# Non-Conventional Energy Resources
## Unit-II

**Solar Thermal Energy:** Solar radiation, flat plate collectors and their materials, applications and performance, focusing of collectors, solar thermal power plants, thermal energy storage for solar heating and cooling, limitations.

**2.1 Solar Radiation:** The solar radiations received by the earth's surface depends on various factors, like location, weather conditions, climate, absorption, reflection, scattering and attenuation by aerosol, particulates present in the atmosphere. The solar radiation may be explained in two categories:

**2.1.1 Extraterrestrial Solar Radiation:** The intensity of sun's radiation outside the earth's atmosphere is called extraterrestrial radiation. It has no diffuse components. The radiations are measured as an average earth-sun distance on a surface normal to radiation. The energy flux is called solar radiation and may be defined as:

**"The energy received from the sunper unit time on a unit area of surface, perpendicular to the direction of propagation of the radiation at the earth's mean distance from the sun outside the atmosphere."**

*It is denoted by $I_{SC}$ and is estimated as*1367 W/m$^2$.

1. The value of solar constant remains constant throughout the year.
2. Its value changes with location.

The extraterrestrial radiation observed on different days is known as apparent extraterrestrial solar radiation (irradiance) and can be calculated on any day of year with given equation:

$$I_{O=}I_{SC}\left[1 + 0.033cos\frac{360n}{365}\right]$$

$I_O$ = apparent extraterrestrial solar irradiance (W/m$^2$)
$n$ = No. days of the year
$I_{SC}$ = 1367 W/m$^2$ (approx)

**2.1.2 Terrestrial Solar Radiation:** The radiations receive on the earth surface is called the terrestrial radiation and is nearly 70% of extraterrestrial solar radiation. Its maximum value on horizontal earth surface is 1000 W/m$^2$, because a large part of radiations are absorbed, reflected, attenuated back by earth's atmosphere.

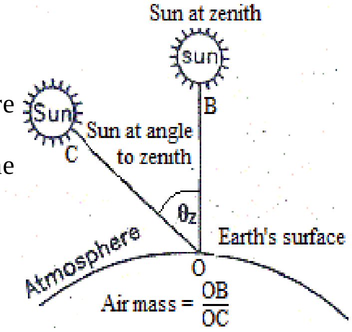
**(A) Direct or Beam Radiation ($I_b$):** The radiation received on the earth's surface directly without change in direction and does not get absorbed, reflected and scattered while passing through atmosphere.

**(B) Diffuse radiation ($I_d$):** The radiation received on earth surface at a location from all the directions. This radiation changes the original direction after scattering, reflection in the atmosphere as well as by ground surface. Its average value is nearly 20% in the morning hrs and decreases to 5-10% of the total radiation during the clear day but increase in the hazy and cloudy conditions of sky.

**(C) Total or Global Radiation ($I_t$):** The sum of beam and diffuse radiation intercepted at the surface of the earth per unit area of location is called the total /global radiation or insolation: $\mathbf{I_t = I_b + I_d}$

**2.2 Air Mass:**

- It is a term used to assess the distance travelled by a beam radiation through the atmosphere before reaching the location on the earth's surface.
- It is defined as the ratio of the path of the sun's ray through the atmosphere to the length of the path when the sun is directly over head or sun is at its zenith.
- Air mass(m) = $\frac{path\ of\ the\ sun's\ ray\ through\ atmosphere}{The\ length\ of\ the\ path\ when\ sun\ is\ derectly\ over\ hear}$




**2.3 Basic Sun-Earth Angles:**

**2.3.1. Angle of latitude of a particular location (□):** It is the vertical angle between the line joining that point of location to the centre of the earth and its projection on an equatorial plane. It is 0$^0$ for a point on the equator and ±90$^0$ for a point at the poles.

**2.2.2. Declination angle (δ):**It is the angle made between the line joining the sun to earth and its projection on the equatorial plane. Due to the inclination of earth's axis, the line joining the Sun and Earth will not lie on the equatorial plane. It varies through the year from + 23.45$^0$ to -23.45$^0$.

Its value can be calculated as: $\delta = 23.45sin\frac{(284+n)\times 360}{365}$; n = no. of days in year

**2.3.3. Hour angle (ω):** It is the angle representing the position of the sun with respect to clock hour and with reference to sun's position at 12 noon. In other words it represents the angle through which the earth must rotate so that the meridian at a point comes into alignment with sun's rays. It is a constant and equal to 15$^0$/hr.

**2.3.4. Solar altitude angle (α):** It shows a horizontal plane drawn at any place on earth.At any point the line joining sun to the centre of this horizontal plane and the line joining the projection of sun and the centre of the horizontal plane makes a vertical angle α, which is called the **altitude angle.**

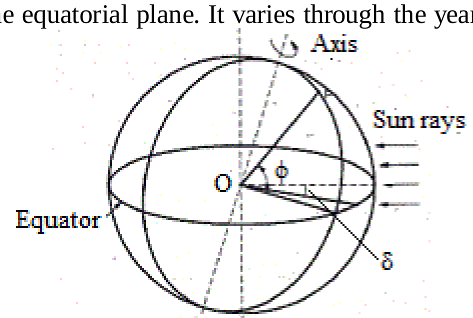



Fig. Sun Earth angles

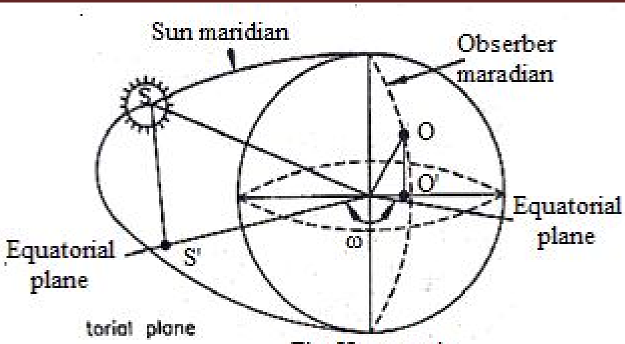



Fig. Hour angle

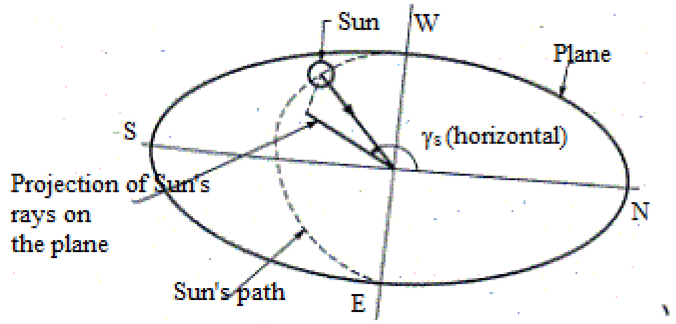



Fig. Solar azimath angle ($\gamma_s$)

**2.3.5. Zenith angle ($\theta_Z$):** If a vertical line is drawn to this horizontal plane, at its centre, the line joining sun and the centre of the plane will make an angle $\theta_Z$ with this vertical. This angle is called the **zenith angle.**

**2.3.6. Local solar time (LST):** This is also called **Local Apparent Time (LAT)** $t_d$ calculated using various values of $\theta_Z$. The time so calculated the **Local Solar Time.**This will vary from the actual clock time by approximately 4 minutes. This variation changes with the month of the year.

**2.4Solar Thermal Energy:** The application of solar thermal energy ranges from solar cooker of 1 kW to power plant of 200 MW. These systems are grouped into **low temperature (< 150$^0$C), medium temperature (150$^0$ - 300$^0$C) and high temperature (500$^0$ – 1000$^0$C).**

**2.5Solar Collectors:**

- Solar collectors are used to collect the solar energy and convert the incident radiations in thermal energy by absorbing them.
- This heat is absorbed by flowing fluid in the tube of collector.
- These are of two types: **1. Non concentrating collectors, 2. Concentrating collectors.**

**2.5.1Non concentrating collectors:** In these collectors the area of collector to intercept the solar radiation is equal to the absorber plate and has concentration ratio of 1. These can be categorized as:

**2.5.1(a) Flat Plate Collectors:**

- These are the most important part of any solar thermal energy system.
- It is simplest in design and absorbs direct and diffuse radiations both and converts it into useful heat.
- It is suitable for heating to temperature below 100$^0$C.

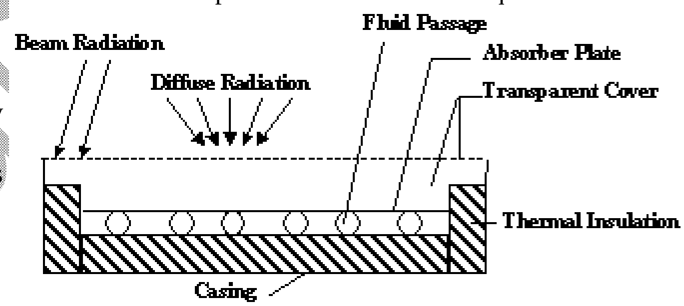



Fig. Liquid Flate plate collector

| Advantages | Disadvantages |
|---|---|
| **1.** Utilizes the both the beam as well as diffuse radiation for heating | **1.** Large heat losses by conduction and radiation. |
| **2.** Less maintenance requires | **2.** No tracking of sun. |
| | **3.** Low water temperature is achieved. |

**2.5.1(b) Vacuum Tube Collectors:**

- Looks like fluorescent lamp contains several individual parallel glass tubes.
- Each tube contains an absorber tube bounded to a heat pipe, covered with selective coating and suspended in vacuum.

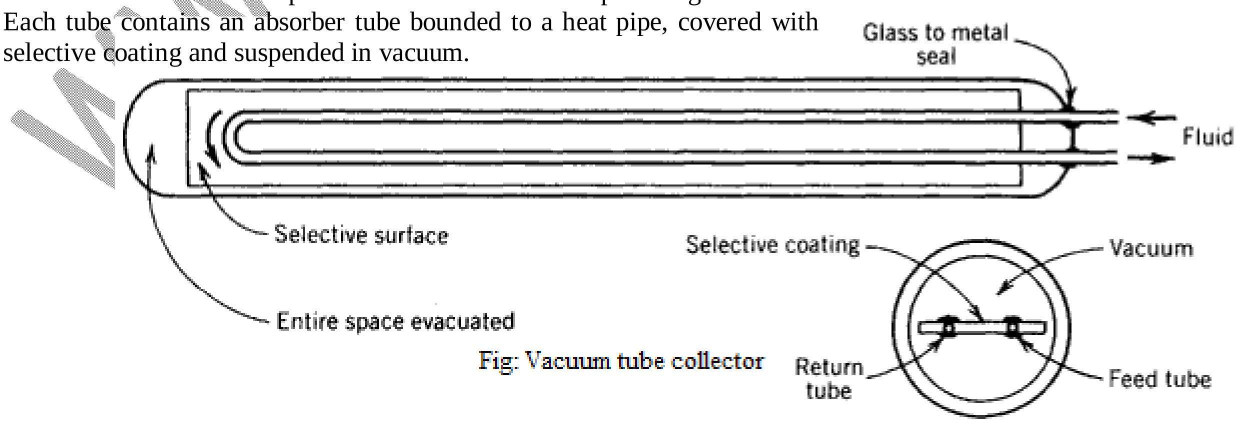
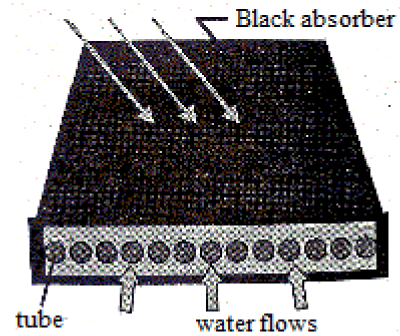



Fig: Vacuum tube collector

- These tube collectors are more efficient than flat collectors because they perform well in both direct and diffuse solar radiation.
- These collectors are best suited for moderate temperature applications where the demand temperature is above $95^0$C and very cold climates.

**2.5.1(c) Unglazed Flat Plate Collectors:**




- Specially designed for low-temperature applications such as the heating of swimming pools etc where demand of temperature is at below $30^0$C.
- Made-up of either rubber or UV- stabilized black polymer plastic.
- A large portion of sun's energy is absorbed and lost both due to the absence of glazing.
- Having life span of 15-20 years.

**2.5.2 Construction and Materials for Flat Plate Collectors:**

Material needed for flat plate collectors can be classified into following groups:

- Physical properties – tensile strength, density etc.
- Thermal properties – thermal conductivity, heat capacity etc.
- Environmental properties – corrosion resistant, degradation of material due to UV radiation, moisture penetration etc.

The materials generally used for various components of a flat plate collector are as given below:

**(a) Absorber Plate and Tubes:**

- These plates should have high tensile strength; high thermal conductivity and it should be corrosion resistant (generally made of copper, aluminum, steel etc).
- Generally black chrome, black copper oxides, black nickel etc are used for its coating to having high absorptivity.

**(b) Thermal Insulation:**

- The material used for insulation should have low thermal conductivity, stability at high temperature up to $200^0$C, non-corrosive.
- Insulating materials generally used are mineral wool, rock wool, glass, thermo Cole, foam etc.

**(c) Transparent Cover Plates:**

- Cover plates must have high strength, high solar energy transmittance and high durability against UV radiation.
- Usually plain glass plates or toughened of 4 to 5 mm thickness are used.

**(d) Casing:**

- This contains all the above components which is placed at an angle facing south at an inclination to the horizontal equal to the latitude of the place plus $15^0$.
- It is made of aluminum, steel or fiber glass in rectangular shape.

**(e) Selective Coating:**

- This surface has high absorptivity of incoming solar radiation and low value of emissivity.
- Selective surfaces are essential to reduce the heat losses from absorber plate and increase the temperature of absorbing surface *i.e.* it should have high collector efficiency.
- Various methods of these coatings which are employed are by electroplating, anodic oxidation, chemical conversion etc.
- Generally Black chrome, black nickel, aluminum nitride etc are used for this purpose.

**2.5.3Performance of Flat Plate Collectors:**

**(a) Fin Efficiency Factor (F):**

$$F = \frac{Actual\ rate\ of\ heat\ transferred\ to\ tube\ base}{Heat\ transferred\ if\ fin\ area\ at\ base\ temprature} = \frac{Q_{act}}{A_C[\alpha_0\tau_0 I_t - U_L(T_p - T_a)]}$$

- It indicates the effectiveness of a fin in transferring the thermal energy to the tube from the projected plane.
- It is defined as a ratio of actual heat transferred to the heat temperature.It is represented by letter F.

Where: $Q_{act}$ = actual rate of heat transferred to tube base (W/m$^2$)
$A_C$ = collector area (m$^2$); $I_t$ = incident total radiations (W/m$^2$); $U_L$ = overall heat loss coefficient (W/m$^2$ $^0$C);
$T_p$= plate temperature ($^0$C); $T_a$ = ambient temperature ($^0$C); $\alpha_0\tau_0$ = product of absorptivity and transmitivity;
$\alpha_0\tau_0 I_0$ = heat energy absorbed by collector / area (W/m$^2$); $U_L(T_p - T_a)$ = overall heat loss / area (W/m$^2$).

**(b) Collector Efficiency Factor (F'):**

$$F' = \frac{Actual\ rate\ of\ heat\ transferred\ to\ fluid}{Rate\ of\ heat\ transferred\ to\ the\ fluid, if\ the\ fin\ is\ at\ local\ fluid\ temprature} = \frac{Q_u}{A_C[\alpha_0\tau_0 I_t - U_L(T_f - T_a)]}$$

- It is defined as the ratio of useful heat removed by flowing fluid in the tubes to the heat removed with assumption that collector absorbing plate is at local fluid temperature ($T_f$) throughout.
- This factor is constant for given collectors and depends on design and flow rate of fluid through tubes.
- Decreases with increase in spacing between the tubes and increases with thermal conductivity of material and its thickness.

**(c) Collector Heat Removal Factor ($F_R$):**

- It is defined as a ratio of actual useful energy gain by fluid to the energy gain if the entire collector is at fluid inlet temperature.
- It reduces the actual useful heat gain by flowing fluid in the tube.

$$F_R = \frac{Actual\ rate\ of\ heat\ absosbed\ by\ fluid}{Rate\ of\ heat\ transferred\ to\ the\ fluid, if\ the\ fin\ is\ at\ inlet\ fluid\ temprature} = \frac{mC_f(T_{fo} - T_{fi})}{A_C[\alpha_0\tau_0 I_t - U_L(T_{fi} - T_a)]}$$

Where: $T_{fo}$= outlet fluid temperature; $T_{fi}$= inlet fluid temperature ($^0$C); $m$ = mass flow rate of fluid (Kg/s); $C_f$ = specific heat capacity of fluid (KJ/Kg K).

**(d) Collector Efficiency (η):**

- It is the ratio of useful energy absorbed by collector to the incident solar energy over it.

$$\eta = \frac{Q_u}{A_c I_t}$$

**2.5.4 Factor Affecting the Performance of Flat Plate Collectors:**

**(a) Incident Solar Radiation:** As the solar flux increases, the heat absorbed by the collector increases, thereby the performance of the collectors improves.

**(b) Selective Surfaces:** By using materials for surfaces which are highly sensitivity to the radiation, the absorption could be maximized. The selective surface should able to withstand high temperature of 300$^0$-400$^0$C should not oxidize and be non-corrosive.

**(c) Number of Cover Plates:** The increase in number of cover plate reduces the internal convective heat losses but also prevents the transmission of radiation inside the collector. More than two cover plate should not be used to optimize the system.

**(d) Spacing between Absorber Plates and Glass Cover:** The more space between the absorber and cover plate the less internal heat losses. The collector efficiency will be increased. However on the other hand, increase in space between them provides the shading by side wall in the morning and evening and reduces the absorbed solar flux.

**(e) Collector Tilt:** The flat plate collectors do not track sun and should be tilted at angle latitude of the location for an average better performance. The collector is placed with south facing at northern hemisphere to receive maximum radiation throughout the day.

**(f) Fluid Inlet Temperature:** As the inlet temperature of the fluid increases, the operating temperature of the collector increases. This lead to increased losses and decrease in efficiency.

**(g) Dust on Cover Plate:**The efficiency of collector decreases with dust particles on the cover plate because the transmission radiation decreases by 1%. Frequent cleaning is required to get the maximum efficiency of collector.

**2.6 Concentrating Type Collectors:**

- These types of collectors are also known as **focusing collectors.**
- These are used for medium (100-300$^0$C) and high temperature (above 300$^0$C) application such as steam production for the generation of electricity.
- The collector system comprises of a concentrator and absorber (receiver). The concentrator is an optical system in the form of reflecting mirrors or reflecting lenses.
- The collector is installed with a tracking device for continuously following the sun.
- The receiver includes an energy absorbing surface, transparent cover and other accessories.
- The system receives the solar radiation on the large concentration area and focused it on to a an absorber having relatively much lesser area.
- These systems have high collector efficiency which lies between 50-70%.

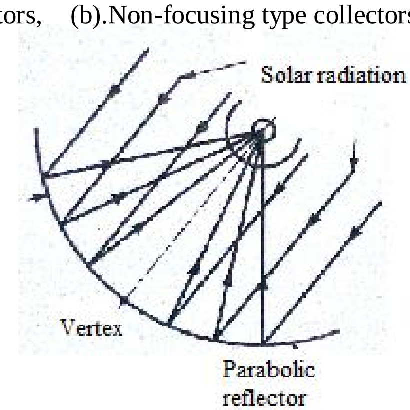
**2.6.1Types of Solar Concentrating Collectors:**

These are further divided into two categories (a). Focusing type or concentrating type collectors, (b).Non-focusing type collectors.

**2.6.1(a) Focusing Type Concentrator:**

**1.** Parabolic trough reflector, **2.** Mirror strip reflector,
**3.** Fresnel lens collector, **4.** Parabolic dish collector

**1. Parabolic Through Reflector:**



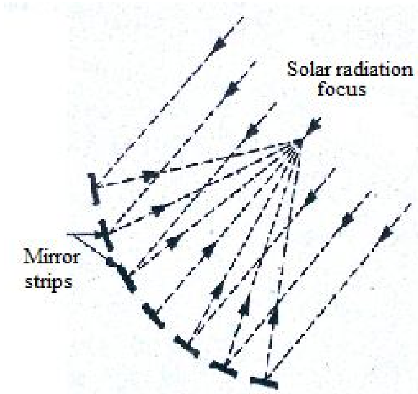

- This type is line focusing type collector.
- In this type of collector, the solar radiations falling on the area of the parabolic reflector are concentrated at the focus of parabola.
- These are usually made of highly polished or glass like shine surfaces.
- The temperature at the absorber tube is obtained at nearly 400$^0$C.
- Because of its parabolic shape, it can focus the sun at 30 to 100 times its normal intensity on a receiver.

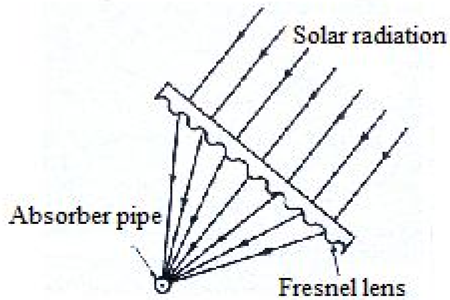
**2. Mirror Strip Reflector Type Concentrating Collector:**

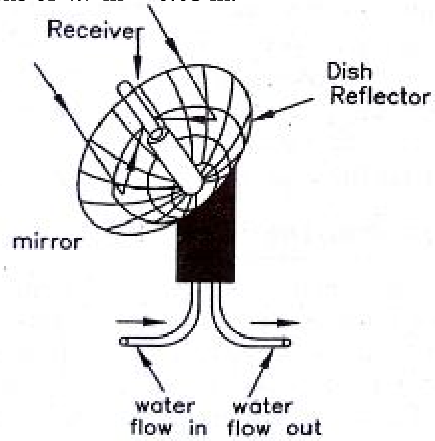
- It has the plane or slightly curved mirror strips mounted on a flat base.
- The individual mirrors are placed at such an angle that reflected solar radiations fall on the same focal line where the absorber pipe is placed.
- The collector pipe is rotated so that the reflected rays on the absorber remain focused with respect to changes n sun’s elevation.

**3. Fresnel Lens Concentrating Collector:**

- In this collector a Fresnel lens which consists of fine, linear grooves on the surface ofrefracting material of optical quality on one side and flat on the other side is used.
- The solar radiations which fall normal to the lens are refracted by the lens and are focused on a line where the absorber (receiver) tube is placed.
- A Fresnel lens collector is generally made of acrylic plastic sheets having overall dimensions of 4.7 m × 0.05 m.




**4. Parabolic Dish Collector:**

- It is point focusing type collector which have a mirror like reflectors and an absorber at the focal point.
- The concentrating ratio of these collectors is 100 and temperature of the receiver can reach up to 2000$^0$C.
- These collectors have higher efficiency for converting solar energy to electricity in the small-power plant.

**2.6.1(b) Non-Focusing Type Collectors:**

1. Flat plate collector with plane reflector, 2. Compound parabolic concentrator

**1. Flat Plate Collector with Plane Reflector:**

- It uses a flat plate collector with plane mirror reflector attached on its edges to reflect the additional solar radiations into the receiver, thus the total solar radiation received by the receiver are increased. The mirrors used are called booster mirrors.
- These collectors utilize direct and diffuse both types of radiations and achieved fluid temperature higher by 30$^0$C than in FPC.

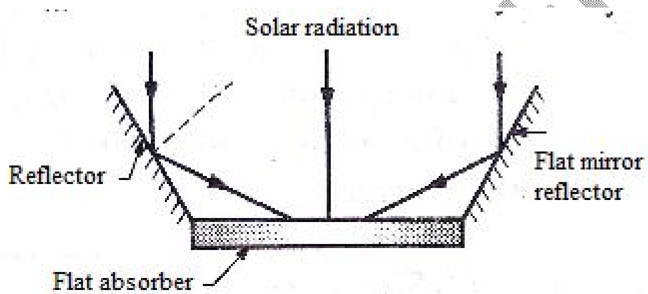


Fig. Flat Plate collector with plane mirror reflector

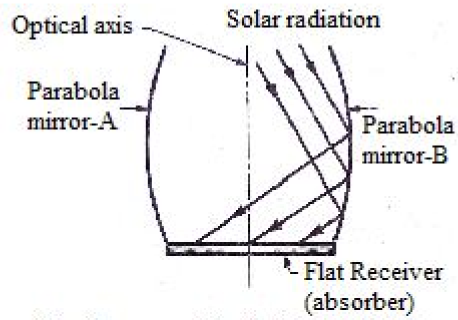


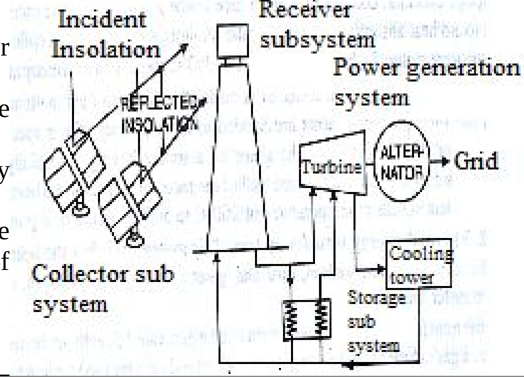
Fig: Compound Parabolic concentrator

**2. Compound Parabolic Concentrator (CPC):**

- It is also called Winston collectors. It consists of two facing parabolic mirror segments attached to a flat receiver (absorber).
- It collects both direct and diffuse solar radiation with high acceptance angle and requires occasional sun tracking.
- The temperature attained is in the range from 100$^0$C to 150$^0$C. However temperature up to 200$^0$C can be achieved using evacuated type of tubular absorber.

**3. Center Receiver Type (Solar Power Tower):** There is one more type of solar collectors, known as solar power tower.

- This system uses 100-1000 of flat tracking mirrors called heliostats to reflect the large solar energy at one point (receiver).
- Each heliostat is rotated into two directions so as to track the sun and they together behave like a broken very large parabolic reflector.
- A concentration ratio up to 3000 can be achieved with this system and capable to generate steam of high pressure and high temperature suited for generation of electricity in steam power plants.



**2.6.2Advantages & Disadvantages of concentrating Collectors Over Flat Plate Collectors:**

| Advantages | Disadvantages |
|---|---|
| 1. Cost of concentrator system/unit area is less. | 1. System needs tracking of sun which increases the capital cost. |
| 2. Requires less absorber area. | 2. Diffuse solar radiations cannot be collected on receiver. |
| 3. Has high collection efficiency since heat losses are less. | 3. Requires higher maintenance to retain the quality of reflecting surfaces. |
| 4. Suitable for large power generation since high temperatures of the fluid can be attained. | 4. Has high initial cost and maintenance cost. |

**2.7Solar Thermal System:** A solar thermal system is use to convert solar energy into other forms of energy which may be utilized for various applications like: 1. Heating water for domestic use and for swimming pools; 2. Heating and cooling of buildings; 3. Day lighting of buildings; 4. Cooking food; 5. Solar distillation (water treatment etc); 6. Electricity generation; 7. Powering earth satellites etc.

**2.7.1Solar Thermal Power plant:** A solar power plant converts solar energy into electrical energy. They can be divided into following categories: **1.** Low temperature solar power plant using flat plate collectors

**2.** Medium temperature solar power plant using concentrated solar collectors

**3.** High temperature solar power plant using tower system.

**1. Low Temperature Solar Power System:**

- The low temperature solar power plants use the working fluid temperatures in the range of $60^0$C to $100^0$C which can be obtained using flat plate collectors.
- Since the water can be only heated $80^0$C in FPC, the systems needs to use a working fluid having low boiling temperature like butane gas.
- The cold water is circulated into the collector with the help of a circulating pump.
- The heated water is circulated in a heat exchanger called butane boiler, where it generates the butane gas at high pressure. This butane gas supplied to a butane turbine to produce mechanical power due to expansion of butane gas.
- The vapour coming out of the turbine is condensed in a condenser and sent back for recirculation with the help of feed pump.
- The mechanical power output of turbine is converted into electric power by generator.

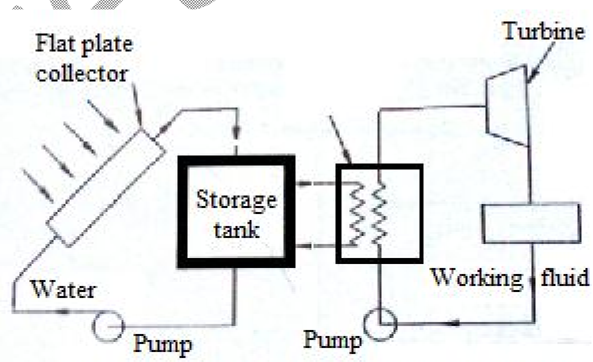


Fig. Working of low temprature solar power plant

**2. Medium temperature Solar Power Plant:**

- These systems employ an array of parabolic through concentrating collectors spread over a large area.
- The general range of working temperature is between $250^0$C to $400^0$C.
- The working fluid, usually water, is heated as it circulates through the receivers.
- This heat is transferred to storage tank and fed to water where the steam is generated in the steam generator.
- This steam is utilized to run a turbine coupled to a electric generator, which converts it into electrical energy by electro-mechanical energy conversion.
- The exhaust of steam turbine is condensed in the condenser with the help of cold water circulated in the condenser.
- A 30 MW plant have been installed in Rajasthan under the department of non-conventional energy sources.

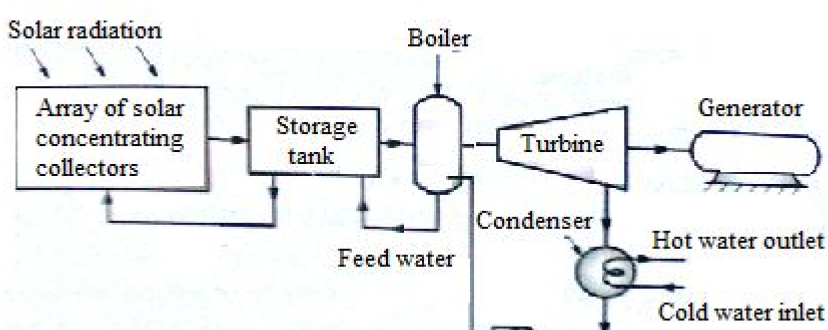


Fig. Medium temprature solar power plant

**3. High Temperature Solar Thermal Power Plants:**

- Such plants use heliostatsand have high thermal efficiency, can build in the capacity of 50 MW to 200 MW.
- The solar dish collectors receive solar radiations which are collected at a common focusing point. Small volumes of the fluid are heated at this point high temperature.
- In central tower receiver an array of plane mirrors called heliostats which are individually controlled and tracked to reflect the solar radiations on a receiver kept on a tower of tower of about 500 m height.
- The feed water in the absorber-receiver called boiler is converted into high steam of about $600^0C$- $700^0C$.
- This steam is supplied in a conventional steam power plant coupled to an electric generator to generator electrical power.

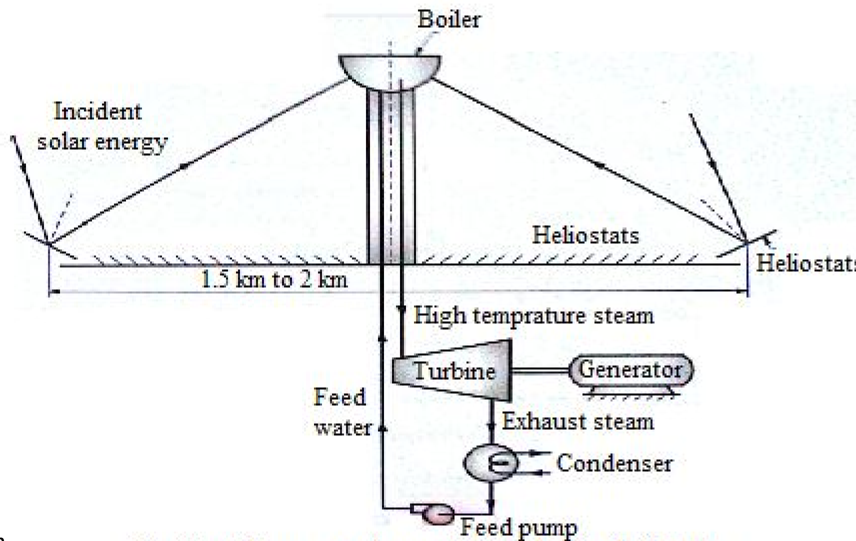


Fig. Central tower receiver power plant using heliostats

**2.7.2 Solar Pond:**

- The concept of solar pond is based on the observation that some natural lakes have higher temperature at bottom where salt concentration is higher.
- The heat of hot brine solution from solar pond is used to evaporated the working substance at constant pressure in the boiler.
- This vapour is used to run the vapour turbine to produce mechanical power is utilized to run a generator to produce the electrical power.
- The exhaust of the turbine is condensed in the condenser at constant pressure with the help of cooling water.
- The condensate is returned to the boiler by a pump. Thus the cycle is repeated.

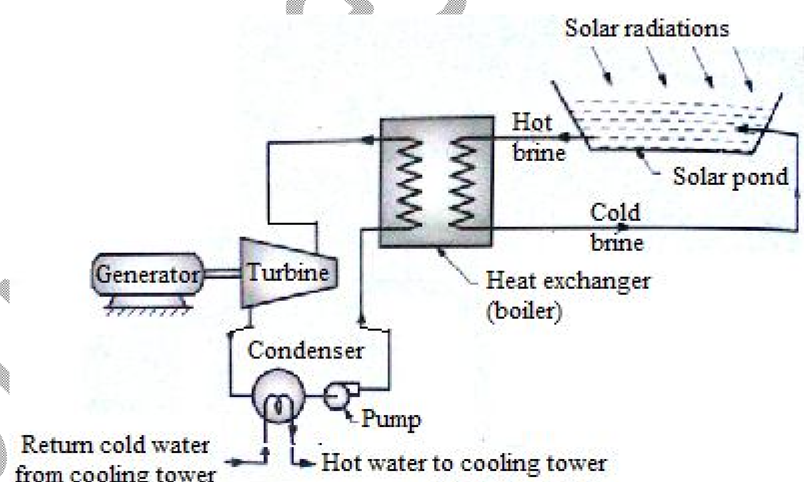


Fig. Solar pond

**2.7.3 Solar Water Heater:**

- The solar water heaters are used to raise the temperature of water and store it for various purposes as when needed.
- It consists of the following main components connected with the help of insulated piping:

(i) Flat plate collector (ii) Storage tank
(iii) Heat exchanger (iv) Pump

- The water is heated in the flat plate collectors. The low temperature water is fed from bottom side of collector and high temperature water is taken out from the top of the collector.
- The storage tank is insulated to retain the heat of water with minimum losses. The heated water is stored in the tank for further use.
- The heat exchanger is incorporated between the collector and storage tank. It is installed and good quality of water is used in primary cycle of the collector.
- Pumps are used for circulation of fluid.

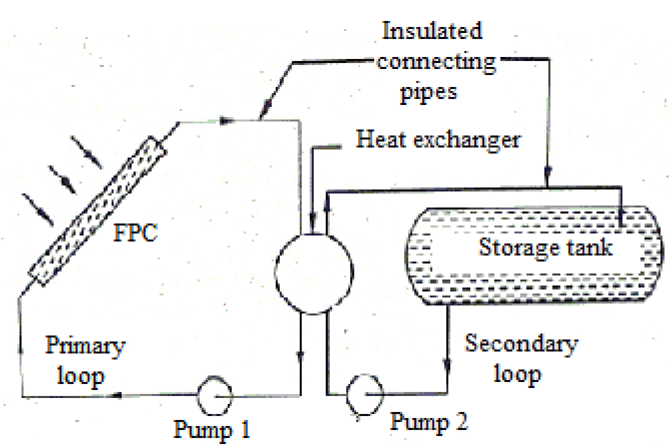


Fig. Water heating system (with heat exchanger)

**2.7.4 Solar Cooling System:**

- The cycle used for cooling with utilization of solar energy is vapour absorption cycle is used in remote area having scarcity of power.
- The performance of vapour absorption system depends upon the working fluid pair *i.e.* refrigerant and absorbent.
- The absorption systems are classified as:

(a)Ammonia/water absorption system
(b)Ammonia/water/hydrogen Electrolux absorption system
(c)Lithium bromide (Libr)/water absorption system.

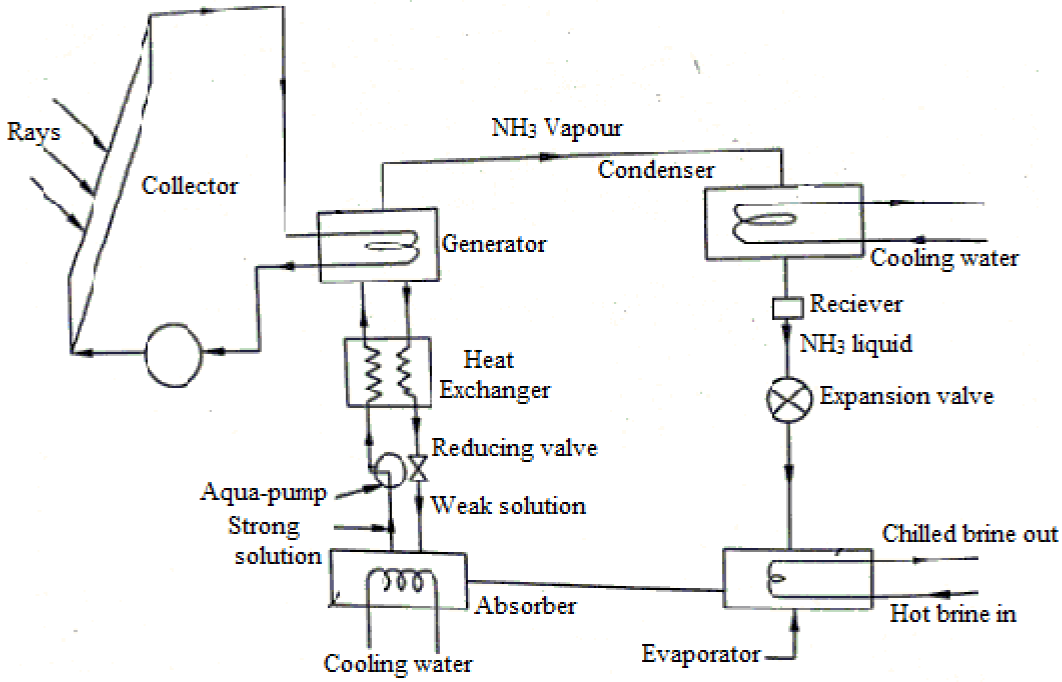


Fig. Solar cooling system

**Simple Ammonia/Water Absorption System**

- The most commonly used refrigerant in absorption system is ammonia. It is cheap and readily available and has great affinity with water is used as absorbent and absorbs $NH_3$ very fast.
- The ammonia-water absorption system is used for cooling duties up to -$50^0$C. The heat required in generator is supplied by water heated in FPC.
- Its main components and their working can be explained as:

**(a)The Absorber:** The absorber acts as a suction pump. The water is used as absorbent to absorb the low-pressure suction vapour of $NH_3$ coming out of evaporator. During absorption the ammonia discharges its latent heat of condensation to the water which raises its temperature. Thus it is always desirable to cool the absorbent solution by cooled circulated external water or by means to keep the absorbent temperature as low as possible.
**(b) Pump:** The $NH_3$ rich solution from the absorber is pumped to the generator by means of using small capacity pump. The pump raises the pressure of mixture.
**(c) Generator:** The heat from collector is supplied to the generator to boil off the rich mixture of $NH_3$/water.
**(d) Pressure Reducing Valve:** The weak solution left in the generator at condensed pressure is returned back to absorber through pressure reducing valve. The pressure reduces from condenser pressure to absorber pressure.
**(e) Condenser:** The high pressure ammonia vapour leaving the generator gets condensed in water-cooled condenser.
**(f) Expansion Device:** The condensed liquid ammonia from condenser is supplied through expansion device to evaporator. The Expansion device lower the pressure and temperature of liquid ammonia.
**(g) Evaporator:** Low temperature and low pressure liquid ammonia enters in the evaporator where it boils of by absorbing latent heat from surrounding to produce refrigeration effect. The liquid $NH_3$ changes to low pressure suction vapour. The suction vapour is absorbed in absorber to maintain the continue circulation of $NH_3$ in system.