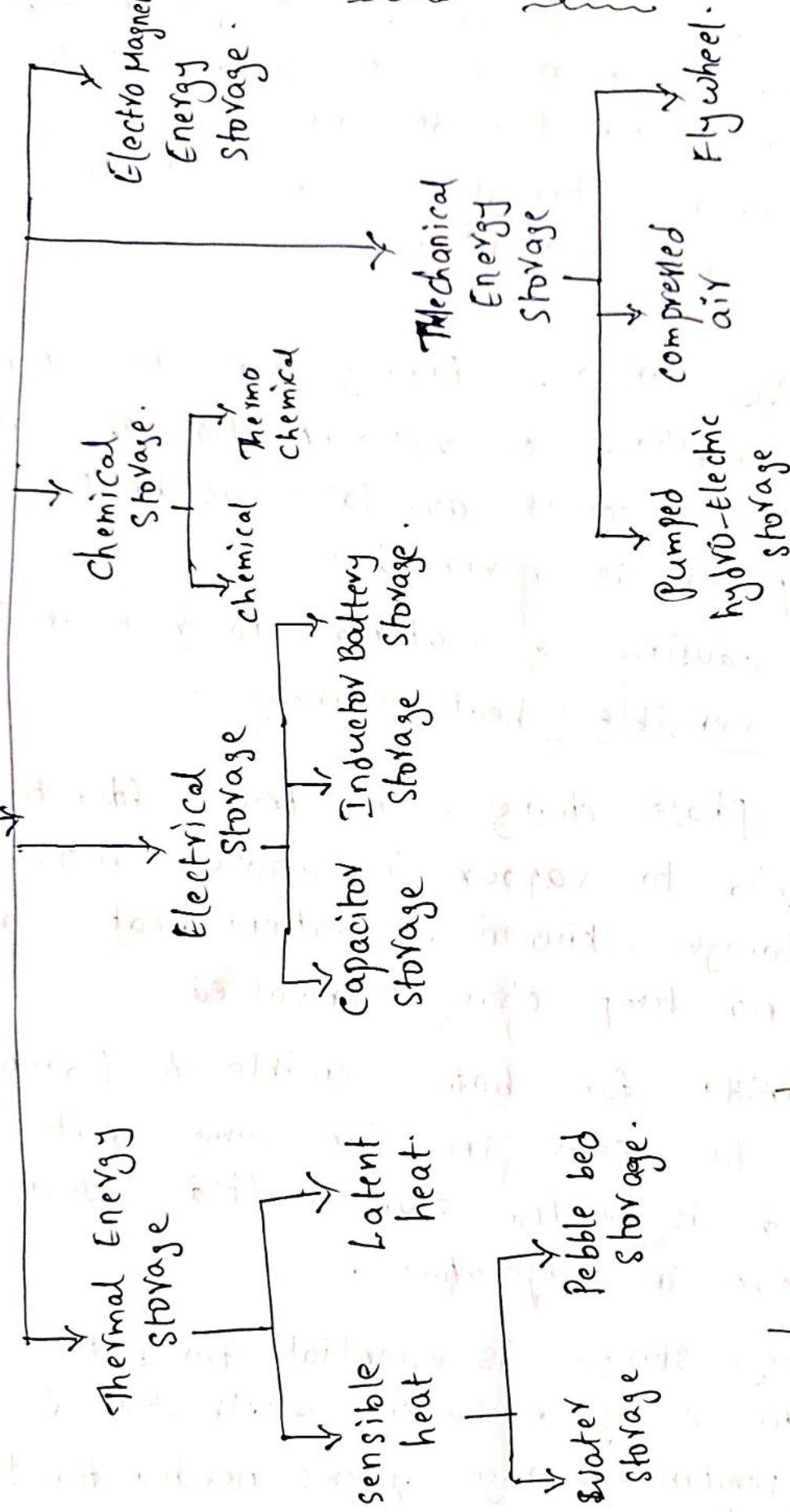


once all the water is evaporated into vapour, the temp of vapour will start to increase & it is increased to 120°C . At this point the vapour can take both

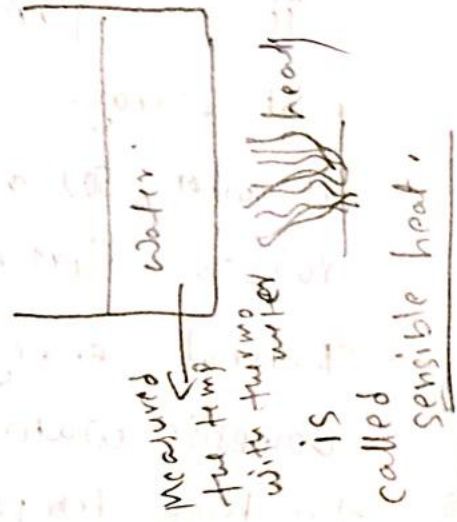
120°C sensible heat
+
Latent heat } Heat which is used for evaporation.

Solar Energy storage

Solar Energy storage systems



If we continuous heat the water its temp will increase & reach 100°C . After reaching 100°C the temp of water will increase further. Even if we apply further heat to the water it converts into vapour state. The heat used for the evaporation is called Latent heat.



solar energy is available only during the sunshine hours, consumer energy demand follow their own time pattern & the solar energy doesn't fully match the demand.

As a result energy storage is a must to meet the consumer requirement.

Thermal Energy storage: - Energy can be stored by heating, melting or vaporization of material & the energy becomes available as heat, when the process is reversed.

Storage by causing a material to rise in temp. is called sensible heat storage.

Storage by phase change, i.e., from solid to liquid or from liquid to vapour is another mode of thermal storage, known as Latent heat storage, in which no temp. change is involved.

→ It is possible for both sensible & latent heat storage to occur in the same material as when solid is heated then melted, then raised further in temperature.

Thermal energy storage is essential for both domestic water & space heating applications & for the high temperature storage systems needed for thermal power applications.

→ The choice of the storage material depends on the particular application & for many domestic applications, water or/and Rock Storage systems have been developed.

→ Water & Rock are the typical examples of material but their use is limited by their comparatively low specific heats.

Glauber's salt ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) is the least expensive & most readily available salt hydrate.

→ For high temperature storage in the order of 200°C to 300°C other salts have been used.

Sensible heat storage :- Sensible heat storage involves a material that undergoes no change in phase over the temperature domain encountered in the storage process. The amount of energy stored is dependent on the temp. change of the material.

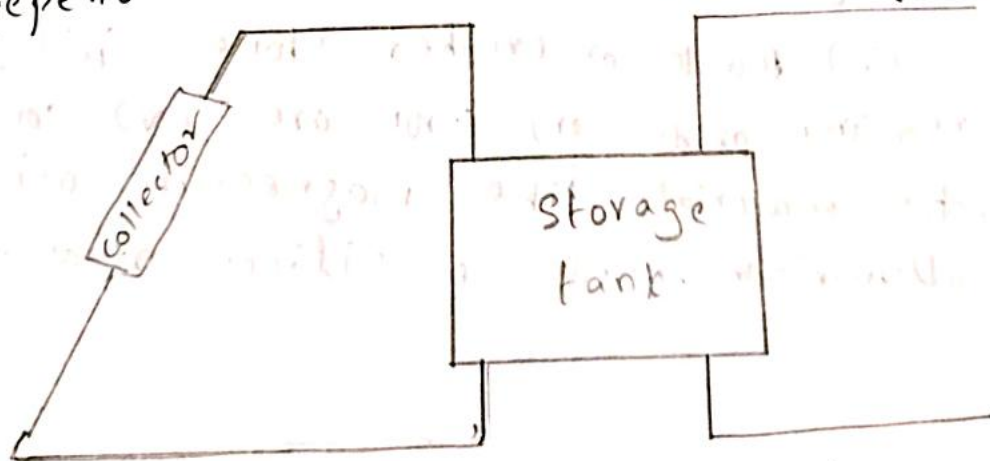


Fig: Water tank storage unit. Energy is added by circulating water through collector & is removed by " " " " Load.

The basic equation for an energy storage unit, is given by $Q_s = m \int_{T_1}^{T_2} C_p dt$

$$\therefore Q_s = (m C_p)_s (T_1 - T_2)$$

where Q_s = Total thermal energy capacity

$T_1 - T_2$ — Temperature swing. with 'm' kg of storage medium

C_p — specific heat of storage medium
Amount of heat required to increase 1°C temp of a unit mass.

The ability of store thermal energy in a given container of volume 'V' is

$$\frac{Q_s}{V} = \rho C_p \Delta T$$

where ρ is the density of the storage medium.

Thus the ability to store heat depends upon the product of ρC_p .

Materials which are generally used for this type of storage are

- (i) water (ii) Rock or crushed stone (iii) Iron shot
- (iv) Iron, red iron oxide (or) Iron ore (v) concrete
- (vi) Refractory materials like magnesium oxide, aluminium oxide & silicon oxide.

(a) Water storage : The most common heat transfer fluid for a solar system is water, & the easiest way to store thermal energy is by storing the water directly in a well insulated tank. Water has the following characteristics for storage medium.

- (i) It is less expensive, readily available & useful material to store sensible heat.
- (ii) It has high thermal storage capacity.
- (iii) Energy addition & removal from this type of storage is done by medium itself, thus eliminating any temp. drop b/w transport fluid & storage medium.
- (iv) Pumping cost is small.

(b) Packed Bed Exchanger storage : -

For sensible heat storage with air as the energy transport mechanism, rock, gravel or crushed stone in a bin has the advantage of providing a large, cheap heat transfer surface.

→ Its thermal capacity, however, is only half that of water, & the bin volume will be about 3 times the volume of a water tank.

Rock has the following advantages over water.

- (i) Rock is more easily contained than water.
- (ii) Rock acts as its own heat exchanger, which reduces total system cost.
- (iii) It can be easily used for thermal storage at high temperatures much higher than 100°C .
- (iv) The heat transfer coefficient b/w the air & solid is high.
- (v) The cost of storage material is low.
- (vi) The conductivity of the bed is low when air flow is not present.

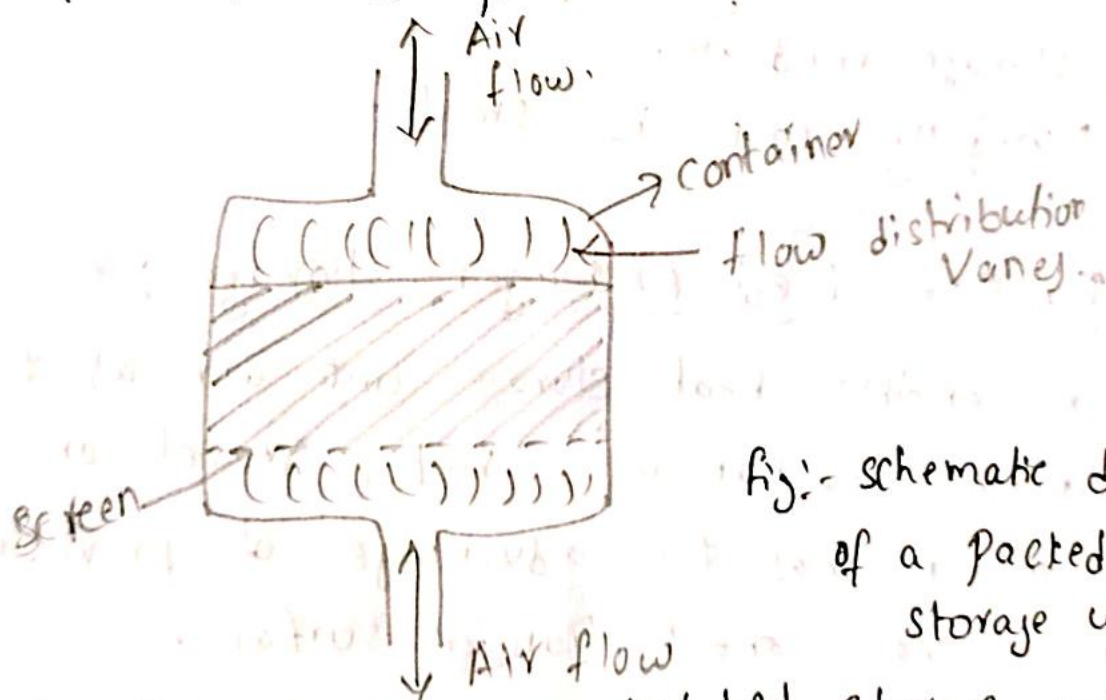


Fig:- schematic diagram of a packed bed storage unit.

Essential features of a packed bed storage unit are a container, porous structure to support the bed & air distributors.

→ A packed bed storage unit which uses the heat capacity of a bed of loosely packed material

through which a fluid usually air is circulated to add or remove heat from the bed.

→ In operation, the flow is maintained through the bed in one direction during addition of heat & in the opposite direction during removal of heat.

→ In this system, the heat addition & removal from the storage can't be carried out simultaneously.

→ pebble bed exchanger have good heat transfer characteristics b/n the air & the solids of ^{the} bed.

→ This type of storage system has been used in the solar houses or with hot air collector system.

Latent heat storage: (Phase change energy storage)

In this system, heat is stored in a material where it melts & extracted from the material when it freezes.

Materials that undergo a change of phase in a suitable temp. range may be useful for energy storage if the following criteria can be satisfied.

Materials for phase change energy storage are $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, water, $\text{Fe}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$.

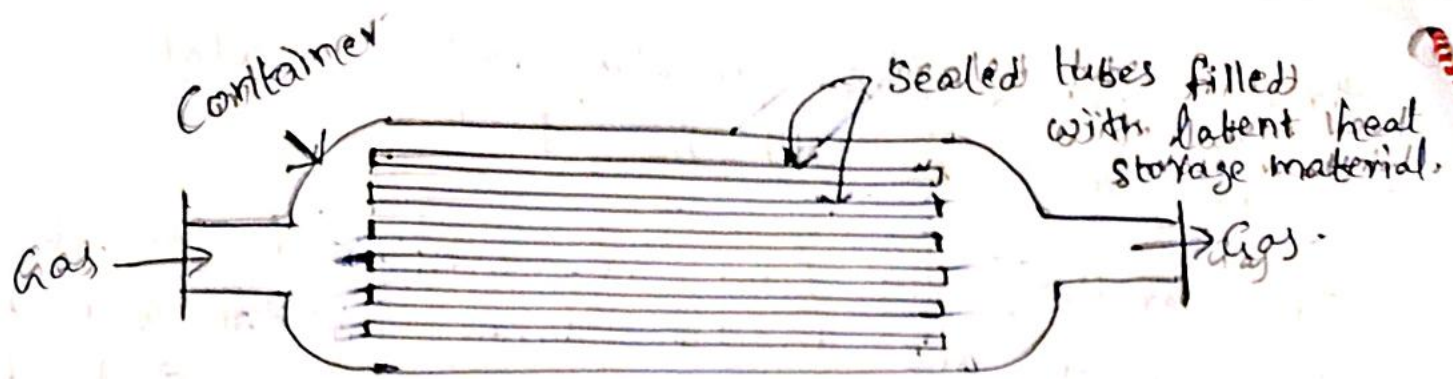


Fig:- A typical latent heat storage arrangements.

- (i) The phase change must be accompanied by high latent heat effect - (means store more energy in a given volume).
- (ii) The phase change must be reversible over a very large no. of cycles without degradation.
- (iii) The phase change must occur with limited super cooling.
- (iv) Means must be available to contain the material & transfer heat into it & out of it.
- (v) The cost of material & its containers must be reasonable.
- (vi) The material must be available in large quantities.
- (vii) The materials must be harmless (non-toxic, non-inflammable, non-combustible).
- (viii) The material should have high thermal conductivity in both the phases.

If these criteria can be met, phase change energy storage systems can be of high capacities when operated over small temperature ranges, with ~~substant~~ substantial reduction in volume & weight.

Compare single axis tracking solar thermal collectors with Dual axis tracking " " collectors.

Solar trackers increase the efficiency of solar systems by providing more sunlight on the collectors. Depending on the location & the specific system, 25% to 40% more energy can be harvested with tracking than without it.

Solar trackers can be categorized into 2 types.
Single axis ^{solar} trackers Δ Dual axis ^{solar} trackers

Single axis ^{solar} trackers

- This type of trackers can move along one axis usually East-West.
- They offer lower precision in tracking the sun.
- They can increase energy output by 25-30% compared to fixed panels.
- Low cost & simple design compared to dual axis trackers

Dual axis solar trackers

- They move along both east-west Δ North-South axes.
- They offer greater precision in tracking the sun.
- They can increase energy o/p by 30-45% & even more in some regions.
- high initial cost: Δ complex design.

→ considered more reliable due to simpler mechanics.

→ Single axis trackers offer a low ROI compared to dual axis trackers.

→ Suitable for various locations, especially where space is limited & cost is a major factor.

May be less reliable due to more complex mechanisms.

Dual axis trackers may offer a better Return on Investment (ROI) in the long run due to higher energy production.

→ Suitable for locations with significant seasonal variations in sun angle & for maximizing energy production from valuable land.

Sunshine Recorder

A sunshine recorder is a meteorological instrument used to measure the duration of bright sunshine in a day.

It doesn't measure intensity but simply records how long the sun has been shining.

Working principle

The most common type is the Campbell-Stokes sunshine recorder 2. Jordan type (photographic paper)

It consists of glass sphere that acts like a lens. Sunlight passing through the sphere is focused onto a specially prepared card strip (paper)

When the sun shines, the focused rays burn or scorch on the card.

The length of the burn marks corresponds to the duration of sunshine

Uses:

- Weather forecasting & climate studies
- Agricultural planning (depends on sunshine)
- Solar energy potential estimation.

UNIT-II

PV Energy systems

Photovoltaic (PV) systems commonly known as solar power systems, convert sunlight directly into electricity using semiconducting materials.

→ These systems are clean, renewable energy source, offering a sustainable alternative to fossil fuels.

→ PV technology is becoming increasingly prevalent, with declining cost & diverse applications ranging from powering individual homes to large scale power plants.

How it works ?

PV systems utilize the photo electric effect where light energy (photons) is absorbed by a semiconductor material (like silicon) causing electrons to be released & creating an electrical current.

PV cells, modules & Arrays:- Individual PV cells are combined into modules (also known as panels) to increase power o/p. Multiple modules can be connected to form larger arrays.

A single solar cell typically generates a voltage b/w 0.5 & 0.6 volts under standard conditions.

This voltage is relatively low, & therefore multiple solar cells are connected in series within a solar panel.

to increase the overall voltage.

→ For example a solar panel might contain 32, 36, 48, 60, 72 or even 96 cells.

System components :- Beyond solar panels, PV systems typically include inverters to convert the direct current into AC.

Other components like charge controllers, batteries & mounting structures may also be included, depending on the system's configuration (ON grid, OFF grid & Hybrid).

Types of PV systems :- Solar PV systems can be broadly categorized into three main types.

- (1) stand alone (off grid)
- (2) grid connected (ON grid)
- (3) Hybrid

These systems differ in their connection to the electricity grid & how they manage the solar energy they generate.

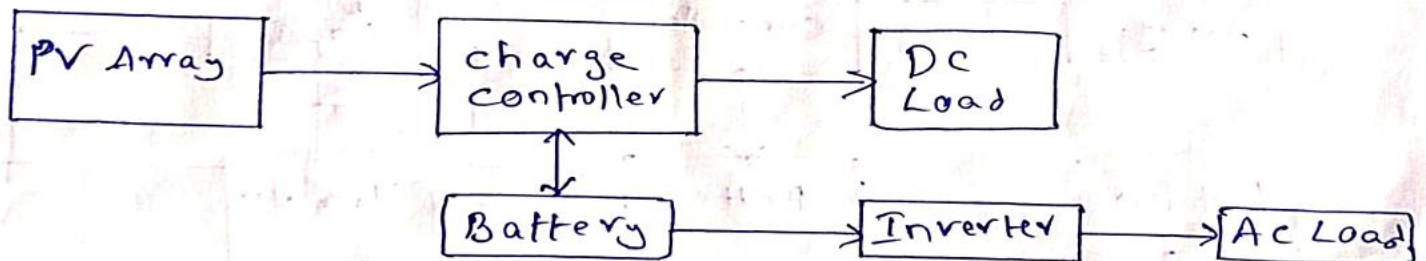
(1) Stand alone (off grid) systems :- These systems are not connected to the utility grid & are typically used remote locations or where grid connection is unavailable.

→ They need batteries to store the electricity generated by the solar panels for use when the sun is not shining.

→ Stand alone systems can be further divided into (i) direct coupled systems (directly connecting solar panels to DC loads)

(ii) systems with battery storage

(iii) Inverters (converting DC to AC for wider appliance use).

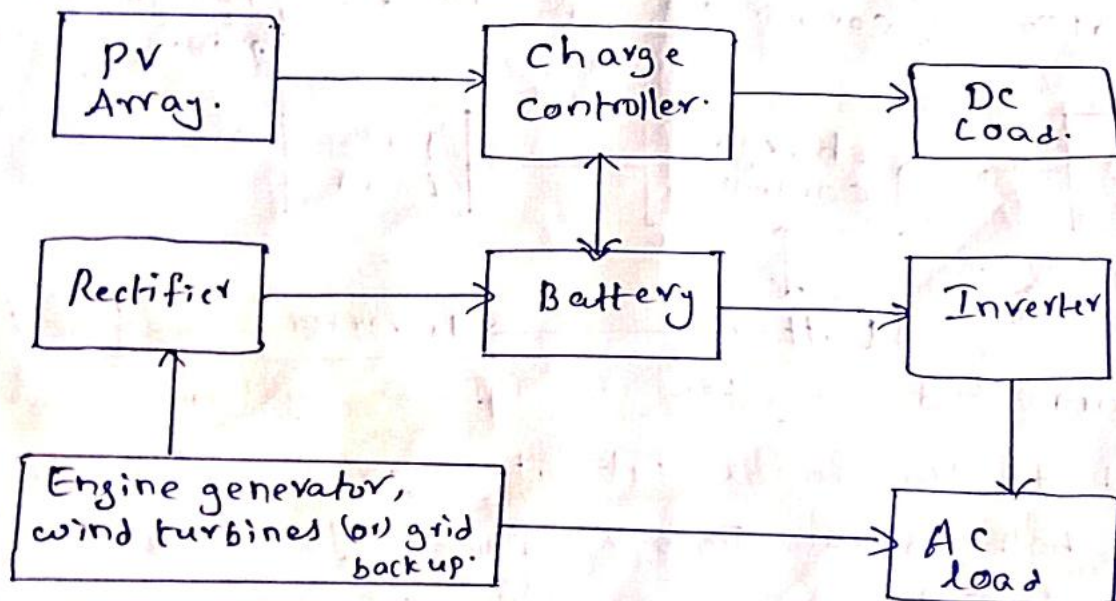


(2) Grid connected system :- These systems are connected to the local utility grid, allowing them to both draw power from the grid & send excess solar energy back to the grid.

→ They don't require batteries as they can take backup power from the grid when solar generation is insufficient.

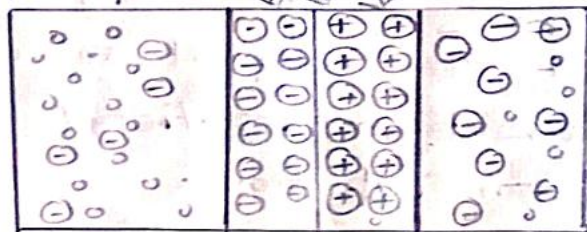


(3) Hybrid systems:- In hybrid energy systems more than a single source of energy supplies the electricity.



PV effect in crystalline silicon :- The photovoltaic (PV) effect in crystalline silicon involves converting light into electricity through the interaction of photons with the semiconductor material.

Basic principle :- A photovoltaic cell is a type of PN Junction diode. Light energy is incident on the N (-ve) side.



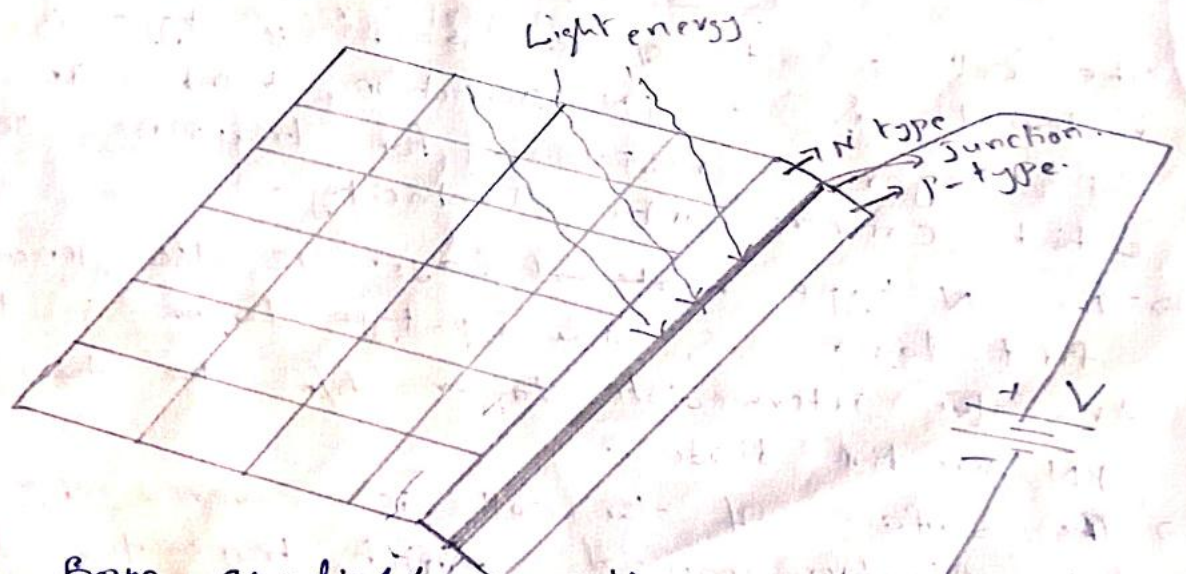
The cell consists of a depletion region. Each region is p-type & n-type material & a PN junction diode is formed between the two. This layer is responsible for trapping solar energy which converts into electricity.

- The N-type material layer is also known as the first layer & the p-type layer is the base layer. And the intermediate layer b/w the two is PN junction diode.
- The surface of the cell is covered by an antireflective material which traps the light energy & avoid any loss of energy.
- The bottom layer, the last ^{one} may completely be covered by the material in which the conductor is made up of.

PV cell working:

→ When the light is incident on the surface of a cell, it consists of photons which are absorbed by the semiconductor & the electron-hole pairs are liberated to produce an external DC supply.

→ If an external current path has been provided then the electrons flow through P-side & travel towards the N-side, eventually generating a DC current & the magnitude of this EMF generated is directly proportional to the intensity of solar radiation.



The energy from sunlight excites the electrons in the silicon, knocking them loose & allowing them to move freely.

Crystalline Silicon PV cells.

When people think of solar panels, they think of crystalline solar panels. These panels, which are usually blue or black, have a hard glass cover & measure about three by five feet.

However there is an entirely different type of solar panel that you can simply ~~roll~~ out & attach to your roof called thin film solar panels.

- A thin film solar cell is a solar cell that is made by depositing one or more thin layers of various photovoltaic materials onto a substrate.
 - Crystalline solar panel cells are 0.15 - 0.2 mm thick, where as thin film cells can be as thin as 0.001 mm and are also much lighter.
 - The crystalline ^{silicon} panels, which are installed on strong rooftops with rugged mounting system tilted at a fixed degree.
 - where as thin film panels can be rolled-out & directly attached to the rooftop on your home or business.
 - one of the major advantage of thin film panels has been cost, which is approximately 30% less than crystalline panels.
- Low cost but no longer usable

crystalline silicon solar panels can be grouped into two categories.

Monocrystalline solar cells $\rightarrow$ made from a single, i.e. continuous crystal of silicon.

Poly crystalline " $\rightarrow$ many silicon fragments melted together.

Monocrystalline

- (1) This type of solar panels ~~prove~~ prove more efficient
- (2) Better performance in higher temperatures
- (3) More cost
- (4) high efficiency

Polycrystalline

less efficient

Low performance in higher temp.

polycrystalline solar panels are less wasteful during manufacturing & come at a lower cost. Lower efficiency.

Advantages of Crystalline

Monocrystalline & polycrystalline panels have several advantages over thin film cells.

- $\rightarrow$ They are more durable 30+ years & have 20% efficiency
- $\rightarrow$ More efficient
- $\rightarrow$ A C-SI solar panel is more environmentally friendly because it doesn't contain any harmful materials.

Thin film PV :- Thin film photovoltaic (PV) cells are the type of solar cell that uses a thin layer of semiconductor material deposited onto a substrate like glass, plastic or metal.

→ Instead of using thick silicon wafers, thin film cells use a thin layer of semiconducting material often only a few nanometers to a few microns thick.

→ In solar photovoltaic (PV) systems, thin films play a crucial role, particularly in thin film solar cells & as encapsulation layers for both traditional & thin film panels.

→ They offer advantages like flexibility, lightweight design, & potentially lower production costs.

→ Thin films also enhance panel performance through antireflective coatings & passivation layers.

Materials used :- Thin film solar cells utilize various semiconductor materials like.

→ cadmium telluride (CdTe)

→ Amorphous silicon (a-Si)

→ copper indium gallium selenide (CIGS)

Advantages

- Protection & Insulation: Thin films are used as protective layers in solar modules. They provide insulation, mechanical strength & resistance to environmental factors.
- Antireflective coatings: Thin films are used to reduce light reflection, increasing the amount of sunlight absorbed by solar cell.
- Low cost by replacing silicon with other rare materials.
- When several thin film modules that require less silicon in the manufacturing process.

Disadvantages: Thin film panels contain Cadmium, a known carcinogen that can harm people.

- Recycling & disposing of toxic cadmium also presents issues.
- And yet, there is a silver lining: "Although pollutants & toxic substances are emitted during the PV manufacturing process, life cycle emissions are low."

→ The durability of C-Si also makes it perfect for extreme heat or temperature variants as it loses approximately 1% of power o/p annually.

Layers of Thin Film PV Panels:

→ Thin film solar panels typically consists of 3 to 5 layers of different materials on a substrate.

→ These layers are (1) transparent conductive oxide

(2) a window layer → helps to create a p-n junction ^{↓ allows sunlight to pass}

(3) an absorber layer → absorbs light ^{↓ layer absorbs light}

(4) a back contact layer → provides conductive path for electrons to flow ^{↓ provides conductive path for electrons to flow}

(5) sometimes a buffer layer. ^{↓ out of the cell into an external circuit}

[↓]
added b/n window & absorber layer to improve performance

(1) Transparent conductive oxide layer allows sunlight to pass through to the active photovoltaic material.

(2) Window layer helps to improve the efficiency of the solar cell by controlling the flow of charge carriers.

(3) Absorber layer is the layer where sunlight is converted into electricity.

(4) Back contact layer → This layer provides a conductive path for the separated electrons to flow out of the cell & into an external ckt.

(5) Buffer layer :- In some cases, a buffer layer (like zinc oxide) is added b/n the window & absorber layers to improve performance.

These layers are deposited on a substrate like glass, plastic or metal to form the thin-film solar panel.

Layers of crystalline silicon PV panel:

A typical crystalline silicon solar panel has 6 main layers. These layers work together to protect the silicon solar cell, convert sunlight into electricity.

- (1) Glass cover
- (2) EVA encapsulant (1st layer)
- (3) Solar cell
- (4) EVA encapsulant (2nd layer)
- (5) Back sheet
- (6) Aluminium frame.

Glass cover :- $\rightarrow$ It acts as a protective shield from the environmental factors like dust, rain etc.

$\rightarrow$ It also improves the panel's efficiency by allowing max. light transmission to the cells

$\rightarrow$ It minimizes the reflection losses through antireflective coatings.

Some solar glasses are designed with self-cleaning properties, reducing the need for frequent maintenance.

EVA Encapsulant (1st layer) :- Ethylene vinyl acetate (EVA) is a type of plastic that acts as an adhesive, bonding the solar cell to the glass cover & back sheet & also providing the electrical insulation.

Solar cell :- This is the core component where sunlight is converted into electricity. Typically made of crystalline silicon either monocrystalline or polycrystalline.

EVA Encapsulant (2nd layer) :- Another layer of EVA, providing a second barrier of protection & insulation for the solar cell.

Back sheet :- This layer provides a weather proof barrier, protecting the back of the solar panel from moisture & other environmental factors.

→ It also provides the electrical insulation, preventing short ckt & provides safe operation of the module.

Aluminium Frame :- The aluminium frame provides structural support, allowing the solar panel to be mounted on various surfaces & protecting the edges of the panel.

The Indian govt often encourage to home owners of housing societies installing on-grid rooftop solar system under the PM Surya Mahatma Bijli Yojana.

Other PV Technologies :-

In India, besides the common monocrystalline & polycrystalline solar panels, other PV technologies include thin-film, bifacial panels, Building - Integrated photovoltaics (BIPV).

Additionally, India is exploring advanced technologies like TOPCON, heterojunction (HJT) panels & perovskite solar cells.

First generation solar panels

(1) Monocrystalline solar panels are crafted from a single, unbroken crystal structure of high purity silicon.

Efficiency : 19% to 20%

Life span : 30 to 40 years

Best suited for : Homes, commercial rooftop systems, smart lighting, public infrastructure.

Adv:- Max. efficiency, highly durable.

Disadv:- It is affected by a phenomenon known as Light Induced Degradation (LID). Due to LID the power o/p typically drops by about 2-2.5% during the first year.

LID refers to the initial drop in power o/p that occurs when solar cells are ^{first} exposed to sunlight. This occurs a few hours or days in

(2) Poly crystalline solar panels are almost obsolete types of solar panels in India for home use due to their lower efficiency & lower heat tolerance. Instead of using single crystals, solar panel manufacturers melt silicon fragments & mold them into square cells.

Efficiency : 16-17%

Lifespan : 20-25 years

Best suited for : Solar farms, off grid solar PV systems.

Adv :- Low cost

Disadv : low efficiency than monocrystalline

Second generation solar panels

3) Thin film solar panels are the most widely recognized among second generation technologies.

The materials like silicon, cadmium, Indium are few micrometers thick.

These panels are drastically lighter than traditional silicon modules.

Efficiency : 11-12%

Lifespan : 10-20 years.

Best suited for : Industrial rooftops, vehicles temporary structures, portable kits

Adv :- Ultra light weight, cost efficient, flexible

Disadv :- Lower energy o/p for homes. ^{Installation} not suited for rooftop solar

Third generation solar panels :- The different types of solar panels in the third generation explore various materials, ranging from crystal hybrids to nanotechnology.

While many third generation panels are still in the development stages, they have already shown impressive performance in the laboratory settings. Let's explore the different types of solar panels in the third generation.

(4) Dye-sensitized solar cells (DSSCs) represent a completely different approach to harvesting solar energy. Instead of using silicon, these panels use a special dye coated onto a semiconductor (material titanium dioxide) to absorb light & initiate the energy conversion process.

Efficiency : Around 11% (upto 14% in the lab settings)

Life span : 6 years

Best suited for : urban environments with irregular sunlight

Adv :- Inexpensive to make, also works in low sunlight, good thermal resilience.

These types of solar panels shine in conditions where sunlight is inconsistent. They don't need direct rays to perform making them effective in shaded environments.

(5) Organic photovoltaic panels (OPV) use organic polymers & carbon based materials instead of traditional semiconductors.

→ OPV solar panels are light weight, semi-transparent & can be printed like a film.

Efficiency : 10-12% upto 19% in lab conditions.

Lifespan : 10+ Years

Best suited for : smart architecture, temporary structures, experimental technique.

Adv :- Light weight, low cost production, eco-friendly

Upto now, their real world performance remains moderate, & their durability doesn't yet match up to other solar types, making OPVs more suitable for low load applications.

(6) Perovskite solar panels are quickly becoming the star of the solar market.

what makes them especially attractive is their sky-high potential efficiency.

Efficiency : 25-35% (experimental) refers to achieving a high level of productivity & effectiveness.

Lifespan : 2-5 Years (continued efforts being made to increase their life)

Best suited for : Research labs, pilot installations, futuristic solar designs.

Adv : High potential efficiency

Beyond performance, perovskites are easily manufactured using low cost techniques such as solution processing or printing. Their lightweight & flexible nature also makes them a candidate for rollable & transparent solar applications.

(7) Concentrated Photovoltaic Panels (CPV) take a different approach by concentrating sunlight before it reaches the solar cell.

Using lenses or mirrors to focus sunlight onto a small but highly efficient cell.

Efficiency : up to 41% (depending on conditions)

Lifespan : 20+ years

Best suited for : desert installations, utility-scale solar farms, research projects.

Adv : Highest η available, excellent for sunny climates.

disadv : Expensive setup, requires tracking systems

CPV systems excellent under direct, focused sunlight

However, they depend heavily on solar trackers to maintain alignment perpendicular to the sun which involves complexity & cost.

For this reason they are best suited to large scale solar farms or industrial setups.

(8) Bifacial solar panels are designed to capture sunlight from both the front & the rear back surface of the panel. Unlike standard panels that only utilize one face, these modules take advantage of reflected light bouncing off the ground, rooftops or surrounding objects, making them efficient in open, reflective environments.

Efficiency : up to 22%

Life span : 25+ Years

Best suited for: Homes with reflective rooftops, open yards,

Adv :- Higher energy yield, performs well in diffuse light

Disadv :- needs specific placement, higher initial cost.

These types of solar panels are typically constructed using crystalline silicon while capturing energy on both sides.

(9) PERC solar panels

PERC stands for Passivated Emitter & Rear contact, a technology that improves conventional solar cells by adding an extra layer SiN_x on the back improving passivation & reducing absorption losses. [SiN_x layer is a semiconductor material that has been doped with an impurity like phosphorus, giving it an excess of free electrons.] This additional layer helps trap more sunlight within the cell.

Efficiency : 19-22%

Life span : 25-30 Years

Best suited for : Small rooftops, urban homes, areas with variable sunlight.

Adv:- Enhanced η , strong low light performance

(10) Mono - PERC Half-cut Bifacial solar panels

Half cell panels, sometimes referred to as split cell modules, take a clever approach to minimizing energy loss.

Each standard solar cell is cut in half, allowing better current flow through the module.

This design also helps panels perform more efficiently in particularly shaded conditions, ideal for homes surrounded by trees or tall buildings.

Efficiency : up to 22.5%

Lifespan : 25-30 years

Suited for : Homes with partial shading, high heat areas, compact rooftops.

Adv: Great shade tolerance, heat resistant, long
They require less space for installation. lasting

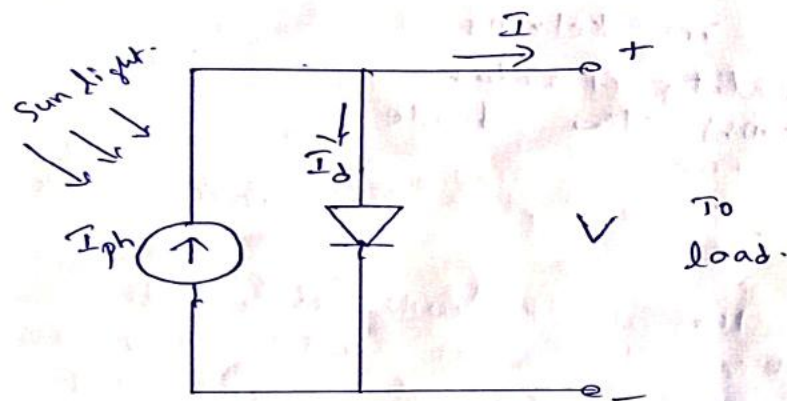
Disadv:- high cost.

There are different types of solar panels in India. out of those, bifacial solar panels & Mono PERC half cut bifacial solar panels are the best for houses. These types offer the max. return on investment & have a longer lifespan & higher η than most other types of solar panels in the market.

Equivalent circuit of ideal solar cell

Ideal solar cell is the solar cell which is having no losses. (that means which don't have resistance to produce heat losses)

A simple equivalent ckt model for an ideal photovoltaic cell consists of a diode in parallel with an ideal current source as shown below.



$I_{ph} \rightarrow$ photons generated current

The current generated as a result of receiving solar radiation or photons.

I_{ph} is directly proportional to solar irradiance i.e. power in the solar cell.

$I_{ph} \propto$ Sun's radiation

Intensity of solar radiation.

I_d is the diode current.

Some part of the current I_{ph} will flow through the diode (I_d) & remaining current flows to the load (i.e. o/p).

The current flowing out of solar cell is given as

$$I_{ph} = I_d + I$$

$$I = I_{ph} - I_d$$

$$= I_{ph} - I_0 \left(e^{\frac{qV}{kT}} - 1 \right)$$

I_{ph} = photon current at a given irradiance

I_0 = Dark / Reverse saturation current of the diode

q = charge of an electron ($1.602 \times 10^{-19} \text{ C}$)

k = Boltzmann's Constant = $1.381 \times 10^{-23} \text{ J/K}$

T = Diode Junction Temperature in kelvins.

α = Diode Ideality factor

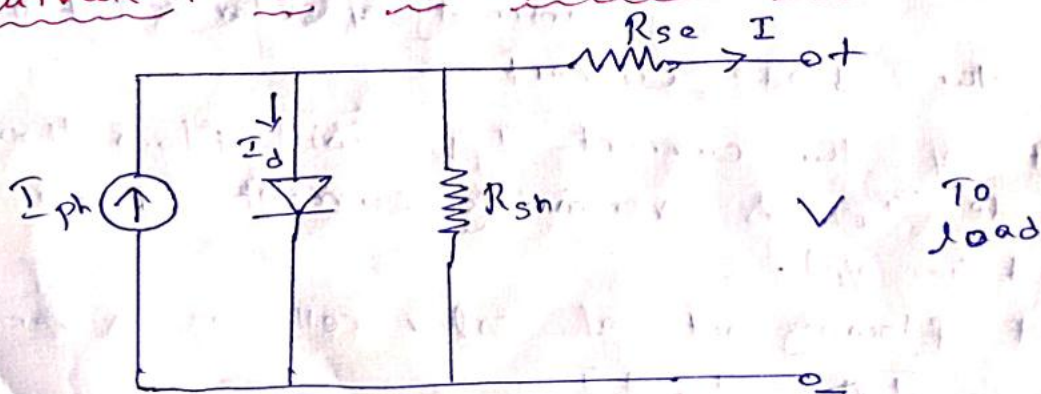
V = voltage across the diode.

Why it is called a Dark current?

When there is no solar radiation i.e. under dark condition i.e. $I_{ph} = 0$.

Under this condition, this diode will be reverse biased the current flowing through the diode will be reverse Saturation current I_0 . That's why I_0 is also called as dark current.

Equivalent ckt of practical solar cell



All solar cells are not ideal solar cells.

Practically we should have some losses in the solar cell.

So in order to account for all these losses we have to include the resistances in the equivalent circuit of practical solar cell.

In the equivalent ckt we have R_{se} & R_{sh} .

Now let us see how these R_{se} & R_{sh} arises from where.

$R_{se} \rightarrow$ series resistance due to combined resistances of contacts, metal grids & p & n layers.

$R_{sh} \rightarrow$ shunt resistance due to leakage current through the p-n junction (or) depletion layer.

In order to represent this leakage current, a shunt resistor is added.

The current flowing through that of the solar

cell is given as

$R_{sh} \rightarrow$ should have high value

$R_{se} \rightarrow$ should have low value

$$I_{ph} = I_d + I_{Rsh} + I$$

$$I = I_{ph} - I_d - I_{Rsh}$$

$$I = I_{ph} - I_0 \left(e^{\frac{q(V + IR_{se})}{kT}} - 1 \right) - \frac{V + IR_{se}}{R_{sh}}$$

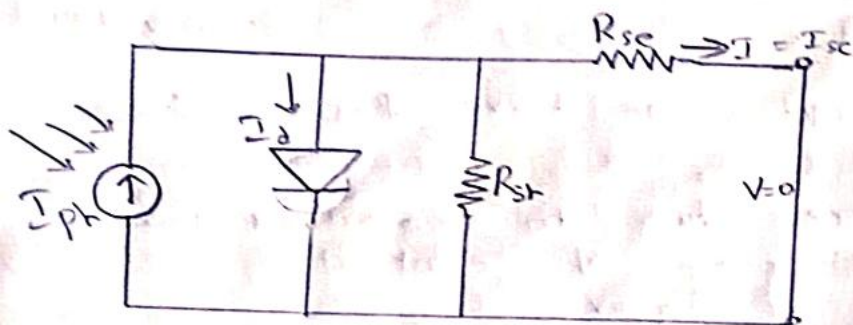
As we know the construction of p-n junction in a solar cell, we know there are metallic contacts b/w p-layer & n-layer.

& also p-layer & n-layer also have some resistances to the flow of current. All these combined together & they are represented as R_{se} .

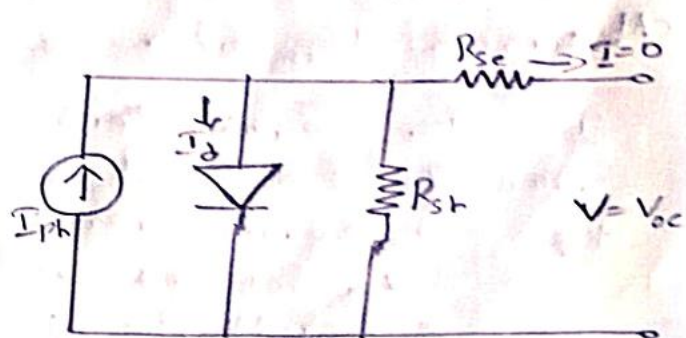
Electrical characteristics of a solar cell

Here we will have two characteristics

- (i) $I - V$ characteristics
- (ii) $P - V$ characteristics.



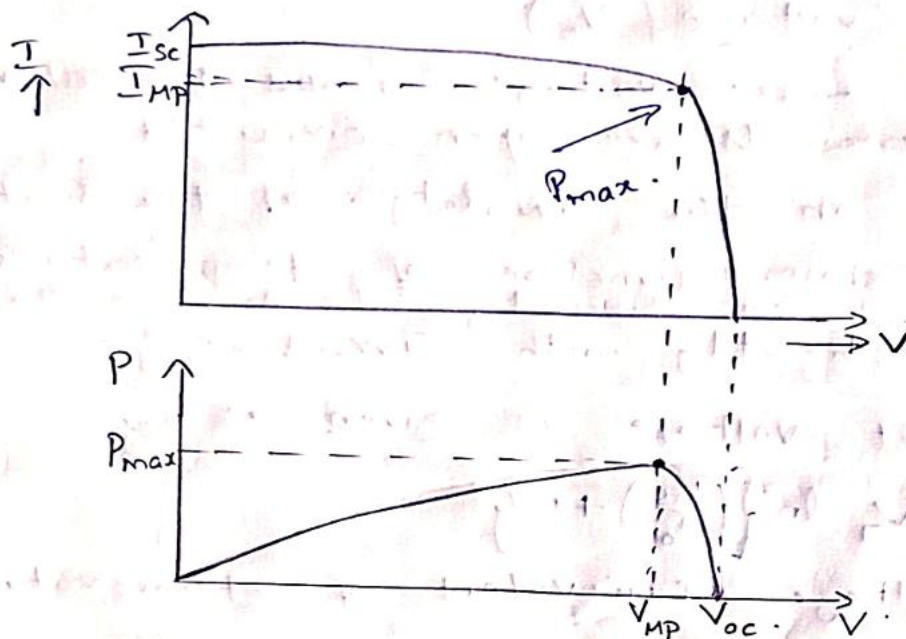
short circuit.



open circuit

The Electrical characteristics of PV cell & module are crucial for understanding their performance & how they convert sunlight into electricity.

- These characteristics include
- (i) short circuit current (I_{sc})
 - (ii) open circuit voltage (V_{oc})
 - (iii) Fill factor
 - (iv) maximum power point (Mpp)
 - (v) efficiency.



Both characteristics drawn against voltage on x-axis.
Under s.c, $V=0$

$$I \rightarrow \text{max.} = I_{sc}$$

Under o.c, $I=0$

$$V \rightarrow \text{max.} = V_{oc}$$

$$W \cdot 10^{-3}$$

$$P = VI$$

(1) Short circuit current I_{sc}

→ This is the max-current obtained from a solar cell when the terminals are short circuited.

→ I_{sc} depends on:
(i) solar irradiance level
(ii) Area of the solar cell
(iii) characteristics of the material

→ I_{sc} varies linearly with irradiance level.

ie., $I_{sc} \propto$ to the solar irradiance level
ie., I_{ph} .

→ Variation of I_{sc} with temperature can be neglected.

I_{sc} depends on temp. of the solar cell but it varies slightly that's why can be neglected.

(2) open circuit voltage (V_{oc})

- This is the max. voltage across the solar cell when the terminals are open circuited.
- V_{oc} depends on the quality of the ^{materially used} ~~for making solar cell~~.
- V_{oc} is a strong function of temperature. Higher cell temperatures typically decrease the V_{oc} .
- It varies slightly with Irradiance.
- open circuit voltage is given as:

$$V_{oc} = V_T \ln \left\{ \left(\frac{I_{sc}}{I_0} \right) + 1 \right\}$$

V_T → voltage equivalent of temperature.

(3) Fill factor :- It is the ratio of max. power generated by a solar cell to the product of open circuit voltage & short circuit current.

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}}$$

- Fill factor determines the quality of the solar cell. & If the fill factor is nearer to 1 then the more power the solar cell can provide.
- Typical values of Fill factor b/n 0.7 & 0.8.

(4) Efficiency :- The efficiency of a PV cell or array is the ratio of the max. electrical power that the cell or array can produce to the amount of solar irradiance incidence on the cell or array.

$$\eta = \frac{o/p}{i/p} = \frac{V_{mp} I_{mp}}{P_{sun}}$$

→ The efficiency of a typical solar cell is normally low at around 10-12% depending on the type of cells being used.

(5) Maximum power point (MPP) :- This is the point on the current-voltage ~~current~~ ^{curve} where the product of voltage & current is maximized. i.e. V_{mp} & I_{mp} .

Understanding these electrical characteristics is essential for designing, installing & maintaining PV systems to ensure optimal performance & energy generation.

PV systems for remote power :-

Off-grid PV systems are ideal for providing power to remote locations where grid connection is unavailable.

These systems rely on solar panels, charge controllers, batteries & inverters to generate, store & distribute electricity.

They are sustainable & reliable solution for powering homes, businesses & various applications in areas lacking grid access.

Components of an off-grid PV system.

Solar panels :- capture sunlight & convert it into direct current (DC) electricity.

Charge controller :- Regulates the flow of electricity from the solar panels to the batteries, preventing overcharging & damage.

Batteries :- Store the electrical energy generated by the solar panels for use when sunlight is unavailable.

Inverter :- Converts the DC electricity stored in the batteries into alternating current (AC) electricity, which is compatible with most household appliances.

Mounting Systems :- provides a secure & stable platform for the solar panels, often designed to withstand various weather conditions.

cables & wiring :- connects all the components & ensures safe & efficient power transmission.

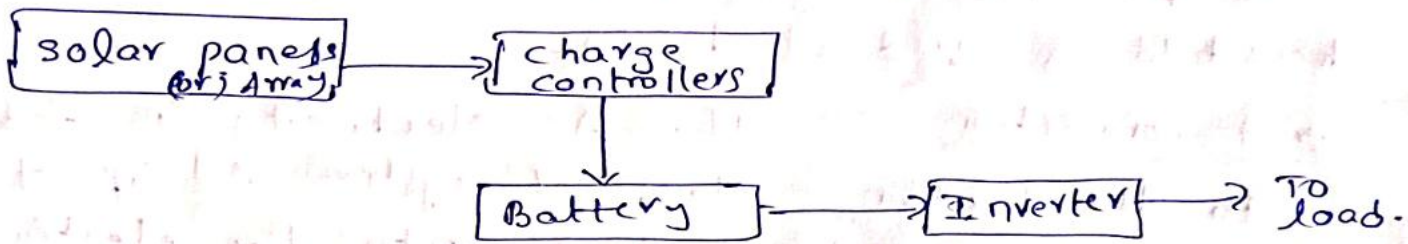
Advantages of off-grid PV systems :

- (i) Reliable power in Remote Areas.
- (ii) Reduced Reliance on Fossil fuels.
- (iii) Emergency Backup power.

Considerations for Remote PV systems

- (i) Sunshine Availability :- The amount of available ~~sun~~ sunlight is a crucial factor in determining the size & capacity of the system.
- (ii) Load Requirements :- Accurate calculation of power consumption (lighting, appliances etc) is essential for proper system sizing.
- (iii) Battery capacity :- Adequate battery storage is needed to ensure power availability during periods of low sunlight or high demand.
- (iv) Regular Maintenance :- Regular Maintenance of solar panels, batteries & other components is crucial for optimal performance & longevity.

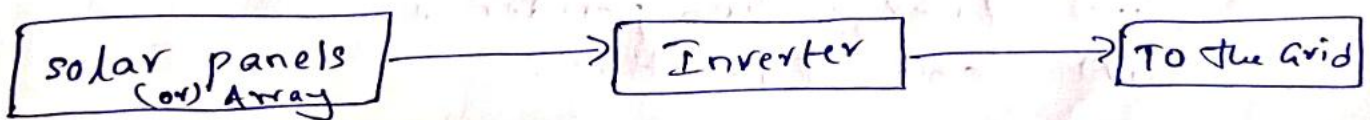
Remote Monitoring! - Remote monitoring systems can help track performance, identify potential issues & optimize system efficiency.



Grid connected PV systems

A grid connected PV system, also known as grid-tied or on-grid solar system, is a renewable energy system that uses solar panels to generate electricity & is connected to the main electrical grid.

This allows excess electricity generated by the solar panels to be fed back into the grid, while also providing a backup power source when solar generation is insufficient.



Components of Grid Connected PV Systems

Solar Panels :- Solar panels capture sunlight & convert it into ~~sola~~ direct current (DC) electricity.

Inverter :- The DC electricity is then converted into AC electricity, which is compatible with household & grid electricity.

Grid connection :- The AC electricity is fed into the building's electrical system & if there is excess production, back into the electrical grid.

Net Metering :- A bidirectional meter tracks the electricity flow, allowing homeowners to receive credit for the excess electricity they send to the grid.

Back up power :- When solar generation is low (eg. at night or on cloudy days), the building draws electricity from the grid.

Benefits :-

- (i) Reduced Electricity Bills
- (ii) Environmental Sustainability
- (iii) Energy Independence
- (iv) Cost Effective.

UNIT - III

①

Wind Energy

Wind results from air in motion.

→ Solar energy is responsible for wind because the sun heats the Earth's surface unevenly, causing differences in air temperature & pressure.

[ie, wind energy is indirect form of solar energy]
[wind is caused by the solar energy irradiating the earth.
That's why wind utilization is considered a part of solar technology]

→ Warm air rises in low pressure areas, while cooler, denser air decreases in high pressure areas. This pressure difference creates the movement of air, known as wind, as air flows from high pressure to low pressure zone.
(ie, air circulates from cold to warm areas producing winds)

→ Sun heats the Earth's surface unevenly & it is very clear that land & water ~~with~~ has ~~their~~ unequal solar absorptivities & thermal time constants.

→ During day light the land heats up rapidly compared to nearby sea or water bodies, & there tends to be a surface wind flow from ~~the~~ the water to the land.

At night the wind reverses, because the land surface cools faster than the water. (ie, wind flow from land to water).

Local winds :- Local winds are caused by two mechanisms.

The first mechanism of local winds is caused by land & water.

During the day,
→ The land mass becomes hotter than the water, which causes the air above the land to heat up & become warmer than the air above water.

→ The warmer lighter air above the land rises, & the cooler heavier air above the water decreases. This pressure difference creates the movement of air, known as wind & it flows from cold areas to warm areas.

→ At night, the direction of wind reverses because the land mass cools more rapidly than the water.

The second mechanism of local winds is caused by hills & mountain sides.

→ The air above the slopes heats up during the day & cools down at night, more rapidly than the air above the low lands.

This causes the heated air ~~the~~ flows along the slopes in daytime & relatively cool heavier air to flow down at night.

Basic principle of wind energy conversion

The circulation of air in the atmosphere is caused by the non-uniform heating of the Earth's surface by the sun.

That means, air circulates from cold to warm areas causing winds.

The factors which affect the circulation of air in the atmosphere are

- (i) Latitude of location
- (ii) Nature of cloud
- (iii) angle of the sun in the sky.

The principle of wind energy conversion is the transformation of the wind's kinetic energy into mechanical energy & then the mechanical energy is converted into electrical generated energy with the help of generator.

wherever the wind flows over the turbine blades, creating a pressure difference that causes blades to be moved. This rotational turbine blades are connected to the generator with the help of shaft. The generator converts mechanical energy that is then sent to the grid.

→ wind energy conversion devices are commonly known as wind turbines because they convert the energy of wind stream into energy of rotation.
 $K-E \rightarrow M-E$

→ wind turbines produce rotational motion, wind energy is readily converted into Electrical energy by connecting the turbines to an electric generator.
 $K-E \rightarrow M-E$ $M-E \rightarrow E-E$
combination of wind turbine & generator is

Sometimes referred to as an Aerogenerator.

→ Windmills have been used for more than a dozen centuries for grinding grains & pumping water, later they are used for Electric power generation.

In India the interest in the windmills was shown in the last fifties & early sixties. Later some new designs were also developed but it was not sustained.

An important reason for this lack of interest in wind energy must be that wind, in India are relatively low & vary appreciably with the seasons.

According to Data quoted by some scientists that in India wind speed value lies b/n 5 km/hr to $15-20 \text{ km/hr}$. These low & seasonal winds implies a high cost of wind power generation & distribution.

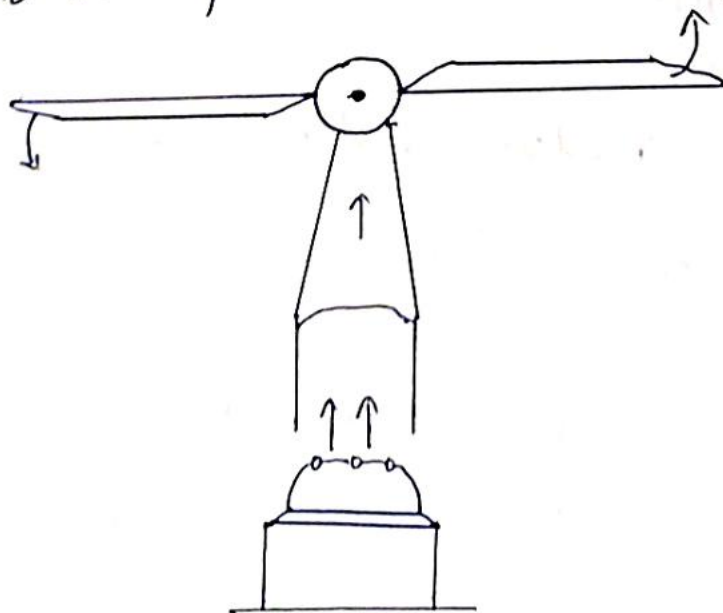
Role and Potential of Wind Energy

(3)

Winds are essentially caused by uneven falling of sun's radiation on the earth's atmosphere. They carry enormous quantity of energy. In early days wind mills has been used to sail vessels, pumping water, grind wheat & corn etc. This kind of power generation is advantageous due to it is plentiful, inexhaustible, renewable, non-polluting etc. operating cost of WECS is negligible & no harm to the atmosphere.

→ The K.E of the wind available per second is $0.5 \rho V^3$, where ρ is air density in kg/m^3
 V is the wind velocity in m/sec

Hence it is clear that the output power of a wind mill varies as the cube of the wind velocity. So, the wind mill produces max. power at high velocity.



The fig. shows the wind turbine run due to wind, coupled to alternator. The hollow blades of about 25 metre diameter are arranged on a tower.

The air passes through the hollow blade ends & due to centrifugal forces the blades rotate.

As ^{Air} passes continuously into the tower, it drives the wind turbine & thus generates electrical energy. For the speed of 40-80 kmph & an o/p of 100kw can be obtained.

Site selection

K.E of the wind $\propto \rho V^3$

✓ Suitable studies are carried out for deciding the location for the wind energy conversion system (WECS).
air density $\downarrow$ Wind velocity $\downarrow$

Four types of sites are considered suitable.

- (i) Plane land sites
- (ii) Hill top sites
- (iii) Sea-shore sites
- (iv) Off-shore shallow water sites

The main considerations in selection of site for WECS are based on its technical feasibility, economics, social environment & other considerations. Some of the important criteria for selection of site are

- (1) Located where the high average wind velocities available are in the range of 6 m/s to 30 m/s, since power developed is proportional to cube of wind velocity.
- (2) The WECS must be located far away from cities & forests since the buildings & forests offer resistance to the air movement. There should be no tall structures in 3 km radius from the installation.
- (3) The wind farms are located in flat open areas, deserts, sea shores & off shores site, since wind velocities are high in these locations.
- (4) wind velocities must be measured by Anemometer at several heights from the ground.
The velocity of wind increases with height $[C \propto H^{1/4}]$
Applicable in the range of 50 m to 250 m height.
- (5) Historical data of wind speed must be collected to select the site needed for installation of wind farms.
- (6) Ground surface should have high soil strength to reduce the cost of installation foundation.
- (7) Approach roads to the installation need to be constructed.

- (8) If small trees exist at a particular location, then it would need to increase the height of tower since any obstructions reduce the wind velocity. It causes the increase in cost of installation.
- (9) It should be installed away from localities so that the sound pollution caused by wind mills does not affect the inhabitants in near areas.
- (10) It should have low land cost & be near the consumers, to reduce the total cost of installation & reduce the transmission losses.
- (11) The minimum wind speeds at the selected site must be higher than 3.5 to 4.5 m/s, which is the lower limit at which the present wind energy conversion system (WECS) starts turning. It is called cut-in speed. Up to this speed no power will be generated by the system.

max. velocity of wind for the safe rotation of blades is 25 m/s.

And it is also called as cutout speed.

Max speed of blades after that the blades will not rotate.

Basic components of a wind energy conversion system. ⁽⁵⁾

The main components of WECS as shown in fig.

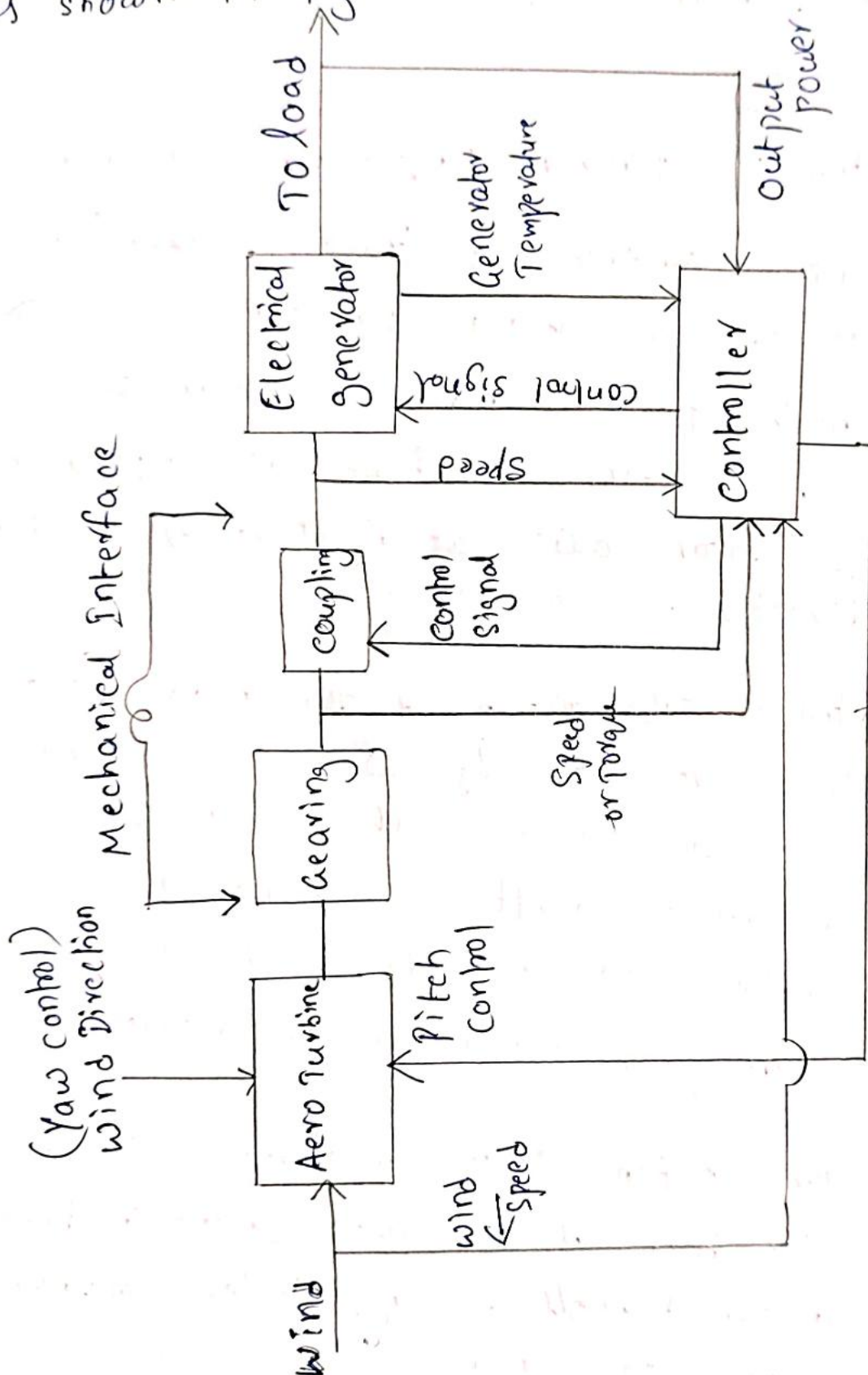


Fig:- Basic components of a wind energy conversion system.

Aero turbine :- convert kinetic energy of wind into mechanical energy.

The turbine shaft speed is stepped up with the help of gears.

Yaw control :- provide proper face in direction of wind.

Yaw control continuously tracks & keeps the rotor axis in the wind direction.

During high speed wind, i.e., more than cut-out speed, the machine is stopped by turning the rotor axis at right angles to the wind direction. [As the wind direction changes, a motor rotates the turbine slowly about the vertical axis so as to face the blades into the wind.]

Pitch control :- The pitch of the blade (0° to 30°) is controlled automatically so as to provide the feathering action. Thereby the power & speed of the wind turbine shaft is adjusted to match the generator speed & its electrical output i.e., find turning of speed is incorporated by pitch control.

The pitch control mechanism is provided through the hub of the rotor using hydraulic jack in the nacelle. The controller continuously adjusts the pitch to obtain the optimum performance.

Coupling:- It connects the gear shaft with the generator shaft.

Electrical generator:- It converts ME into EE & the electrical energy is given to the load or to the utility grid.

Controller:- The purpose of controller is to

- sense the wind speed, wind direction, shaft speeds & torques at one or more points,
- senses the output power & generator temperature

and appropriate control signals for matching the electrical output to the wind energy i/p & protect the system from extreme conditions brought upon by strong winds electrical faults.

Modern wind energy conversion systems are more correctly referred to as 'WECS', 'Aero generators', 'wind turbine generators' or simply 'wind turbines'.

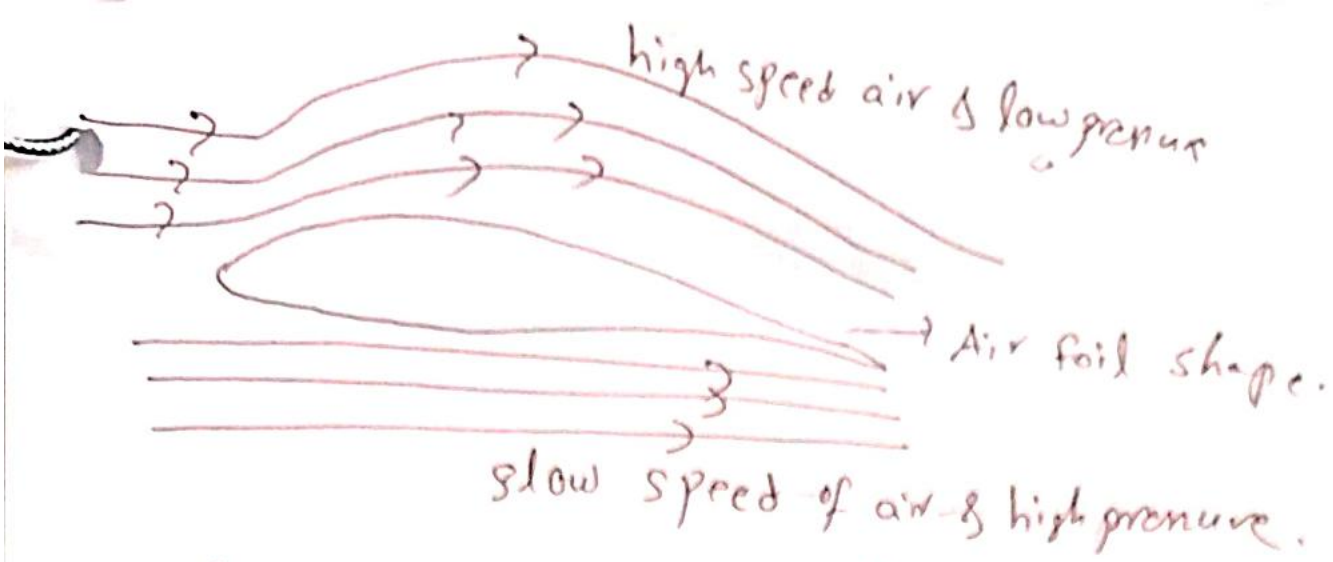
In the small turbines, Yaw action is controlled by a tail vane.

Anemometer is placed at tail vane & that meter measures the wind velocity & the information is passed to the controller.

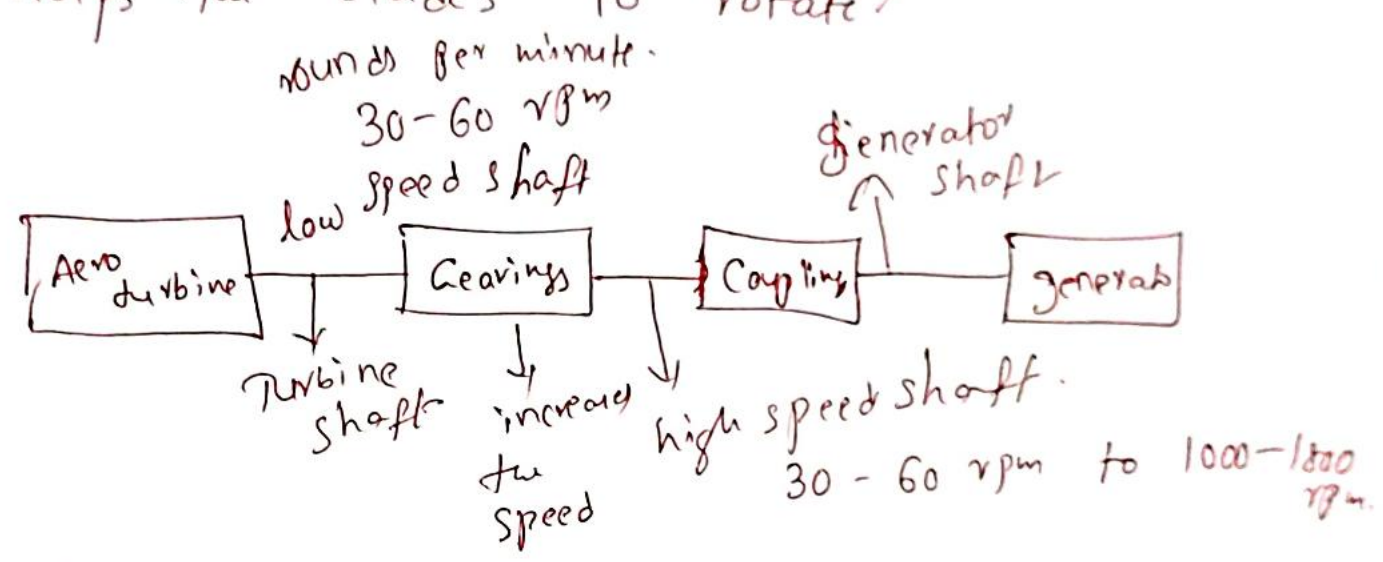
The controller sends the signal to Yaw control to change the direction of wind turbine blade to that of the wind direction.

If the wind speed is 8-16 miles per hour then the turbine blades start to rotate.

If the wind speed is 55 miles per hour, using the Electrical or Mechanical brakes the turbine blades will stop to rotate in order to avoid the damage of blades.



Whenever wind flows from high pressure to low pressure there exists a lift force & it will helps the blades to rotate.



Generator can produce the o/p power when it is rotates at a speed of minimum 1000 rpm.

~~1000 rpm~~
Anemometer measures & calculate the wind velocity.

8-16 miles per hour
wind turbine blades can rotate.

55 miles per hour
↓
blades can't rotate i.e. using the electrical or mechanical brakes the blades will stop to rotate.

The physical embodiment of an Aew generator

The sub components of the wind mill are

- wind turbine or rotor
- will mill head
- Transmission & control
- supporting structure.

Rotors :- Rotors are mainly of two types.

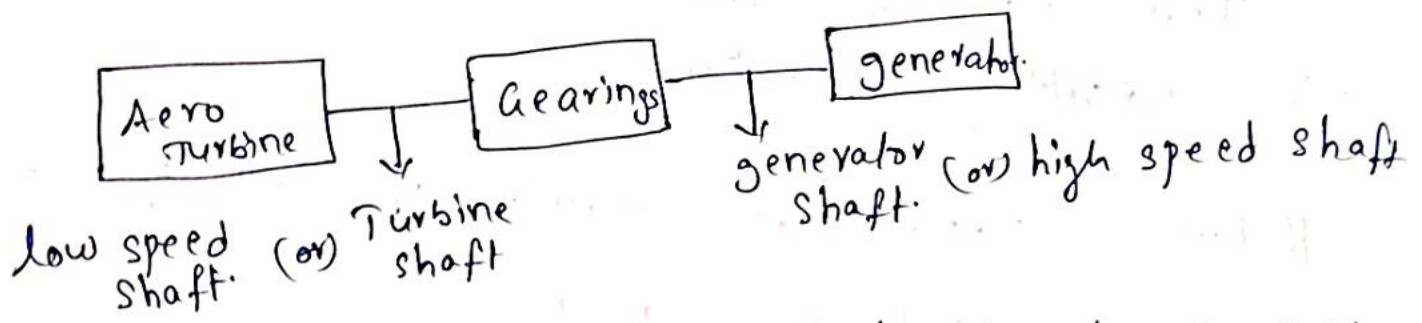
- (i) Horizontal Axis rotor
- (ii) Vertical Axis rotor

One of the advantage of vertical axis machines is that they operate in all wind directions & thus need no yaw adjustment.

The rotor is only one of the important components. For an effective utilization, all the components need to be properly designed & matched with the rest of the components.

The wind mill head It supports the rotor, housing the rotor bearings. It also houses any control mechanism incorporated like changing the Pitch of the blades & tail vane to orient the rotor to face the wind.

Transmissions The rate of rotation of large wind turbines generators operated at rated capacity is it is conveniently controlled by varying the pitch of the rotor blades but it is low about 30 to 50 rpm.



The turbine shaft is rotated at 40 to 50 rpm. But this rpm is not sufficient to the generator to generate the output power. The generator can able to produce the o/p power at a speed of 1000 - 1800 rpm. So it is necessary to increase the speed of generator shaft.

So Fixed Ratio Gears are recommended for top mounted equipment because of their high efficiency.

For bottom mounted equipment which requires large diameter bearings with ring gears to increase the turbine shaft speed to generator shaft speed.

(8)

Generator :- Either constant or variable speed generators are a possibility but variable speed units are expensive.

Among constant speed generators, synchronous induction & permanent magnet types are used.

Controls :- The controllers can perform the following functions.

- (1) The orientation of the rotor into the wind.
- (2) startup & cut-in of the equipment.
- (3) power control of the rotor by varying the pitch of the blades.
- (4) generator output monitoring
- (5) shut-down & cutout ~~referring~~ to very high winds
- (6) protection for the generator.

To

Towers:- Four types of supporting towers deserve consideration. These are

- (i) the reinforced concrete tower
- (ii) the pole tower
- (iii) the built up shell tube tower
- (iv) the truss tower.

Among all these the truss tower is favoured because it is widely used, cost is low, parts are readily available & transported & also it is potentially stiff.

→ shell tube towers also have attractive features & may prove to be competitive with truss towers.

The minimum tower height for a small WECs is about 10 m & the max. practical height ~~for a~~ is estimated to be about 60 m.

Classification of wind turbines & generation.

(A) Wind turbines are classified as follows.

(1) The orientation of the axis of rotation of rotor.

- (a) Horizontal Axis wind mills
- (b) Vertical Axis wind mills.

(2) Aerodynamic principle used

- (a) Lift type wind mills
- (b) Drag type wind mills.

(3) Types of rotors used in turbine.

- (a) Multiblade rotor (Horizontal axis)
- (b) propeller rotor (Horizontal axis)
- (c) Savonius rotor (Vertical axis)
- (d) Darrieus rotor (" ").

(4) Based on speed

- (a) slow speed
- (b) high speed

(B) The ~~real~~ classification is also based on generation output.

(C) Size of machines.

- (a) small scale upto 2 kw size.
- (b) Medium " b/n 2 & 100 kw size
- (c) Large scale 100 kw & above size.

(2) Type of o/p

- (a) DC o/p
- (b) AC o/p. $\rightarrow \begin{pmatrix} (i) \\ (ii) \end{pmatrix}$

- (i) Variable frequency, variable or constant
(ii) constant frequency, " " voltage.

(3) Rotational speed of the aeroturbine

- (a) constant speed with variable pitch blades
(synchronous generator with constant frequency ω_g)
(b) nearly constant speed with fixed blades (induction generator)
(c) variable speed with fixed pitch blades.

(4) Utilization point of view.

- (a) Battery storage
(b) Direct connection to electro mechanical energy converter.
(c) Inter connection with electric utility grid.

Horizontal Axis wind mills :-

10

Wind mill components
Horizontal Axis wind mills may be propeller type or multibladed type as shown in fig. The orientation of the axis of their rotors are kept along the horizontal axis, which should be adjusted so that it is parallel to the direction of wind stream.

Most commonly used wind mills are propeller type with two or three blades for economical reasons. Though the two blade designs are more cost effective but it faces the difficulty of vibrations during orientation to wind direction called "Yaw control".

→ Three blades designs are otherwise preferable since its rotor is naturally balanced. These are used for power generation in low capacity of 15 kW upto 3 MW.

→ Blades of propeller type wind turbines are made of aerofoil section. The mills are mounted on the top of the tower. The rotational speeds of propeller type are in the range of 300-400 rpm, while the speeds of multiblade type wind mills are 60-80 rpm.

The material used for blades is glass fibre reinforced plastic.

→ Multiblade rotor consists of number of curved sheet metal blades with increasing chord length away from the centre. No. of blades used are 12 to 20, which are having their inner & outer ends fixed on to the respective rims. Diameter of rotors used generally varies from 2 m to 5 m.

Number of Blades : Wind turbines have been built with upto six propeller type blades. But two or three bladed propellers are most common.

A one bladed rotor with a balancing counter-weight, has some advantages, including lower weight & cost & simpler controls, over the multi-blade type.

However the starting requires high wind speeds, & vibration & other forces can be large.

Turbines with three blades have been used in several WEC machines in order to avoid vibrations experienced with one & two bladed rotors.

These vibrations are related to the turning of the rotor in order to face it into the wind. However the problem can be overcome by controlling the "Yaw rate". Because they are less cost to fabricate in large sizes & are capable of operating with a high tip-speed ratio.

The ratio of the speed of the rotor blade tips to the speed of the wind is called Tip-speed Ratio.

$$\text{Tip speed ratio (TSR)} = \frac{\text{Speed of Rotor blade tips}}{\text{speed of the wind}}$$
$$\text{TSR} = \frac{V_{\text{tip}}}{V}$$

Every Rotor has an optimum tip-speed ratio at which its max. efficiency is achieved.

High TSR means Faster a rotor runs with respect to wind speed.

High TSR needs less material & can have relatively slender blades.

However because it rotates at higher speeds, it requires slight angle of attack of the tip & a high lift drag ratio is essential to produce a driving torque.

∴ High speed low solidity wind rotors need good airfoils. (similar to those used for aircraft)

They must also be made with a good surface finish & the structural integrity necessary to withstand high rotational speeds.

For this reason, cost/m² of good, high speed rotors is often greater than the low speed rotors.

Blades Design:- Wind turbine blades have an air foil type & variable pitch.

They are slightly twisted from the outer tip to the root (where blade is attached to the hub), to reduce the tendency for the rotor to stall.

→ In a few devices, the blades had a 12 constant chords length.

However for better performance is obtained with blades that are narrower at the tip than at the root.

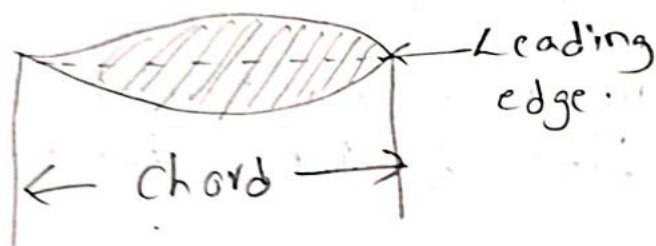


Fig (1)

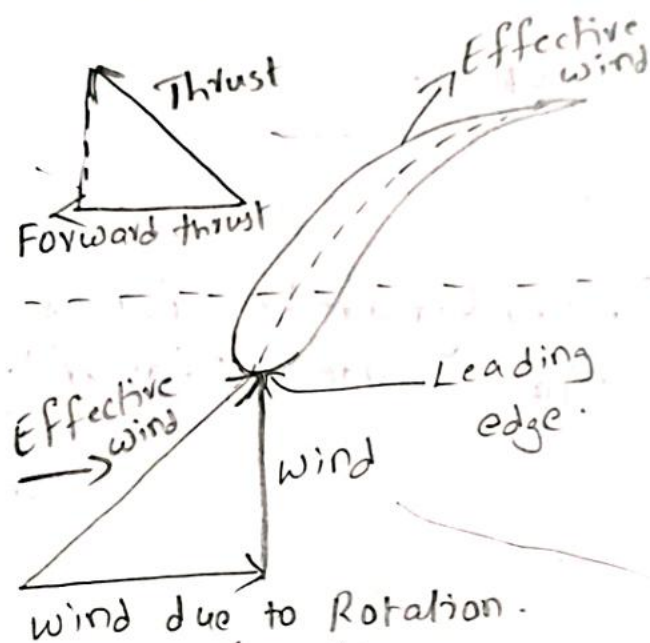


Fig (2)

The motion causing due to 'motion of wind' is the rotation of the blades.

At the tip of the blades of modern wind turbine the velocity is about six times the wind velocity.

A fundamental problem in wind turbine design is to allow for the many forces to which the blades are subjected during normal operation.

In addition to vibrational stresses resulting from rotation, there are some other forces

→ wind turbulence

→ directional changes in the wind

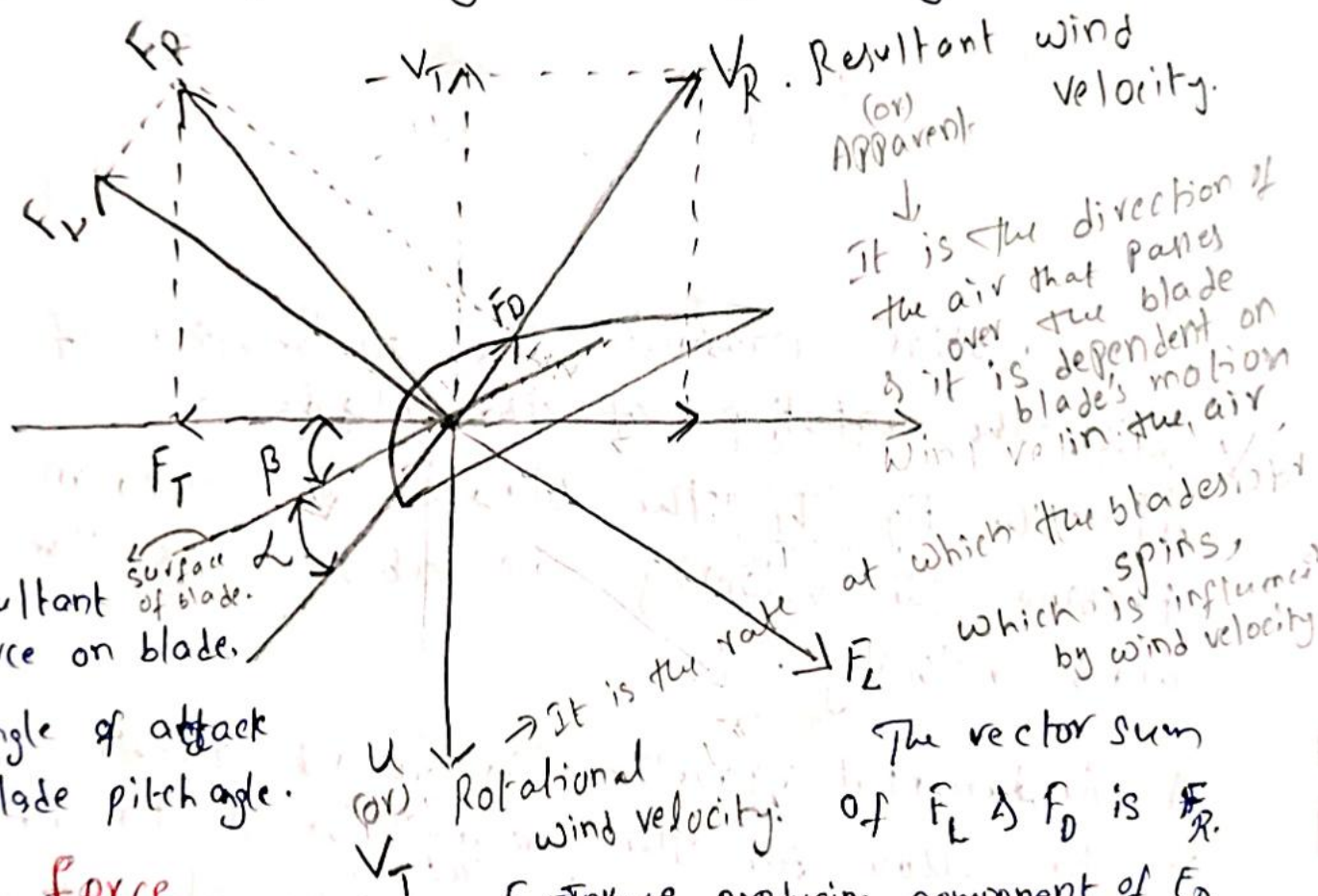
→ vibrations of wind speed with height

- gravitational forces,
- the pressure of the tower.

The blades are constructed & attached to the hub in such a manner as to withstand these forces.

Analysis of Aerodynamic forces acting on a Blade

Aerodynamic forces on a wind turbine Blade are primarily Lift & Drag forces.



where

F_R → Resultant force on blade.

α - angle of attack

β → Blade pitch angle.

Lift force

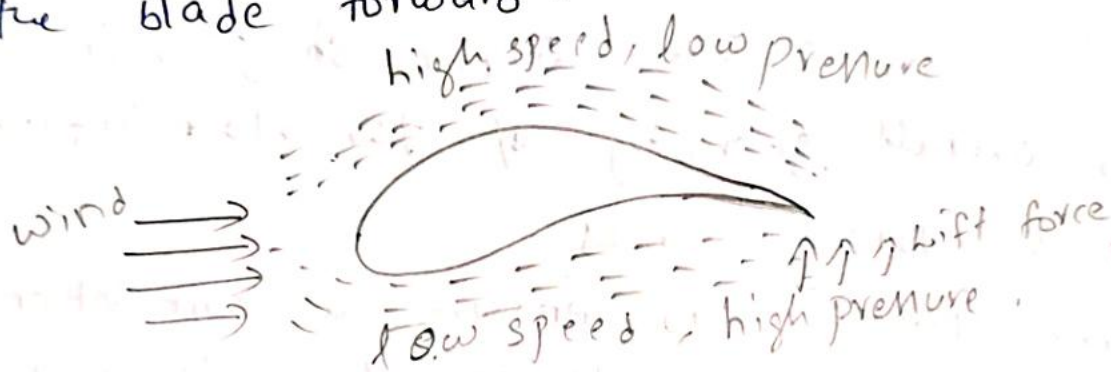
The Lift force is generated by the difference in air pressure as the wind flows over the air foil-shaped blade, similar to an Aeroplane wing.

Lift force acts perpendicular to the relative wind flow.

$F_T = F_{\text{torque}}$ producing component of F_R making aeroturbine rotate.

The dominant Lift force causes the rotor to spin & generate electricity.

It is created because the curved shape of the blade causes the air on one side to travel faster than the air on the other side, resulting in lower pressure on the curved side & higher pressure on the flat side, pushing the blade forward.



Drag force :- Drag force opposes the motion.

An opposing force that acts parallel to the relative wind flow. While it resists the blades motion & reduces efficiency.

It is a necessary component of the overall aerodynamic interaction that enables lift to function effectively.

The Resultant force on the blade is a vector sum of the lift & drag forces.

→ This resultant force has a component that creates torque, driving the turbines rotation.

→ This rotational motion is then used to spin the generator converting the mechanical energy into electrical energy.

Factors influencing the Forces:

Angle of Attack:- The angle b/n the (chord) blades surface & the Apparent wind. Designers carefully choose blade shapes to achieve a high Lift to Drag ratio, with the Ideal angle of attack for optimal performance.

Blades Design:- The airfoil shape, thickness, twist & overall geometry of the blade influence the lift & Drag forces.

Blades are twisted to ensure a consistent & optimal angle of attack along their length.

Tip - Speed Ratio:- The speed of the blade tip relative to the wind speed. This affects the apparent wind & thus the forces on the blade.

Thrust:- Thrust is the total aerodynamic force exerted by the wind on the rotor blades, acting axially along the axis of rotation. direction of the wing flow.

Gravitational force is the backward force.
Thrust is the forward force.
Lift is the upward "
Drag is " backward "

Introduction to HEV (Hybrid Electric Vehicle)

(14)

A proper balance of lift & drag is crucial for efficient operation.

Angle of attack is crucial for determining the lift & drag forces that makes the blades rotate & generate power.

→ Maintaining the AoA within a specific optimal range, often b/n 25° - 35° , for maximizing energy extraction.

This is achieved through the turbine's pitch control system that adjusts the blade's angle.

Lift force overcomes the gravitational force.
Thrust " " the Drag force.

Power in the wind: wind power energy (15)

by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller can extract part of the energy & convert it into useful work. Three factors determine the o/p from the wind energy ~~energy~~ converter.

- (i) wind speed
- (ii) the cross section of wind swept by rotor &
- (iii) the overall conversion efficiency of the rotor, transmission system & generator.

No device, however well designed, can extract all the wind's energy because the wind would have to be brought to a halt & this would prevent the passage of more air through the rotor.

→ A 100% efficient aerogenerator can able to convert around 60% of the available energy ^{in wind} into mechanical energy.

→ well designed blades will extract 70% of ~~the~~ the theoretical maximum, but losses incurred in the gearbox, transmission system & generator could decrease overall wind turbine η to 35% or less.

The wind mill works on the principle of converting kinetic energy into mechanical energy.

kinetic energy of the wind ($K.E$) = $\frac{1}{2} m v^2$

$m = \text{mass} - \text{kg.}$

$V = \text{velocity m/s.}$

Power in the wind is equal to energy per unit time.

$$P_{\text{wind}} = \frac{K.E}{t} = \frac{1}{2} \frac{m v^2}{t}$$



The amount of air passing in unit time, through an area 'A', with velocity 'V'

$$\text{then } m = \rho A V$$

$$\therefore P_{\text{wind}} = \frac{1}{2} \frac{m v^2}{t} = \frac{1}{2} \left(\frac{\rho A V}{t} \right) v^2$$

$$P_{\text{wind}} = \frac{1}{2} \rho A V^3$$

The area is normally circular of diameter 'D' in horizontal axis aeroturbines then $A = \pi r^2$

$$A = \frac{\pi}{4} D^2$$

$$\therefore r = \frac{D}{2}$$

$$K.E = \frac{1}{2} m v^2 = \frac{1}{2} \rho A V^3$$

$$= \frac{1}{2} \rho \frac{\pi}{4} D^2 v^3$$

Available wind power

$$K.E = \frac{1}{8} \rho \pi D^2 v^3$$

→ ①

It is clear that doubling the diameter of the

rotor will result in a four times increase in the available wind power. (16)

That's why the designer of an aeroturbine for wind electric use would place such great emphasis on the turbine diameter.

The fraction of the free flow wind power that can be extracted by a rotor is called power coefficient.

$$\text{Power coefficient} = \frac{\text{Power of wind rotor}}{\text{Power available in the wind.}}$$

It is clear from equ (1) the power available in the wind increases

→ as cube of the wind velocity

→ doubling the diameter of the turbine's rotor.

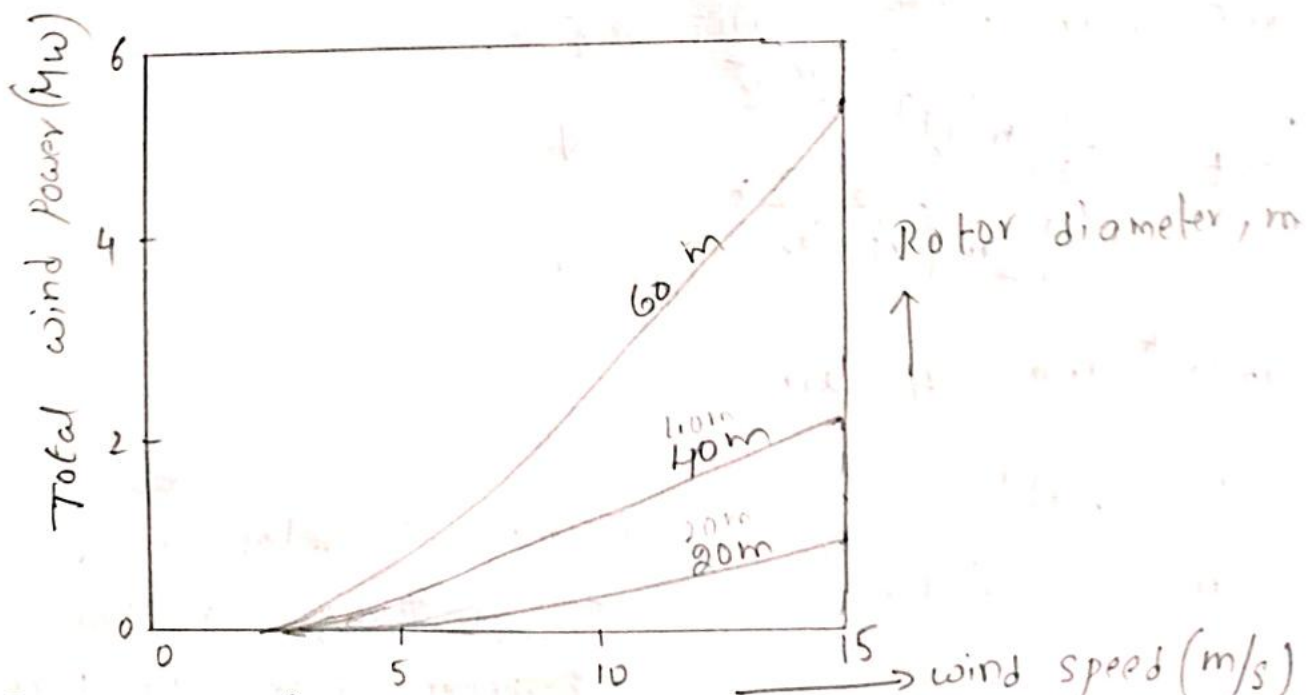


Fig. 1. Dependence of wind power on wind speed & rotor diameter.

Maximum Power :- The total power in the wind can't be converted Mechanical energy.

Let us consider a horizontal axis propeller-type windmill or wind turbine, which is the most common type used today.

Assume that the wheel of such a turbine has thickness ab as shown in fig.

Let P_i & V_i are the wind pressure & velocity at the upstream of the turbine

P_e & V_e are pressure & velocity at downstream of the turbine.

$$(V_e < V_i)$$

The wind velocity across the turbine decreases from a to b .

Since K.E is converted into

$$ME \text{ there } K.E_{out} = K_a - K_b$$

$$P_{out} = P_a - P_b = \frac{1}{2} m V_i^2 - \frac{1}{2} m V_e^2$$

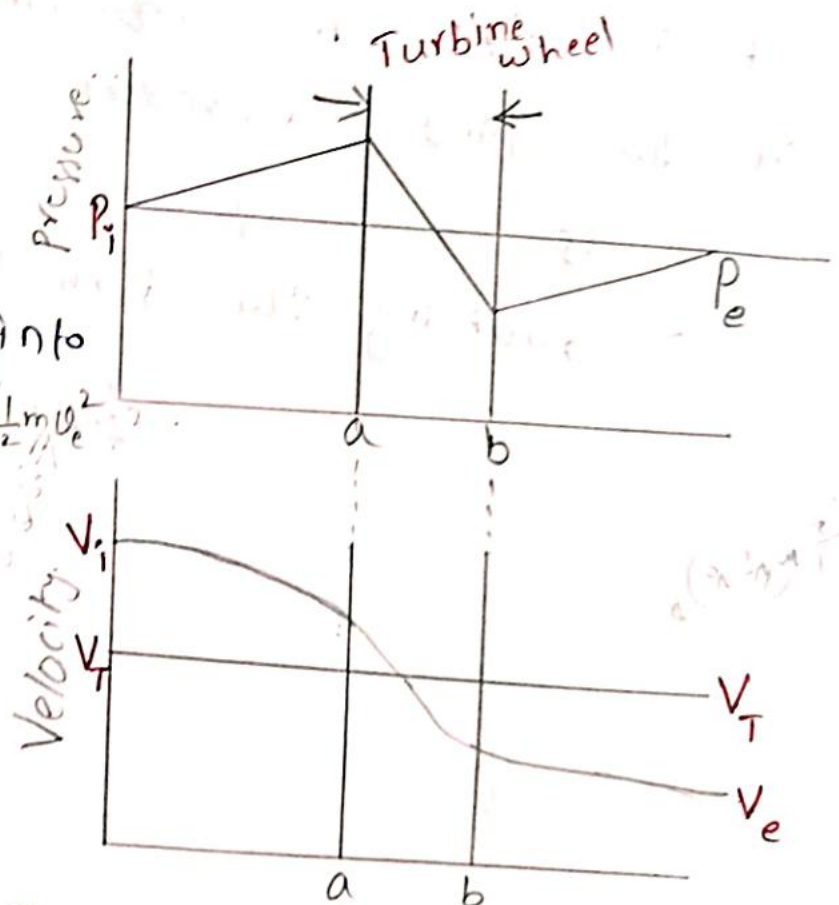
$$P_{out} = \frac{1}{2} m V^2$$

$$= \frac{1}{2} m (V_i^2 - V_e^2)$$

where m = mass of air

$$m = \rho A V$$

$$m = \rho A \left(\frac{V_i + V_e}{2} \right)$$



Pressure & velocity of wind flowing through a horizontal axis propeller-type wind turbine.

$$\begin{aligned} P_{out} &= \frac{1}{2} \rho A \left(\frac{V_i + V_e}{2} \right) (V_i^2 - V_e^2) \\ &= \frac{1}{4} \rho A (V_i + V_e)(V_i^2 - V_e^2) \\ &= \frac{1}{4} \rho A (V_i^3 - V_i V_e^2 + V_e V_i^2 - V_e^3) \\ &= \frac{1}{4} \rho A V_i^3 \left[1 - \frac{V_i V_e^2}{V_i^3} + \frac{V_e V_i^2}{V_i^3} - \frac{V_e^3}{V_i^3} \right] \end{aligned}$$

$$P_{out} = \frac{1}{4} \rho A V_i^3 \left[1 - \left(\frac{V_e}{V_i} \right)^2 + \frac{V_e}{V_i} - \left(\frac{V_e}{V_i} \right)^3 \right]$$

Let $\frac{V_e}{V_i} = x$ ∴ w.k.t Power of the wind $P_w = \frac{1}{2} \rho A V^3$

$$\begin{aligned} P_{out} &= \frac{P_w}{2} (1 - x^2 + x - x^3) \\ &= \frac{P_w}{2} (1 + x - x^2 - x^3) \end{aligned}$$

The maximum power output can be obtained

$$\frac{dP_{out}}{dx} = 0 \Rightarrow \frac{d}{dx} \left\{ \frac{P_w}{2} (1 + x - x^2 - x^3) \right\} = 0$$

$$\frac{d}{dx} (1 + x - x^2 - x^3) = 0$$

$$0 + 1 - 2x - 3x^2 = 0$$

$$3x^2 + 2x - 1 = 0$$

$$x = -1, \frac{1}{3}$$

characteristic equation

Max. power output can be obtained at $x = \frac{1}{3}$

$$(P_{out})_{max} = \frac{P_w}{2} \left[1 + \frac{1}{3} - \left(\frac{1}{3}\right)^2 - \left(\frac{1}{3}\right)^2 \right]$$

$$= \frac{16}{27} P_w$$

$$\frac{V_e}{V_i} = \frac{1}{3}$$

$$P_{out(max)} = 0.593 P_w$$

Power coefficient $C_p = \frac{\text{Power o/p from wind Machine}}{\text{Power available in wind}}$

$$C_p = 0.593$$

The factor 0.593 is known as the Betz Coefficient. It is the max. fraction of the power in a wind stream that can be extract.

20

433	453				
	450				Re 452
435	455				450
437	458				466
440	460		LE 430		462
441	462		428		
442	465		422		23
443	467				436
445	468				426
446	470				434
	420				
	421		427		
	424		437		
			440		

Design considerations of HAWT's

HAWT's stands for Horizontal axis wind Turbines, which are the most common type of wind turbines used for converting wind energy into Electrical energy.

These turbines have a horizontal axis of rotation, with a blades spinning ~~the~~ around a central hub.

The Design considerations are

- (1) Key components
- (2) Aerodynamic Design
- (3) Structural Design
- (4) Site considerations.

Key components

- (i) Rotor blades : The blades are airfoils that capture the energy from the wind & convert it into rotational energy. They are usually made of composite materials & come in various lengths, shapes & designs to optimize energy capture.
- (ii) Hub :- The hub connects the rotor blades to the main shaft, allowing them to rotate as a single unit.

It also houses the pitch control mechanism, which adjusts the angle of the blades to optimize power production.

(iii) Gearbox :- In most HAWT's, a gearbox is used to increase the rotational speed of the blades & transmit the power to the generator at higher speeds.

However, some modern designs use direct drive systems, eliminating the need for a gearbox.

(iv) Generator :- The generator converts the rotational energy of the blades into Electrical energy. It is usually located in the nacelle, which is the housing at top of the tower.

(2) Aerodynamic Design

(i) Blades profile & airfoil selection :- The Aerodynamic design of the rotor blades is crucial for efficient energy capture. Engineers carefully select airfoil shapes & blade profiles to optimize lift & minimize drag, which ultimately determines the turbines performance.

(ii) Lift & Drag considerations: The lift force⁽¹⁹⁾ is generated by the pressure diff b/n the upper & lower surfaces of the blades airfoil as wind flows over it. This lift force contributes to the rotation of the blades. Drag, on the other hand, is the resistance force experienced by the blades as they move through the air.

Engineers aim to maximize lift & minimize drag to improve overall turbine efficiency.

(iii) Wind tunnel testing: - Before constructing full-scale wind turbines, small scale models are tested in wind tunnels to evaluate their aerodynamic performance.

Wind tunnel testing helps identify potential design improvements & ensures that the final turbine design is efficient & stable under various wind conditions.

(3) Structural Design: -

(i) Material selection: - HAWTs are subjected to significant stresses & loads due to wind forces & their rotational nature. Engineers carefully choose materials, often composites or metals, that offer a balance of strength, weight & durability to withstand

these forces over the turbine's operational lifespan.

- (ii) stress & fatigue analysis - The structural components including the blades, hub, tower & supporting structures, undergo stress & fatigue analysis to ensure their integrity & safety during their operational life time. Continuous cyclic loading from wind forces requires a thorough analysis of potential fatigue failure to prevent unexpected damage.
- (iii) Tower design -

The tower provides support & elevation for the wind turbine components. The height of the tower is determined based on the wind conditions at the site & the desired power o/p. The tower's design must also account for factors like wind-induced vibrations & tower resonance.

(4) Site consideration.

- (i) wind speed & direction :- The success of a wind farm heavily depends on the wind resource at the site. Engineers perform detailed wind resource assessment to determine the average wind speed, duration & turbulence intensity. This data helps in optimizing the turbine layout & selecting appropriate turbine model.

Grid Integration: - Wind farms need to integrate with the existing electrical grid to deliver the electricity they generate.

Environmental Impact: - Before constructing wind farms, an environmental impact assessment is conducted to evaluate potential effects on local ecosystems, wildlife, & nearby communities. This assessment helps ensure that wind farms are developed responsibly, minimizing negative impacts on the environment.

Design considerations of VAWTs

VAWTs can capture wind from any direction & are often used in urban environments due to their compactness & lower height requirements.

Aerodynamic Design

(i) Blade shape & orientation: - Blade shape & orientation play a crucial role in the performance of VAWTs. Blade profiles need to be designed to efficiently convert wind energy into rotational motion.

(ii) Start up wind speed: VAWTs often require specific wind speeds to start turning, so the blade design must be optimized to achieve self-starting at the lowest possible wind speed.

(iii) Torque Ripple: Torque ripple refers to fluctuations in the torque during the turbine's operation, leading to vibrations. The design must consider smoothing the torque to reduce mechanical stress.

Structural Design

(i) Support structure: The support structure must be robust & lightweight to withstand wind forces & vibrations while minimizing material costs.

(ii) Durability & longevity: Designing for durability is key to ensuring a long lifespan as VAWTs are exposed to constant fatigue loading & environmental effects.

(iii) Material Innovation: New materials & manufacturing techniques can improve efficiency, reduce weight & enhance durability, offering opportunities for design optimization.

UNIT - IV

Geothermal Energy

Geothermal energy is the heat energy generated & stored inside the Earth.

It is a renewable energy source that comes from the Earth's core & can be used for Electricity generation, heating, & other application.

- The word Geothermal comes from the Greek word, geo (Earth) & thermal (heat).
- Geothermal Energy is a renewable & sustainable energy source derived from the Earth's natural ^{heat} (because the heat is continuously produced inside the ^{Earth}).
- Geothermal energy is a clean, renewable resource that can be harnessed for use as heat & electricity.
- Extraction of heat can be done by conventional method by natural or forced circulation of water. The generated steam from water can be used to rotate the turbine.
- ~~This heat~~ Geothermal energy is essentially the heat within the Earth.
- This heat is a result of the Earth's formation & the continuous radioactive decay of elements deep inside the Earth.

Heat generation within the earth is near about 2700 GW & it depends on Thermal properties of Earth's interior & movements of fluids or solid rocks & radio activity.

→ Heat generation depends on Thermal or Temperature gradient.

$$\text{Temperature gradient} = \frac{\text{heat flux}}{\text{Thermal conductivity}}.$$

→ A various processes help in partial melting of different plates on the surface of earth.

→ The Molten masses penetrate the surrounding rocks & rise towards earth at rates varying from few centimeter per day to per year, which results in volcanic activity.

The extraction of heat from earth's interior is done by heat exchanger. In many earth heat areas, natural or forced water circulating systems bring out this heat giving rise to hot springs.

Geothermal energy contained in the rocks & fluids beneath the earth's crust & can be found as far down to the earth's hot molten rock & magma.

Geothermal system consists of following sections.

- (i) At a depth, connecting Magma → very hot liquid rocks found below the earth's surface.
- (ii) Above magma, crystalline rocks.
- (iii) Above which, permeable rocks localised pockets.
- (iv) Localised pockets are bounded by fracture zones or faults with movements of rocks takes place.
- (v) circulation of water along fault lines, gets heated by permeable layer & due to conduction from connecting Magma.
- (vi) Hot water comes from another fault line & forms hot spring.

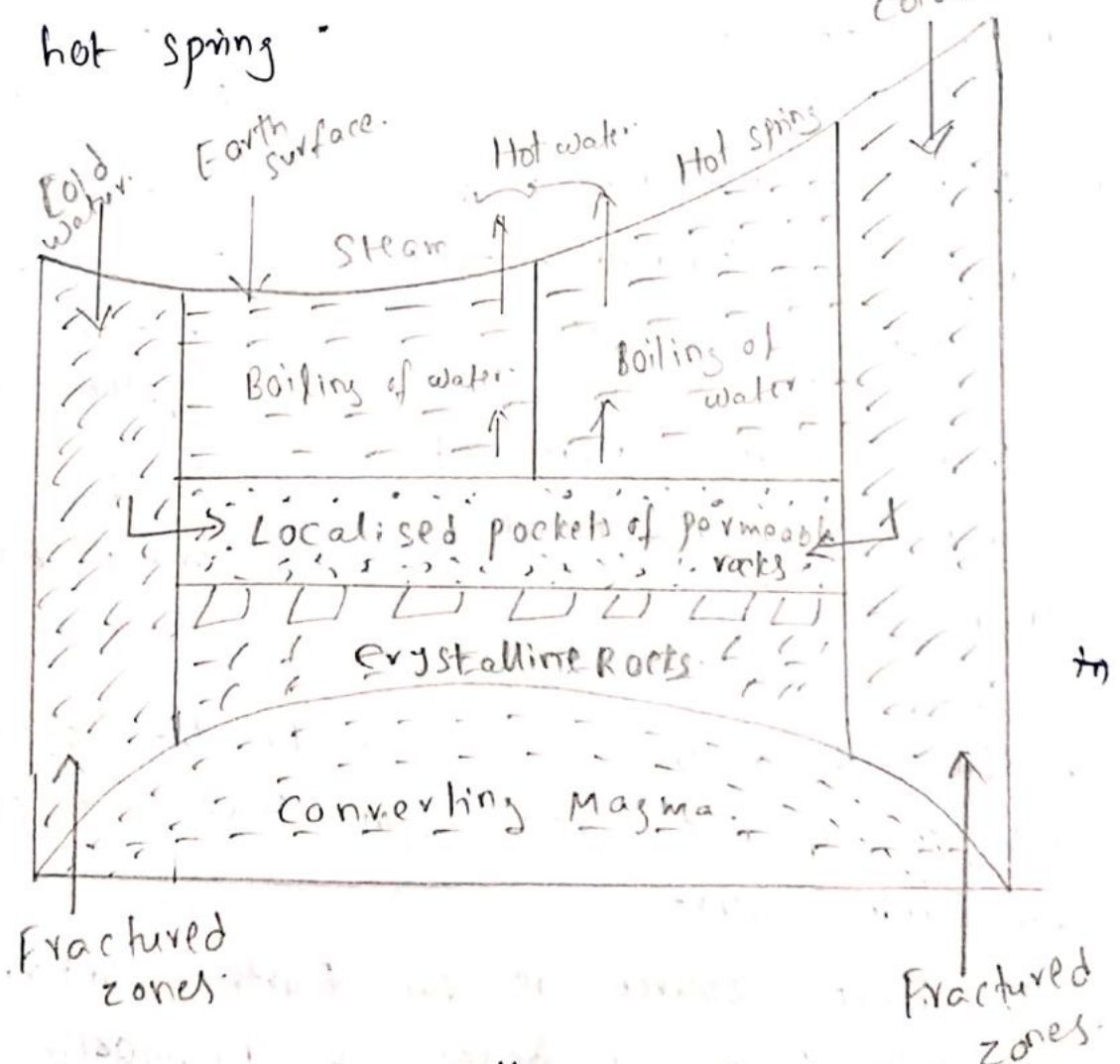


Fig:- Schematic representation of Geothermal System,

Advantages & Disadvantages of Geothermal Energy

Advantages

- (1) Geothermal energy is environmental friendly.
- (2) Geothermal energy is reliable source of renewable energy.
- (3) Geothermal systems have high efficiency.
- (4) There is no need of high maintainance for geothermal systems.
- (5) There is an unlimited supply of geothermal energy.

Disadvantages

- The extraction of geothermal energy causes greenhouse emissions.
- There is a possibility of depletion in geothermal sources.
- There is high cost investment needed for geothermal systems.
- It is very hard to implement or install geothermal systems in big cities.
- Geothermal reservoirs can't easily be found.

Geothermal resources are naturally occuring deposits of hot water &/or steam, trapped beneath the Earth's surface.

→ The heat source is the Earth's internal temp., primarily from the decay of radioactive materials & residual heat from the earth's formation.

Estimation of Geothermal power :- The estimation varies very widely. However the following give a rough estimate. For a depth of 3 kms, the total energy stored is approximately 8×10^{21} Joules.

→ For a depth of 10 kms, the total stored energy is estimated 4×10^{22} Joules.

→ The energy stored in the hot springs is about 10% of the above quantities.

→ If the above energy is extracted from 3 km depth with 1% thermal energy recovery factor at a uniform rate of over a 50 years period thermal energy power of 50 GW is obtained.

Nature of Geothermal Fields :- It is convenient to classify earth's surface into 3 broad groups.

- (i) non thermal areas having a temp. gradient of $10 - 40^\circ \text{C}$ per km depth.
- (ii) semi thermal areas having a temp gradient of 70°C per km. depth.
- (iii) Hyper-thermal areas where the temp. gradients are many times greater than in non-thermal areas.

Hyper thermal fields (or) areas are further classified into

Hyper thermal Fields

- (i) Wet fields : where the water is pressurized & temperatures are above 100°C . When they are led to the surface a fraction will be splashed into steam & a major part remains as the boiling water.
- (ii) Dry fields : They produce dry saturated steam or superheated steam at pressure above atmospheric.

Geothermal resources are most commonly found in areas with high geothermal activity, such as near tectonic plate boundaries, volcanoes & hot springs.

These areas can be identified by geological surveys, including temperature gradient measurements.

There are at least 7 types of geothermal resources. They are (i) Dry steam (ii) wet steam (iii) hot water (iv) Geopressure (v) Magma deposit (vi) Hot dry rocks & (vii) Volcanoes.

Depending on the temp. & depth of permeable rock, above first 3 are called Hydro thermal systems.

Geothermal Resources - Geothermal resources are the sources of heat derived from within the Earth's crust, primarily from the Earth's core & radioactive decay.

These resources can be tapped for various applications including electricity generation, heating & industrial processes.

Geothermal energy is considered a renewable energy source because the Earth's internal heat is constantly replenished.

Origin of Geothermal Energy:- The Earth's core is extremely hot, & this heat is constantly flowing outwards towards the surface. This heat is generated from the decay of radioactive elements within the Earth's core as well as from the Earth's formation.

Geothermal energy can be usefully extracted from four different types of geologic formations.

- (i) Hydrothermal
- (ii) Geopressurized
- (iii) Hot dry rock
- (iv) Magma

└─ Dry steam
└─ Wet steam
└─ Hot water

(i) Hydro thermal systems :- Hydrothermal systems in geothermal sources are natural systems where ^{heat} from the Earth's interior is transferred to circulating water, creating hot water or steam reservoirs. These systems are crucial for geothermal energy production as they provide the heat & water needed to generate electricity or for other uses.

(a) Dry steam :- The temp. of rock is very high. The whole water is get converted into steam. The steam is clean & easy to convert into Electrical energy.

The steam is collected from production well, filtered & passed through the steam turbines coupled to electric generators.

(b) Wet steam :- The temperature of permeable rock is not very high. By the time water comes out only a part of it gets converted into steam. Hence it gives a mixture of hot water & steam under high pressure. The steam is separated & expanded in turbines to generate electricity, & hot water for other purposes like removal of minerals, agricultural or municipal purposes, air conditioning & refrigeration, heating of buildings & industrial purposes.

It is a type of rock that allows fluids to pass through its fractures.

Even hot water can be used to generate electricity by transferring its heat to a secondary medium having boiling point lower than that of water & then expanding its vapour through vapour turbines.

(c) Hot water :- The temperature of permeable rock is rather low. Hot water gushing out from Earth's interior can be used to evaporate butane or from to run vapour turbines & thereby generate electricity. The temperature ranges from 50 to 80°C.

(ii) Hot Dry Rocks :- Hot dry rock (HDR) geothermal energy refers to the heat stored within the Earth's crust in hot, dry & impermeable rocks, typically found deep beneath the surface. This heat can be accessed by drilling wells into the rock, creating a fractured reservoir through hydraulic fracturing, & then circulating water through the fractures to extract the thermal energy.

This extracted heat can then be used to generate electricity or for other heating applications.

→ These rocks are typically found at depths of several kilometers & are heated by the Earth's internal temperature.

How it works

Reservoir creation :- Wells are drilled into the hot, dry rock formation. One well is used to inject cold water while another is used to extract the heated water.

Hydraulic fracturing :- Hydraulic fracturing is used to create a network of fractures in the rock, increasing its permeability & surface area for heat transfer.

This allows the injected water to circulate & absorb heat from the surrounding rock.

Heat Extraction :- The heated water is pumped to the surface & used to generate electricity in a power plant or for other applications like heating.

closed loop system :- The cooled water is then reinjected into the reservoir to repeat the process, creating a closed loop system.

(iii) Geopressurized system :- A geopressured geothermal system is a type of geothermal resource found in deep sedimentary basins where high pressure, hot water & dissolved methane gas are trapped beneath layers of Earth.

& industrial purposes.

→ These systems offer the potential to extract energy from three sources.

(i) Thermal energy of the hot water

(ii) the pressure of the fluid &

(iii) the methane gas.

The hot & high pressure hot water is brought to the surface & used to generate electricity.

The high pressure fluid itself can be used to drive turbines, providing mechanical energy for various applications.

The dissolved methane gas can be extracted & used as a fuel source, either directly or after processing.

(iv) Magma :- Molten rock under^{the} Earth's surface is called Magma. It is a mixture of molten or semi molten rock, along with dissolved gases & sometimes crystals, found beneath the Earth's crust. When Magma erupts on to the surface, typically volcanoes, it's then called Lava.

Magma, a source of intense heat deep within the Earth, plays a crucial role in geothermal energy resources.

Its molten rock formed in the Earth's mantle & lower crust, & its heat is transferred to surrounding rocks & underground water, creating geothermal reservoirs.

→ This heat is extracted through drilling & other methods, can then be used to generate electricity or provide direct heating.

Formation of Magma

→ Deep within the Earth, at depths around 150 kms, the temperature & pressure are high enough to melt rock into Magma.

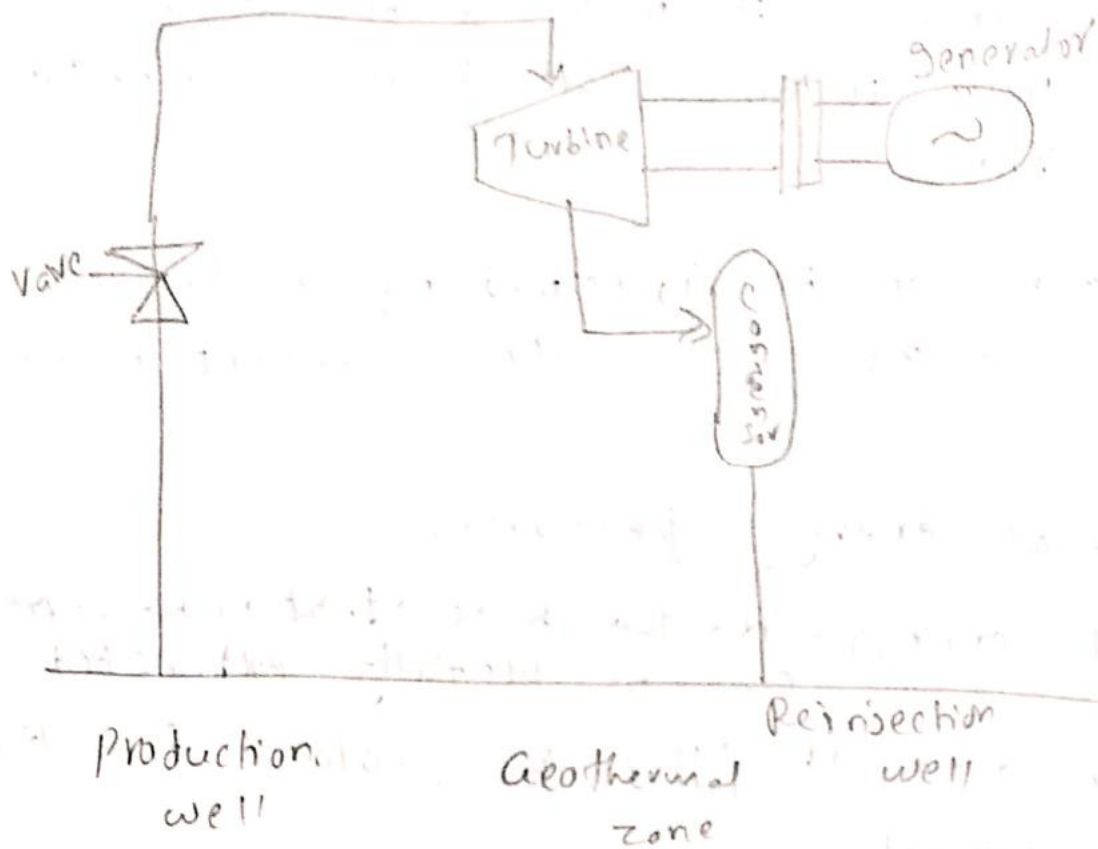
→ Magma is less dense than the surrounding solid rock, causing it to rise towards the Earth's surface.

→ Sometimes, Magma reaches the surface through volcanic eruptions, becoming Lava.

Finally, Magma acts as a natural heat reservoir, providing the foundation for geothermal energy extraction.

→ The heat from this molten rock is transferred to surrounding materials, creating usable geothermal resources that can be harnessed for various applications.

Schematic layout of Geothermal power plant



Geothermal power plants :- There are 3 types of Geothermal power plants to generate electricity.

- (i) Dry steam power plant
- (ii) Flash
- (iii) Binary cycle power plant

Dry steam geothermal power plant :-

A dry steam geothermal power plant uses naturally occurring underground steam to generate electricity. These plants utilize steam directly from geothermal reservoirs, which is then piped to a turbine to drive a generator, producing electricity. After turning the turbine, the steam is often condensed & returned to the earth.

The components associated with a dry steam geothermal power station include (i) vapour dominated reservoir (ii) production well (iii) Injection well (iv) steam turbine (v) AC generator.

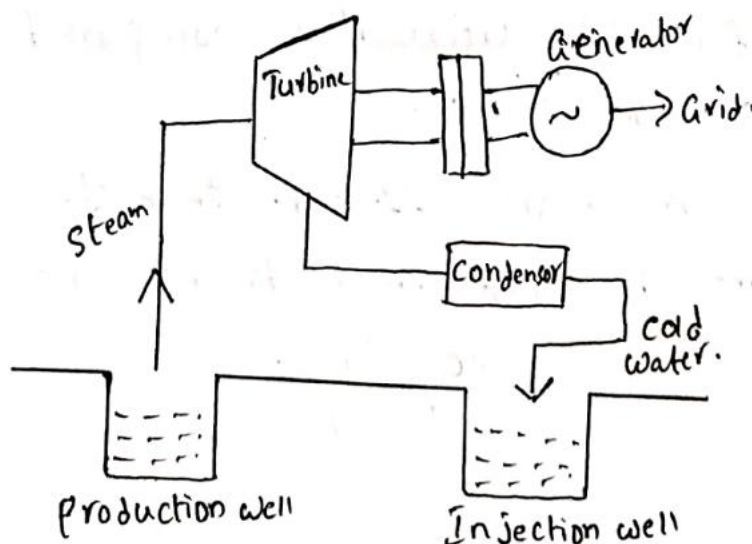


Fig:- Dry steam power plant

Detailed Explanation :-

- Dry steam is one of the geothermal resource that is naturally occurring from steam reservoirs deep underground.
 - Unlike other geothermal systems that use hot water, dry steam power plants utilize steam that is already in the gaseous state.
 - The steam is piped directly to a turbine, which spins a generator to produce electricity.
 - After the steam passes through the turbine, it is typically condensed back into water & then reinjected into the geothermal reservoir.
 - Dry steam power plants are the oldest type of geothermal power plant.
 - Dry steam geothermal resources are rare & only available in Italy & California.
- As this type of geothermal resource is rare, there is less potential for wide utilization compared to the other two types of plants.
- Dry steam plants are more efficient than the other two types of plant because they do not need to pump large volumes of geo fluid.
(steam)

Flash steam geothermal power plant :- A flash steam power plant is a type of geothermal power plant that uses high temperature, high pressure geothermal fluids to produce electricity.

The process involves reducing the pressure on the hot water, causing some of it to flash into steam, which then drives a turbine connected to a generator.

This method is commonly used when geothermal resources have temperatures above 182°C .

Flash also termed as wet steam power plant i.e. where a mixture of liquid water & steam is produced from the wells.

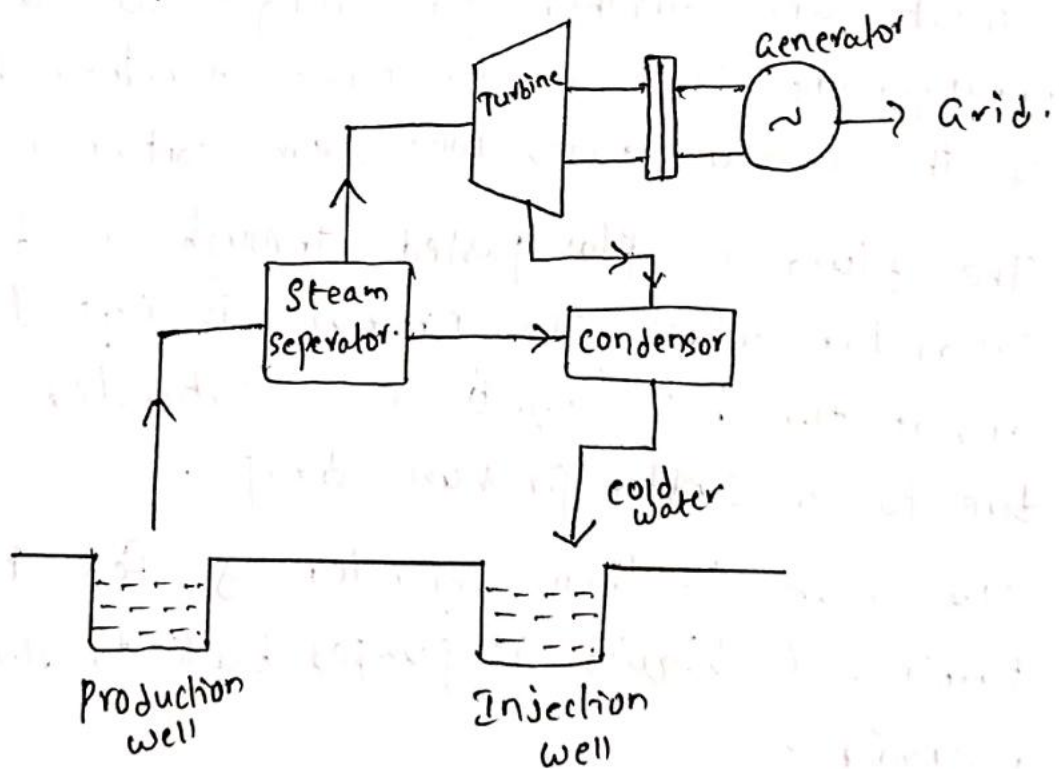


Fig:- Flash steam geothermal power plant.

These types are the most common types of geothermal electricity plants where steam is separated from the water through a separation process called flashing.

→ The steam is then directed to turbines in the same way as in the dry steam power plants.

→ Flash steam power plants use reservoirs with a temperature greater than 180°C . i.e. $>180^{\circ}\text{C}$.

Most of the geothermal resources contain fluid that is blend of steam & liquid.

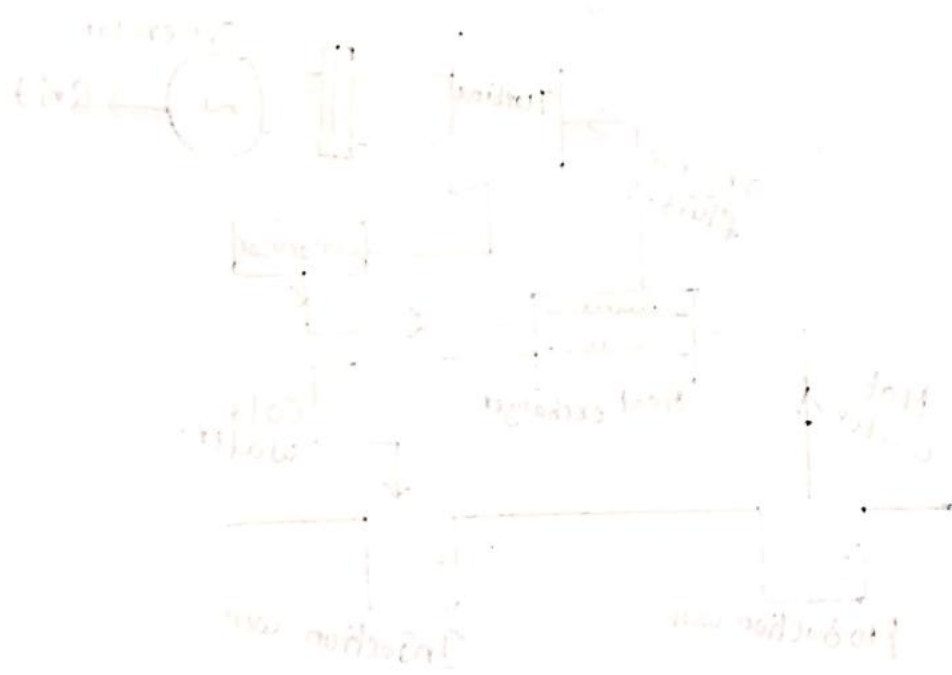
→ The easiest way is to separate both & use steam as input to turbines.

But steam is in very low quantity if used without any further processing. So, a special arrangement is made to take further benefit of this mixture. (i.e., wet steam contains both water & vapour)

→ The fluid is ~~has~~ passed through a flash separator where the pressure is kept low to convert the hot liquid into saturated vapours due to a sudden pressure drop.

→ The steam is then separated & fed to the turbines & liquid is pumped back to the geothermal reservoir.

→ In the turbine, the steam expands & gets cooled while turning the turbine shafts, hence producing mechanical energy. The shaft is connected to the generator to produce electric power.



→ (or) Organic Rankine cycle (ORC) Binary cycle geothermal power plant

A binary cycle geothermal power plant is a system that generates electricity by utilizing two separate fluid cycles :
a primary geothermal fluid
a secondary working fluid .

This system is particularly well suited for harnessing geothermal energy from moderate temperature reservoirs , where traditional flash steam or dry steam systems are not suitable.

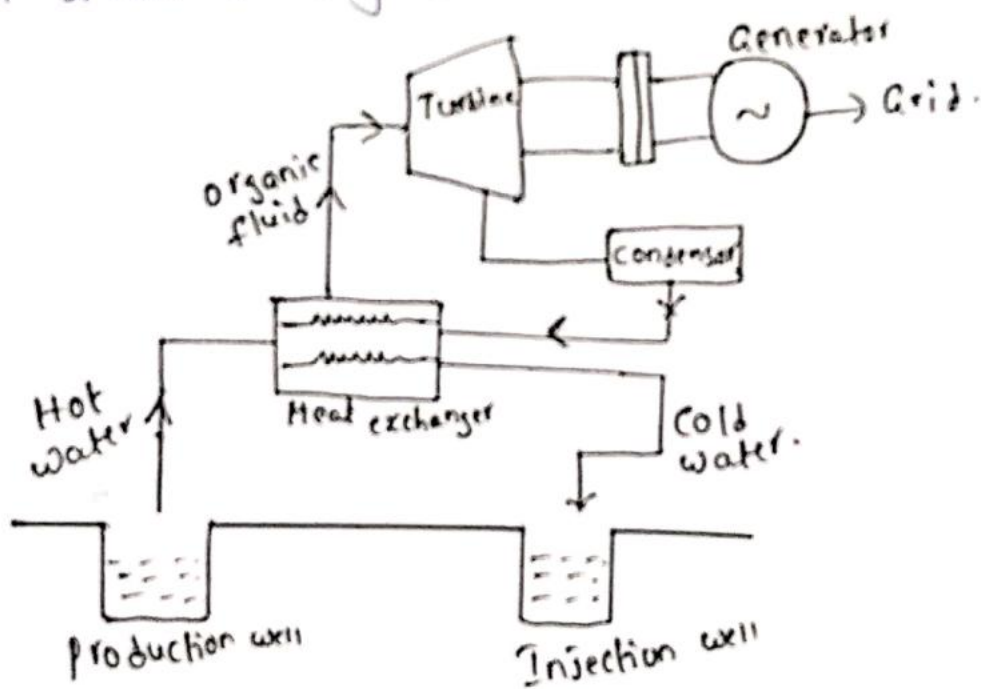


Fig:- Binary cycle Geothermal power plant
working:- Hot water (or) brine is pumped from a geothermal reservoir through production wells.

→ The geothermal fluid is passed through the heat exchanger , where it transfers its heat to a secondary working fluid with a low boiling point.

- The secondary fluid, is passed thru often an organic compound like isobutane or pentane, vaporized due to the heat absorbed from the geothermal fluid.
- The pressurized vapour expands & drives a turbine connected to a generator, producing electricity.
- The vapour is condensed back into a liquid & recycled through the heat exchanger, completing the closed loop system.
- The cooled geothermal fluid is typically re-injected back into the reservoir to maintain pressure & sustainability.
- Binary cycles permits electricity generation even from low temperature geothermal resources i.e. < 180°C

A binary cycle is a method of generating electrical power from geothermal resources & employs two separate fluid cycles, hence binary cycle. The primary cycle extracts the geothermal energy from the reservoir. The secondary cycle converts or exchange the geothermal energy into heat some other fluid & hence to drive the generator & generate electricity.

Difficulties & Disadvantages of Geothermal energy

The use of geothermal energy has the following difficulties & disadvantages.

- (1) The geothermal water has been found to be highly corrosive & abrasive.
 $\downarrow$
 it is a substance that is able to destroy solid material by chemical reaction. $\rightarrow$ causing damage.
- (2) As more & more of heat extraction takes place the mean temperature of rocks is likely to fall.
 As such the capability of power plant is likely to decrease over the years.
- (3) In low rain fall areas the sub-soil water depletion may occur. It may then be necessary to reinject water into earth.
- (4) Transmission :- In most of the cases the geothermal power has to be utilised within a short distance from the site.
- (5) Environmental problems :- The most serious environmental aspect is the disposal of high salinity water after its heat has been utilised.
 Dry steam plants are very noisy & emit hydrogen, nitrogen, ammonia & hydrogen sulphide.
- (6) Seismic effects :- If a balance b/n the rate of inflow & rate of withdrawal of water is upset, the geothermal reservoirs would experience a change

Porosity & fluid pressure with a danger of seismic effects.

If underground nuclear explosions are done to increase the permeability of rocks, the seismic effects may become more dangerous.

Remedies :- It has been estimated that technological progress in the following three areas could accelerate the setting of Geothermal plants.

(1) Improvement in generating fissures system

At present heat extraction from impermeable rocks is difficult because water can not circulate through these rocks.

- Efforts are being made to increase the permeability of rocks by hydraulic, chemical or nuclear fracturing.
- The nuclear fracturing, however increases the seismic activity. If any technique for generating fissure system in impermeable rocks is successfully developed, geothermal contribution would increase.

(2) Development of vapour turbine cycle : If better vapour turbine cycle is developed so that low enthalpy water can be utilised for electric generation, the role of geothermal energy would increase. At present the enthalpy values of over 200 cal/gm are needed for power generation.

(3) Advancement in drilling technology :- The

Geothermal wells being used at present are 2 km deep. If advancement in drilling technology could increase the depth to 4 km, or so for the same drilling cost, more & more geothermal areas could be developed.

UNIT-V

(1)

Tidal Energy

Basic principal of Tidal Power

Tides are produced ^{mainly} by the gravitational attraction of the moon & the sun on the water of solid earth & the oceans.

About 70% of the tide producing force is due to the moon & 30% due to sun.

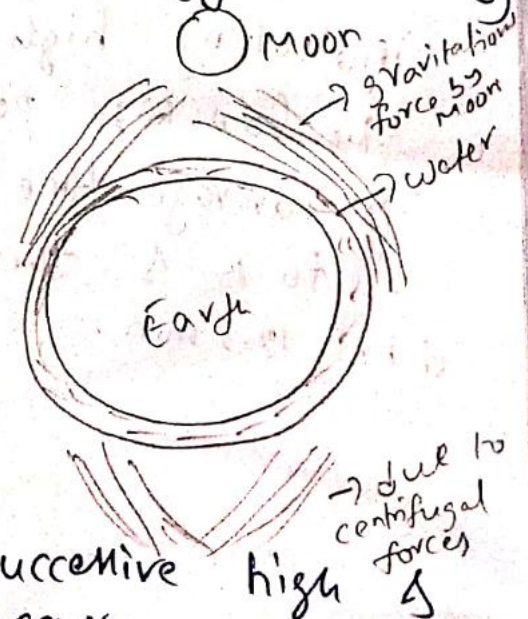
The moon is thus the major factor in the tide formation.

Surface water is pulled away from the earth on the side facing the moon. (gravitational force of attraction by the moon)

That means, A high tide will be experienced at a point which is directly under the moon.

At the same time, a diametrically opposite point on the earth's surface also experiences a high tide due to centrifugal forces by the earth. (dynamic balancing)

Thus high tides occur in these two areas with low tides at intermediate points. As the earth rotates, the position of a given area relative to the moon changes, & also the tides changes. Thus a periodic low tides will



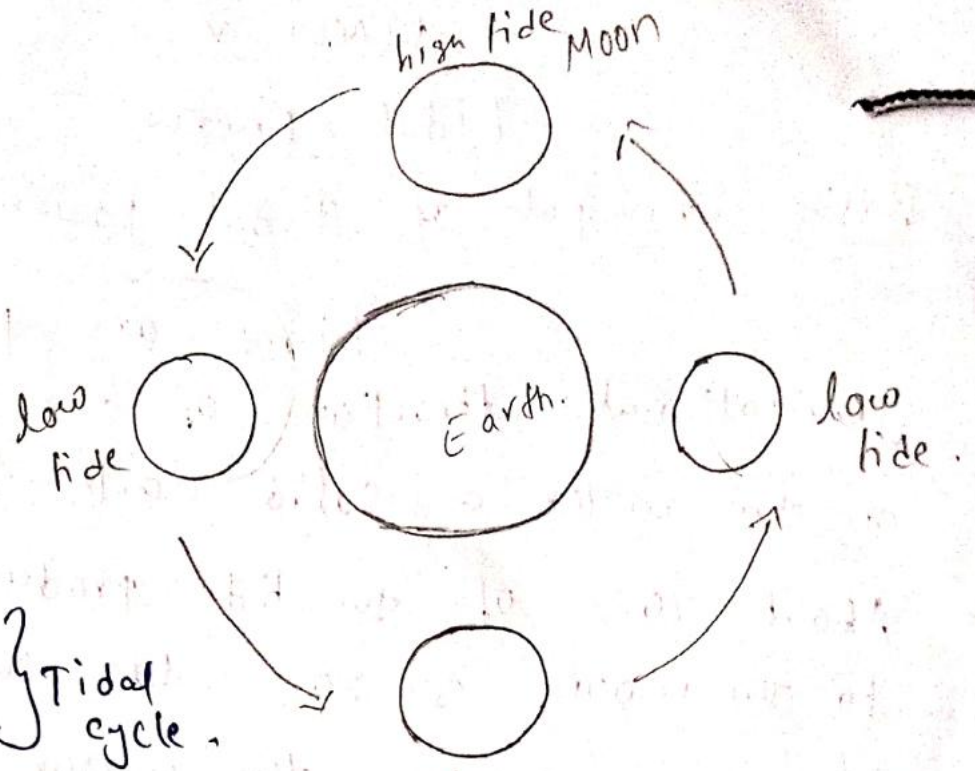
successive high & low tides will occur.

Lunar day

The Apparent time of revolution of the moon around the earth:

24 hrs, 50 mins

one high tide & } Tidal cycle.
one low tide

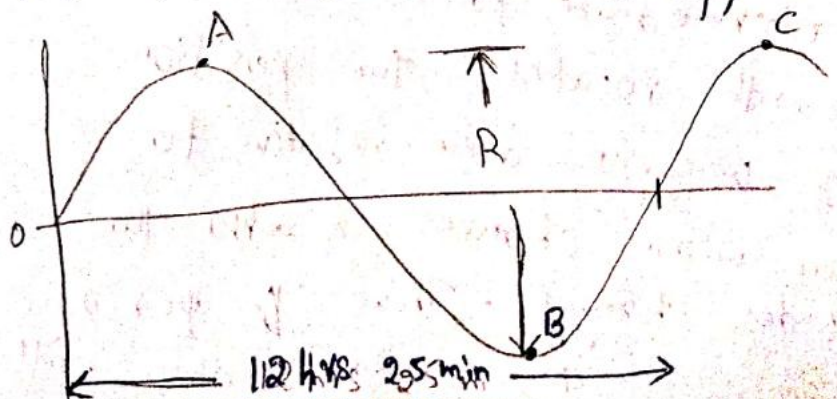


There are two tidal cycles (ie, two high tides & two low tides) will occur during the lunar day of 24 hrs 50 mins.

one tidal cycle will be occurred in the duration of 12 hrs 25 mins.

The rise & fall of the water level follows a sinusoidal curve shown in fig with point 'A' indicating high tide point & point 'B' indicating the low tide point.

The average time for the water level to fall from A to B & then rise from B to C is approximately 6 hrs 12.5 min.



The difference b/n high & low water levels is called the Range of the tide.

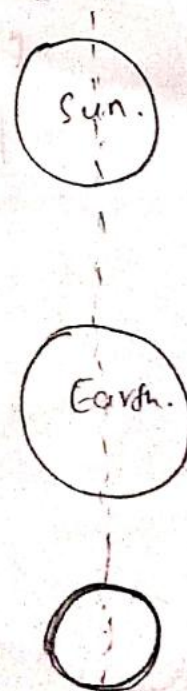
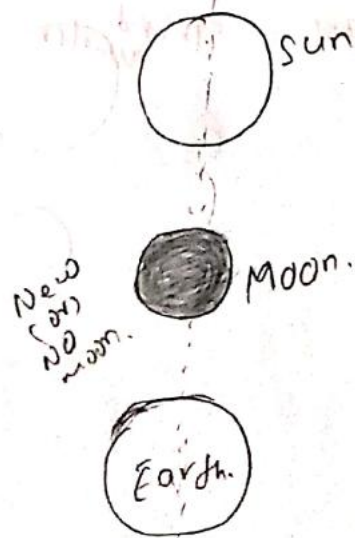
The tidal Range 'R' is defined as.

$R = \text{water elevation at high tide} - \text{water elevation at low tide}$

Because of the changing positions of the moon & ~~earth~~ ~~the~~ sun relative to the earth, the range varies continuously.

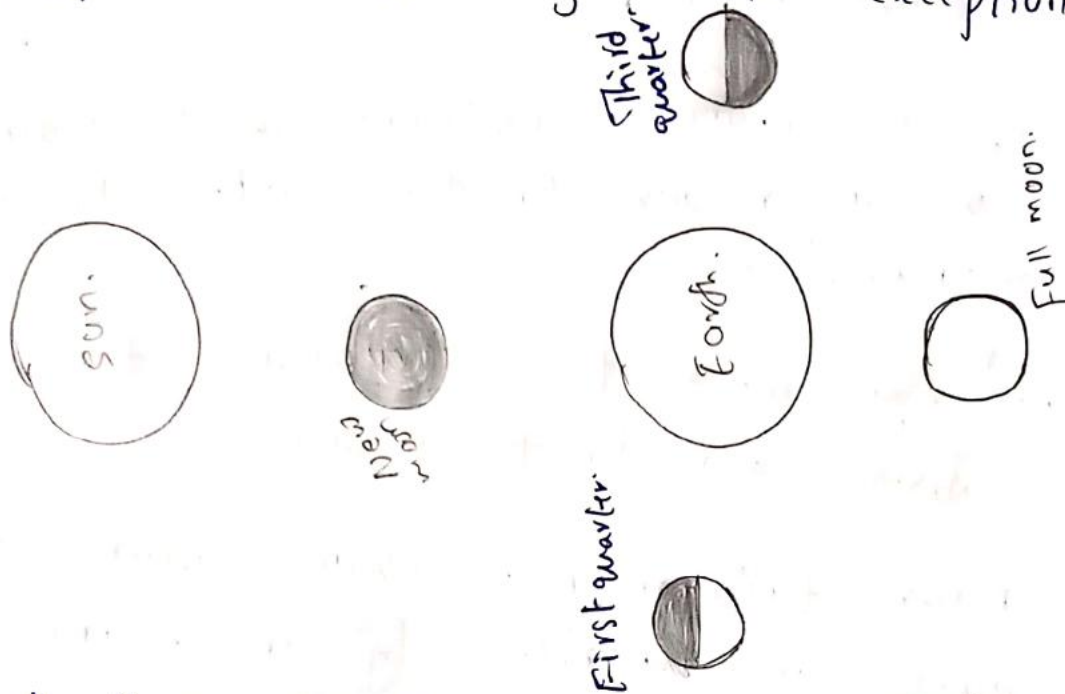
Tides are ^{very} high when the gravitational force of sun is added ~~aided~~ to the moon.

At times near full or new moon, when sun, moon & earth are approximately in a line, the gravitational forces of sun & moon enhances (increases) each other. The tidal range is exceptionally large, the high tides are higher & low tides are lower than the average.

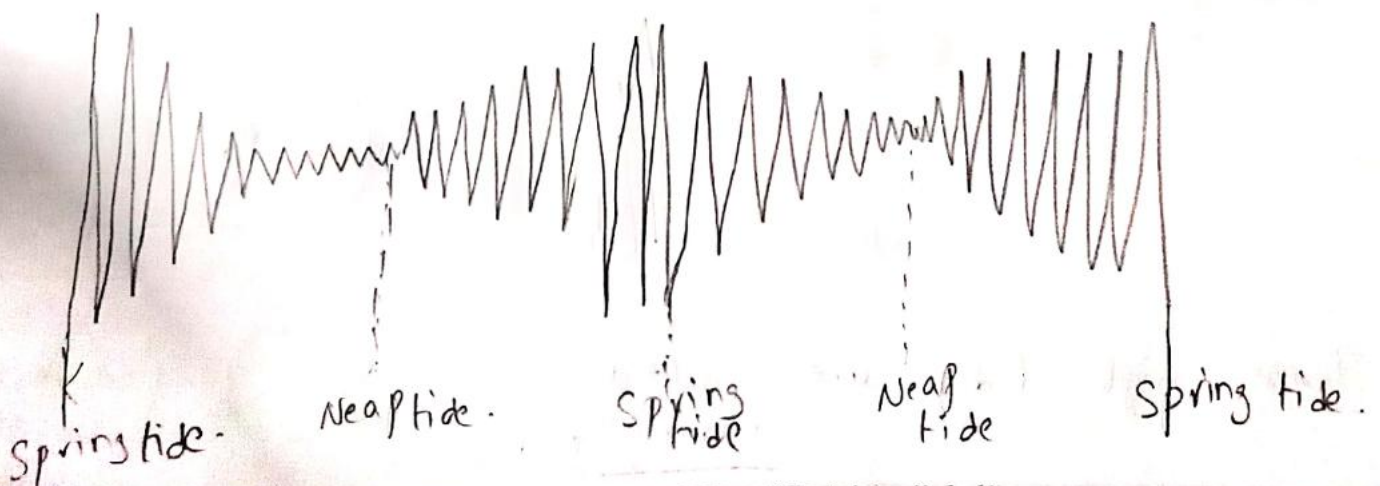


These high tides are called spring tides

On the other hand, near the first & third quarters of the moon, when the sun & moon are at right angles with respect to earth, neap tides occur. The tidal range is then exceptionally small.



At the time of full & new moon, the tides are very high called spring tides & they are minimum at the time of first & third quarters of the moon, called neap tides.
 Right angle to the sun.



The actual variations of in range are somewhat³ complicated by seasonal variations caused by the ellipticity of the earth's orbit around the sun.

—The variations in the periodicity of monthly & seasonal ranges must, of course, be taken into account in the design & operation of tidal power plants. The tides are however usually predictable, & fairly accurate tide tables are usually available.

Tidal ranges vary from one earth location to another. They are influenced by water depth & local shoreline. When these are favourable, a very high tidal range is occurred.

Tidal Ranges have to be very large to justify or satisfy the huge costs of building dams & associated hydro electric power plants. Such tides are occurred only in a few locations in the world.

Imp → No two tides in any cycle are alike. Since the relative positions of sun & moon & their distances from earth are continuously changing, the tides are also influenced accordingly.

→ Out of the two high tides in a single day, one tide is higher than the other.

→ In any month, the tides on the full moon & no moon days are particularly higher than the rest, as on these days sun's & moon's attraction acts in a directly additive manner.

Components of Tidal power plants

There are 3 main components of a tidal power plant.

- (1) The power house
- (2) The dam or barrage
- (3) sluice-ways from the basins to the sea & vice versa.

→ The turbines, electric generators & other auxiliary equipments are the main components of a powerhouse.

→ The function of dam to form a barrier b/n the sea & the tidal basin (or) ^{one} basin & the other basin in case of multiple basins.

→ The sluice ways are used either to fill the basin during the high tide or empty the basin during the low tide. These are gate controlled devices.

It is generally convenient to have the power house as well as the sluice ways in alignment with the dam.

If reversible pump turbines are provided, the pumping operation can be taken over at any time by the same M/c. The modern turbines are so versatile that they can be used either as turbines or as pumps in either direction of flow.

Tidal energy & its conversion :- working principle

Tidal energy harnesses the kinetic & potential energy of tides, converting it into electricity primarily through 2 methods.

Tidal barrages & Tidal stream generators.

→ A dam-like structure is built across an estuary or bay with a large tidal range.

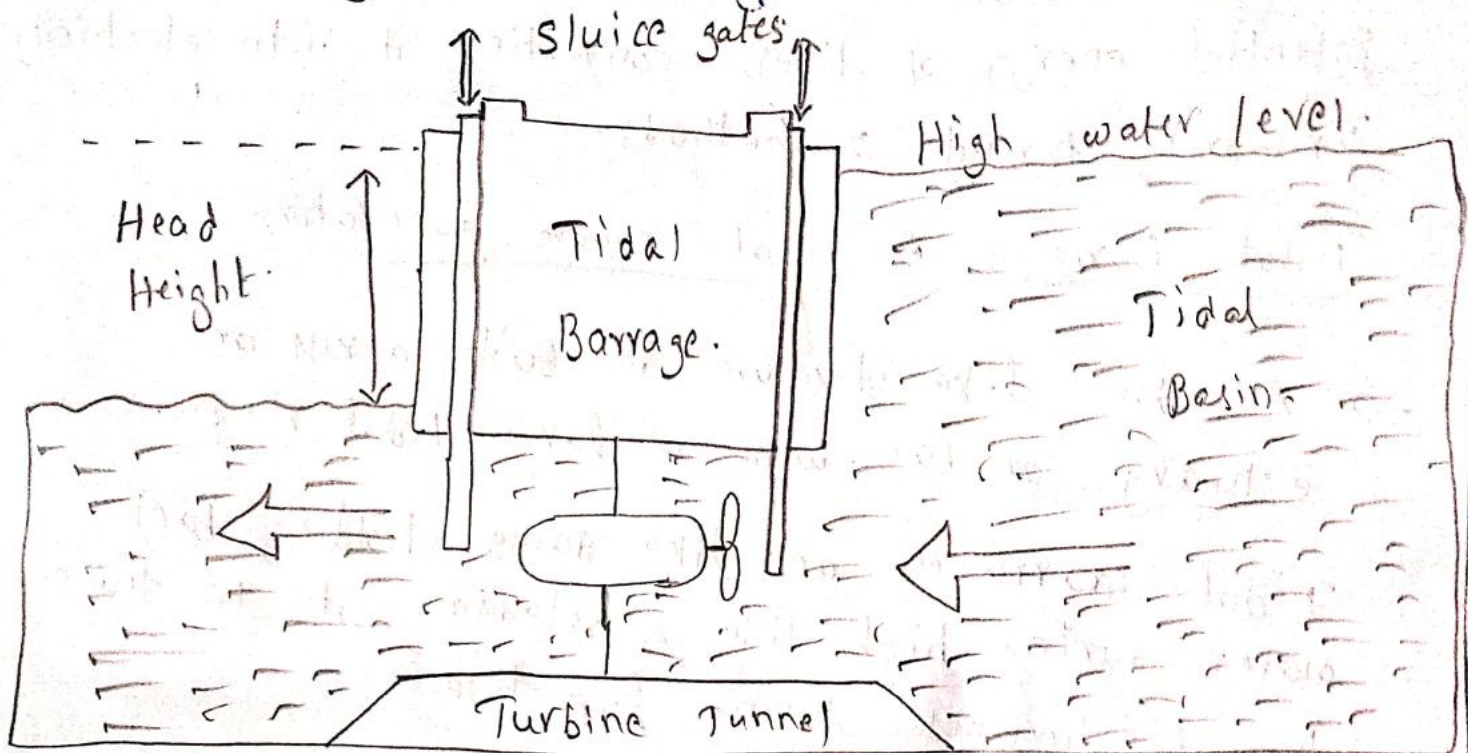
Tidal barrages act like dams, holding back water during high tide & releasing it to the sea through turbines during low tide.

→ Sluice gates on the barrage are opened to let water flow into the basin during the high tide & let the water flow from the basin into the sea during the low tide.

→ Tidal stream generators are like underwater wind turbines that are placed in areas with strong tidal currents.

→ The flow of the fast moving water pushes the turbine blades, which spins the rotor. The rotor is connected to a generator that produces electricity.

Two way tidal power systems can generate electricity from both incoming & outgoing tides.



Finally the kinetic energy of moving water into Mechanical energy by spinning a turbine, which in turn converts it into Electrical energy via a

Operational methods of utilization of tidal energy.

The generation of electricity from water power requires that there should be a d/f in levels (or heads) between which water flows. A no. of concepts have been proposed for generating electricity by utilizing the head that can be produced by the rise & fall of the tides to operate a hydraulic turbine.

The power generation from tides involves flow between an artificially developed basin & the sea.

However in order to have a continuous generation of power, the basic ~~sceme~~ scheme can be elaborated by having two or more basins.

According we can distinguish the following types of arrangements.

- (1) Single basin Arrangement
- (2) Double basin Arrangement.

Single basin schemes can generate power only intermittently, but the double basin scheme can provide the power continuously or on demand, which is a tremendous advantage.

→ The drawback is that the civil works become more extensive.

In the double basin scheme there must be a dam b/n each basin & the sea, and also a dam b/n the basins, containing the power house. one basin is maintained always at a lower level than the other.

Single Basin Arrangement : - In a single ~~basin~~ arrangement there is only one basin interacting with the sea. The two are separated by a barrage (dam) & the flow b/n them is through sluice gates located conveniently along the dam.

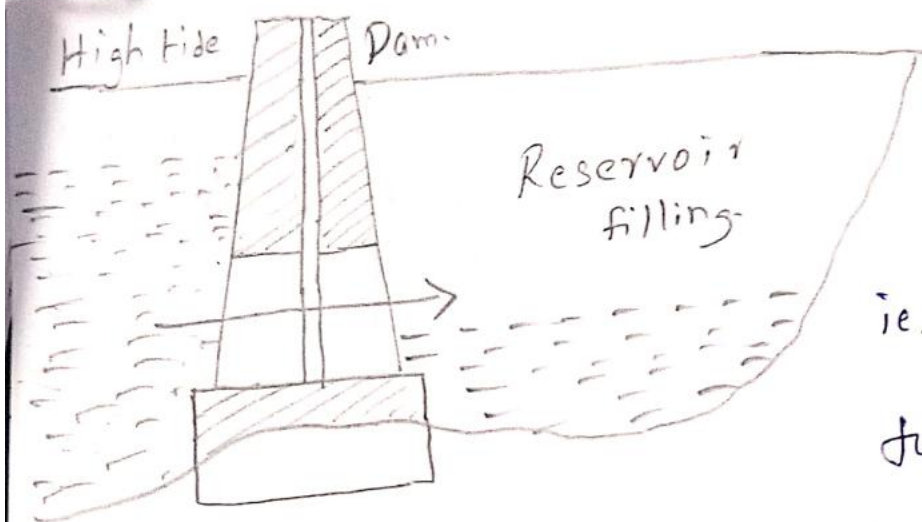
The generation of power can be achieved in a single basin arrangement either as a

- (a) Single ebb-cycle system (or)
- (b) single tide (or) single flood cycle system (or)
- (c) Double cycle system.

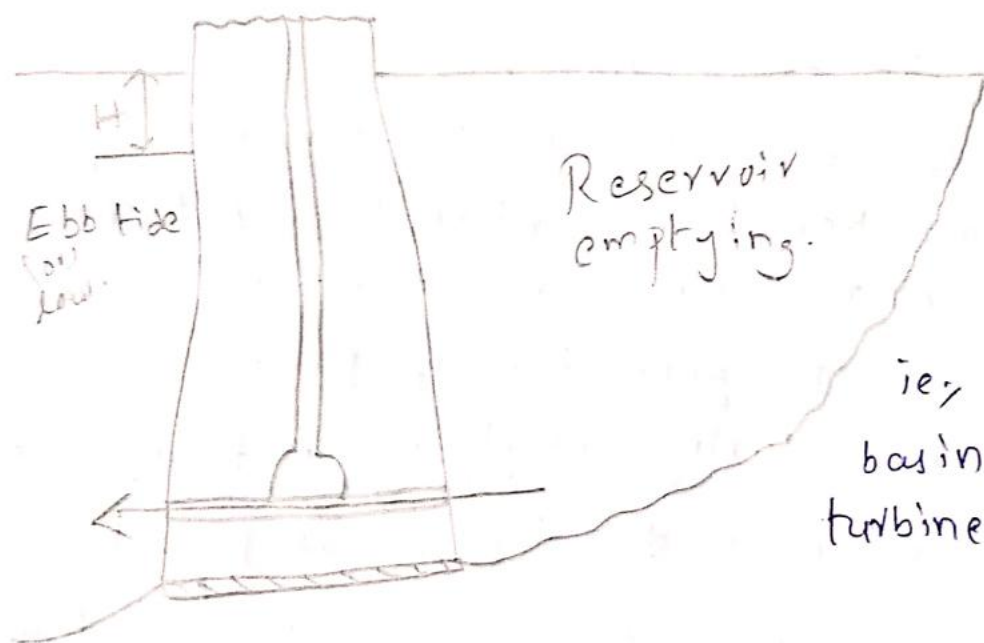
(a) single ebb cycle system : - When the high tide comes in, the sluice gates are opened to permit sea-water to enter the basin (or) reservoir while the turbine sets are shut down (not rotate)

→ The basin thus starts filling while its level rises, till the max. tide level is reached.

→ Whenever the low tide starts i.e. reducing the level of sea water, the sluice gates are closed. Then the generation of power takes place when the sea is ebbing (flowing back of tide) & the water from the basin flows over the turbines into the sea.



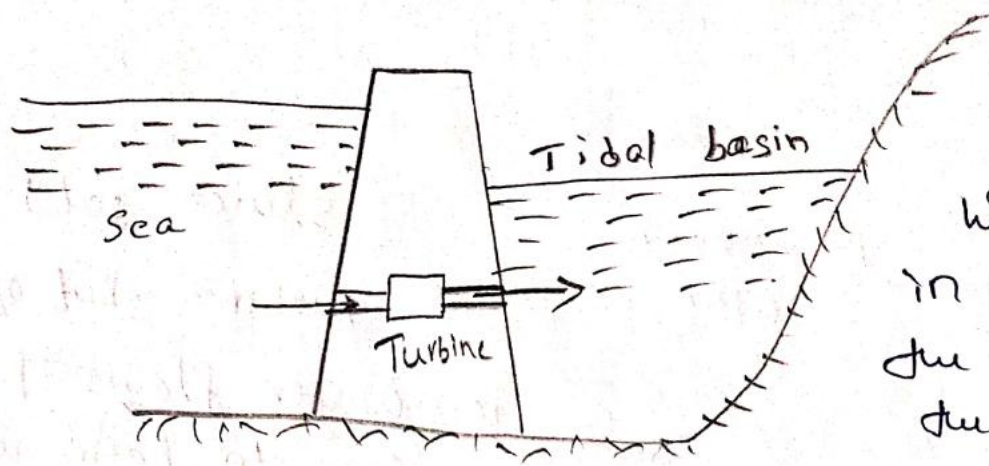
sluice gates open,
Turbine shut off
ie, water flows from
sea to basin when
the high tide occurs.



sluice gates are
closed & turbine
operated
ie, water from the
basin flows over the
turbine to the sea.

(b) single tide cycle system :- In a single tide cycle system, the generation is started when the sea is at flood tide (high tide).

→ The water of the sea is admitted into the basin over the turbines. As the flood tide period is over & the sea level starts falling again, the generation is stopped. The basin is drained into the sea through the sluice gates.



Water is entered
in to basin through
the turbines when
the high tide occurs.

High (or) Flood tide

(c) Double cycle system :- In Double cycle system the power generation is affected during the ebb as well as in flood tides.

→ The direction of flow through the turbines during the ebb & flood ~~ing~~ tides alternates, but the machine acts as a turbine for either direction of flow.

(→ In this method, the generation of power is accomplished both during emptying & filling cycles.
Filling the basin when the sea is at high tide

Emptying " " " " " " " " low tide.

→ The flow of water in both directions is used to drive a number of reversible water turbines, each driving an electrical generator.

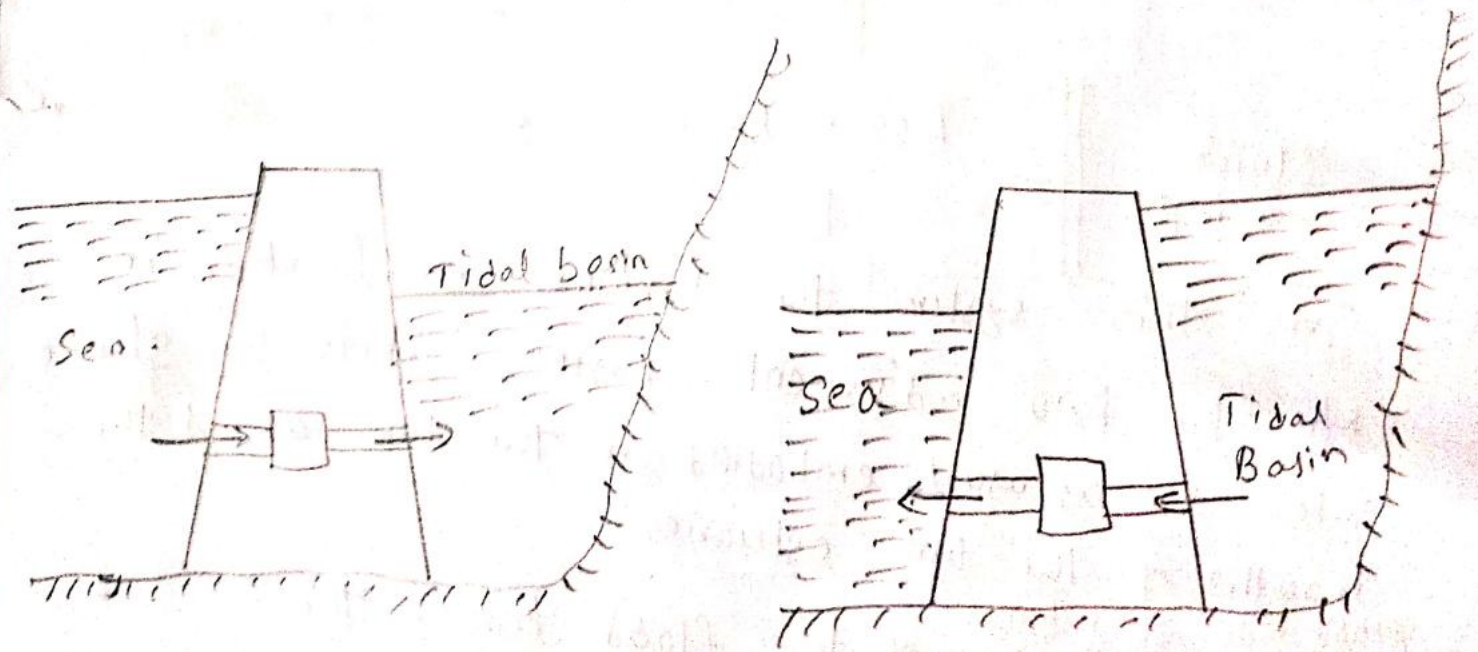
→ Electric power would thus be generated during two short period during each tidal period of 12 hrs 25 min or once every 6 hrs, 12.5 min.

The main disadvantages in both the ebb-cycle as well as the tide cycle systems is the intermittent (not continuous) nature of their operation.

Though the double cycle system has only short duration interruptions in the turbine operation, yet a continuous generation of power is still not possible.

These problems are solved to some extent in the two-basin scheme.

However, a fundamental drawback to all methods for generating tidal power is the variability in output caused by the variations in the tidal range.



(a) High tide -

water flows from sea to the basin when high tide occurs

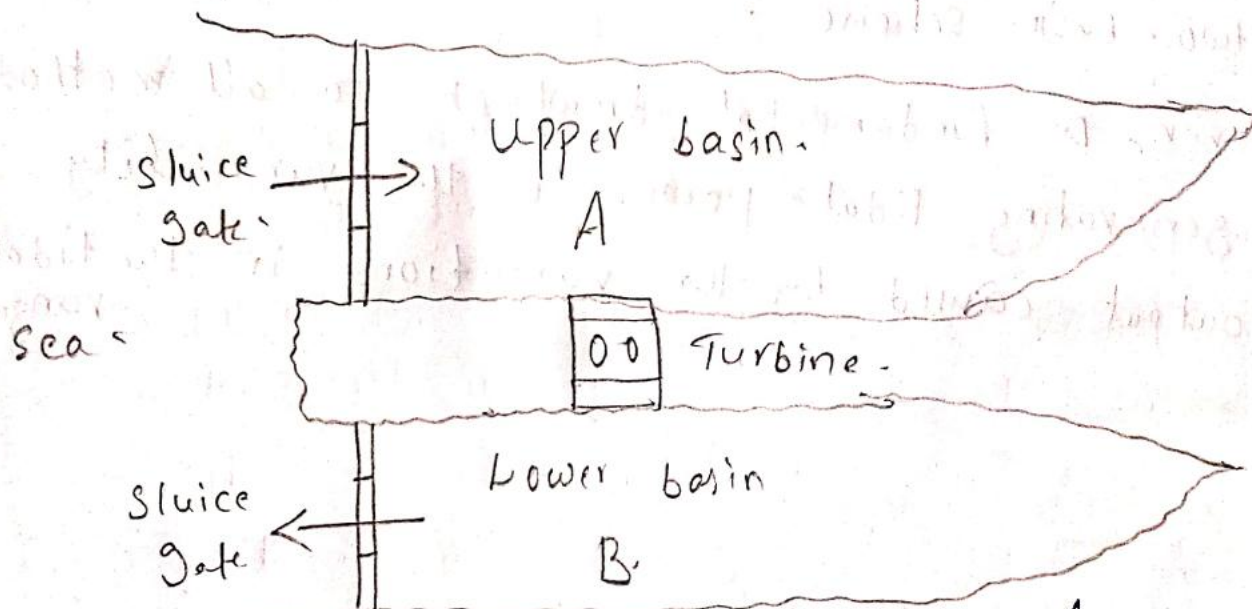
(b) Low tide -

water flows from basin to the sea when the low tide occurs.

(2) Double Basin arrangement :- It requires two separate but adjacent basins.

In one basin called "upper basin" (or high pool), the water level is maintained above that in the other, the lower basin.

Because there is always a head b/w upper & lower basins, electricity can be generated continuously, although at a variable rate.



In this system the turbines are located in b/w the two adjacent basins, while the sluice gates are as usual embodied in the dam across the mouths of the two estuaries.

Flood tide operation

At the beginning of the flood tide, the

→ turbines are shut down,

→ upper basin gates (A) are opened → A starts filling

→ lower basin gates (B) are closed → B remains empty

- As water level in 'A' rises & provides a sufficient ~~head~~ difference of head b/n the two basins, the turbines are started.
- The water flows from A to B through the turbines, generating power.
- The power generation thus continues simultaneously with the filling up of the basin.

End of Flood Tide:

- At the end of the flood tide,
- 'A' is full & the water level in it is the max., & its sluice gates are closed.
- When the ebb tide ^{level} ~~starts~~ gets lower than the water level in B, its sluice gates are opened.
- This continues until the difference of head & water levels in A & B is sufficient to run the turbines.

Ebb tide Ends :- With the next flood tide the ~~next~~ cycle repeats itself.

once the operating difference of heads are lost, turbines are stopped.

Otherwise with this twin basin system, a longer & more continuous period of generation per day is possible.

Wave Energy

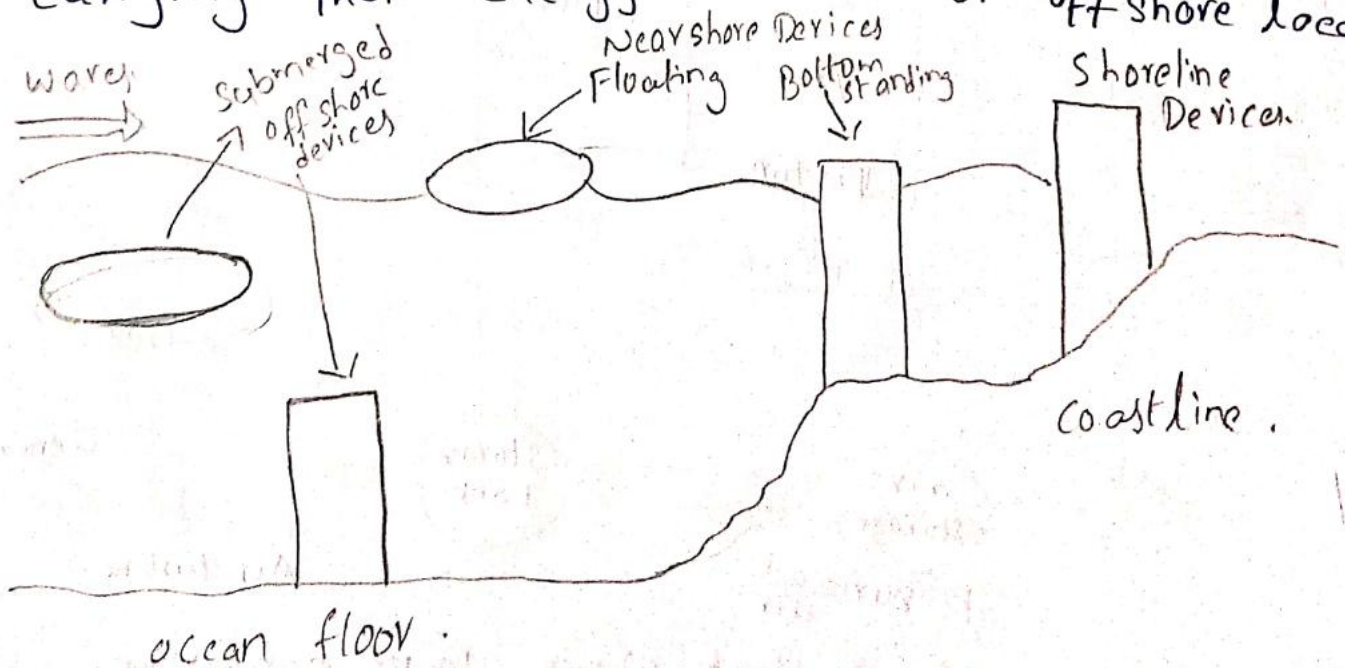
Introduction :- Wave Energy is a renewable energy source that captures & converts the kinetic & potential energy of ocean waves into electricity using specialized devices called Wave Energy converters.

Ocean & sea waves are caused indirectly by solar energy like the wind.

Wind energy is caused by uneven heating of the Earth's surface due to sun, which creates high & low pressure areas. Air moves from high to low pressure areas creating wind.

As wind blows across the surface of the ocean, it transfers energy to the water, creating ripples that grow into waves.

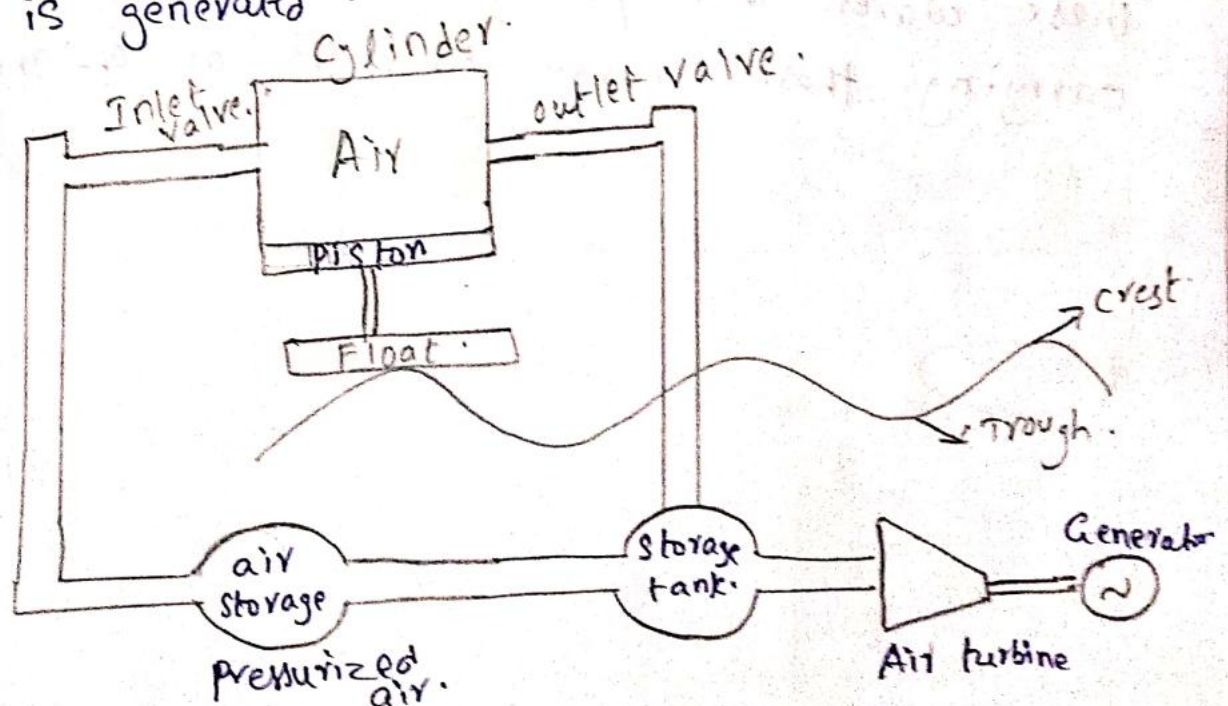
These waves then propagate across the ocean, carrying their energy to shore or offshore locations.



The potential & kinetic energy in water are converted into Mechanical energy in the "wave machine" in two ways.

- (1) Wave Machine drives gears & electrical generator
- (2) Wave Machine drives air compressor to store energy in tanks, drive another machine for energy conversion.

Wave energy conversion by floats :- Wave motion is primarily horizontal. Mechanical power is obtained by floats making the use of motion of water. The concept visualizes a large float that is driven up & down by the water within relatively stationary guides. This reciprocating motion is converted to mechanical & then electrical power is generated.



Schematic of a float wave power conversion device.

It consists four vertical main folds that are ⁽²⁾ part of a platform. There are four large under water floatation tanks which stabilizes the platform. Platform is supported by buoyancy forces & no vertical & horizontal displacement occurs due to wave motion. Thus the platform is made stationary in space.

A piston which is attached to float as shown in fig. moves up & down inside a cylinder. The cylinder is attached to platform & is therefore relatively stationary.

- The downward motion of the piston draws air into the cylinder via inlet check valve.
- The upward motion compresses the air & sends it through an outlet check valve to the four underwater floatation tanks via the four mainfolds.
- The compressed air in the air storage tanks is used to drive an air turbine that drives an electric generator. The

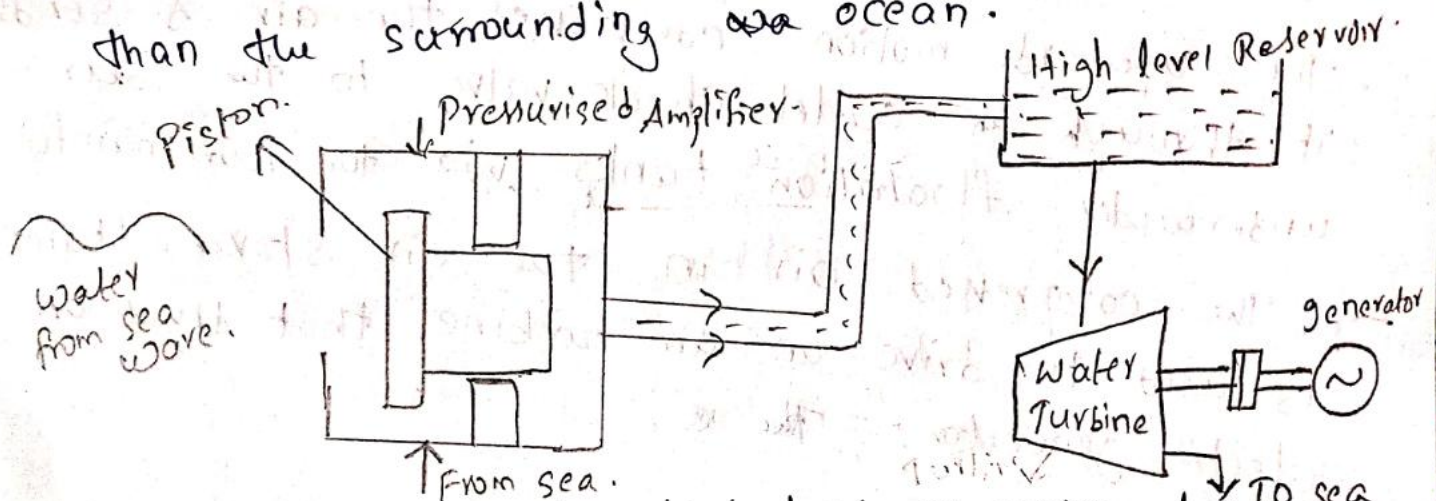
High level Reservoir wave Machine :-

A high level reservoir wave Machine, also known as an overtopping device, is a type of wave energy converter that uses waves to fill a reservoir above sea level. The potential energy of the water in the reservoir is then captured as it flows back to the sea through turbines, which generates electricity.

This method works by using the force of the waves to push water into the reservoir.

Working

→ The force of waves drives water into a reservoir that is built at a higher elevation than the surrounding sea.



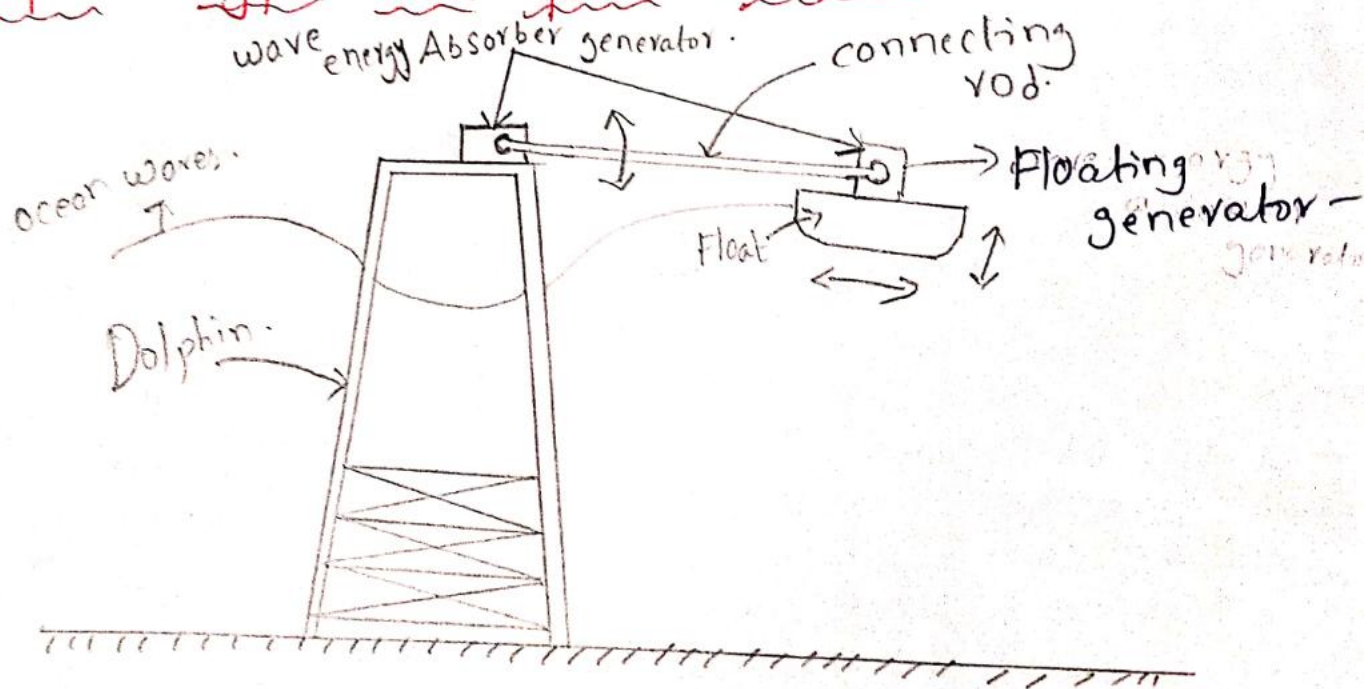
→ The water in the high level reservoir has potential energy due to its height. This potential energy is converted into kinetic energy when the water is released.

(3)

As the water flows from the reservoir back into the sea, it passes through turbines, which spin a generator to produce electricity & then back to the sea level.

Calculations made shown that a 20 m diameter generator can produce 1 MW power.

Dolphin type wave power Machine



The system consists of following major parts.

- (i) a dolphin (ii) a float (iii) a connecting rod
- (iv) Two Electrical generator.

This device uses the float which has two motions.

- (i) The first is a rolling motion about its own fulcrum with the connecting rod.

Revolving movements are caused b/n the float & the connecting rod.

(ii) The other is nearly vertical motion.

It causes relative revolving movements b/n the connecting rod & the stationary dolphin.

In both the cases, the movements are amplified & converted by gears into continuous rotary motions that drive the two electrical generators.

Bio-Mass Energy

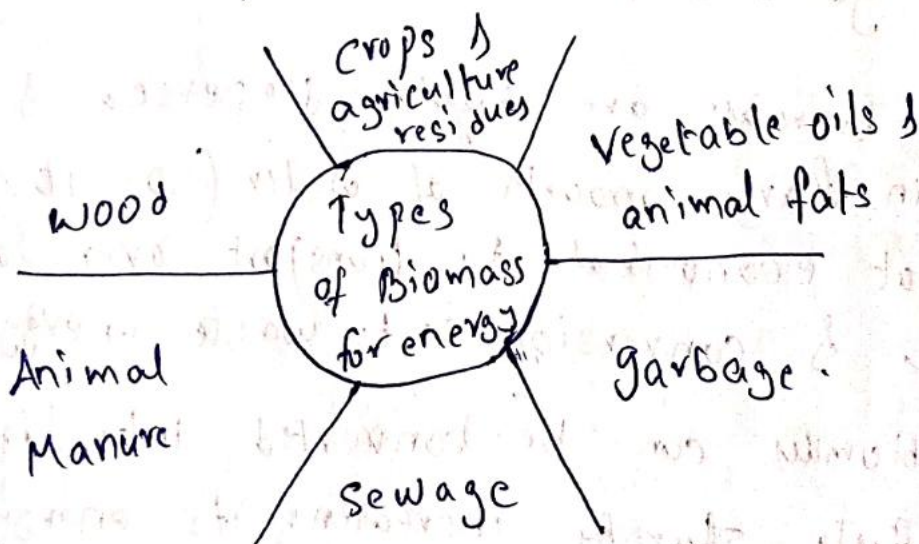
Biomass is renewable organic matter produced by plants & animals.

→ Plant life renews & adds to itself every year.

→ It can also be considered as a form of solar energy as the latter is used indirectly to grow these plants by photosynthesis.

solar Energy → Photosynthesis → Biomass → Energy generation.

out of several resources of renewable energy like solar, wind, ocean thermal energy, tidal wave energy, Geothermal energy, nuclear energy, energy from biomass are important feature in our country.



Biomass resources fall into 3 categories.

(i) Biomass in its traditional solid mass

(wood & Agriculture residue)

(ii) Biomass in non-traditional form (converted into liquid fuels).

(iii) The third category is to ferment the biomass anaerobically to obtain a gaseous fuel called biogas.

Biomass includes wood waste & bagasse, which have potential of generating substantial electric power.

The first category is to burn the biomass directly & get the energy.

In the second category, the biomass is converted into ethanol & methanol to be used as liquid fuels in engines.

In the third category, the biomass is converted into gaseous fuel.

All these biomasses are highly dispersed & bulky & contain large amounts of water (50-90%). Thus it is not economical to transport over longer distances, & conversion into usable energy.

However, biomass can be converted into liquid or gaseous fuels, thereby increasing its energy density, making feasible transportation over long distances.

Biomass conversion! Biomass conversion or Bio conversion can take many forms. Mainly, Biomass conversion technologies transform organic matter into the energy through the

- (1) Direct combustion
- (2) Thermochemical conversion
- (3) Biochemical conversion

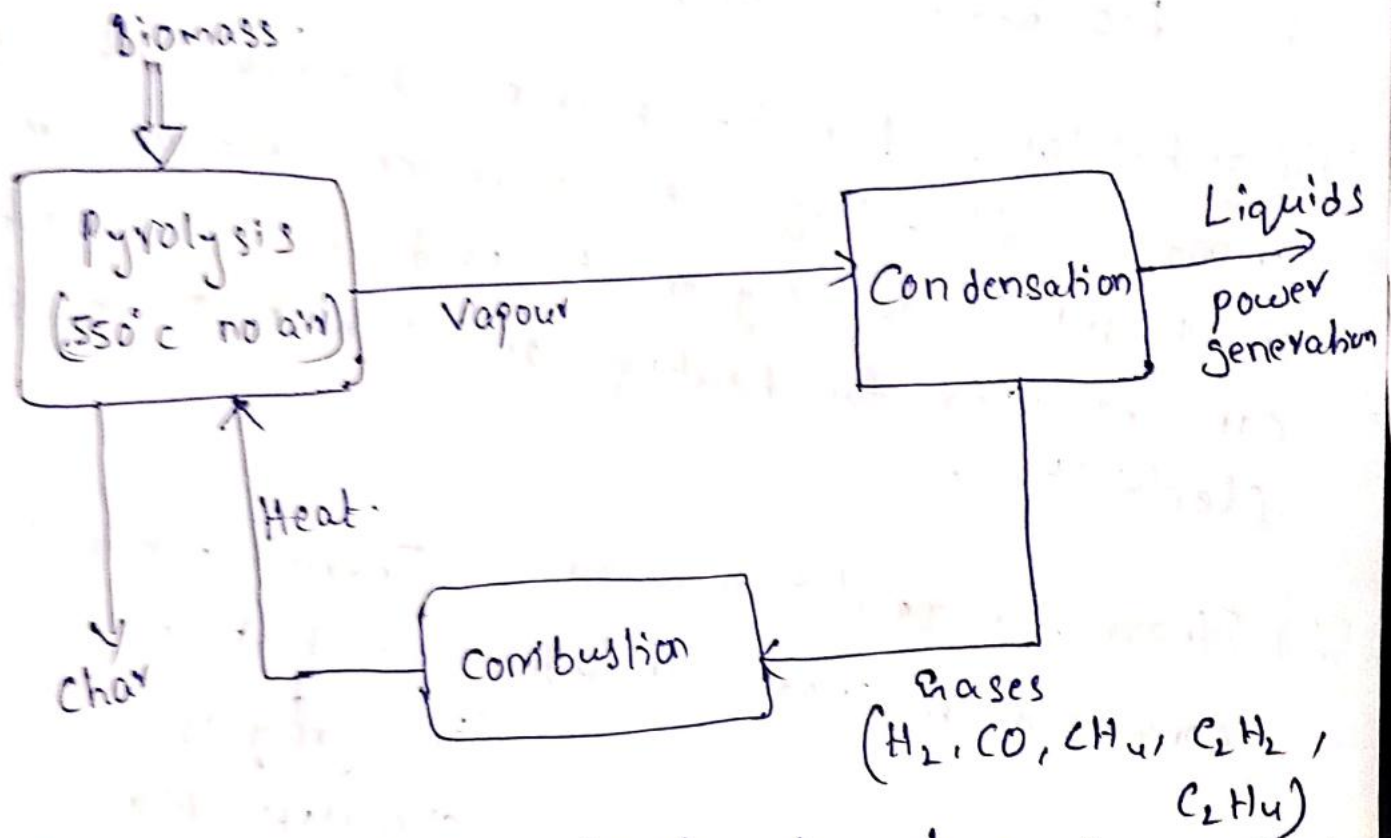
(1) Combustion: Directly burning biomass such as wood waste, bagasse (sugar cane refuse) in the presence of oxygen to produce heat, which can be used for heating or generating steam for electricity.

(2) Thermochemical conversion: Thermochemical conversion methods include (a) combustion, (b) Pyrolysis, (c) Gasification, (d) Liquefaction.

(b) Pyrolysis: Heating of biomass in the absence of oxygen to produce charcoal, bio-oil & synthesis gases.

Pyrolysis is the thermal decomposition of organic matter in the absence of oxygen to produce three main products. Bio charcoal (solid), Bio oil (liquid), Synthesis gases (gas).

This process uses heat typically ($450 - 800^{\circ}\text{C}$) to break down complex biomass molecules into simpler compounds, offering a pathway to convert biomass into useful fuels & chemicals.



Pyrolysis requires an inert atmosphere to prevent combustion, ensuring that the biomass breaks down into products rather than burning.

Working
Heating

→ Biomass is heated in a controlled, low-oxygen environment within a pyrolysis reactor.

→ Decomposition: - At high temperatures, the biomass undergoes thermal cracking & depolymerization, breaking down its complex structures.

(3)

Product Formation: The cracked molecules then reassemble into the gaseous, liquid, & solid Pyrolysis products.

Product: (i) Biochar:- The solid carbon-rich residue, which can be used as a soil to retain carbon.

(ii) Bio-oil:- A complex liquid mixture containing oxygenated organic compounds, which can be a fuel or chemical feedstock.

(iii) Synthesis gases:- A mixture of gases, including hydrogen, methane, carbon monoxide, & carbon dioxide which are combustible.

(c) Gasification: Gasification takes place by heating the biomass with limited oxygen to produce low heating value gas or by reacting it with steam & oxygen at high pressure & temperature to produce medium heating value gas.

How Gasification is different from combustion.

Combustion
oxidation process is substantially completed in one step.

Gasification
converts the intrinsic chemical energy of the carbon in the biomass into a combustible gas in 2 stages.

→ Gasification is a process of conversion of Biomass into combustible gas mixture.

The process which we follow is by a partial oxidation of Biomass at high temperature ($800^{\circ}\text{C} - 900^{\circ}\text{C}$) & in gasification medium.

Gasification medium consists of it may be

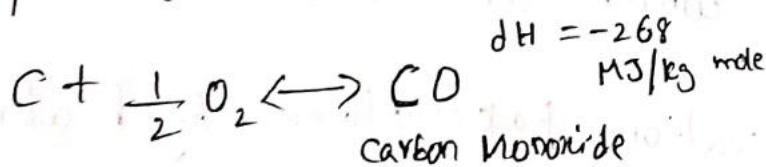
Air, oxygen, steam

As said earlier Gasification is a process of conversion of Biomass into combustible gas in 2 stages.

Stage 1

Partial oxidation

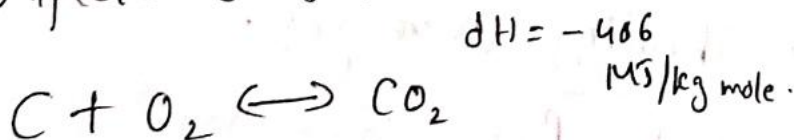
Heat of reaction.



$\Delta H = -268$
MJ/kg mole

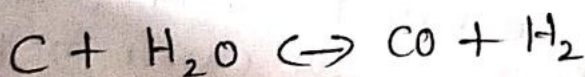
When carbon is giving partial oxidised it produces Carbon Monoxide.

Complete oxidation



$\Delta H = -406$
MJ/kg mole.

Water gas reaction



$\Delta H = +118$ MJ/kg mole.

Stage 2

(Exothermic)

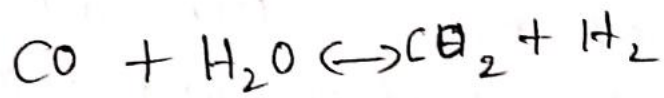
'-' sign indicates that Heat is generated

'+' sign indicates that Heat is absorbed.

(Endothermic)

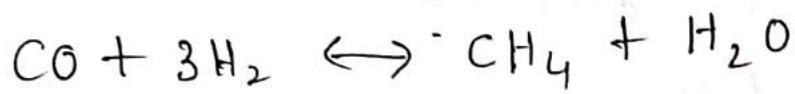
Stage - 2

Water gas mixture shift reaction.



Heat of reaction $\Delta H = -42 \text{ MJ/kg mole.}$

Another reaction is formation of Methane.



$\Delta H = -88 \text{ MJ/kg mole.}$

Product gas from Gasification is a mixture of $\text{CO} + \text{CO}_2 + \text{CH}_4 + \text{H}_2 + \text{H}_2\text{O}(\text{steam})$

3) Bio chemical conversion :- A bio-chemical

conversion process uses $\downarrow$ microorganisms or enzymes to convert organic matter into valuable products like biofuels and biogas.

Common methods include

(i) Anaerobic digestion

(ii) Fermentation

The above methods are often more sustainable and operate at lower temperatures than thermochemical methods, making them suitable for materials with high water content.

Anaerobic digestion :- Anaerobic digestion involves the microbial digestion of biomass. An Anaerobe is a micro-organism that can live & grow without air or oxygen, it gets its oxygen by the decomposition of matter containing it.

It has already been used on animal manure but it also possible with other biomass. The process takes place at low temperature upto 65°C & requires a moisture content of at least 80%.

→ It generates a gas consisting of CO_2 & methane (CH_4) with minimum impurities such as hydrogen sulfide. The gas can be burned directly or upgraded to synthetic natural gas by removing CO_2 .

(5)

Biomas used for anaerobic digestion are wet sewage sludge, animal dung or green plants in the absence of oxygen.

- Feedstocks like wood shavings, straw, & refuse may be used but digestion takes much longer.
- The natural decay process "anaerobic decomposition" can be speeded up by using a thermally insulated, air tank ^{light} with a stirrer unit & heating system.
called digestor. The gas collects in the digester tank above the slurry & can be piped off continuously.
- At optimum temp. (35°C) complete decomposition of animal or human ~~sewa~~ ^{dung} takes around 10 days.
- Each kilogram of organic material (dry weight) can be expected to yield 450-500 litres of biogas (9-12 MJ).
- The residue left after digestion is valuable fertilizer. It is also rich in protein & could be dried & used as animal feed supplement.

For 2 marks: What is meant by anaerobic digestion?

- Anaerobic digestion is a biological process, where microorganisms break down biodegradable organic matter in the absence of oxygen to produce biogas & a nutrient-rich material called digestate, which is used as a fertilizer or soil conditioner.

Fermentation:- Fermentation is the breakdown of complex molecules in organic compound under the influence of a ferment such as yeast, bacteria, enzymes etc.

Fermentation is a well-established & widely used technology for the conversion of grains & sugar crops into ethanol.

This process requires high cost & high energy required.

→ One scheme considered for reducing costs of ethanol production by fermentation is in finding less expensive grains or sugars & a process that requires less energy.

As stated ^{above}, ethanol (ethyl alcohol) is produced by the fermentation of sugar solution by natural yeasts.

→ After about 30 hrs of fermentation the brew (or beer) contains 6-10% alcohol & this can readily be removed by distillation.

→ Fermentable sugars which are used in fermentation process for the production of ethanol can be getting from different residues like

- (i) plant crops like sugar cane ~~bagasse~~ bagasse
 - (ii) Feed stocks include crushed sugar cane, beet etc
 - (iii) sugarcane also be manufactured from vegetable starches, cellulose, maize, wheat grain, or potatoes
- They must be ground or pulped & then cooked with

enzymes to release the starch & convert it to fermentable sugars to produce ethanol.

→ After fermentation, the residue from grains & other feed stuffs contains high protein content & is a useful cattle-feed supplement.

How Anaerobic digestion process works:

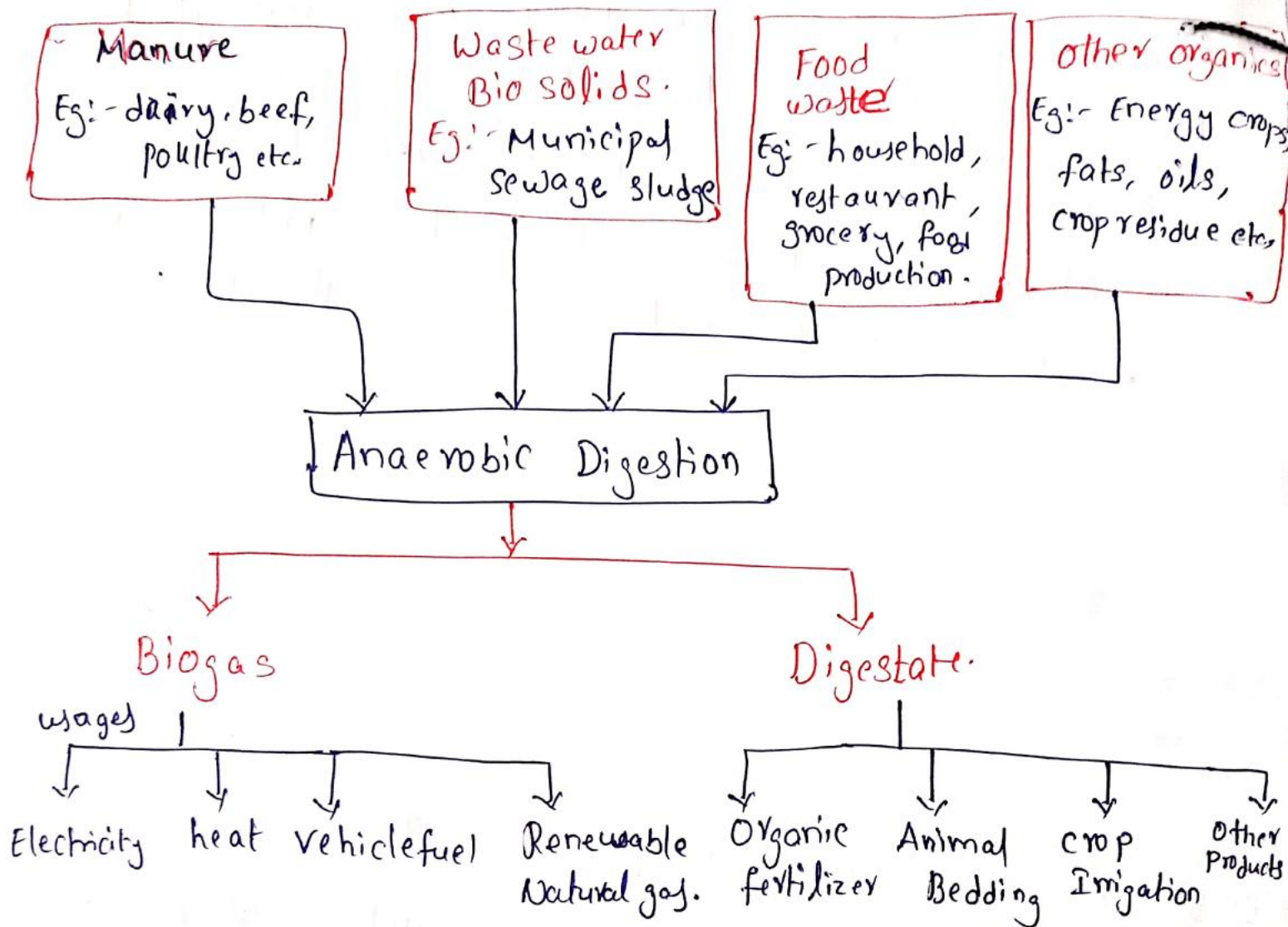
A complex community of bacteria decomposes the organic waste, which can include sewage sludge, animal manure, food scraps, & crop residues.

→ The process takes place in a sealed vessels called digesters, which are designed to operate in oxygen free conditions.

→ The two main products which are getting from anaerobic digestion are Biogas & digestate.

Biogas → CO_2 & CH_4 that can be used for heat Electricity or as a natural gas substitute.

Digestate → A liquid or solid residue rich in nutrients, applied for a fertilizer used as fertilizer.



Bio gas Generation :- Biogas is a mixture

containing 55-65% methane (CH_4), 30-40% CO_2 & the rest being the impurities, can be produced from the decomposition of animal, plant & human waste.

- It can be used directly in cooking, reducing the demand for fire wood. Moreover, the material from which the biogas is produced retains its value as a fertilizer & can be returned to the soil.
- Biogas has been popular on the name "Gobar Gas" mainly because cow dung has been the material for its production. It is not only the excreta of the cattle, but also the piggery waste as well as poultry droppings are very effectively used for biogas generation.
- A few other materials through which biogas can be generated are crop residue, garbage, kitchen wastes, paper wastes, sea weed, human waste, waste from sugarcane refinery, etc; apart from the above mentioned animal wastes.

Biogas is produced by mainly Anaerobic digestion, pyrolysis or hydrogasification.

Digestion is a biological process that occurs in the absence of oxygen & in the presence of anaerobic organisms at ambient temperatures & pressures of $30-70^\circ\text{C}$.

The container in which this digestion takes place is known as digester.

→ Biogas technology is concerned to microorganisms. These are living creatures which are microscopic in size & are invisible to our eyes.

There are different types of microorganisms. They are called bacteria, fungi, virus etc.

→ Bacteria again can be classified into two types.

(i) Beneficial bacteria (ii) Harmful bacteria.

(ii) Bacteria causing cholera, typhoid, diphtheria are the examples of harmful bacteria. This type of bacteria which causes disease both in animals & human beings is called pathogen.

(i) Compost making, production of biogas, vinegar etc. are examples of beneficial bacteria.

Bacteria can be divided into two major groups based on their oxygen requirement.

Those which grow in presence of oxygen are called aerobic while the others grow in the absence of gaseous oxygen are called anaerobic.

(8)

When organic matter undergoes Fermentation (process of chemical change in organic matter brought about by living organisms) through anaerobic digestion, gas is generated, known as Bio gas.

→ Aerobic fermentation produces CO_2 , NH_3 etc, ^{Mainly}

→ Anaerobic fermentation " CO_2 , CH_4 , H_2 etc, ^{Mainly}

In a biogas power plant the main aim is to generate methane & hence anaerobic digestion is used.

As already mentioned the treatment of any slurry or sludge containing a large amount of organic matter, utilizing bacteria & other microorganisms under anaerobic conditions is commonly referred to as anaerobic digestion or simply digestion.

This anaerobic digestion consists broadly of 3 phases,

- (i) Enzymatic hydrolysis
- (ii) Acid Formation (Acidogenesis)
- (iii) Methane Formation (Methanogenesis)

(i) Hydrolysis : - Complex organic polymers like carbohydrates, proteins & fats are broken down into simpler & soluble molecules like sugars, amino acids & fatty acids.

- This stage is carried out by hydrolytic bacteria that release enzymes to break the large molecules.
- It is often the slowest step in the process, & its efficiency can determine the overall rate of digestion.

(ii) Acid formation ^(a) (Acidogenesis). Acidogenic bacteria further ferment the simple molecules from hydrolysis.

→ This process converts sugars, amino acids, fatty acids into volatile fatty acids along with ammonia, CO_2 & hydrogen.

~~(iii)~~ ~~Methane~~ ^(b) Acetogenesis! - In this stage, acetogenic bacteria further breakdown the volatile fatty acids produced in the acidogenesis stage into Acetic acid, hydrogen & CO_2 .

Acetogenesis is an essential step before methane production can occur.

(iii) Methane formation! - Where organic acids i.e. Acetic acid, hydrogen & CO_2 are produced in the previous stages are then converted into Methane (CH_4) & carbon dioxide (CO_2).

This stage is where the majority of biogas production occurs, with methane being the primary component of biogas.

(9)

These stages are interconnected & depend on the presence of specific groups of microorganisms to efficiently breakdown organic matter & produce biogas.

The overall process is sensitive to environmental factors such as temperature, pH & substrate composition, which can influence the efficiency of biogas production.

→ pH value b/n 6.5 to 8 is the best for fermentation & normal gas production.

→ Methane bacteria works best at a temp. of b/n 35° - 38°c.

The fall in gas production starts at 20°c & stops at a temp. of 10°c.

Some other factors affecting the generation of Biogas.

are (i) As we know pH & temperature which can influence the n of Biogas.

- (ii) Seeding
- (ix) preure, type of feed stock.
- (iii) Total solid content of the feed material
- (iv) Loading rate
- (x) Rate of feeding
- (v) Diameter of depth ratio.
- (vi) Nutrients
- (vii) carbon to nitrogen ratio
- (viii) Mixing of the content of the digester.

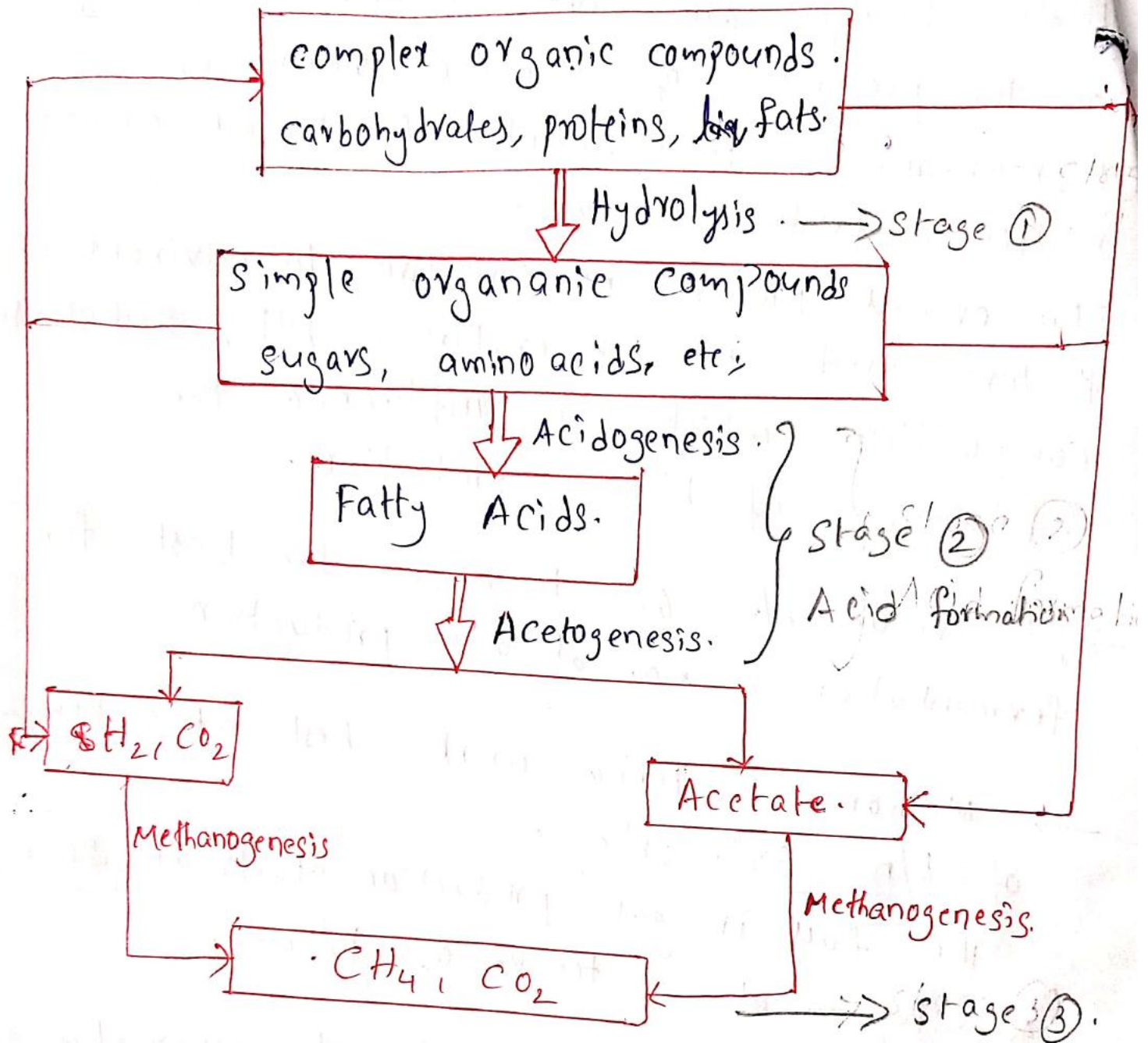


fig- Stages of Anaerobic digestion.

Biogas generation plants :- Biogas generation plants are facilities that convert organic waste into renewable energy through a process called anaerobic digestion, where microorganisms break down biodegradable material in the absence of oxygen.

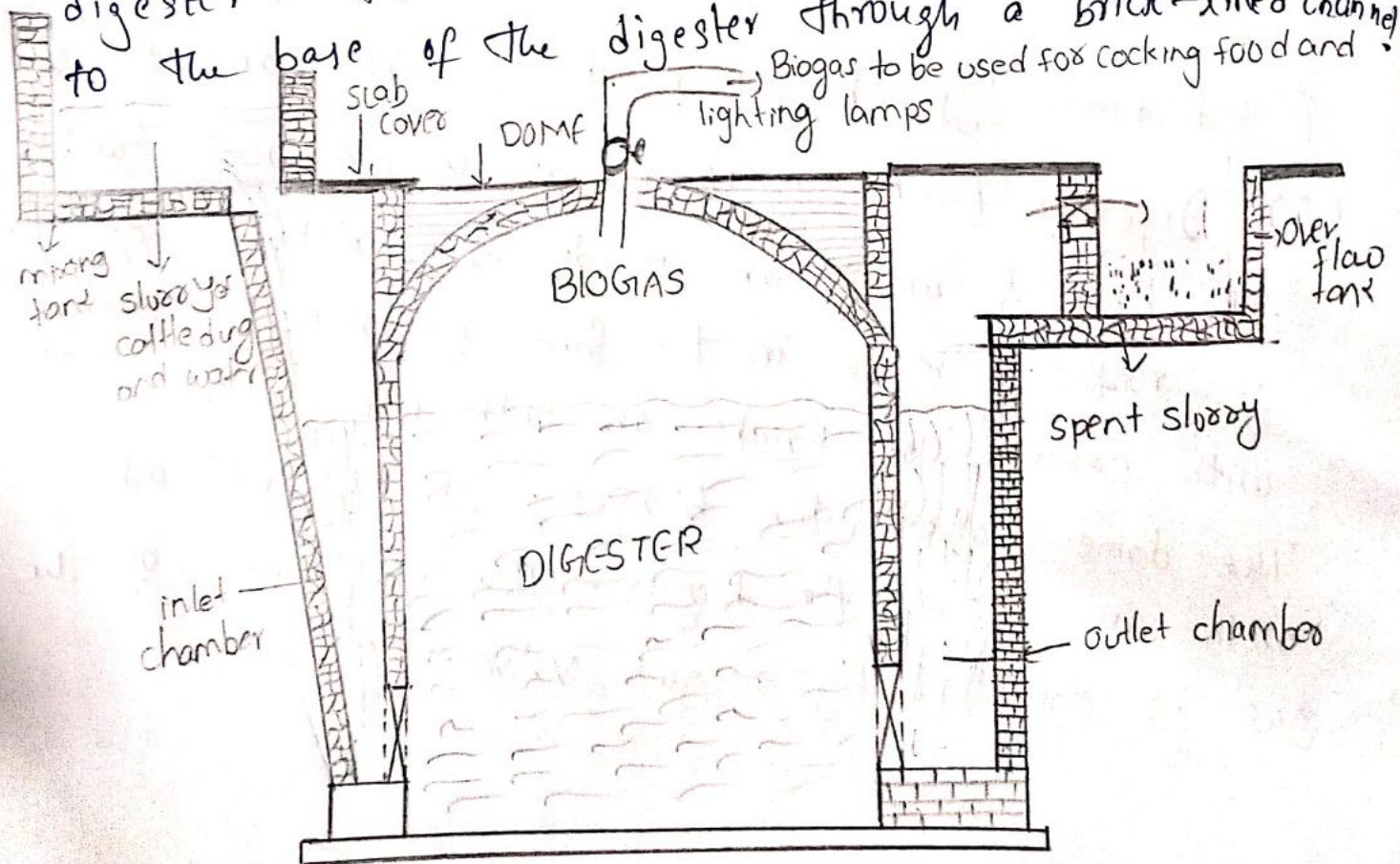
- They consists of → an inlet for feeding organic material like animal waste or food scraps, ,
 → a digester tank for the fermentation process &
 → a gas holder to store the produced biogas.

The captured biogas is then used for cooking, heating or electricity generation, while the leftover material can be used as fertilizer.

Fixed dome type biogas plant :- It consists of
 (i) Digester tank :- It is an underground tank, Its base & walls are made of bricks & cement. Its roof is made in the form of dome either with cement or bricks or with concrete.
 The dome collects the biogas. It is provided with an outlet for biogas. The outflow of the gas is controlled by a gas valve.

(ii) Slurry mixing tank :- On the left hand side of the digester is constructed a brick-lined tank above the ground level. The bottom of this tank connects the digester through a brick-lined channel near the base. The fresh slurry of animal dung & water in equal proportions is poured into the slurry mixing tank. This slurry slowly flows into the digester.

(iii) Spent slurry tank :- On the right hand side of the digester is constructed spent slurry tank, below the ground level. The base of this tank is in line with the lowest point of the dome of the digester. The base of this tank is connected to the base of the digester through a brick-lined channel.



working: Everyday the slurry of animal dung & water in equal proportions is poured into the mixing tank. (11)

- This slurry flows into the digester.
- In the digester anaerobic fermentation process starts with the release of biogas.
- The biogas formed collects in the dome.
- As more & more slurry flows into the digester every day, the level of slurry rises up.
- It takes about 30 to 60 days for the slurry to fill the digester depending upon the temperature within the digester.
- During this time the biogas collects in the dome under pressure.
- When the pressure of biogas exceeds a certain limit, the biogas forces the spent slurry into an overflow tank.
- The biogas is withdrawn from the dome through the outlet pipe. Its flow is regulated by a gas valve.
- The spent slurry is periodically removed & is allowed to dry. It is then used as manure.
- Once the biogas plant gets operative, it is a continuous process. The every day fresh slurry is added in the mixing tank & spent slurry is removed from the overflow tank.

Floating dome type biogas plant :- A Floating drum type biogas plant uses an underground digester to break down organic matter & (gas holder) a movable, floating steel drum for gas storage.

→ In a floating dome biogas plant, the gas holder is separate from the digester.

But in the fixed dome digester, the gas holder & the digester are combined.

The family size biogas plants available today in India are broadly of two types.

(i) The Khadi village Industries commission model (or) Floating gas holder design. (KVIC)

(ii) Tanta model or fixed dome digester, similar in construction to KVIC model except that the steel drum is replaced by a fixed dome roof.

The working of Floating dome type is same as that of Fixed dome type Biogas plant.



Introduction to fuel cells.

A fuel cell is a device that generates electricity by a chemical reaction (chemical energy converted into Electrical energy).

Every fuel cell has two electrodes, the ^(-ve electrode) anode & the cathode (+ve electrode).

The reactions that produce electricity take place at the two electrodes.

Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other electrode & a catalyst which speeds the reactions at the electrodes.

Multiple fuel cells are usually assembled into a stack & generate direct current (DC).

→ Fuel cells produce electricity and heat as long as fuel is supplied.

Despite being invented in the year 1838, fuel cells began commercial use only a century later when they were used by NASA to power space satellites. Today these devices are used as primary or secondary source of power for many facilities including industries, commercial buildings, residential buildings.

The fuel cell serves two purposes
→ It was used as fuel source as well as source drinking water. (the water vapour produced from the cell, when condensed it was used for human consumption).

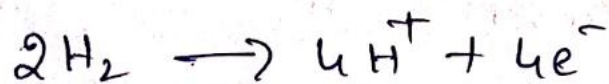
Construction of Hydrogen Fuel cell (or) H_2O_2 fuel cell

It has two electrodes, the anode (-ve electrode) & the cathode (+ve electrode).

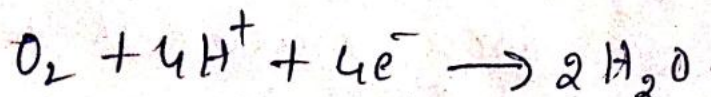
It also has an electrolyte (used as polymer electrolyte membrane, also called as proton exchange membrane) which carries electrically charged particles from one electrode to the other electrode.

Working: - H_2 is fed at anode & O_2 usually from air fed at cathode.

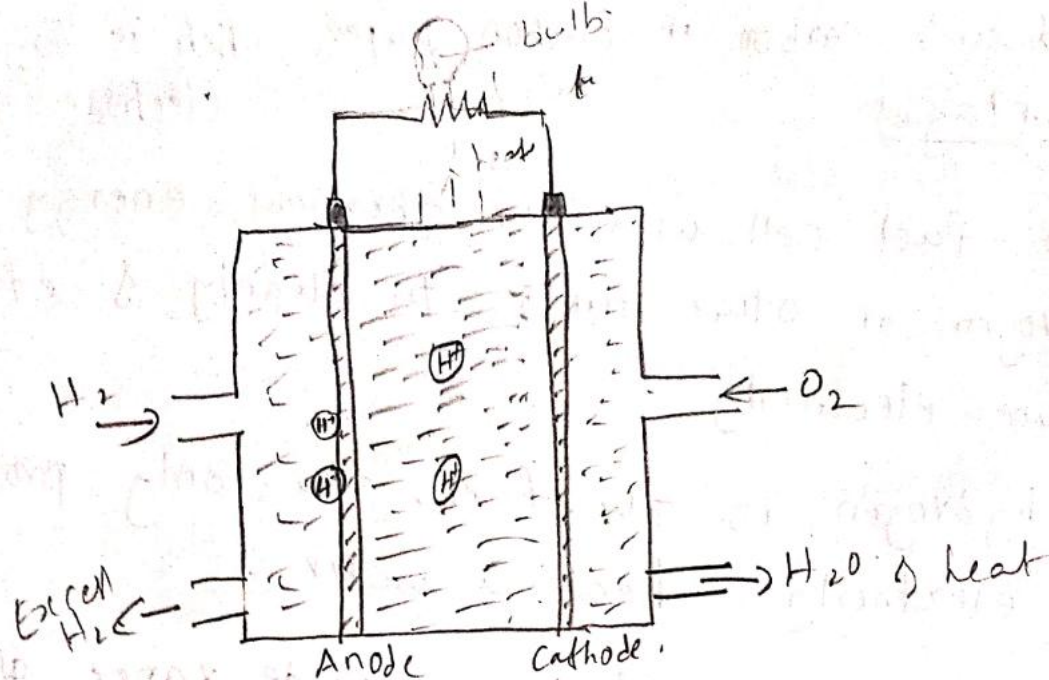
At anode, the H_2 gas ionizes releasing electrons & H^+ ions (or) protons.



At cathode, O_2 reacts with electrons & protons to form water.



The above reaction is continuous, electrons produced at anode pass through an electrical circuit to the cathode.



In a hydrogen fuel cell, H_2 is fed at anode it split into protons & electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity.

The protons migrate through the electrolyte to the cathode, where they unite with oxygen & the electrons to produce water & heat.

Basically the reaction process in fuel cell is very slow. To increase reaction process fastly a suitable catalyst is added. This increases the temp. The fuel cell electrode is highly coated with platinum catalyst.

Here the platinum is highly expensive. [water formed at cathode removed periodically by the process of gas diffusion layer formed on the surface (or)]

Coated with carbon or carbon paper which is layered on electrode surface.

Advantages

→ A fuel cell uses the chemical energy of hydrogen or other fuels to cleanly & efficiently produce electricity.

If hydrogen is the fuel, the only products are electricity, heat & water.

→ It can be used in a wide range of applications, providing power for applications across multiple sectors, including transportation, industrial/commercial/residential buildings, & long term energy storage for the grid in reversible systems.

→ Fuel cells can operate at high efficiency than combustion engines.

→ It has lower or zero emissions compared to combustion engines.

→ It emits only water addressing critical climate challenges as there are no CO_2 emissions.

→ There also no air pollutants that create smog & cause health problems at the point of operation.

→ Fuel cells are quiet during operation as they have few moving parts.

Types of fuel cells

Fuel cells are classified primarily by the kind of electrolyte they employ.

This classification determines the kind of electro-chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, & other factors.

→ These characteristics, in turn, affect the applications for which these cells are most suitable.

There are several types of fuel cells currently under development, each with its own advantages, limitations & potential applications.

- (1) Polymer electrolyte Membrane fuel cells operation temp. $\rightarrow 80^{\circ}\text{C}$
- (2) Direct methanol fuel cells
- (3) Alkaline fuel cells
- (4) phosphoric acid fuel cells
- (5) Molten carbonate fuel cells High temp
- (6) Solid oxide fuel cells High temp
- (7) Reversible fuel cells

Low temp $\rightarrow 25 - 100^{\circ}\text{C}$

Medium temp $\rightarrow 100 - 500^{\circ}\text{C}$

High temp $\rightarrow 500 - 1000^{\circ}\text{C}$

Very high $\rightarrow > 1000^{\circ}\text{C}$

Main issues in fuel cell

There are few challenges for ~~for~~ fuel cells to overcome. These are.

- (1) Cost :- Fuel cells are more costly than IC engines & even more premium than HEVs!
- (2) Water Management :- Water Management is important & difficult issue with Automobile fuel cells.
- (3) Cooling :- Thermal management is extremely difficult than IC engines.
- (4) Hydrogen supply :- H_2 is difficult in storing & producing.

(1) Alkaline fuel cell → used in space vehicles
(AFC)

Ions → OH^-

operating temp :- $50 - 200^\circ\text{C}$.

(2) proton exchange membrane → used in vehicles & mobile applications for low power systems.
fuel cell (PEMFC)

Ions → H^+

operating temp :- $30^\circ\text{C} - 100^\circ\text{C}$

(3) Direct Methanol fuel → used in portable electronic systems of low power, running for long times.
Cell (DMFC)

Ions → H^+

operating temp :- $20^\circ\text{C} - 90^\circ\text{C}$.

(4) phosphoric acid fuel → Large no's of 200 kW CHP systems in use.
Cell (PAFC)

Ions → H^+

operating temp :- 220°C .

(5) Molten carbonate fuel → suitable for medium to large scale systems upto MW capacity.
Cell (MCFC)

Ions → CO_3^{2-}

operating temp. - 650°C .

(6) solid oxide fuel cell → suitable for all size CHP from 2 kW → MW. systems.
(SOFC)

Ions → O^{2-}

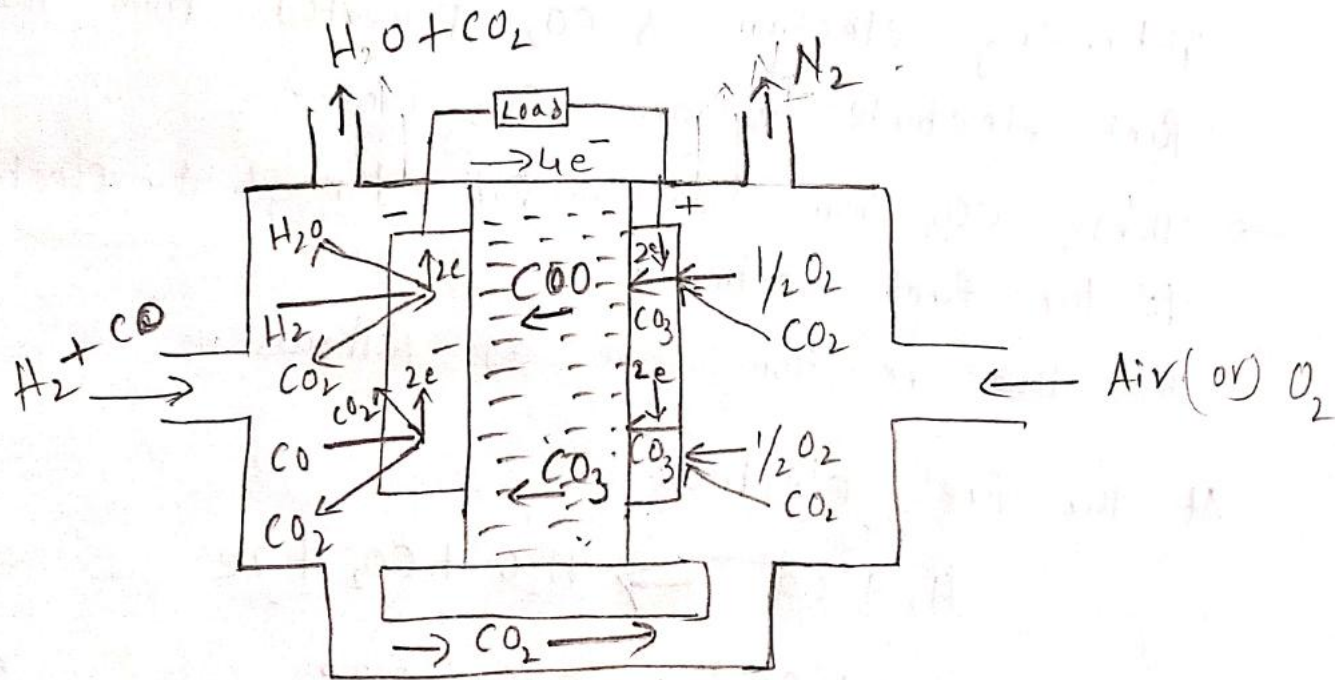
operating temp. → $500^\circ\text{C} - 1000^\circ\text{C}$.

Among all fuel cells proton exchange membrane fuel cell is mostly used due to its simplicity.

Molten carbonate fuel cells :- These are high temp. fuel cells, with a Molten carbonate mixture as the Electrolyte.

A special feature of these cells is that during operation they can oxidize carbon monoxide to carbon dioxide as well as hydrogen to water.

Hence gaseous mixture of hydrogen & carbon monoxide, which are relatively inexpensive to manufacture, can be used in the cell, the presence of carbon dioxide would have only a minor effect.



Molten carbonate fuel cell.

The mixture of Hydrogen & carbon monoxide is supplied to the negative electrode & oxygen from the air to the positive electrode. The discharge emf of the cell is about 0.8 Volts.

→ Metallic electrodes are placed in direct ~~contact~~ with this solid electrolyte.

→ A hydrocarbon fuel, such as methane or kerosene is used.

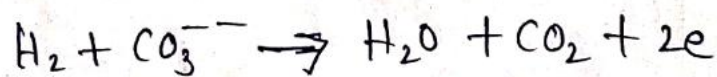
→ The fuel is reacted inside the cell to produce H_2 & CO . At the fuel electrode, H_2 & CO react with CO_3 ions in the electrolyte, releasing electrons to the electrode & forming H_2O & CO_2 .

→ At the oxygen electrode O_2 reacts with the returning electrons & CO_2 diverted from the fuel electrode to form CO_3 ions.

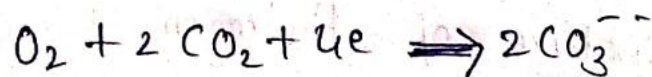
→ These CO_3 ions then migrate through the electrolyte to the fuel electrode.

Thus the reactions are as follows.

At the fuel electrode:



At oxygen electrode,



~~over~~ ^{over} all cell reaction,

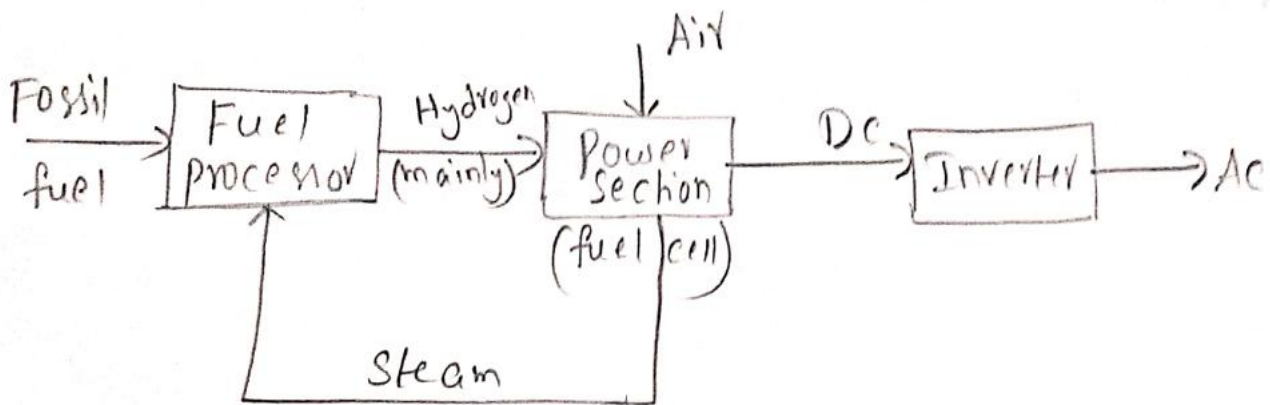


An important aspect of the molten carbonate fuel cells is that the discharged gases, consisting mainly,

of the steam & carbondioxide products & nitrogen⁽⁶⁾
from the air, are at a temp. exceeding 540°C .

Advantages of fuel cell

Main components of fuel cell system.



- (1) Fuel processor which converts the fossil fuel into a hydrogen rich gas.
- (2) The power section consisting of the actual fuel cell (combination of cells) &
- (3) The inverter for changing the direct current generated by the fuel cell into AC to be transmitted to user.

Main components of fuel cell system are shown in Fig above.

The most highly developed fossil fuel cells are phosphoric acid cells, molten carbonate cells, solid oxide electrolyte cell.

→ The operating temp. is 150 to 200°C & the discharge voltage is 0.7 to 0.8 volt.

→ Each cell unit is only a few millimeters thick so that a large number can be stacked in a package of reasonable size to produce the desired voltage & power.

Stack :- No. of fuel cells are connected in series to produce the desired voltage.