Non-Conventional energy Sources :—

The energy sources which are ~~Capte~~ capable of being replaced (or) renewed by natural processes are called Non-Conventional energy Sources.

These natural resources are in exhaustible and can be used to produce energy again & again. Therefore they are also called Alternative energy Sources.

The important non-conventional energy sources are :—

1. Solar energy
2. Wind energy
3. Hydropower energy
4. Biomass energy
5. Tidal energy.
6. Geothermal energy.
7. Hydrogen energy & Fuel. cell.

1. Solar energy :—

* The Sun is a Source of solar energy.
* It is a large hydrogen reactor in which Continuous nuclear fusion reaction produces enormous amount of energy in the form of Solar radiation.
* The Sun is 150 million km away from the ~~ar~~ earth and most of energy lost in the travelling, ~~towards the earth~~. only 4% of the total Solar energy reaches to surface of the earth.

2. Wind energy:-

* Wind energy describes the process by which wind is used to generate electricity. There is no pollution because no fossile fuels are burnt.
* As the wind increases, power output increases upto the maximum capacity of turbine.
* These are generally located at high altitudes.
* The wind energy potential in India is estimated upto 20,000 to 25,000 MW.

3. Bio mass Energy:-

* Biomass energy is originates from plants, animals, wood & sewage.
* It produces the heat energy which is converted into electrical energy.
* The chemical composition is varied for different species but ~~the~~ in each composition 25% of lignin & 75% of carbohydrates are present.
* Most of the biomass energy is utilized in cooking and lighting purpose.
* Energy contribution of biomass ~~on~~ is approximately 14% compared to other sources.

4. Biogas:-

* Main source of this energy is cow dung.
* Due to availability of large cattle population in India (250 millions), the energy source becomes significant.
* Other sources produces the Biogas are
  - i) Sewage
  - ii) Crop residue
  - iii) Vegitable waste etc.

5. **Tidal Energy:—**

* Tides are produced due to Universal gravitational effect between the Sun and Moon.
* Tidal energy is form of Hydropower.
* If the tide hight is more than sealevel mean hight it is called flood tide
* If the tide hight is less than mean level of sea, it is called ebb tide.
* Gulf of Cambay, Gulf of Kutchh } are the Sources of tidal Energy.
  Sundarbans in West Bengal }

6. **Geothermal:—**

* Geothermal energy is heat energy from the earth - Geo (earth) + thermal (heat).
* Geothermal resources are reservoirs of hot water that exist (or) are human made at Varying temperature and depths below the Earth's Surface.
* The promising geothermal sites for direct heat use applications are Rajgir in Bihar, Manikaran in Himachal pradesh, Surajkund in Jharkhand.

———o———

Environmental Impact of Solar Power:-

Solar energy is available in abundance and considered the easiest and the cleanest ~~one~~ renewable energy source. However, the main problems associated with tapping solar energy are

* High cost in populated areas because of large area of land requirement.
* Solar thermal system use heat transfer fluids like glycol ~~and~~ nitrates and sulphases and for high temperature applications, CFCs and aromatic alcohols are required. these fluids may pose a health hazards in public domain due to careless disposal.
* Due to the presence of arsenic and cadmium in solar photovoltaic modules pose disposal problems
* Solar reflectors Hazard to eye sights.
* Solar thermal collectors and photovoltaic (PV) systems have now become an integral part of high-rise buildings in metropolies in large scale. Which limits the daylight due to changes in albedo.

Solar energy ~ Option:-

Solar energy can be a major source of power. Its potential is 178 billion mw., which is about 20,000 times the world's demand.

→ This solar energy can be utilised as thermal and photovoltaic.

→ The energy radiated by the sun on a bright day is approximately 1 kw/m^2.

→ The utilization of solar energy is of great importance to India. Since it lies in a temperature climate of the region of the world where sun light is abundant for a major part of the year.

→ The applications of solar energy which are enjoying most success today are:

1. **Heating and cooling of residential buildings:**

   The heat from solar energy can be used to cool buildings, using the absorption cooling principle operative in gas-fired refrigerators.

2. **Solar water heating:-**

   A solar water heater commonly comprises a blackened flat plate metal collector with an associated metal tubing, which is facing towards the general direction of the sun. The collector is provided with an transparent glass cover a layer of thermal insulation under the plate. The collector ~~plate~~ tubing is connected by a pipe to an insulated tank that stores the hot water during non-sunny ~~days~~ periods.

3. **Solar Distillation:—**

In the solar distillation process solar energy is used to evaporate water and its Condensate is collected within the same closed system. Unlike other forms of water purification methods, This method can be used to turn salt or brackish water into fresh drinking water. Solar distillation is simply boiling water due to its usage of 'free' and ecofriendly solar energy.

4. **Solar drying of agricultural and animal products :—**

The principle of Solar drying technique is to Collect Solar energy by heating-up the air volume in solar Collectors and Conduct the hot air from the collector to an attached enclosure there the products to be dried ~~at~~ are laid out.

Solar dryers are economical Compared to dryers that rely on Conventional fuel/electricity.

5. **Solar Cookers:—**

Solar cooker works on the principle that Sunlight warms the pot, which is used for cooking the food. Now, the warming of the pot occurs by Converting light energy to heat energy. Concave mirrors are used in these types of Cookers because these mirrors reflect Sunlight into a single focal point.

6. **Solar refrigerators:—**

Solar powered refrigerator is a refrigerator which runs on energy directly provided by Sun, either photovoltaic (or) Solar thermal energy.

These are typically used in off-grid locations where AC power is not available

7. Electrical Energy from Solar Energy:-

Solar electric power generated by

i) ~~Sto~~ ~~Sl~~ Solar ponds

ii) stream generators heated by rotating reflectors (heliostat mirror), or by tower concept

iii) Reflectors with lenses and pipes for fluid circulation (cylindrical parabolic reflectors)

iv) Solar ~~pol~~ photovoltaic cells, which can be used for conversion of solar energy directly into electricity (or) for water pumping in rural agricultural purposes.

Physics of the Sun:-

Solar physics is the branch of Astrophysics which specifises the study of the sun. and it deals with the detailed measurement of our closest star.

→ The structure of the sun contains 80% Hydrogen, 19% Helium, and remaining 1% ~~Contain~~ Consists more than 100 elements.

→ Sun is huge ball of Hydrogen and helium hold together by its own gravity which satisfies all our energy needs.

→ The principle of solar energy is "Thermal nuclear fusion Reaction". According to This, the solar energy created by nuclear fusion that takes place due to the collision of Hydrogen atoms inside the core of the sun, which results Helium atoms and a lot of heat energy.

→ The following figure shows the different layers of the sun.

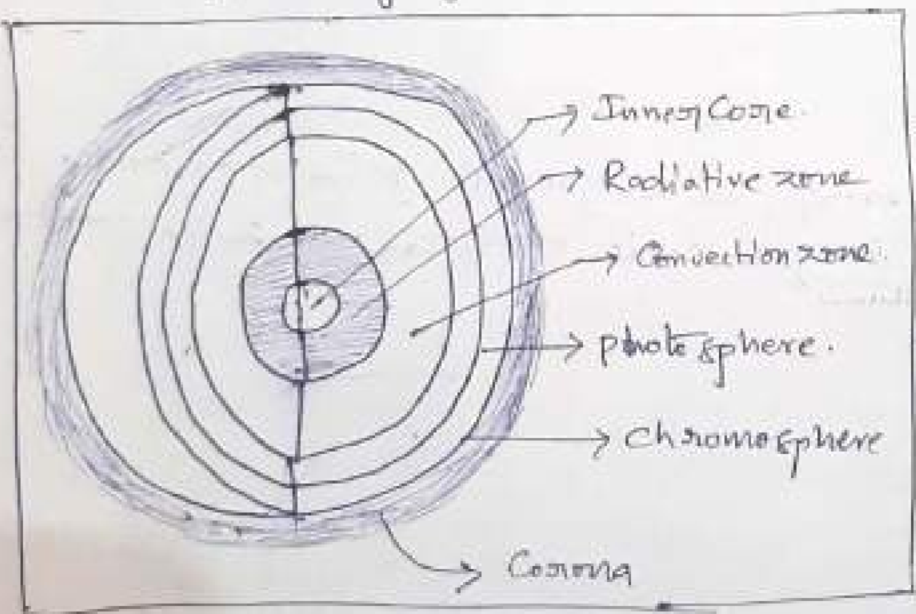


Fig: Structure of the Sun.

Inner layers

1. Core:- where energy is produced based on thermonuclear reaction.

2. Radiation zone:- Energy from the core is carried away in the form of Electromagnetic waves.

3. Convective zone:- Outermost zone of solar interior where the gas converts heat to surface.

Outer layers:-

photosphere:- This is the surface of the sun

Chromosphere:- In this layer low density gases of the Atmosphere are formed.

Corona: This is the outer part of Atmosphere.

The spectral regions in radiation zone are shown in following table

Spectral region	% of total Energy	wave length
UV	7%	< 0.39 μm
Visible	47%	0.39 – 0.78 μm
Infrared	46%	> 0.78 μm

Measurements of the Sun:—

1. Diameter of the Sun 1.39×10^6 km
   Where earth diameter is 1.27×10^4 km.
2. Distance b/w earth & Sun is 150×10^6 Km.
3. Sun generates 9×10^{25} cal/sec of energy.
4. Temperature of the outer layer is 5785°c.
5. Temperature of the Centre of the core is 20×10^6 °c
6. Rate of energy transmission 3.8×10^{23} kW.

——— o ———

* Solar Constant :-

→ The rate at which the solar energy arrives at the top of the earth atmosphere is called the solar constant " I_{sc}.

"This is the amount of energy received in unit time on unit area perpendicular to sun's direction at the mean distance of the earth from the sun."

→ The National Aeronautics and Space Administration's (NASA) gives the standard value for solar constant, expressed in three common units

1). 1.353 Kilowatts per square metre (or) 1353 watts per square metre.
2). 1165 Kcal per sq.m. per hour.
3) 429.2 Btu per sq.ft per hour.

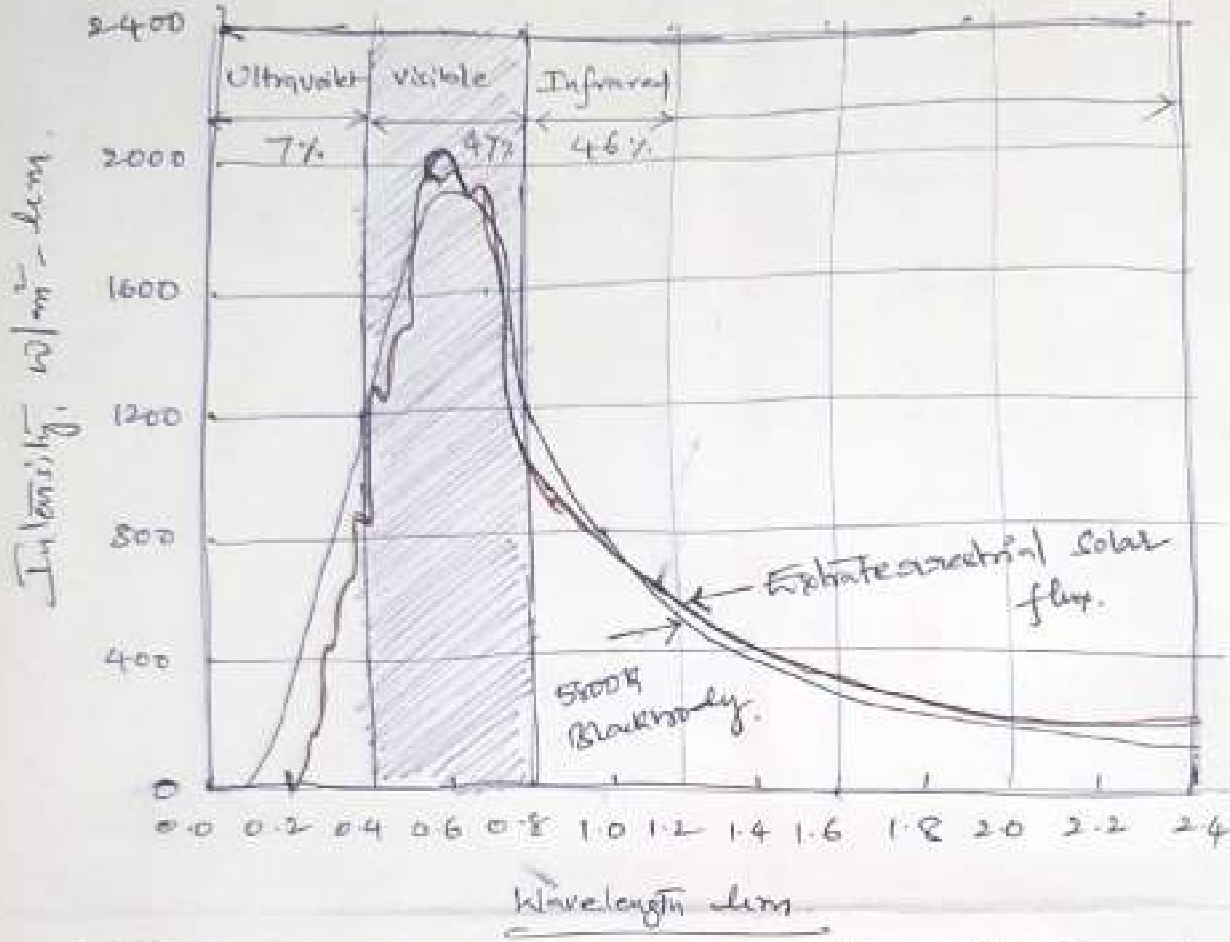
→ ~~The distance b/w~~ As the distance b/w earth & sun is varies a little through the year the extraterrestrial flux also varies.

→ The earth closest to the sun in ~~w~~ summer and farthest in winter. Hence the intensity 'I' of the solar radiation is reaches the earth like sinusoidal. This can be approximated by equation.

$$\boxed{\begin{aligned}\frac{I}{I_{sc}} &= 1+0.033\cos\frac{360(n-2)}{365} \\ &\simeq 1+0.033\cos\frac{360\times n}{365}\end{aligned}}$$

where 'n' is the day of the year

→ It is also useful to know the spectral distribution of extraterrestrial solar radiation. Which is shown by the fig.



→ The maximum value of solar radiation intensity at outer limit of atmosphere is 2074 W/m².

** Solar Radiation at the Earth's Surface :-

Solar radiation received at the surface of the earth is entirely different due to the various reasons. Before studying the it is important to know the following terms.

1. Beam and Diffuse solar Radiation :-

The solar radiation that penetrates the earth's atmosphere and reaches the surface differs in both amount and character than it is entered into atmosphere.

In the first place part of radiation is reflected back into space, especially by clouds. Furthermore, the radiation entering the atmosphere is partly absorbed by molecules in the air. Oxygen and ozone (O_3) formed from oxygen, absorb nearly all ultraviolet radiation; and water vapour and carbon dioxide absorb some of the energy in the infrared range.

→ In addition, part of the solar radiation is scattered (i.e., its direction has been changed) by droplets in clouds by atmosphere molecules, and by dust particles.

Beam:- Solar radiation that has not been absorbed (or) scattered and reaches the ground directly from the sun & called "direct radiation" or "Beam radiation".

→ It is the radiation which produces a shadow when interrupted by an opaque object.

Diffuse radiation:-

The solar radiation received from the sun after its direction has been changed by reflection and 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.

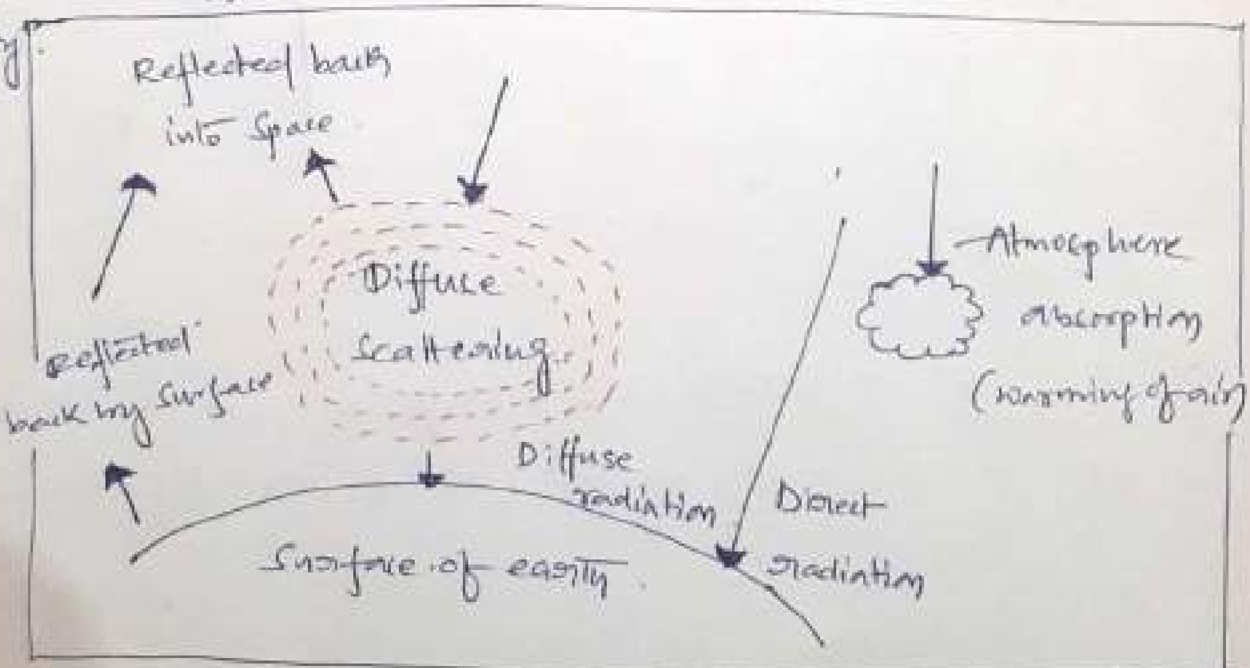


Fig: Direct, diffuse and total radiation.

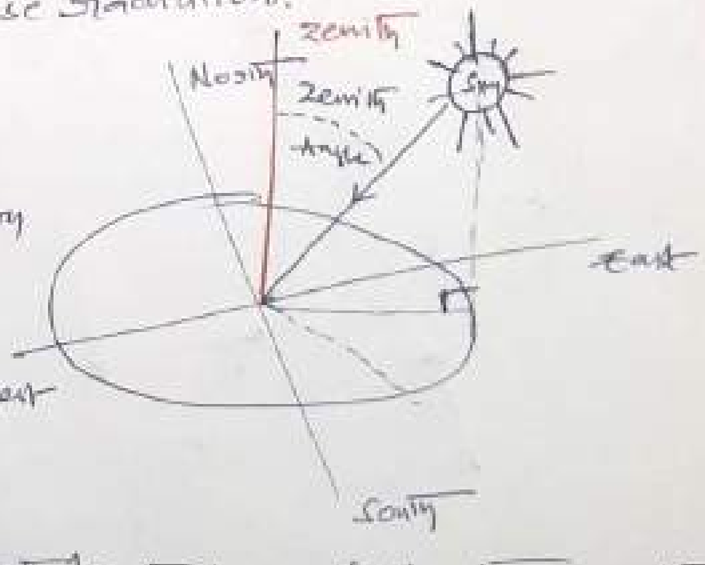
The total solar radiation received at any point on the earth's surface is the sum of the direct and diffuse radiation. This is refferred to in a general sense as the insolation at that point.

Insolation :— The insolation is defined as the total solar radiation energy received on a horizontal surface of unit area (e.g. 1 sq.m) on the ground in unit time (e.g., 1 day).

* The insolation at a given location on the earth's surface depends on the altitude of the sun in the sky. (The altitude is the angle between the sun's direction and the horizontal)
* The smaller the sun's altitude, the greater the thickness of atmosphere through which the sun radiation passes, as a result of absorption and scattering, the insolation on the surface of the earth is less.
* On a clear, cloudless days, about 10 to 20 percent of insolation is from diffuse radiation.

2. Sun at Zenith :—

It is defined as the position of the sun directly over the head.



3. Air mass (m) It is the path length of radiation through the atmosphere, considering the vertical path at sea level as unity.

→ The air mass m is the ratio of the path of the sun's rays through the atmosphere to the length of the path when the sun is at the zenith.

→ Except for very low solar altitudes angles the air mass is equal to the Cosecant of the altitude angles. line at sealevel msl.

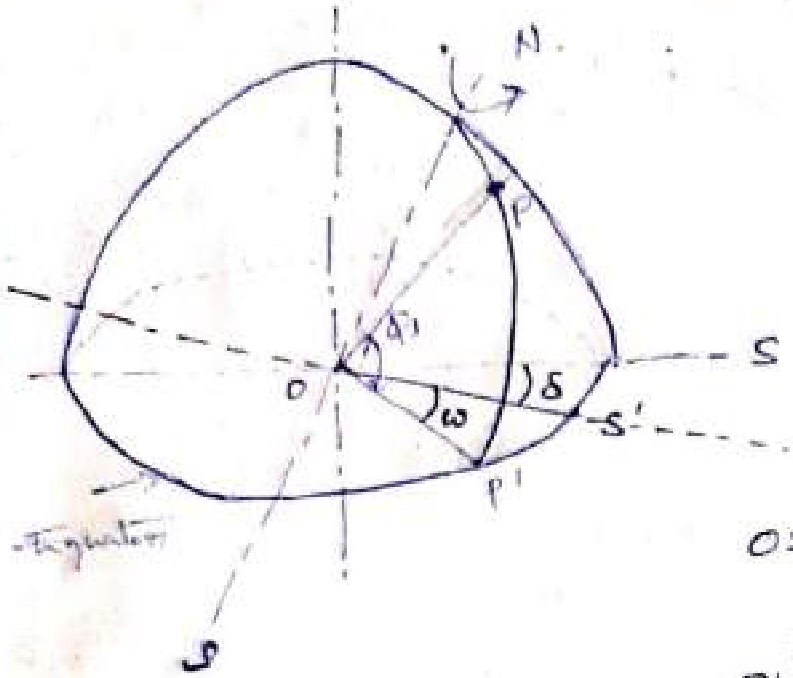
→ m=1 when the sun is at zenith, i.e., directly over head.

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

m= Secθ_z. When m>3.

m=0 just above the earth's atmosphere.

The Solar Radiation Geometry :-



O – Centre of the earth

OP – radial line joining location 'p' to the Centre of the earth.

OP' – projection on the equatorial plane.

S – centre of the sun.

Equatorial line.

OS → line joining earth centre to Centre of the Sun.

OL' → projection on the equatorial plane.

1. Latitude of location (or) ~~lat~~ angle of latitude :-

the latitude ϕ_l of a point (or) location is the angle made by the radial line joining the location to the Centre of the earth with the projection of the line on the equatorial plane.

~~From the figure~~ it is the angle b/w line OP and the projection OP' on the equatorial plane.

2. Declination angle 'δ' :-

It is the angle b/w a line extending from the Centre of the Sun to Centre of the earth and the projection of the line upon the earth's equatorial plane.

the variation of Sun's declination is ~~from~~ b/w 23.5° on June 22 to 23.5° on December 22.

The following figure shows the approximate variation of Sun's declination throughout the year.

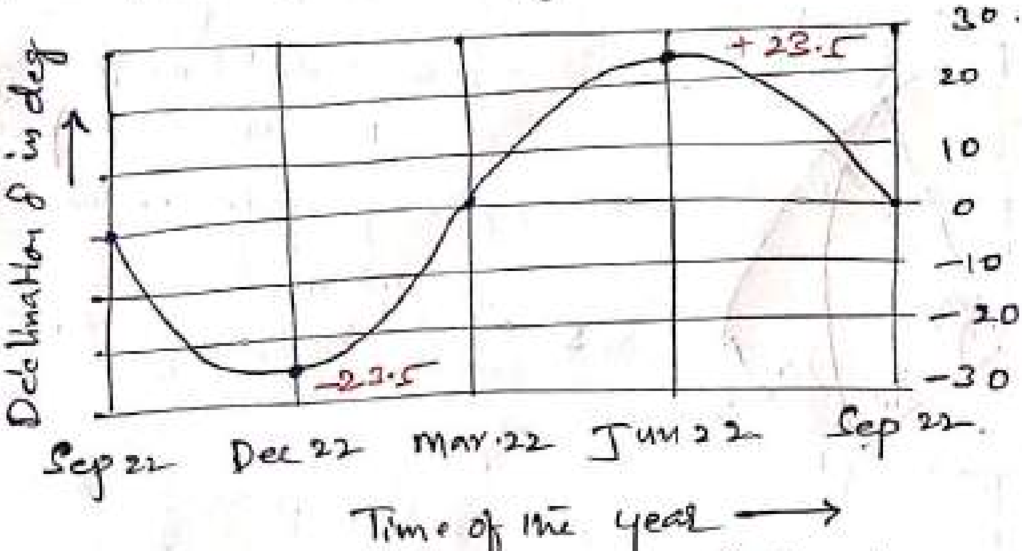
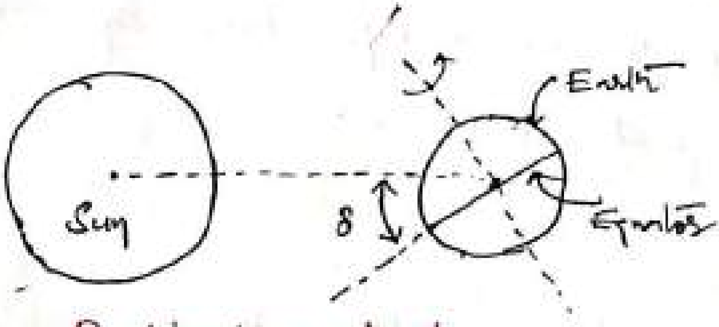


Fig: Variation of Sun's declination.

It is zero on the two equinox days of March 22 and Sept 22. The declination in degrees for any given day may be calculated from the approximate equation of Cooper.

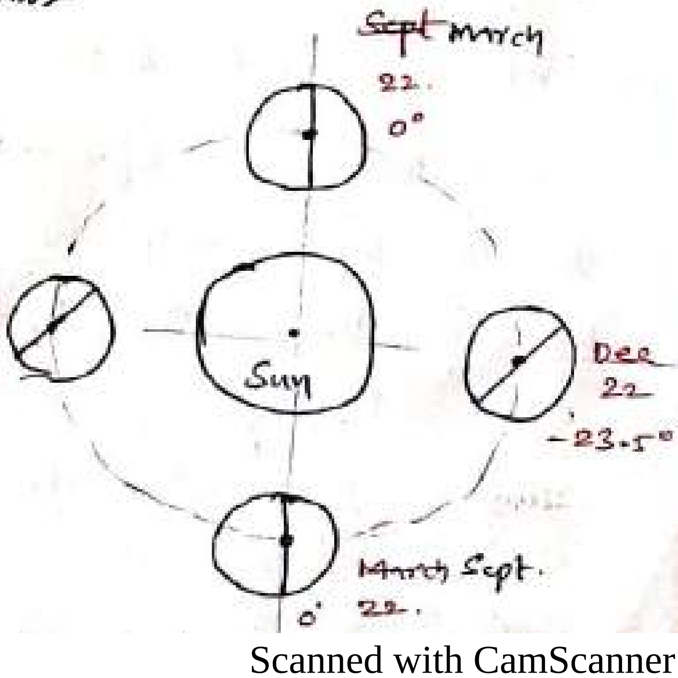
$$\delta \text{ (in degrees)} = 23.45 \sin\left[\frac{360}{365}(284+n)\right]$$

3. ~~Hour Angle~~ (ω)



Declination Angle

Variation of Sun's declination.

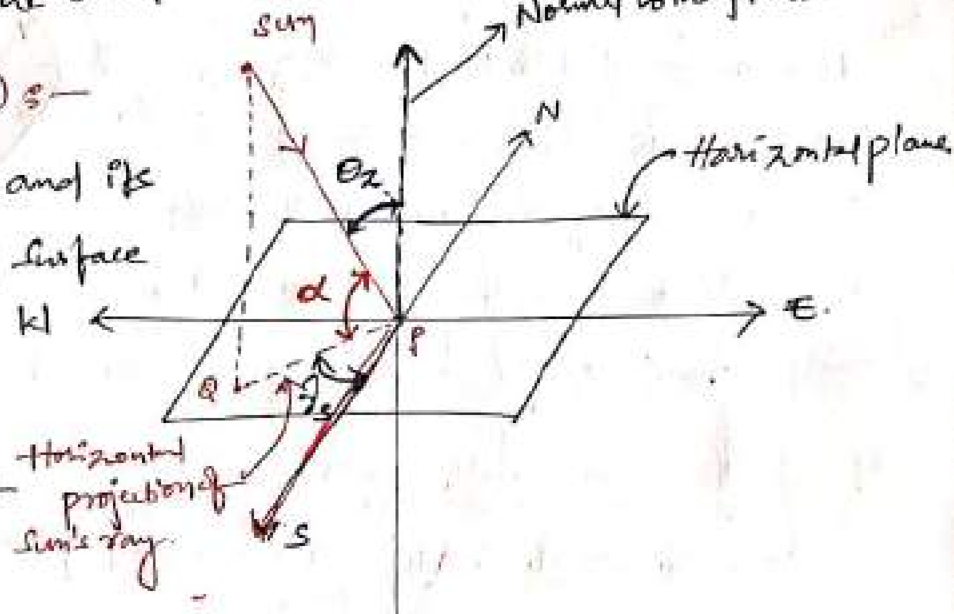


3. Hour Angle :- (ω). It is the angle through which the earth must turn to bring the meridian of a point directly in line with the Sun's rays. The hour angle 'ω' is equivalent to 15° per hour.
- Also it is measured in the earth's equatorial plane, between the projection of OP and the projection of the line from the Centre of Sun to the Centre of the earth.

4. Inclination angle (α) :-

The angle b/w Sun's ray and its projection on a horizontal surface is known as the inclination angle (α).

→ At Sunrise and Sunset the value of $\alpha = 0^\circ$.



5. Zenith angle (θ_z) : The angle b/w the Sun's ray and the perpendicular (normal) to horizontal plane is known as the zenith angle (θ_z).

Also, Zenith angle is Compliment of inclination (altitude) angle,

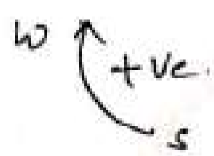
i.e., $\alpha + \theta_z = 90^\circ$.

Hence, at Sunrise zenith angle is $+90^\circ$, where as -90° at Sunset.

6. Solar azimuth angle (γ_s)

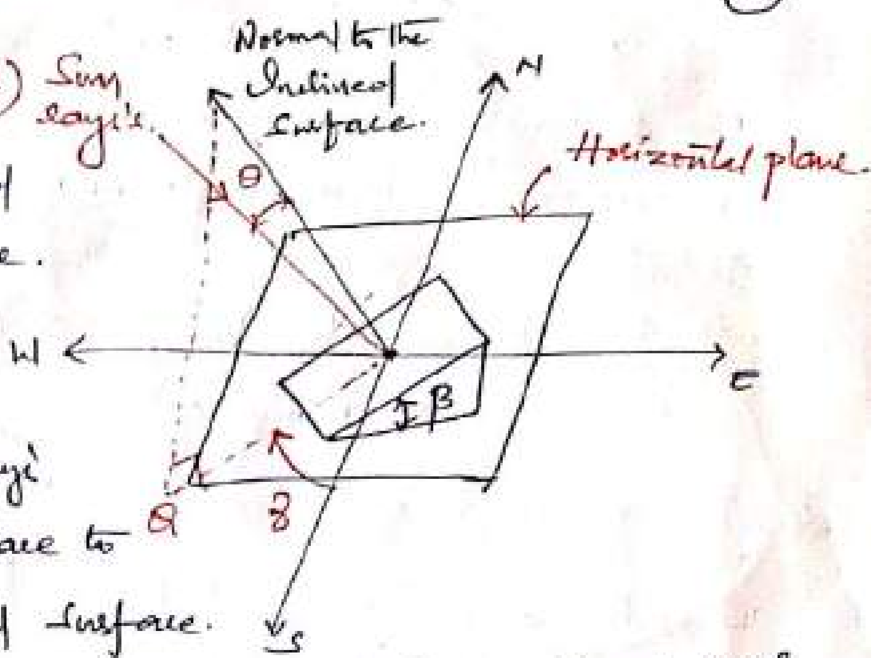
The angle on a horizontal plane, b/w the line due South and the projection of Sun's ray on the horizontal plane is known as solar azimuth angle (γ_s).

It is Considered as positive when it is measured from South towards west.



7. Tilt-Angle (or) Slope :- (β)

It is the angle b/w the inclined surface and the horizontal plane.



8. Angle of Incidence (θ)

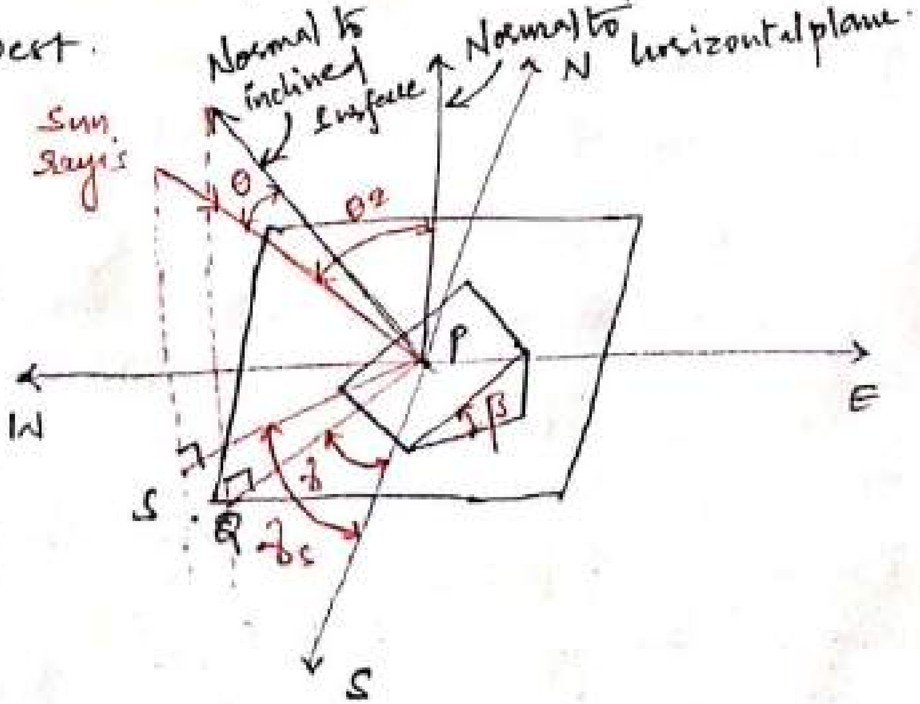
It is the angle b/w the Sun rays's Located on the inclined surface to the normal of the inclined surface.

It is denoted with 'θ'. For horizontal surface, Slope β = 0°, and zenith Angle θ_z = Angle of Incident. θ.

9. Surface Azimuth angle (γ)

It is the angle in the horizontal plane, b/w the line due to South and the horizontal projection of the normal to the inclined plane surface.

→ It is like Solar azimuth angle which is projected from South to West and measured as positive from South toward west.



From spherical geometry the relation b/w θ and other angles is given by the equation.

$$\cos\theta = \sin\phi_l(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta)$$
$$+\cos\phi_l(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta)$$
$$+\cos\delta\sin\gamma\sin\omega\sin\beta \quad \text{—— (1)}$$

Where ϕ_l = latitude $\qquad \beta$ = slope (or) tilt angle.

δ = declination angle $\qquad \gamma$ = surface azimuth angle.

ω = hour angle.

→ At solar noon the hour angle is zero and each hour angle equating to $15°$. and it can expressed as

$$\boxed{\omega = 15°(12 - LST)}$$

Ex:- ($\omega = +15°$ for 11:00 and $\omega = -37.5°$ for 14:30)

Case i) For vertical surface, $\beta = 90°$, equation (1) becomes

$$\cos\theta = \sin\phi\cos\delta\cos\gamma\cos\omega - \cos\phi\sin\delta\cos\gamma$$
$$+\cos\delta\sin\gamma\sin\omega.$$

Case ii) For horizontal surface $\beta = 0°$, $\theta = \theta_z$ zenith angle.

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

i.e., $\boxed{\cos\theta = \cos\theta_z = \sin\alpha.}$

Case iii) For surfaces facing due south $\gamma = 0$,

$$\boxed{\cos\theta_T = \cancel{\sin\phi}\cos(\phi-\beta)\cos\delta\cos\omega + \sin(\phi-\beta)\sin\delta.}$$

" Incident angle 'θ' is expressed as θ_T, denoting the surface as tilted one".

Day length :- At the time of sun rise (or) sunset, the zenith angle, $\theta_z = 90°$, from the spherical geometry equation, sunrise hour angle (ω_s)

$$\cos(\omega_s) = -\frac{\sin\phi \sin\delta}{\cos\phi \cos\delta} = -\tan\phi \tan\delta$$

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta)$$

Since $15°$ of the hour angle are equivalent to 1 hour, the day length (in hours)

$$t_d = \frac{2\omega_s}{15} = \frac{2}{15}\cos^{-1}(-\tan\phi . \tan\delta).$$

Therefore, the length of the day (t_d) is a function of latitude and solar declination.

Local Solar Time :-

The time used for calculating the hour angle in all the equations called the local solar time (or) local apparent time, which does not coincide with the local clock time.

The solar time can be obtained from the standard time observed on a clock by applying two corrections as given as

Local solar time (LST)

= standard time $\pm$ 4 (standard time longitude − longitude of location) + (Equation of time correction)

'−' sign is applicable for the eastern hemisphere.

Estimation of Average Solar radiation :-

One of the earliest expression for monthly average horizontal solar radiation H_{av} was given by Angstrom, which is

$$H_{av} = H_0' \left[a' + b' \cdot \frac{n}{N}\right] \quad \text{——— (1)}$$

where, a' and b' are arbitrary constants. (Freitz ras1, suggested that $a' = 0.35$ and $b' = 0.61$).

H_0 = the monthly average horizontal solar radiation for a clear day.

$\bar{n}$ = average daily hours of bright sunshine for same period.

N = maximum daily hours of bright sunshine for the same period.

Values H_a for use in equation (1) can be obtained from charts of ~~Fig.~~ following ~~figure~~. which are directly give the solar radiation.

The day length N can be obtained from a nomograph developed by Whillier (or) can be calculated from the equation

$$N = t_d = \frac{2}{15} \cos^{-1}(-\tan\phi \tan\delta). \quad \text{—— (2)}$$

Further, the modified equation for average solar radiation is given by.

$$\boxed{H_{av} = H_0 \left(a + b\frac{\bar{n}}{N}\right)} \quad ** \text{—— (1)}$$

where, H_0 = the average monthly. insolation at the top of the atmosphere.

a and b are the modified constants depending upon the location; and these are obtained from standard tables.

The H_0 can be obtained from charts (or) it can be calculated by following empirical relation **

$$\boxed{H_0 = \frac{24}{\pi} I_{sc} \left[\left\{1 + 0.033 \cos\left(\frac{360 n}{365}\right)\right\}. \left(\cos\phi \cos\delta \sin\omega_s + \frac{2\pi\omega_s}{360} \sin\phi \sin\delta\right)\right]}$$

Where, I_{sc} = Solar constant per hour.

n = day of the year.

ω_s = Sunrise hour angle. and it can be obtained from the relation $\boxed{\omega_s = -\tan\phi \tan\delta.}$

the declination angle δ can be obtained from Cooper's equation

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

* Solar Radiation on Tilted Surfaces:—

→ the rate of receipt of solar energy on a given surface on the ground depends on the orientation of the surface with reference to the sun.

→ A fully suntracking surface that always faces the sun receives the maximum possible solar energy at the particular location.

→ A surface of the same area oriented in any other direction will receive a smaller amount of solar radiation.

→ Because most of the solar collectors (or) solar radiation collecting devices are tilted at an angle to horizontal.

→ Hence it is necessary to convert data for a hourly radiation (measured (or) estimated) on a horizontal surface ~~to~~ a radiation on a tilted surface.

Beam Radiation:—

In most cases; the tilted surface faces due south i.e., $\gamma = 0$, for this case

$$\cos\theta = \sin\delta \sin(\phi-\beta) + \cos\delta \cos\omega \cos(\phi-\beta)$$

For horizontal surface $(\theta = \theta_z)$

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

It follows that the ratio of the beam radiation falling on the tilted surface to that falling on a horizontal surface is given by

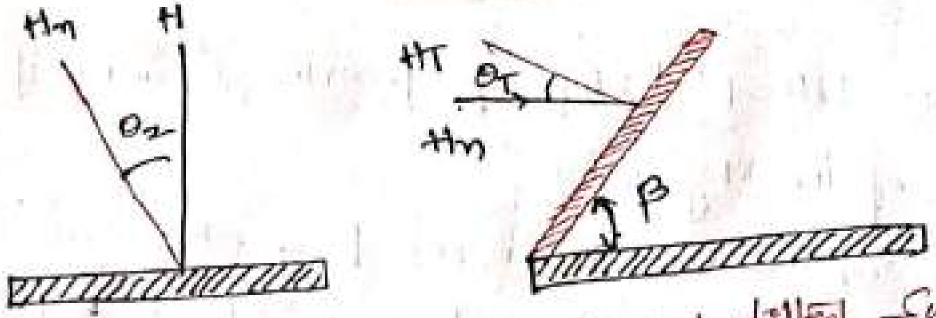


Fig. Radiation on horizontal and tilted surface.

$$R_b = \frac{H_T}{H} = \frac{H_n \cos\theta_T}{H_n \cdot \cos\theta_z} = \frac{\cos\theta_T}{\cos\theta_z}$$

$$= \frac{\sin(\phi-\beta)\sin\delta + \cos(\phi-\beta)\cos\delta\cos\omega}{\sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega} \quad \text{—— (1)}$$

This ratio is called the "tilt factor" for beam radiation.

Total Radiation:— Beam and diffuse component of solar radiation are observed in flat plate type collector.

→ The angular correction factor has been determined for beam radiation as given by equation (1).

→ Correction for diffuse radiation can be applied for clear days, for such cases R may be assumed to R_b, where 'R' is the correction factor for both direct and diffuse radiation.

$$R = \frac{H_T}{H}$$

$$\text{(or)} \quad H_T = R(H_b + H_d) \quad \text{—— (2)}$$

→ For cloudy (or) hazy days diffuse radiation can be assumed as uniformly distributed over the sky.

→ The effective ratio of solar energy on the tilted surface to that on the horizontal is then

$$R = \frac{H_T}{H} = \frac{H_b}{H} R_b + \frac{H_d}{H} \quad \text{—— (3)}$$

→ Conversion factor for diffuse radiation (R_d) is given by

$$R_d = \frac{(1+\cos\beta)}{2}$$

→ A surface tilted at slope 'β' from the horizontal sees $\frac{(1+\cos\beta)}{2}$ of the sky dome.

→ The tilted surface also sees ground or other surroundings and if these surroundings have a diffuse ~~reflection~~ reflectance of 'ρ' for solar radiation, the reflected radiation from the surrounding on the surface from total solar radiation is

$$(H_b + H_d)(1-\cos\beta)\frac{\rho}{2}.$$

→ Hence, three components; the beam radiation, diffuse solar radiation and solar radiation reflated from surroundings are considered by Liu and Jordan.

→ Hence, by combining these three terms.

$$H_T = H_b R_b + H_d \frac{(1+\cos\beta)}{2} + (H_b + H_d)\frac{(1-\cos\beta)}{2}.\rho$$

and $$R = \frac{H_b}{H} R_b + \frac{H_d}{H}\frac{(1+\cos\beta)}{2} + \frac{(1-\cos\beta)}{2}\rho.$$

→ The values of diffuse reflectance are.

$\rho = 0.2$ - where there is no snow.

$\rho = 0.7$ when there is snow cover.

∴

→ Therefore for Indian conditions, a value around 0.2 is generally expected.

— o —

* Solar Radiation Measurements:-

→ Measurements of solar radiation are important because of the increasing number of solar heating and cooling applications

→ And 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 and diffuse solar radiation.

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

1. Pyrheliometer : which collimates the radiation to determine the beam intensity as a function of incident angle.

2. Pyranometer :- which measures the total hemispherical solar radiation. These are most commonly used.

1. Pyrheliometers:-

→ A pyrheliometer is an instrument which measures beam radiation.

→ In contrast to a pyranometer, the sensor disc is located at the base of a tube whose axis is aligned with the direction of the sun rays.

→ Thus diffuse radiation is essentially blocked from the sensor surface.

→ Most pyrheliometers used for routine measurements operate on the thermopile effect, and are similar to pyranometers in this respect.

→ In practice, direct solar radiation is measured by attaching the instrument to an electrically driven mount for tracking the sun.

→ The diffuse component is avoided by installing a collimator tube over the sensor with a circular cone angle of about 5°.

→ Current practice in solar radiometry relies primarily on thermoelectric transducers. However, relatively low cost photovoltaic transducers are becoming more popular.

→ Three pyrheliometers have been in wide-spread.

i) Angstrom pyrheliometer.
ii) The Abbot silver disc pyrheliometer.
iii) Eppely pyrheliometer.

→ The instruments provide primary and secondary standard of solar radiation measurements.

i) Angstrom Compensation Pyrheliometer :-

→ In this pyrheliometer, a thin blackened shaded manganin strip (size 20×2×0.1 mm) is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation.

→ It is drawn schematically in the following figure

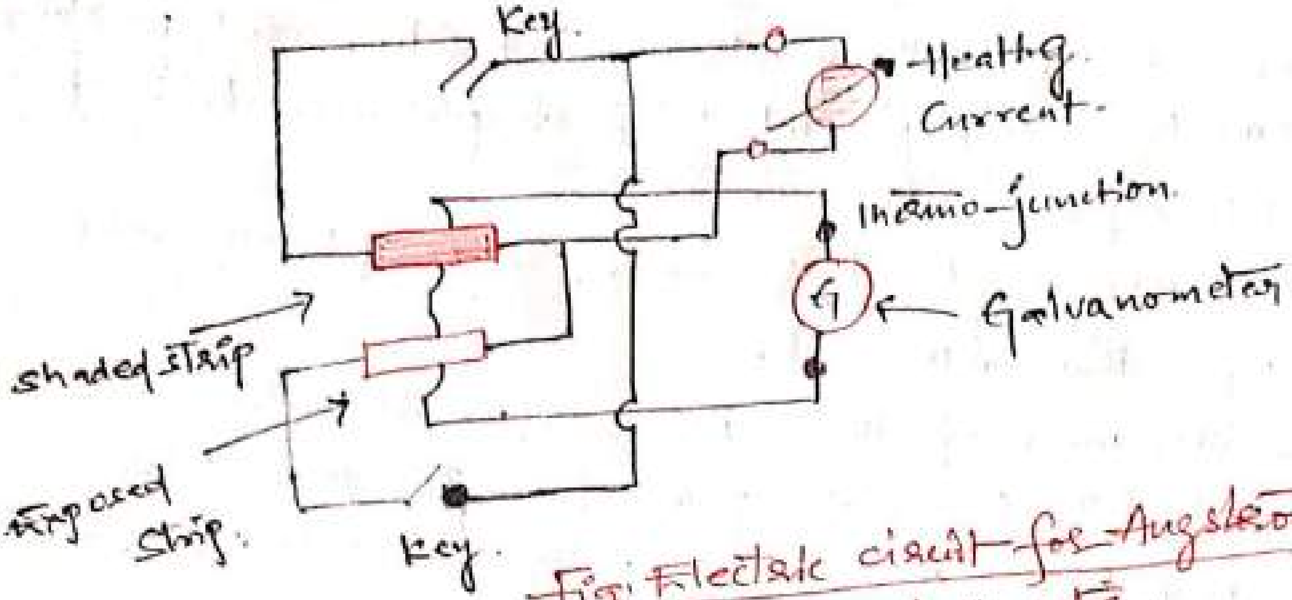


Fig: Electric circuit for Angstrom pyrheliometer.

→ Under steady state Condition, (both strips at identical temperature) the energy used for heating is equal to the absorbed energy.

→ The thermo couples 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 temperature.

→ The energy 'H' of direct radiation is Calculated by means of the formula,

$$H_{DN} = K i^2$$

where, H_{DN} = Direct radiation, Incident on an area normal to Sun's rays.

i = Heating Current in amperes

K = a dimension and instrument Constant.

$= R/W\alpha$.

where R = Resistance per unit length of the absorbing strip (Ω-cm),

W = Mean width of the absorbing strip

α = Absorbing coefficient of absorbing strip.

ii. Abbot Silver disk Pyrheliometer :-

→ It consists essentially of a blackened silver disk 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 of the disk.

→ A shutter made of three polished metal leaves is provided at the upper end of the tube to allow solar radiation to fall on the disk at regular intervals. and corresponding changes in temperature of the disk are measured.

→ The thermometer stem is bent through 90° so that it lies along the tube to minimize its exposure to the sun.

→ They are widely used for calibrating pyranometers.

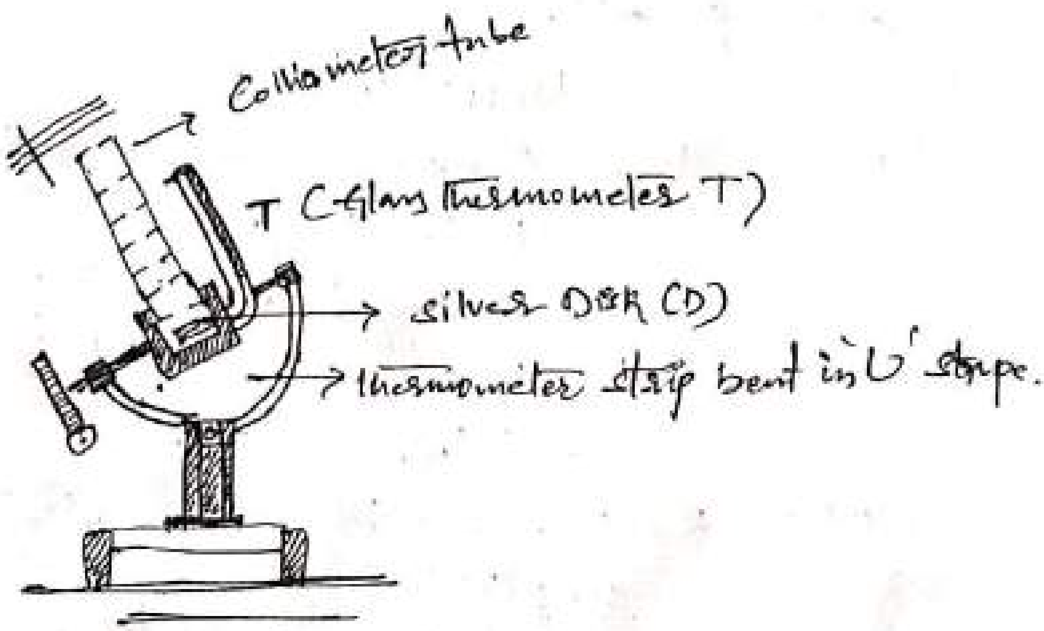


Fig: Abbot silver disk pyrheliometer

iii) Eppley Pyrheliometers:—

→ The sensitive element in an Eppley pyrheliometer is a temperature compensated 15 junction bismuth silver thermopile mounted at the base of a brass tube, the limiting diaphragms of which subtend an angle of 5.7°.

→ A thermopile is basically a series arrangement of thermo couples used to develop a much greater voltage.

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

→ It is a stable instrument and can be used as a substandard.

v. Pyranometers:—

→ A pyranometer is an instrument which measures total (or) global radiation over a hemispherical field of view.

→ The following shows the pyranometer with alternate black and white sensor segments.

→ It is based on the principle as stated above that there is a difference b/w the temperature of black surface (which absorbs most solar radiation) and white surface (which reflect most solar radiation).

→ The detection of temperature difference is achieved by thermopile.

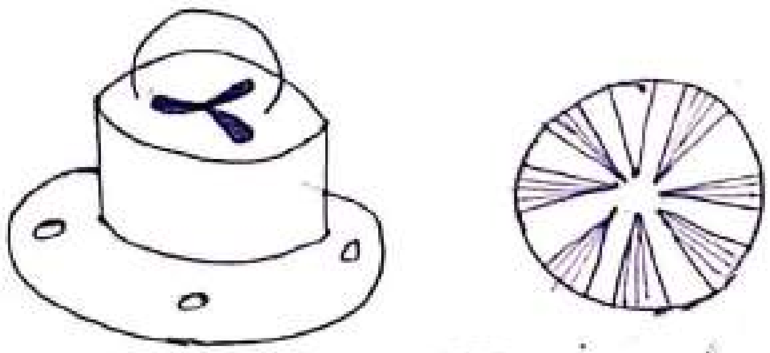


Fig Pyranometer with alternate black and white sensor segments.

~~Angstrom pyrheliometer~~ :-

→ ~~Direct / Beam radiation~~

→ ~~Normal to the surface~~ (solar direction)

→ ~~structure is shown Fig.~~

→ ~~reliable instrument to measure the direct solar radiation~~

→ ~~A Copper - Constantan thermocouple is attached to each Consor strips.~~

There are following types of pyranometers:-

i> Eppley pyranometer

ii> Yellot solarimeter

iii> Bimetallic Actiono-graphs of the Rabitzsch type.

iv> Velochme pyranometer

v> Thermo electric pyranometer. etc.

** Solar Radiation Data :-

Solar radiation data are available in several forms and should include the following requirements

1. Whether they are instantaneous measurements (or) values integrated over some period of time.
2. The time (or) time period of the measurements.
3. Whether the measurements are of beam, diffuse (or) total radiation.
4. The receiving surface orientation.
5. If averaged (Monthly average of ~~the~~ daily radiation).

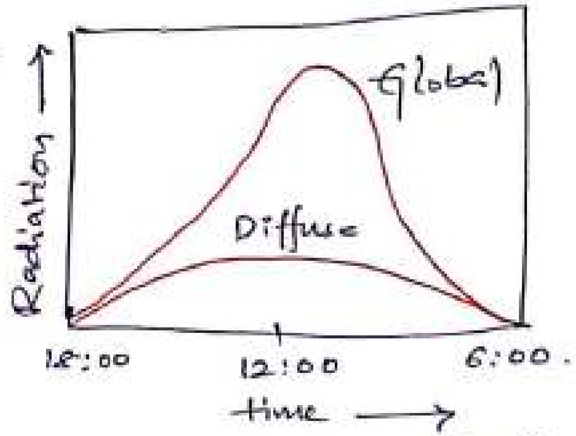
→ Most of the data on solar radiation received on the surface of the earth are measured by Solarimeter which give readings for instantaneous measurements.

It should be pointed out that solar radiation flux is generally reported in langleys per hour (or) per day.

(1 langley = 1 cal/cm²)

→ A typical daily record of the global and diffuse radiation measured on a clear day is shown in Figure (A).

→ In contrast to the smooth variation, a jagged variation with many peaks is obtained on a cloudy (or) a partly cloudy day. is shown in Figure (B).



A. A typical daily record of Global and Diffuse radiation

→ India lies b/w latitude 7° and 37°N, and receives an annual average intensity of solar radiation b/w 16700 – 29260 KJ/m²/day. (400–700 cal/cm²/day).

B. A typical global and diffuse radiation on a cloudy day.

———o———

Solar Energy Collections and Direct Energy Conversion

Solar Energy Collectors—

Introduction:— A Solar Collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collectors these are general of two types.

i) Non concentrating or flat plate type solar collector.

ii) ~~Solar~~ Concentrating (focusing) type solar collector.

The major difference b/w these two types is the surface area (collector area) is same as the absorber area in flat plate collector, where as in another type the collector area is much greater than absorber area.

Flat plate Collectors:—

↳ These are adequate for the temperature below 90°c, and made in rectangular shape panels, from about 1.7 to 2.9 sq.m, in area.

↳ These are relatively simple to construct and erect, flat plates can collect and absorb both direct and diffuse solar radiation.

↳ Flat-plate solar collectors are may be divided into two main classifications based on the type of heat transfer fluid used.

↳ The majority of the flat plate collectors 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.

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 and sides to minimize the heat losses. Standard insulating materials such as fibre glass (or) styro-foam are used for this purpose.

v) The casing (or) container which enclose the other components and protects them from the weather.

(A) A Typical Liquid Collector :-

There are many flat-plate collector designs, but most are based on the principle shown in following Fig.

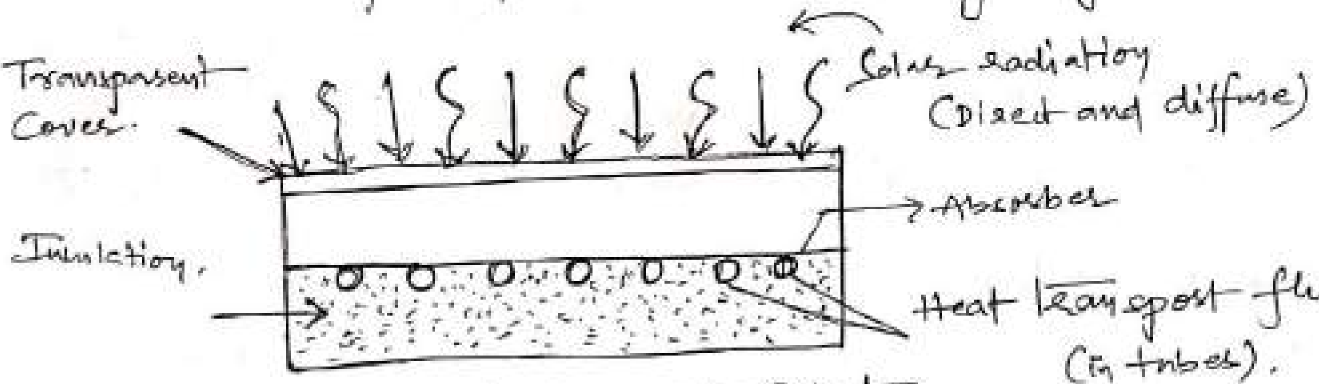


Fig: A Typical flat-plate Collector

It is the plate and tube type collector. It basically consists of a flat surface with high absorbing capacity for solar radiation. Typically, a metal plate, usually of copper, steel or aluminium material with tubing of copper in thermal contact with the plates, are the most commonly used materials.

The absorber plate is usually made from a metal sheet of 1 to 2 mm thickness, while the tubes, which are also of metal, ~~can~~ range in diameter from 1 to 1.5 cm.

Heat transport System :-

The heat generated in the absorber is removed by continuous flow of a heat-transport (or heat transfer) medium either water or air.

In the example shown in Figure, the tubes are ~~connected~~ connected to common headers at each end of the collector

→ Cooler water then enters at the bottom header, flow upward through the tubes. Where it is warmed by the collector absorber, and leaves by way of the top header.

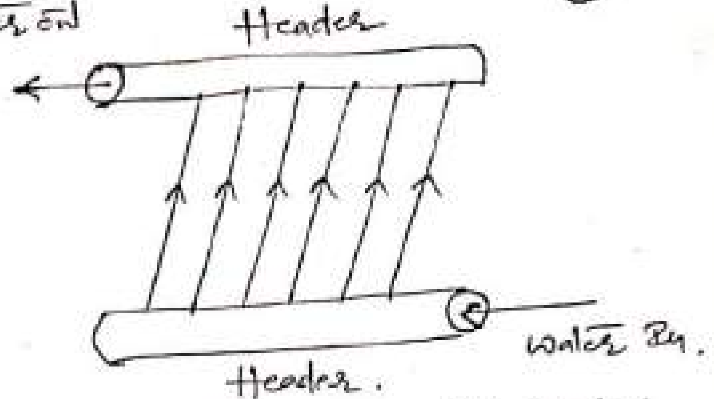


Fig: Water flow in flat-plate Collector

→ Water is a very effective heat transport medium, but it suffers from certain drawbacks, one is the possibility of freezing in the collector tubes in cold climates during cold nights.

→ As stated earlier ethylene glycol is added to prevent freezing but this generally adds to the complexity of the heating system.

(B) Typical Air Collectors and (or) Solar air Heaters :-

→ The following figure shows a schematic flat-plate collector where an air stream is heated by the back side of a collector plate.

→ Fins attached to the plate increase the contact surface.

→ The back side of the collector is heavily insulated with mineral wool (or) some other material.

→ The most favourable orientation of a collector, for heating only is facing due South at an inclination angle of +15° to the ~~hor~~ horizontal Latitude.

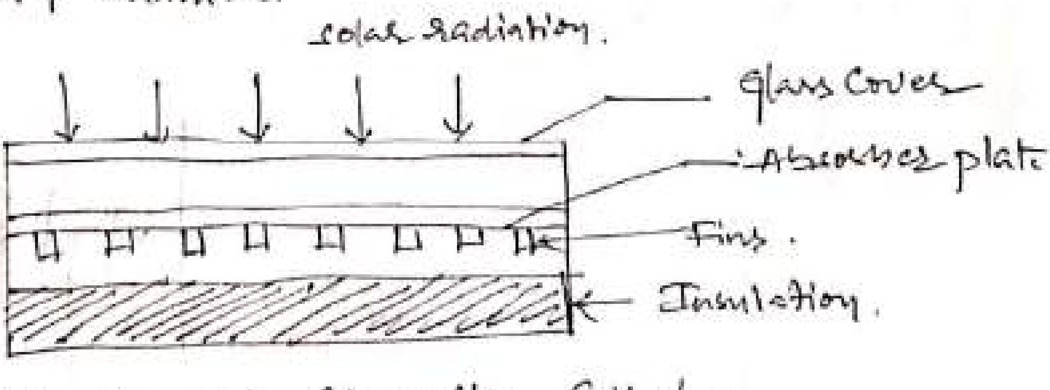


Fig: Typical Solar Air Collector

→ The use of air as the heat-transport fluid eliminates both freezing and corrosion problem.

→ The possible applications of solar air heaters are

Ex:- Drying.

- Curing of agricultural products.
- Curing of Industrial products.

→ Basically air heaters are classified in the following two categories.

1) Non-porous absorber plate type Collectors:-

→ In this type of solar air collector, the stream of air does not flow through the absorber plate.

→ This is because, the plate does not have pores to let the air flow through it.

→ The air flow above (or) behind the absorber plate and thus cools the absorber plates.

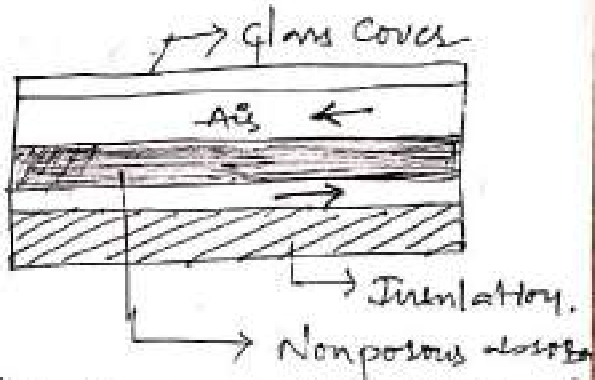


Fig: Non-porous Type Solar air-Heater.

→ The collector efficiency of this type of collector can be improved by selective coating.

→ Also, use of fins helps in improving the collector performance.

2) Porous-Absorber Solar air Collector:-

→ In this type of solar air collector, the absorber being porous, air circulates all through it.

→ The solar radiation are absorbed gradually and depends on matrix structure.

→ From top to bottom of the matrix as the air circulates through it.

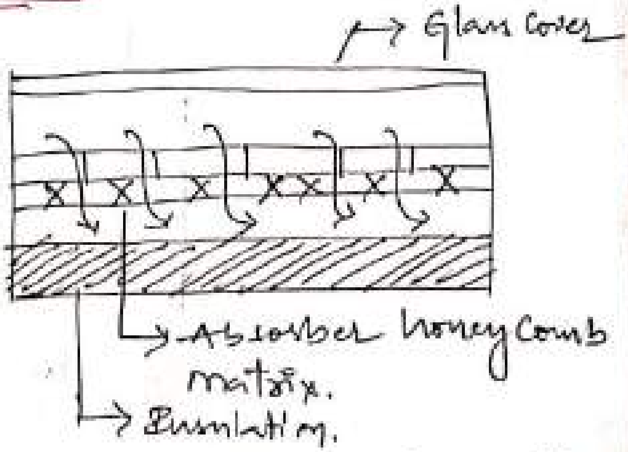


Fig. Porous-Absorber Type air Collector

→ The pressure drop in this solar air collector is lower than the non-porous absorber.

(B) Concentrating (or) focusing solar collectors :—

→ It consisting of concentrating device like mirrors attached to a flat plate. The mirrors are set to be an angles so that they reflect solar radiation on to the absorber plate.

→ Thus, the flat plate absorbs reflected radiation in addition to that normally falling on it.

→ Some part of the radiation falls directly on to the absorber plate and the part that reaches on the mirror is reflected to the absorber plate.

→ Thus, the concentration effect arises mainly from the increase in direct radiation reaching the absorber plate.

→ Due to the apparent motion of the sun the concentrating surface is unable to redirect the sunrays on the absorber throughout the day, if both the concentrating surface and the absorber surfaces are stationary.

→ So the angles of the mirror has to be changed according to the sun altitude changes.

Classification of concentrating collectors as follows.

1. Non-focusing type concentrating collectors.
2. Compound parabolic collector.
3. Cylindrical parabolic collector.
4. Moving absorber and fixed concentrator.
5. Fresnel lens concentrating collector.

1. Non-focusing type concentrating collector :—

This type of concentrating collector uses a flat plate collector. In this, mirrors are used as reflectors which are adjustable.

→ The mirrors are placed at the corners of the collector to reflect solar radiation onto the absorber.

→ The concentrating ratio of this type of collector is slightly greater than 1.

→ This type of collectors are useful for obtaining temperatures upto 140°c.

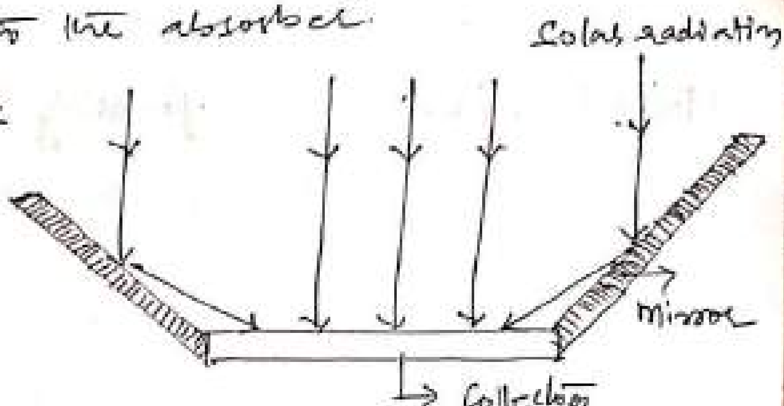


Fig. Non-focusing type Concentrating Collector

2. Compound parabolic Concentrating Collector :-

—A Compound parabolic Concentrating Collector consists of reflectors which are parabolic in shape. This type of collector is a non-image type. The concentration ratio of this type of collector varies b/w 3 to 10.

The following fig shows the compound parabolic concentrating collector.

The high acceptance angle which does not require frequent tracking is the main advantage of this type of collector.

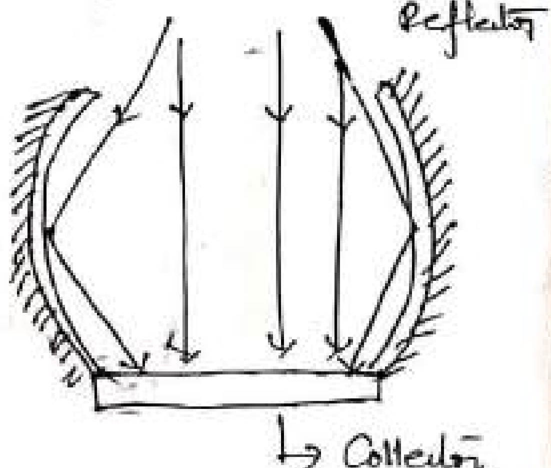


Fig: Compound parabolic Concentrating Collector.

3. Cylindrical parabolic collector :-

—A cylindrical parabolic collector is also called a parabolic trough (or) a linear parabolic collector.

In this type of collectors, the concentrator rotates along the motion of the sun. An image forms at the focal axis of the parabola.

The following fig. shows the cylindrical parabolic collector.

The Concentration ratio CR for this Collector varies b/w 10 to 80 can produce a temperature of 150°C to 400°C.

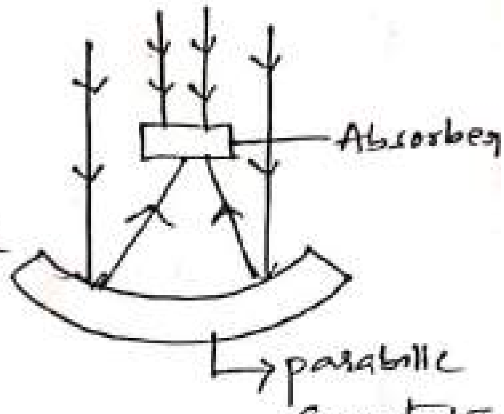


Fig: Cylindrical parabolic Concentrator

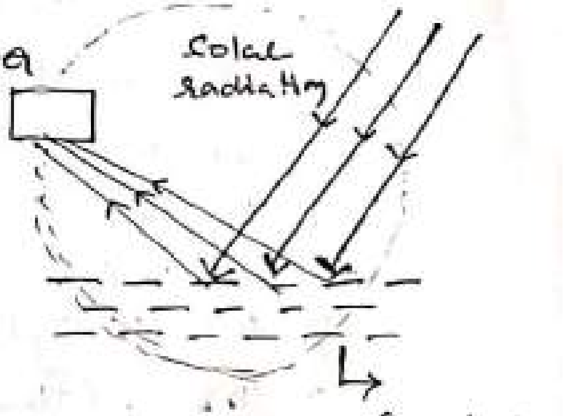
4. Moving Absorber and fixed Collector type Concentrating Collector

→ In this type of Concentrating Collector, the Concentrator is fixed and the absorber (or) receiver rotates. The Concentrator Consists of mirror strips which are long and narrow.

→ These mirror strips are along a cylindrical surface.

→ This Collector type is an image type.

→ In order to track the circular path of the sun, the absorber has to be moved.



5. Fresnel Lens Concentrating Collector :-

→ This type of Concentrating Collector Uses a Fresnel lens. The Fresnel lens Concentrator Consists of a Thin glass sheet whose one surface is plain and other surface has vertical groves.

→ The plain surface exposed to solar radiation whereas groves exposed to absorber.

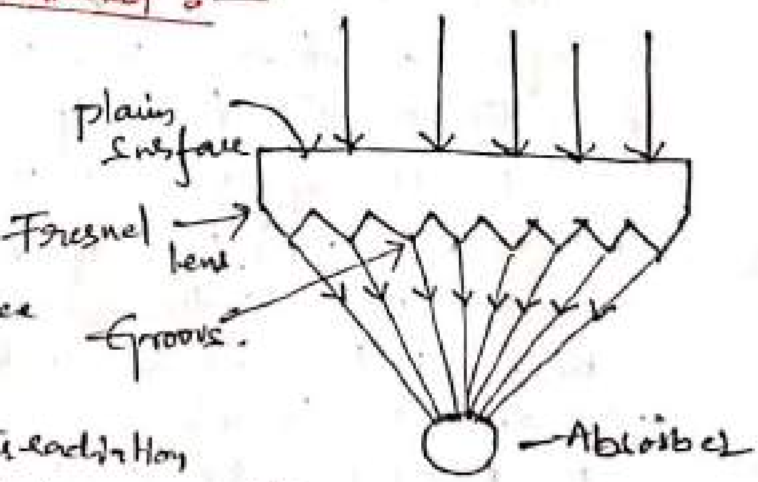


Fig: Fresnel Lens Concentrating Collector.

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Direct Energy Conversion

Need For DEC:—

* No Conversion of Energy into mechanical and to Electrical.
* Less Losses in Conversion process.
* More efficient process.
* Cost also reduced.

Principle:— "It is a device which converts heat energy (Thermal energy) into electrical energy through semiconductor (or) conductor by direct conversion ~~into~~ without any conventional electric generator is direct energy conversion."

List of various direct energy Conversion devices:—

Some of the direct energy Conversion devices are,

1. Fuel cells
2. Solar cells.
3. Magneto Hydrodynamic power generation device (MHD)
4. Thermoelectric power generator.
5. thermoionic power generator.
6. Ferroelectric power generator.

Carnot Cycle:—

The Carnot Cycle is an externally reversible power cycle. It is composed of two reversible isothermal processes and two reversible adiabatic (Isentropic) processes.

It has little specific work that any friction in the actual process can cause frictional losses of the total work output and drastically reduces cycle efficiency. Hence, it is not a practical power cycle.

The Carnot heat engine cycle with T-S and P-V diagrams are shown in the figure.

The total four thermodynamic processes are operated b/w the two temperature limits T_1 and T_2.

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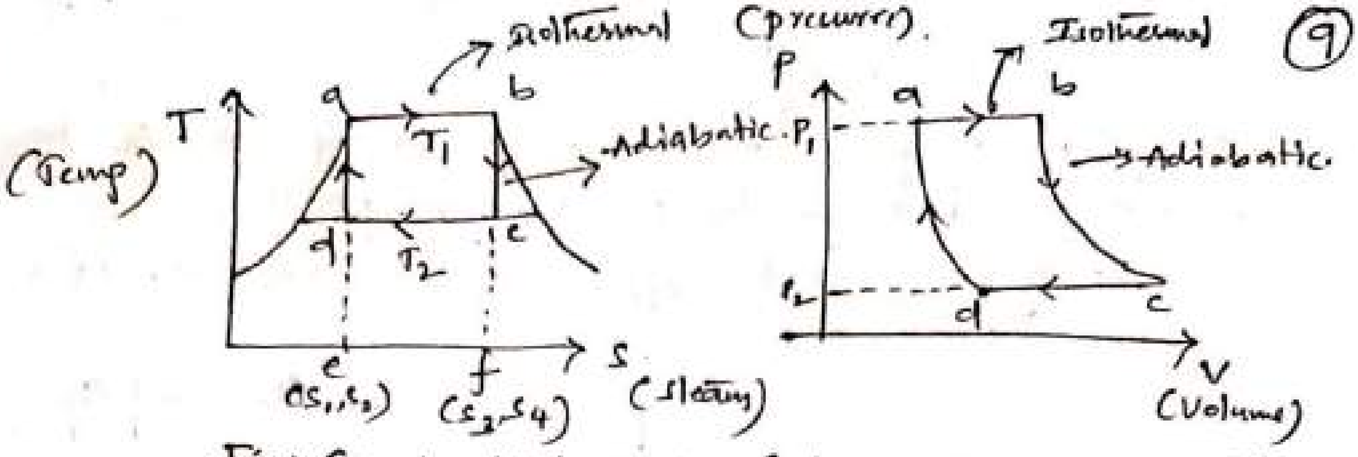

Fig: Carnot Heat Engine Cycle on T-s and p-v diagrams

→ In the operation 'ab' a boiling water is heated at temperature 'T_1'. During this operation heat is being absorbed at constant temperature (T_1) and pressure (P_1).

→ In the operation 'bc', the temperature is changes to (T_2) and pressure (P_2) to expand the steam.

→ Now, the operation is shifted to 'cd', where the heat is removed at constant pressure (P_2) and temperature (T_2).

→ When the steam is completely used it gets cooled down. In the operation 'dc', the steam again retain its temperature and pressure through compression and the cycle complete.

→ Now the heat supplied during the operation 'ab' at constant temp T_1 is given by.

$$\text{Area of "abfe"} = T_1(s_1 - s_4) \text{ or } T_1(s_2 - s_1) \quad \text{— ①}$$

→ Heat removed during the operation 'cd' at constant temp T_2 is given by.

$$\text{Area of "cdef"} = T_2(s_2 - s_3) \quad \text{— ②}$$

→ Therefore, the workdone = Heat supplied − Heat removed

$$= T_1(s_2 - s_1) - T_2(s_2 - s_1)$$

$$= (T_1 - T_2)(s_2 - s_1) \quad \text{— ③}$$

→ The Carnot efficiency is a function of temperature T_1 and T_2 is given by

$$\text{Carnot efficiency: } \eta = \frac{\text{work done}}{\text{Heat supplied}} = \frac{(T_1 - T_2)(s_2 - s_1)}{T_1(s_2 - s_1)} \Rightarrow \boxed{\eta = \frac{T_1 - T_2}{T_1}}$$

Limitation of Carnot Cycle:—

1. The cycle is not of practical use as super heated steam is to be supplied at constant temperature which is not possible.
2. Carnot cycle cannot be applied in the estimation of efficiency of thermo electric power generator.
3. The factors such as material properties, geometry and operating temperature of the converter are not considered.
4. The thermo electric power of each wire (or) metal is dependent of temperature which is not considered.

Thermo electric power

Introduction:—

In 1822 the German Scientist Seebeck discovered that a loop of two dissimilar metals developed an e.m.f. when the two junctions were kept at different temperatures.

This effect has long been used in thermo-couples to measure temperature.

This phenomenon offers one method of producing electrical energy directly from the heat combustion, but its thermal efficiency is very low, of the order of 1 to 3%.

Basic Principle of thermo electric power Generation:—

Thermo electric generator is a device which converts heat energy (thermal energy) into electrical energy through semiconductor (or) conductor.

The direct conversion of heat energy into electric energy based on the "Seebeck thermo electric effect".

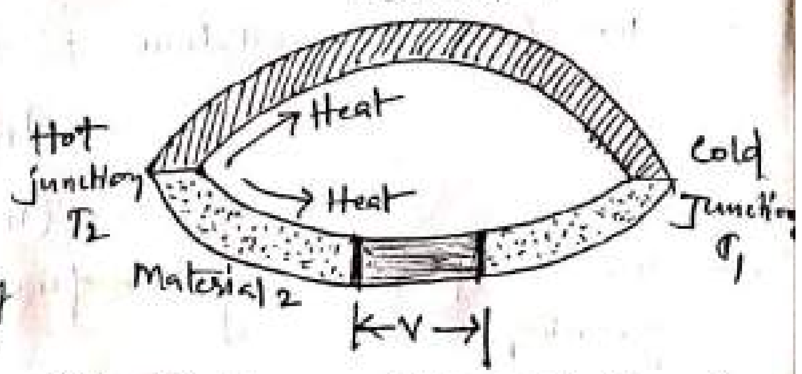

Fig: Seebeck effect principle of thermal couple.

Consider two dissimilar materials joined together in the form of a loop so that there are two junctions. Such a system is illustrated in the figure.

If a temperature difference is maintained b/w these two junctions, an electric current will flow around the loop.

The magnitude of the current will depend on both the materials used and the temperature diff of the junctions ($\Delta T = T_2 - T_1$). If the circuit is broken an open circuit voltage 'V' appears across the terminals of the break as shown in Fig.

The thermo emf, V produced by the device is given by

$$\boxed{V = \alpha_{s_{1-2}} \Delta T}$$

Where, $\alpha_{s_{1-2}}$ is the Seebeck Coefficient. The subscript 1-2 indicates that the value is particular to the materials composing the loop.

Joule Effect:—

This refers to the irreversible conversion of electrical energy into heat. When a current I flows through a resistance R, an amount of heat equal to I^2R is generated per unit time. This heat is called the Joulean heat.

$$\boxed{Q_j = I^2R}$$

The selection of proper material is therefore important to reduce the above loss in the output.

Peltier Effect:—

When an electric current flows across an isothermal junction of two dissimilar materials, there is either an evolution ~~of two~~ or absorption of heat at the junction. This effect is called the peltier heat.

This effect is a reversible effect because if heat is evolved when the current flows in one direction, the same amount of heat is absorbed at the junction if the current flow is reversed.

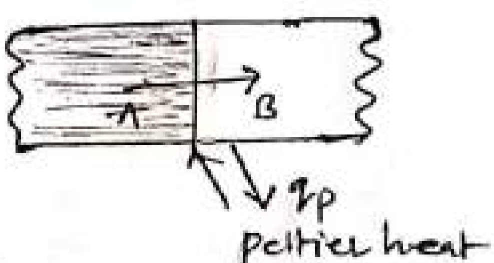

Fig: Peltier Effect.

The Peltier Coefficient $\alpha_{P_{1-2}}$, is defined as the heat evolved (12)
(or) absorbed at the junction per unit current flow, per unit time.

$$\boxed{\alpha_{P_{1-2}} = \alpha_{P_1} - \alpha_{P_2} = \frac{q_P}{I}}$$

I = Peltier heat per unit time.

Thomson effect :—

When an electric current flows through on material having a temperature gradient, there is an evolution (or absorption) of heat.

This phenomenon is called the "Thomson Effect". It is also reversible because reversing the direction of current flow reverses the direction of heat transfer without changing the magnitude.

The Thomson Coefficient 'σ' is defined as the Thomson heat absorbed (or evolved) per unit time per unit electric current and per unit temperature gradient;

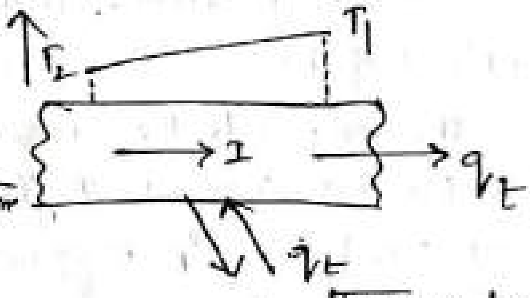

Fig: Thomson Effect

$$\boxed{\sigma = \frac{dq_T/dx}{dT/dx}}$$

Where, $\frac{dq_T}{dx}$ = heat interchange per unit time per unit length of conductor

$\frac{dT}{dx}$ = Temperature gradient.

—— o ——

Thermoelectric Power Generator :-

→ A simple arrangement for utilizing the Seebeck coefficient is shown in Fig.

→ The thermo couple material A and B are joined at the hot end, but the other ends are kept cold; an electric voltage (or electro motive force) is then generated b/w cold ends.

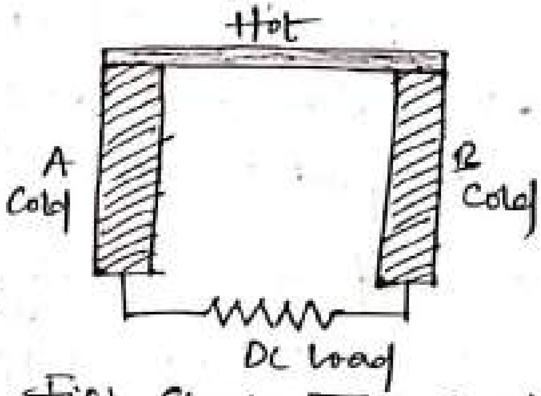

Fig: Simple thermo couple arrangement.

→ A direct current will flow in a circuit (or) load (e.g., a motor, resistance, etc.) connected b/w these ends.

→ The current will continue to flow as long as the heat is supplied at the hot junction and removed from the cold ends.

→ For a given thermocouple, the voltage and power output are increased by increasing the temperature difference b/w the hot and cold ends.

→ In a practical thermo electric converter, several couples are connected in a series to increase both voltage and power. shown in following figure.

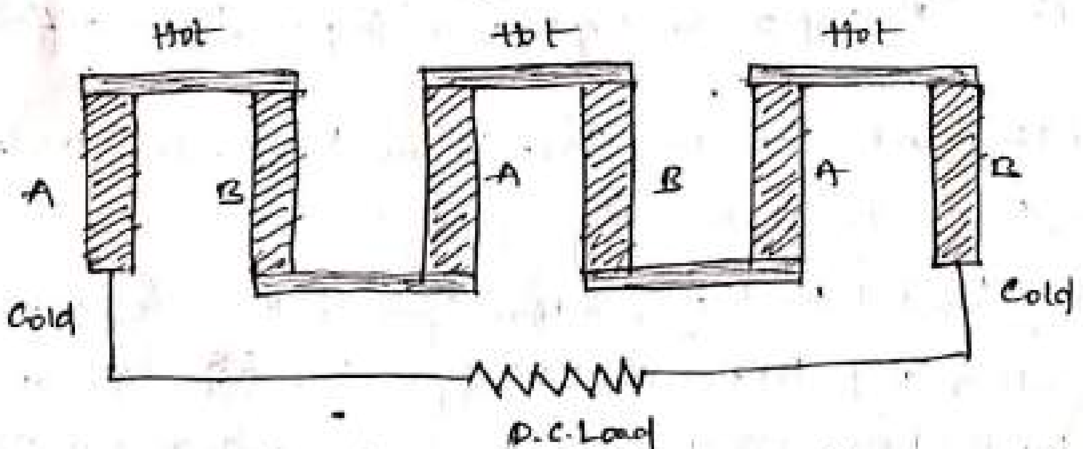

Fig: Thermo couples in series to increase voltage.

→ A thermo electric converter is a form of heat engine. Heat is taken up at an upper temperature (i.e., hot junction) and part is converted into electrical energy; the remaining is removed at cold junction (or) lower temperature.

→ Thermoelectric generators have been built with power outputs ranging from a few watts to kilowatts.

→ An Important application is the use of radioactive decay heat to generate power in space and other remote locations.

** Performance Analysis of Thermo electric power Generator (Figure of Merit) :-

The following figure shows the schematic diagram of thermo-electric converter.

→ It consists of two blocks A and B of semiconductor materials connected together by a conductor.

→ The conductor receives heat from a thermal source and the lower open ends of the blocks reject heat to a low temperature sink.

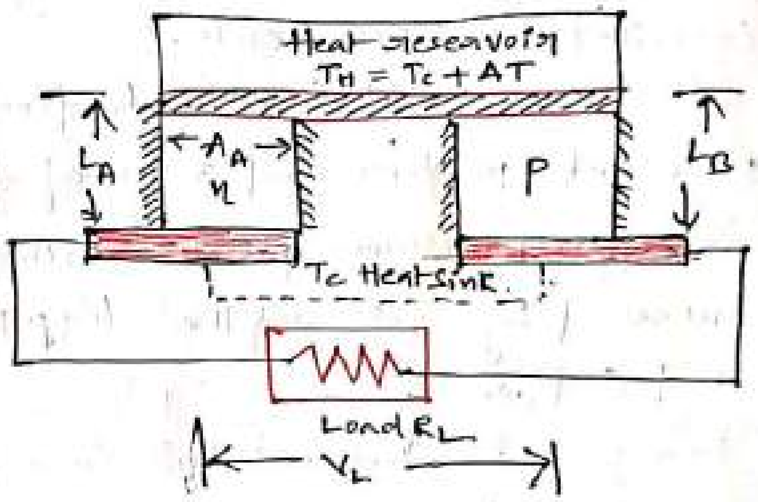

Fig: Schematic of Thermoelectric Generator

→ The two junctions 1 and 2 are kept at a temperature difference ΔT.

→ The sides of the blocks are insulated. Hence, heat flow occurs along the length of the blocks only.

→ By supplying heat to the hot junction causes the electrons in the n type block and holes in the 'p' type block to flow away from the hot junction, thereby producing a potential difference b/w two open ends.

→ If the circuit is completed at the cold junction, an electric current will flow through the load.

The operation of the system can be reversed by supplying electrical energy in place of heat. The current will flow now save to remove heat from one junction and to deliver heat to the other junction.

The device can then be represented by an emf '$\alpha_{SAB} \cdot \Delta T$' with an internal resistance R, which is the total series resistance of the two parts A and B of the electric thermo electric circuit.

If an external load resistance R_L is applied, the current is $\boxed{I = \alpha_{SAB} \cdot \Delta T / (R + R_L)}$, and power is given by.

$$P = \left[\frac{\alpha_{SAB} \cdot \Delta T}{(R+R_L)}\right]^2 \cdot R_L \quad \text{——} (1)$$

Which has the maximum value at $R = R_L$.

i.e., $$P_{max} = \frac{\alpha^2_{SAB} \cdot \Delta T^2}{4R} \quad \text{——} (2)$$

The factor $\boxed{\left(\frac{\alpha^2_{SAB}}{R}\right)}$ is called the "figure of merit" for this application.

→ For optimizing the power, it is often more meaning-ful to optimize the efficiency 'η'. defined as the ratio of the power. P_L developed into the load resistance R_L to the heat flow q_H form the source at the hot junction.

$$\boxed{\eta = \frac{P_L}{q_H}} \quad \text{——} (3)$$

Now $P_L = I^2 R_L$, $I = \frac{\alpha_{SAB} \cdot \Delta T}{R + R_L}$.

Let us now apply the first law energy balance to the hot plate for which during a unit time the energy effect are.

(a)- An amount of energy q_H is supplied to the plate from the source.

(b). Since, a current flows through the circuit, an amount of heat q_p (Peltier effect) is absorbed at the junction.

(c)- An amount of heat q_c is conducted away from the plate through the two blocks.

(d)- An amount of heat $q_j/2$ is transfered to the plate.

Hence,
$$q_H = q_c + q_p - \frac{1}{2} q_j$$
$$= K\Delta T + (T+\Delta T)\,\alpha_{SAB} I - \frac{1}{2} I^2 R.$$

where. I is the current flowing through the circuit.

R is the resistance of the thermocouple $= (R_A + R_B)$

K is the thermal conductance $= (K_A + K_B)$.

$T + \Delta T$ is the temperature of the hot junction.

$(T+\Delta T)\,\alpha_{SAB}$ — the Peltier Coefficient.

and $T + \Delta T = T_H$.

then,
$$\eta = \frac{I^2 R_L}{K\Delta T + \alpha_{SAB} T_H I - \frac{1}{2} I^2 R} \quad \text{——— (4)}$$

Substituting for I and introducing $m = \frac{R_L}{R}$, as a new variable they.

$$\eta = \frac{\left[\frac{\alpha_{SAB}\,\Delta T}{R+R_L}\right]^2 \cdot R_L}{K\Delta T + \alpha_{SAB} T_H \left[\frac{\alpha_{SAB}\cdot\Delta T}{R+R_L}\right] - \frac{1}{2}\left[\frac{\alpha_{SAB}\cdot\Delta T}{R+R_L}\right]^2 R}$$

By simplifying.

$$\eta = \frac{m\left[\frac{\Delta T}{T_H}\right]}{\frac{(1+m)^2}{T_H}\cdot\frac{RK}{\alpha^2_{SAB}} + (1+m) - \frac{1}{2}\frac{\Delta T}{T_H}} \quad \text{——— (5)}$$

$$\eta = \frac{\left(\frac{T_1 - T_2}{T_1}\right) x m}{\left[\frac{(1+m)^2}{T_1}\frac{(K_A+K_B)(R_A+R_B)}{\alpha^2_{SAB}} + (1+m) - \frac{1}{2}\left(\frac{T_1-T_2}{T_1}\right)\right]} \quad — (6)$$

where $T_1 \rightarrow T_H$. (Higher Temp).

$T_2 \rightarrow T_C$ (lower temp.)

$$K_A = \frac{k_A \cdot A_A}{L_A} ; \; K_B = \frac{k_B A_B}{L_B}.$$

k_A & k_B are thermal Conductivities of the materials A and B respectively.

$R_A = R_B$ = Electrical resistance.

$$R_A = \frac{\rho_A \cdot L_A}{A_A} ; \; R_B = \frac{\rho_B L_B}{A_B}.$$

↳ In equation (6) the first term equals the Carnot efficiency for an engine working b/w T_1 and T_2 and the value of the second term depends upon the material properties, geometry and operating temperatures of the Converter.

An index used in rating thermoelectric Converters is called the figure of merit, 'Z' defined for a single material as

$$= \frac{\alpha_s^2}{\rho K} (°K^{-1}) \; \frac{\alpha_s^2}{\rho K} (°K^{-1})$$

$$= \left[\frac{\alpha_{SA} - \alpha_{SB}}{\sqrt{\rho_A K_A} + \sqrt{\alpha_B \cdot K_B}}\right]^2.$$

The figure of merit depends on the properties of thermo electric materials used.

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Thermoelectric Materials :—

The following materials have been found suitable for use in thermoelectric elements:

Lead telluride (PbTe) in n and p-type forms,
Bismuth Telluride (Bi_2Te_3),
Bismuth Sulfide (Bi_2S_3).
Antimony telluride (Sb_2Te_3),
Tin Telluride (SnTe),
Indium arsenide,
Germanium Telluride (GeTe),
Cesium Sulfide (CeS), and
Zinc antimonide (ZnSb).

→ Lead telluride (PbTe), a compound of lead and telluride, containing small amounts of either bismuth (n-type) or sodium (P-type) has been commonly used in recent times for thermoelectric conversion.

→ However, the proportion of heat supplied that is converted to into electrical energy is only about 5 to 7%.

→ The figure of merit of some thermoelectric materials are given in Table.

Materials	z ($°K^{-1}$)
Bismuth Telluride (doped with Sb or Se)	4×10^{-3}
Lead Telluride	1.5×10^{-3}
Germanium Telluride (with bismuth)	1.5×10^{-3}
Zinc antimonide (doped with silver)	1.5×10^{-3}
Cesium Sulfide	1.0×10^{-3}.

* The larger the value of 'z' is, the higher the quality of the thermo couple.

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Magneto Hydro Dynamic (MHD). power Generation.

→ As its name implies magneto hydro dynamics (MHD) is concerned with the flow of a conducting fluid in the presence of magnetic and electric field.

→ The fluid may be gas at elevated temperature (or) liquid metal like sodium (or) potassium.

→ An MHD Generator is a device for converting heat energy of a fuel directly into electrical energy without a conventional electrical generator.

→ In this system, an MHD converter system is a heat engine, in which heat taken up at a higher temperature is partly converted ~~to~~ into useful (electrical) work and the remainder is rejected at a lower temperature.

* principle of MHD power Generation:—

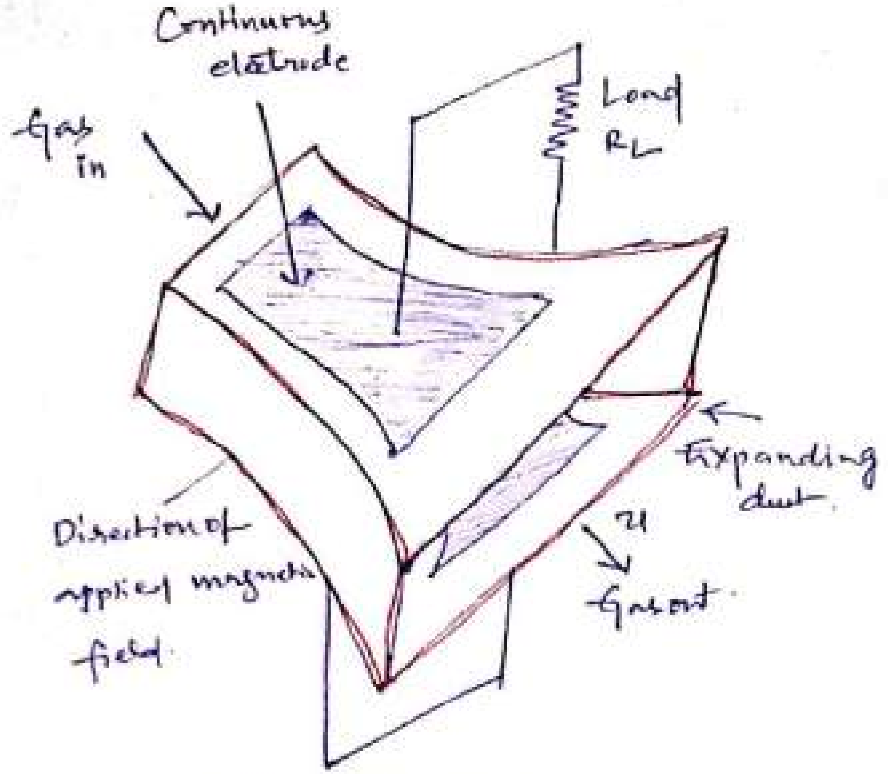
→ The principle of MHD generation is simply that discovered by Faraday: when an electric conductor moves across a magnetic field, a voltage is induced in it. Which produces an electric current.

→ This is the principle of the conventional generator also, where the conductor consists of copper strips.

→ In MHD generator, the solid conductors are replaced by a gaseous conductor, an ionised gas.

→ If such a gas is passed at a high velocity through a powerful magnetic field, a current is generated and ~~an~~ can extracted by placing electrode in a suitable position in the stream.

→ The following ~~fig~~ figure illustrate the arrangement MHD power generation principle.



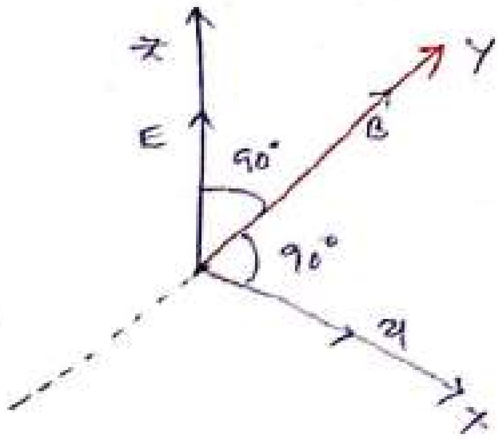


Fig: principle of MHD power Generation

→ The principle can be explained as follows. An electric conductor moving through a magnetic field × experiences a retarding force as well as an induced electric field and current.

→ This effect is a result of Faraday's law of electromagnetic induction. The induced emf is given by.

$$\boxed{\vec{E}_{ind} = \vec{u} \times \vec{B}}$$

where u → velocity of the conductor

B → Magnetic field intensity.

→ The induced current density is

$$\boxed{\vec{J}_{ind} = \sigma \vec{E}_{ind}}$$

where 'σ' is electric conductivity.

→ The retarding force on the conductor is the Lorentz force given by

$$\boxed{\vec{F}_{ind} = \vec{J}_{ind} \times \vec{B}}$$

→ From the energy point of view, the movement of the force through a displacement (mechanical work) is converted to electrical work (current flow against potential difference) by means of the electrical/magnetic induction principle.

→ A schematic of MHD generator is shown in Fig. the conducting flow fluid is forced b/w the plates with a kinetic energy and pressure differential sufficient to overcome the magnetic induction force Find.

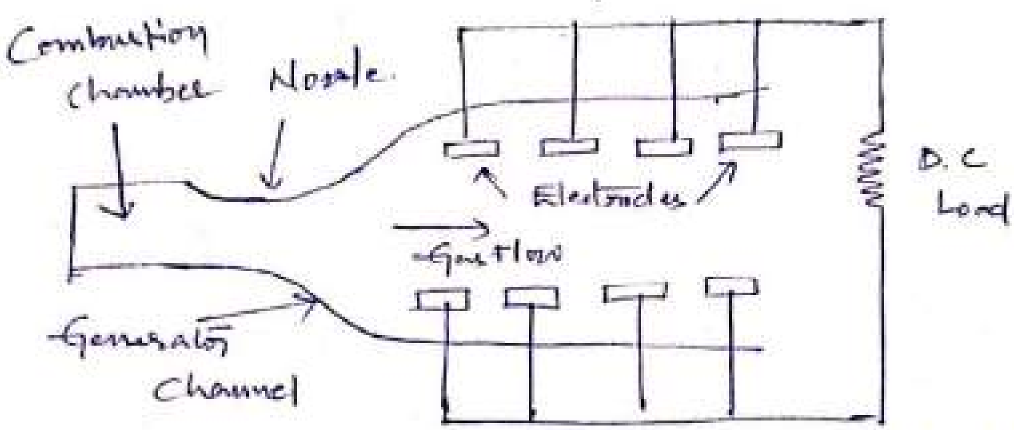


Fig: Simple MHD Generator (magnetic field perpendicular to the plane of the page)

→ The end view drawing illustrates the construction of the flow channel. An ionised gas is ~~employed~~ employed as the conducting fluid.

→ Ionisation is produced either by thermal means i.e, by an elevated temperature (or by seeding with substance like cesium (or) potassium vapours which ionize at relatively low temperature.

→ For the overall power cycle, the MHD converter takes the place of a turbine in a conventional vapour (or) gas turbine cycle.

→ A schematic of the MHD power cycle is shown in Fig(a) and Fig (b) along with T-s diagram.

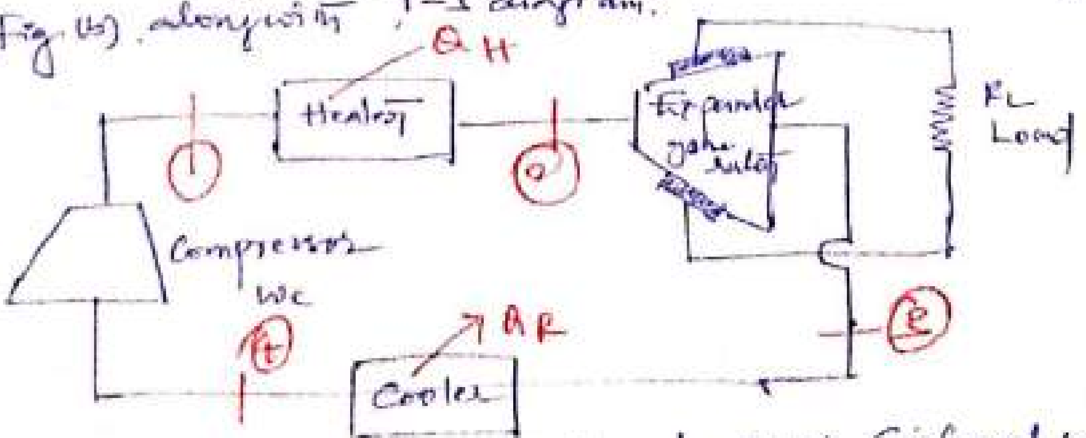


Fig: power cycle of MHD (closed loop)

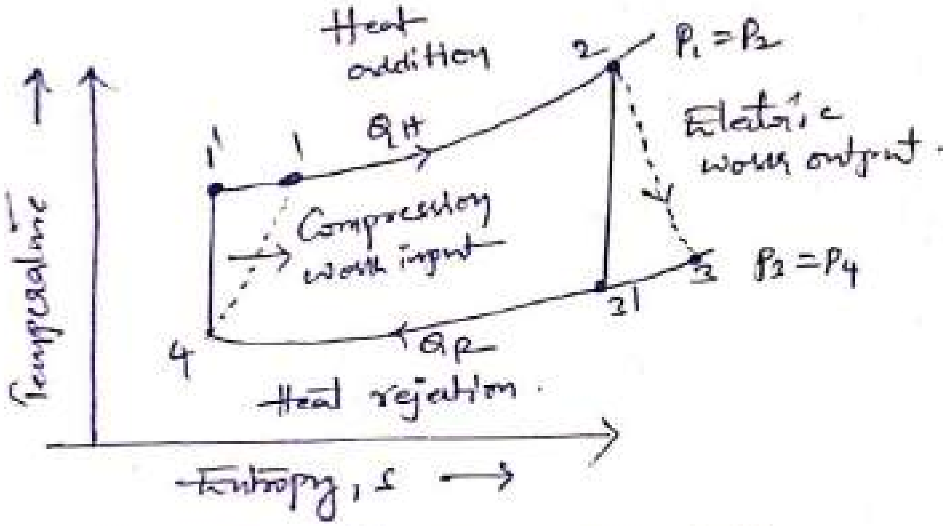


Fig: T-s diagram for cycle

→ In addition to the induced electric field kind, there is also some applied field $\vec{E}'$ at the electrodes. The total current and force are then,

$$J = \sigma(\vec{E} + \vec{u} \times \vec{B})$$

$$F = \vec{J} \times \vec{B} = \sigma(\vec{E} + \vec{u} \times \vec{B}) \times \vec{B}.$$

→ Thermal Efficiency:-

Clearly the overall MHD cycle is thermal power cycle and as such is limited by the Carnot efficiency. In terms of T-s diagram of Fig., the cycle thermal efficiency may be written as

$$\eta_{Th} = \frac{\text{work output}}{\text{heat input}} = \frac{(h_{20} - h_{30})(h_{10} - h_{40})}{(h_{20} - h_{10})}.$$

——— 0 ———

* MHD Systems :-

→ Magneto Hydrodynamic Conversion systems can operate in either open (or) closed cycles

→ In an open cycle system, the working fluid is used only once through bases. The working fluid after generating electrical energy is discharged to the atmosphere through stack.

→ In closed cycle, system the working fluid is continuously recirculated.

→ In an open cycle system the working fluid is air. In closed cycle system helium (or) argon is used as the working fluid.

→ In open-cycle system, the hot combustion gases offer sealing, can be used directly as the working fluid, where as in closed cycle systems, heat is transferred from the combustion gases to the working fluid by means of a heat exchanger.

→ Thus the MHD systems can be classified broadly as follows:

(1) open cycle system

(2) Closed cycle system. This may be further sub classified as:

i) Seeded inert gas system

ii) Liquid metal system.

(1) Open-Cycle Systems :-

→ The arrangement of the system is shown schematically in figure. In this system, fuel used may be oil through an oil tank (or) gasified coal through a "Coal gasification plant"

→ The fuel (coal, oil (or) natural gas) is burnt in the combustor (or) combustion chamber.

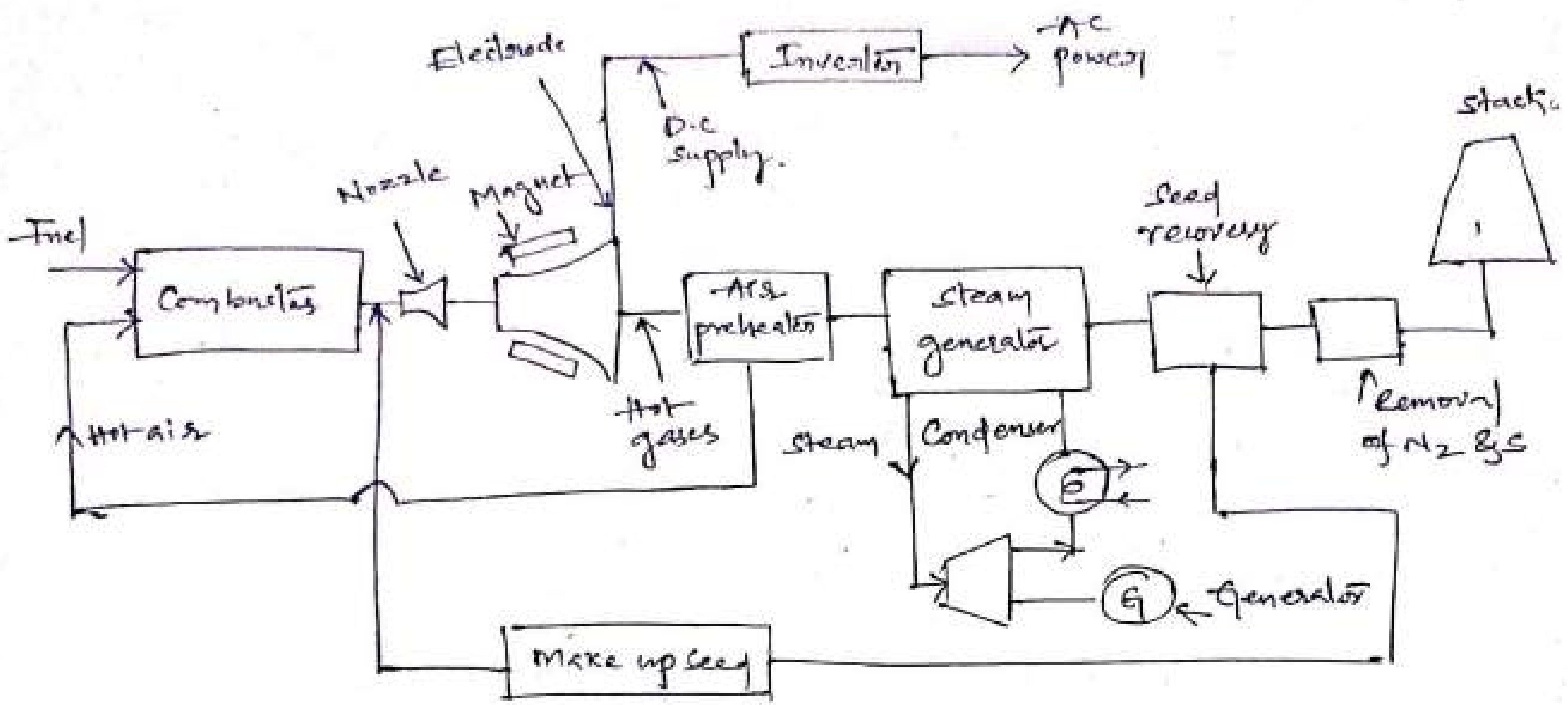


Fig: Schematic of an open cycle MHD Generators

→ The hot gases from combustor is then seeded with a small amount of an ionized alkali metal (cesium (or) potassium), to increase the electrical conductivity of the gas.

→ The seed material, generally potassium carbonate, is injected into the combustion chamber, the potassium is then ionized by the hot combustion gases at temperatures of roughly (2300 to 2700°C).

→ To attain such high temperatures, the compressed air used to burn the coal (or other fuel) in the combustion chamber, must be preheated to atleast 1100°C.

→ The hot gas expands through the rocket like generator surrounded by powerful magnet.

→ During the motion of the gas the positive and negative ions move to the electrodes and constitute an electric current.

→ The magnetic field direction, which is at right angles to the fluid flow, would be perpendicular to the plane of paper.

→ A number of oppositely located electrode pairs are inserted in the channel to conduct the electric current generated to an external load.

→ The electrode pairs may be connected in various ways one of which is shown in the following figure.

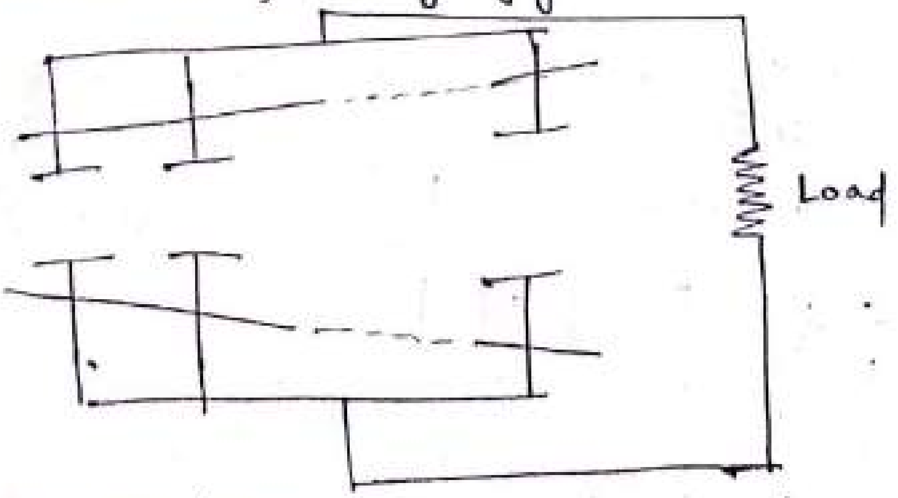


Fig: MHD electrode connections

Hall effect :-

The arrangement of the electrode connections is determined by the need to reduce losses arising from the "Hall effect".

By this effect, the magnetic field acts on the MHD - generated (Faraday) current and produces a voltage in the flow direction of the working fluid rather than at right angles to it. The resulting current in any external load is then called the Hall current.

Various electrode connections schemes have been proposed to utilise the Faraday current while minimizing the Hall current. A simple way, although ~~noth~~ not the best is shown in ~~figure~~. above figure.

A better, but more complicated alternative is to connect each electrode pair across a separate load as shown figure.

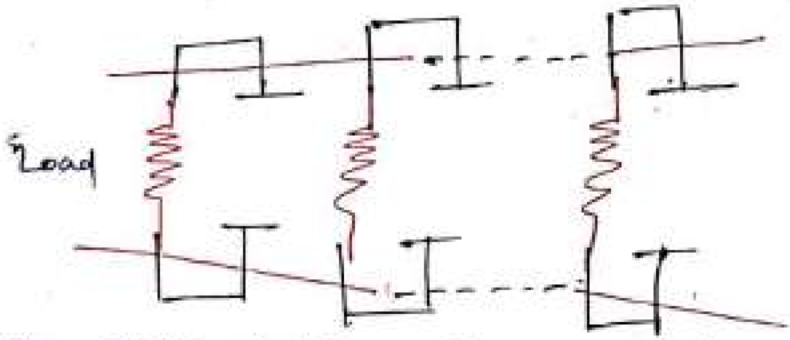


Fig: MHD. electrode connections to minimize Hall current.

Another possibility is to utilize the Hall current only; each electrode pair is short-circuited outside the generator, and the load is connected b/w the electrodes at the two ends of the MHD. generator.

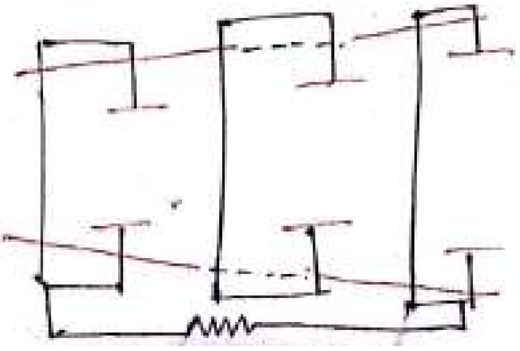
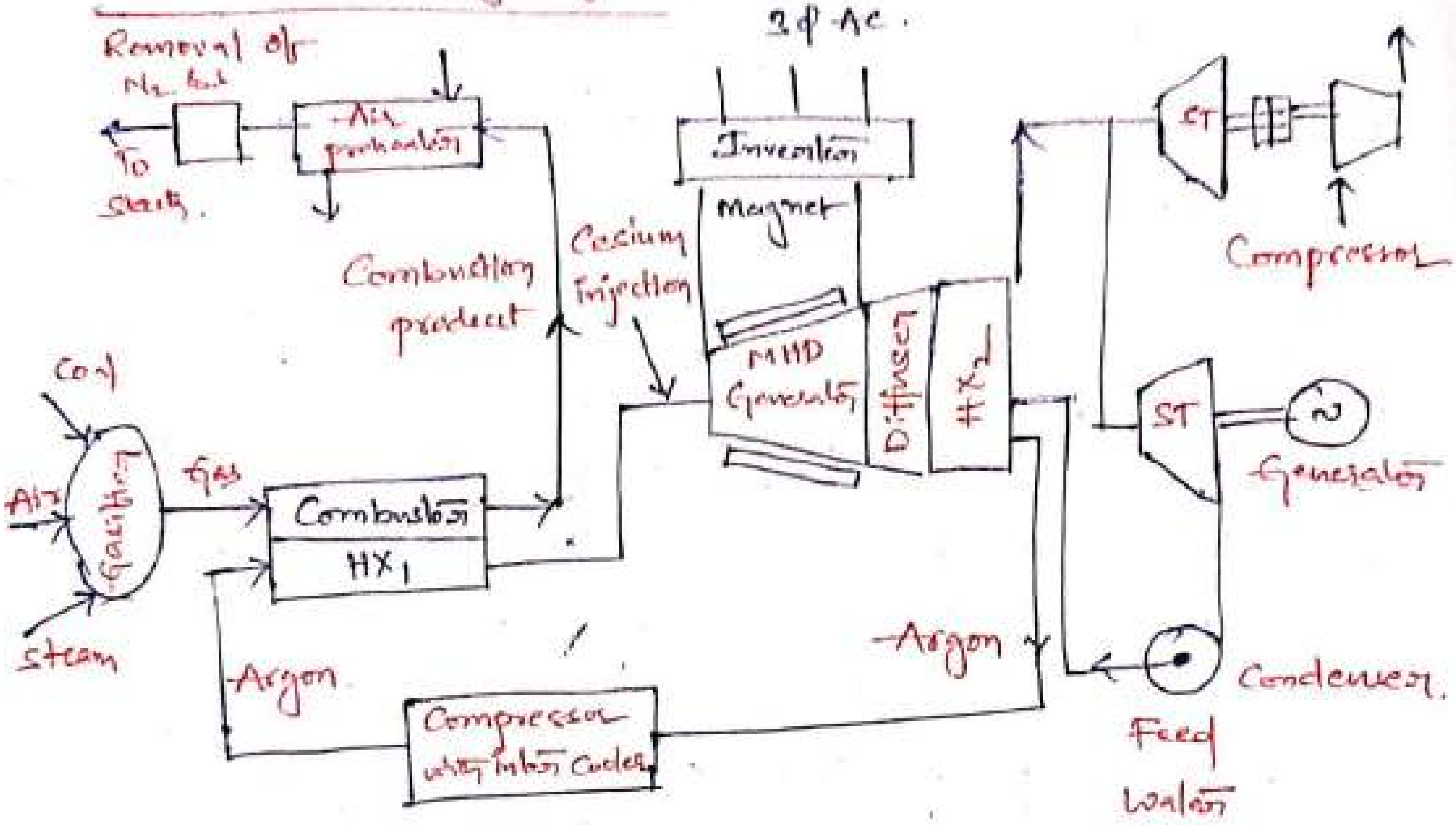


Fig: Use of Hall current in MHD-Generator

Closed Cycle System :-

Two general types of closed cycle MHD generator are being investigated. In one type, electrical conductivity is maintained in the working fluid by ionization of a seed material, as in open cycle systems; and the other, a liquid metal provides the conductivity.

1. Seeded inert gas system :-



HX_1 — primary heat exchanger.
HX_2 — Heat exchanger - 2.

Figure :- A closed cycle MHD system

In a closed cycle system the carrier gas (argon/helium) operates in a form of "Brayton cycle". The gas is compressed and heat is supplied by the source, at essentially constant pressure; the compressed gas then expands in the MHD generator, heat is removed from the gas by a cooler, this is the heat rejection stage of the cycle. Finally the gas is recompressed and returned for reheating.

A closed cycle MHD system is shown in figure. The complete system has three distinct but interlocking loops. One the left is the external heating loop. Coal is gasified and the gas is burnt in a combustor to provide heat. In the primary heat exchanger, this heat is transferred to a carrier gas argon/helium (working fluid) of the MHD cycle.

The loop in the centre is the MHD loop. The hot argon gas is seeded with cesium and resulting working fluid is passed through the MHD generator at high speeds. The d.c. power out of MHD generator is converted to A.c by the inverter and is then fed into the grid.

The loop shown on the right hand side in figure is the steam loop for further recovery of the heat of working fluid and converting this heat into electrical energy. In the diffuser the working fluid is slowed down to a low subsonic speed.

The hot fluid enters a secondary heat exchanger, which serves as a waste heat boiler to generate ~~supplying~~ steam.

This steam is partly utilized to drive a turbine generator and for driving a turbine which runs the argon (or helium) compressor.

The output of the generator is also fed to the main grid. The working fluid is returned back to primary heat exchanger after passing through compressor and inter cooler.

A closed cycle system can provide more useful power conversion at lower temperature (around 1900K as compared to 2500K for open cycle system), which is advantage of permitting a wider choice of materials.

(2). Liquid metal System

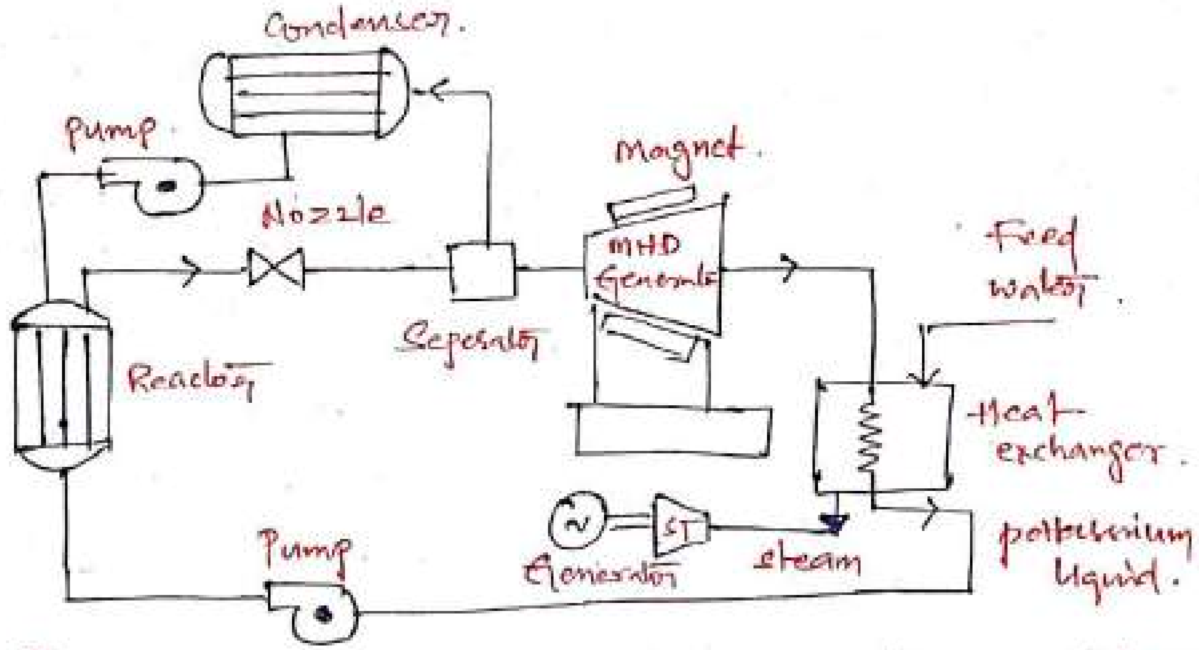


Fig: Closed cycle MHD generator using liquid metal as working fluid Coupled with steam generator.

A liquid metal MHD cycle is illustrated in figure, in which liquid potassium after being heated in breeder reactor is passed through a nozzle to increase its velocity. The vapour formed due to nozzle action are seperated in the seperator and condensed and then pumped back to the reactor as shown.

Then the liquid metal with high velocity attained is passed through MHD generator to produce d.c. power. The liquid potassium ~~com~~ coming out of MHD generator is passed through the conventional steam plant, where in the heat exchanger the heat of liquid potassium is utilized to generate steam to run steam turbine generator.

Fuel Cells

Introduction :-

A Cell (or Combination of cells.) capable of generating an electric current by converting the chemical energy of a fuel directly into electrical energy. The fuel cell is similar to other electric cells in the respect that it consist of positive and negative electrodes with an electrolyte between them. Fuel in a suitable form is supplied to the negative electrode and oxygen, often from air, to the positive electrode when the cell operates, the fuel is oxidised and the chemical reaction provides the energy that is converted into electricity. The fuel cells different from conventional electric cells in the respect that the active material are not contained within the cell but are supplied from outside.

But for its costs, pure hydrogen gas would be preferred fuel for fuel cells. Alternatively impure hydrogen obtained from hydro carbon fuels, such as natural gas or substitute natural gas, liquified petroleum gas (Propane and butane) or liquid petroleum products, can be used in fuel cells. Efforts are being made to develop cells that can use carbon monoxide as the fuel; if they are successful, it should be possible to utilise coal as the primary energy source. Main uses of fuel cells are in power production, automobile vehicles and in special military use.

10.2.2. Design and principle of operation of a fuel cell (with special reference to H_2, O_2 cell)

As stated there are electrochemical devices in which the chemical energy of fuel is converted directly into electric energy. The chemical energy is the free energy of the reactants used. This conversion takes place at constant temperature and pressure. The basic feature of the fuel cell is that the fuel and its oxidant are combined in the form of ions rather than neutral molecules.

The first practical fuel cell was demonstrated by Francis T. Bacon and J.C Frost of Cambridge university in 1959. As per the fuel is used the main types of fuel cells are:

(i) Hydrogen (H_2) fuel cell, (ii) Hydrazine (N_2H_4) fuel cell (iii) Hydro carbon fuel cell, and (iv) Alchohal (methanol) fuel cell.

The operation of the fuel cell can best be described with reference to a specific device. Fuel cell can be adopted to a variety of fuels by changing the catalyst. Here hydrogen oxygen (Hydrox) cell is described for example. These types are the most efficient and the most highly developed.

The main components of a fuel cell are:

(i) a fuel electrode (anode)

(ii) an oxidant or air electrode (cathode), and

(iii) an electrolyte.

In most fuel cells, hydrogen (pure/impure) is the active material at the negative electrode and oxygen (from the oxygen or air) is active at the positive electrode. Since hydrogen and oxygen are gases, a fuel cell requires a solid electrical conductor to serve as a current collector and to provide a terminal at each electrode. The solid electrode material is generally porous.

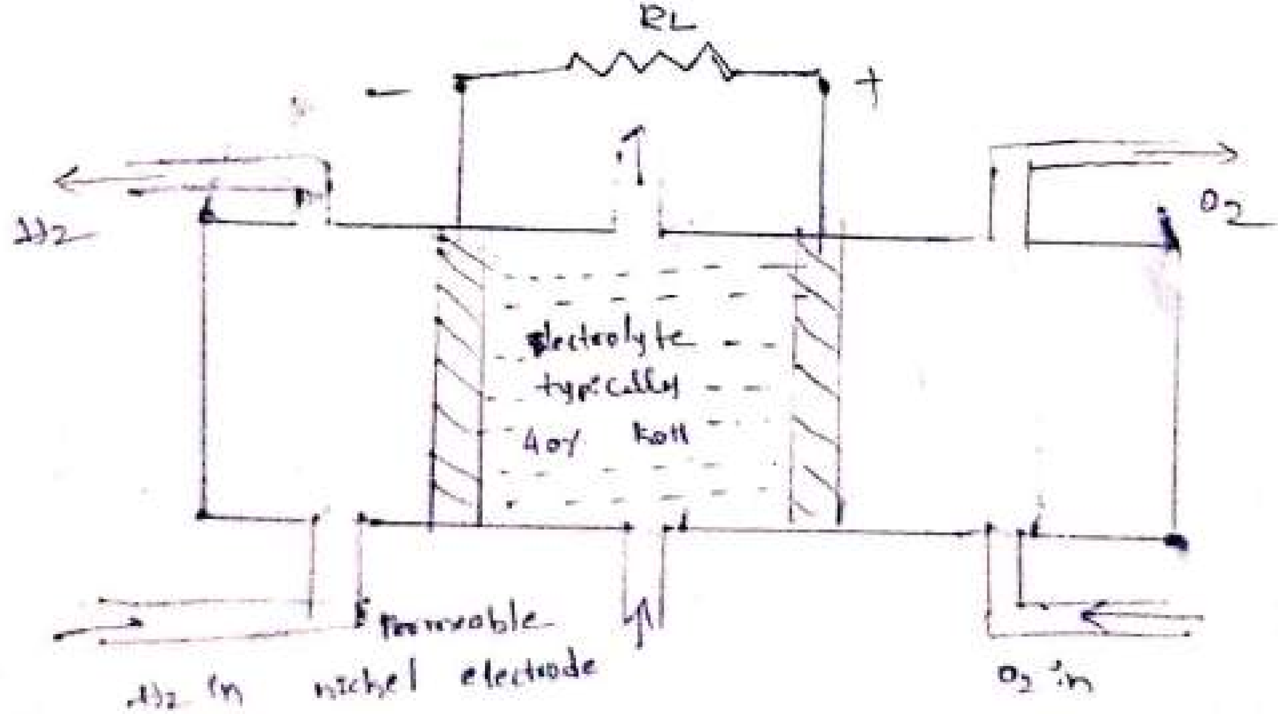


Fig. 10.1 A hydrox (H_2, O_2 cell)

Porous nickel electrodes and porous carbon electrodes are generally used in fuel cells for commercial applications. platinum and other precious metals are being used in certain fuel cells which have potential utility in military and space applications. The porous electrode has a larger number of sites, where the gas, electrolyte and electrode are in contact; the electro chemical reactions occur at these sites. The reactions are normally very slow, and catalyst is included in the electrode to expedite them. The best electro chemical catalysts are finely divided platinum or platinum like material deposited on or incorporated with the porous electrode material. since the platinum metals are expensive, other catalysts, such as nickel (for hydrogen) and silver (for oxygen), are used where possible. The very small catalyst particles provide a large numbers of active sites at which the electro-chemical reactions can take place at a fairly rapid rate.

Although practical fuel cells differ in design details, the essential principles are the same, as indicated by the schematic illustration in Fig. 10.1 hydrogen gas is supplied to one electrode and oxygen gas (or air) to the other. Between the electrodes is a layer of electrolyte. Most existing fuel cells operate at temperature below about 200°C.; the electrolyte is then usually and aqueous solution of an alkali or acid. The liquid electrolyte is generally retained in a porous membrane; but it may be free following in some cells. Different electric current is drawn from the cell in the usual manner by connecting a load between the electrode terminals.

The electro chemical reactions occurring at the electrodes of a hydrogen - oxygen cell may vary with the nature of the electrolyte, but basically they are as follows. At the negative electrode, hydrogen gas (H_2) is converted into hydrogen ions (H^+) i.e., hydrogen with a positive electric charge, plus an equivalent number of electrons (i.e., $\bar{e}$): thus

$$H_2 \longrightarrow 2H^+ + 2\bar{e}$$

At the electrode, hydrogen is diffused through the permeable in which is embedded a catalyst. The catalyst enables the hydrogen molecules, H_2 to be obsorbed, on the electrode surface as hydrogen atoms, which react with the hydroxyl ions (OH^-) in the electrolyte to form water.

when the cell is operating and producing current, the electrons flow through the external load to the positive electrode; here they interact with oxygen (O_2) and water (H_2O) from the electrolyte to form negatively charged hydroxyl (OH^-) ions; thus

$$\frac{1}{2} O_2 + H_2O + 2\bar{e} \longrightarrow 2OH^-$$

The hydrogen and hydroxyl ions then combine in the electrolyte to produce water. $H^+ + OH^- \longrightarrow H_2O$.

The electrolyte is typically 40% KOH solution because of its high electrical conductivity and it is less corrosive than acids.

The above equations show that hydroxyl ions produced at one electrode are involved in the reaction at the other. Also electrode electrons are absorbed from the oxygen electrode and released to the hydrogen electrode. Addition of the three forgoing reactions show that when the cell is operating, the overall process is the chemical combination of hydrogen and oxygen (gases) to form water that is

$$H_2 + \frac{1}{2} O_2 \longrightarrow H_2O.$$

10.2.5 Advantages and Disadvantages of Fuel cell

Advantages. (1) It has very high conversion, efficiencies as
high as 70% have been observed, since it is a direct conversion
process for generating electricity, heat energy produced by
combustion of the fuel is converted partially into mechanical
energy in a steam turbine and then into electricity by means
of a generator. The efficiency of a heat engine is limited
by the operating temperatures, and in the large modern
steam - electric plants above 40% of the heat energy of the
engine and are not subjected to their temperature limitations

(2) Fuel cells can be installed near the use point
thus reducing electrical transmission requirements and
accompanying losses. Consequently considerably higher
efficiencies are possible.

(3) They have few mechanical components; hence,
they operate fairly quietly and require little attention
and less maintenance.

(4) Atmospheric pollution is small if the primary
energy source is hydrogen, the only waste product is water;
if the source is a hydrocarbon, carbon dioxide is also produced
nitrogen oxides, such as accompany combustion of fossil
fuels in the air, are not formed in the fuel cell. Some
heat is generated by a fuel cell. but it can be dissipated to
the atmosphere or possibles used locally.

(5) There is no requirement for large volumes of cooling water such are necessary to condense exhaust system steam & turbine in conventional power plant.

(6) As fuel cells do not make noise, they can be readily accepted in residential areas.

(7) The fuel cell takes little time to go into operation.

(8) The space requirement for fuel cell power plant is considerably less as compared to conventional power plants.

Disadvantages. The main disadvantages of fuel cells are their high initial costs and low service life.

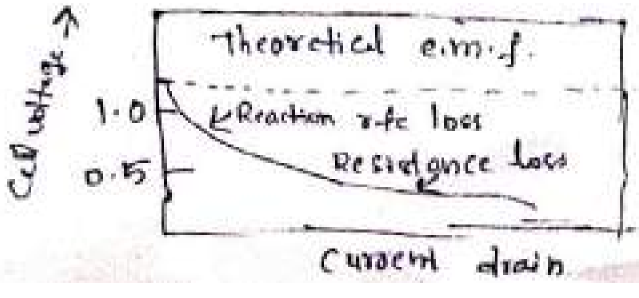
Thermo Dynamic Aspects :-
~~Conversion~~ ~~Efficiency~~ ~~of Fuel~~ ~~cells~~.

The electrical energy generated by a fuel cell depends on what is called the 'free' energy rather than on the heat energy of the overall cell reaction. The free energy of formation of 1 mole (18 grams) of liquid water from hydrogen and oxygen gases at atmospheric pressure is 56.67 kcal or 237 kJ at 25°C. The heat energy (or enthalpy) of the reaction under the same conditions is 68.26 kcal (286 kJ). The theoretical efficiency of the conversion of heat energy into electrical energy in a hydrogen - oxygen fuel cell is thus (56.67/68.26) x100 = 83.!

Efficiences as high as 70% have been observed, but the practical cells using pure hydrogen and oxygen generally have conversion efficiencies in the range of 50 to 60%. The efficiencies are some what lower when air is the source of oxygen. The overall thermal to electrical conversion efficiencies are also lower when the hydrogen is derived from hydro carbon sources. Nevertheless, they should be higher than those obtainable from the same fuels is most steam electric plants.

The theoretical emf (or voltage) of a fuel cell can be calculted from the reaction free energy. For the hydrogen - oxygen cell at 25°C with the gases at atmospheric pressure, the ideal emf is 1.23 volts. at 200°c, it is about 1.15 volts. The discharge voltages observed in actual cells are always below the theoretical value, the difference increasing with increasing strength of the current drawn from the cell.

For the moderate currents at which fuel cells normally operate the emf is 0.7 to 0.8 volts. The deviation from the theoretical emf account for the ~~conversion~~ conversion efficiency of a fuel cell being below the ideal maximum value.



Operating. Conditions:-

In a practical fuel cell the theoretical output voltage is not attained for several reasons, as outline below. The difference between the theoretical voltage and the actual voltage is known as the polariction. Some authors call this the overvoltage, by analogy with the electrolysers. The effect of polarisation is to reduce the efficiency of the cell from the theoretical maximum. The significant drop in voltage and hence energy loss takes place as the current density is increased as shown in Fig 10.9

Three main types can be distinguished

(1) Activation polarisation
(2) Resistance or ohmic polarisation, and
(3) concentration polarisation.

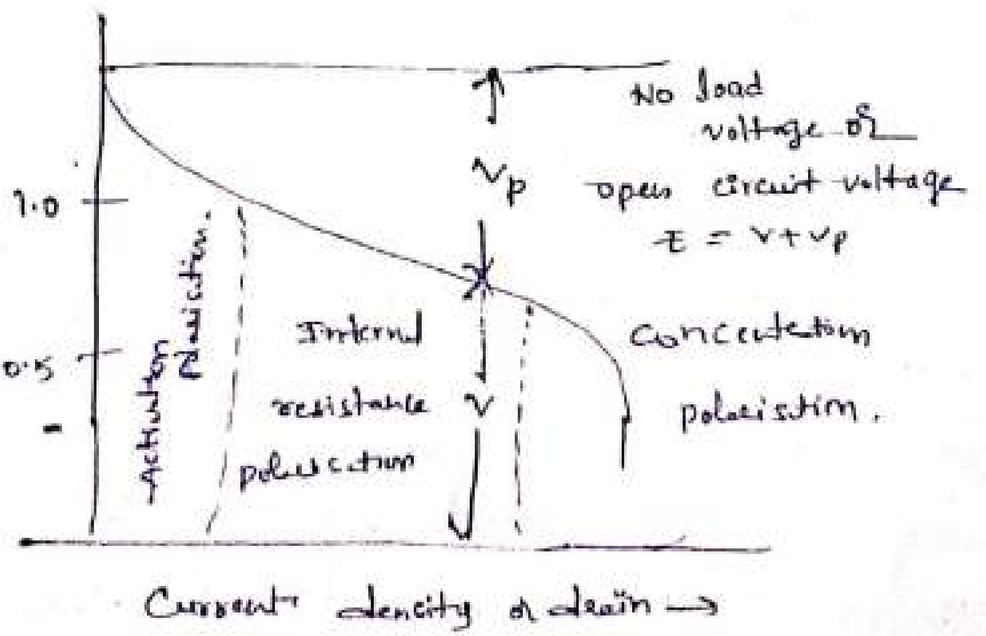


Fig 10.9. polarisation in fuel cells.

(1) Activation polarisation (chemical polarisation).:-

This is related to the activation energy barrier for the electron transfer process at the electrode. In fuel cells electrons are liberated and reaction is chemisorption reaction. At low current densities significant number of electrons are not emitted, which results in such a potential loss. This process requires that certain minimum activation energy supplied so that sufficient number of electrons are emitted, this energy is supplied by output of the cell. This loss is known as activation or chemical polarisation.

This polarisation may be reduced by using better electrode catalysts, increasing surface area, and by raising the operating temperature.

(2) Resistance polarisation.:-

The voltage drop is linearly related to the current flow according to ohm's law. The internal resistance is composed of the electrode resistance, the bulk electrolyte resistance, and interface contact resistance between electrode and electrolyte. The loss due to resistance polarisation is significant when current density is quite large. The reduction is internal resistance is the main design ~~certain~~ of criterion for low resistance polarisation losses. With large electrodes the resistance may be quite significant, particularly when there are made thin or consist of extremely thin coating on a non conducting support & when the electrode catalyst is a poor electric conductor.

The electrolyte resistance can be decreased usually by using a more concentrated electrolyte by closer spacing of electrodes and by increased temperature. Hence loss due to resistance polarisation can be reduced by:

(i) selecting proper shape of the electrode to have minimum contact between electrode and electrolyte.

(ii) Reducing the gap between electrodes

(iii) By using concentrated electrolyte.

(3) Concentration polarisation :-

This type of polarisation tends to limit the current drawn, as shown in the figure. This broad heading covers a slow step in any of the mass transport processes in the cell, and is generally divided into two categories ~~ed~~ i.e,

(1) Electrolyte side polarisation and

(2) Gas side polarisation.

The electrolyte - side polarisation is due to slow diffusion in the electrolyte causing a change in a concentration at the electrode. This effect can be minimized by increasing the electrolyte concentration or by stirring or circulating the electrolyte.

Gas side polarisation is caused from slow diffusion of reactants through a porous electrode to the reaction site. or of slow diffusion of products away from the reaction site. The loss in voltage due to gas side polarisation is reduced by using electrodes of smaller pore size. concentration polarisation is also reduced by increasing temperature.

We have observed that all the three losses in a fuel cell are decreased by increasing temperature, due to this. a given cell is usually operated in practice at the higher end of its temperature range.

All the losses in a fuel cell may be included under voltage efficiency and it can be expressed as

$$\eta_v = \frac{\text{operating voltage}}{\text{theoretical voltage}}$$

$$= \frac{\text{on load voltage}}{\text{open circuit voltage}} = \frac{V}{E}$$

where V = operating voltage at a given current density and
E = the theoretical open circuit voltage (emf)

In the case of fuel cell which acts ideally, the terminal cell potential is constant and is equal to the thermo dynamic reversible potential of the cell at any value of the current density drawn from the cell. In order that the efficiency of electrochemical energy converters may be compared with those of other energy conversion devices. it is necessary to have a common base. most of the energy converters convert heat energy into electricity. The heat energy in many cases is provided by the heat of a chemical ~~rea~~ reaction. The efficiency of these cells is defined as the work output divided by the heat input.

~~they, in an analogues manner~~

Thus, the ideal efficiency of an electrochemical energy converter is defined by the equation

$$\eta_i = \frac{\Delta G}{\Delta H} = -\frac{nFE}{\Delta H}.$$

Where, n = number of electrons transferred per molecule of the reactant.

F = Faraday's Constant

E = e.m.f of cell.

Generally, ΔG is quite close to ΔH and hence the efficiency of fuel cell ideally would be close to unity.

———o———

Wind Energy

Wind energy is the Kinetic energy possesed by the air due to its velocity. It is a renewable source of Energy. Wind turbines Convert the kinetic energy of the wind into Mechanical power. This mech power can be converted into electrical power/Energy by using a generator.

Sources–
The main sources of wind Energy are

- Uneven heating of the atmosphere by the sun,
- Variation in the earth's surface,
- Rotation of the earth.

So, the main source of wind energy is from solar radiation only. About 1–2% of the total solar radiation that reaches the earth's surface is transformed into wind energy due to uneven heating of the atmosphere.

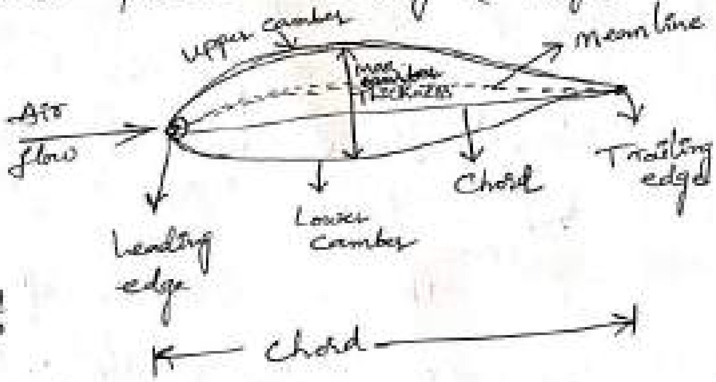
Potential of wind Energy–
India is the 4th Largest installed wind power capacity in the world. The recent assessment indicates a gross wind power potential of 302 GW in the country at 100 meters and 695.5 GW at 120 meters above ground level.
Wind energy in India may be considered cost effective alternative to conventional sources of electrical power.

Factors involved in site selection for wind mills–

i) Availability of wind with sufficient Kinetic energy
ii) The Magnitude of wind velocity should be high.
iii) The wind availability should be throughout the year
iv) The site should be free from obstacles.
v) Availability of open land at a lower land cost
vi) The construction materials should be available & cheaper
vii) Away from the populated places, but not from load Centre.
viii) No possibility of floods, earthquakes, storms etc.
ix) Availability of technicians & Skilled workers for controlling

Terms used in Wind Energy—

Airfoil (or) Aerofoil— A stream lined curved surface designed for air to flow around it in order to produce low drag & high lift forces.



Blade— A part of wind turbine that extracts wind energy.

Leading edge— It is the front edge of the blade that faces towards the direction of wind flow.

Trailing edge— It is the rear edge of the blade that faces away from the direction of wind flow.

Chord line— Line joining the leading & trailing edges.

mean line— A line that is equidistant from the upper & lower surfaces of the airfoil.

Camber— It is the max. distance b/w mean line & chord line which measures the curvature of airfoil.

Rotor— It is the prime part of wind turbine that extracts energy from the wind.

Hub— Blades are fixed to a hub which is a central solid part of the turbine.

propeller— It is the turbine shaft that rotates with the hub and blades.

~~Blade chord~~ pitch angle— Angle b/w blade chord & the plane of the blade rotation.

pitch control of blades— A system where pitch angle of the blades changes according to the wind speed for efficient operation.

Swept area— The area covered by the rotating rotor.

Drag force (F_D)— It is the force component which is in line with the velocity of the wind.

Lift force (F_L)— It is the force component perpendicular to the drag force.

Nacelle— It houses the Generator, gear box, hydraulic system and yawing mechanism.

Yaw control— As the direction of the wind changes frequently, the yaw control is provided to steer the axis of turbine in the direction of the wind.

Wind vane – It monitors the wind direction. It sends a signal to the controlling computer system which activates the Yaw mechanism to make the ~~rotor~~ face the wind direction.

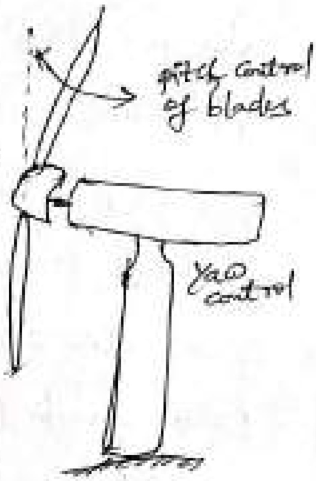
Cut-in speed – the wind speed at which the wind turbine starts to operate.

Cut-out speed – The wind speed at which the wind turbine is designed to shut-down to prevent damage from high winds.

Rated wind speed – The wind speed at which the turbine attains its maximum output.

Down wind – It is the opposite side of the direction from which the wind is blowing.

Up wind – It is the side of the direction from which the wind is blowing in the path of the oncoming wind.



Solidity – It is the ratio of the blade area to the swept area.

Tip speed ratio (TSR) – It is the ratio of the speed of outer blade tip to the undisturbed natural wind speed.

The basic of wind Energy conversion –

The extraction of power (Energy) from the wind depends on creating certain forces & applying them to rotate a mechanism.

The primary mechanisms to produce forces from the wind are – Lift & Drag forces.

Lift force (F_L) act perpendicular to the air flow, while drag force (F_D) act in the direction of flow. Lift forces are produced by changing the velocity of the air stream flowing over either side of the lifting surface. i.e. any change in velocity generates a pressure difference across the lifting surface. This pressure difference produces a force that begins to act on the high pressure side and moves towards the low pressure side of the lifting surface which is called an "Air foil".

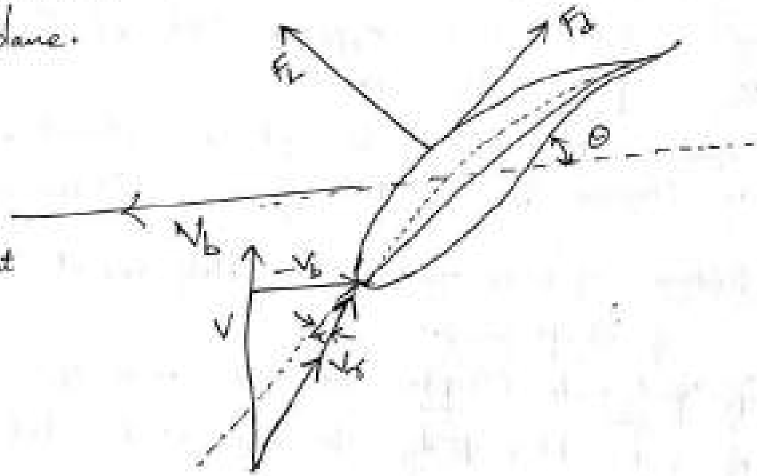
A good airfoil has a high lift/Drag ratio, in some cases it can generate lift forces perpendicular to the air stream direction that are 30 times as great as the drag force parallel to the flow.

* The design of each wind turbine specifies the angle at which the air foil should be set to achieve the max. lift/drag ratio.

Wind turbines can be identified based on their geometry and the manner in which the wind passes over the blades.

→ Slow speed turbines are mainly driven by drag forces acting on the rotor. The torque at the rotor shaft is comparatively high which is of prime importance for mechanical applications such as water pumps.

→ High speed turbines utilize lift forces to move the blades, which phenomenon is similar to what acts on the wings of an aeroplane.



$V \rightarrow$ free wind velocity

$V_b \rightarrow$ velocity of airfoil element

$V_r \rightarrow$ resultant wind

$F_L \rightarrow$ lift force $\perp$ to V_r.

$F_D \rightarrow$ drag force

$\theta \rightarrow$ angle of twist ; $\alpha \rightarrow$ angle of incidence.

Classification of Wind Energy conversion (WEC) systems –

The WEC systems are classified as –

① According to orientation of axis of rotor –
  i) Horizontal axis wind turbine (HAWT)
  ii) Vertical axis wind turbine (VAWT)

② According to the size –
  i) Small scale o/p → upto 2kW o/p
  ii) Medium scale → 2kW – 100kW o/p
  iii) Large scale → Above 100kW o/p.

③ According to the type of rotor
  i) propeller type (It is horizontal axis high speed rotor)
  ii) Multiblade type (It is horizontal axis low speed rotor)
  iii) Savonious type (vertical axis rotor)
  iv) Darrieus type (vertical axis rotor)

④ According to type of o/p power
  i) DC output → DC generator, Alternator rectifier
  ii) AC o/p → Variable freq & variable or constant AC voltage
  Const freq & variable or constant AC voltage

(5) According to the rotational speed

i) Const. speed with variable pitch blades (Using syn. generators)
ii) Nearly const. speed with fixed pitch blades (Using Ind. Generators)
iii) Variable speed with fixed pitch blades
(Using field modulated systems, AC-DC-AC link, Double o/p Ind. Generator, AC Commutator generators etc).

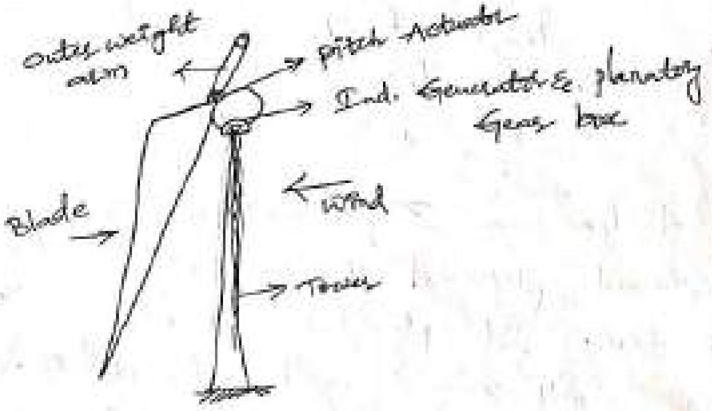
(6) According to Utilization of o/p pwr

i) Battery Storage ii) Direct connection to electro magnetic energy converter iii) Inter connection with conventional electric utility grids iv) Other forms of storage like thermal potential etc.

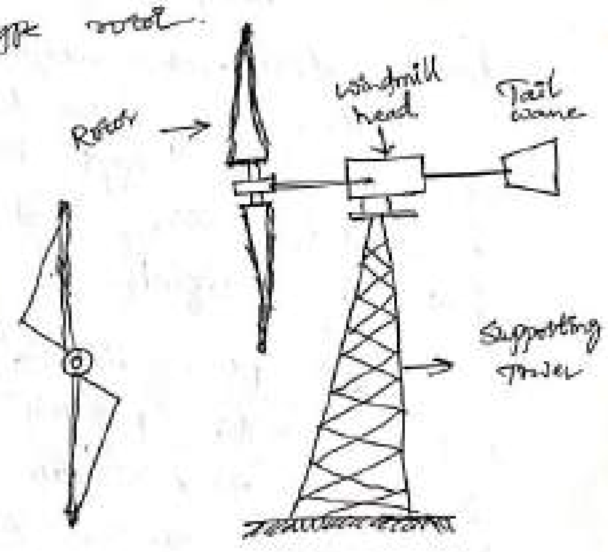
Horizontal Axis Wind turbines (HAWT) —

These turbines have rotor axis of rotation parallel to the wind stream. These are simple in principle, but the design of the system is complex.

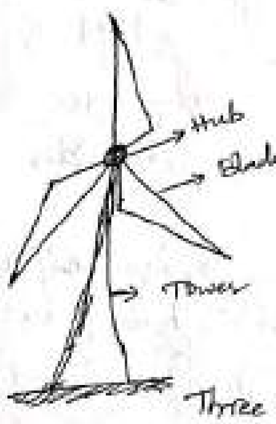
Some of the horizontal axis type wind machines are — propeller type — single blade, two blade, three blade, multiblade rotor
Sail wing rotor, Dutch type rotor.



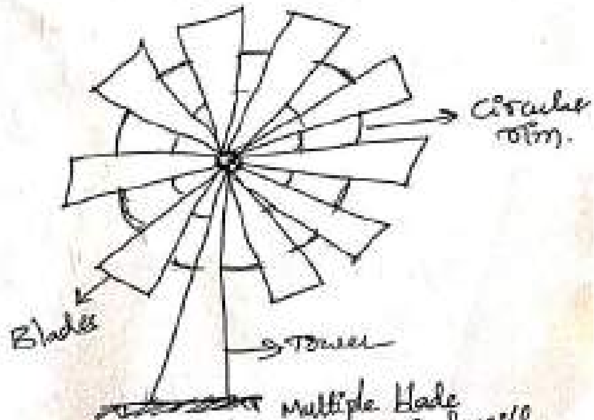
Single blade wind mill



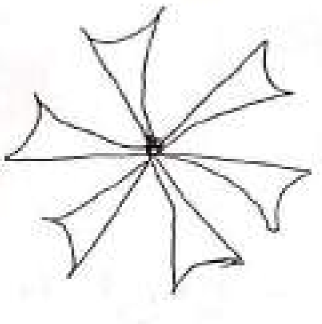
Two blade windmill



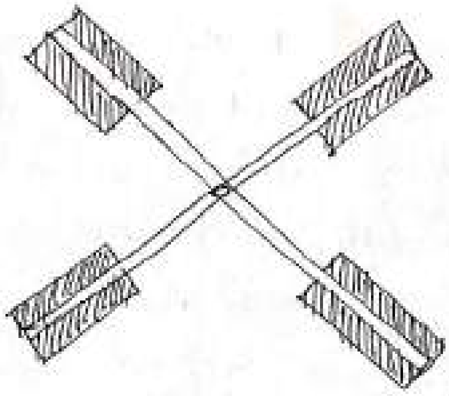
Three blade wind mill



Multiple blade wind mill.



Sailing type wind mill.



Dutch type wind mill.

* In single blade wind mill, a long blade (about 60m) is mounted on the rigid hub. and to reduce rotor cost, use of low cost counter weight is recommended which balance long blade centrifugally.

It has lower blade weight & cost, blade control is simple. But vibration produced due to aerodynamic torque.

* In double blade wind mill, the rotor drives a generator through a stepup gear box. The blade rotor is usually designed to be oriented downwind of the tower.

Compared to 3-bladed rotor, two bladed wind turbine having less rotor weight, so 30% less heavy than 3-bladed rotor and these are operate at higher rotational speed, the torque on the shaft is lower & they can be turned horizontally during storms, so they are less likely to be hit by lightning.

* Most modern wind turbines are 3-bladed designs with the rotor position maintained upwind using electrical motors in their yaw mechanism. It provides the high energy yield, greater stability low weight and durability.

When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates lift & drag.

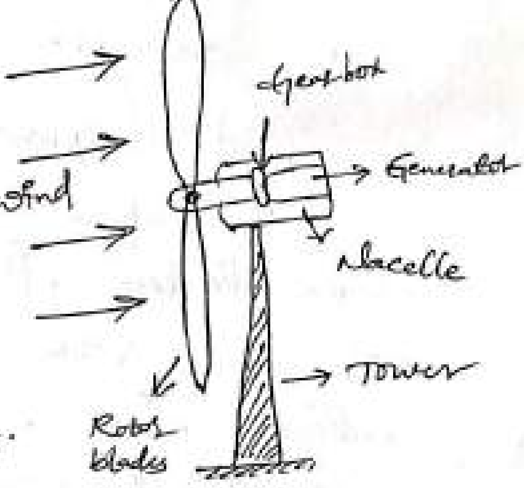
The blade slope is designed by using the same aerodynamic theory as for aircraft. The diameter of the rotor ranges → 2m to 25m.

The 3-bladed wind turbines have more efficiency compared to other type. These turbines have very less vibration, high rotational speed and minimum stress.

The multiblade rotor is fabricated from curved sheet metal blades. The width of the blades increases outwards from the centre. Blades are fixed at their inner ends on a circular rim. They are also welded near their outer edge to another rim to provide a stable support. The no. of blades used ranges from 12 to 18 commonly. The rotor blades are made from sheet metal (or) Aluminium.

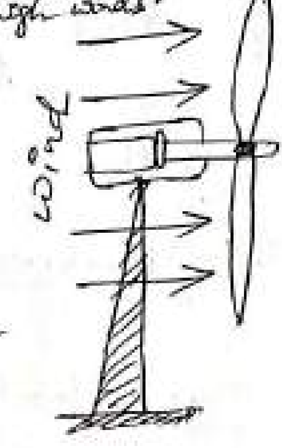
The Dutch type is one of the oldest methods of designs. The blade surfaces are made from an array of wooden slats which "feather" at high wind speeds.

The Sailwing type is of recent origin. The blade surfaces is made from cloth, nylon (or) plastics arranged as mast and pole (or) sailwings. There is also variation in the no. of sails used.



* Upwind HAWT —

The generator shaft is positioned horizontally and wind hits the blade before the tower. Blades are placed at considerable distance in front of the tower and are tilted up a small amount. These turbines require complex yaw control to keep the blades facing into the wind. Most modern wind turbines are of the upwind type and these are operate more smoothly and delivers more power. The blades are stiff to prevent from being pushed into the tower at high winds.



* Down wind HAWT —

The Generator shaft is positioned horizontally, and the wind hits the tower first and then the blade. These turbines doesn't need an additional mechanism for keeping it in line with the wind and in high winds, the blades can be allowed to bend which reduces their swept area and thus their wind resistance. It increases blade noise & decreases o/p power.

Vertical Axis Wind turbines (VAWT) –

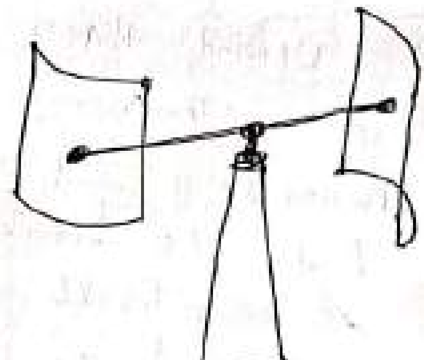
In these type of turbines, the rotor axis of rotation is perpendicular to wind stream. i.e. main rotor shaft is set transverse to the wind, while the main components are located at the base of the turbine.

Generator shaft is positioned vertically with the blades pointing up with the generator mounted on the ground or a short tower.

The major types of VAWT are

i) Savonious rotor   ii) Darrieus rotor

i) Savonious rotor –

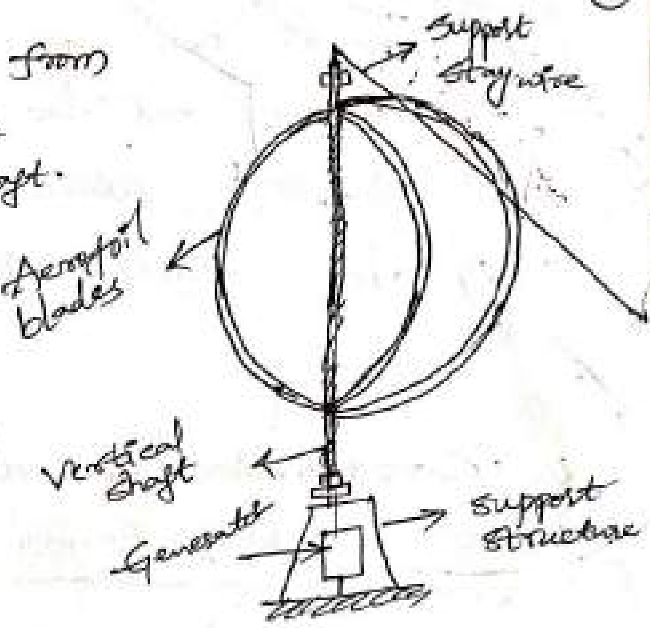


It comprises two identical hollow semi-cylinders fixed to a vertical axis. The inner side of the two half-cylinders face each other to have an 'S' shaped cross-section.

Irrespective of wind direction, the rotor rotates due to pressure difference b/w the two sides. It is self starting and the driving force is mainly of drag type. The rotor possesses high solidity so as to produce a high starting torque & hence this rotor is suitable for water pumping.

ii) Darrieus rotor –

This rotor has two or 3 thin curved blades of flexible metal strips. It looks like an egg beater



and operates with the wind coming from any direction. Both the ends of the blades are attached to a vertical shaft. It has an advantage that, it can be installed close to the ground eliminating the cost of the tower structure.

Lift is the driving force, creating max. torque when the blade moves across the wind.

They have relatively low solidity and low starting torque, but high tip to wind speeds and therefore, relatively high power o/ps per given rotor weight and cost. They are used for decentralized electricity generation.

Advantages of VAWT–

i) Wind from any direction rotates blades.

ii) Yaw mechanism is not needed to turn the rotor against the wind.

iii) The tower may not be needed as the generator, gear-box, and controllers are placed on the ground.

iv) The tower can be lightened even further when guy wires are used.

v) The tower itself need not be structurally as strong as that for HAWT.

Disadvantages of VAWT–

i) Blades are relatively close to the ground where wind speeds are lower.

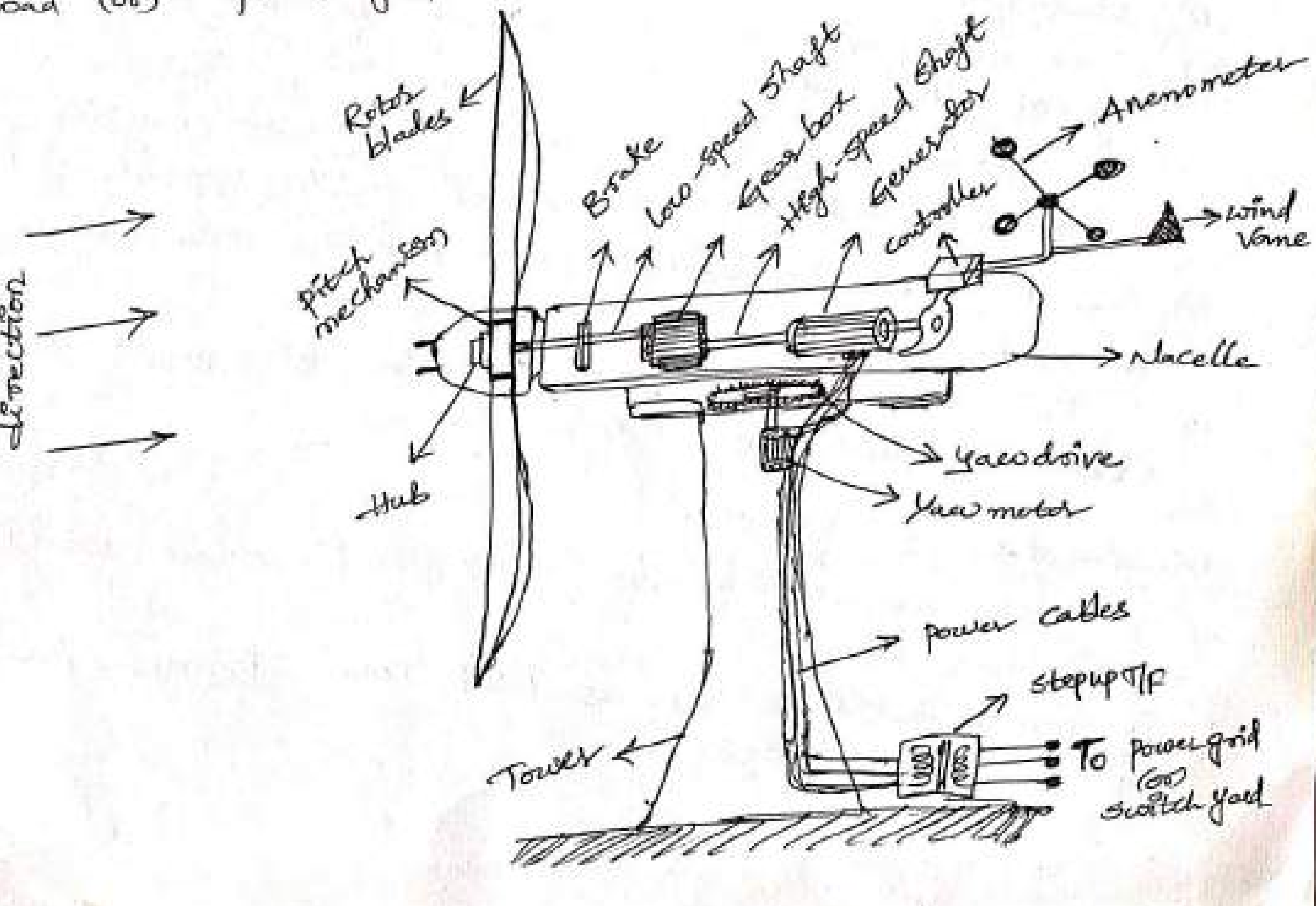
ii) Power output is less as wind power increases as the cube of velocity.

iii) winds near the surface of the earth are not only slower, but also more turbulent (change in pressure and velocity), which increases stresses on VAWTs.

iv) Low starting torque & low swept area.

* Construction of a wind turbine / Basic Components of a Wind Energy Conversion System (WECS) —

The main components of a WECS are shown in the figure. This Aero turbines convert energy in the wind to rotary mechanical energy. They require pitch control and yaw control for proper operation. A mechanical interface consisting of a step up gear and suitable coupling transmits the rotary mechanical energy to an electrical generator. The o/p of this generator is connected to the load (or) power grid.



Wind turbine tower — It made from tubular steel, and supports the structure of turbine. As the wind speed increases with height, taller towers enables turbines to capture more energy & generate more electricity. winds at elevations of 30 mtrs (about 100 feet) (or) higher are also less turbulent.

Wind direction — It determines the design of the turbine. Upwind turbines are face into the wind & downwind turbines face away. Most utility scale Land-based wind turbines are upwind turbines.

Wind Vane — It measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Anemometer — It measures wind speed and transmits wind speed data to the controller.

Blades — These are made mostly of fiber glass reinforced plastic. Turbine blades vary in size, but a modern Land-based wind turbine has blades of over 170 feet (52 mtrs).

When wind flows across the blade, the air pressure on one side of the blade decreases. This difference in air pressure across the two sides of the blade creates both lift & drag forces. The force of the lift is stronger than the drag & this causes the rotor to rotate.

Pitch mechanism — It adjusts the angle of the wind turbine's blades w.r.t the wind, controlling the rotor speed. By adjusting the angle of turbine blades, the pitch system controls how much energy the blades can extract. The pitch system can also "feather" the blades, adjusting their angles so they donot produce force that would cause the rotor to spin. Feathering the blades slows the turbine's rotor to prevent damage to the machine when wind speeds are too high for safe operation.

Hub — It is a part of turbine's drive-train, turbine blades fit into the hub that is connected to the turbine's main shaft.

Gear box — The drive-train is composed of the rotor, main bearing, main shaft, gear box & generator. The drive train converts the low-speed, high-torque rotation of the turbine's rotor into electrical energy.

Rotor — The blades & hub together form the turbine's rotor.

Yaw system — The yaw drive rotates the nacelle on upwind turbines to keep them facing the wind when wind direction changes. The yaw motors power the yaw drive to make this happen.

Downwind turbines don't require a yaw drive, because the wind manually blows the rotor away from it.

Nacelle — The nacelle sits atop the tower and contains the gear box, low & high speed shafts, generator & brake. Some nacelles are larger than a house & for a 1.5MW geared turbine, it can weigh more than 4.5 tons.

Low speed shaft — It is a part of turbine's drive train, it is connected to the rotor & spins b/w 8-20 rotations per minute.

Main shaft bearing — It supports the rotating low-speed shaft & reduces friction b/w moving parts. So that, the forces from the rotor don't damage the shaft.

High speed shaft — It connects to the gear box and drives the generator.

Brake — A turbine brake keeps the rotor from turning after it's been shutdown by the pitch system. Once the turbine blades are stopped by the controller, the brake keeps

the turbine blades from moving, which is necessary (7)
for maintenance.

Controller — The controller allows the machine to start at wind speeds of about 7–11 miles/hr and stops the machine when wind speeds exceed 55–65 miles/hr. The controller turns off the turbine at higher wind speeds to avoid damage to different parts of the turbine.

Generator — It is driven by the high-speed shaft. Copper windgs turn through a magnetic fld in the generator produce electricity.

Some generators are driven by gear boxes & others are directly drives, where the rotor attaches directly to the generator.

Transformers — These are receives AC electricity from generators through power cables at one voltage & increases the voltage to deliver the electricity as needed. For wind power plants, step-up T/Fs are used to increase the vltage (reducing the required current), which decreases the power losses that happen when transmitting large amounts of current over long distances with T/m lines.

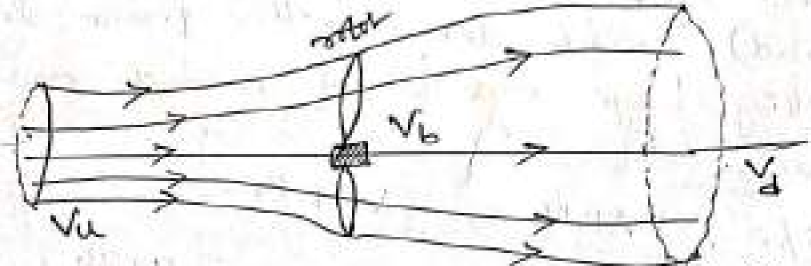
Comparison b/w HAWT & VAWT —

HAWT	VAWT
i) Axis of the rotation is llel to the wind stream	i) Axis of rotation is perpendicular to the wind stream.
ii) High swept area	ii) Low swept area.
iii) Less noise	iii) more noise
iv) High cost	iv) Low cost
v) More power o/p from wind	v) Less power o/p from wind
vi) more efficient	vi) Less efficient
vii) Smooth o/p power obtained	vii) Fluctuating o/p power obtained.
viii) Low starting torque	viii) High starting torque
ix) operates at moderate wind speed.	ix) operates even in low wind speeds.
x) Technically Fully developed and widely used.	x) Technically Under developed and rarely used.
xi) This turbines uses lift forces to rotate the rotor.	xi) This turbines uses lift and drag forces to rotate the rotor.

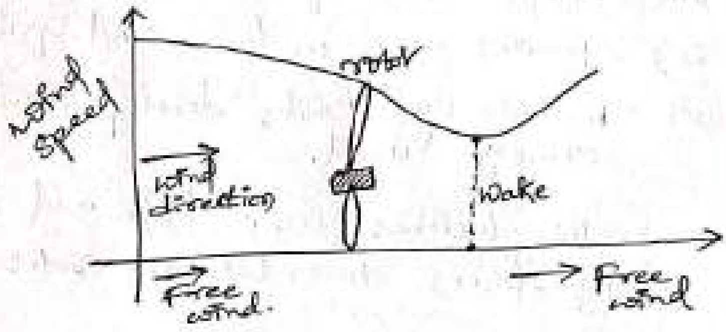
xii) It has tall tower structure xii) Short tower structure.
xiii) Yaw mechanism is needed to turn the rotor xiii) No need of Yaw mechanism.

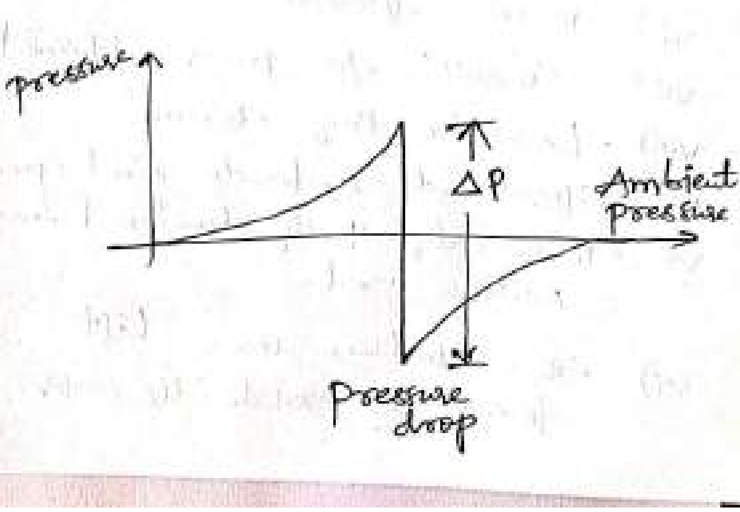
Energy/power Extraction from the wind turbine (Betz criteria)-

Wind turbines extract energy from wind stream by converting the kinetic energy of the wind to rotational motion required to operate an electric generator.
It is assumed that, the mass of the air which passes through rotor is only affected and remains separate from the air which does't pass through the rotor. Accordingly, a circular boundary surface is drawn showing the affected air mass and this boundary is extended upstream as well as downstream



As the free wind (stream) interacts with the turbine rotor, the wind transfers part of its energy into the rotor and the speed of the wind decreases to a min. leaving a trail of distributed wind called 'Wake'. The variation in velocity is considered to be smooth from upstream to downstream. However, the fall in static wind pressure is sharp. The wind leaving the rotor is below the atmospheric pressure, but at far downstream it regains its value to reach the atmospheric level.





wind flow is considered incompressible and hence the air stream flow diverges as it passes through the turbine. Also the mass flow rate of wind is assumed constant at far upstream, at the rotor and at far down stream. To compute mathematical relationships, Let –

$\rho \rightarrow$ air density, A — Area of the blades,

m — mass flow rate of wind,

V_u — velocity of wind upstream of wind turbine

V_b — velocity of wind at blades

V_d — velocity of wind downstream of wind turbine before the wind front reforms & regains the atmospheric level

The K.E. of wind at upstream of wind turbine $(E_1) = \frac{1}{2} m V_u^2$

" " " " downstream " " $(E_2) = \frac{1}{2} m V_d^2$

Hence, the K.E. of wind changed during the flow of this quantity of air from upstream to downstream. i.e.

$$E_1 - E_2 = \frac{1}{2} m V_u^2 - \frac{1}{2} m V_d^2 = \frac{1}{2} m (V_u^2 - V_d^2)$$

We Know, the power extracted from the wind is the Kinetic energy changed/sec. during flow of mass 'm' of air from upstream to downstream. i.e.

Power extracted can be written as,

$$P = \frac{1}{2} m (V_u^2 - V_d^2) \quad \text{——— (1)}$$

The mass flow rate of wind will be the same at upstream & downstream at every cross-sec. of the blades. Since whatever the quantity of air is entering, the same is coming out from the blades. Then mass flow rate of wind can be represented as,

$$\text{Mass flow rate} = \text{mass/sec} = \frac{\text{density} \times \text{area} \times \text{length}}{\text{sec}}$$

$$= \text{density} \times \text{area} \times \text{velocity}$$

i.e. $m = \rho A V_b$

Then from eqn ①,

$$P = \frac{1}{2}\rho A V_b \left(V_u^2 - V_d^2\right) \quad \text{--- ②}$$

As the turbine is assumed to be placed at the middle of the blades, the wind velocity of the turbine blades can be considered as average velocity of upstream and downstream velocities. i.e. $\frac{V_d + V_u}{2} = V_b$

Then, sub. in eqn ②,

$$P = \frac{1}{2}\rho A \left(\frac{V_u + V_d}{2}\right)\left(V_u^2 - V_d^2\right)$$

$$= \frac{1}{4}\rho A \left(V_u^3 - V_d^3 - V_u V_d^2 + V_u^2 V_d\right)$$

$$= \frac{1}{4}\rho A V_u^3 \left(1 - \left(\frac{V_d}{V_u}\right)^3 - \left(\frac{V_d}{V_u}\right)^2 + \left(\frac{V_d}{V_u}\right)\right) \quad \text{--- ③}$$

To obtain max. power from wind, differentiate above eqn w.r.t. 'V_d' and equate to zero. i.e.

$$\frac{dP}{dV_d} = \frac{1}{4}\rho A V_u^3 \left(0 - \frac{3V_d^2}{V_u^3} - \frac{2V_d}{V_u^2} + \frac{1}{V_u}\right) = 0$$

$$= \frac{1}{4}\rho A \left(-3V_d^2 - 2V_d V_u + V_u^2\right) = 0$$

$$\frac{1}{4}\rho A \left(-3V_d^2 - 3V_d V_u + V_d V_u + V_u^2\right) = 0$$

$$\frac{1}{4}\rho A \left(-3V_d (V_u + V_d) + V_u (V_u + V_d)\right) = 0$$

$$\frac{1}{4}\rho A \left[(-3V_d + V_u)(V_u + V_d)\right] = 0$$

Here, ρ, A and $(V_u + V_d)$ can't be zero, therefore,

$$-3V_d + V_u = 0 \implies \frac{V_d}{V_u} = \frac{1}{3}$$

substitute $\frac{V_d}{V_u} = \frac{1}{3}$ in eqn ③,

$$P_{max} = \frac{1}{4}\rho A V_u^3 \left(1 - \left(\frac{1}{3}\right)^3 - \left(\frac{1}{3}\right)^2 + \left(\frac{1}{3}\right)\right) = 0.5925 * \frac{1}{2}\rho A V_u^3 \quad \text{--- ④}$$

$$\therefore \boxed{P_{max} = 0.5925 \times P_{available}}$$

From the above eqn, we can conclude that, the max. power extracted from the wind is in the fraction of 0.5925 of it's total kinetic power available. This fraction is known as the "Betz criteria". This calculated power is according to the theory of the turbine. But actual mech. power received by the generator is lesser than that and it is due to losses for friction rotor bearing & inefficiencies of aerodynamic design of the turbine.

From the eqn ④, it is observed that,

Extracted power is,

i) $P \propto \rho$ $\Rightarrow$ as $\rho\uparrow$, 'P' also increases.

ii) $P \propto$ swept area (A) $\Rightarrow$ If the length of blade increases, the radius of swept area ↑, so power also ↑.

iii) $P \propto V^3$ $\Rightarrow$ If the velocity of wind doubles, the turbine power increases to 8 times.

Power Co-efficient (C_p) (or) power efficiency

$$C_p = \frac{P_{max}}{P_{total}} = 0.5925.$$

∴ Max. power extracted by turbine rotor is 59.25% of the total wind energy in the area swept by the rotor.

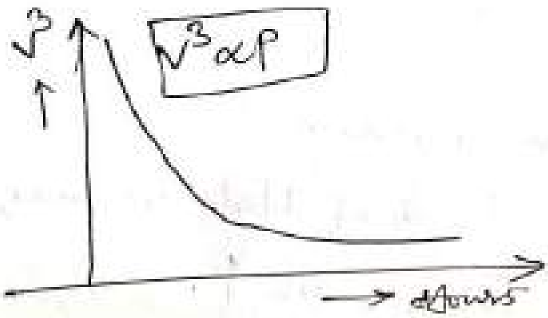
Performance characteristics of wind turbines—

* We know, the available power of the wind is,

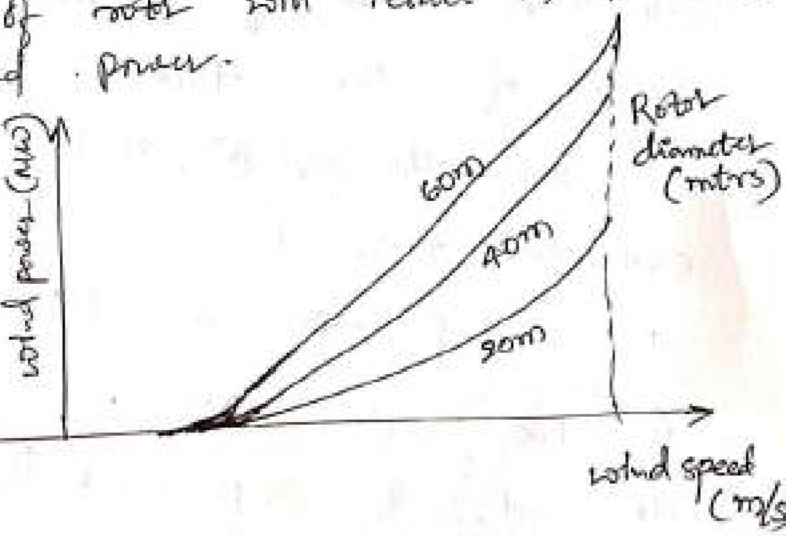
$$P = \frac{1}{2}\rho A V^3 = \frac{1}{2}\rho\left(\frac{\pi}{4}D^2\right)V^3 = \frac{1}{8}\rho\pi D^2 V^3$$

i.e. the max. power available from the wind varies according to the square of the diameter of rotor (D), normally taken to be swept area of aero turbine.

Thus doubling the diameter of rotor will result in 4-times increase in available wind power.

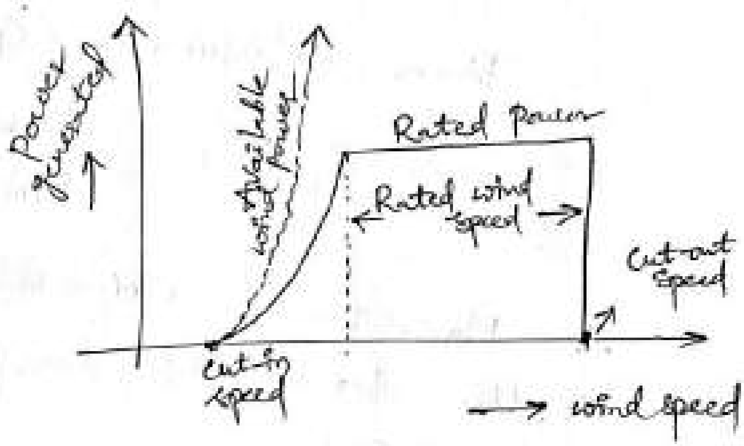


Power duration curve



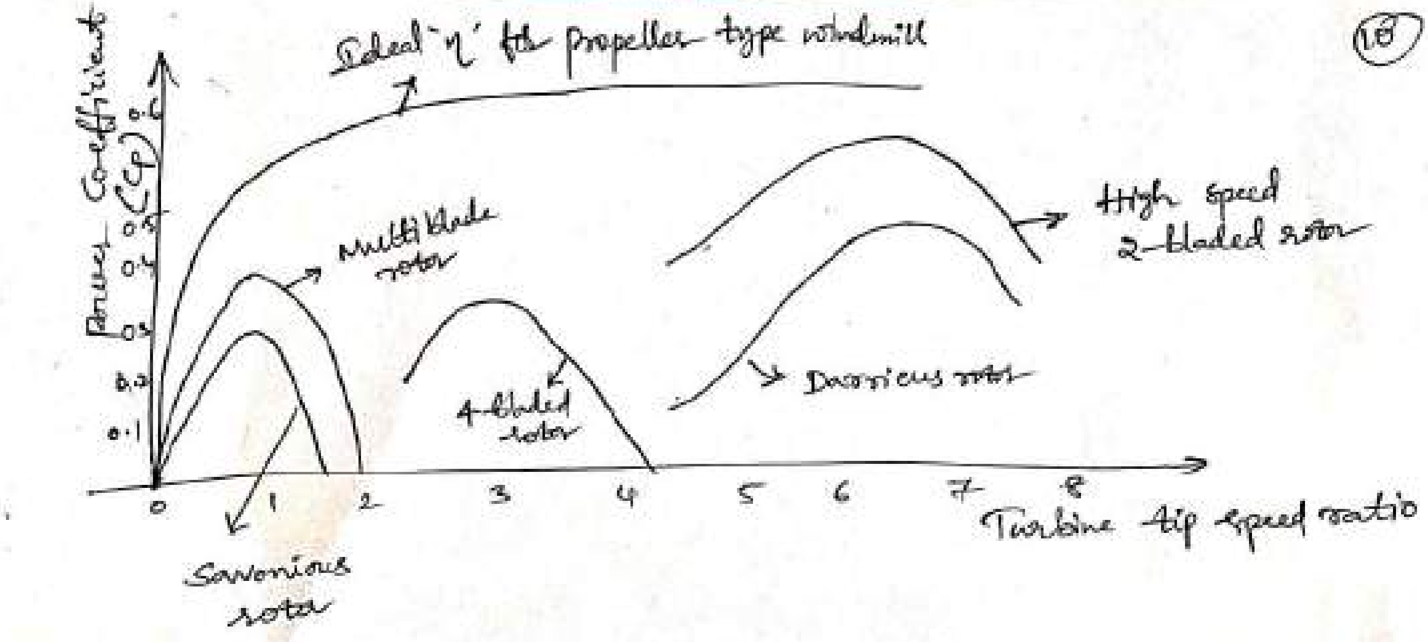
* Power duration curve is useful for establishing the wind energy potential of a place and the design wind speed.

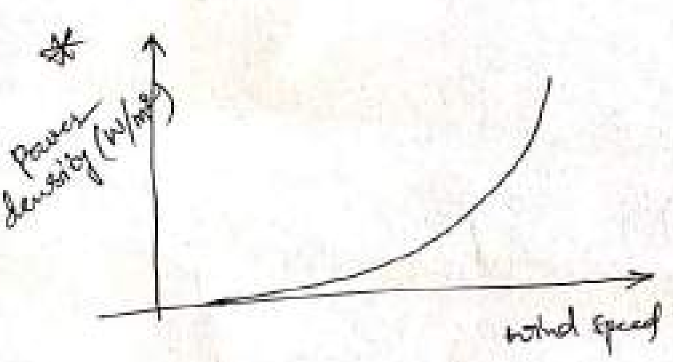
* The variation of generated power with wind speed is shown here.

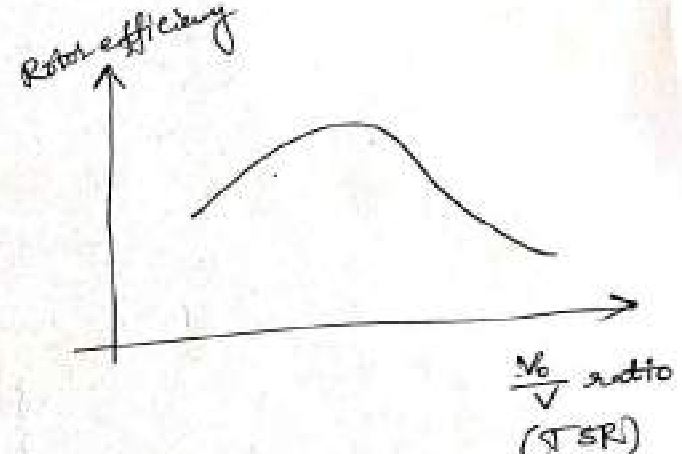


* The dependence of the power co-efficient on the tip speed ratio for some common rotor types is indicated below.

Here the 2-bladed propeller type of rotor can attain a much higher power co-efficient than multi blade wind mill & Dutch 4-bladed wind mill. In practice, 2-bladed propeller rotors are found to attain a max. power co-efficient of 0.4 to 0.45 at tip speed ratio in the range about 6 to 10.







Advantages & Dis-advantages of WECS—

Adv—

i) Renewable Energy.
ii) Non-polluting, no effect on environment.
iii) Avoid fuel provision & transport
iv) Less cost for small scale; and for Large scale, Lower costs could be achieved by mass production.

Dis-adv—

i) Wind energy is fluctuating in nature (irregularity of wind availability)
ii) needs storage capacity due to irregularity of wind.
iii) Noisy in operation.
iv) High overall weight due to gear box, hub, pitch changer, generator coupling shaft etc.
v) Large areas are needed.
vi) Not practically reliable, needs maintenance.
vii) Low overall efficiency (practically 35-45%).

12

BIOMASS ENERGY

12.1 INTRODUCTION

Biomass refers to solid carbonaceous material derived from plants and animals. These include residues of agriculture and forestry, animal waste and discarded material from food processing plants. Biomass being organic matter from terrestrial and marine vegetation, renews naturally in a short span of time, thus, classified as a renewable source of energy. It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from the atmosphere to form hexose (dextrose, glucose, etc.) expressed by the reaction

$$6CO_2 + H_2O \xrightarrow[\text{photosynthesis}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Biomass does not add CO_2 to the atmosphere as it absorbs the same amount of carbon in growing the plants as it releases when consumed as fuel. It is a superior fuel as the energy produced from biomass is 'carbon cycle neutral'.

Biomass fuel is used in over 90% of rural households and in about 15% urban dwellings. Agriculture products rich in starch and sugar like wheat, maize, sugarcane can be fermented to produce ethanol (C_2H_5OH). Methanol (CH_3OH) is also produced by distillation of biomass that contains cellulose like wood and bagasse. Both these alcohols can be used to fuel vehicles and can be mixed with diesel to make biodiesel.

✓12.2 BIOMASS RESOURCES

Biomass resources for energy production are widely available in forest areas, rural farms, urban refuse and organic waste from agro-industries. Biomass classification is illustrated in Figure 12.1.

India produces over 550 million tonnes of agricultural and agro-industrial residues every year. Similarly, 290 million cattle population produces about 438 million tonnes of dung annually. Prime biomass sources are discussed below:

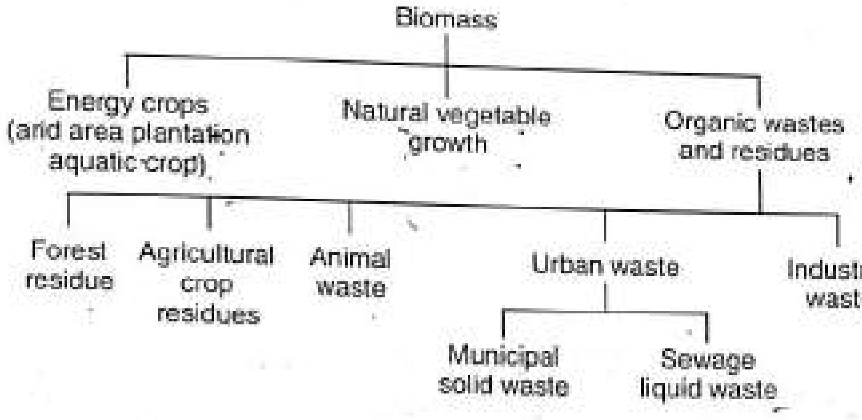


Figure 12.1 Biomass classification.

Forests

Forests, natural or cultivated are a rich source of timber, fuel wood, charcoal and raw material for paper mills and other industries. Fast growing trees like Eucalyptus, Neem, Kikar and Gulmohar are grown along canals, railway tracks and on lands of marginal quality. Wood, saw dust, and bark residue are generated in sawmills. Forests also provide foliage and logging residues. An important characteristic of forest residue is its calorific value, which is 4399 to 4977 kcal/kg for softwood foliage and 3888 to 5219 kcal/kg for hard wood species.

Agricultural crop residues

Crop residues are available in abundance as natural resource, easily collected and stored. These are, rice husk, wheat straw, corn cobs, cotton sticks, sugarcane bagasse, groundnut and coconut shells. These are converted into briquettes or pellets for use as clean fuel. These are called 'biofuels' which are high efficiency solid fuels.

Energy crops

Energy farming refers to the cultivation of fast growing plants which supply fuel wood, biomass that can be converted into gaseous and liquid fuels like biogas, vegetable oil and alcohol. To harvest biomass for power generation, energy plantation is done on degraded or wastelands which are saline, wind eroded lands in arid areas and water-logged lands.

Energy farming is promoted by MNRE in nine different agro-climate regions, namely, Garhwal (U.P.), Gwalpahar (Haryana), Udaipur (Rajasthan) and Shantiniketan (West Bengal). The other four centres are Madurai (Tamil Nadu), Calicut (Kerala), Raipur (Chhattisgarh), Bhubaneswar (Orissa). These centres produce quality seedlings of about 35 tree species through clonal propagation. These fast growing fuel wood species produce 20–25 tonnes of biomass per hectare per year. The Biomass Research Centre Lucknow found the 'Kubabul' tree that grows well on saline and rocky soils, provides wood of high calorific value (4500 kcal/kg).

Vegetable oil crops

Oil can be extracted from fertile area crops such as, sunflower, cotton seed, groundnut, rapeseed, palm and coconut. These oils after purification can be blended with diesel oil suitable as engine fuel.

There is an arid area shrub 'Jajoba', its seeds provide oil which is an important renewable source of energy. It is cultivated in Rajasthan, Gujarat and Orissa under hot-arid conditions. It is an ideal plant for areas of scanty rain with low fertility soil and produces up to 2000 kg of dry seed per hectare annually. Jajoba oil having good insulating property can be used as transformer oil. Its products are high quality lubricants and waxes, suitable for industry and transport sector. It is a good raw material for paints and varnishes.

Aquatic crop

Aquatic crop constitutes three water plants, namely algae, water hyacinth and sea weed. These plants grow abundantly in water bodies and provide organic matter for biogas plants.

Energy plantation programme is directed to bring sub-standard soil under cultivation. It restores the fertility of land, halts desertification, prevents soil erosion, reduces flooding and improves microclimate.

Animal waste

Animal waste, an organic material with combustible property, is a rich source of fuel. Dung cakes prepared with animal waste are used for cooking in rural and semi-urban areas. It is also a raw material for biogas plants.

Urban waste

Urban waste is of two types: (i) Municipal Solid Waste (MSW) which includes human excreta, household garbage and commercial waste. (ii) Liquid Waste from domestic sewage and effluents from institutional activities. As per MNRE estimate about 42 million tonnes of solid waste (1.15 lakh tonnes per day) and 6000 million cubic metres of liquid waste are generated every year in urban areas. At present MSW is dumped in sanitary landfills, where fuel gas is produced which is a valuable source of renewable energy. Sewage is suitably processed to produce biogas.

Industrial waste

Energy recovery from industrial waste was taken up in 1994. Projects are implemented with technical assistance of national laboratories. Projects developed under this programme are:

Pulp and Paper Industry Effluent, Starch and Glucose Industry Waste, Palm Oil Industry, Distillary Waste and Tanneries Waste. Each project is aimed to treat its waste for the production of bio-energy which can be used for power generation.

12.3 BIOFUELS

Biomass is an organic carbon-based matter obtained from plants. Biomass is a source of energy and 40% of the total energy consumed in India comes from wood, crop residues, cow dung, etc. for cooking and various domestic uses. Dry biomass gives heat energy by direct combustion.

Direct burning of firewood in traditional chulhas utilises only 10% heat. Besides inefficient burning, smoke discharge in kitchens is a health hazard. To harness fuel value, technologies are required to convert biomass into a high quality usable solid, liquid and gaseous fuels called 'biofuels'. Such fuels are discussed below.

Charcoal

Charcoal is a smokeless dry solid fuel with high energy density. Modern charcoal retorts (furnaces) operate at about 600°C to produce charcoal from 25–35% of dry biomass feed. It contains 75–80% carbon and is useful as a compact fuel. It can be burnt to provide heat for domestic, commercial and industrial applications.

Briquetting

Biomass briquetting is densification of loose biomass into a high density solid fuel. Biomass of any form such as cotton sticks, rice husk, coconut shells, saw dust and wood chips can be converted into briquetts. It reduces the volume-to-weight ratio, thus making transportation easy for efficient commercial and industrial use. The calorific value is about 3500 kcal/kg. Biomass briquettes can replace 'C' grade coal used in industrial boilers.

Vegetable oil

Vegetable oils such as rapeseed, palm, coconut and cotton seed oil can substitute diesel as engine fuel. Jajoba trees cultivated in marginal lands produce oil seeds. Jajoba oil is considered liquid gold like crude oil as it can be processed into a wide range of products like motor oil, lubricants, mono-unsaturated alcohols and oil of cosmetic value. Euphorbia species produce latex which after water removal give light hydrocarbon oil.

12.4 BIOGAS

Biogas can be produced by digestion of animal, plant and human waste. Digestion is a biological process that takes place in a digester with anaerobic organism in absence of oxygen at a temperature between 35°C and 70°C. In rural areas, household biogas plants operate from cow and buffalo dung which provide gas for cooking and lighting. Biogas is a mixture of CH_4 (55% to 65%), CO_2 (30% to 40%), H_2, H_2S and N_2 (< 10%) having a calorific value between 5000 and 5500 kcal/kg.

12.5 PRODUCER GAS

Producer gas is obtained by partial combustion of wood or any cellulose organic material of plant origin. It is a mixture of a few gases and its constituents are CO_2 (19%), CH_4 (1%),

H_2 (18%), CO_2 (11%) and N_2 (45–60%). Hydrogen and methane keep heating value between 4.5 MJ/m^3 and 6 MJ/m^3 depending upon the volume of its constituents. Producer gas can be burnt in a boiler to generate steam. It is used as fuel in IC engines used for irrigation pumps, in spark ignition engines and gas turbines for power generation.

12.6 LIQUID FUEL (ETHANOL)

Ethanol (C_2H_5OH) is a flammable colourless biofuel. It can be produced by fermentation of any feedstock which contains sugar or starch and even cellulose material. Biomass containing sugar are: sugar-beets, sugarcane, sweet sorghum; starch crop covers corn, wheat, cassava and potato. Cellulose is found in all plant tissues, is available in wood, solid waste and agriculture residues. Ethanol is suitably used as a fuel additive to cut down a vehicle's carbon monoxide and other smog-causing emissions. In nine sugar producing Indian states, petrol blended with 5% ethanol is supplied.

12.7 BIOMASS CONVERSION TECHNOLOGIES

Biomass material from a variety of sources can be utilised optimally by adopting efficient and state-of-the-art conversion technologies such as:

1. Densification of biomass
2. Combustion and incineration
3. Thermo-chemical conversion
4. Bio-chemical conversion

Densification

Bulky biomass is reduced to a better volume-to-weight ratio by compressing in a die at a high temperature and pressure. It is shaped into briquettes or pellets to make a more compact source of energy, which is easier to transport and store than the natural biomass. Pellets and briquettes can be used as clean fuel in domestic chulhas, bakeries and hotels.

Combustion

Direct combustion is the main process adopted for utilising biomass energy. It is burnt to produce heat utilised for cooking, space heating, industrial processes and for electricity generation. This utilisation method is very inefficient with heat transfer losses of 30–90% of the original energy contained in the biomass. The problem is addressed through the use of more efficient cook-stove for burning solid fuels.

Incineration

Incineration is the process of burning completely the solid biomass to ashes by high temperature oxidation. The terms incineration and combustion are synonymous, but the process of combustion is applicable to all fuels, i.e., solid, liquid and gaseous. Incineration is a special process where the dry Municipal Solid Waste (MSW) is incinerated to reduce the volume of solid refuse (90%) and to produce heat, steam and electricity.

Waste incineration plants are installed in large cities to dispose off urban refuse and generate energy. It constitutes a furnace with adequate supply of air to ensure complete combustion up to a capacity of 1000 tonnes/day.

Thermo-chemical conversion

Thermo-chemical conversion is a process to decompose biomass with various combinations of temperatures and pressures. It includes 'pyrolysis' and 'gasification'.

Pyrolysis

Biomass is heated in absence of oxygen, or partially combusted in a limited oxygen supply, to produce a hydrocarbon, rich in gas mixture (H_2, CO_2, CO CH_4 and lower hydrocarbons), an oil like liquid and a carbon rich solid residue (charcoal).

The pyrolitic or 'bio-oil' produced can easily be transported and refined into a series of products similar to refining crude oil. There is no waste product, the conversion efficiency is high (82%) depending upon the feedstock used, the process temperature in reactor and the fuel/ air ratio during combustion.

Gasification

Gasification is conversion of a solid biomass, at a high temperature with controlled air, into a gaseous fuel. The output gas is known as producer gas, a mixture of H_2 (15–20%), CO (10–20%), CH_4 (1–5%), CO_2 (9–12%) and N_2 (45–55%). The gas is more versatile than the solid biomass, it can be burnt to produce process heat and steam, or used in internal combustion engines or gas turbines to generate electricity. The gasification process renders the use of biomass which is relatively clean and acceptable in environmental terms.

Liquefaction

Liquefaction of biomass can be processed through 'fast' or 'flash' pyrolysis, called 'pyrolytic oil' which is a dark brown liquid of low viscosity and a mixture of hydrocarbons. Pyrolysis liquid is a good substitute for heating oil.

Another liquefaction method is through methanol synthesis. Gasification of biomass produces synthetic gas containing a mixture of H_2 and CO. The gas is purified by adjusting the hydrogen and carbon monoxide composition. Finally, the purified gas is subjected to liquefaction process, converted to methanol over a zinc chromium calatyst. Methanol can be used as liquid fuel.

12.8 BIOCHEMICAL CONVERSION

There are two forms of biochemical conversions:

1. Anaerobic digestion
2. Ethanol fermentation

12.8.1 Anaerobic Digestion (Anaerobic Fermentation)

This process converts the cattle dung, human wastes and other organic waste with high moisture content into biogas (gobar gas) through anaerobic fermentation in absence of air. Fermentation occures in two stages by two different metabolic groups of bacteria. Initially the organic material is hydrolyzed into fatty acids, alcohol, sugars, H_2 and CO_2. Methane forming bacteria then converts the products of the first stage to CH_4 and CO_2, in the temperature range 30–55°C. Biogas produced can be used for heating, or for operating engine driven generators to produce electricity. Fermentation occurs in a sealed tank called 'digester' where the sludge left behind is used as enriched fertilizer.

12.8.2 Ethanol Fermentation

Ethanol can be produced by decomposition of biomass containing sugar like sugarcane, cassava sweet sorghum, beet, potato, corn, grape, etc. into sugar molecules such as glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$).

Ethanol fermentation involves biological conversion of sugar into ethanol and CO_2.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2C_2H_5OH + 2CO_2$$

Ethanol has emerged as the major alcohol fuel and is blended with petrol.

12.9 BIOMASS GASIFICATION

Biomass gasification is thermo-chemical conversion of solid biomass into a combustible gas fuel through partial combustion with no solid carbonaceous residue. Gasifiers use wood waste and agriculture residue.

12.9.1 Gasifiers

Gasifiers (fixed bed type) can be of 'updraft' or 'downdraft' type depeding upon the direction of the air flow. The working of biomass gasification can be explained by considering a typical downdraft gasifier (Figure 12.2) where fuel and air move in a co-current manner. In the updraft gasifier, fuel and air move in a countercurrent manner. However, the basic reaction zones remain the same.

* Fuel is loaded in the reactor from the top. As the fuel moves down it is subjected to drying (120°C) and then pyrolysis (200–600°C) where solid char, acetic acid, methanol and water vapour are produced. Descending volatiles and char reach the oxidation zone where air is injected to complete the combustion. It is the reaction zone and the temperature rises to 1100°C. This helps in breaking down the heavier hydrocarbons and tars.

As these products move downwards, they enter the 'reduction zone' (900–600°C, reaction being endothermic) where producer gas is formed by the action of CO_2 and water vapour on red hot charcoal as detailed below:

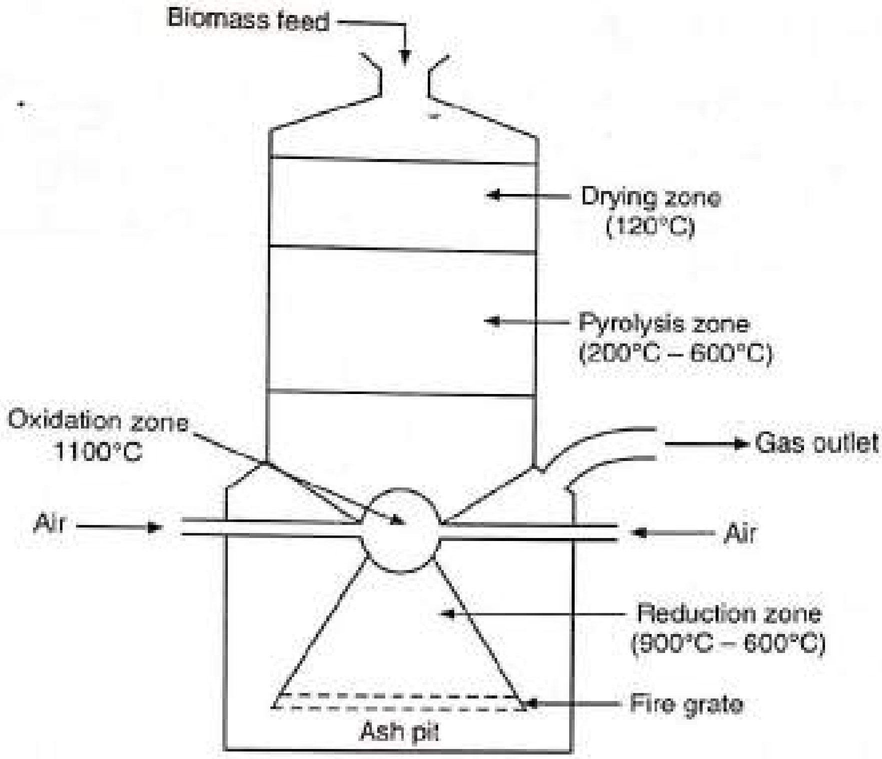


Figure 12.2 Downdraft gasifier.

$$\text{Moist biomass} + \text{Heat} \rightarrow \text{Dry biomass} + \text{Water vapour}$$

$$C + O_2 \rightarrow CO_2 + 393.8 \text{ kJ/mole (combustion)}$$

$$C + H_2O \rightarrow CO + H_2 - 131.4 \text{ kJ/mole (water gas reaction)}$$

$$CO + H_2O \rightarrow CO_2 + H_2 + 41.2 \text{ kJ/mole (water shift reaction)}$$

$$C + CO_2 \rightarrow 2CO - 172.6 \text{ kJ/mole}$$

$$C + 2H_2 \rightarrow CH_4 + 75.0 \text{ kJ/mole (hydrogenation reaction)}$$

Producer gas formed in the reduction zone contains combustible products like CO, H_2 and CH_4. Hot gas flowing out is usually polluted with soot, tar and vapour. For purifying, it is passed through coolers, tar is removed by condensation, whereas soot and ash are removed by centrifugal separation.

Clean producer gas provides the process heat to operate stoves (for cooking), boilers, driers, ovens and furnaces. The major application is in area of electric power generation either through dual-fuel IC engines (where diesel oil is replaced to an extent of 60%–80%), or through 100% gas-fired spark ignition engines.

A biomass gasifier-based electricity generation system costs from ₹ 4.0 crores to 4.5 crores/MW and the power generation cost is between ₹ 2.50 and ₹ 3.50 per kWh.

Fixed bed gasifiers can attain efficiency up to 75% for conversion of solid biomass to gaseous fuel. However, the performance depends on fuel size and moisture content, volatiles and ash content.

12.9.2 Fluidized Bed Gasifier

Fluidized Bed Combustion (FBC) is a better option to use than the problematic biomass of farm residues like rice husk (high ash content), bagasse, industrial waste such as saw dust and pulping effluents, sewage sludge etc. FBC constitutes a hot bed of inert solid particles of sand or crushed refractory support on a fine mesh or grid. The bed material is fluidized by an upward current of air as shown in Figure 12.3.

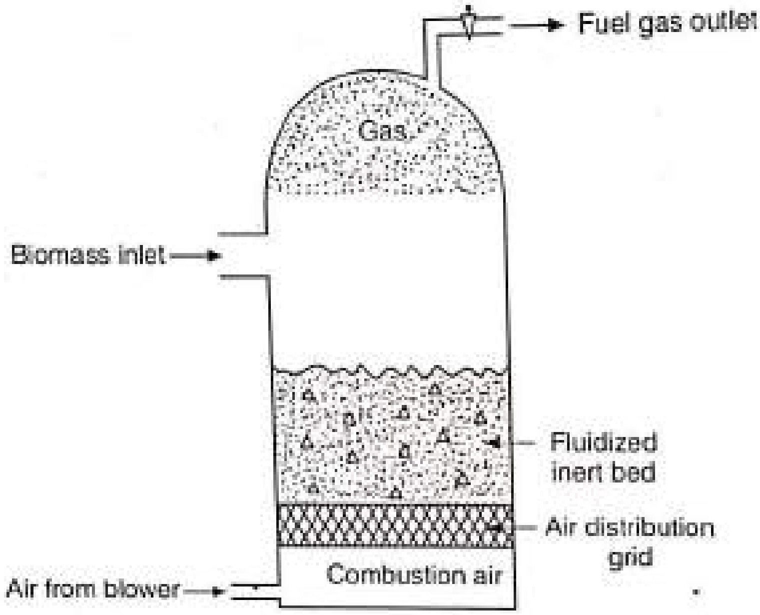


Figure 12.3 Fluidized bed gasifier.

Pressurized air starts bubbling through the bed and the particles attain a state of high turbulence, and the bed exhibits fluid like properties. A uniform temperature within the range of 850–1050°C is maintained. Large surface area is created in the fluidized bed and the constantly changing area per unit volume provides a higher conversion efficiency at low operating temperatures compared to the fixed beds. High heating capacity of sand and the uniform temperature of fluidized bed makes possible to gasify low-grade fuels of even non-uniform size and high moisture content.

When the gasifier is put in use, the bed material is heated to ignition temperature of the fuel, biomass is then injected causing rapid oxidation and gasification. Fuel gas so produced contains impurities, dust, char particles and tar. It needs conditioning and cleaning for utilization as an engine fuel.

12.10 BIOGAS

Biogas is a renewable energy derived from organic wastes such as cattle dung, human waste, etc. It is a safe fuel for cooking and lighting. Left-over digested slurry is used as enriched manure in agriculture lands.

12.10.1 Biogas Technology

Biogas is produced from wet biomass through a biological conversion process that involves bacterial breakdown of organic matter by micro-organisms to produce CH_4, CO_2 and H_2O. The process is known as 'anaerobic digestion' which proceeds in three steps.

1. Hydrolysis
2. Acid formation
3. Methane formation

Hydrolysis

Organic waste of animal and plants contains carbohydrates in the form of cellulose, hemicellulose and lignin. A group of anaerobic micro-organisms (celluolytic bacteria/hydrobytic bacteria) breaks down complex organic material into simple and soluble organic components, primarily acetates. The rate of hydrolysis depends on bacterial concentration, quality of substrate, pH (between 6 and 7) and temperature (30°C–40°C) of digester contents.

Acid formation

Decomposed simple organic material is acted upon by acetogenic bacteria and converted into simple acetic acid.

Methane formation

Acetic acid so formed becomes the substrate strictly for anaerobic methanogeric bacteria, which ferment acetic acid to methane and CO_2. Gas production is stable for pH between 6.6 and 7.6.

Biogas consists of CH_4, CO_2 and traces of other gases such as H_2, CO, N_2, O_2 and H_2S. Gas mixture is saturated with water vapour. The methane content of biogas is about 60% which provides a high calorific value to find use in cooking, lighting and power generation.

12.10.2 Factors Affecting Biogas Production

There are eight major factors which affect the quality and quantity of biogas.

Solid-to-water ratio

Cattle dung (gobar) contains about 18% solid matter and the remaining 82% is water. Anaerobic fermentation proceeds at a faster rate if the slurry contains about 9% solid matter. Digester feed is prepared by mixing water in the ratio 1 : 1 by weight to reduce the solid content. To increase the solid matter, crop residues and weed plants may be mixed with the feed stock.

Volumetric loading rate

It is expressed as the quantity of organic waste fed into the digester per day per unit volume. In general, the municipal sewage treatment plants operate at a loading rate of 1.0 to 1.5 kg/m^3/day. Overloading and underloading reduce the biogas production with a fixed retention time. For a desired retention period of 30 days, a quantity equal to 1/30th of digester volume needs to be fed daily.

Temperature

Temperature affects bacterial activity; methane formation is optimum in the temperature range 35°–38°C. Biogas production decreases below 20°C and stops at 8°C. In cold regions a solar canopy is built over the biogas plants to maintain the desired temperature.

In hot regions, another micro-organism called 'thermophilic' is utilised for anaerobic fermentation in the temperature range 55°C–60°C. Gas production rises with the increase in average ambient air temperature. As the temperature increases, the total retention period decreases and vice-versa. However, the total gas production remains practically the same.

Seeding

Cattle dung contains both acid forming bacteria and methane forming bacteria. Acid forming bacteria multiply fast, while the methane forming bacteria grow slowly. To start and accelerate fermentation, seeding of methane forming bacteria is required. Accordingly, a small quantity of digested slurry rich in methane-forming bacteria is added to freshly charged digester.

pH value

Measure of pH value indicates the concentration of hydrogen ions. Micro-organisms are sensitive to pH of the digested slurry. For optimum biogas production, pH can be varied between 6.8 and 7.8. At pH of 6.2, acid conditions prevail which restrain the growth of methanogenic bacteria. Control on pH should be exercised by adding alkali when it drops below 6.6.

Carbon-to-nitrogen (C/N) ratio

Methanogenic bacteria needs carbon and nitrogen for its survival. Carbon is required for energy while nitrogen for building cell protein. The consumption of carbon is 30 to 35 times faster than that of nitrogen. A favourable ratio of C : N can be taken as 30 : 1. Any deviation from this ratio lowers the biogas production. A proper balance of C : N ratio is maintained either by adding saw dust having a high C : N ratio or by poultry waste having a low C : N ratio.

Retention time

The period for which the biomass slurry is retained inside the digester is called 'retention time'. It refers to the volume of digester divided by the volume of slurry added per day. Thus, a 120 litre digester which is fed at 5 litres per day would have a retention time of 24 days. It is optimized to achieve 80% complete digestion considering ambient temperature. Indian states are divided into three zones where the retention period is decided in days for cattle dung feedstock detailed in Table 12.1.

Table 12.1 Retention time

Zone	*States*	*Mean ambient temp (°C)*	*Retention time (in days)*
I	Kerala, T.N., A.P., Andaman, Karnataka, Maharashtra	>20	30
II	W.B., Bihar, Orissa, MP, UP, Rajasthan, Haryana, Punjab	15–20	40
III	North-eastern region, Sikkim, Uttarakhand, Himachal, J&K and areas with long winter	10–15	50

Stirring digester contents

Stirring the contents of the digester is necessary to mix the bacteria rich fluid in the slurry. It provides better contact between micro-organism and the substrate and uniformly distributes the volatile solids in the slurry. Gas production improves by 15% over the full cycle.

12.11 BIOGAS PLANTS

The biogas plant is a device that converts cattle dung and other organic matter into inflammable gas called biogas and into a good quality organic manure under anaerobic conditions. There are two popular designs of biogas plants: (i) Floating drum (constant pressure) type and (ii) Fixed dome (constant volume) type.

Ral 7.10

12.11.1 Floating Drum Type Biogas Plant

A popular model developed by Khadi Village Industries Commission (KVIC) was standardized in 1961. It comprises an underground cylindrical masonary digester having an inlet pipe for feeding animal dung slurry and an outlet pipe for sludge. There is a steel dome for gas collection which floats over the slurry. It moves up and down depending upon accumulation and discharge of gas guided by the dome guide shaft (Figure 12.4).

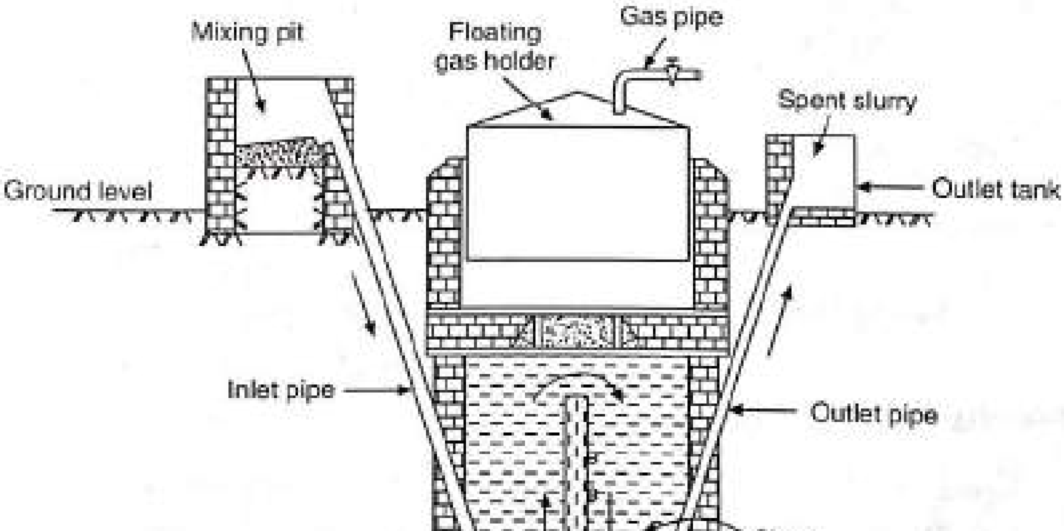


Figure 12.4 Floating drum biogas plant (KVIC model).

A partition wall is provided in the digester to improve circulation, necessary for fermentation. The floating gas holder builds gas pressure of about 10 cm of water column, sufficient to supply gas up to 100 metre. Gas pressure also forces out the spent slurry through a sludge pipe.

12.11.2 Fixed Dome Type Biogas Plant

It is an economical design where the digester is combined with a dome-shaped gas holder (Figure 12.5). It is known as Janata model; the composite unit is made of brick and cement masonary having no moving parts, thus ensuring no wear and tear and longer working life. When gas is produced, the pressure in the dome changes from 0 to 100 cm of water column. It regulates gas distribution and outflow of spent slurry.

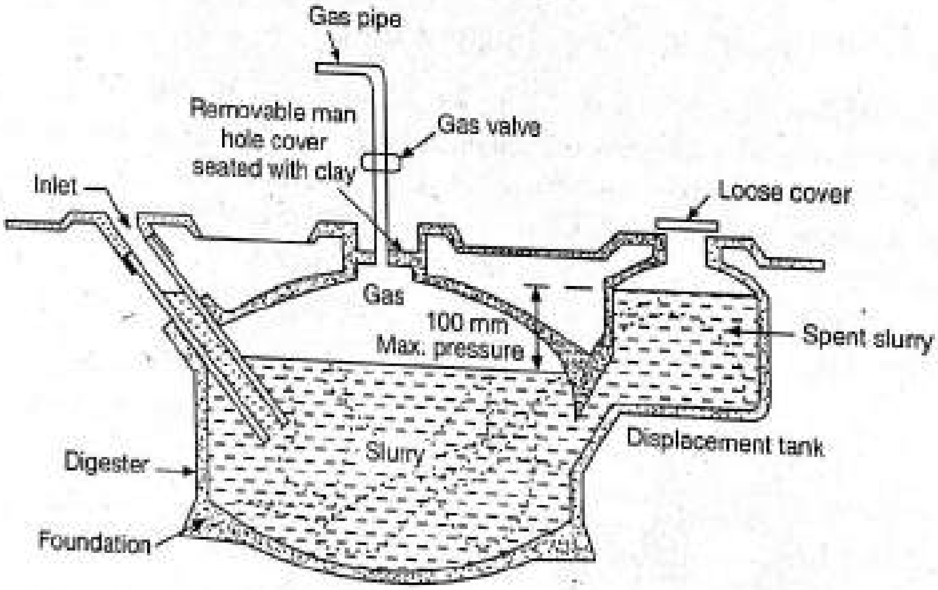


Figure 12.5 Fixed dome biogas plant (Janata model).

12.11.3 Deenbandhu Biogas Plant (DBP)

This plant developed by AFPRO (Action For Food Production) with the objective to extend the biogas technology to places where the availability of bricks is a limiting factor and bamboo is easily available. Its cost is reduced as the surface area is minimized by joining segments of two different diameter spheres at their bases as given in Figure 12.6. This plant requires less space being mainly undergound. It is 30% economical compared to the Janata biogas plant. After intensive trial and testing it has been approved by MNRE for family size installation.

12.11.4 Community Night-soil Based Biogas Plant

Community night-soil based biogas plants have been developed to facilitate sanitary treatment of human waste at community and institutional level (Figure 12.7). This installation constitutes

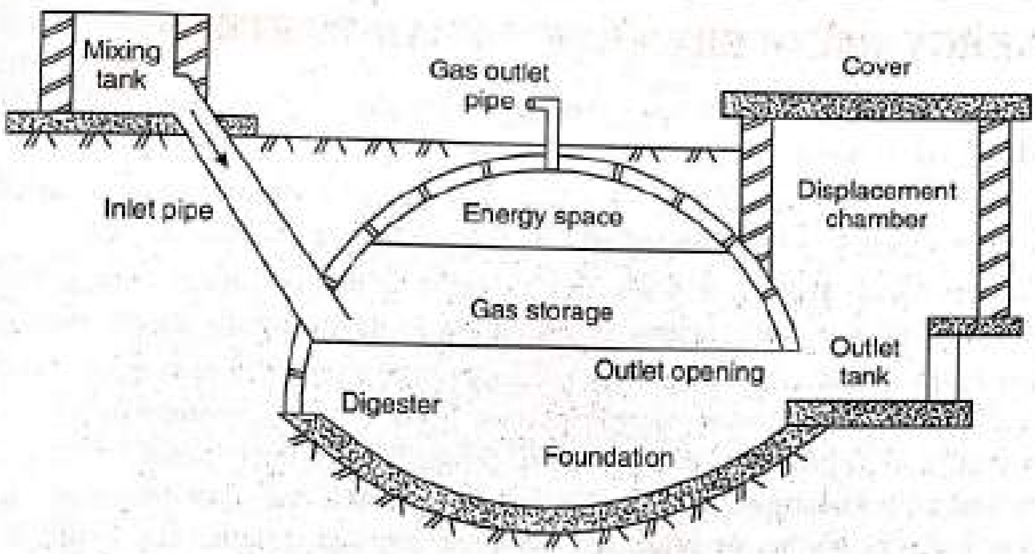


Figure 12.6 Deenbandhu biogas plant.

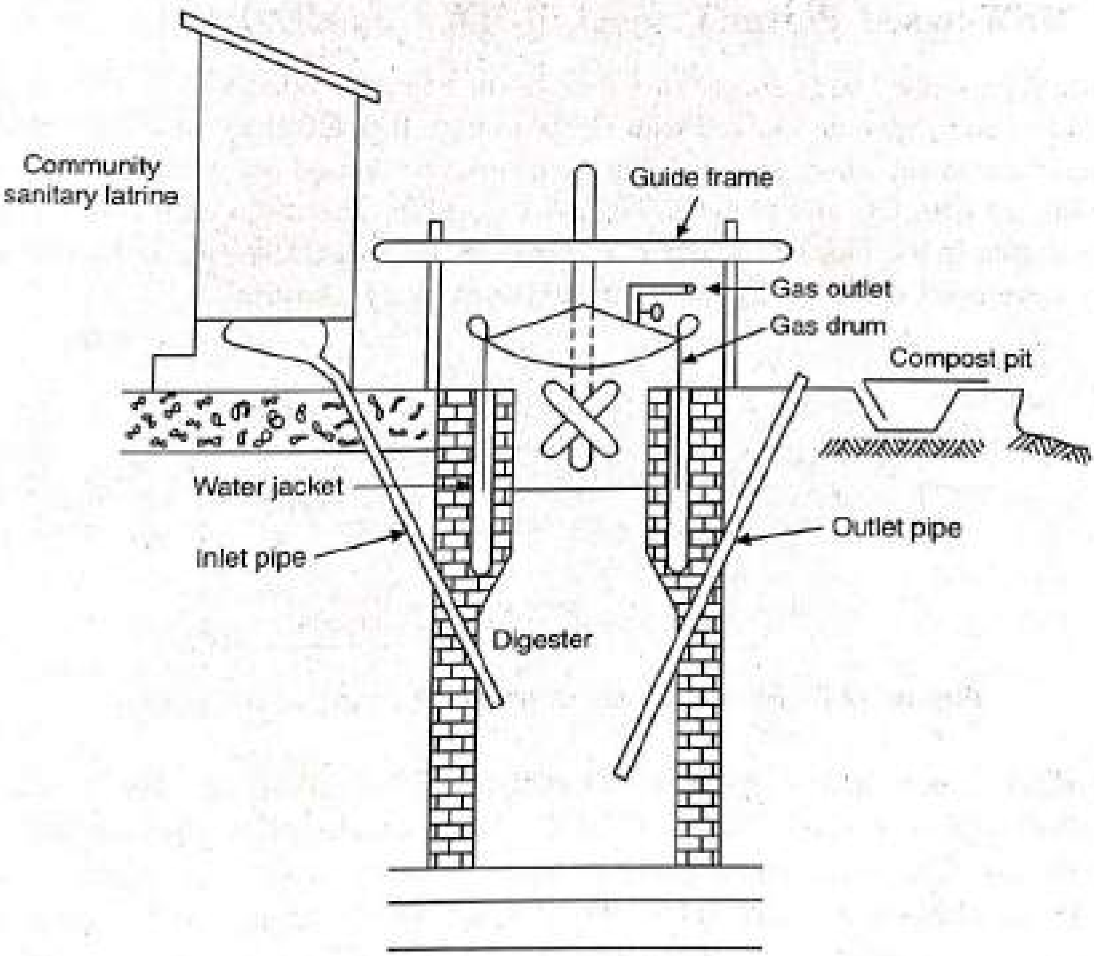


Figure 12.7 Community night-soil based biogas plant.

a floating metal drum with a water jacket. It is linked with community toilets and serves a population of about 1000 persons to provide fuel for cooking, operate dual-fuel engines for water supply and generate electric power.

12.12 ENERGY RECOVERY FROM URBAN WASTE

Rapid urbanization and industrialization have resulted in the creation of enormous quantities of wastes in urban and industrial areas. Study of waste to energy can be divided into:

1. *Municipal Solid Waste* (MSW) Each year about 42 million tonnes of municipal solid waste is collected in the country and is disposed of in landfill dumps.
2. *Municipal Liquid Waste* Sewage in cities is a source of biomass energy and in India about 6000 million cubic metres of liquid waste needs proper disposal every year.
3. *Urban Industrial Waste* Industries produce a large number of residues as by-products that can be used as biomass energy sources. Food industry includes pealings and scraps from fruit and vegetables. Wine making produces distillary waste water (spent wash). Paper and pulp making effluent is 'black liquor' which is a source for bio-oil. Starch and glucose industry wastes are maize husk, tapioca fibre and stems. Rice mills provide large volumes of rice husk. Sugar mills waste is a source of huge quantity of bagasse.

12.12.1 MSW-based Power Project (5 MW Capacity)

Urban waste represents a large source of substrate for energy production. It contains dry waste of household (waste paper etc.) mixed with kitchen scrap. It is subjected to a segregation system where inorganics (metal, glass, grit) and plastic material are sorted out, keeping items which are largely cellulosic with fats and proteins, i.e., are digestible. The major components of a power project are shown in the block diagram of Figure 12.8. It is based on high-rate biomethanation technology developed by ENTEC, Environment Technology, Austria.

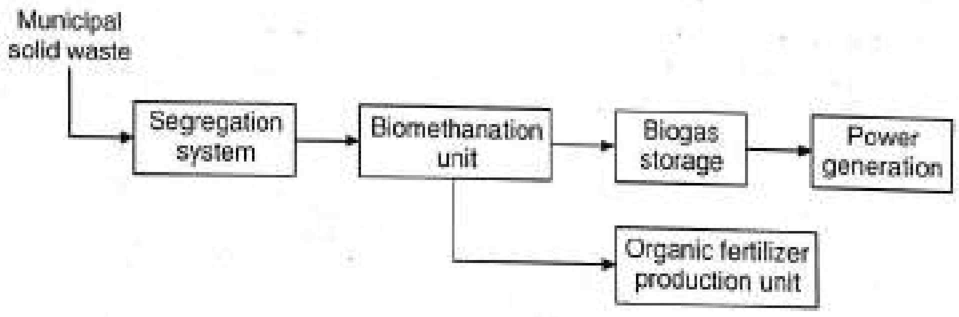


Figure 12.8 Block diagram of an MSW-based power project.

The project is designed to process 500–600 tonnes of MSW per day from a city. The collected MSW is converted into about 115 M.T. of dry volatile solids which produce 50,000 m^3 of biogas per day. The spent slurry in the digester (75 MT) is used as organic fertilizer. The biogas so produced is fed into five 100% biogas engines to generate 5 MW grid-quality power.

12.13 POWER GENERATION FROM LANDFILL GAS

Recycling of city garbage and MSW poses a serious problem due to its enormous quantity. Its sanitary disposal through landfill is a successful method even in the UK and USA. A large pit at the outskirt is prepared and a pipe system for gas collection is laid down before the waste is filled. For anaerobic digestion, MSW is buried, eventually the gas produced does not escape into the atmosphere. After 2–3 months, depending on the climate, landfill gas can be extracted by inserting perforated pipes into the landfill (Figure 12.9).

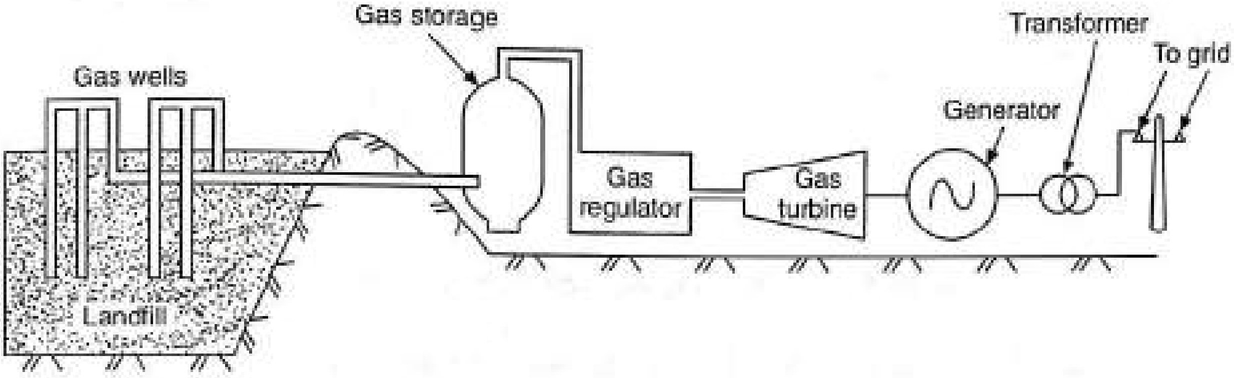


Figure 12.9 Landfill gas for power generation.

The gas flows through pipes under natural pressure. As the gas has calorific value of about 4500 kcal/m^3 it can be used either for direct heating/cooking applications or to generate power through IC engines. One of the largest landfill gas plants in the world is a 46 MWe plant in California.

12.14 POWER GENERATION FROM LIQUID WASTE

12.14.1 Sewage

Sewage is a source of biomass energy similar to other animal wastes. Energy can be extracted from sewage, using anaerobic digestion to produce biogas.

Anjana Sewage Treatment Plant (STP) at Surat has three sludge digesters with a total capacity of 82.50 million litres per day and generates about 2500 m^3 biogas daily from each digester. Gas is cleaned up of H_2S by a scrubber system for use into a 100% biogas engine for electricity generation. Electric power (0.5 MW) thus produced accrues to the STP in a saving of ₹ 10 lakhs per month.

12.14.2 Distillary Waste

Distillary liquid wastes carry rich raw material for producing biogas. Liquid effluent from a distillary is collected in a tank where the suspended solids settle down. Decanted effluent which contains fermented molasses is pumped into a digester through a heat exchanger. Effluent is cooled to maintain the digester temperature at 36–38°C, allowed to be digested anaerobically for about 12–15 days, during which biogas is produced (Figure 12.10).

Biogas accumulates in a gas holder and is stored under pressure using a pressue control device. Generation of power is based on two IC engines, each coupled with 1 MW capacity generator, fuelled solely by biogas. Distillary waste is sufficient to produce about 21000 m^3 of biogas per day.

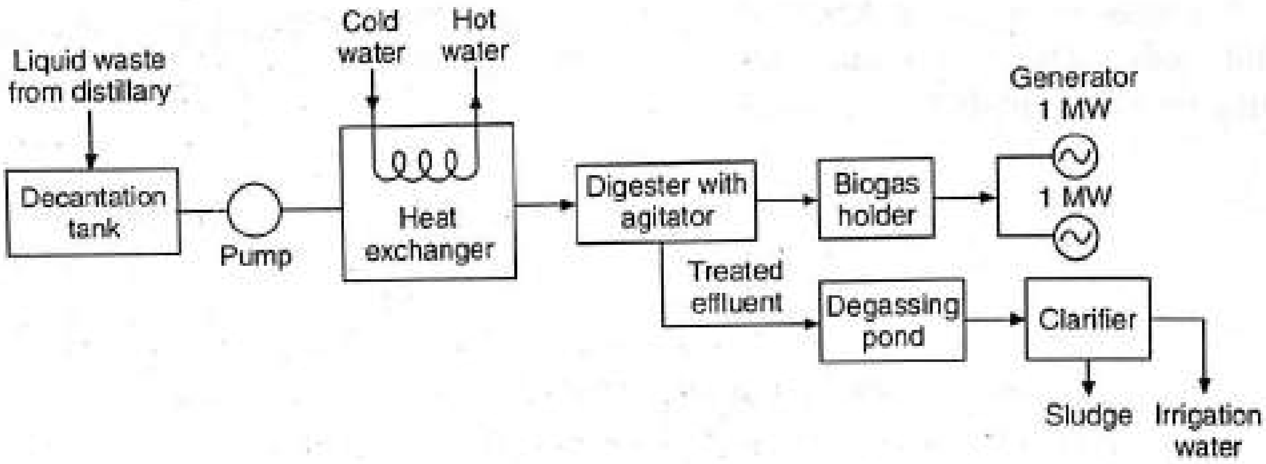


Figure 12.10 Power generation from distillary waste.

The treated effluent overflows into a degassing pond to remove traces of gas. The liquid then flows into a clarifier where the sludge collects to be used as farm manure. The clarified water is utilised for irrigation after secondary treatment.

12.14.3 Pulp and Paper Mill Black Liquor Waste

The pulp and paper industry consumes a large amount of energy and water in its various unit operations. The waste discharged water contains compounds from wood and raw material, useful for recovery of energy.

A plant for biomethanation of bagasse wash effluent is installed at Karur in Tamil Nadu, based on UASB technology. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) removal is 94% and 89% respectively with gas production of 0.37 cu metre per kg.

Presently about 15000 m^3 of gas is generated every day, which is used in a lime-mud re-burning kiln. The gas output from the plant meets 50% heat load of the kiln, equivalent to 12–13 kilolitre of furnace oil.

12.15 BIOMASS COGENERATION

Cogeneration is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy is used to drive an alternator for producing electricity. Thermal energy can be used either for direct process applications or for producing steam.

Sugar industry in India uses bagasse-based cogeneration for achieving self sufficiency in steam and electricity. Cogeneration cleans up the environment, generates power for in-house consumption and earns additional revenue from the sale of surplus electricity.

The main equipment required for bagasse-based cogeneration projects comprises high-temperature/high-pressure bagasse-fired boilers, a steam turbine and a grid-interfacing system. Experience shows that when steam generation temperature/pressure is increased from 400°C/32 bar to 485°C/66 bar, more than 80 kWh of additional electricity is generated from each tonne of cane crushed. Additional power generation with increase in pressure and temperature of a typical 2500 TCD sugar mill is tabulated in Table 12.2.

Table 12.2 Biomass cogeneration as function of steam pressure/temperature

Steam pressure/ temperature	*Electricity generation (MW)*	*In-house consumption (MW)*	*Surplus electricity (MW)*
21 bar/300°C	2.0	2.5	−0.5
33 bar/380°C	3.5	3.5	0
45 bar/440°C	6.0	4.0	2.0
64 bar/480°C	13.5	4.5	9.0
85 bar/510°C	17.0	6.0	11.0

Case study

A progressive sugar mill in UP crushing 11000 tonnes of cane per day is deployed at 87 bar/525°C steam configuration to cogenerate over 18 MW of surplus electricity.

The existing 430 sugar mills have an estimated cogeneration power potential of 5000 MW. Around 491 MW of such power plants has already been commissioned up to 31-12-05 and more is under construction.

12.15.1 Cogeneration Plant in Rice Mill

Rice production from paddy has undergone changes from traditional soaking and drying to modern method of parboiling at higher temperature. It results in increased productivity of husk and quality rice. Husk produced is effectively utilised for steam production, which is used for both process and power generation. The characteristics of rice husk as fuel are given in Table 12.3 where the figures show percentage by weight.

Table 12.3 Ultimate analysis of rice husk-fuel

Carbon	36.14
Hydrogen	3.70
Sulphur	0.08
Nitrogen	0.46
Oxygen	29.34
Water	8.92
Ash	21.36

The calorific value of rice husk varies from 2637 to 3355 kcal/kg depending on variety. Rice husk is difficult to handle because of its silica-cellulose structure. Considering this aspect the 'Fluidized Bed Combustion' (FBC) boiler is used to ensure complete combustion as firing is balanced between buoyancy and gravitational force. Steam from the boiler (6000 kg/h) is fed to the back pressure turbine* coupled with a 350 kW electric generator as shown in Figure 12.11. Input steam conditions are: 6000 kg/h having pressure 32 atm at 400°C.

* Turbine efficiency (45%) and generator efficiency (90%) collected from M/S Veesons Energy System Pvt. Ltd Trichy.

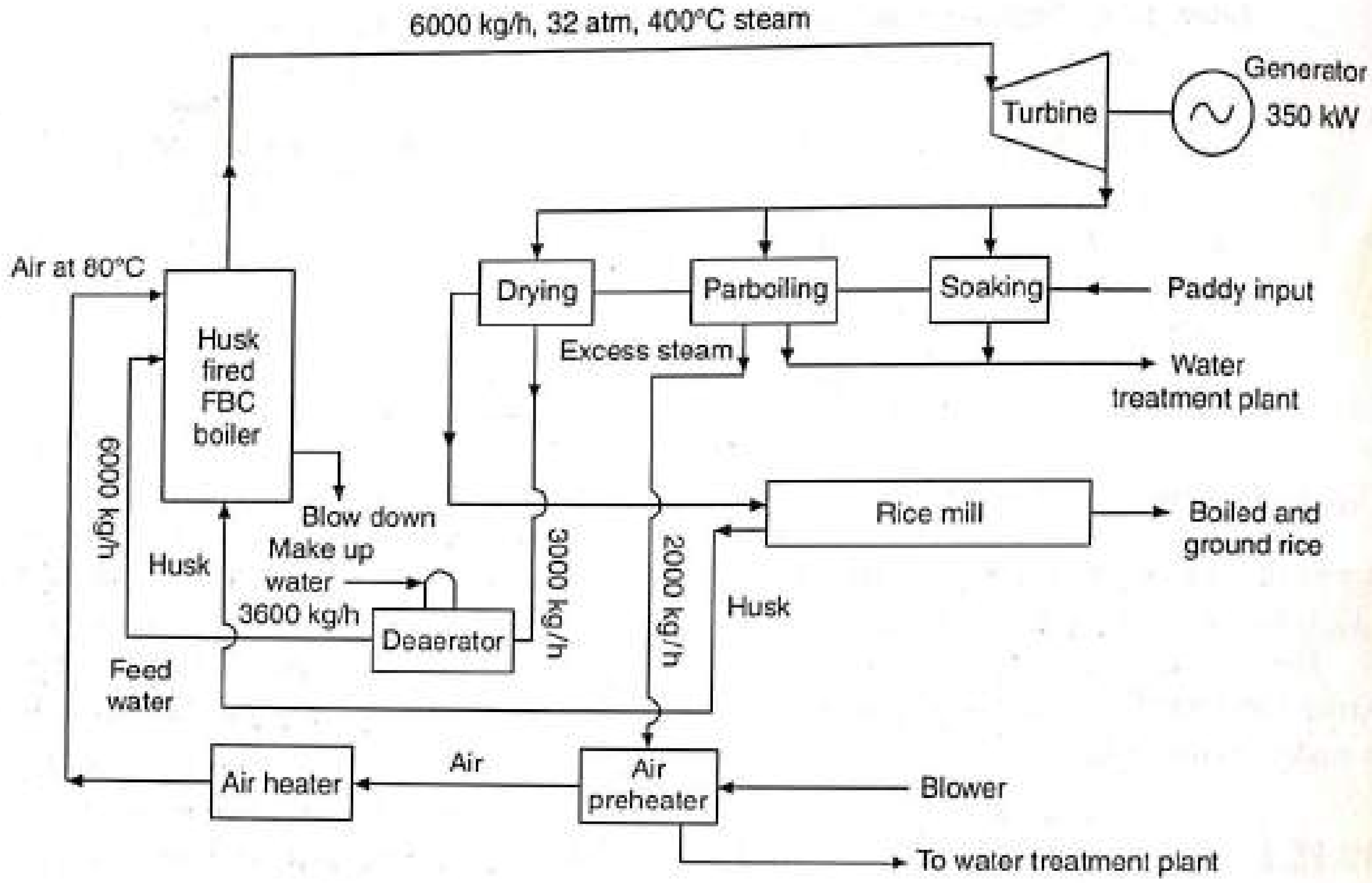


Figure 12.11 Cogeneration plant in a rice mill (50 tonnes capacity).

Steam pressure after expanding in turbine 3.5 kg/cm^2 is utilised for three processes (i) Soaking (ii) Parboiling and (iii) Drying. Pressurized deaerator supplies water at 6000 kg/h to the boiler. Make-up water 3600 kg/h at 30°C is added into deaerator besides 3000 kg/h of hot water received from turbine exhaust after the drying process. Excess steam from parboiling process is fed into an air preheater and the hot air is further heated to maintain 80°C before feeding into the boiler.

Thus, a 50 tonne/batch capacity rice mill generates 350 kW from rice husk which is normally dumped and wasted. At present 47% rice husk is used as energy source.

Cogeneration in India excluding sugar industry has a potential of 10,000 MW from rice mills, distillaries, paper mills, petrochemicals and fertilizer plants.

12.16 ETHANOL FROM BIOMASS

Ethanol is ethyl alcohol (C_2H_5OH), a colourless flammable liquid. It is a renewable energy source which can substitute petroleum products. Ethanol can be produced from a variety of biomass materials, containing sugar, starch and cellulose. The best-known feedstock under three categories are:

Sugars: sugarcane, sugar beet, sweet sorghum, grapes, molasses

Starches: maize, wheat, barley, potatoes, cassava, rice

Cellulose: wood, straw, stems of grasses, bamboo, sugarcane bagasse.

Production process

Sugar rich crops, especially the sugarcane which contains the valuable raw material for crystal sugar, and by-products from sugar mills are molasses that contain 50% to 55% sugar content. It is monosaccharide form of sugar which refers to the glucose ($C_6H_{12}O_6$) and fructose ($C_6H_{12}O_6$) content in cane. Sweet fruits like ripe grape, mangoes, etc. contain glucose in natural form. Juice containing sugar can easily be fermented into ethanol by adding yeast. Yeasts are micro-organisms called *Saccharomyces Cerevisiae* which produce enzymes, that convert sugar to ethanol.

$$C_6H_{12}O_6 \xrightarrow{\text{Yeast}} 2C_2H_5OH + 2CO_2$$

Molasses also contain fermentable sugar comprising glucose, sucrose and fructose which are converted into alcohol. One tonne of sugarcane with average sugar content of 12.5% yields 70 litres of ethanol by direct fermentation of juice. One tonne of molasses yields nearly 230 litres of ethanol. Directly fermented sugarcane juice yields much higher ethanol compared to molasses.

Starch crops constitute grains which are rich in carbohydrates. Starch $(C_6H_{10}O_5)_n$ has a complicated structure having many glucose molecules linked together in a long chain called disaccharide forms of sugar. It requires starch chain to be converted into sugar prior to fermentation. Yeast culture cannot convert starch into fermentable sugars. Conversion can be done either by hydrolysis of starch with dilute H_2SO_4 or through enzymatic method. Starch is converted into maltose and glucose prior to initiating ethanol production.

$$\underset{\text{(Starch)}}{2(C_6H_{10}O_5)_n} + nH_2O \xrightarrow{\text{Hydrolysis}} \underset{\text{Maltose}}{nC_{12}H_{22}O_{11}}$$

$$C_{12}H_{22}O_{11} + H_2O \longrightarrow 2C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow{\text{Fermentation}} 2C_2H_5OH + 2CO_2$$

Cellulosic material comprises dry biomass abundantly available, but difficult to utilise carbohydrate in cellulose. Cellulose contained in wood, grasses and crop residue contain a long chain of sugars and lignin available in plants which hinders hydrolysis to sugars. This complex material is called 'polysaccharides' in which breaking the chemical bond of cellulose is not as easy as that of a starch to simple sugars.

The conversion of cellulosic material is carried out by special hydrolysis with dilute H_2SO_4 at high temperature 180°–200°C, which causes the product sugar to decompose into glucose.

$$\underset{\text{(Cellulose)}}{(C_6H_{10}O_5)_n} + nH_2O \longrightarrow \underset{\text{(Glucose)}}{nC_6H_{12}O_6}$$

Optimum glucose production is achieved by adjusting three variables, i.e., acid concentration, operating temperature and reaction time. Finally, ethanol is obtained by fermentation of glucose sugars.

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{Fermentation } 32^\circ\text{C}} \underset{\text{(Ethanol)}}{2C_2H_5OH} + 2CO_2$$

Ethanol production from various biomass crops is given in Table 12.4.

Table 12.4 Ethanol production from biomass crops

Raw material	*Ethanol* (litre) *per tonne of crop* (l/t)	*Ethanol* (litre) *per hectare per year* (l/ha)
Sugar beet	90–100	3800–4800
Sugarcane	60–80	3500–7000
Sweet sorghum	80–90	2500–3500
Potato	100–120	2200–3300
Maize	360–400	1500–3000
Cassava	175–190	2200–2300
Wheat	370–420	800–2000
Barley	310–350	700–1300
Soft wood (hydraulic agent dilute acid)	190–220	1800–3100
Hard wood (dilute acid)	160–180	1500–2500
Straw (dilute acid)	140–160	200–500

Source: Internet Alternate Energy Development Board (Biomass Energy Systems)

Microbial growth and conversion of sugars to ethanol is best at its 10% concentration as the fermentation process drops down (micro-organism in the yeast is poisoned) with increase in alcohol concentration. Concentration of ethanol can be increased to 95% by volume by successive fractional distillation. The product is called hydrated ethanol and used as fuel in modified IC engines.

Removal of balance 5% water from 95% ethanol concentration is not possible by simple distillation as a constant boiling mixture (azeotrope) is formed which prevents further separation due to the absence of differential vaporization. An hydrous ethanol is produced with azeotropic removal of water by co-distillation using benzene as solvent. Production of ethanol from three biomass resources is given in Figure 12.12.

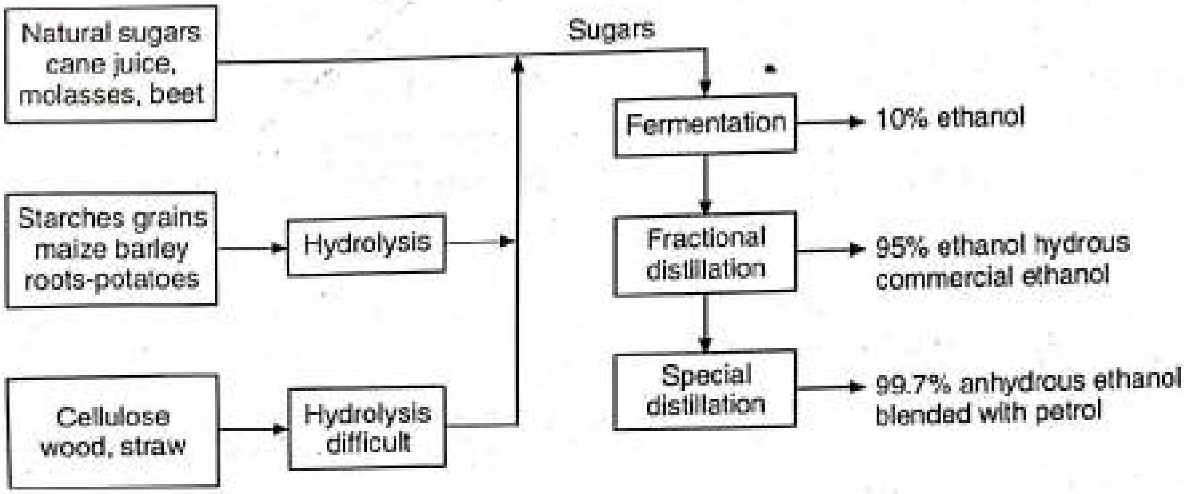


Figure 12.12 Ethanol production from biomass.

12.16.1 Ethanol as Fuel

In the USA, anhydrous ethanol (10%) is blended with petrol (90%) to produce 'gasohol' a good substitute for petrol in automobiles without any engine modifications. Ethanol being a high octane fuel raises the octane rating of the mixture. Octane rating is explained as the fuel's quality to increase its antiknock property. Considering the advantage, Canada and Sweden also utilise 10% ethanol blended petrol. Brazil, the leader in ethanol production enhanced ethanol doping to 25–26% with petrol to tide over the soaring oil prices.

The level of sugar production in India is 18 million tonnes per year, ensuring ethanol production to 1700 million litres. It is assessed that the requirement for potable purpose and chemical sector shall consume 1200 million litres—leaving a clear balance of 500 million litres, sufficient for 5% blending with petrol in the country.

Molasses is a residue of sugar factory from which balance 40–47% sugar cannot be obtained by conventional methods. But molasses are fermented with a yeast (*saccharomyces cerevisiae*) and alcohol is separated in a distillation column. In Indian conditions, alcohol recovery from molasses is about 230 litres from one tonne of molasses.

Ethanol yield is 6 times higher if the sugarcane juice is directly fermented instead of molasses. One tonne of sugarcane with sugar content of 13% yields about 70 litres of ethanol through direct fermentation of juice. Sugar content in molasses is only 2%. The Reliance group of industries is venturing for such a project in Maharashtra to reduce crude oil import.

12.17 BIODIESEL

Biodiesel is a liquid fuel produced from non-edible oil seeds such as Jatropha, Pongamia pinnata (Karanja), etc. which can be grown on wasteland. However, the oil extracted from these seeds has high viscosity (20 times that of diesel) which causes serious lubrication, oil contimination and injector choking problems. These problems are solved through trans-esterification, a process where the raw vegetables oils are treated with alcohol (methanol or ethanol with a catalyst) to form methyl or ethyl esters. The monoesters produced by trans-esterifying vegetable oil are called 'biodiesel' having low fuel viscosity with high octane number and heating value. Endurance tests show that biodiesel can be adopted as an alternative fuel for existing diesel engines without modifications.

In EU and USA, edible vegetable oil like sunflower, groundnut, soyabean and cotton seed, etc. are used to produce biodiesel. India is endowed with a number of non-edible vegetable oil producing trees which thrives in inhospitable conditions of heat, low water, rocky and sandy soils, a renewable resource of economic significance (Jojoba in Rajasthan).

Biodiesel is the name of diesel fuel made from vegetable oil or animal fats. The concept dates back to 1885, when Dr. Rudolf Diesel developed the first diesel engine to run on vegetable oil. In recent past the use of bio oil as an alternative renewable fuel to compete with petroleum was proposed during 1980.

The advantages of biodiesel as engine fuel are: (i) biodegradable and produces 80% less CO_2 and 100% less SO_2 emissions, (ii) renewable, (iii) higher octane number, (iv) can be used as neat fuel (100% biodiesel) or mixed in any ratio with petro-diesel, and (iv) has a higher flash point making it safe to transport. Selected fuel properties of biodiesel and petrodiesel are given in Table 12.5.

Table 12.5 Properties of biodiesel and petrodiesel

Properties	*Petrodiesel*	*Biodiesel*
Boiling point, °C	188–343	182–338
Viscosity at 40°C	1.3–4.1	1.9–6.0
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, wt%	0	11
Sulphur, wt%	0.05 max	0.0–0.0024
Heating value, kcal/litre	7278	6491

12.17.1 Production of Biodiesel from Jatropha

Jatropha curcas drought resistant perennial shrub with 4–5 metre height is ideally suited to green up the wastelands in arid areas. Commercial seed production commences from the 6th year onwards with yield of 6000 kg/ha under rain-fed conditions and 12000 kg/ha in irrigated areas. The average oil production is 0.25 kg oil/kg seed. The oil cake is used as organic fertilizer.

Scientists of Central Salt & Marine Chemical Research Institure (CSMCRI) Bhavnagar (Gujarat) have confirmed the use of Jatropha curcas and Jojoba seed oil as promising substitutes for diesel. The yield of Jojoba seed is 0.5 kg per plant after 10 years of plantation, Jojoba seed costs ₹ 200/kg, so presently it is uneconomical as feedstock for engine oil.

The characteristics of four biodiesels obtained from vegetable oils of peanut, soyabean, sunflower Jatropha and diesel are given in Table 12.6

Table 12.6 Characteristics of four biodiesels

Name	*Flash point* (°C)	*Density at* 20/40°C	*Viscosity*	*Octane number*	*Heating value* (MJ/litre)
Diesel	32	0.82–0.86	2.0–7.5	42	34.5–36.0
Biodiesel (Jatropha)	161	0.878	4.54	65	33.7
Biodiesel (Sunflower)	183	0.880	4.60	49	33.5
Biodiesel Soyabean	178	0.885	4.50	45	33.5
Biodiesel Peanut	176	0.883	4.90	54	33.6

The heat of combustion for biodiesel is up to 95% by volume of conventional diesel, but biodiesel being oxygenated provides the same fuel value as the diesel. The parameters in Table 12.5 justify Jatropha seed (cost ₹ 5.0/kg) as an economically favourable feedstock to produce biodiesel.

Oil is extracted from Jatropha seeds in an oil press. It is treated with methanol (CH_3OH) to produce three methyl ester molecules and one glycerol molecule. Alkalis like NaOH or KOH are used to catalyze the reaction having the following constituents: 1000 litre Jatropha oil + 400 litre

(CH_3OH) + 10 litre catalyst. The reaction process is completed rapidly, glycerol is separated and methyl ester is obtained as biodiesel.

The Ministry of Petroleum and Natural Gas has opened a biofuel centre in Delhi to build awareness of importance of Jatropha curcas cultivation and manufacture of biodiesel. The Indian Oil Corporation (IOC) has already established a biodiesel plant at Faridabad and another one being established in Panipat refinery to prepare 30,000 litres of biodiesel daily by crushing 100,000 kg Jatropha seeds. Biodiesel shall be blended with diesel to the extent of 5% in different Indian climatic conditions. Approximately, 40 million tonnes of HSD is consumed annually in India, thus, only 5% replacement of petroleum fuel by biodiesel would save the country approximately ₹ 4000 crores in foreign exchange yearly.

12.18 BIOFUEL PETROL

Shell oil company started selling petrol containing 10% cellulosic ethanol in Ottawa. Biofuel is produced from wheat straw. Logen's process converts biomass into cellulostic ethanol using a combination of thermal, chemical and biochemical techniques. Yield of cellulosic ethanol is 340 litres per tonne of fibre. Lignin is the plant fibre is used to drive the process by generating stream and electricity, thus, eliminating the need of coal or natural gas. Cellulosic ethanol is identical to ethanol, but produces up to 90% less CO_2 than petrol.

12.19 BIOMASS RESOURCE DEVELOPMENT IN INDIA

The energy scenario in India indicates that 'biomass' is a promising form of renewable energy matching with the agricultural base in rural areas and industrial development in urban set-ups. The estimated potential and physical achievement of biopower are given in Table 12.7.

Table 12.7 Potential vis-a-vis achievement in the field of biopower

Resource	*Estimated potential* (MW)	*Achievement up to* January 2009 (in MW)
Biopower (woody biomass)	52000	683
Waste to energy		
(i) Grid-interactive power	5000	34.95
(ii) Distributed power	50,000	11.03
Rural–30,000 MW (Captive generation–industrial 20,000 MW)		
Biomass gasifiers	–	87
Co-generation (bagasse)	5000	1034
Family type biogas plants	120 lakhs	39.8 lakhs

12.20 FUTURE OF BIOMASS ENERGY IN INDIA

Use of Biomass is growing globally. Modern biomass has potential to penetrate in four segments.

- Process heat applications in industries generating biomass waste.
- Cooking energy in domestic and commercial sectors (through charcoal and briquetts).
- Electricity generation and
- Transportation sector with liquid fuels.

Future of biomass energy lies in its use with modern technologies.

12.21 GLOBAL SCENE

In US 45 billion kWh of electricity is from biomass and 4 billion gallon of ethanol is used in vehicles. Biomass supports 66000 jobs in the US. In Sweden, biomass and peat contribute 12% of total energy while in Austria this-figures is 13%. World wide biomass contributes 14% of total energy and it is 38% in developing countries especially in rural sector.

12.22 ENVIRONMENTAL BENEFITS

Biomass energy brings several environmental benefits–reduces air and water pollution, increases soil quantity and reduces erosion, and improve wildlife habitat.

Biomass reduces air pollution by being a part of carbon cycle. Actually, carbon cycle is nature's way of moving carbon around to support life on the earth. CO_2 is common vehicle for carbon. Plant photosynthesis breaks CO_2 in two, keeping carbon to form carbohydrates that make the plant, releasing oxygen into air. When plant is burnt, it gives its carbon back to air, which is reabsorbed by other plants.

On the other hand, when fossil fuels are burnt, there is no extra plant to absorb that carbon, so, the cycle becomes out of balance. There are two different carbon cycles in operation now; the natural one between plants and air, which is in balance, and man made cycle, where carbon is pulled from the earth (fossil fuel) and emitted into the atmosphere. Thus, biomass use for energy reduces CO_2 emissions by 90% compared with fossil fuel.

Water pollution is reduced, as little fertilizers and pesticides are used to grow energy crops. Planting poplar trees in buffers along water ways, runoff from corn field is captured, making streams cleaner.

High-yield food crops pull nutrients from the soil, while energy crops improve soil quality. Prairie grasses, with their deep roots, build up top soil, putting nitrogen and other nutrients into the ground.

Finally, biomass crops create better wildlife habitat than food crops, being native plants which attract birds and small mammals.

In addition to above, biomass offers economic and energy security benefits. By growing our fuel at home, oil import is reduced and farmers get money for their products.

Keeping in view above, Ministry of Environment and Forest (MOEF) in December 2009, exempted biomass and nonhazardous municipal water power plants up to 15 MW from environmental clearance.

If planned well, our capital requirement for pellitser machines, biomass fuel fired stoves and agroprocessing industries can be financed by earning large carbon credits.

10

GEOTHERMAL ENERGY

10.1 INTRODUCTION

The earth is a great reservoir of heat energy in the form of molten interior. Surface manifestation of this heat energy is indicated by hot water springs and geysers discovered at several places. Heat can be experienced from the temperature rise of the earth's crust with increasing depth below the surface. Radial temperature gradient increases proportionally to depth at a rate of about 30°C per km. At a depth of 3–4 km, water bubbles up; while at a depth of 10–15 km the earth's interior is as hot as 1000° to 1200°C. The core of the earth consists of a liquid rock known as **'Magma'** having a temperature of about 4000°C.

This geothermal heat is transferred to the underground reservoir of water which also circulates under the earth's crust. Its heat dissipates into the atmosphere as warm water and the steam vents up through the fissures in the ground as hot springs and geysers. Limitless heat content in magma plus the heat generated by radioactive decay of unstable elements such as K_{40}, Th_{232} and U_{235} which are abundant in the earth's crust are forms of geothermal energy and considered as a renewable energy resource.

10.2 STRUCTURE OF THE EARTH'S INTERIOR

The earth consists of a series of concentric shells. Its internal structure can be divided into three parts—Crust, Mantle and Core—as shown in Figure 10.1.

The crust

The solid crust of the earth is 70–100 km thick and can be divided into continental crust 20–65 km under the continents and oceans crust 7 km under the ocean basins. The study of seismic waves has indicated that the earth's crust underneath the continents is thicker than that underneath the oceans as seismic waves travel faster in oceanic crust than in continental crust. The oceanic crust consists of low-density rocks (basalt) whereas the continental crust largely contains the granite.

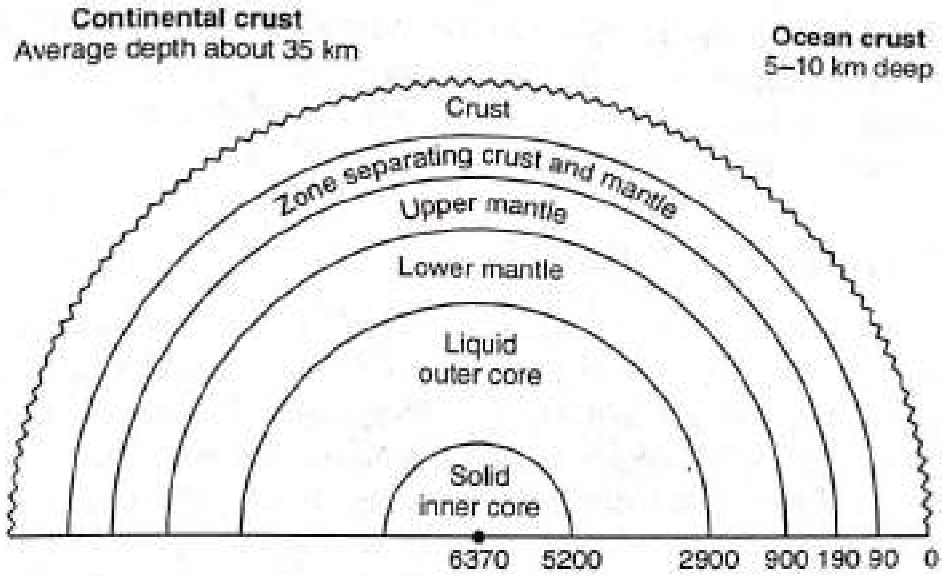


Figure 10.1 Half-cross section of the earth. Distances are from the surface in km.

The mantle

The upper rigid part of the mantle extends up to 100 km below the separating crust and contains mainly iron and magnesium. The crust and upper mantle form the 'lithosphere'. The lower mantle extending up to 2900 km below the earth's surface is less rigid and is hotter. This is known as the 'asthenosphere' and is capable of being deformed. The phenomena of plate tectonics, i.e., the movement of the earth's crust is caused by the movement of the lithosphere over the asthenosphere as shown in Figure 10.2.

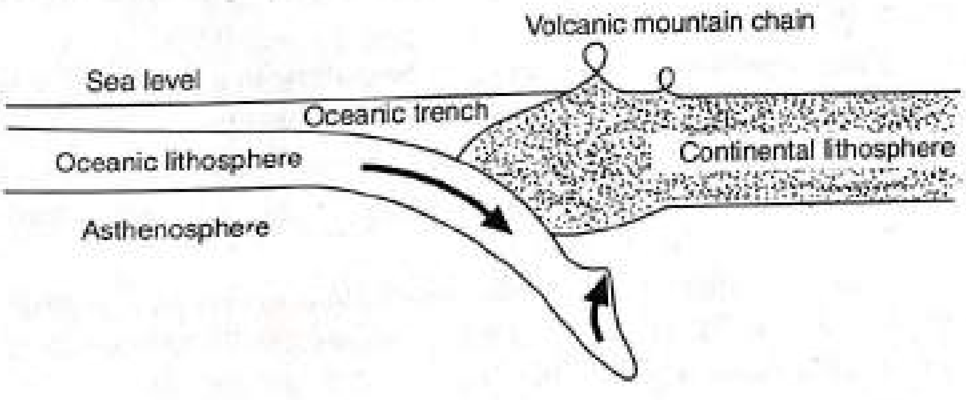


Figure 10.2 Movement of the lithosphere over the asthenosphere.

The core

It forms about 33% of the earth's mass and has a radius of 3500 km. The outer core is molten or liquid while the inner core (radius 1170 km) is believed to contain nickel-iron alloy. The hot molten rock of the mantle is called 'Magma'.

The outer core being in the molten state behaves like a liquid responsible for all the earthquakes and volcanic activities. A thermal gradient is created from 'core' to 'mantle' and 'earth crust'. The outward flow of heat energy from molten hot interior of the earth to the cooler surface makes the earth to operate like a heat engine.

10.3 PLATE TECTONIC THEORY

The lithosphere which constitutes the crust and the upper mantle, is divided into plates. These plates are in a state of constant relative motion at a speed of few cm per year. The plate tectonics concept represents the continents and the sea-floor slides on the surface of the plastic asthenosphere. When they collide or grind, the earthquakes and volcanic eruptions take place. It is near the junctions of these plates that heat travels rapidly from the interior magma to surface volcanoes. The active volcanoes are due to geothermal activity.

Most volcanoes and the earthquakes occur in narrow bands along the major dislocations in the earth's substructure that mark the edges of the crustal plates. The oceanic survey revealed the world-wide system of mid-oceans ridges along which new crust is continuously formed, and at the same time, seismographic observations showed that many earthquakes had their focal points beneath the oceans trenches. Movements that produce earthquakes were analysed and it was observed that the plate generated at a mid-oceans ridge was far away, plunging down an earthquake-ridden subduction zone. In this way the boundaries of the plates are identified.

The boundaries between the plates are of three types: (i) diverging plate boundaries, (ii) converging plate boundaries, and (iii) conservative plate boundaries.

(i) Diverging plate boundaries (or constructive boundaries) are formed when two plates move apart, allowing up-welling of molten magma from asthenosphere to create new lithosphere. Thus, mid-oceanic ridges are formed which sometime rise above sea level as Iceland and Azores island.

(ii) Converging plate boundaries (or destructive boundaries) are formed when two plates, i.e., oceanic crust and continental crust collide and one plate sinks beneath the other, which is re-absorbed into the mantle and destroyed (process known subduction). Melting of the sinking plate creates pods of magma that rise into the upper plate and become a heat source for geothermal reservoir.

(iii) Conservative plate boundaries occur, where one plate grinds jerkily past another and no lithosphere is either destroyed or created. Example is California's San Andreas fault which caused earthquake in 1906.

10.4 GEOTHERMAL SITES, EARTHQUAKES AND VOLCANOES

Geothermal resources are associated with tectonic activity, as it allows ground water to be heated with the subsurface heat source. Geothermal fields require a combination of three geological conditions—a natural underground source of water; an impermeable layer that traps water and allows formation of steam; and, a large mass of hot rock in the vicinity of water system. In the plate boundaries, earthquakes, volcanoes and regions of heat flow are largely located.

Most of the world's volcanic activities and geothermal sites are located in the circum-pacific belt known as 'rim of fire'. It starts from New Zealand, encompasses Philippines, Japan, West coasts of North America and Mexico. Another belt runs from Iceland touching the British Isles, through Azores across the Atlantic to the West Indies, with a branch running through the Mediterranean Sea (Figure 10.3).

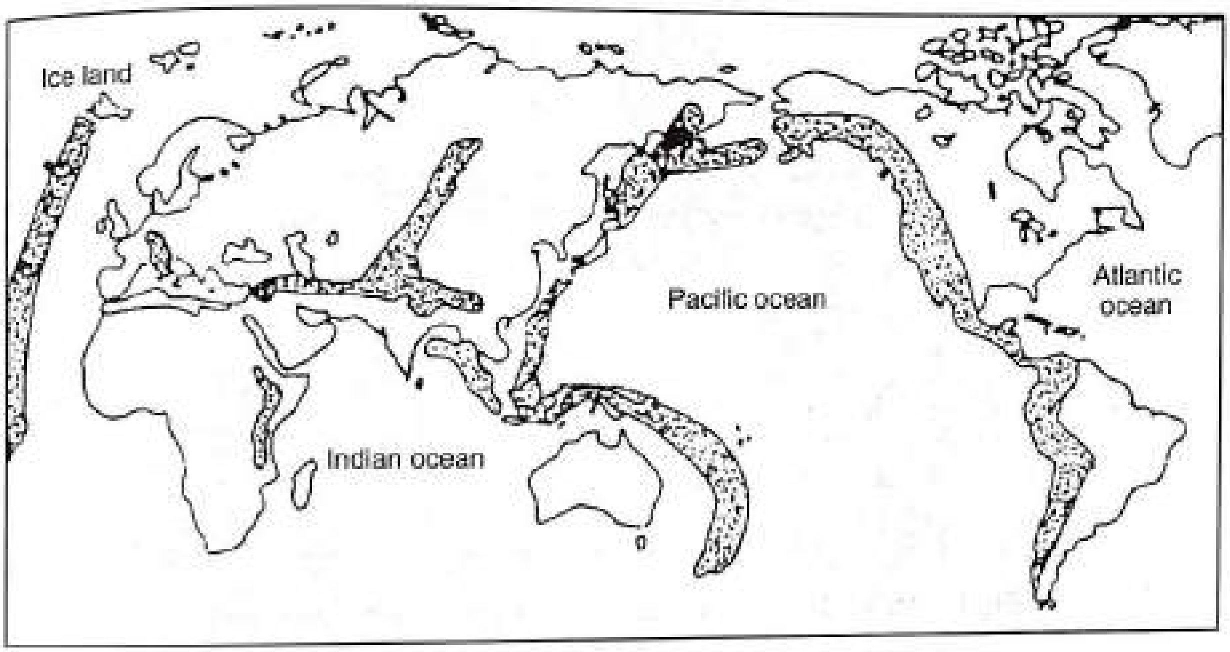


Figure 10.3 Regions of geothermal sites, earthquakes and volcanic activity.

Geothermal fields exist in subduction zones where oceanic plateau bend downwards under a continental plate near Japan, Indonesia, New Zealand and Central America. Geothermal sites are also found where collision of continental plates occurs as north west area of Indian–Australian and Eurasian plates. Himalayan geothermal fields on Indian and Chinese side are due to this same reason.

10.5 GEOTHERMAL FIELD

A typical geothermal field is shown in Figure 10.4. Cool rainwater percolates underground from a large surface area (1000 sq. km) and then circulates downwards. At depths of 2 km to 6 km, water is heated by conduction from hot rocks, which in turn are heated by molten rocks.

Water expands on heating and flows buoyantly upwards in a restricted cross-sectional area (1–50 km^2). If rocks have many inter-connected fractures or pores, heated water rises rapidly to the surface in the form of hot water springs or shows up as geysers. However, if the upward movement of heated water is impeded by rocks with few fractures and pores; geothermal energy is stored in the reservoir rock below the impeding layers.

Whenever such a site is drilled, steam and hot water gush out through the drilled hole and become a source of geothermal energy for use in a power plant.

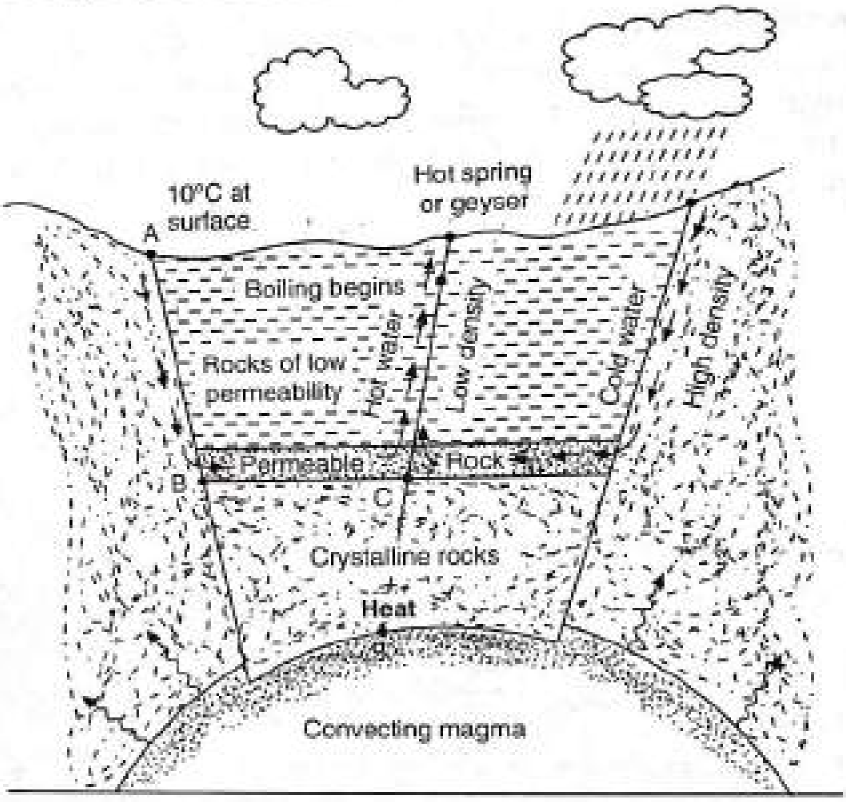


Figure 10.4 High temperature hot water geothermal field.

10.6 GEOTHERMAL GRADIENTS

To utilise geothermal energy, a steady rise of the earth's temperature with increasing depth is necessary. It is called geothermal gradient as represented in Figure 10.5.

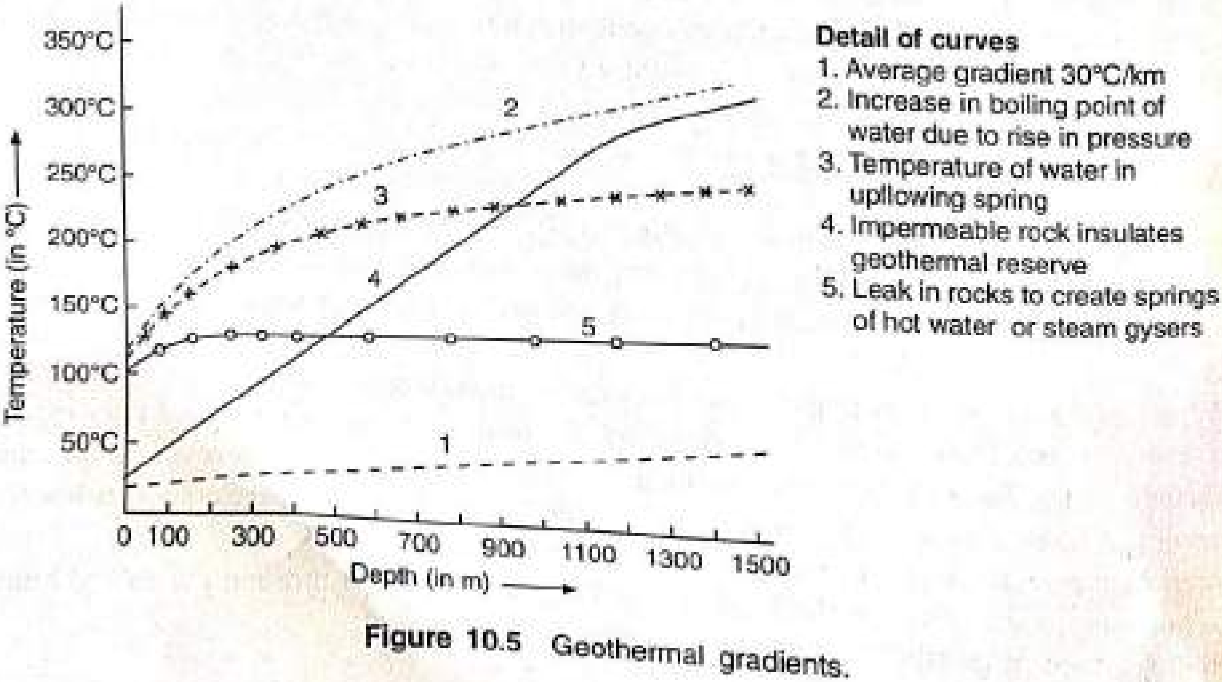


Figure 10.5 Geothermal gradients.

The figures are based on measurements within a few km of the earth's surface. The average gradient near the surface is about 30°C/km, as represented by curve 1. Boiling temperature of water is expressed by curve 2 which goes above 100°C with increase in depth, causing a rise in pressure. At locations where the crust is fractured, water percolates downwards, gets heated and gushes upwards in the form of hot springs. It is represented by curve 3, such manifestations of hot water springs exist in Iceland. Curve 4 depicts the effect of impermeable rock which locks up geothermal fluid and does not allow heat flow towards the earth's surface. There are locations with leaks in impermeable rocks, where water generates steam which is released to surface in the form of geysers represented by curve 5. Such phenomena are seen at Lardarello in Italy and geysers of California in the USA. The geothermal gradient is expressed in °C and heat flow in mW/m^2.

10.7 GEOTHERMAL RESOURCES

Geothermal resources are of five types:

1. Hydrothermal
   (a) Hot water
   (b) Wet steam (superheated water from highly pressurized underground reservoirs)
2. Vapour dominated resource
3. Hot dry rock resource
4. Geo-pressured resource
5. Magma resource.

10.7.1 Hydrothermal Resource

Hydrothermal resources (geothermal reservoirs) are hot water or steam reservoirs that can be tapped by drilling to deliver heat to the surface for thermal use or generation of electricity. Such fields exist in zones of structural weakness as given in Figure 10.6.

It may be seen that only a part of the rock is permeable constituting the geo-fluid reservoir, so the field is able to produce commercially a viable resource. Sites of these resources adopt the geographical name of their locality such as Larderallo field in Italy, Wairakei field in New Zealand and Geysers geothermal field in California.

Hot water fields

At these locations hot water below 100°C gushes out as hot spring. The geothermal aquifers being covered by confining layers keep the hot water under pressure. Generally the geothermal water contains sulphur in colloidal form widely used as medicated curative water for skin diseases. In northern India, such a spring exists at Tatapani on the right bank of river Sutlej 54 km from Shimla. Other locations are 'Sahestra Dhara' near Dehradun, sacred kund at Badrinath in Uttarakhand, Sohna sulphur water tank in Gurgaon (Haryana) and Manikaran in Kulu Valley (Himachal Pradesh). Internationally known fields are Pannonian basin (Hungary), Po river valley (Italy) and Klamath Falls Oregon (USA).

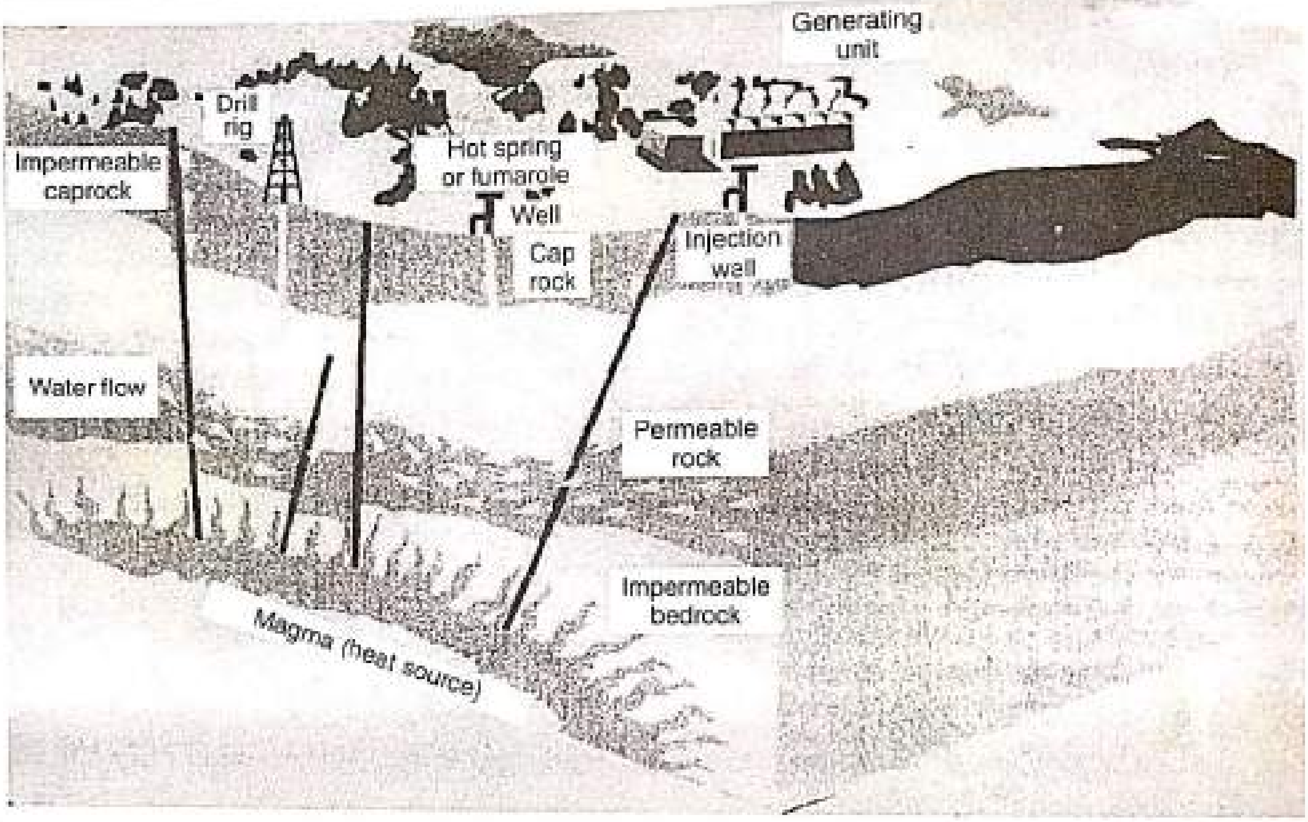


Figure 10.6 Cross-section showing the characteristics of a hydrothermal geothermal site.

Wet steam fields

The pressurized water is at more than 100°C and contains small quantities of steam and vapour in the geothermal reservoir (370°C). With this formation, liquid is in dominant phase that controls pressure in the reservoir. Steam occurs in the form of bubbles surrounded by liquid water. Sites where the steam escapes through cracks in the surface are called 'fumaroles'.

An impermeable cap-rock prevents the fluid from escaping into the atmosphere. Drilling is carried out to bring the fluid to the surface. The fluid is used to produce steam and boiling water in predominant phase.

Examples of wet steam fields generating electrical energy are: Los Azufre (Mexico), Puna (Hawaii, USA), Dieng (Indonesia), Azores (Portugal), Latera (Italy) and Zunil (Guatemala).

10.7.2 Vapour-dominated Resource

Vapour dominated reservoirs produce dry saturated steam of pressure above the atmosphere and at high temperature about 350°C. Water and steam co-exist, but steam is in dominant phase and regulates pressure in the reservoir. Steam obtained from such a geothermal field directly drives a turbine. Major geothermal power plants in the world are: Malsukawa (Japan), The Geysers California (USA), Mt. Amiata (Italy) and Kamojang (Indonesia).

A hot dry rock field also comes under this category. This is the geological formation with high temperature rocks at 650°C, heated by conductive heat flow from magma but contains no water. To tap its energy the impermeable rock is fractured and water is injected to create an artificial reservoir. Water circulates and hot fluid returns to the surface through the other drilled well as steam and hot water which are used to generate electricity.

10.7.3 Geopressured Resource

Geopressured resources contain moderate temperature brines (160°C) containing dissolved methane. These are trapped under high pressure (nearly 1000 bar or 987 atmosphere) in a deep sedimentary formation sealed between impermeable layers of shale and clay at depths of 2000 m–10,000 m. When tapped by boring wells, three sources of energy are available—thermal, mechanical (pressure) and chemical (methane).

Technologies are available to tap geopressured brines as investigated in off-shore wells in Texas and Louisiana at the US Gulf Coast zone up to a depth of nearly 6570 m but have not proved economically competitive. Extensive research is yet to confirm the long-term use of this resource.

10.7.4 Magma

Magma is a molten rock at temperatures ranging from 700°C to 1600°C. This hot viscous liquid comes out at active volcanic vents and solidifies. It may form reservoirs at some depth from the earth's surface. Magma Chambers represent a huge energy source, but the existing technology does not allow recovery of heat from these resources.

10.8 GEOTHERMAL POWER GENERATION

Electric power from geothermal resources can be developed in the following manner.

1. Liquid-dominated resource
   (a) Flashed steam system
   (b) Binary cycle system
2. Vapour-dominated resource

10.8.1 Liquid-dominated Resource

Geothermal fluid is either available from natural outflow or from a bored well. The drilling cost increases greatly with depth and the technically viable depth is 10 km. Thus, only the geothermal wells of maximum output at shallow depths offer the best prospects for power generation.

Flashed steam system

The choice of geothermal power plant is influenced by brine characteristics and its temperature. For brine temperatures more than 180°C, the geothermal fluid is used. This flashed steam system is suitable for power generation as detailed in Figure 10.7.

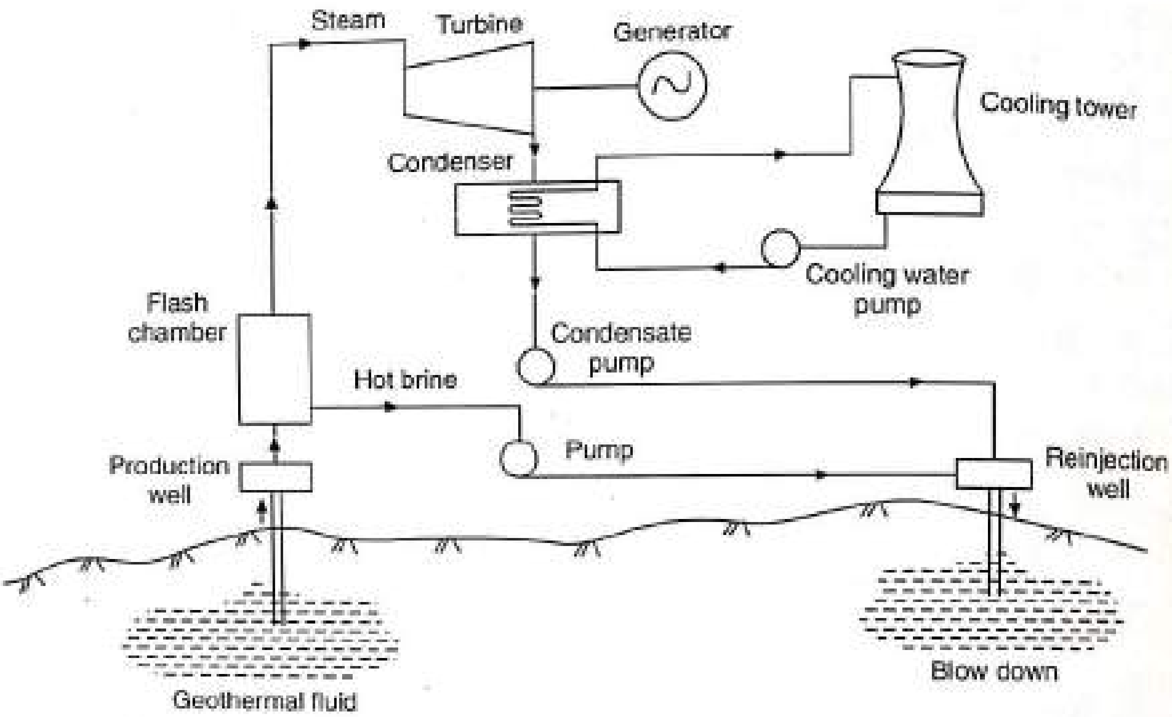


Figure 10.7 Flashed steam geothermal power plant.

Geothermal fluid is a mixture of steam and brine, it passes through a flash chamber where a large part of the fluid is converted to steam. Dry saturated steam passes through the turbine coupled with the generator to produce electric power. Hot brine from the flash chamber and the turbine discharge from the condenser are reinjected into the ground. Reinjuction of the spent brine ensures a continuous supply of geothermal fluid from the well.

Commercially available turbogenerator units in the range of 5–20 MWe are in use. To improve the total efficiency of the system, hot water is utilised for poultry farming in cold regions.

Binary cycle system

A binary cycle is used where geothermal fluid is hot water with temperature less than 100°C. This plant operates with a low boiling point working fluid (isobutane, freon) in a thermodynamic closed Rankine cycle. The working fluid is vaporized by geothermal heat in a heat exchanger as shown in Figure 10.8.

Vapour expands as it passes through the turbine coupled with the generator. Exhaust vapour is condensed in a water-cooled condenser and recycled through a heat exchanger. Power plants of 11 MW in California and 10 MW at Raft River Idaho USA operate on binary cycle.

10.8.2 Vapour-dominated Geothermal Electric Power Plant

In a vapour-dominated plant, steam is extracted from geothermal wells, passed through a separator to remove particulate contents and flows directly to a steam turbine (Figure 10.9).

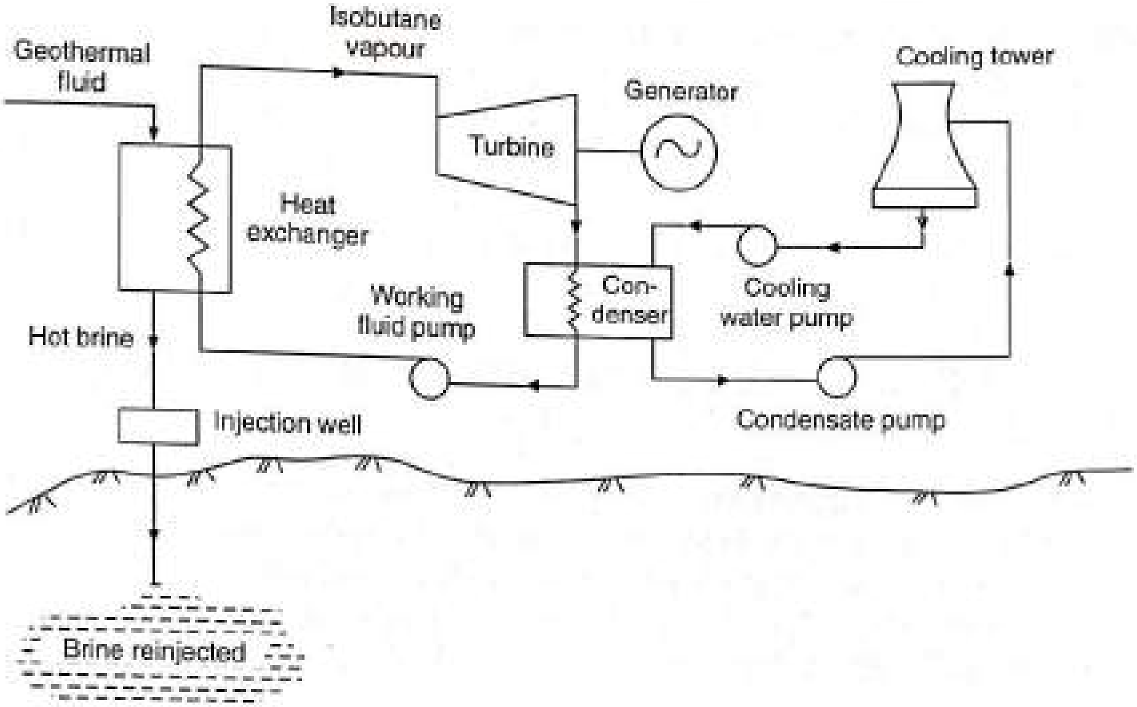


Figure 10.8 Binary cycle geothermal power plant.

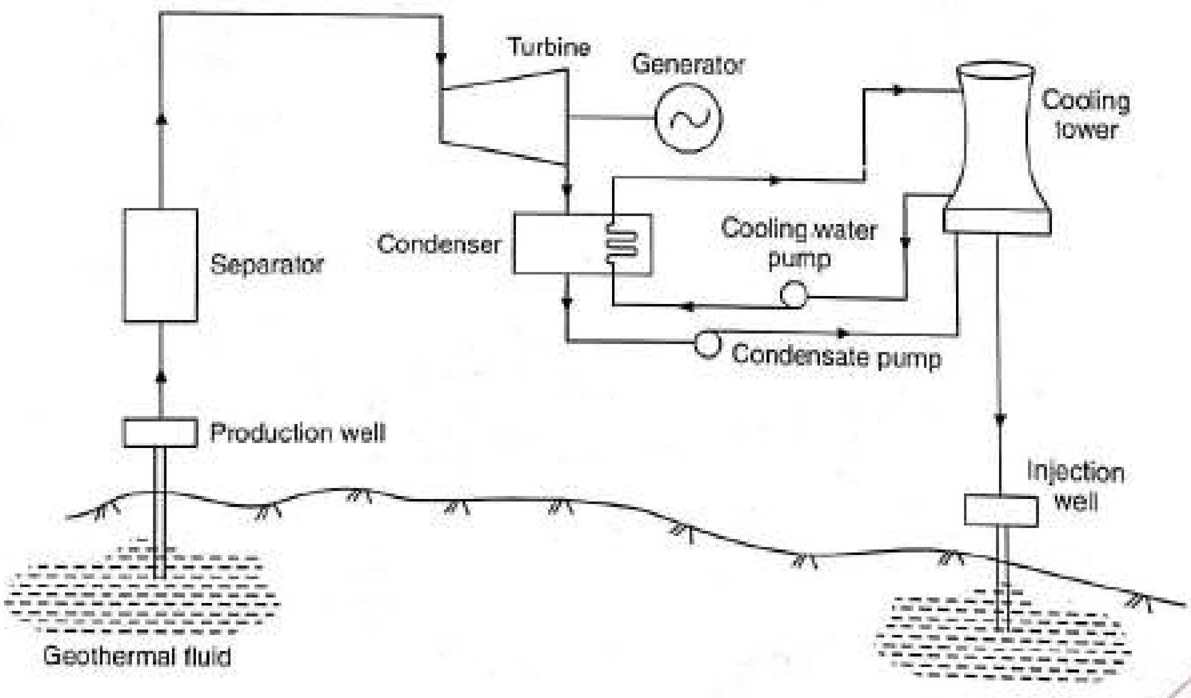


Figure 10.9 Vapour dominated geothermal power plant.

Steam that operates the turbine coupled with the generator is at a temperature of about 245°C and pressure 7 kg/cm^2 (7 bar) which are less than those in conventional steam cycle plants (540°C and 130 kg/cm^2). Thus, the efficiency of geothermal plants is low, i.e., about 20%.

Exhaust steam from the turbine passes through a condenser and the water so formed circulates through the cooling tower. It improves the efficiency of the turbine and controls environmental pollution associated with the direct release of steam into the atmosphere. Waste water from the cooling tower sump is reinjected into the geothermal well to ensure continuous supply.

At present such a system is being operated to generate power at Larderallo Italy, and at the Geysers in California.

10.9 GEOTHERMAL—PREHEAT HYBRID WITH CONVENTIONAL PLANT

Geothermal brine at low temperature is usefully utilised to heat feed water in conventional fossil-fuelled power plants as shown in Figure 10.10. Geothermal heat replaces all low-temperature feed water heaters used ahead of the deaerating heater. Then, the boiler feed pump (BFP) takes over prior to high pressure (HP) feed water heaters which receive heat from the steam bled from the high pressure (HP) turbine. Feed water then flows into the economizer before entering the boiler drum.

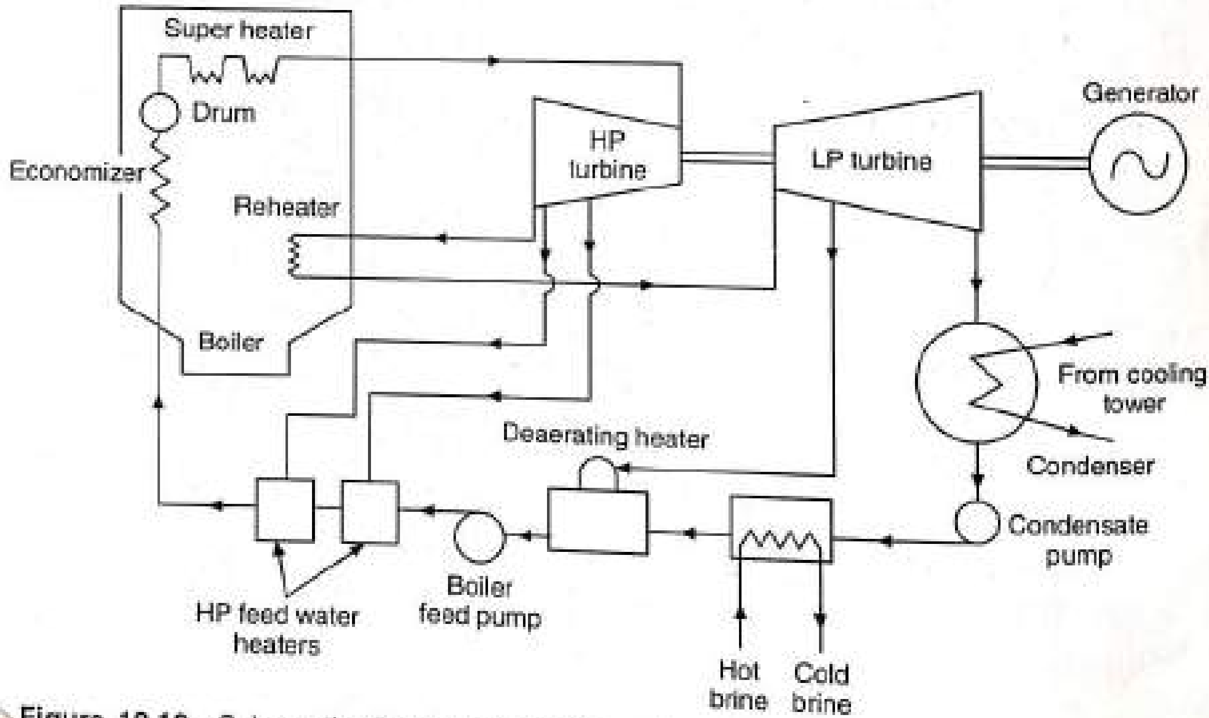


Figure 10.10 Schematic diagram of geothermal preheat hybrid with conventional plant.

10.10 IDENTIFICATION OF GEOTHERMAL RESOURCES IN INDIA

India has good potential for geothermal energy. Govt. of India Ministry of New and Renewable Energy (MNRE) have estimated the capacity to produce 10,600 MW of power. However, geothermal power has not yet been exploited and India does not appear on the geothermal power map of the world.

National Geophysical Research Institute (NGRI) conducted surveys and have identified several sites which are suitable for power generation as well as for direct use. The geothermal springs are clustered in seven provinces given below, and detailed in Figure 10.11.

1. The Himalaya
2. Cambay
3. West coast
4. Son-Narmada-Tapi (SONATA)
5. Bakreswar
6. Godavari
7. The Barren Island

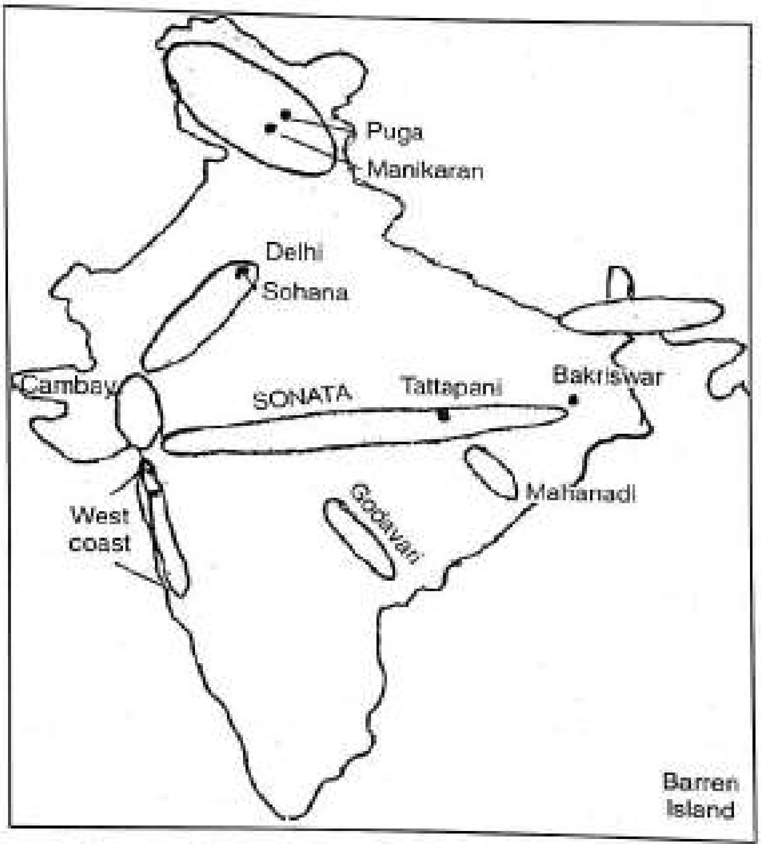


Figure 10.11 Geothermal provinces of India.

The Himalaya Province

It is most promising provinces in the coldest part of the country and contains about 100 thermal springs with high surface temperature of 90°C, discharging more than 190 tonne/hour of thermal water. A pilot project binary 5 kW power plant was operated by Geological Survey of India at Mainkaran. Presence of epidote in drill-cuttings recovered from 500 m drill-holes support, estimated reservoir temperature of 260°C.

Cambay Province

This province forms a part of Cambay basin, where 15 discharge sites are located with surface temperatures varying from 40°C to 90°C. Steam discharge in few oil wells exceed 3000 m^3/day. Reservoir temperature estimated at two sites (Tuwa and Tulsi Shyam) are greater than 15°C.

West Coast Province

This province is located within Deccan flood basalts of Cretaceous age. West Coast province enjoys a thin lithosphere of 18 km thickness, thereby making this province a most promising sites for exploitation.

SONATA Province

This province extends from Cambay in the west to Bakreswar in the east with high geothermal gradient and encloses Tattapani geothermal province spread over an area of 80,000 sqm. Tattapani province encloses 23 thermal discharge sites with surface temperature varying between 60°C and 95°C and flow rate more than 4000 L/min.

Bakreswar Province

It falls in Bengal and Bihar districts and marks the junction between SONATA and Singh bhum shear zone. High helium (He) gas is found in all thermal discharges (water and gases). The He discharge is 4L/hour and a pilot plant is proposed to recover it.

Godavari Province

Godavari valley in Andhra Pradesh consists 13 thermal discharges having range of surface temperature between 50°C to 60°C. It is estimated that 38 MW power can be generated from this province.

The Barren Island

This province forms a part of the Andaman–Nicobar Island chain in the Bay of Bengal and is located 116 ENE of Port Blair. Fumarolic discharge carry temperature between 100°C and 500°C. Detailed exploration work shall be carried out in this province.

10.11 UTILISATION OF GEOTHERMAL ENERGY

Geothermal energy available in India is at low temperature (150°C) and is used for different projects including pilot power plants.

Power generation

A 5 kW pilot geothermal power plant has been installed at Manikaran by the GSI and National Aeronautical Laboratory (NAL), Bangalore. This plant operates on a closed loop Rankine cycle utilising Freon–113 as the working fluid, have been designed and fabricated by NAL.

The National Geophysical Research Institute of Hyderabad conducted Magnets Telluric (MT) studies in Tattapani geothermal field in Chhattisgarh. Based on these findings the installation of a demonstration power plant of 300 kW capacity is under consideration. Similar studies for Puga geothermal fields in Jammu and Kashmir (J&K) by NGRI Hyderabad are in progress.

Space heating

Puga (J&K) being at high altitude, experiences low ambient temperatures up to −35°C during winter. Here, a 62.5 m^3 hut is heated with geothermal water, which helps to maintain the inside temperature at 20 ± 2°C.

Extraction and refining of borax and sulphur

Geothermal hot water in Puga valley is used for refining the locally occurring borax and sulphur and for processing of Tsokar lake salt. The extraction plant has the capacity to handle 2 tonne/day of borax ore, while the refining plant can process 500 kg/day of borax. The pilot plant for sulphur refining can process 100 kg sulphur per day.

Greenhouse heating

Geothermal water is used at Chumathang (J&K) for greenhouse cultivation. A suitable temperature (20–25°C) for agriculture production is maintained inside the greenhouse during winter where the outside temperature dips down to −25°C. Several varieties of vegetables and flowers are grown in the greenhouse—a boon to local population.

Refrigeration

A geothermal energy-based absorption refrigeration system operates a 7.5 tonne capacity cold storage plant at Manikaran (HP). The plant uses ammonia as the refrigerant and geothermal water at 90°C.

10.12 GLOBAL STATUS OF ELECTRICITY GENERATION FROM GEOTHERMAL RESOURCES

The geothermal-based electrical energy generation capacity in the world stands at approximately 10715 MWe. A global-level study of renewables in the year 2000 showed that geothermal energy ranked third after small hydro and biomass. There are several countries where geothermal energy is dominant.

Iceland began to use natural hot water in 1930 for greenhouses and domestic space heating. The island is situated on an exposed segment of mid-Altantic ridge, which is a boundary between the Eurasian and the American continental plate. It is rich in geothermal resource—an entire city building of Reykjavik and Hveragerdi town are heated by natural hot water with a distribution pipe line of 64 km. Steam from one of its large geothermal reservoirs was used during 1969 to feed a 17 MWe power generating plant. The total installed geothermal generating capacity stood at 202 MWe during the year 2005.

New Zealand is another country that has exploited geothermal energy since early 1960s, where a 192 MWe plant was installed at Wairakei in North Island. In addition, a 110 MW (thermal) plant at Kawerau feeds natural steam to Tasman pulp and paper mill. The present geothermal generating capacity of the country is nearly 437 MWe.

Philippines uses geothermal energy for several low-grade heat (200–250°C) industrial processes. Its installed capacity of geothermal power stood at 1931 MWe in the year 2005.

Italy is the first country where steam from Larderallo field was used to produce electricity in 1904. Its installed capacity rose to 127 MW in 1944. The total capacity of geothermal electric power reached 790 MWe in the year 2005.

In Japan, geothermal power production in mid-1960s was 13 MWe at Otak, and 20 MWe at Matsukawa. The installed capacity rose to 546.9 MWe in the year 2000 using the Hot Dry Rock (HDR) technology.

The United States of America started late in geothermal energy extraction and installed 420 MWe near the Geysers field on the West coast. This site is in proximity to the tectonic plate boundaries that gives rise to high temperature gradients, permitting both power generation and direct applications. In the year 2005, the geothermal generating capacity in the USA rose to 2544 MWe—the highest in the world. Many towns in the USA, namely California, San Bernardino, Colorado and Oregon use geothermal energy.

There are a few more countries who have done dominant work in installing geothermal generating units as detailed in Table 10.1.

At present, 35 countries of the world use 15,144 MWe geothermal energy for space heating, industrial and agricultural applications whereas 21 countries utilise geothermal energy for electricity generation.

Table 10.1 Geothermal generating units

Country	*Installed up to the year 2005* (MWe)
China	29.17
Costa Rica	163
El Salvador	161
Guatemala	33.4
Indonesia	797
Kenya	127
Nicaragua	77
Russia	79
Portugal	20
Turkey	20
Italy	790 MW
Mexico	953 MW

(*Note:* Countries with installed capacity less than 20 MWe are not shown in Table 10.1.)

10.13 ADVANTAGES OF GEOTHERMAL ENERGY

Various advantages associated with electricity generation from geothermal energy are:

- Electricity generation from geothermal source is pollution free and does not contribute to green house effect.
- It is economical as power stations need small space.

- No fuel is needed, so recurring expenditure is small.
- Once geothermal power station is built, the energy is almost free.
- Geothermal energy is renewable. It is a constant energy source and also ubiquitous, its cost will not rise with time.
- Geothermal electric power plants are on line 97% of the time, whereas nuclear plants average only 65% and coal plants only 75% online time.
- Geothermal plants are modular, and can be installed in increments as required.
- Construction time is only 6 months for plants in the range 0.5 MW to 10 MW, and as little as 2 years for cluster of plants.
- Geothermal plants can be used both as base line and peaking power.

REVIEW QUESTIONS

1. What is geothermal energy? What is plate tectonic theory and how is it related to geothermal energy?
2. What do you understand by geothermal fields?
3. How are geothermal sites, earthquakes and volcanoes related?
4. How can geothermal energy be extracted for useful purposes?
5. What are the various types of geothermal resources available?
6. Define and discuss geothermal gradients.
7. Discuss the various ways of geothermal power generation.
8. Discuss the indirect utilisation of geothermal energy.
9. Write short notes on the environmental impacts of geothermal energy.
10. Discuss the global status vis-à-vis the current status of geothermal energy in India.
11. Enumerate advantages of geothermal power plants.