Module 2 Solar Energy

Throughout the world the energy consumption has been growing with advances in civilization. Today energy consumption is directly related to the standard of living of the people and degree of industrialization. The energy sources like fossil fuel may not be the adequate to meet the increasing energy demands and these energy resources are also exhausting in nature and may be exhausted in a short time. Thus, a necessary exists to look for other form of energy sources i.e., non-conventional energy sources such as geothermal, ocean tides, wind, solar, etc. Among all these energy sources, solar energy is the most promising alternative energy source which will meet considerable part of energy demand.

Solar energy is a renewable resource and cannot be depleted. It has the greatest potential of all renewable energy sources. The sun constantly delivers 1.36 kW (1360 joules/sec) of energy per square meter to the earth. Il is one of the promising alternative energy sources and its nature and magnitude available on earth's surface varies depending on the location and weather conditions.

The applications of solar energy are:

Space heating or cooling for residential building.
Solar water heating iii. Solar cookers
Solar distillation on a small scale
Food refrigeration
Drying of agricultural and animal products by suitable solar driers
Electric power generation etc

Solar radiation

The sun is considered as a large sphere of diameter 1.39 x 10^6 km, consisting of very hot gases. The earth's diameter is 1.27 x 10^4 km and the average distance between the earth and sun is 1.496 x 10^8 km. The earth receives beam radiation from the sun, almost parallel because of very large distance between the sun and the earth. Even though sun's brightness varies from centre to its edge, we assume that the brightness is uniform all over the solar disc.

The energy flux radiated from the sun outside the earth's atmosphere is considered to be constant and this yields the definition of solar constant. ***Solar constant is the rate at which solar energy reaches at the top of the atmosphere and is denoted by Isc***. This is the amount of energy received from the sun in unit time on a unit area perpendicular to the sun's direction and at the mean distance of the earth from the sun.

The distance between the earth and the sun varies as earth revolves around the sun in an elliptical orbit with a small eccentricity and sun at one of the foci. This changes the solar radiation and hence the energy flux reaching the earth's atmosphere. Thus the solar constant value obtained is the average one and a standard value of 1353 W/m^2 was adopted in 1971. Later, the solar constant value was revised to 1367 W/m^2, through measurements.

The radiation reaches the earth may varies day by day depending on the geological and atmospheric changes, but that can be measured with the help of the relation given below.

$$I = I_{sc}[1 + 0.033 \cos\frac{360n}{365}]$$

Where I = Extra terrestrial radiation

n = Day of the year

Solar radiation at earth surface

The solar energy received at the earth's surface depends on the time of day, the time of year, local latitude and amount of cloud cover, amount of atmospheric pollution etc. The solar radiation received at the earth's surface is composed of beam and diffuse radiation, scattered component and the reflected short wavelength radiation from the surrounding terrestrial surfaces after subjected to the mechanisms of absorption and scattering during its travel through the earth's atmosphere.

The ozone, water vapour and to some extent other gases (like CO_2, NO_2 CO, O_2 and CH_4) absorb all the ultraviolet solar radiation and energy in the infrared range. This absorption of solar radiation by the atmosphere increases its internal energy and results in narrowing of the band width.

The presence of all gaseous molecules and particulate matter or dust particles in the atmosphere, scatters the solar radiation i.e., changes its direction. The scattered radiation is redistributed in all the directions, a portion of which goes back into the space and remaining reaches the earth's surface as diffuse radiation. Thus, the radiation finally reaches the earth 's surface consists partly of beam radiation and partly of diffuse radiation.

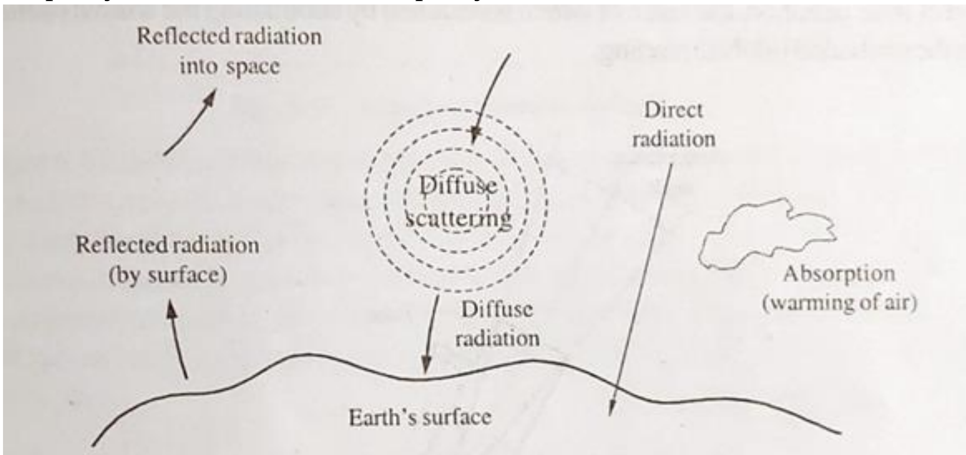


Figure: Direct, Diffuse and Total Radiation

Some important Definitions:

Angles on Horizontal Plane

1. **Hour angle(ω):**
   It is the angle between the meridian of the observer and the meridian whose plane having sun
   $$\omega = 15(t_s - 12$$
2. **Angle of Declination(δ):**
   It is the angle between the line extended from the centre of the sun to the centre of the earth and projection of this line upon the earth equatorial plane
   $$\delta = sin[\frac{360}{365}(284 + n)]$$
3. **Angle of latitude:**
   It is the angle between the line joining the point of the location to the centre of the earth and its projection on equatorial plane
4. **Inclination angle(α):**
   The angle between the sun ray and its projection on a horizontal surface

5. **Zenith angle(θ_z):**
   It is the angle between the suns ray and the normal to the horizontal plane

6. **Solar Azimuth angle(γ_s):**
   It is the angle on horizontal plane between the line due south and the projection of the suns ray on horizontal plane

Angles on Inclined plane:

1. **Tilt angle/Slope(β):**
   It is the angle between the inclined surface and the horizontal plane
2. **Angle of incidence(Θ):**
   It is the angle between the suns ray on the plane and the normal to the surface plane
3. **Surface Azimuth angle(γ):**
   It is the angle in the horizontal plane between the line due south and the horizontal projection of the normal to inclined surface

In general, θ is given by:

$$\text{Cos}\,\theta = \sin\phi\,(\sin\delta.\cos\beta + \cos\delta.\sin\beta.\cos\omega.\cos\gamma) + \cos\phi\,(\cos\delta.\cos\beta\cos\omega - \sin\delta\sin\beta\cos\gamma) + \cos\delta\sin\beta\sin\gamma\sin\omega$$

Special cases:

i. Vertical surface: ($\beta = 90^o$)

$$\text{Cos}\,\theta = \sin\phi\cos\delta\cos\gamma - \cos\phi\sin\delta\cos\gamma + \cos\delta\sin\beta\sin\gamma\sin\omega$$

ii. Horizontal surface ($\beta = 0^o$)

$$\text{Cos}\,\theta = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega = \cos\theta z$$

iii. Surface facing due south ($\gamma = 0^o$)

$$\text{Cos}\,\theta = \sin\phi\,(\sin\delta\cos\beta + \cos\delta\sin\beta\cos\omega) + \cos\phi\,(\cos\delta\cos\beta\cos\omega - \sin\delta\sin\beta)$$

Or

$$\text{Cos}\,\theta = \sin\delta\sin(\phi - \beta) + \cos\delta\cos(\phi - \beta)\cos\omega$$

iv. Vertical surface facing due south ($\beta = 90^o$, $\gamma = 0^o$)

$$\text{Cos}\,\theta = \sin\phi\cos\delta\cos\omega - \cos\phi\sin\delta$$

Note: 'θ' can also be expressed in terms of

$$\text{Cos}\,\theta = \cos\theta z\,\cos\beta + \sin\theta z\sin\beta\cos(\gamma - \gamma_s)$$

Solar Radiation Measurement

It is necessary to measure solar radiation because of use of solar heating and cooling devices and the results of the measurements are used to predict the performance of the devices. The instruments used for measurement of solar radiation includes measurement of direct solar radiation and diffuse solar radiation or total solar radiation (global solar radiation)

The instruments which are commonly used for measuring the solar radiation are

1. Pyrheliometer: An instrument which measures beam radiation intensity as a function of incident angle, and
2. Pyranometer: An instrument used to measure total or global solar radiation
3. Sunshine Recorder: To measure the day length or total visibility time of sun

1. Pyrheliometer

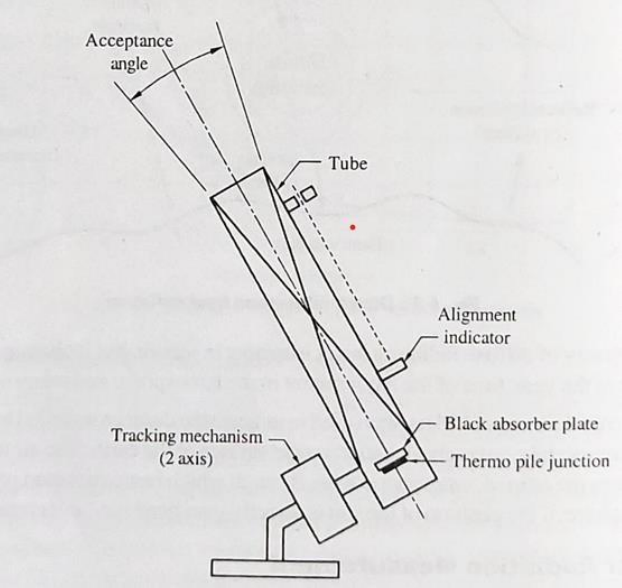


Figure: Pyrheliometer

Pyrheliometer is the device which is used to measure only beam radiation or straight radiation of the sun.

The main parts of the Pyrheliometer

1. **Tube:** It is a housing for the black absorber and thermopile, and it is designed in such a way that it allows only the beam radiation to strike the black absorber.
2. **Black absorber:** It absorbs the beam radiation which enters the tube.
3. **Thermopile Junction:** It is the junction where number of thermocouples are placed in series and measures the solar radiation by measuring the radiation absorbed by the absorber.
4. **Tracking mechanism:** It tracks the position of the sun time to time and position the pyrheliometer towards the sun to absorb the beam radiation.

Working

During the working process, the tracker tracks the position of the sun and positions the pyrheliometer tube towards the sun so that the radiation passes in the tube easily. When the solar radiation passes through the tube, the tube absorbs the diffuse radiation and allows only the beam radiation to travel towards black absorber, when the radiation strikes the black absorber, it absorbs the beam radiation and hence the surface temperature of the black absorber increases. This temperature is measured by the thermopile and the signals are sent to the reader where we get the amount of solar beam radiation at that area.

2. Pyranometer

Pyranometer is the device which is used to measure global radiation or total radiation and also it measures only diffuse radiation with the help of extra attachment called shading ring.

The main parts of the Pyrheliometer

Glass dome: Which covers the black absorber and protect it from dust particles

Black absorber: It absorbs the solar radiation which enters the tube.

Levelling screw: To adjust the pyranometer level.

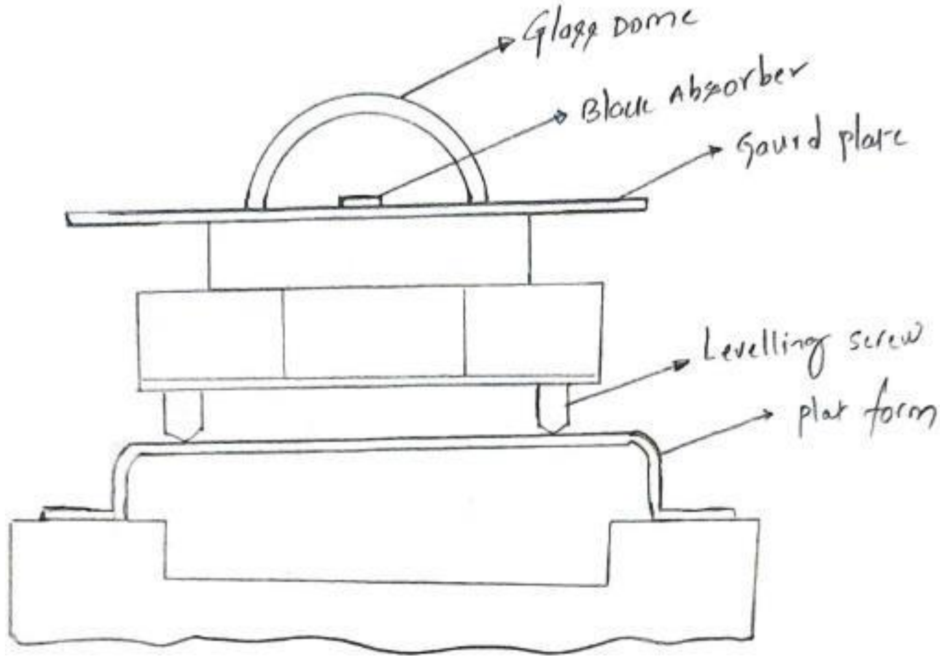


Figure 1. Pyranometer

Working

During working process, the radiation both beam and diffused radiation falls on the absorber and absorber absorbs the radiation and gets heated up. Then the temperature of the black absorber is measured by the thermopile which is kept at the bottom of the black absorber and that gives the total radiation at that place

To measure diffuse radiation:

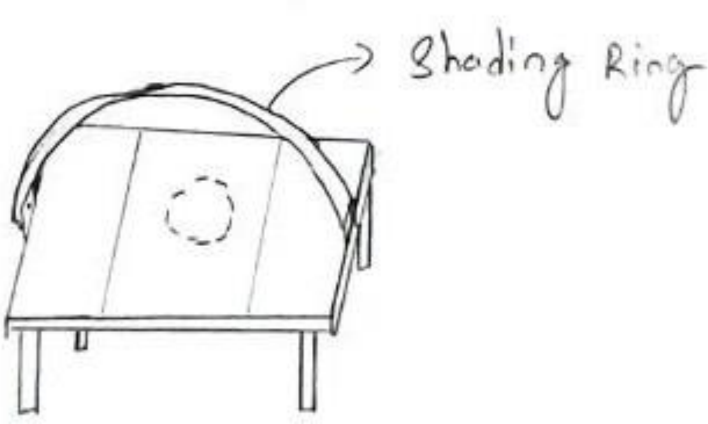
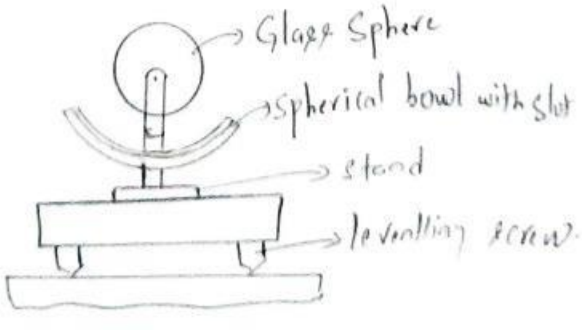


Figure 2. Shading ring

To measure diffuse radiation an extra attachment is used called shading ring as shown in figure 2, during the process the pyranometer is kept in the shading ring. The ring is having tracking mechanism hence it tracks the position of the ring and ring moves accordingly, while moving it blocks the beam radiation and allows the only diffuse radiation to fall on the black absorber, the black absorber absorbs only the diffused radiation and heated up. Then the temperature of the black absorber is measured by the thermopile which is kept at the bottom of the black absorber and that gives the total radiation at that place

3. Sunshine Recorder



It is used to measure the duration of proper sun shine in a day

The main parts of the Sunshine Recorder

Glass sphere: Which act as magnifying lens.

Spherical bowl: It is placed behind the glass sphere; it has a slot where a card strip is placed to measure the sunshine.

Card Strip: It is a paper strip having a engraved lines on it as a scale to measure the sunshine

Working Process:

During the process whenever there is a bright solar radiation, that radiation will pass through the glass sphere and gets magnified by the glass sphere and falls on the card strip, when this magnified solar radiation falls on the card strip it forms the burning marks on the card strip. The card strip has a engraved lines on it which act as scale, hence it measures the total time of bright sunshine in a day in that particular position

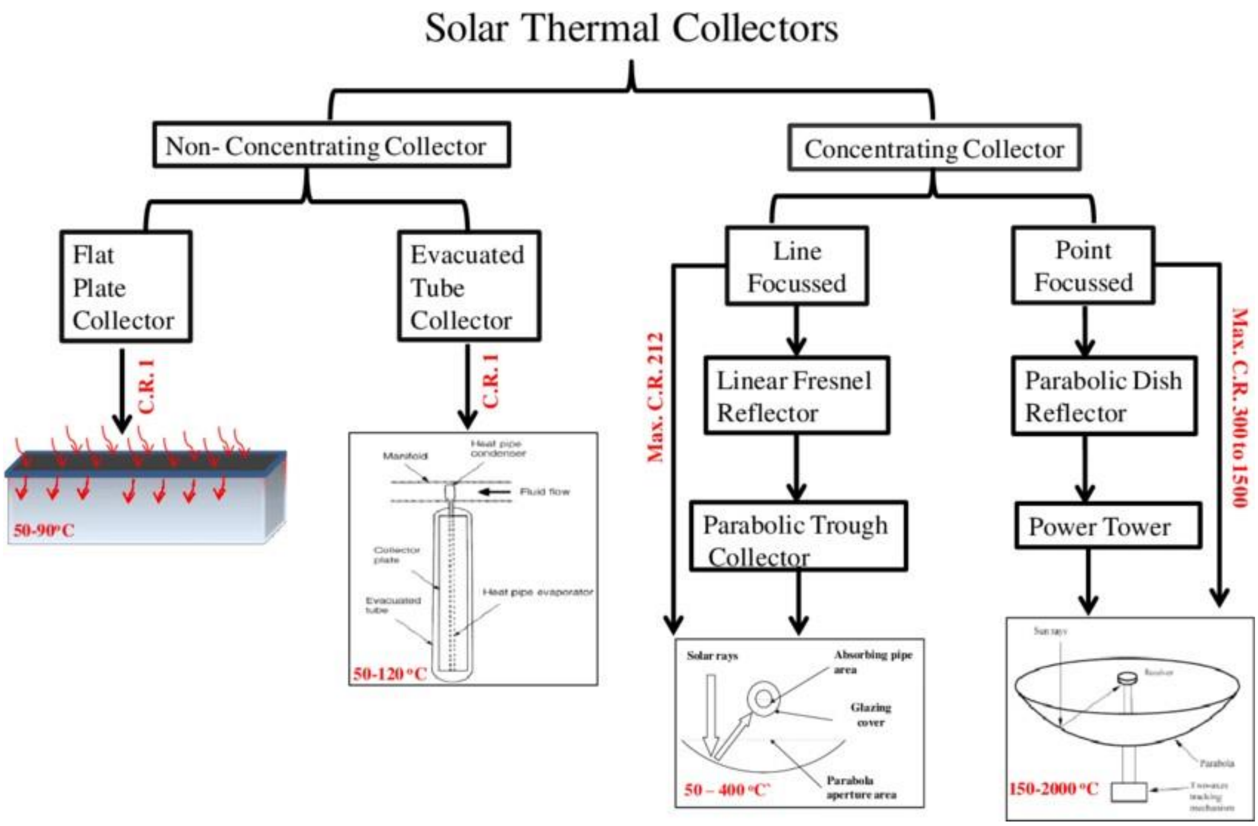
Thermal application of solar energy

In thermal application the solar energy gets converted in to heat energy with the help of a device called collectors

A solar collector is a device that collects and/or concentrates solar radiation from the Sun. These devices are primarily used for active solar heating and allow for the heating of water for personal use. These collectors are generally mounted on the roof and must be very sturdy as they are exposed to a variety of different weather conditions

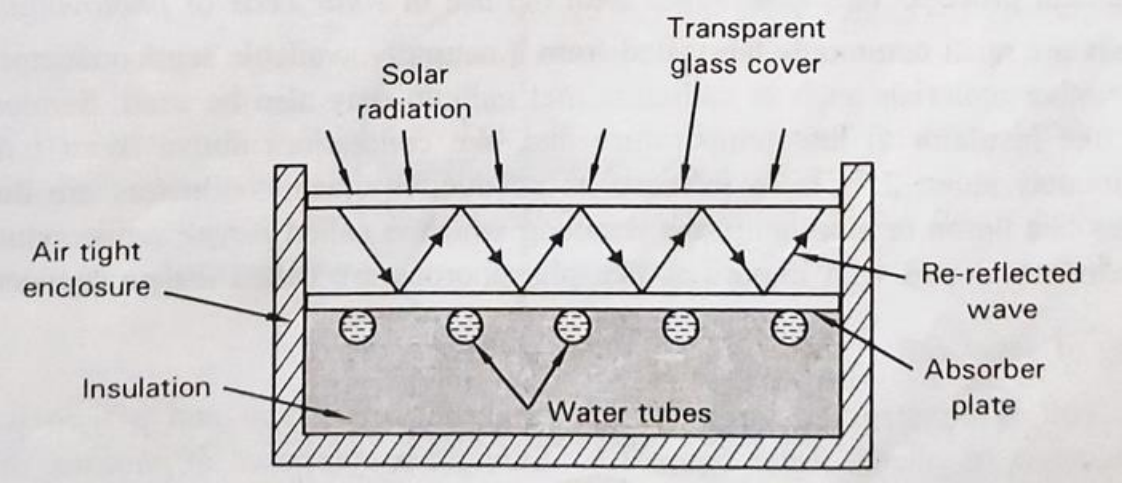
The use of these solar collectors provides an alternative for traditional domestic water heating using a water heater, potentially reducing energy costs over time. As well as in domestic settings, a large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants.

Classification solar collector



1. Flat plate collector or Non focusing

An example to utilizing solar energy using flat plate collector for heating cold water



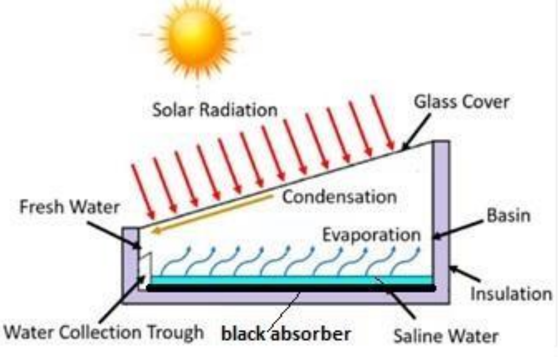
It consists of the following components

Absorber plate: It is usually made of copper and is coated with black so as to absorb the solar rays falling on it.
Transparent cover: It is made of a toughened glass, usually 4 mm thick, and helps in reflecting the incident solar energy back to the absorber plate.
Water tubes: These are metallic tubes through which water circulates. The tubes are attached to the absorber plate.
Insulation: Thermal insulation by means of resin bonded rock wool is provided below the water tubes so as to prevent heat losses by conduction.
In operation, cold water from the overhead tank is made to flow through the water tubes of the solar heater. When the sun rises to a certain level, it's energy, passes through the transparent cover and falls on the absorber plate. The heat energy absorbed by the absorber plate is transferred to the cold water flowing through the tubes.

2. Solar Distillation

Solar water distillation is the process of separating fresh water from the from salts or other contaminants using solar energy.

A solar distillation works on two principles they are evaporation (Heating water to vapor state) and condensation (cooling the vapor to liquid state)



Working

During the process, the sun light enters through the glass cover falls on the water and black absorber which is at the bottom of the instrument. As the sun ray strikes the black absorber it absorbs the radiation from the sun and gets heated up. This heat is extracted from the saline water in the instrument and water become hot, and finally the water gets converted to vapor leaving the impurities and salt content behind. This vapor moves upward and collected at the inner layer of the glass because of its low density. Finally this vapor particles gets condensed or cooled and collected as shown in figure. This collected water is the fresh water.

Advantages:
1. It is a relatively cheap and low-maintenance system.
2. It can be used at the household level and scaled up through programmatic approaches.
3. There are climate change adaptation and mitigation benefits.
4. There are no energy costs.
5. There are no moving parts.

Disadvantages:
1. Rate of distillation is usually very slow (6 litres of water per sunny day).
2. It is not suitable for larger consumptive needs.
3. The materials required for the distiller may be difficult to obtain in some areas.
4. If not correctly disposed of, the distillation process waste stream can be a potential source of environmental pollution (high concentrations of salts and pollutants).
5. Solar energy is only available during the day.

Solar distillation systems can be classified as

1) Passive
2) Active

Solar radiation is the input energy of the passive solar stills, but the efficiency of the system is low. Attempts have been made to increase the efficiency and productivity by preheating the saline water in solar stills. This method is called active solar distillation.

In the case of active solar distillation, an additional source of thermal energy is required for faster evaporation inside the same passive solar still. The additional source may be a solar-energy-based system or thermal energy contained in hot water which is discharged by other industries. There are many ways to make a solar still and different materials that can be used.

3. SOLAR POND

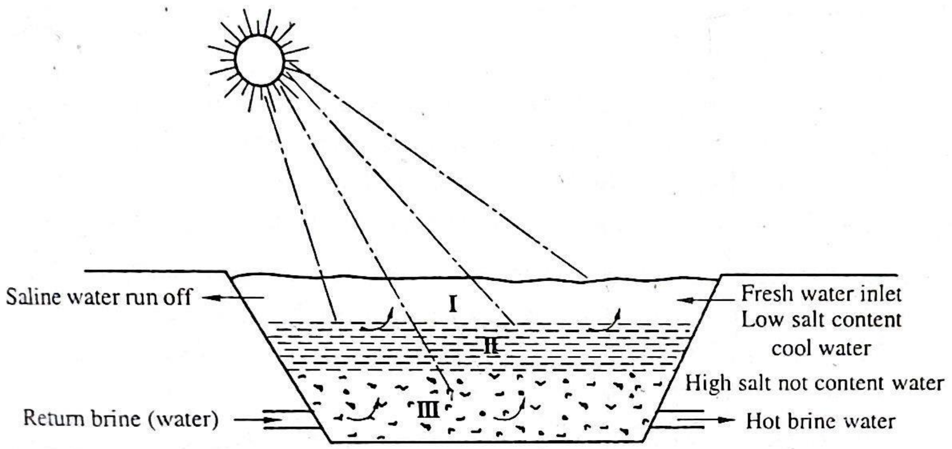
A solar pond is another type of solar collector which is used for applications where large temperatures are not necessary.

It is used for generating heat or electricity, for desalination of water, for low temperature applications in industry and agriculture.

Principle of working

When the water is heated the hot water rises up because of its decrease in density, In a solar pond the heat is trapped by increasing the density of water by adding the salt and maintaining the salt concentration gradient from top layer to bottom layer (the concentration increasing with depth) so that after heating also the water does not rise up Because of its high density compare to top and middle layer of water.

Construction:



I - Surface or upper convective zone (UCZ)

II - Non convective or Intermediate gradient zone.

III - Storage zone or lower convective zone.

Salt dissolved in water - magnesium chloride, sodium chloride or sodium nitrate.

A solar pond is about 3 to 5 ft deep with a black bottom to absorb solar radiation. The bed is made up of insulating material to minimize the heat loss to the ground.

In order to reduce the heat loss the salt concentration gradient is maintained depending on the salt concentration gradient the water layers are classified into 3 layer

There are 3 distinct layers of water in the pond:

- **I Zone:** The top zone or the surface zone is called the UCZ (Upper Convective Zone) and is atmospheric temperature. It has little salt content.
- **II Zone:** The bottom zone is the hot zone also called the LCZ (Lower Convective Zone). Temperatures in the range of 70°– 85° C. It has a high concentration of salt. It stores the energy in the form of heat.
- **III Zone:** The zone of separation is called NCZ (Non-Convective Zone). The salt content increases in this zone as the depth increases. Water in a particular layer cannot rise as the water above it is lighter due to lower salt content and vice versa. The salt gradient also acts as an insulator trapping the sunlight.

Working:

During this process, the solar radiation passes through the top and intermediate zones and enters the storage zone, where the energy from the sun radiation is absorbed by salty water in the storage zone and it gets heated up, this hot water again used to generate the electricity, the figure shows the electricity generation using solar pond.

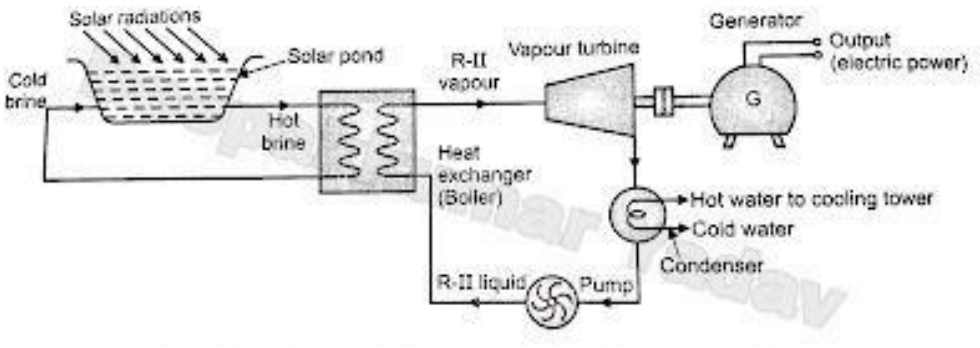


Figure: Generating electricity using solar pond

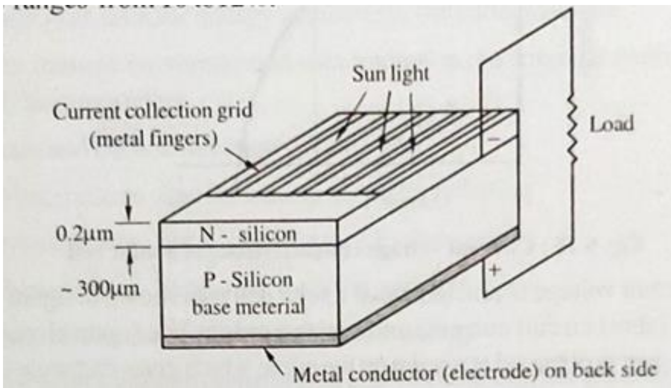
The heated hot water in the storage zone is sent to heat exchanger where the heat from the salty water is absorbed by the R II liquid (secondary liquid) and this R II liquid heated up and converted to steam, further this steam is sent to the vapor or steam turbine where the R II liquid vapor strikes the turbine blades and turbine rotates intern this turbine operates the generator where the electricity is generated. The vapor after operating turbine enters the condenser where it is cooled, and vapor gets converted to R II liquid and again this liquid pumped to the heat exchanger with the help of pump and the cycle repeats. The hot brine or salty water which is used to heat the R II liquid in heat exchanger is again sent to solar pond as shown in figure.

Solar Electric power generation – PV CELL

Solar cells, also known as photovoltaic (PV) cells, are devices that convert sunlight directly into electrical energy through the photovoltaic effect

Principle of working

Solar cells contain a material such as silicon that absorbs light energy. The energy knocks electrons loose so they can flow freely and produce a difference in electric potential energy, or voltage. The flow of electrons or negative charge creates electric current.



Basically, PV cell contains 4 layers, glass, n-type semiconductor, P-type semiconductor, and metal sheet/metal conductor.

1. Glass: It is a top layer through which sun light passes, below that we can see a metal finger which act as a current collection grid/terminal or electrode
2. Metal sheet/Metal conductor: It is a bottom layer placed below the P-type semiconductor which act as another terminal or electrode.
3. N-type: It is a thin layer of semiconductor with high doping.

4. P-type: It is a thick layer of semiconductor with light doping.
5. During construction when N type semiconductor placed on P type semiconductor it forms a junction called PN junction
6. AT PN junction the electrons from N type starts move towards P type, forms a new layer of electrons at P type semiconductor, and holes from P types starts move towards N type, forms a new layer of holes at N type semiconductor,
7. The new region between the N type and P type layer is called depletion region.
8. The atoms in the depletion region is called neutral atoms
9. During the process, when the sun radiation falls on the PV cell it penetrates through glass and N type layer and the photons of sun light strikes the neutral atoms in the depletion region.
10. When the photons strike the neutral atoms they emits the electrons and these electrons from the depletion region starts to move towards N type layer and starts to flow in the circuit and produces potential difference causes to generate electricity in PV Cell

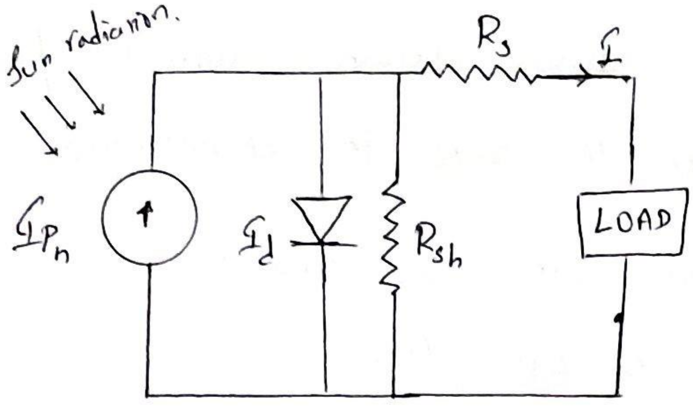
Advantages

1. Solar cells offer an excellent possibility to reduce your power cost.
2. Most importantly, solar energy is a completely renewable energy source.
3. The cost of maintenance is far too low.
4. Solar cells generate cost-effective electricity.
5. Solar cells respond to a wide range of incident wavelength
6. They require no external source
7. They can produce large photocurrent
8. They are robust and do not get damaged easily

Disadvantages

1. Solar cells have a slow operation
2. They are temperature sensitive
3. The output voltage and current is very low
4. Solar cells are expensive
5. Conversion efficiency is low

Equivalent circuit for PV cell



Equivalent circuit is the representation of PV cell in the form circuit

where the current generated in the PV cell is represented by 'I_{Ph}'. It is known that the total amount of current generated is not passed to load because there will be some leakage, that leakage current is represented by diode 'I_d' which is placed parallel to 'I_{Ph}'.

There are two resistance (R_{sh}) shunt resistance and (R_s) Series resistance that offers the resistance to the flow of current due to that there will be a some loss of current

Shunt resistance (R_{sh}):- It is the resistance offered by the material due defects in it.

Series resistance (R_s):- It is the resistance produced due to contacts etc.

∴ The total current reached to load 'I'

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

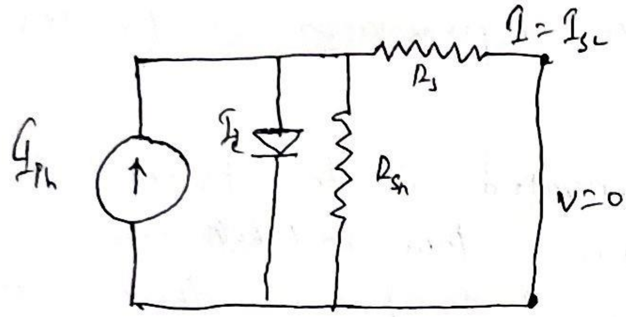
Where:-
I_{Ph} = Photon current
I_0 = Reverse saturation current
q = charge of an electron
= Boltzmann's Constant

characteristic curve:-

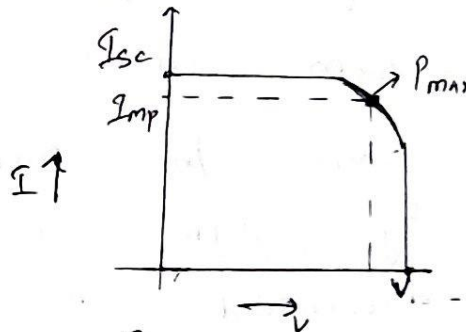
There are the curves drawn between current (I) / voltage (V) & power (P) v/s voltage (V) to study the characteristics of PV cell

To study this we use two circuits

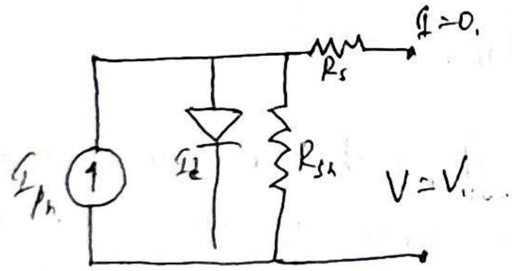
1) Short circuit 2) open circuit



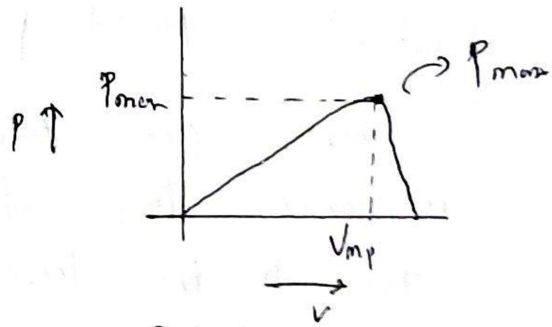
Short Circuit



I-V curve



open circuit



P-V curve

1) Short the circuit by connecting the terminals. then current I becomes maximum current I_{sc}, & voltage $V = 0$. mark it on IV plot

2) Make the open circuit without connecting terminal then current at $I = 0$, & voltage $V = V_{oc}$ maximum voltage. mark it on IV plot & draw the smooth curve as shown in IV curve

3) By using this we can calculate power using equation $P = IV$ at any point & we can plot it as shown