Module-2

SOLAR ENERGY

Syllabus

Solar Energy:

- Fundamentals
- Solar Radiation
- Estimation of solar radiation on horizontal and inclined surfaces
- Solar radiation Measurements- Pyrheliometers, Pyrometer
- Sunshine Recorder.
- Solar Thermal systems: Flat plate collector
- Solar distillation
- Solar pond electric power plant.

Solar electric power generation:

- Principle of Solar cell
- Photovoltaic system for electric power generation
- Advantages, Disadvantages and applications of solar photovoltaic system.

2.1 Fundamentals: Introduction

The sun's energy that reaches the earth is the Solar energy. It is received in the form of radiation, can be converted directly or indirectly into other forms of energy, such as **heat and electricity**. It may be regarded as an inexhaustible source of useful energy since the sun is expected to radiate for a few billion years. The major drawbacks to the extensive application of solar energy are:

1. The intermittent and variable manner in which it arrives at the earth's surface and

2. The large area required to collect the energy at a useful rate.

Experiments are underway to use this energy for power production, house heating, air-conditioning, cooking and high temperature melting of metals.

Energy is radiated by the sun as electromagnetic waves of which 99 per cent have wave lengths in the range of 0.2 to 4.0 micrometers (1 micrometer = 10^{-6} meter).

Solar energy reaching the top of the earth's atmosphere consists of about 8% ultraviolet radiation (short wave length, less than 0.39 micrometer), 46% visible light (0.39 to 0.78 micrometer), and 46% infrared radiation (long wave length more than 0.78 micrometer).

2.2. Solar Constant

The diameter of Sun is 1.39 x 106 km while that of the earth is 1.27 x 104 km. The mean distance between the two is 1.50 x 108 km. The radiation coming from the sun appears to be essentially equivalent to that coming from a black surface at 57620K.

The rate at which solar energy arrives at the top of the atmosphere is called the **solar constant I_{sc}**. This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun. The National Aeronautics and Space Administration's (NASA) standard value for the solar constant, expressed in three common units, is as follows: 1.353 kilowatts per square metre or 1353 watt per square metre. 116.5 langleys (calories per sq. cm) per hour, or 1165 kcal per sq. m per hour (1 langley being equal to 1 cal/cm2 of solar radiation received in one day). 429.2 Btu per sq. ft. per hour.

The earth is closest to the sun in the summer and farthest away in the winter. This variation in distance produces a nearly sinusoidal variation in the intensity of solar radiation I that reaches the earth. This can be approximated by the equation

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

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

where, n is the day of the year. As the distance between earth and sun varies a little through the year, due to it extraterrestrial radiation also varies.

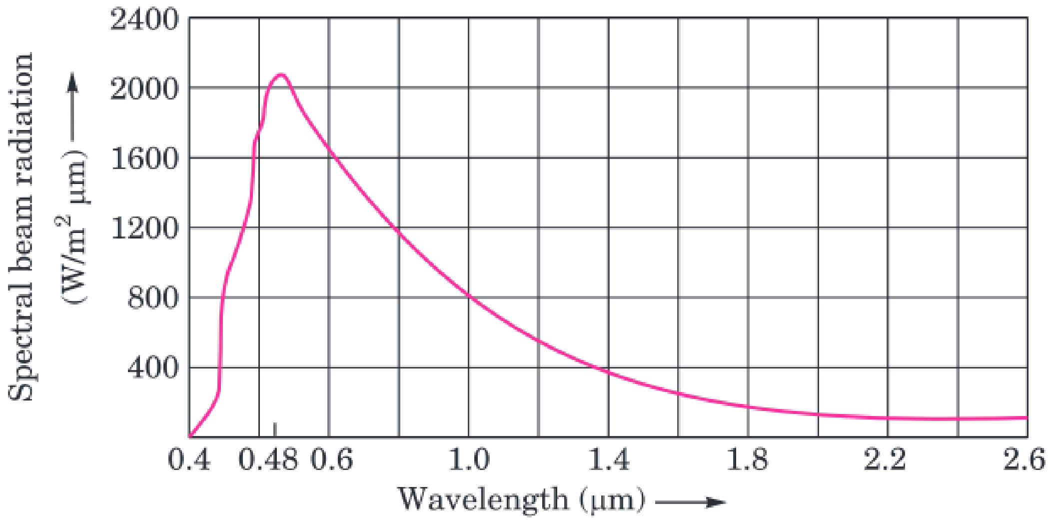


Fig. 2.1. Spectral distribution of solar radiation intensity.

2.3. Solar Radiation at the Earth's Surface

2.3.1. Beam and Diffuse Solar Radiation:

The solar radiation that reaches the earth's atmosphere differs. A part of the radiation is reflected back into the space, especially by clouds. The radiation entering the atmosphere is partly absorbed by molecules in the air. Oxygen and ozone (O_3) formed from oxygen, absorb nearly all the 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 by droplets in clouds by atmospheric molecules, and by dust particles.

Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called "**direct radiation**" or **Beam radiation**. It is the radiation which produces a shadow when interrupted by an opaque Object.

Diffuse radiation is that 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. The total solar radiation received at any point on the earth's surface is the sum of the direct and diffuse radiation. This is referred to as the insolation at that point. Hence, 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).

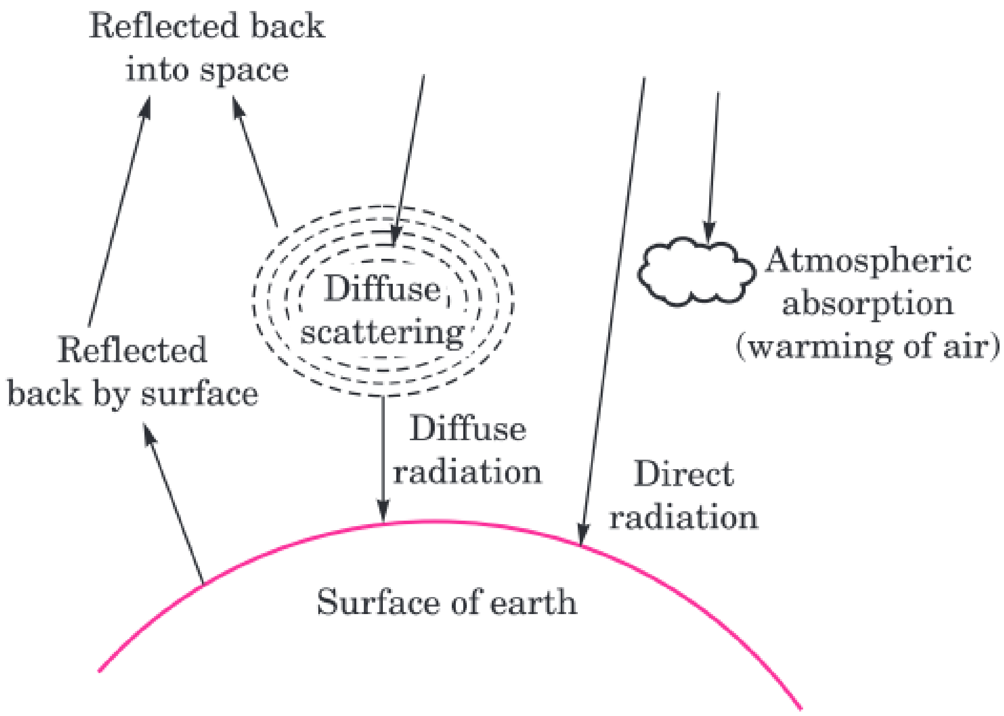


Fig. 2.2. Direct, diffuse and total radiation.

2.3.2. Sun at Zenith. Position of the sun directly over head.

2.3.3. 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 path when the sun is at the zenith. Except for very low solar altitude angles, the air mass is equal to the cosecant of the altitude angle.

Thus at sea level m = 1.

m = 1 when the sun is at zenith, i.e., directly over head.
m= 2 when zenith angle is 60^0 (Θ_z, the angle subtended by the zenith and the line of sight to the sun).
m= sec Θ_z, when m > 3.
m= 0 just above the earth's atmosphere.

2.3.4. Attenuation of Beam Radiation: 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 ultraviolet rays are absorbed by the ozone in the atmosphere and the long wave infrared waves are absorbed by the carbon dioxide and moisture in the atmosphere. This results in narrowing of the band width. In fact most of the terrestrial solar energy (i.e., energy received by the earth) lies within the range of 0.29u to 2.5 u.
(ii) Scattering- As solar radiation passes through the earth's atmosphere, the components of atmosphere such as water vapour and dust scatter apportion of the radiation. A portion of this

scattered radiation always reaches the earth's surface as diffuse radiation. Thus radiation finally received at the earth's surface consists of beam and diffuse radiation.

For terrestrial application of solar energy, only wavelength between 0.29 and 2.5um need to be considered. The maximum intensity observed at noon on an oriented surface at sea level is 1kW/m^2.

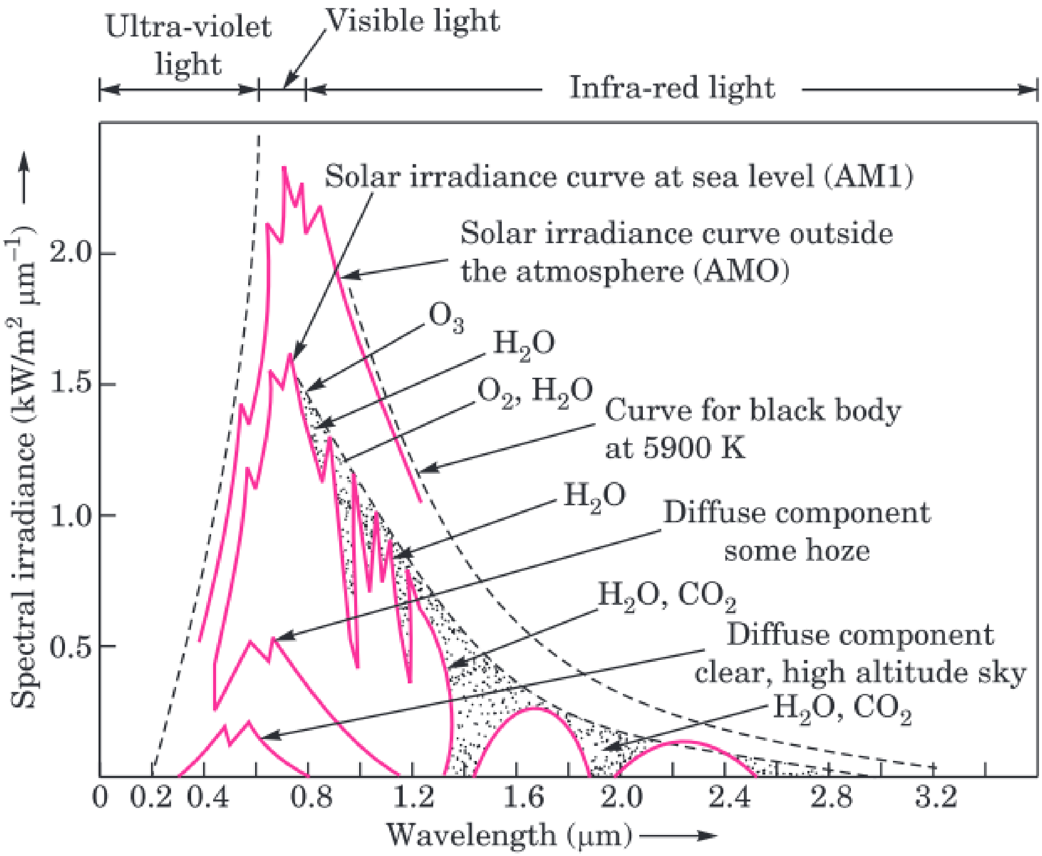


Fig. 2.3. The solar spectrum outside the atmosphere at a ground level.

2.4. Solar Radiation Geometry

In solar radiation analysis, the following angles are useful:

In solar radiation analysis, the following angles are useful:

ϕ_l = latitude of location

δ = declination

ω = hour angle

γ_s = solar Azimuth angle

s = slope

α = altitude angle

θ_z = zenith angle.

If Θ is the angle between an incident beam radiation I and the normal to the plane surface, then the equivalent flux or radiation intensity falling normal to the surface is given by I cos Θ. Θ is called incident angle.

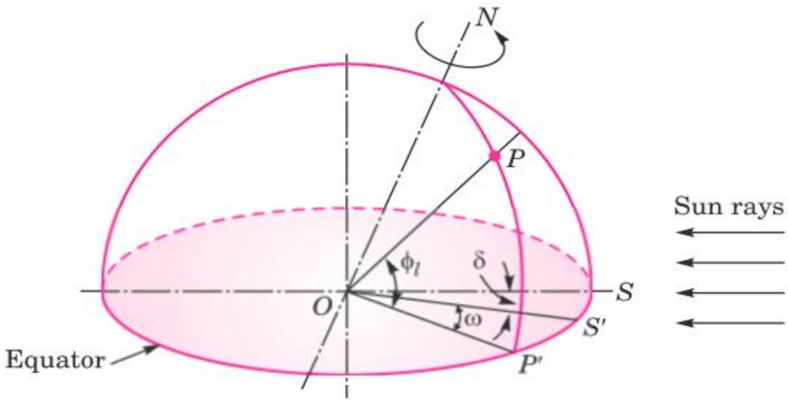


Fig. 2.4. Latitude ϕ_l, hour angle ω, and sun's declination δ.

Terms:

The **altitude** $\boldsymbol{\Theta_l}$ 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. It is the angular distance north or south of the equator measured from centre of earth. As shown in Fig. 2.4, it is the angle between the line OP and the projection of OP on the equatorial plane. Point P represents the location on the earth surface and O represents the centre of the earth

The **declination δ** is the angular distance of the sun's rays north (or south) of the equator. It is the angle between a line extending from the centre of the sun to the centre of the earth and the projection of this line upon the earth's equatorial plane.

The declination reaches a maximum of 23.45° on June 22 (**summer solstice** in the northern hemisphere) and a minimum of -23.45° on December 21-22 (**winter solstice** in the northern hemisphere). The declination is zero at the **equinoxes** (March 22 and September 22), positive during the northern hemisphere summer and negative during the northern hemisphere winter.

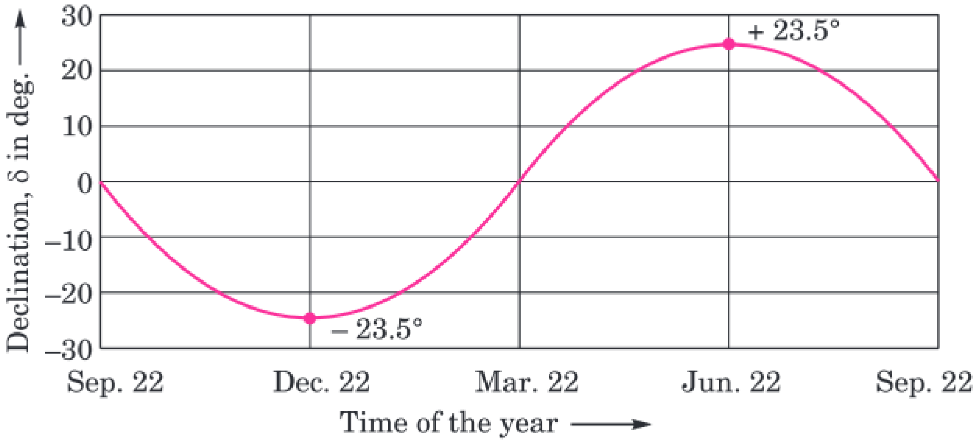


Fig. 2.5. Variation of sun's declination.

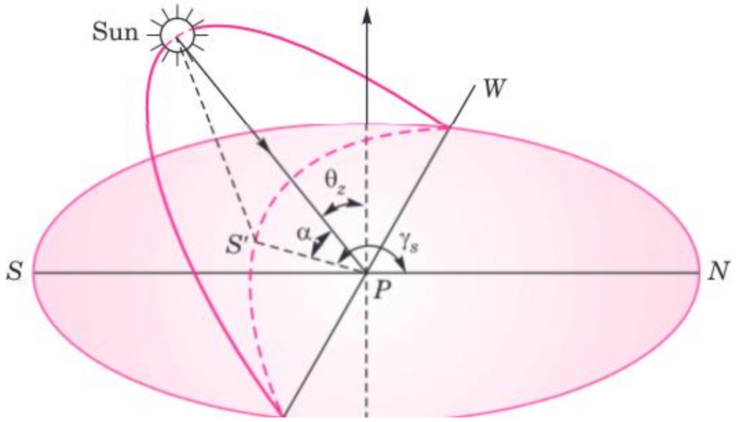
The declination in degrees for any given day may be calculated from the approximate equation of Cooper (1989).

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

where n is the day of the year, [e.g., 21 June, 1988 is the 173th (31 + 29 + 31 + 30 + 31 + 21) day of 1988 i.e., n = 1731.

The **hour angle ω** measures the angular distance between a celestial object and the observer's meridian at a given time. The hour angle **ω** is equivalent to 15^0 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.

Altitude angle (solar altitude) α : It is a vertical angle between the projection of the sun's rays on the horizontal plane and the direction of sun's rays.



Zenith angle θ_z : It is 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 i.e., the angle between the beam from the sun and the vertical

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

Solar Azimuth angle γ_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 horizontal projection of the sun's rays. This angle is positive when measured west wise.

The **Slope (s):** Is the angle made by the plane surface with the horizontal. It is taken to be positive for surfaces slopping towards the south and negative for surface slopping towards the north.

Surface Azimuth angle (γ): It is the angle of deviation of the normal to the surface from the local meridian, the zero point being south, east positive and west negative.

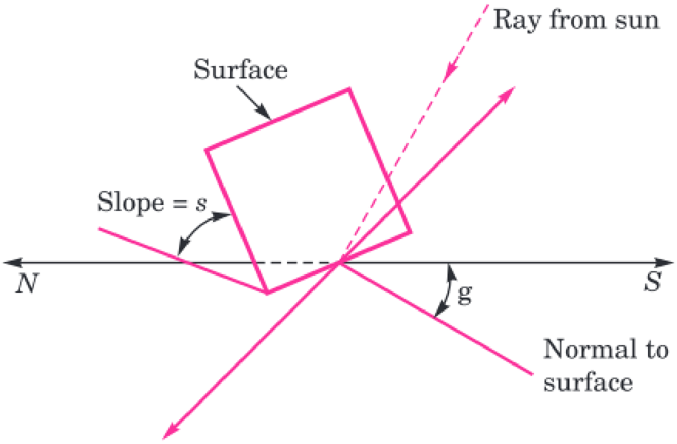


Fig. 2.7. Surface azimuth angle and slope defined.

Incident angle (θ). It is the angle being measured between the beam of rays and normal to the plane.

Local Solar Time (LST): Local Solar Time (LST) refers to the time of day based on the position of the Sun in the sky at a specific location.

LST=Standard Time ± 4(Standard time longitude-longitude of location)+(Equation of time correction)

Example 2.1. *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″).*

Solution. ∴ The local solar time

= IST – (Standard time longitude – longitude of location)

+ Equation of time correction

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

Indian Standard Time (IST) is the local civil time corresponding to 82.5° E longitude

$= 12^h\ 30' - 4 \times 5 - 1'\ 01''$

$= 12^h\ 8'\ 59''$. **Ans.**

Declination δ can be obtained by Cooper's equation *i.e.,*

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

$$= 23.45 \sin \left[\frac{360}{365}(284 + 170)\right]$$

(n is the day of the here = 170 on June 19)

$$= 23.45 \sin 86°$$

$$= 23.43°. \quad \textbf{Ans.}$$

or $= 23°\ 25'\ 56''$.

Example 2.2. *Calculate the angle made by beam radiation with the normal to a flat collector on December 1, at 9.00 A.M., solar time for a location at 28° 35′ N. The collector is tilted at an angle of latitude plus 10°, with the horizontal and is pointing due south.*

Solution. $\gamma = 0$ since collector is pointing due south. For this case we have the equation

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

Declination δ can be obtained with the help of Cooper equation on December 1, $n = 335$.

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

$$= 23.45 \sin \left[\frac{360 \times (284 + 335)}{365}\right] = -22.11°.$$

Hour angle ω corresponding to 9.00 hour = 45°

Hence, $\cos \theta_T = \cos(28.58° - 38.58°) \cos(-22.11°)$

$\cos 45° + \sin(-22.11°) \sin(28.58° - 38.58°)$

$= \cos 10° \cos 22.11° \cos 45° + \sin 22.11° \sin 10°$

$= 0.6451 + 0.0653 = 0.7104$

or, $\theta_T = 44.72°$. **Ans.**

2.5. Solar Radiation Measurements.

Two basic types of instruments are employed for solar radiation measurement:

(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. The pyranometer measurements are the most common.

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's rays. Thus diffuse radiation is essentially blocked from the sensor surface. There are different types of pyrheliometers available, but the most commonly used type is the thermopile pyrheliometer. It consists of a blackened receiver plate that absorbs solar radiation and converts it into heat. This heat is then transferred to a thermopile, which is a device that generates an electric voltage in response to temperature differences. The generated voltage is proportional to the solar irradiance, allowing for the measurement of solar radiation. The use of correction factors is not only involved but somewhat unreliable. The direct solar component on a horizontal surface may also be obtained using a shading ring, this is done by subtracting the shaded (diffuse) from the unshaded (global) reading. normal to direct solar rays, i.e., a line joining the sun and receiver.

Three 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.

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 x 2 x 0.1 mm) is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation.

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 (or other null detector), are used to test for the equality of temperature.

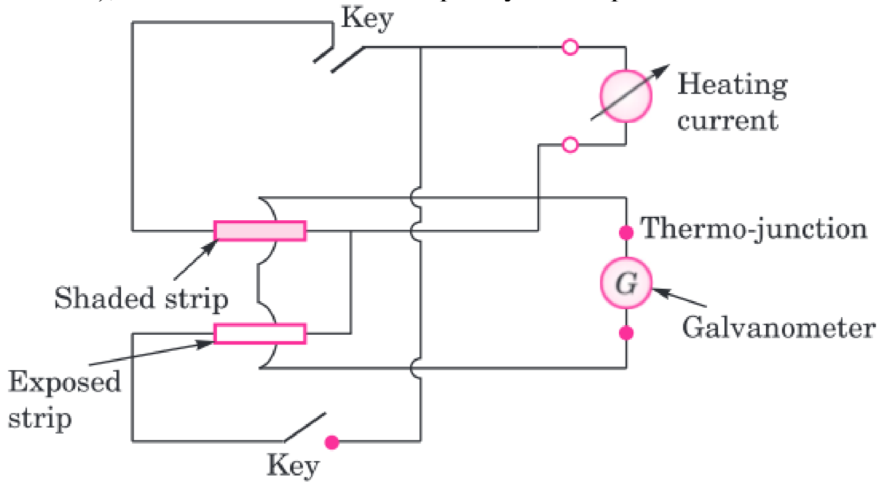


Fig. 2.9. Electric circuit for Angstrom Pyrheliometer.

(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 5.7^0. 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 temperature of the disk are measured.

(iii) Eppley Pyrheliometer. 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 5.7^0. 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. A filter wheel is standard.

2. Pyranometers: A pyranometer is an instrument which measures total or global radiation over a hemispherical field of view. If a shading ring is attached, the beam radiation is prevented from falling on the instrument sensor and in then measures only the diffuse component of the radiation. In most pyranometers, the sun's radiation is allowed to fall on a black surface to which the hot junctions of a thermopile are attached. The cold junctions of the thermopile are located in such a way that they do not receive the radiation. As a result, an e.m.f. proportional to the solar radiation is generated. This e.m.f. which is usually in the range of 0 to 10 mV can be read, recorded or integrated over a period of time with regular calibration of about ± 2 percent can be obtained.

There are following types of pyranometers:

(i) Eppley pyranometer,
(ii) Yellot solarimeter (photovoltaic solar cell),
(iii) Moll-Gorczyheski solarimeter,
(iv) Bimetallic Actiono-graphs of the Rabitzsch type,
(v) Velochme pyranometer,
(vi) Thermoelectric pyranometer etc.

First two types are described briefly in the following paragraphs.

(i) Eppley pyranometer: It is based on the principle that there is a difference between the temperature of black surfaces (which absorb most solar radiation) and white surfaces (which reflect most solar radiation). The detection of temperature difference is achieved by thermopile. It uses concentric silver rings 0.25 mm thick, appropriate coated black and white, with either 10 or 50 thermocouple junctions to detect temperature differences between coated rings. Later models use wedges arranged in a circular pattern, with alternate black and white coatings. The disks or wedges are enclosed in a hemispherical glass cover.

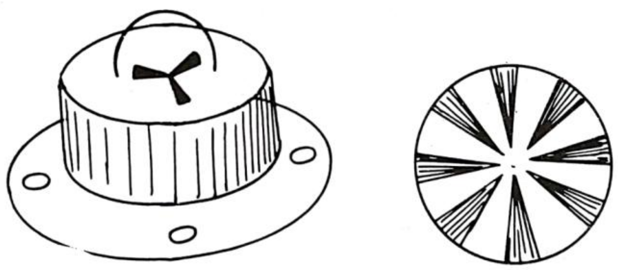


Fig. 2.5.2. Pyranometer with alternate black and white sensor segments.

(ii) Yellot Solarimeter (Photovoltaic solar cell): Pyranometers have also been used on photovoltaic (solar cell) detectors. Silicon cells are the most common for solar energy. Silicon solar cells have the property that their light current (approximately equal to the short circuit current at normal radiation levels) in a linear function of the incident solar radiation. They have the disadvantages that the spectral response is not linear, so instrument calibration is a function of the spectral distribution of the incident radiation.

2.6. Sunshine Recorder

The duration of bright sunshine in a day is measured by means of a sunshine recorder. The sun's rays are focussed by a glass-sphere to point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere. Whenever there is a bright sunshine, the image formed is intense enough to burn a spot on the card strip. Through the days the sun moves across the sky, the image moves along the strip. Thus a burnt space whose length is proportional to the duration of sun shine is obtained on the strip.

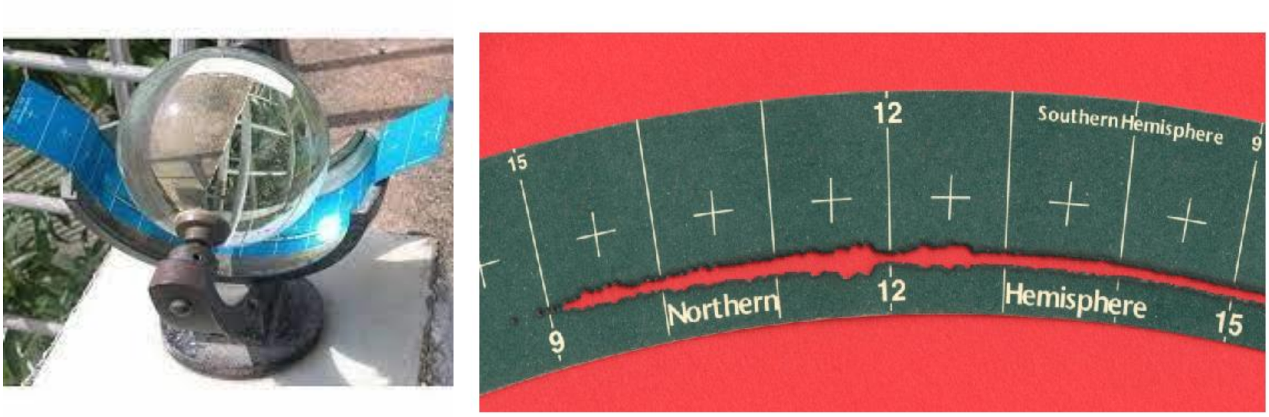


Fig: Sunshine Recorder and Strip

2.7 Solar Energy Collectors:

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) Concentrating (focusing) type solar collector.

(i) Flat-Plate Collectors

Where temperatures below about 900C are adequate, as they are for space and service water heating flat plate collectors, which are of the non-concentrating type, are particularly convenient. They are made in rectangular panels, from about 1.7 to 2.9 sq. m, in area, and are relatively simple to construct and erect. Flat plates can collect and absorb both direct and diffuse solar radiation, they are consequently partially effective even on cloudy days when there is no direct radiation

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

Liquid heating collectors are used for heating water and non-freezing aqueous solutions and occasionally for non-aqueous heat transfer fluids. Air or gas heating collectors are employed as ***solar air heaters.***

The principal difference between the two types is the design of the passages for the heat for the transfer fluid.

The majority of the flat-plate collector have five main components as follows:

(i) A transparent cover which may be one or more sheets of glass or radiation transmitting plastic film or sheet.

(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 minimise 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.

Typical Liquid Collector

It is the plate and tube type collector. It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface. Typically a metal plate, usually of copper, steel or aluminium material with tubing of copper in thermal contact with the plateas, are the most commonly used materials. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also of metal, range in diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom (in some cases, to the top) of the absorber plate with the pitch ranging from 5 to 15 cm. In some designs, the tubes are also in line and integral with the absorber plate. For the absorber plate corrugated galvanized sheet is a material widely available throughout the world, Fig. 3.5 (a) and (b) show two ways in which it has been used.

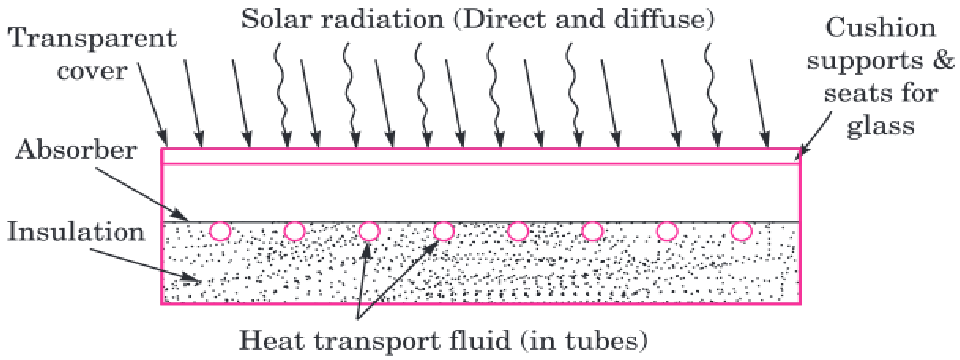


Fig: Section through flat plate collector

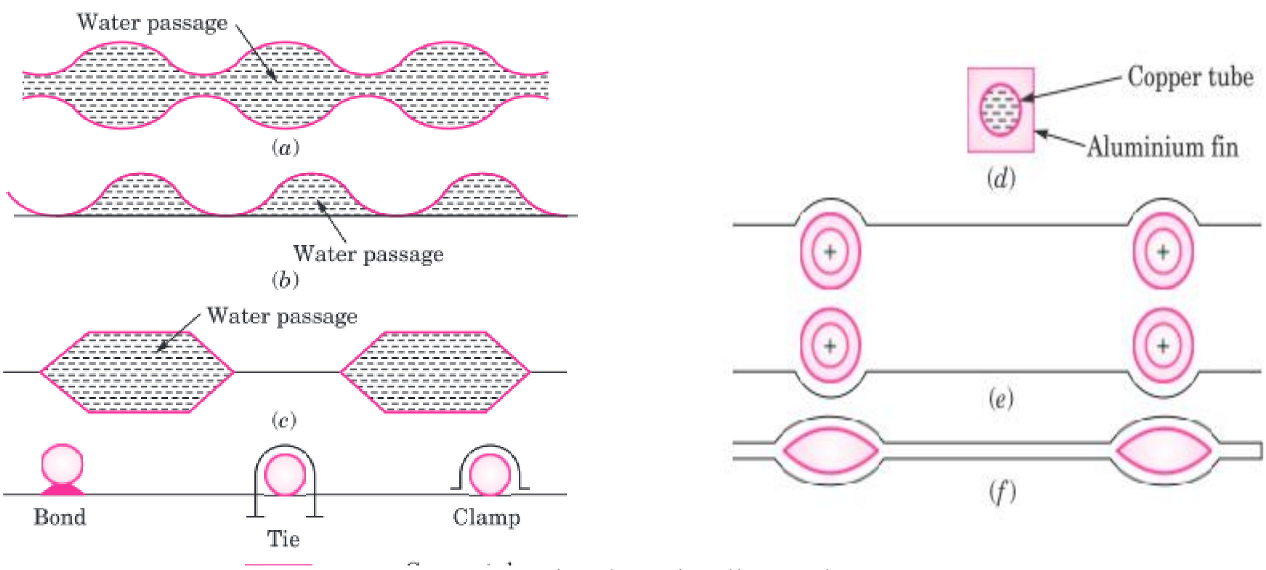


Fig: Cross Section through collector plates

Heat is transferred from the absorber plate to a point of use by circulation of fluid (usually water) across the solar heated surface. The front covers are generally glass that is transparent to in coming solar radiation and opaque to the infra-red re-radiation from the absorber.

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. When water is used, it is most commonly passed through metal tubes, either circular or rectangular cross-section. In order to maximise the exposure to solar radiation, collectors are almost invariably sloped. Cooler water then enters at the bottom header, flows upward through the tubes where it is warmed by the absorber, and leaves by way of the top header.

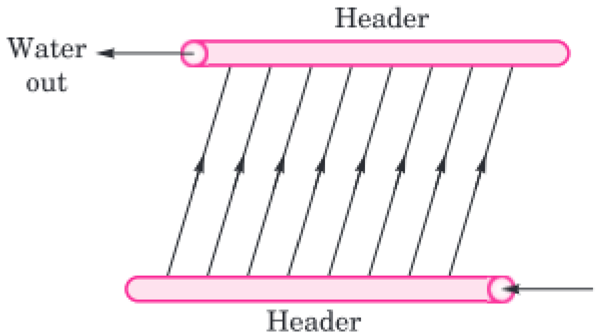


Fig. 3.6. Water flow in flat-plate collector.

Advantages Of Flat-plate Collectors

(i) They have the advantages of using both beam and diffuse solar radiation.

(ii) They do not require orientation towards the sun.

(iii) They require little maintenance.

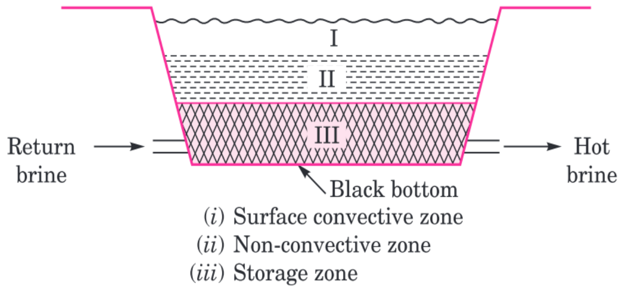
(iv) They are mechanically simpler than the concentrating reflectors, absorbing surfaces and orientation devices of focusing collectors.

2.8 Solar pond

It a solar energy collector, large in size, that looks like a pond. This type of solar energy collector uses a large, salty lake as a kind of a flat plate collector that absorbs and stores energy from the Sun in the warm, lower layers of the pond.

A solar pond is a mass of shallow water about 1 or 2 metres deep with a large collection area, which acts as a heat trap. It contains dissolved salts to generate a stable density gradient. Part of the incident solar radiation entering the pond surface is absorbed throughout the depth and the remainder which penetrates the pond is absorbed at the black bottom. If the pond were initially filled with fresh water, the lower layers would heat up, expand and rise to the surface. Because of the convective mixing and heat loss at the surface, only a small temperature rise in the pond could be realized. On the other hand, convection can be eliminated by initially creating a sufficiently strong salt concentration gradient. In this case, thermal expansion in the hotter lower layers is insufficient to destabilize the pond. With convection suppressed, the heat is lost from the lower layers only by conduction. Because of the relatively low conductivity, the water acts as an insulator and permits high temperature (over 900C) to develop in the bottom layers. At the bottom of the pond, a thick durable plastic liner is laid. Materials used for the liner include butyl rubber, black polyethylene and hypalon reinforced with nylon mesh.

The solar pond has three zones with following salinity with depth:
(i) Surface convective zone or upper convective zone:(0.3—0.5 m), salinity < 5%.
(ii) Non-convective zone 1 to 1.5 m, salinity increases with depth.
(iii) Storage zone or lower convective zone: 1.5 to 2 m, salinity 20%



Solar Pond Electric power plant with cooling tower:

A solar pond electric power plant with a cooling tower is a type of power generation facility that combines the concept of a solar pond with conventional power generation methods to produce electricity.

Working:

Solar Pond: Solar pond is designed to collect and store solar energy. The solar pond operates based on the salinity gradient principle. It traps and stores solar heat effectively.

Heat Extraction: The heat from the solar pond is transferred to a heat transfer fluid, such as water or a specialized heat transfer fluid, circulating through a heat exchanger submerged in the lower layers of the solar pond.

Steam Generation: The heated heat transfer fluid is then sent to a steam generator or boiler, where it produces high-pressure steam. The steam is generated by transferring the heat from the heat transfer fluid to water, which is converted into steam under high pressure.

Power Generation: The high-pressure steam drives a turbine connected to a generator. As the steam expands through the turbine blades, electricity is generated through the attached generator.

Cooling Tower: The excess heat from the steam turbine's exhaust is extracted using a cooling tower, helping to maintain the efficiency of the power generation process.

Condensation and Recirculation: After passing through the turbine, the steam is condensed back into water using a condenser. The condensed water is then recirculated back to the solar pond or the heat transfer fluid system, completing the cycle.

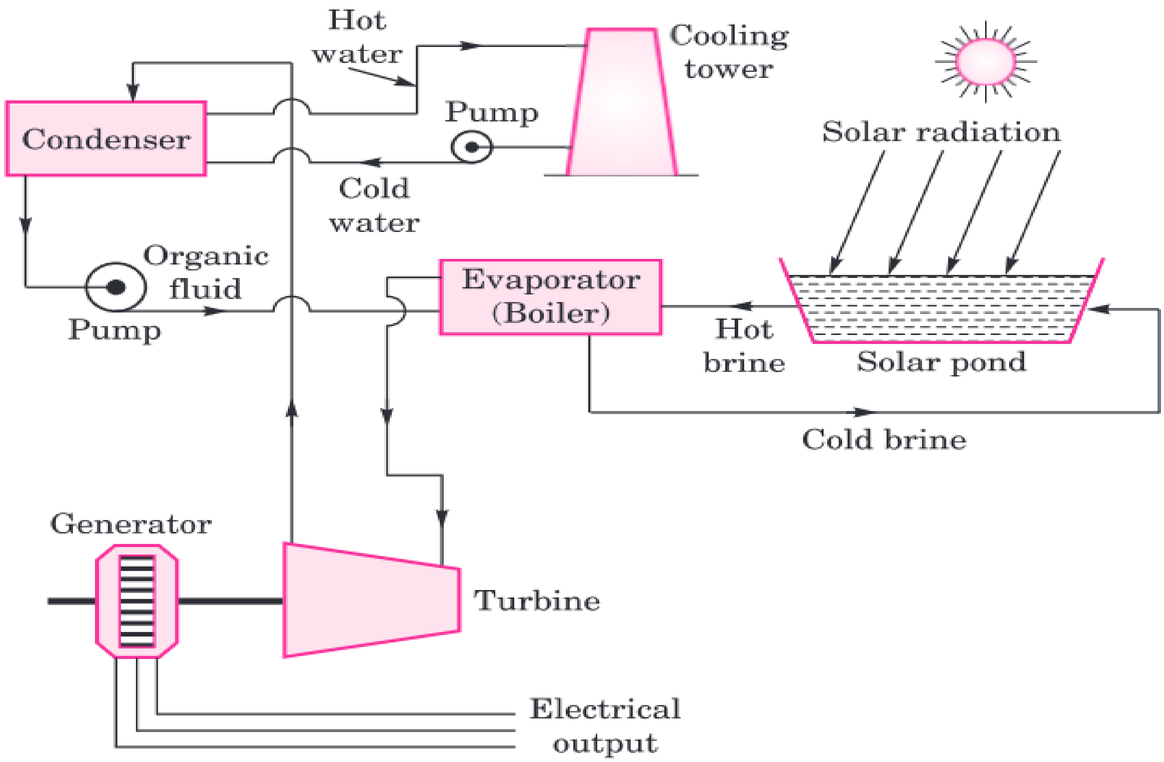


Fig. 4.6. Solar pond electric power plant with, cooling tower.

Applications of Solar pond:

(1) Heating and Cooling of Buildings: Because of the large heat storage capability in the lower convective zone of the solar pond, it has ideal use for heating even at high latitude stations and for several cloudy days.

(2) Production of Power: A solar pond can be used to generate electricity by driving a thermo-electric device or an organic Rankine cycle engine—a turbine powered by evaporating an organic fluid with a low boiling point.

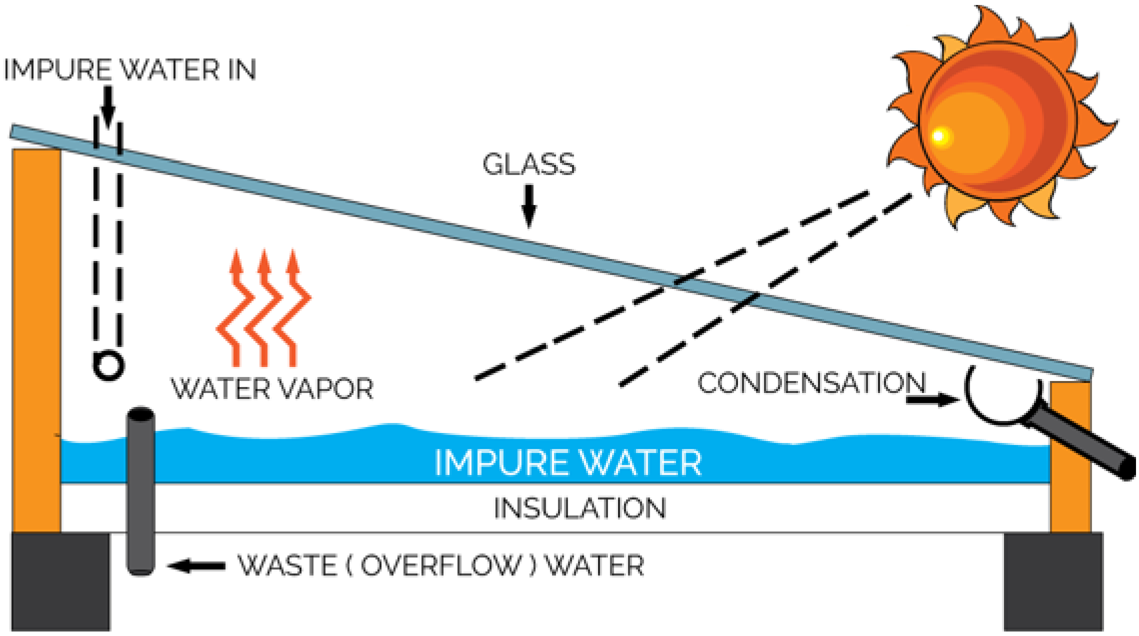
(3) Industrial Process Heat: the solar pond can play a significant role in supplying the process heat to industries thereby saving oil, natural gas, electricity, and coal.

(4) Desalination: The low cost thermal energy can used to desalt or otherwise purify water for drinking or irrigation.

(5) Heat for biomass conversion: solar ponds could provide heat to convert biomass to alcohol or methane.

2.9 Solar Distillation

Solar energy is plentiful and can be used for converting saline water into distilled water. The pure water can be obtained by distillation in the simplest solar still, generally known as "Basin Solar Still", shown in fig. It consists of a blackened basin containing saline water at a shallow depth, over which there is a transparent air tight cover that encloses completely the space above the basin. basin. It has a roof-like shape. The cover, which is usually glass, may be of plastic, is sloped towards a collection trough. Solar radiation passes through the cover and is absorbed and converted into heat in the black surface. Impure water in the basin or tray is heated and the vapour produced is condensed to purified water on the cooler interior of the roof. The transparent roof material, (mainly glass) transmits nearly all radiation falling on it. The condensed water flows down the sloping roof and is collected in troughs at the bottom. Saline water can be replaced in the operation by either continuous operation or by batches. Operating efficiencies of 35 to 50% for basin type still have been achieved in practical units, as compared with a theoretical maximum of slightly more than 60%.



The performance rating and efficiency of the solar still is determined by plotting the graph of the amount of fresh water produced per unit of basin area in one day versus the solar radiation intensity over the same period. Such curves for several stills are drawn. Efficiency is defined as

$$\eta = \frac{w\Delta h}{H}$$

where, w = weight of distillate per square meter per day.
Δh = enthalpy change from cold water to vapour.
H = Solar radiation intensity per square meter per day.
Here area of the water surface is to be considered. Ah includes the latent heat of vaporization, which is being taken as average value 594.5 kcal/kg (2489 kJ/kg).
Solar Still installations may provide about 15 to 50 litres per day per 10 sq m

2.10 Solar Electric Power Generation: Solar Photovoltaics

2.10.1: Introduction.

Energy conversion devices which are used to convert sunlight to electricity by the use of the photovoltaic effect are called solar cells. A single converter cell is called a solar cell that is a photovoltaic cell, and combination of such cells; designed to increase the electric power output is called a solar module or solar array.

Photovoltaic cells are made of semiconductors that generate electricity when they absorb light. These devices have theoretical efficiencies of the order of 25 percent. Actual operating efficiencies are less than half this value

2.10.2: Solar Cell Principles:

When photons from the sun are absorbed in a semiconductor, they create free electrons with higher energies. Once these electrons are created, there must be an electric field to induce these higher energy electrons to flow out of the semiconductor to do useful work. The electric field in most solar cells is provided by a junction of materials which have different electrical properties.

To obtain a useful power output from photon interaction in a semiconductor three processes are required.

1. The photons have to be absorbed in the active part of the material and result in electrons being excited to a higher energy potential.
2. The electron hole charge carrier created by the absorption must be physically separated and moved to the edge of the cell.
3. The charge carriers must be removed from the cell and delivered to a useful load before they loose their extra potential.

The flow of electrons through the external conductor constitutes an electric current which will continue as long as more free electrons and holes are being formed by the solar radiation. This is the basis of photovoltaic conversion, that is, the conversion of solar energy into electrical energy. The combination of n-type and p-type semiconductors thus constitutes a photovoltaic (P V) cell or solar cell. All such cell, generate direct current which can be converted into alternating current if desired.
The most normal configuration for a solar cell to make a p-n junction semiconductor is as shown schematically in Fig. The back is completely covered by a metallic contact to remove the charges to the electric load. The collection of charges from the front of the cell is aided by a fine grid of narrow metallic fingers. An anti-reflective coating is applied on the top of the cell.

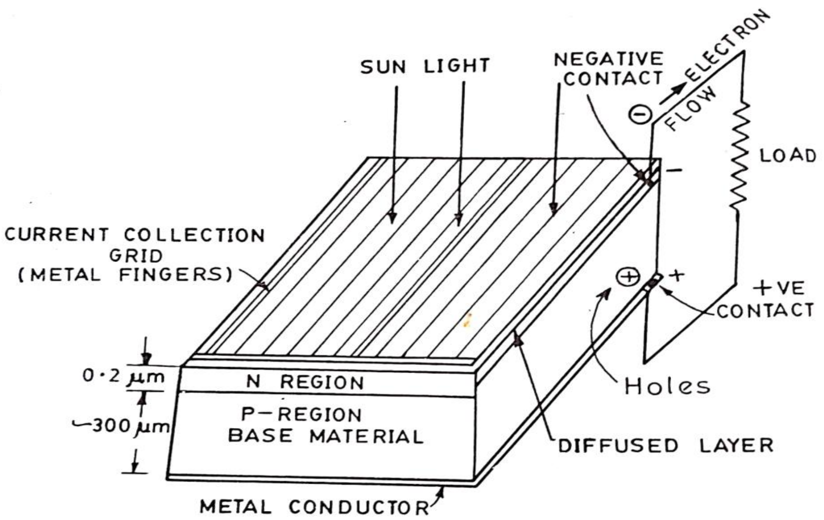


Fig. 5.6.1. Schematic view of a typical solar cell.

The rate at which solar energy reaches the top of the atmosphere (i.e., the solar constant) is 1.353 kilowatts/sq. m (1.353 kW/sq. m). Part of this energy is reflected back to the space, and part is absorbed by the atmosphere. In full sunlight, the solar energy may reach the ground at a rate of roughly 1 kW/sq. m.

2.10.3 A Basic Photovoltaic System for Power Generation

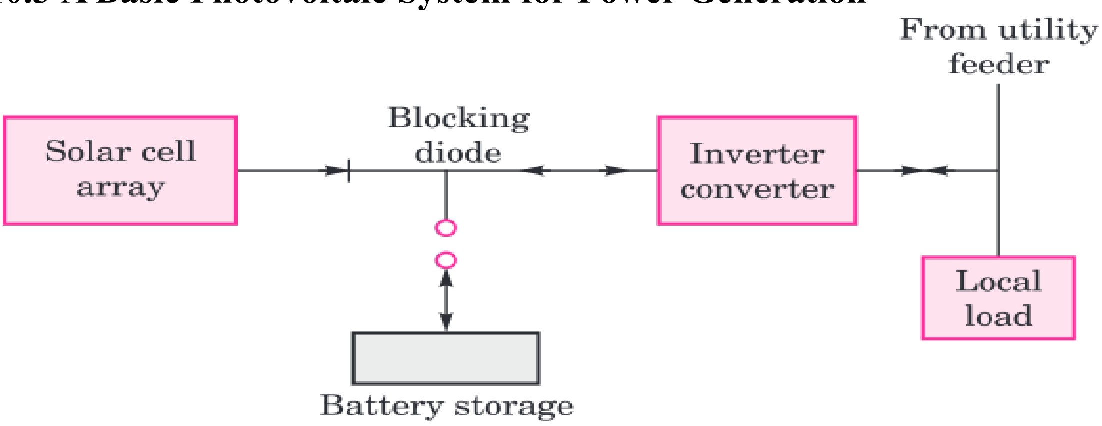


Fig. 5.25. Basic photovoltaic system integrated with power grid.

A basic photovoltaic system integrated with the utility grid is shown in Fig. It permits solarly generated electrical power to be delivered to a local load. It consists of:
(i) Solar Array: converts the insolation to useful DC electrical power.
(ii) A Blocking Diode: which lets the array-generated power flow only toward the battery or grid. Without a blocking diode the battery would discharge back through the solar array during times of no insolation
(iii) Battery Storage: solar generated electric energy may be stored.
(iv) Inverter/converter: converts the battery bus voltage to AC of frequency and phase to match that needed to integrate with the utility grid. Thus it is typically a DC, AC inverter. It may also contain a suitable output step up transformer, filtering and power factor correction circuits, power conditioning, i.e., circuitry to initiate battery charging and to prevent over charging.
(v) Appropriate switches and circuit breakers: to permit isolating parts of the system as the battery and breakers protect PV system and grid

2.10.4: Applications of Solar Photovoltaic System

The terrestrial applications of these include provision of power supply to:
(i) water pumping sets for micro irrigation and drinking water supply,
(ii) radio beacons for ship navigation at ports,
(iii) community radio and television sets,
(iv) cathodic protection of oil pipe lines,
(v) weather monitoring,
(vii) battery charging,
(vi) railway signalling equipment,
(viii) street lighting.
The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of:
(a) a photovoltaic (P V) array,
(c) power control equipment,
(b) storage battery,
(d) motor pump sets, and
(e) water storage tank.

2.10.5: Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages:
(i) Direct room temperature conversion of light to electricity through a simple solid state device.
(ii) Absence Of moving parts.
(iii) Ability to function unattended for long periods as evidence in space programme.
(iv) Modular nature in which desired currents, voltages and power levels can be achieved by mere integration.
(v) Maintenance cost is low as they are easy to operate.
(vi) They do not create pollution.
(vii) They have a long effective life.
(viii) They are highly reliable.
(ix) They consume no fuel to operate as the sun's energy is free.
(x) They have rapid response in output to input radiation changes; no long- time constant is involved, as on thermal systems, before steady state is reached.

(xi) They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays. Solar cells can be used in combination with power conditioning circuitry to feed power into utility grid.
(xii) They are easy to fabricate, being one of the simplest of semi conductor devices.
(xiii) They have high power to weight ratio, this characteristic is more important for space applications than terrestrial, may be favourable for some terrestrial applications,
(xiv) Amenable to on site installation- decentralised power
(xv) They can be used with or without sun tracking for wide range of applications

Disadvantages:
High cost
Energy storage is required because of no insolation at night.
Efforts are being made world-wide to reduce costs through various technological innovations.