# Renewable Energy sources

## Introduction:

Energy : Energy is the capacity of a physical system to do work

various forms of Energy :

The following forms of Energy sources

1) chemical Energy
2) Nuclear Energy
3) (stored) Mechanical Energy
4) Electrical Energy
5) Thermal Energy
6) Light Energy
7) Nuclear Energy
8) Gravitational Energy

## Sources of Energy :

There are Two sources of Energy

1) Non Renewable sources 2) Renewable Sources

## 1) Non Renewable Sources of Energy :

Non renewable sources of energy (or) conventional sources of energy are being accumulated in nature for a very long time and can't be replaced if exhausted.

Nature gifted resources which are consumed, cannot be replaced, is called Non renewable sources.

Eg: coal, petroleum, natural gas and nuclear power etc.

Coal: Coal comes from the remains of plant that died hundreds of millions of years ago. It has the highest level of carbon of all fossil fuels.

Oil: oil also known as petroleum, can be extracted and refined in order to make products such as gasoline, diesel and jet fuel.

Natural gas: Natural gas was formed from the remains of tiny sea plants and animals that died millions of years ago. It is mainly composed of methane.

Nuclear Energy: It is primarily obtained through the mining and refining of Uranium ore, a naturally occuring radio active element below the earth's surface. This uranium generates power through a process known as Nuclear fusion, which creates pressure to run turbines and generate nuclear power.

Advantages of Non Renewable energy:

1) It is easy to store
2) It can be efficiently converted into the type of energy required.
3) It is easy to transport.

4) A power plant which runs on non-renewable source of of energy can be located anywhere as long as fuel is available

5) It is cheaper to obtain than other resources.

6) It provides a stronger energy output.

## Dis advantages of Non renewable energy :-

1) Non renewable energy sources cannot be replaced once their energy source is used.

2) It leads to high levels of pollution

3) It releases toxic gases in the air when burnt, which are the major cause for global warming.

4) It also increases green house gases.

5) The by-products of non renewable energy causes environmental damages.

6) Its product pose Potential threat to human health.

## 2) Renewable Energy Sources :

Energy sources which are continuously and freely produced in the nature and are not exhaustible are known as renewable sources of energy.

Renewable energy is also called clean energy (or) green energy (or) non conventional sources of energy because it doesnot pollute the air (or) the water.

Eg: Solar Energy, wind Energy, Geothermal energy Biomass, Hydro energy, Tidal energy etc.

Solar Energy: Sun is the big source of energy. The energy That comes from the sun is called solar energy. Solar energy is the light and heat that come from the sun. All the natural phenomenon like flowing of wind, water cycle, photosynthesis etc, are possible only due to solar energy. Photo Voltaic cells convert sunlight in to Electricity.

Wind energy: wind energy is obtained from moving air. The windmill is a source of electrical energy. These windmills are generally established only at places where most of the days in a year Experience strong winds. The energy from this wind is used for grinding grain, pumping water, and to produce electricity.

Geothermal Energy: Geothermal Energy is the heat that comes from the sub-surface of the earth. It is contained in the rocks and fluids beneath the earth's crust and can be found as far down to the Earth's hot molten rock. This Geothermal energy can be used for heating & cooling purposes or generate clean electricity.

**Biomass :** Biomass is renewable organic material that comes from plants and animals. Biomass contains stored chemical energy from the sun. plants produce biomass through photosynthesis. Biomass can be burned directly for heat or converted to renewable liquid and gaseous fuels through various processes. Biomass sources include wood and wood processing wastes, agricultural crops & waste material, animal manure and humane sewage, etc.

**Hydro energy :** Hydro energy also called Hydro power or hydro electricity is a form of energy that harness the power of water in motion such as water flowing over a waterfall to generate electricity.

**Tidal energy :** Tidal energy is produced by the surge of ocean waters during the rise and fall of tides. Tidal energy is harnessed by converting energy from tides into useful forms of power, mainly electricity using various methods.

## Advantages of Renewable Energy Sources :

1) They will never run out and can be used again and again.
2) produce clean energy that does not pollute the environment
3) They don't damage our planet
4) Maintenance requirements are lower.

5) Renewable energy save money

6) It can be used to recycle our waste products.

7) Less global warming

8) Improved public heath.

9) Reliability and resilience.

10) Provide Jobs and other economic benefits.

## Dis advantages of Renewable Energy:

1) Renewable energy is not available round the clock.

2) Efficiency of renewable technologies is low.

3) Initial cost of renewable energy is high.

4) Renewable energy sites require a lot of space

5) Renewable energy devices need recycling.

6) Expensive storage costs.

7) Renewables are not always 100% carbon free.

8) weather can affect energy supply.

9) Limited distribution of energy sources.

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# Unit-1

# Solar Energy

## Introduction :

Solar Energy is the radiant light and heat that comes from the sun.

Solar energy received in the form of radiation can be converted directly or indirectly into other forms of energy, such as heat and electricity, which can be utilized by man.

## advantages of solar energy :

1) It is considered as an in exhaustible source of useful energy, since the sun is expected to radiate at an essentially constant rate.

2) It provides clean renewable energy

3) Non toxic (or) polluting emissions into the air

4) Reduces the use of fossil fuels.

5) Increasingly competitive energy source

6) Reduces the need to rely on the electricity grid or natural gas.

7) Generates wealth and local employment.

8) Subsidies for self supply.

9) Reduces Electricity bills.

## Disadvantages of Solar energy :

1) The intermittent and variable manner in which it arrives at the earths surface.

2) Large area required to collect the energy.

3) High initial investment.

4) Solar energy storage is expensive.

5) Lower solar production in the winter months.

## Applications of Solar Energy :

1) Solar Electric power generation

2) Solar water heating

3) Solar heating of buildings

4) Solar pumping

5) Solar distillation

6) Solar drying of agricultural and animal products.

7) Solar furnaces

8) Solar Cooking

9) Solar Thermal power production

10) Solar green houses etc.

→ **Terms used in solar energy :**

**Irradiance :** It is the rate at which radiant energy is incident on a surface per unit area $W/m^2$ (watt / metresquare) and it is represented by symbol G.

**Irradiation :** It is the incident energy per unit area $(J/m^2)$ on a surface determined by integration of irradiance over a specificied time, usually an hour or a day.

**Insolation :** It is a term used to indicate 'Solar Energy radiation'. It is the total amount of solar energy received at a particular location during a specified time period, often in units of $kWh/(m^2)$ ~~day~~.

**Extra Terrestrial and Terrestrial Radiation :**

**Extra Terrestrial :** The solar radiation which are incident ~~rad~~ outside the atmosphere is called Extra Terrestrial solar radiation.

**Terrestrial Radiation:** It is the solar radiation that reaches the surface of earth after passing through earth's atmosphere. However, as the sun's rays flow through atmosphere, the upper layer of atmosphere absorbs some of the heat. Terrestrial radiation is radiation emitted by the earth.

# Solar Constant

- Sun the source of solar energy is a huge, glowing sphere of hot gases. Most of the gas is hydrogen (about 70%) and helium (about 28%)
- The diameter of the Sun is $1.39 \times 10^6$ Km, while that of the earth is $1.27 \times 10^4$ Km. The mean distance between the two is $1.50 \times 10^8$ Km.
- Although the Sun is large, it subtends at an angle of only 32 minutes at the earth's surface, because it is also at a very large distance.
- Thus the beam radiation received from the sun on the Earth is almost parallel.

Solar constant (Isc): The rate at which solar energy arrives at the top of the atmosphere is called solar constant, Isc.

Solar constant is the energy received in the unit time on a unit area perpendicular to the sun's direction at the mean distance of the Earth from the sun.

Solar constant is characterised by the following:

(i) It is constant and not affected by daily, seasonal, atmospheric condition, clarity of atmosphere etc.

(ii) It is on a unit area imaginary spherical surface around earth's atmosphere for mean distance between the sun and the earth.

(iii) It is on surface normal to sun rays.

(IV) It has a measured value of 1353 $W/m^2$.

The National Aeronautics and Space Administration's (NASA) standard value for the solar constant expressed in three common units is as follows:

a) 1.353 Kilo watts per square metre or 1353 watt per square metre.

b) 116.5 langleys (calories per sq cm) per hour or) 1165 Kcal per sq mtr per hour

c) 429.2 Btu per sq ft per hour.

→ The value of solar constant remains constant through out the year. However this value changes with location because earth-sun distance changes seasonally with time.

→ The Extra-terrestrial relation observed on different days is known as apparent extra terrestrial solar irradiance and can be calculated on any of the year using the following relation.

$$I_o = I_{sc}\left[1 + 0.033 \cos\left(\frac{360(n-2)}{365}\right)\right]$$

$$\frac{I}{I_{sc}} \cong 1 + 0.033 \cos \frac{360n}{365}$$

where $I$ = Apparent extraterrestrial solar irradiance $W/m^2$.

$I_{sc}$ = Solar constant = 1353 $W/m^2$.

$n$ = ~~number of~~ days of the year.

## Solar Radiation at Earth's Surface :

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

→ In the first place, part of radiation is reflected back into the ~~atmosphere~~ space especially by clouds. Furthermore the radiation entering the atmosphere is partly absorbed by molecules in the air.

Solar radiation reaching the earth surface can be

1) Direct or beam radiation
2) Diffuse radiation.

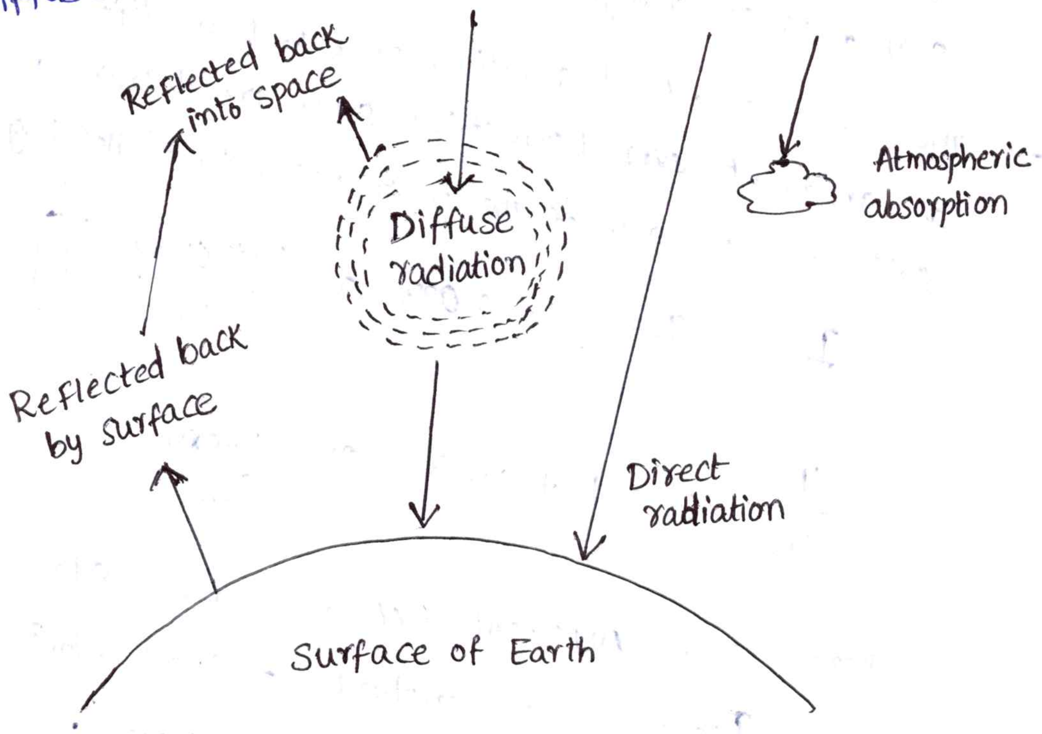



Fig : Direct, diffuse, and Total radiation.

(i) Direct or Beam radiation : Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called Direct (or) Beam radiation. ($I_b$)

(ii) Diffuse radiation : The solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere is known as Diffuse radiation. ($I_d$)

(iii) Total ~~Solar~~ radiation : The sum of beam and diffuse radiations intercepted at the surface of earth per unit area of location is known as Total radiation ($I_T$). It is also known as Insolation.

$$I_T = I_b + I_d$$

→ Attenuation of Beam Radiation by the atmosphere :

↳ The variation in solar radiation reaching the earth than received at the outside of the atmosphere is due to absorption and scattering in atmosphere.

(i) Absorption : As solar radiation passes through the earth's atmosphere the short wave ultra violet rays are absorbed by the ozone in the atmosphere and the long wave infra red waves are absorbed by the carbon dioxide and moisture in the atmosphere.

→ This results in narrowing of band width.

→ Most of the Terrestrial solar energy (i.e, energy received by the earth) lies within the range of 0.29 μ to 2.5 μ.

(ii) Scattering : As solar radiation passes through the earth's atmosphere, the components of the atmosphere such as water vapour and dust, scatter a portion of the radiation.

→ A portion of this scattered radiation always reaches the earth's surface as diffuse radiation.

↳ Thus the radiation finally received at the earth's surface consists partly of beam radiation and partly of diffuse radiation.

## → Characteristics of Solar radiation & Radiation Spectrum :

→ The characteristics of solar radiation are explained with the help of solar spectrum plots which give data on intensity as spectral content.

→ These characteristics are normally shown at Extra Terrestrial (above the atmosphere) level and at Terrestrial level (sea level) in comparison with a standard a Black body at 5762° K.

→ The solar spectrum typically extends from Infra Red to the Ultra Violet region, wavelength range from 3 μm to 0.2 μm.

→ ~~Air mass~~ Sun at Zenith: Position of the sun directly over head.

→ Airmass (m) : It is the path length of radiation through the atmosphere, considering the vertical path at sea level as unity.

The airmass ratio (m) is the ratio of path of sun's rays through the atmosphere to the length of path when the sun is at zenith.

$m = 1$, when the sun is at zenith, i-e, directly overhead

$m = 2$, when zenith angle is $60°$

$m = \sec \theta_z$ when $m > 3$.

$m = 0$ just above atmosphere of earth.

Fig shows below, the spectral distribution curves.

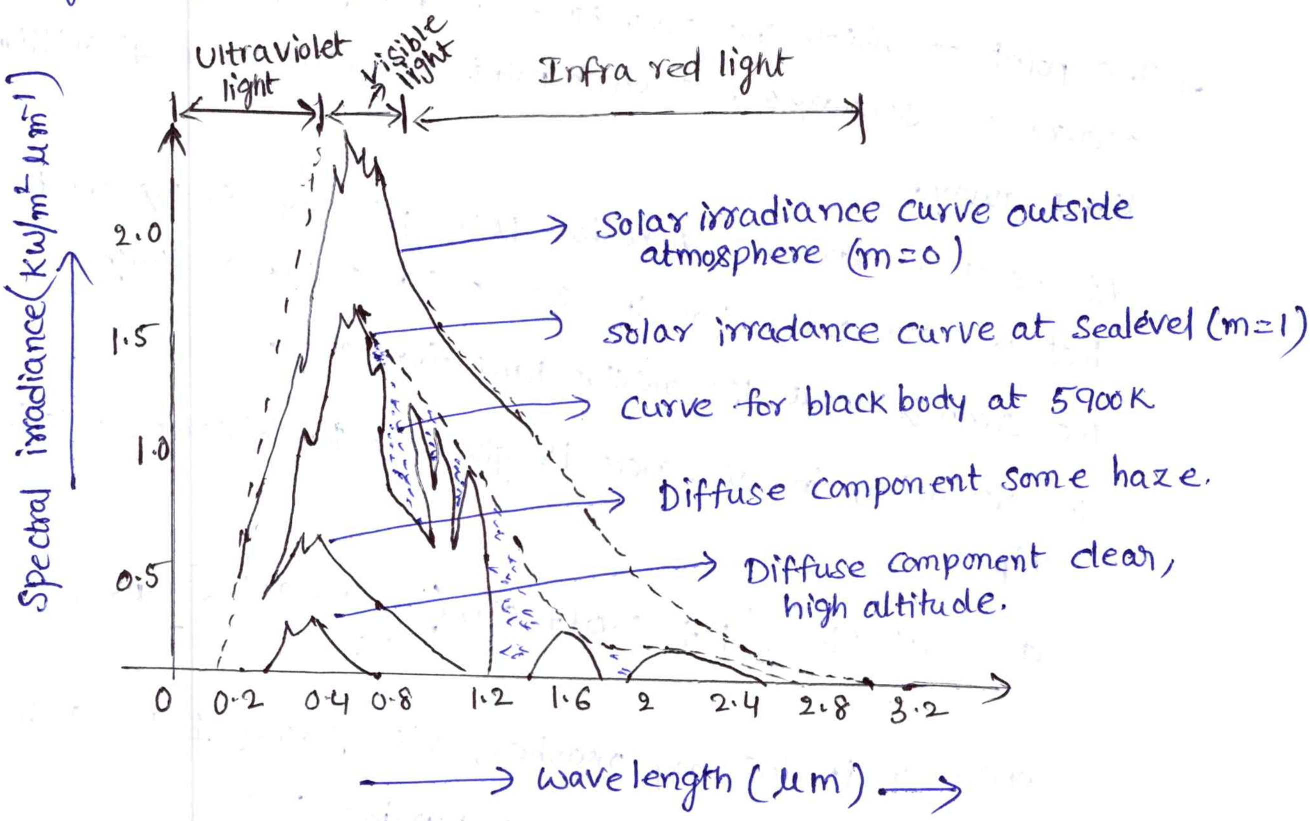



Fig : Solar spectrum outside atmosphere at ground level.

## Solar Radiation Geometry (or) Earth - sun angles :-

**Earth's orbit around the Sun:** The earth revolves around the Sun in an eleptical orbit, every 365.25 days making one rotation a day around its own North south axis.

- The point at which the Earth is nearest the sun, the Perihelion occurs on January 2, at which point is a little over 147 million Kms away.
- At the other extreme, Aphelion is the point of Earths orbit, that is far away from the sun which occurs on July 3, The earth is about 152 million Kms from sun.

The variation in distance is given by the following relation-ship:

$$d = 1.5 \times 10^{8} \left[ 1 + 0.017 \sin\left\{ \frac{360(n-93)}{365} \right\} \right] \text{km.}$$

where $n$ is the day number, with January 1 as day 1 and December 31 being day number 365.

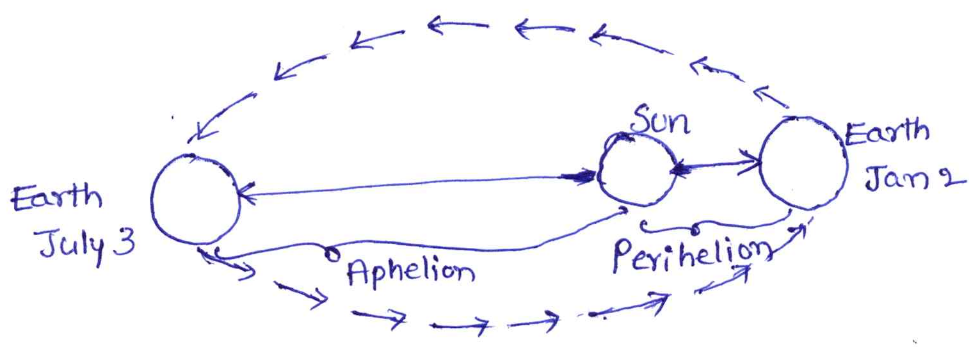



Fig (1) Aphelion & perihelion.

Solstice : Either of the Two times in the year, the summer solstice, June $21^{st}$ and the winter solstice, December $21^{st}$.

on June 21, the sun reaches its highest point in the sky at noon, marked as longest day.

one December 21, the sun reaches its lowest point in the sky, marked as shortest day.

Equinox : The time or date (twice each year) at which the sun crosses the equator when day and night are of equal length.

Equinox occurs on $21^{st}$ september and $21^{st}$ March.

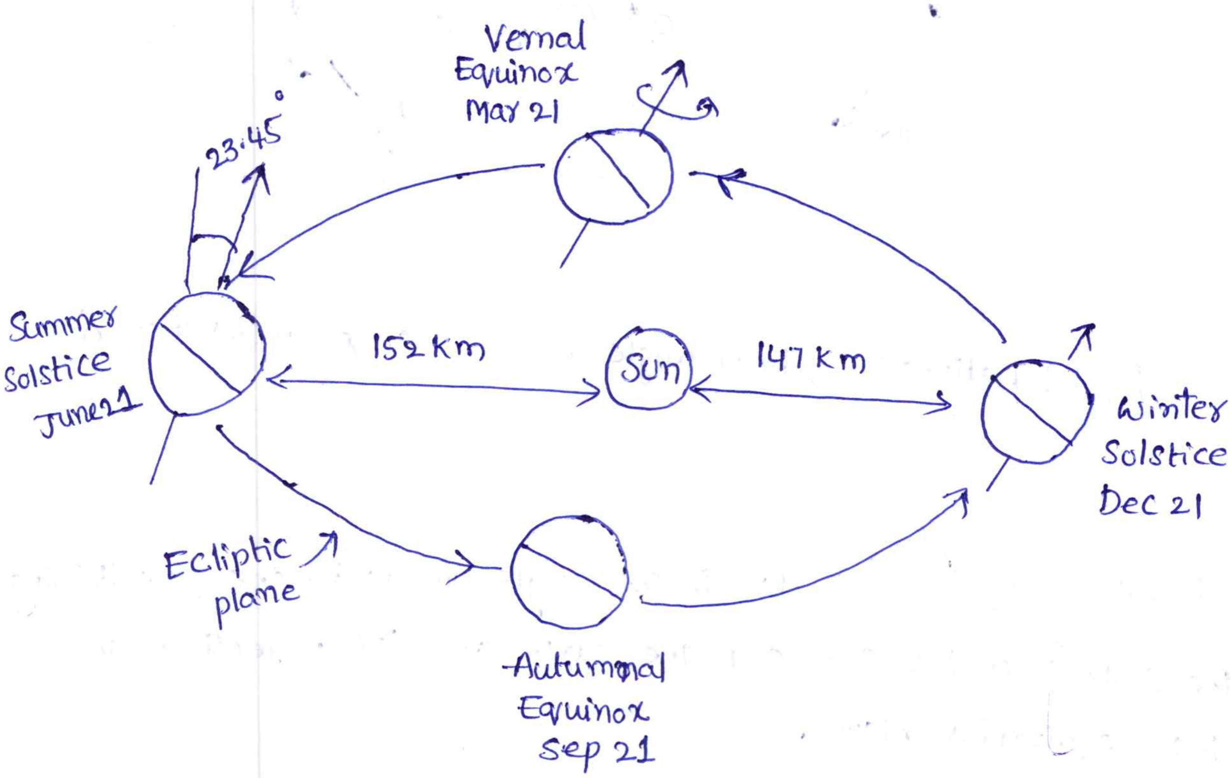



Fig : The tilt of Earth's spin axis withrespect to ecliptic plane is what causes our seasons.

## ↳ Various Earth Sun angles :

The various angles which are useful for conversion of beam radiation on the arbitrary surface are :

$\phi$ = latitude of location

$\delta$ = declination

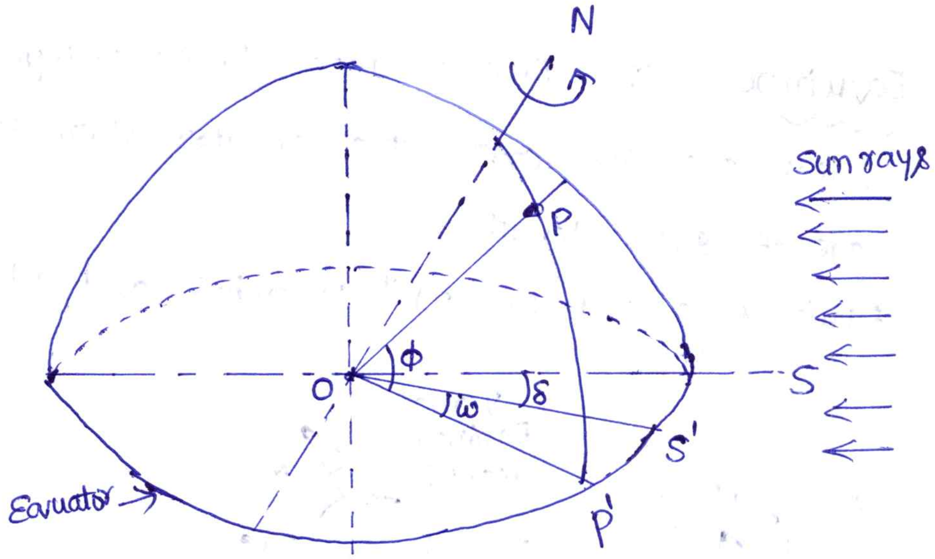
$\omega$ = hour angle

$\gamma_s$ = Solar Azimuth angle

$s$ = slope

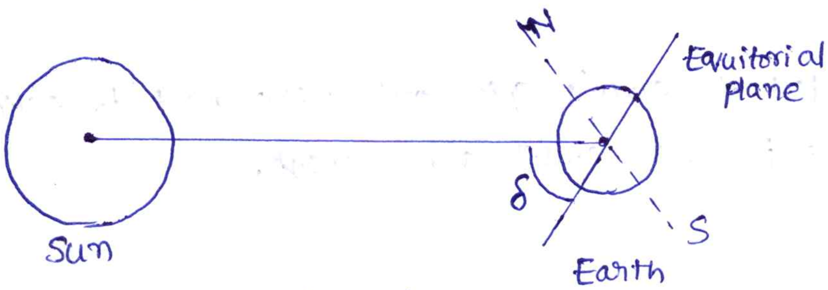
$\alpha$ = altidute angle

$\theta_z$ = zenith angle




Fig(1): Latitude $\phi$, hour angle $\omega$, and sun's declination $\delta$.

**Declination ($\delta$) :-** It is the angle made by the line Joining the centres of the sun and the earth with its projection on the Equitorial plane.




Fig(2): declination.

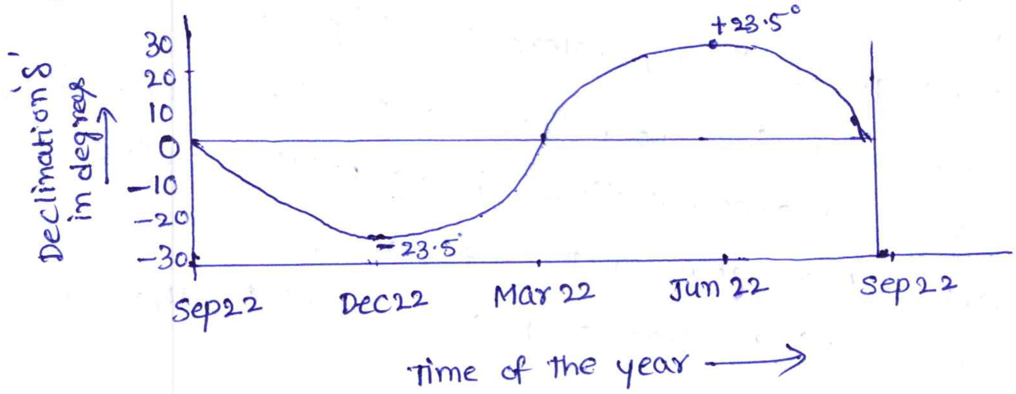
→ The declination angle varies from a maximum value of $+23.5°$ on June 21 to minimum of $-23.5°$ on December 21.

→ The declination (in degrees) for any day may be calculated from the ~~ea~~ approximate equation of "cooper".

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

where $n$ is the day of the year

Fig (3) shows the variation of declination angle.




Fig(3): Variation of Sun's declination.

## 2) Latitude angle (or) latitude of location ($\phi$):

→ It is the angle made by the radial line joining the location to the centre of Earth with the projection of the line on the equitorial plane.

→ It is the angular distance north or south of the equator measured from the centre of earth.

→ As shown in fig(1), it is the angle between the line $\overline{OP}$ and the projection $\overline{OP'}$ on the equitorial plane.

→ Point P represents location of earth surface and O represents the centre of earth.

→ The latitude angle is taken as 'positive' for any location towards the Northern hemisphere and 'negitive' towards Southern hemisphere.

→ The latitude angle at equator is 0° and at north and South poles are +90° and −90° respectively.

## 3) Hour angle ($\omega$):

→ It is the angle through which the earth must be rotated to bring the meridian of the plane directly under the sun.

→ The hour angle $\omega$ is equivalent to 15° per hour.

→ It is measured from noon based on the Local Solar Time (LST). or local apparent time, being positive in the morning and negative in the afternoon.

(Eg: $\omega = +15°$ for 11.00 and $\omega = -37.5°$ for 14.30)

→ Hour angle can be expressed as

$$\omega = 15(12 - LST)$$

where $\omega$ = hour angle

LST = Local Solar Time.

## 4) Altitude angle ($\alpha$) (or) solar altitude:

It is the vertical angle between the projection of the Sun's rays on the horizontal plane and the direction of Sun's rays passing through the point P.

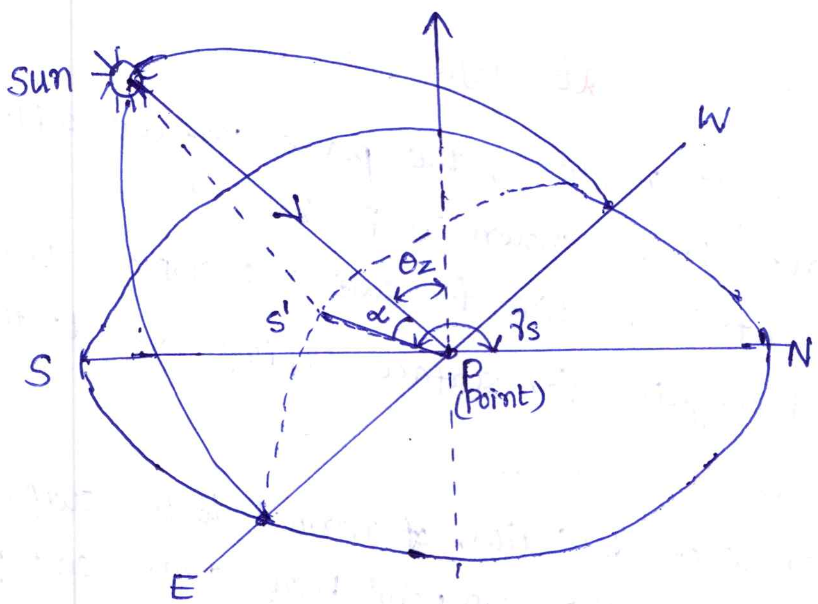
It is shown in Fig(4)

5) Zenith angle ($\theta_z$) :

It is the complimentary angle of sun's altitude angle. It is a vertical angle between the sun's rays and a line perpendicular to the horizontal plane through the point P. i.e., the angle between the beam from sun and the vertical.

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

It is shown in fig(4)




Fig(4): Sun's Zenith angle $\theta_z$, altitude ($\alpha$), and azimuth angle $\theta_z$.

6) Solar Azimuth angle ($\gamma_s$)

→ It is the solar angle in degrees along the horizon east or west of north. (or)

→ It is a horizontal angle measured from north to the projection of the sun's rays. This angle is positive when measured from west wise.

It is shown in fig.(4)

→ Altitude angle $\alpha$, Zenith angle $\theta_z$ and Solar azimuth angle $\gamma_s$ can be expressed interms of $\phi_l$ latitude angle, declination $\delta$, and hour angle $\omega$, which are also basic angles.

The expressions are :

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

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

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

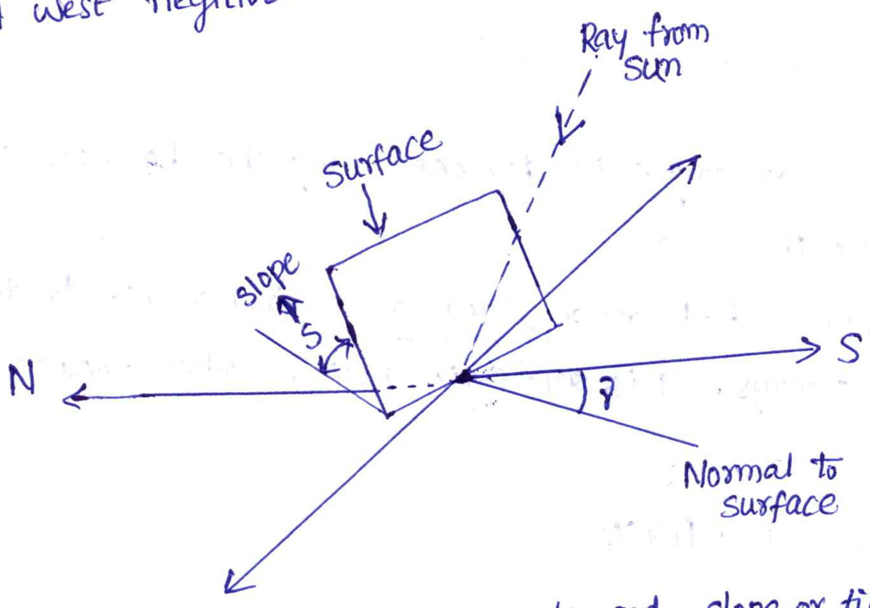
## 7) Slope angle or tilt angle (S) :

It is the angle made by the plane surface with the horizontal. It is shown in fig below (5)

It is taken to be positive for surfaces sloping towards the south and negitive for surface sloping towards the north.

## 8) Surface azimuth angle ($\gamma$) :

It is the angle of deviation of normal to the surface from the local meridian, the zero point being south, east positive and west negitive.




Fig(5): surface azimuth angle and slope or tilt angle.

## 9) Incident angle (θ):

It is the angle being measured between the beam of rays and normal to the plane.

→ Calculation of $\cos\theta$ for any hour and any location:

The power collected by the collector surface is less than the power available from the suns rays by factor $\cos\theta$.

The angle of incident $\theta$ depends on the position of sun in the sky.

General equation for $\cos\theta$:

$$\cos\theta = \sin\phi_l \left(\sin\delta \cos s + \cos\delta \cos\gamma \cos\omega \sin s\right) + \cos\phi_l \left(\cos\delta \cos\omega \cos s - \sin\delta \cos\gamma \sin s\right) + \cos\delta \sin\gamma \sin\omega \sin s. \longrightarrow (1)$$

where $\phi_l$ = latitude (north positive)

$\delta$ = declination (north positive)

$\omega$ = hour angle, it is positive between solar mid night and noon. otherwise negative.

(1) For vertical surfaces, $s = 90°$, Eq (1) becomes

$$\cos\theta = \sin\phi \cos\delta \cos\gamma \cos\omega - \cos\phi \sin\delta \cos\gamma + \cos\delta \sin\gamma \sin\omega \longrightarrow (2)$$

(2) For horizontal surfaces, $s = 0°$, $\theta = \theta_z$ zenith angle

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

$$= \sin\alpha$$

$$\cos\theta = \cos\theta_z = \sin\alpha. \longrightarrow (3)$$

(3) surface facing South $\gamma = 0$,

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

$$\Rightarrow \cos\theta = \sin\delta \, \sin(\phi - s) + \cos\delta \cos\omega \cos(\phi - s) \rightarrow (4)$$

(4) vertical surface facing South $s = 90^\circ$, $\gamma = 0^\circ$

$$\cos\theta = \sin\phi \cos\delta \cos\omega - \cos\phi \sin\delta \rightarrow (5)$$

Fig shows the schematic representation for different angles:

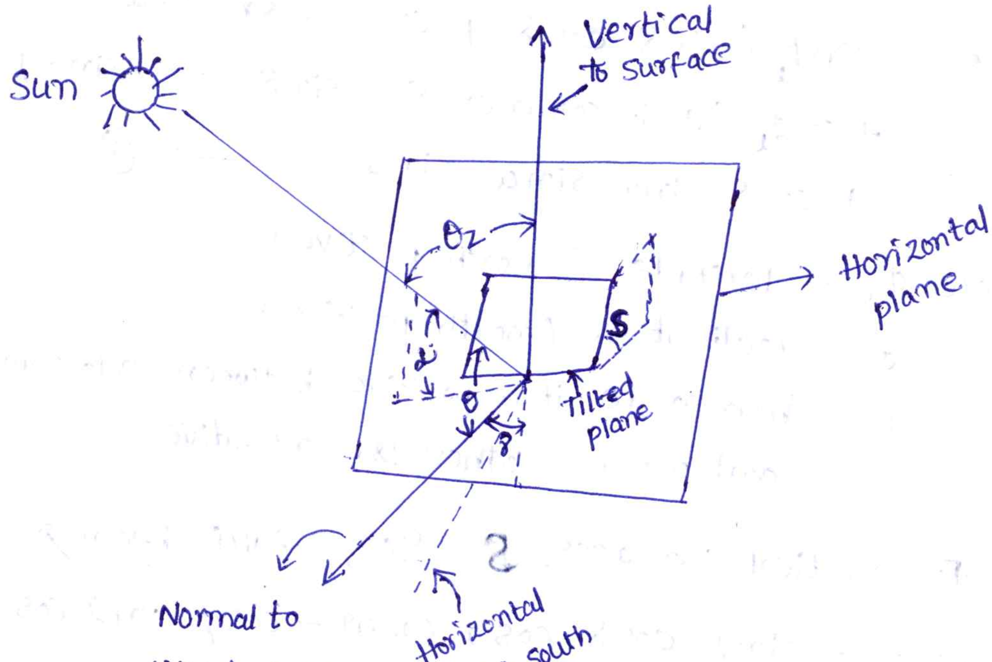



Fig: schematic representation of different angles

$\theta$ = Incident angle, $\alpha$ = Altitude angle.
$\theta_z$ = zenith angle  $s$ = Tilt angle (or) slope
$\gamma$ = surface azimuth angle.

## → Sun rise, sun set and day length :

→ During 'winter' the sun rises late and sets early, the day length is shorter.

→ During 'summer' sun rises early, sets late and day length is longer.

→ with the increase of angle of latitude (from equator to north pole) the difference in day length between summer and winter becomes more and more prominent.

→ The Sun rise hour, sunset hour and day-length depend upon latitude of location and season and day in the year.

The expressions are derived as follows :

→ for a horizontal surface on the ground,

$$\cos\theta = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega_s. \rightarrow (6)$$

For sun rise & sunset the hour angle is designated as $\omega_s$.

→ The hour angle $\omega$ varies during the day.

→ At sunrise, as the sun light is parallel to the ground surface, Therefore angle of incidence $\theta = 90°$, $\cos\theta = 0°$.

$$\cos 90° = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega_s.$$

$$0 = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega_s.$$

$$\sin\phi \sin\delta = -\cos\phi \cos\delta \cos\omega_s.$$

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

$$= -\tan\phi \tan\delta.$$

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta) \rightarrow (7)$$

↳ Day length ($t_{day}$) in hours :

Total day length $t_d = \omega_s + \omega_s$

$$= 2\omega_s. \rightarrow (8)$$

Since 15° of hour angle is equivalent to 1 hour, hence $2\omega_s$ corresponds to $\frac{2\omega_s}{15}$ hours.

$$t_d = \frac{2\omega_s}{15} \rightarrow (9)$$

Day length, $t_d = \frac{2}{15}\cos^{-1}(-\tan\phi \tan\delta)$ hours $\rightarrow (10)$

→ Thus the length of day ($t_d$) is a function of latitude and solar declination.

→ The angle hour at sunrise or sunset on an inclined ~~angle~~ surface ($\omega_{st}$) will be lesser than the value obtained by the Eq(6) if the corresponding angle of incidence ($\theta$) comes out to be more than 90°, Thus for an inclined surface facing south, substituting $\theta = 90°$, in Eq(4) of above topic we get

$$\omega_{st} = \cos^{-1}[-\tan(\phi - s)\tan\delta] \rightarrow (11)$$

The corresponding day length (in hours) is then given by

$$t_d = \frac{2}{15}\cos^{-1}[-\tan(\phi - s)\tan\delta] \rightarrow (12)$$

→ Local Solar Time (LST) or Local Apparent Time (LAT):

→ The time used for calculating the hour angle is the Local solar Time or local apparent time.

→ LST can be obtained from the standard time observed on a clock by applying the following two corrections:

(i) The correction which arises due to the differences in longitude between a location and the meredian on which standard time is based.

This correction has a magnitude of 4 minutes for every degree difference in longitude.

(ii) The second correction is called the Equation of time correction is due to the fact that earth's orbit and rate of rotation are subject to small perturbations. This correction is based on experimental observations and plotted in Fig below.

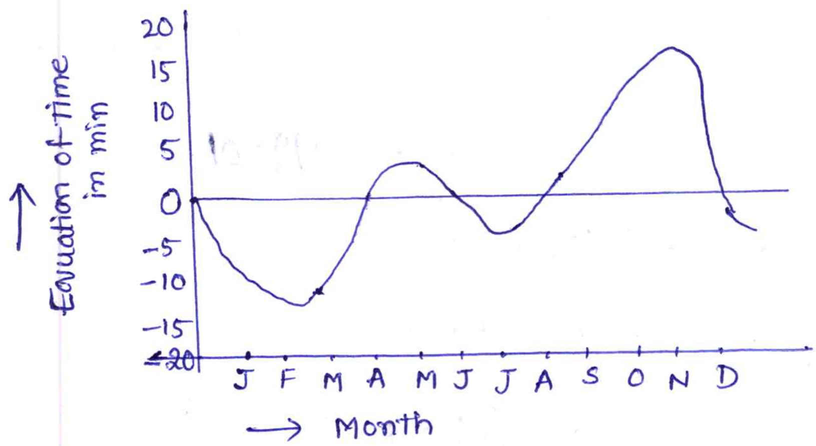



Fig: Graph of Equation of time (E) Correction.

Thus, Local Solar Time (LST) = standard time ± 4 (standard time longitude − longitude of location) + Equation of time correction.

Here. +ve sign for western hemisphere, −ve sign for Eastern hemisphere

## Problems :

1) Determine the sunset hour angle and day length at a location latitude of 32° on March 30.

Sol) Given latitude $\phi = 32^\circ$

Day of the year = March 30

Sunset hour angle $(\omega_s)$ :-

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

let us first calculate value of $\delta$, by using

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

Here $n$ = number of days = 89 for March 30

[Since, $n = \underset{\text{Jan}}{31} + \underset{\text{Feb}}{28} + \underset{\text{Marc}}{30} = 89$].

$\therefore \delta = 23.45 \left[\frac{360}{365}(284 + 89)\right] = 3.22^\circ$

Hence sunset hour angle $\omega_s = \cos^{-1}[-\tan\phi \tan\delta)$

$= \cos^{-1}(-\tan 32^\circ \tan 3.22^\circ)$

$\Rightarrow \omega_s = 92.01^\circ$

Day length $(t_d)$ (hours) :

Day length is calculated by using

$t_d = \frac{2}{15}\left[\cos^{-1}(-\tan\phi \tan\delta)\right]$, hours

$= \frac{2}{15}[\omega_s]$

$= \frac{2}{15} \times \cancel{92.01^\circ}\ 92.01^\circ$

$= 12.28$ hours.

2) Determine the day length in hours at delhi (latitude = 28.6°) on June 28 in a leap year

Sol: Given latitude $\phi = 28.6°$

Day of leap year = June 28

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

where $n$ = number of days = 180 for June 28

[ since, $n = \underset{\text{Jan}}{31} + \underset{\text{Feb}}{29} + \underset{\text{Mar}}{31} + \underset{\text{Apr}}{30} + \underset{\text{May}}{31} + \underset{\text{June}}{28} = 180$ ].

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+180)\right] \simeq 23.24°$$

$$\text{day length, } t_d = \frac{2}{15}\left[\cos^{-1}(-\tan\phi \tan\delta)\right]$$

$$t_d = \frac{2}{15}\left[\cos^{-1}(-\tan 28.6° \tan 23.24°)\right]$$

$$= 13.8 \text{ hours.}$$

3) Determine the Local Solar Time and declination at a location latitude 23° 15' N longitude 77° 30' E at 12.30 IST on June 19. Equation of time correction is given from standard table or chart = $-(1'01'')$

Sol: Given latitude $\phi$ = 23.25 N

longitude = 77° 30' E

Indian standard Time IST = 12.30

day of the year = July 19

Indian standard Time (IST) is the local civil time corresponding to $82 \cdot 5°$ E longitude. $(82 \cdot 5° = 82° \cdot 30')$

$\therefore$ Local Solar Time, LST = IST − 4(Standard time longitude − longitude of location) + Equation of time correction.

$$LST = 12^h 30' - 4(82° 30' - 77° 30') - 1' 01''$$

$$= 12^h 30' - 4(5) - 1' 01''$$

$$= 12^h 30' - 20' - 1' 01''$$

$$= 12^h 8' 59''$$

[since $30' - 20' - 1' = 9'$
$9' - 01'' = 8' 59''$
9 min − 1 sec]

Declination $\delta$ can be obtained by Coopers Equation i.e.,

$$\delta = 23 \cdot 45 \sin\left[\frac{360}{365}(284 + n)\right]$$

Here $n$ = day of the year, = 170 for June 19

[$n$ = 30 + 28 + 31 + 30 + 31 + 19 = 170].
Jan feb Mar Apr June July

$$\therefore \delta = 23 \cdot 45 \sin\left[\frac{360}{365}(284 + 170)\right]$$

$$\delta = 23 \cdot 43° \text{ (or)}$$

$$23° 25' 56''$$

4) Calculate the angle made by beam radiation with normal to a flat collector on December 1, at 9.00 Am, solar time for a location at $28° 35' N$. The collector is tilted at angle of latitude plus $10°$, with the horizontal and is pointing due south.

Sol: Given latitude location $\phi = 28° 35'$

Solar time LST = 9.00 Am

day of the year = Dec 1.

angle of tilt, $s$ = latitude angle + $10°$

$s = 28° 35' + 10° = 38° 35'$

→ let us first calculate, angle of declination, $\delta$

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

where $n$ = day of the year = 335 for Dec 1

$[n = 31 + 28 + 31 + 30 + 31 + 30 + 31 + 31 + 30 + 31 + 30 + 1 = 335]$

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + 335)\right]$$

$$\Rightarrow \delta = -22.11°$$

→ Hour angle $\omega$ is calculated as

$$\omega = 15(12 - LST)$$

$$\omega = 15(12 - 9) = 15°(3)$$

$$\Rightarrow \omega = 45°$$

→ Now, calculate the angle made by beam radiation with the normal to flat collector, i.e., Incident angle $\theta$.

→ Since collector is facing south, $\gamma = 0$. for this case we have the equation.

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

$$\cos\theta = \sin(-22.11^\circ) \sin(28^\circ 35' - 38^\circ 35') + \cos(-22.11^\circ) \times \cos(45^\circ) \cos(28^\circ 35' - 38^\circ 35')$$

$$= \sin 22.11^\circ \sin 10^\circ + \cos 22.11^\circ \cos 45^\circ \cos 10^\circ$$

$$= 0.3763 \times 0.1736 + 0.9264 \times 0.7071 \times 0.9848$$

$$= 0.0653 + 0.6451$$

$$\Rightarrow \cos\theta = 0.7104 \quad (\text{or})$$

$$\Rightarrow \theta = \cos^{-1}(0.7104) = 44.72^\circ$$

5) Calculate the angle made by beam radiation with the normal to a flat plate collector, pointing the South location in New Delhi (27° 30'N, 76° 42' E) at 10.00 hour solar time on october 29. The collector is tilted at an angle of 35°. with the horizontal. Also calculate the day length.

Sol: Given latitude location $\phi = 27^\circ 30' = 27.5^\circ$

Solar Time LST = 10. hour

day of year = OCT. 29.

angle of tile $s$ = 35°.

Let us first calculate angle of declination $\delta$ from coopers Eq.

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

where $n$ = day of the year = 302 for October 29

$[n = 31+28+31+30+31+30+31+31+30+29 = 302]$

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+302)\right]$$

$$\Rightarrow \delta = -14.43^\circ$$

→ Hour angle is calculated as

$$\omega = 15(12 - LST)$$

$$= 15(12-10)$$

$$\omega = 30^\circ$$

Now calculate angle made by beam radiation with the normal to flate collector i.e, Incident angle.

→ Since collector is facing south, $\gamma = 0$, for this case, we have the equation.

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

$$= \sin(-14.43^\circ)\sin(27.5^\circ - 35^\circ) + \cos(-14.43^\circ) \times \cos 30^\circ \cos(27.5^\circ - 35^\circ)$$

$$= \sin 14.43^\circ \sin 7.5^\circ + \cos 14.43 \cos 30 \cos 7.5^\circ$$

$$= 0.0325 + 0.8315$$

$$\cos\theta = 0.864$$

$$= \cos^{-1} 0.864$$

$$\Rightarrow \theta = 30.23^\circ$$

Now, day length $t_d$ is calculated as

$$\Rightarrow t_d = \frac{2}{15}\left[\cos^{-1}(-\tan\phi \tan\delta)\right] \text{ hour}$$

$$= \frac{2}{15}\left[\cos^{-1}(-\tan(27.5^\circ)\tan(-14.43^\circ))\right]$$

$$\Rightarrow t_d = 10.97 \text{ hours}$$

6) Calculate suns altitude, Zenith and solar azimuth angles at 9.00 Am, solar time on August 30 at latitude 25°N.

Sol: Given latitude $\phi = 25^\circ$

Local solar Time LST = 9 Am

day of the year = Aug 30.

Zenith angle $\theta_z$ :-

Hour angle $\omega = 15(12 - LST)$

$= 15(12-9)$

$\omega = 45^\circ$

angle of declination $\delta$, by using cooper's Eq is given as

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

where $n$ = day of the year = 242, for Aug 30.

$$\left[n = \underset{Jan}{31} + \underset{feb}{28} + \underset{Mar}{31} + \underset{Apr}{30} + \underset{May}{31} + \underset{Jun}{30} + \underset{July}{31} + \underset{Aug}{30} = 242\right]$$

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+242)\right]$$

$$\delta = 8.48^\circ$$

To calculate $\theta_z$, use the relation :

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

$$= \sin 25^\circ \sin 8.48^\circ + \cos 25 \cos 8.48^\circ \cos 45^\circ$$

$$= 0.0623 + 0.6338$$

$$= 0.6961$$

$$\theta_z = \cos^{-1} 0.6961$$

$$\theta_z = 45.88^\circ$$

altitude angle :- $\alpha = \frac{\pi}{2} - \theta_z$

$$= 90 - 45.88$$

$$\alpha = 44.12^\circ$$

Solar Azimuth angle, $\gamma_s$ :-

Using the relation $\cos\gamma_s = \dfrac{\cos\theta_z \sin\phi - \sin\delta}{\sin\theta_z \cos\phi}$.

$$\cos\gamma_s = \frac{\cos 45.88^\circ \sin 25^\circ - \sin 8.48^\circ}{\sin 45.88^\circ \cos 25^\circ}$$

$$\cos\gamma_s = 0.2254$$

$$\gamma_s = \cos^{-1} 0.2254$$

$$\Rightarrow \gamma_s = 76.97^\circ$$

7) Calculate hour angle when it is 3 h after solar noon.

Sol: Local Solar time = 3h after noon

LST = 12 + 3 = 15:00 hr

$\therefore$ hour angle $\omega = 15(12 - 15)$

$$= 15(-3)$$

$\Rightarrow \omega = -45^\circ$ (hour angle is Negative after solar Noon)

## → Measurement of Solar Radiation :-

8) Calculate hour angle when it is 2h 20 min before solar noon.

Sol: hour angle can be calculated as

$$\omega = \frac{1}{4} \times t_m$$

$t_m$ = time in minutes

$$\omega = \frac{1}{4} \times 2h\ 20\ min$$

$$= \frac{1}{4} \times 140$$

$$= 35^\circ$$

## → Measurements of Solar Radiation :-

→ It is important to measure solar radiation, owing to the increasing number of solar heating and cooling applications and the need for accurate solar irradiation data to predict performance.

→ The following three devices are used for measuring the solar radiations.

1) Pyrheliometers 2) pyranometer 3) sunshine recorders

### 1) Pyrheliometer :-

A pyrheliometer is a device used to measure "beam or direct radiations". It collimates the radiation to determine the beam intensity as a function of incident angle.

→ This instrument uses a collimated detector for measuring solar radiation from the sun and from a small portion of the sky around the sun at normal incidence.

→ Three types of pyrheliometers have been in wide spread use to measure normal incident beam radiation

(i) The Angstrom pyrheliometer

(ii) The Abbot silver disc pyrheliometer

(iii) Eppley pyrheliometer.

#### (i) Angstrom compensation pyrheliometer :

→ In this pyrheliometer, a thin blackened shaded maganin strip is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation.

→ It is shown in fig(1).

Under

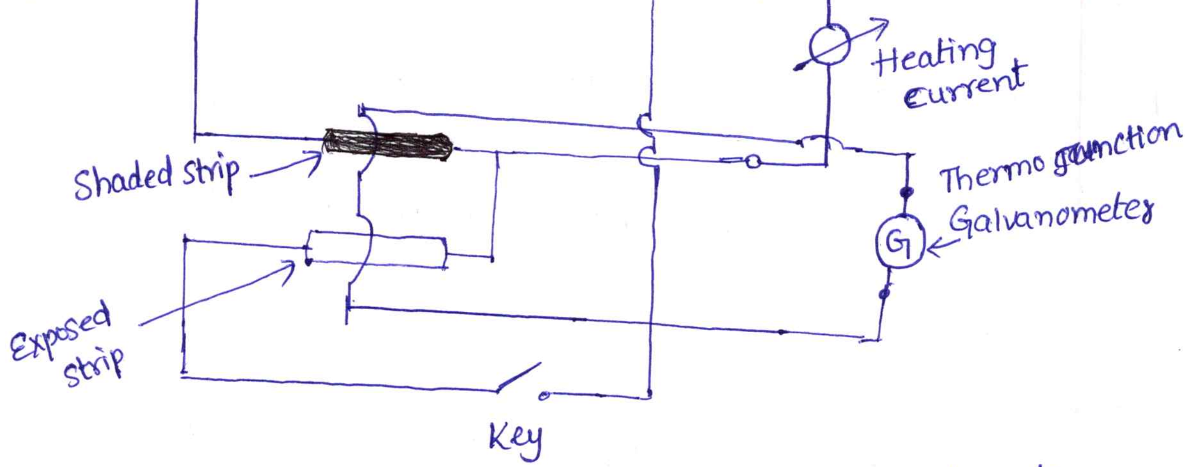



Fig: Electric circuit for Angstrom pyrheliometer.

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

→ The Thermocouples on the back of each strip connected in opposition through a sensitive Galvanometer, are used to test for the equality of temperature.

→ The energy H of direct radiation is calculated by means of 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 & instrument constant $= \frac{R}{W\alpha}$.

where $R$ = Resistance per unit length of absorbing strip ($\Omega$/cm)

$W$ = mean width of absorbing strip

$\alpha$ = absorbing coefficient of absorbing strip.

## (ii) Abbot silver disc pyrheliometer :-

→ It essentially consists of blackened silver disk positioned at the lower end of a tube with diaphragms to limit the whole temperature to 5.7°

→ A mercury in glass thermometer is used to measure the Temperature at 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 the corresponding changes in temperatures ~~ging~~ the disk are measured.

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

→ The stability of this instrument is found to be very good and are widely used for calibrating pyranometers.

## (iii) Eppley pyrheliometer :

→ The sensitive element in an Eppley pyrheliometer is a temperature compensated 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 thermocouples used to develop a much greater voltage than is possible using only one.

→ 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 sub-standard.

## 2) Pyranometer :

→ A pyranometer is an instrument used to measure the total hemispherical solar radiation.

→ The working principle of this instrument is that sensitive surface is exposed to Total (beam, diffuse and reflected from earth and sorrounding) radiations.

Construction :

→ It consists of black surface which receives the beam as well as diffuse radiations which rises heat.

→ A glass dome prevents the loss of radiation received by the black surface.

→ A Thermopile is a Temperature sensor and consists of a number of thermo couples connected in series to increase the sensitivity.

~~working:~~

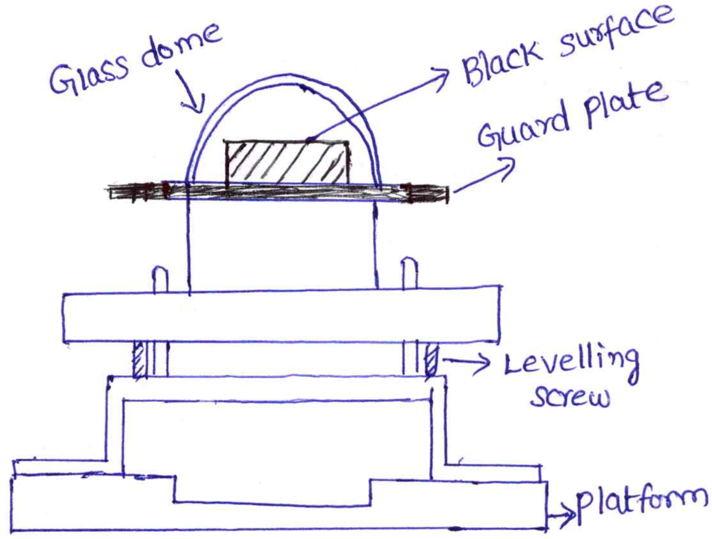



Fig : Pyranometer.

working : when pyranometer is exposed to sun, it starts receiving the radiations. As a result, surface temperature starts rising due to absorption of the radiation.

→ The increase in temperature of the absorbing surface is detected by Thermopile

→ The Thermopile generates a Thermo emf which is proportional to the radiations absorbed.

→ This Thermo Emf is calibrated interms of received radiations. This will measure the global Solar radiations.

The Types of Pyranometers are :

(i) Eppley pyranometer (ii) Yellot Solarimeter (III) Moll Gorezyheski solarimeter (iv) Bimetallic Actiono graphs of Rabitzsch type (V) Velochme pyranometer (VI) Thermo electric Pyranometer.

(i) Eppley pyranometer : It is based on the principle of that Sensitive Surface is exposed to total radiations.

→ There is a difference between the temperature of black surfaces which absorb most solar radiation and white surfaces which reflects most solar radiation.

→ The detection of temperature difference is achieved by Thermopile.

→ The uses concentric silver rings appropriated coated black and white, with Thermo couple junctions to detect temperature difference between coated rings.

→ These disks or wedges are enclosed in a hemispherical glass cover.

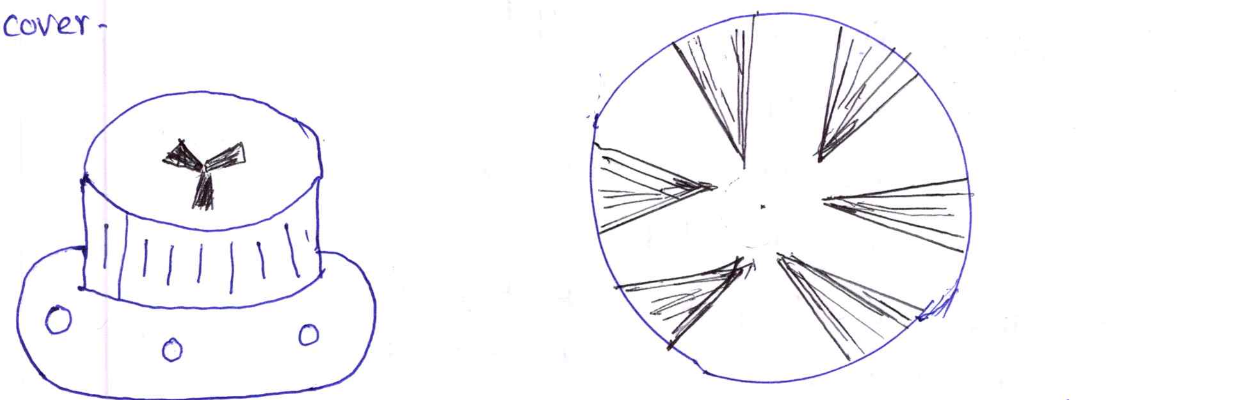


Fig: pyranometer with alternate black and white sensor Segments

Eppley Pyranometers are calibrated in a horizontal position.

(ii) yellot solarimeter (Photo voltaic Solar cell): Pyranometers have also been used on photo voltaic Solar cell detectors.

→ silicon solar cells have the property that their light current is a linear function of incident Solar radiation.

## (3) Sunshine Recorder:

A sunshine Recorder is a device used to measure duration of bright sunshine in a day.

Construction: It consists of a glass sphere installed in a section of spherical metal bowl, having grooves for holding a recorder card strip and the glass sphere.

Working: The glass sphere which acts as convex lens focuses the Sun's rays to a point on the card strip held in a groove in the Spherical bowl.

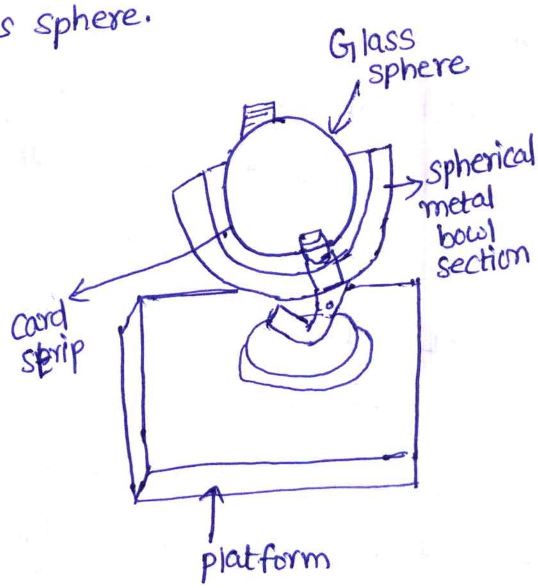



Fig: sunshine recorder

→ whenever there is a bright sunshine the image formed is intense enough to burn a spot on the card strip.

→ Through the day, the sun moves across the sky the images moves along the strip.

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

## → Types of Solar Energy Collectors :

Solar Energy collectors are broadly classified into 2 types :-

1) Flate-plate collector (or) Non concentrating collectors :

(A) Liquid flat plate collectors

(B) Flat plate solar air heater.

2) Concentrating collectors :

A) Focussing Type collectors (or) Concentrating collectors :

(i) parabolic through reflector (ii) Mirror strip collector

(iii) Fresnels lens collector (iv) paraboloid dish collector

B) Non Focussing Type collectors :

(i) Flat plate collector with plane reflector.

(ii) Compound parabolic concentrator. (CPC).

### 1) Flat - plate Collectors (FPC) :

(i) In such collectors, the area of collector to grasp the solar radiation is equal to the absorber plate and has a concentration ratio of 1.

### (A) Liquid flat plate Collector :

Fig (1) shows the Liquid flat plate collector.

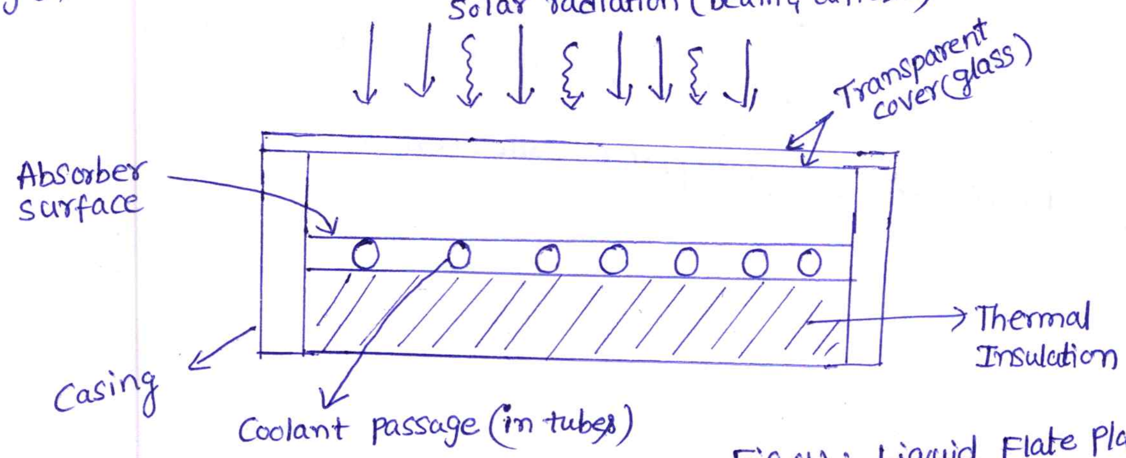



Fig (1) : Liquid Flate Plate Collector.

→ The ~~Flate~~ Liquid Flat plate collector consists of the following parts :

- Transparent cover : ~~It is a box like structure~~
- Absorber plate
- Thermal Insulation
- casing or container
- Tubes fixed to absorber plate to form coolant passages.

→ It is a box like structure. It consists of an absorber plate which receives beam as well as the diffuse solar radiations through the transparent glass covers.

→ The absorbed radiations are partly transferred to the liquid flowing through tube which are either fixed to the absorber plate or they form an integral part of it.

→ The Remaining part of radiant solar energy absorbed by the absorber plate is either re-radiated to the surroundings through the top surface or it is lost by convection.

→ Transparent covers made of glass are provided in one or more numbers for trapping the heat received by the absorber plate. It helps in reducing convective & radiation heat losses.

→ Thermal insulation is provided at the bottom of tubing to minimize the heat losses by conduction.

→ The flat plate collectors are used for Low Temperature applications upto 100°C. The liquid generally used is water.

~~Materials for flat plate Collectors~~ :

→

## (B) Flat Plate Solar Air heater :

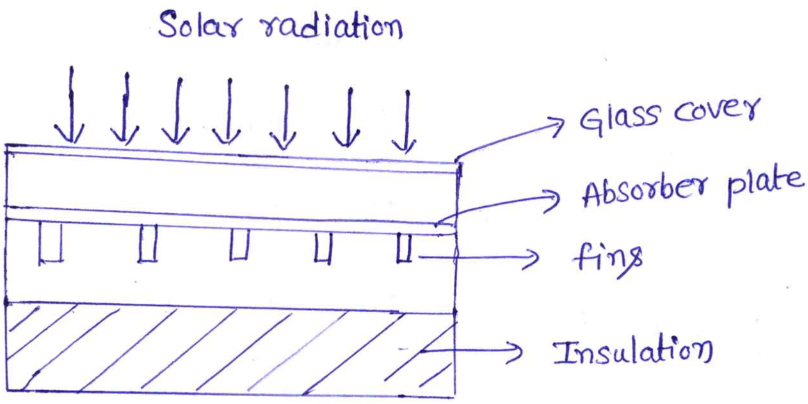



Fig : Typical flat plate solar air heater

- Fig shows a schematic flat plate collector where an air stream is heated by the back side of the collector plate.
- Fins attached to the plate increase the contact surface.
- The backside of the collector is heavily insulated with mineral wool or some other material.
- The air may be passed through a space between the absorber plate and insulator with baffles arranged to provide a long (zig-zag) flow path shown in fig.
- The use of air as the heat transport fluid eliminates both freezing & corrosion problems.
- The orientation of this collector is facing due south at an inclination angle to the horizontal equal to the latitude plus 15°.

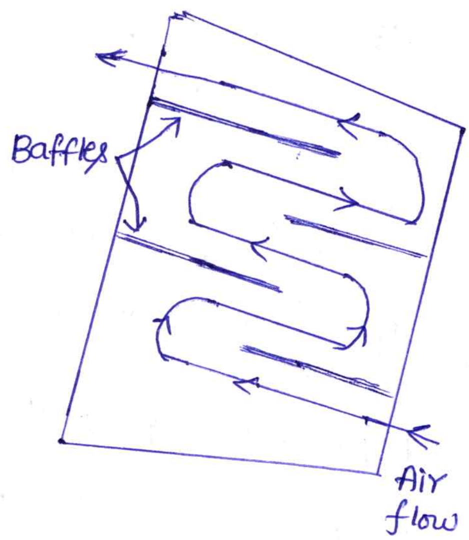



Fig : Zig-zag airflow path in flat plate collector.

## → Materials used for Flat plate collectors :

(1) Absorber plate : Copper, Aluminium, steel, Brass, Silver, etc.

(2) Insulation : crown white wool, Glass wool, Expanded polystrene foam etc

(3) Transparent cover plate : Glass, Teflon, Tedlar, Marlex etc.

## → Advantages of Flat plate collector :

1) It absorbs direct, diffused and reflected components of solar radiations.

2) Low cost and requires little maintenance

3) It is fixed in orientation thus there is no need for sun tracking.

4) Mechanically simpler than the focussing collectors.

## → Dis advantages of Flat plate collector :

1) Heavy in weight

2) They are suitable for low-temperature applications upto 100°C.

3) Large heat losses by conduction due to large area.

4) It has low collector efficiency.

5) Not suitable for large scale power generation.

## → Applications of Flat plate collector :

1) Used in solar water heating

2) Used in Solar heating and cooling

3) Used in low Temperature power generation.

## 2) Concentrating Collectors:

It is a device used to collect solar energy with high intensity of solar radiation on the energy absorbing surface. such collectors generally use optical system in the form of reflectors or refractors.

## 2A) Focussing Type Collectors (or) Concentrating Type Collectors:

→ Concentrating or focussing collectors may be considered in two general categories: line focussing and point focussing Type.

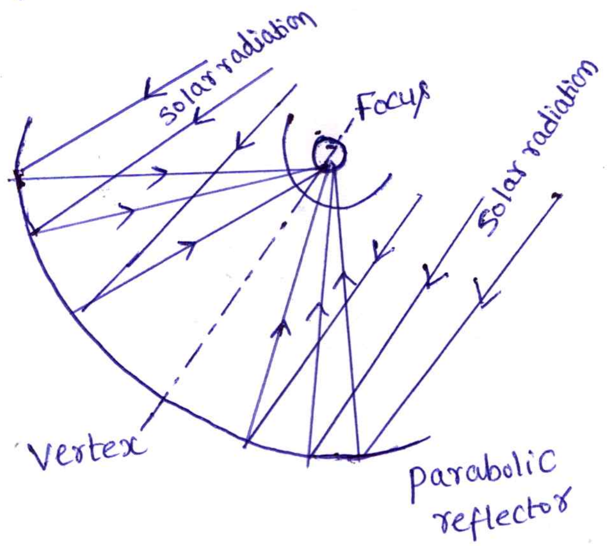
→ The 'line' is a collector pipe and the 'point' is a small volume through which the heat transport fluid flows.

Line focussing Collectors: parabolic trough Collector, Mirror strip reflector, Fresnels lens Collector

point focussing Collector: paraboloid dish collector.

### (i) Parabolic Trough Collector:

Parabolic trough collectors are usually made of highly polished or silvered glass or of film of aluminised plastic on a firm base.



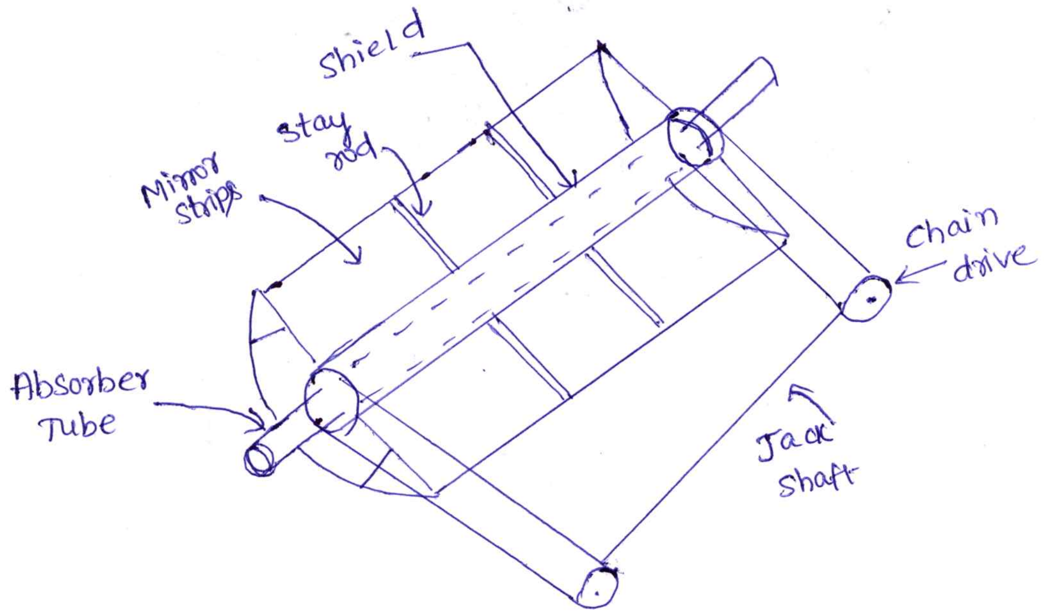

Fig(1) Cross-section of a parabolic Trough collector

Fig(1) shows ~~trough or~~ parabolic trough ~~cylinder~~ collector. The principle of parabolic trough collector is solar radiation coming from the particular direction is collected over the area of the reflecting surface and is concentrated at the focus of the parabola, if the reflector is in the form of trough with parabolic cross-section, the solar radiation is focused alone a line.

→ Mostly cylindrical parabolic concentrators are used in which absorber is placed along focus axis. The collector ~~coating~~ pipe with a selective absorber coating is used as an absorber. This is shown in fig(2).

→ In both parabolic trough or parabolic cylinder collector, the solar radiations are always focussed on a line with respect to changes in sun's elevalation by the parabolic reflector, either trough or collector pipe is rotated continuously about the axis of absorber.

→ The orientation of trough type collectors is kept in the east & west or north-south directions.




Fig(2): Parabolic cylindrical system

## (ii) Mirror strip Reflector:

→ It is the line focussing type Collector as shown in fig.

→ It has the plane or slightly curved (concave) mirror strips mounted on a flat base.

→ The individual mirrors are placed at such an angles that the reflected solar radiations fall on the same focal line where the absorber pipe is placed.

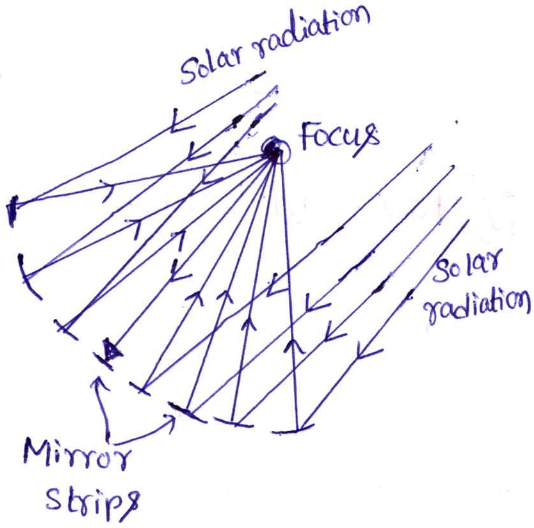



Fig : Mirror strip Solar Collector

→ The Collector pipe is rotated so that the reflected rays on the absorber remain focussed with respect to changes in Sun's elevation.

## (iii) Fresenel Lens concetrating collector:

→ This is also a line focussing type collector.

→ A fresnel lens refracting type Concentrating collector is shown in fig.

→ In this collector, a fresnel lens consists of fine, linear grooves on the surface of refracting material of optical quality on one side and flat on other side is used.

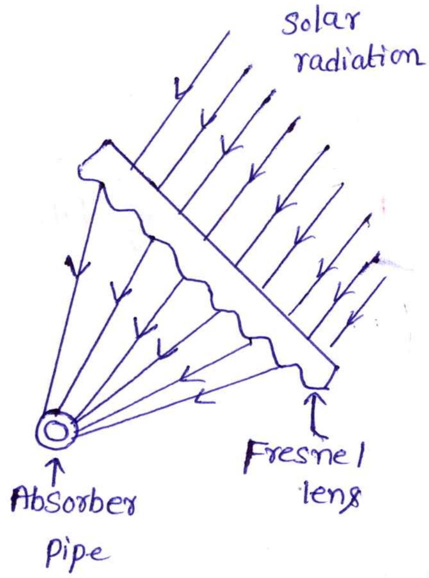



Fig: Fresnel lens Collector.

→ The angle of each groove is so designed that the optical behaviour of fresnel lens is similar to spherical lens.

→ The solar radiations which falls normal to the lens are refracted by the lens and are focussed on a line, where the absorber (receiver) tube is placed to absorb solar radiations.

## (iv) Paraboloidal Dish Collector:

→ It is a point focussing type collector.

→ A paraboloidal dish collector brings solar radiations to a focus at a point where receiver is placed.

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

→ The absorber is located at focus is a cavity made of a Zirconium Copper alloy with a black chrome selective coating.

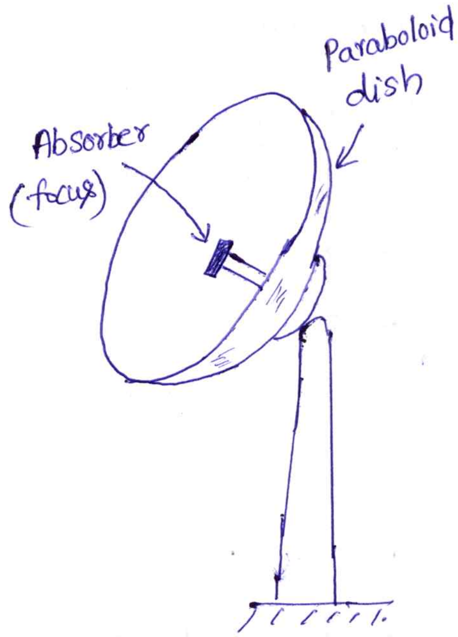



Fig: paraboloidal dish collector.

## 2B) Non Focussing Type Concentrators:

In these type of collectors, the solar radiations are allowed to fall on the absorber after using reflections in the mirror.

Types of Non focussing concentrators are:

(i) Flat plate Collector with plane reflector

(ii) Compound parabolic concentrator.

## (i) Flat plate collector with plane reflector :

→ It is the modified form of flat plate collector.

→ It uses a flat plate collector with plane mirrors reflectors attached on its edges to reflect the additional solar radiations into the receiver.

→ Thus the total solar radiations received by the receiver are increased. The mirrors used are called booster mirrors.

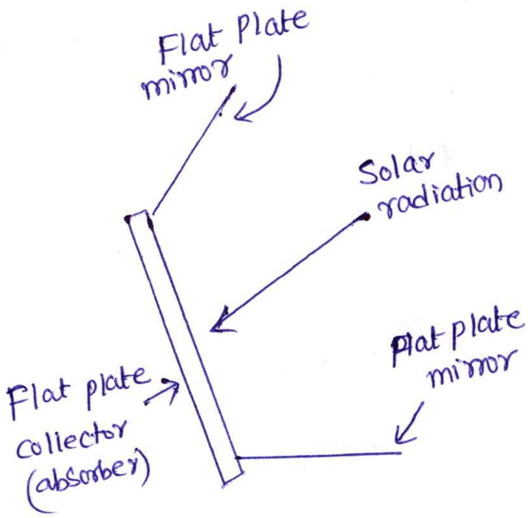



Fig : Flat plate collector with plane mirror reflectors.

→ The flat plate collector facing south with mirrors attached to its north and south edges is shown in fig.

→ For more effective, the angles of the mirrors should be adjusted continuously as the suns elevation changes.

→ These type of concentrators are not used commonly except for specific applications.

## (ii) Compound Parabolic Concentrator (CPC)

→ The compound parabolic concentrator is non focussing type collector. It is also called as winstor collector.

→ It consists of two facing parabolic mirror segments A & B attached to a flat receiver (absorber). It forms a trough.

→ The Solar radiations from all directions are reflected towards the receiver kept at the bottom.

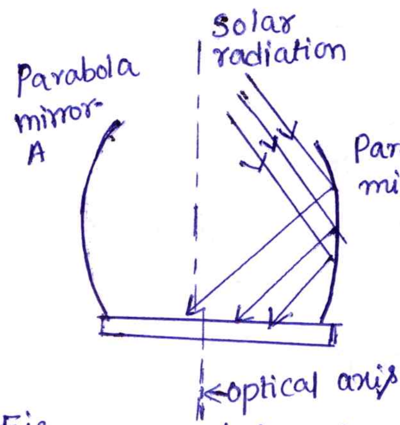



Fig: Compound Parabolic Concentrator

→ It collects both direct & diffused solar radiations with high acceptance angle.

→ The absorbers used in CPC are either fin type (or) Tubular type.

Advantages of CPC :

(i) High concentration ratio 3-7 can be achieved.

(ii) There is no need of tracking if low concentration ratio of about 3-4 are needed.

(iii) Collection efficiency is high.

→ **Advantages and Disadvantages of Concentrating Collectors over Flat plate collectors :**

Advantages :

1) Cost of concentrator system / unit area is less. Since it requires less reflecting surface.

2) Requires less absorber area

3) High collection efficiency, since heat losses are less

4) Suitable for large power generations

5) Heat storage cost is lower, because of higher amount of heat can be stored per unit volume.

6) No anti-freeze solutions are needed.

Disadvantages :

1) System needs tracking of sun, which increases cost of installation.

2) Diffuse solar radiations cannot be collected in focussing type of collectors.

3) Requires higher maintenance to retain the quality of reflecting surfaces.

4) High initial cost & maintenance cost.

## → Solar Energy storage :

## → Need For Solar Energy ~~Energy~~ storage :-

- Solar Energy is available only during day hours and it is not available during night hours and cloudy.
- Therefore the availability of solar energy is time dependent and it is intermittent in nature.
- Any system utilizing this Solar energy either at constant rate or at variable load depending up on its application.
- In otherwords there is always a mismatch between availability of Solar energy and the demand (load) on the system.
- It is necessary to store the excess energy and supply this energy when the available energy is defecient than the demand, to meet the demand.
- Therefore an Energy storage system can be defined as a system which stores the collected amount of energy in excess of requirement of the demand and supplies this energy when the demand is more than energy supply.

## → Types of Solar Energy storage systems :

Solar Energy
- Thermal Energy Storage
  - Sensible heat
    - water Storage
    - Pebble bed storage
  - Latent heat
- Electrical Storage
  - Capacitor storage
  - Inductor Storage
  - Battery storage
- chemical storage
  - Chemical
  - Thermo-Chemical
- Mechanical Storage
  - Pumped hydro Electric Storage
  - Compressed air
  - Flywheel.
- Electromagnetic Energy storage

## Thermal Energy Storage :

- Direct storage of heat in solids & liquids is possible at low temperatures. This heat energy can be recovered later on as heat energy only.
- This energy can be utilized for applications like space heating and industrial applications such as manufacture of paper, plastic, cement, rubber, food processing etc.

Thermal energy can be stored in well insulated fluids or solids. It is generally stored either as :

(1) Sensible heat storage : Storage by causing a material to rise in temperature is called sensible heat storage

(2) Latent heat storage : Storage by phase change, the transistion from solid to liquid or from liquid to vapour known as latent heat storage.

### 1) Sensible Heat Storage

- Sensible heat storage involves a material that undergoes no change in phase over the temperature domain encountered in the storage process.
- The basic equation for an energy storage unit, operating over a finite temperature difference is

$$Q_s = (m\,C_p)_s\,(T_1 - T_2) \longrightarrow (1)$$

where $Q_s$ is Total thermal energy capacity

$m$ is mass of storage medium

$C_p$ is Specific heat

$T_1$ is initial Temperature

$T_2$ is Final Temperature.

The ability of storeg thermal energy in a given container of Volume V is,

$$\frac{Q_s}{V} = \rho C_p \Delta T \longrightarrow (2)$$

wher $\rho$ is density of storage medium.

Thus the ability to store heat depends upon the product of $\rho C_p$.

→ Sensible heat storage system can employ the following materials both for short term and long term usage.

(i) Solids like rocks, pebbles, metal, concrete, sand etc

(ii) Liquids like water, oil, liquid metals, molten salts etc

(iii) Solar ponds using salt for large scale sensible heat storage.

## 1(A) Water storage :

→ The most common heat transfer fluid for a solar system is water and the easiest way to store thermal energy is by storing the water directly in a well insulated tank.

→ The optimum tank size for flat plate collector system is about 70 kg / m².

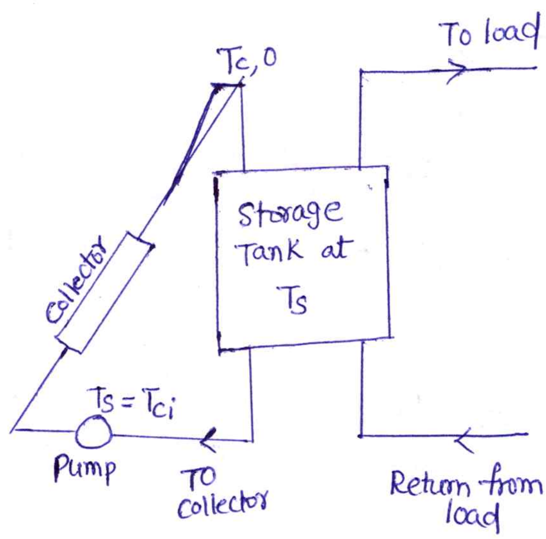



Fig : water Tank storage unit.

→ water has the following characteristics for storage medium:

(i) It is an inexpensive, readily available & useful material to store sensible heat

(ii) It has high Thermal storage capacity.

(iii) Energy addition and removal from this type of storage is done by medium itself, thus eliminating any temperature drop between Transport fluid and storage medium.

(iv) Pumping cost is small.

## (1B) Packed bed (or) Pebble bed Exchanger storage :

→ Solid storage system utilizes the heat capacity of solid materials such as rocks, pebbles, metals, concrete, brick, sand etc, to store the energy. It uses air as ~~Energy~~ energy transport medium.

→ A packed bed storage unit is shown in Fig. which uses the heat capacity of bed of loosely packed material through which air is circulated to add or remove heat from bed.

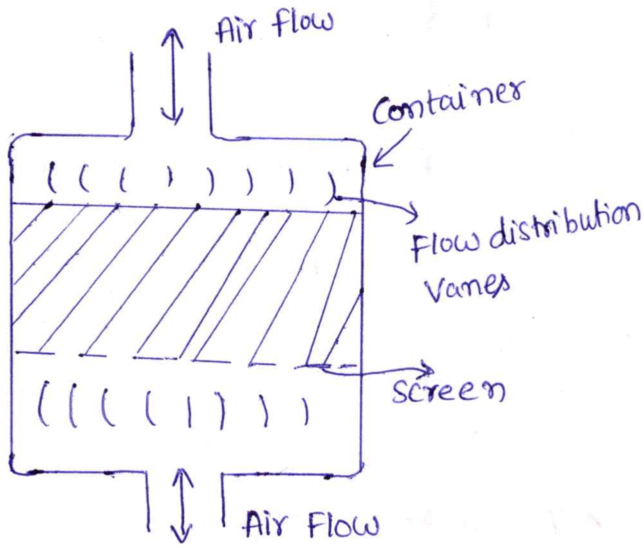



Fig: Pebble bed storage unit

→ It consists of a container, porous structure to support bed and air distributors.

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

→ In this system the heat addition & removal from storage cannot be carried out simultaneously.

### Advantages of pabble bed exchanger storage system :

1) It can be used for both low and high temperature energy storage
2) It has high heat transfer characteristics between air and solids of the bed.
3) cost of energy storage medium is low.
4) No freezing and corrosion problem.

## Dis advantages :

(1) storage volumes are large
(2) High pressure drops.

## 2) Latent Heat storage (or) Phase change Energy storage :-

→ Energy can be stored in the form of latent heat caused by phase change during heating either from solid to liquid or liquid to vapour. This heat energy can be recovered during reversing process of cooling either by solidifying the liquid or by condensation of vapour.

→ The desirable properties of material for energy storage are:

(1) High latent heat
(2) Cost of material should be low
(3) It should be available in large quantities.
(4) It should be non toxic, non-inflammable and non-corrosive
(5) It should not combust with atmospheric air
(6) It has high Thermal conductivity.

### materials for phase change energy storage :

There are several materials that undergo a change of phase. Glauber's salt ($Na_2SO_4 \cdot 10H_2O$), water, $Fe(NO_3)_2 \cdot 6H_2O$ and salt Eutectics are mostly used.

Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) (sodium sulphate deca hydrate), phase changes from solid to liquid requires less energy than those from liquid to gas.

The reaction is given as:

$$Na_2SO_4\,10H_2O + \text{energy} \rightleftharpoons Na_2SO_4 + 10\,H_2O.$$

Energy storage is accomplished by the reaction proceeding from left to right on addition of heat.

Energy Extraction from storage is the reverse procedure with the reaction proceeding from right to left and thermal effects reversed.

→ A latent heat storage arrangement is shown in fig in which the storage material is placed in long thin containers e.g. cylinders and the gas is passed through narrow spaces between the tubes.

→ An advantage associated with this latent storage system is that it is more compact than a sensible heat system.

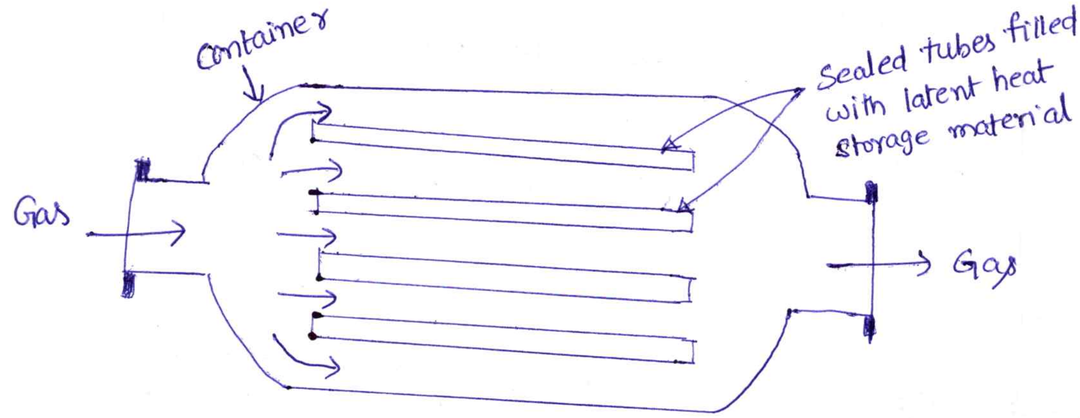



Fig: latent heat storage arrangement