Solar collectors :-

Solar power has low density per unit area i.e $1 kw/m^2$ to $0.1 kw/m^2$. Hence it is collected by solar thermal collectors.

It absorb solar energy as heat & then transfers it to the heat transport fluid efficiently It delivers this heat to a thermal storage tank / boiler / heat exchanger to be utilized in the subsequent stages of the system.

Classification :-

The classification is based on the way they collect solar radiation.

- Solar collectors
  - Non concentrating (Flat-plate collectors)
    - a) Liquid flatplate collector
    - b) Flat-plate airheating collector
  - Concentrating type
    - Focus type
      - Line focus (one axis tracking)
        - a) cylindrical parabolic
        - b) Fixed mirrors solar concentrators
        - c) linear fresnel lens
      - Point focus (two-axis)
        - a) Paraboloidal dish
        - b) Hemispherical bowl
        - c) circular fresnel lens
        - d) central tower reciever
    - Non-focus type
      - a) modified flat-plate
      - b) compound-parabolic

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→ A flat plate collector is simple in construction & does not require sun tracking. As the collector is installed outdoors & exposed to atmospheric distrubances, the flat plate collector requires little maintanance.

The performance of a solar collector is evaluated on the basis of these features.

① Collector effeciency :-

It is defined as the ratio of energy actually absorbed & transferred to the heat-transport fluid by the collector (useful energy) to the energy incident on the collector.

② Concentration Ratio [CR] :-

It is defined as the ratio of the area of aperture of the system to the area of the receiver. The aperture of the system is the projected area of the collector facing the beam.

③ Temperature Range :-

It is the range of temperature to which the heat-transport fluid is heated up by the collector.

→ In flat-plate collectors concentration ratio (CR=1) temperature range is less than 100°c.

→ Line focus collectors have CR = 100, temperature is 150°c - 3

→ point focus collectors have CR = 1000, temperature is 500°c - 10

Differences between Flatplate & Concentrating collectors

	Flatplate collector	Concentrating collector
1.	These collectors are also called non-concentrating type collectors	1. These collectors are also called focusing type solar collectors.
2.	In this type of collectors, the collector area is equal to the absorber area	2. In this type of solar collecti the collector area is very large that of absorber area.
3.	The working fluid in this type of collectors does not attain high temperature.	3. The working fluid in this type of collectors attain very high temperature
4.	There is no use of mirrors & lens to concentrate sun's rays.	4. For focusing the sun's radiation, an arrangements o lenses & mirrors are designe
5.	Effeciency is low	5. Effeciency is high
6.	These collectors are cheaper	6. These collectors are expensive.
7.	The absorber gets uniform radiation	7. The absorber gets non-uni solar radiation.
8.	The intensity of insolation is small	8. The intensity of insolation is large

⊛ Effect of various parameters on performance :-

The various parameters are

① Selective surface :- Absorber plate surfaces which exhibit characteristics of a high value of Absorptivi for incoming solar radiation & low value of emissivi for outgoing radiation. Selective surface layers ar copper oxide, nickel black & black chrome.

② Number of covers :-

With the increase in the number of covers, the Transmittivity & Absorptivity are decreases. so maximum effeciency is obtained with one or two covers.

③ Spacing :- Heat loss also varies with spacing between two covers & that between the absorber plate & first cover. so, the spacing between the covers is 4 to 8cm.

④ Collector tilt :- Flat plate collectors are normally us in a fixed position & do not track the sun. The usual practice is recomended a value of $(\phi+1$ or $(\phi+15^\circ)$ for winter applications. & $(\phi-10^\circ)$ or $(\phi-15^\circ)$ for summer applications.

⑤ Dust on the top of the cover :-

When a collector is deployed in a practical system, dust gets accumulated over it, reducing the transmitted flux through the cover. This requires continuous cleaning of the cover, which is not possible in a practical situation. cleaning is generally done once in a week.

⑥ Inlet of fluid temperature :-

fluid temperature is high, efficiency also high, otherwise it is low.

⑦ Collector Efficiency factor :-

It is defined as the ratio of actual useful heat collection rate to the useful heat collection rate. Its value ranges from 0.90 to 0.95.

— . —

① Liquid Flat-plate collector :-

→ A flat-plate collector is placed at a location in a position towards south to have maximum collection.

→ The basic elements in these collectors are

① Transparent cover (one or two sheets) of glass & plastic

② blackend absorber plate usually of copper, Alumini

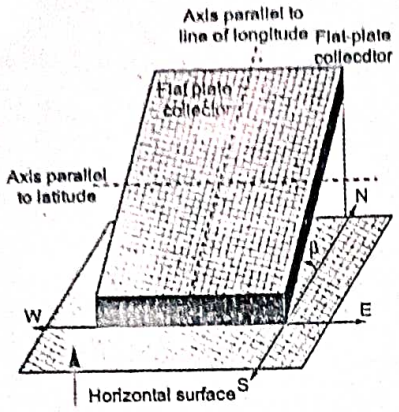


Fig. 5.2 Positioning of flat-plate collector

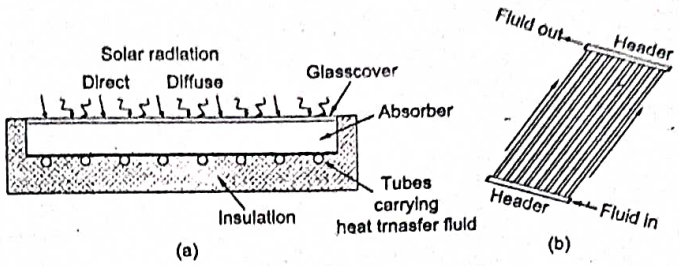


Fig. 5.3 Construction of flat-plate collector

③ Tubes, channels & passages in thermal contact with the absorber plate.

④ weather tight, insulated container to enclose the above components.

→ A liquid, most commonly water, is used as the heat-transport medium from the collector to the next stage of the system.

→ As solar Radiation strikes on a metallic absorber plate, it is absorbed & raises the plate tempera The plate thickness from 0.2 mm to 1mm

→ The metallic tubes range in diameter from 1t 1.5cm.

→ In the bottom & along the side walls, thermal insulation provided by a 2.5cm – 8cm thick. to prevent heat loss.

→ Anti-Reflective coating on the outer surface o the glass is provided to avoid Reflections.

→ Usually 1 & 2 covers with spacing ranging fro 1.5 to 3cm are used.

Flat-plate Air-heating collector [Solar Air heater] :-

A solar Air-heating collector is similar to a liqui flat-plate collector with a change in the configuratio of the absorber & tube.

→ The principal applications of these collectors are drying for agricultural & industrial purposes & space heating.

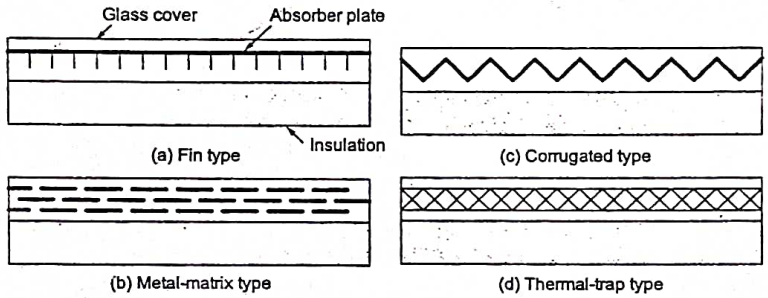


Fig. 5.6 *Various types of flat-plate air heating collector*

Advantages :-

1. It is compact, simple in construction
2. It Requires less maintenance
3. The need of transferring thermal energy from one workin fluid to another fluid is eliminated.
4. Corrosion is completely eliminated.
5. The pressure inside the collector doesnot become very high.

Disadvantages :-

1. Heat transfer between the absorber plate & air is poo
2. There is less storage of thermal energy due to low heat capacity.

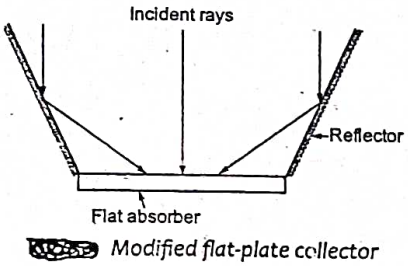
3. Modified-Flat plate collector :-

→ By providing mirrors at the edges of a flat-plate collector to reflect additional radiation into the receiver.

→ The concentration of solar radiation can be increased.

→ This mirrors are also called booster mirrors.

The concentration ratio of these collectors has a maximum value of 4.



Modified flat-plate collector

temperature range is (100-300)

→ such a design is aligned in the east-west directio & requires periodic tilt adjustment.

4. compound parabolic concentrator :-

→ A compound parabolic concentrator consists of two parabolic mirror segments, attached to a flat Receiver.

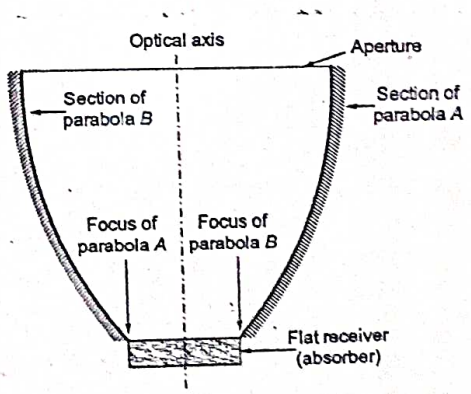


Fig. 5.10 Compound parabolic concentrator

→ the segments are oriented such that the focus of one is located at the bottom end point of the other.

→ Rays at central region undergoes directly to absor but edges are one or more Reflections.

→ The concentration Ratio is 3-7.

5. Cylindrical parabolic concentrator :-

→ It consists of a cylindrical parabolic through reflector & metal tube receiver.

5.1.10 Cylindrical Parabolic Concentrator

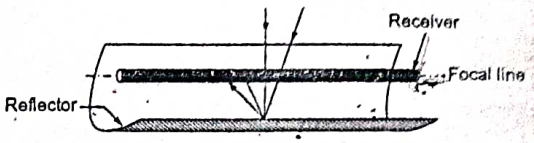


Fig 5.1.10 Cylindrical parabolic concentrator

→ The receiver tube is blackened at the outside surface to increase absorption.

→ It is rotated about one axis to track the sun.

→ The heat transfer fluid flows through the receiver tube, carrying the thermal energy to the next stage of the system.

→ The concentration ratio in the range of 5-30 may be achieved from these collectors.

6. Fixed-mirror solar concentrator :-

The concentrator consists of fixed mirror strips arranged on a circular.

Fig 5.1.11 Fixed-mirror Solar Concentrator

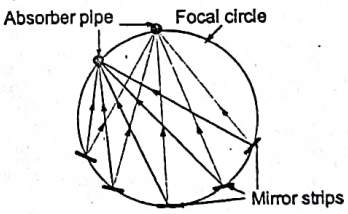


Fig 5.1.11 Fixed mirrors solar concentrator

→ The Receiver tube is made to rotate about the centre to track the sun.

→ The concentration ratio is approximately the same as the number of mirror strips.

—

7. Linear Fresnel Lens collector :-

→ In this collector, a Fresnel lens, which consists of fine, linear grooves on the surface.

→ The beam radiation, which is incident normally, converges on the focal line, where a receiver tube is provide to absorb the radiation.

→ The concentration ratio is 10 - 30.

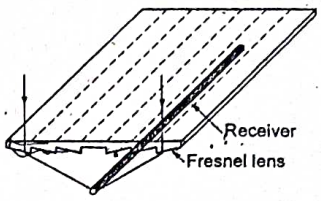


Fig. 5.13 Linear Fresnel lens collector

8. Parabolic Dish collector :-

→ When a parabola is rotated about its axis a paraboloidal shape is produced.

→ This requires two-axis tracking.

→ It can have a concentration ratio ranging from 10 to few thousands.

→ The temperature is up to 3000°c. The dish diameter is 6-7m.

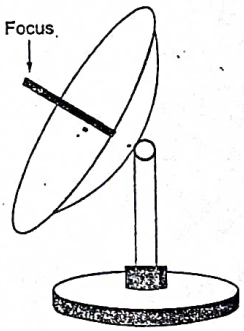


Fig. 5.14 Paraboloidal dish collector (Scheffler solar concentrator)

9. Hemispherical Bowl mirror concentrator :-

→ It consists of a hemispherical fixed mirror, a tracking absorber.

→ All rays entering the hemi sphere after reflection cross the paraxial line at some point between the focus & the mirror surface.

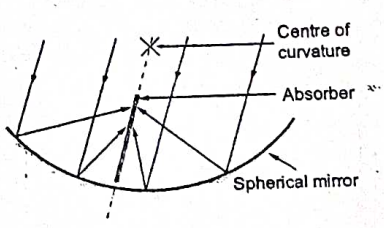


Fig. 5.15 Hemispherical mirror concentrator

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→ The absorber is to be moved so that its axis is always aligned with solar rays passing through the centre of the sphere.
→ This requires two-axis tracking.

10. Circular Fresnel lens concentrator:-

→ These lenses are generally used where high flux is desired.
→ silicon solar cell or gallium arsenide solar cells as Receiver.
→ It is divided into a number of thin circular zones.
→ The concentration ratio may be high.

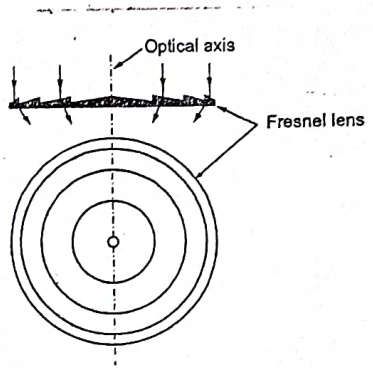


Fig. 5.16 Circular Fresnel lens

11. Central Tower Receiver:-

→ In a central tower receiver collector, the receiver is located at the top of a tower.
→ Beam radiation is reflected on it from a large number of independently, controlled, almost flat mirrors, known as heliostats.
→ Thousands of such heliostats track the sun to direct the beam radiation on the receiver from all sides.
→ The concentration ratio is high (3000).

5.1.16 Central Tower Receiver

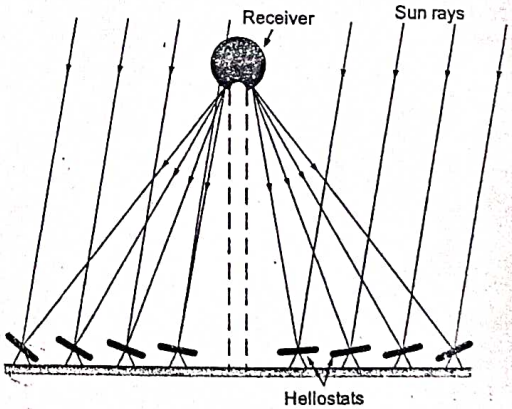
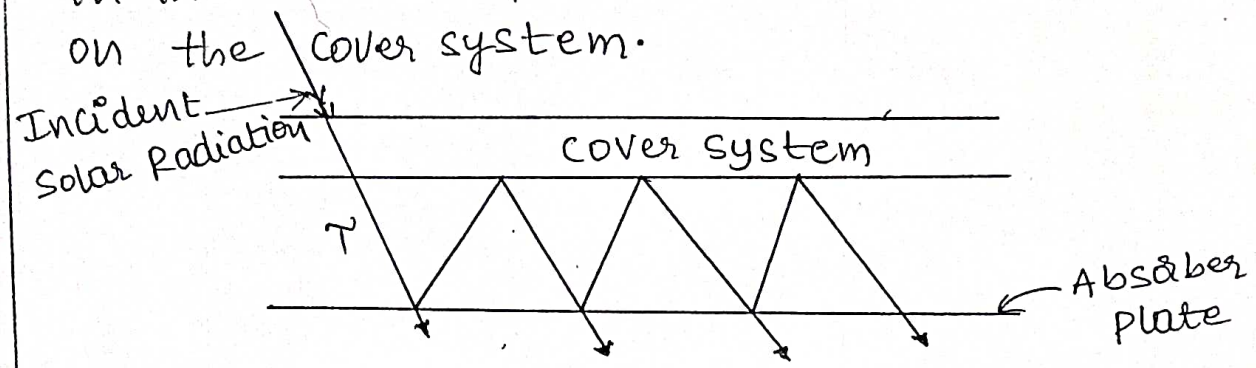


Fig. 5.17 Central tower receiver

Transmissivity - Absorptivity product :-

→ The transmissivity - Absorptivity product is defined as the ratio of the radiation absorbed in the absorber plate to the radiation incident on the cover system.



→ Transmissivity - Absorptivity product

$$(\tau \cdot \alpha) = \frac{\tau \cdot \alpha}{1-(1-\alpha) f_d}$$

Where f_d = Reflected diffuse radation (0.24-0

Collector Effeciency - heat Removal factor :-

Instantaneous collector effeciency is

$$\eta_i = \frac{\text{Useful heat gain}}{\text{Solar radiation incident on the collector}}$$

$$\eta_i = \frac{q_u}{A_p I_T}$$

Where q_u = Useful heat gain (i.e rate of heat tra to the working flui

A_p = area of absorbing plate

I_T = Total radiation incident on the collector.

→ The energy on the absorber plate is given by

$$q_u = A_p S - q_L$$

Where S = Incident solar flux absorbed in the collector plate

q_L = Rate which energy is lost

→ The flux incident on the top cover of the collector

$$I_T = I_b R_b + [I_d R_d + (I_b + I_d) \rho_r]$$

→ TO determine the flux S, multiply each term with transmissivity - Absorptivity product $(\tau \cdot \alpha)$

$$S = I_b \gamma_b (\tau \cdot \alpha)_b + [I_d \gamma_d + (I_b + I_d) \gamma_r] (\tau \cdot \alpha)_d$$

$(\tau \cdot \alpha)_b$ → Transmissivity - Absorptivity product for beam radiation falling on collector.

$(\tau \cdot \alpha)_d$ → Transmissivity - Absorptivity product for diffuse radiation falling on collector.

→ The heat loss from the collector is expressed in terms of overall loss co-effecient

$$q_L = U_L A_p (T_{pm} - T_a)$$

Where U_L = overall loss co-effecient

A_p = Area of Absorber plate

T_{pm} = Average temperature of Absorber plate.

T_a = Temperature of the surrounding Air.

→ The heat lost from the collector is the sum of the heat lost from the top, bottom & sides.

$$q_L = q_t + q_b + q_s$$

Where q_t = heat is lost from the top

q_b = heat is lost from the bottom

q_s = heat is lost from the sides.

$\therefore q_t = U_t A_p [T_{pm} - T_a]$

$q_b = U_b A_p [T_{pm} - T_a]$

$q_s = U_s A_p [T_{pm} - T_a]$

→ From the above equations,

$$U_L = U_t + U_b + U_s$$

$$\therefore q_u = A_p S - U_L A_p [T_{pm} - T_a]$$

→ T_{pm} is replaced by inlet temperature of flu

$$q_u = F' [A_p S - U_L A_p (T_{fi} - T_a)]$$

Where F' = collector effeciency factor.

→ $$q_u = F_R A_p [S - U_L (T_{fi} - T_a)]$$

Where F_R = heat removal factor.

$$F_R = \frac{mC_p}{U_L A_p}\left[1 - \exp\left(\frac{-F' U_L A_p}{mC_p}\right)\right]$$

(*) **Heat Removal Factor (F_R):-**

It is the ratio of the actual useful heat collection rate to the useful heat collection rate. It's value between 0 to 1.

(*) Following data is related to flat-plate collector. location & latitude = Baroda, 22°N on January 1st at 12 noon [LST], annual beam radiation intensity = 350 w/m², Collector tilt = latitude + 14°. number of glass covers = 2, heat Removal factor = 0.81, transmittance of the glass = 0.88, Absorption of the glass = 0.90, top loss coefficient for collector = 7.88 w/m²°c, collector fluid inlet temperat. = 60°c, Ambient temperature = 15°c, Calculate ① Declinat ② solar hour angle (ω) ③ Effeciency of the collector.

Sol:- **Given data:-**

Latitude $\phi = 22°$

Day, $n = 1$, LST = 12 noon

Intensity of beam radiation $I_b = 350\ w/m^2$

Collector tilt $\beta = \phi + 14 = 22 + 14 = 36°$.

→ number of glasses = 2

Reflected diffuse Radiation. $f_d = 0.24$

Heat removal factor = 0.81

Transmittance $\tau = 0.88$

Absorption $\alpha = 0.90$

Top loss coefficient, $U_t = 7.88 \, W/m^2{}^\circ C$

$t_{fi} = 60^\circ C$, $t_a = 15^\circ C$

i) Declination angle (δ) :-

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

$$\boxed{\delta = -23.012^\circ}$$

ii) Hour angle w :-

$$w = [12-12] \times 15^\circ$$

$$\boxed{w = 0^\circ}$$

iii) Effeciency of the collector $\eta = \frac{q_u}{A_p \cdot I_T} = \frac{q_u}{I_b \cdot R_b}$

$$R_b = \frac{\sin\delta \cdot \sin(\phi-\beta) + \cos\delta \cdot \cos w \cos(\phi-\beta)}{\sin\delta \cdot \sin\phi + \cos\delta \cos w \cos\phi}$$

$$R_b = \frac{\sin(-23.01)\sin(22-36) + \cos(-23.01)\cos(0)\cos(22-36)}{\sin(-23.01)\sin(22) + \cos(-23.01)\cos(0)\cdot\cos(2}$$

$$R_b = \frac{0.094 + 0.94}{0.7069} \Rightarrow \boxed{R_b = 1.39}$$

$$(\tau\cdot\alpha)_b = \frac{\tau\alpha}{1-(1-\alpha)\rho_d} = \frac{0.88 \times 0.9}{1-(1-0.9)} = \frac{0.88 \times 0.9}{0.976}$$

$$(\tau\cdot\alpha)_b = 0.811$$

$$q_u = F_R A_p \left[(I_b R_b)(\tau\cdot\alpha)_b - (T_{fi} - T_a)\right]$$

$$q_u = 0.81\{350(1.39)(0.811) - (60-15)\} = 283.13$$

$$\%\eta = \frac{q_u}{I_b R_b} = \frac{283.13}{350 \times 1.39} = 58.19\%$$

Solar Energy storage :-

The solar energy is variable, Intermittent, unpredictable nature. It is collected & stored during sunshine hours only.

→ The storage is necessary when the Requirement is less than the collected.

* **Buffer storage :-** It stores the energy only for a short intervals of time & it is relatively small in size.
* **Diurnal storage :-** It is larger than buffer storage It stores the energy over two days.
* **Annual storage :-** The excess energy has to be stored over a period of months.

* There are Three basic methods for storing thermal energy.
  1. sensible heat storage
  2. Latent heat storage
  3. Thermo chemical storage.

① Sensible heat storage :-

Heating a liquid or solid which doesnot change phase. The amount of energy stored is dependent on the temperature change of the material.

Ex:- solar heaters [cold water is converted to hot water].

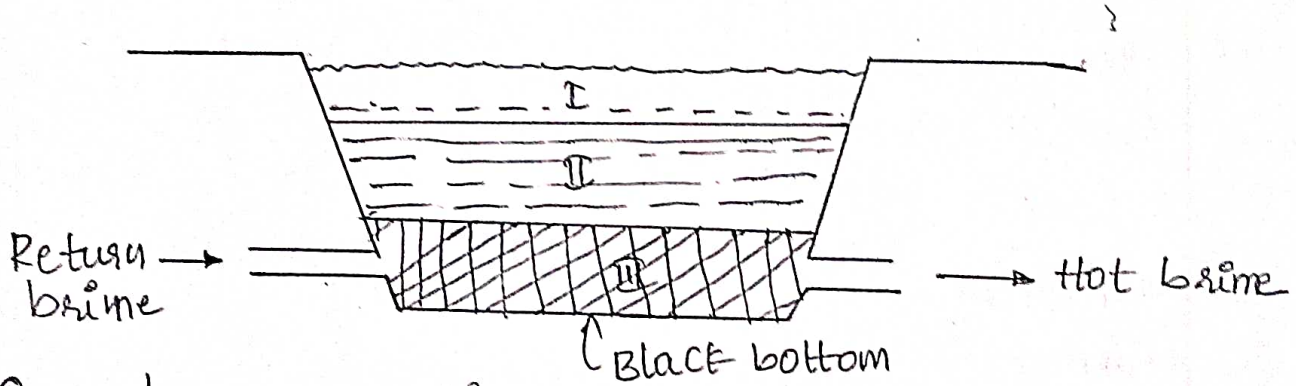
② Latent heat storage :-

Heating a material which undergoes a phase change. Ex:- water is converted to steam.

③ Thermo chemical storage :-

Using heat certain chemical reaction is processed, & then storing the products.

④ solar pond :-



① Surface convective zone

② Non-convective zone

③ storage zone.

① Surface convective zone :-

It is also called Upper convective zone. The depth is 0.3 - 0.5m, contains 5% of salt water. Uniform temperature.

② Non-convective zone :- It is much thicker & occupies more than half the depth of the pond. It serves mainly as an insulating layer & reduce heat loss in the upward direction.

The thickness of this zone is 1 to 1.5 m. (10)

(3) Staage zone (or) lower convective zone :-

The depth of this zone is 1.5 to 2m, & 20% of salt water. The deeper the zone, the more heat is stored. Even during long periods of cloud cover or even ice cover the stored energy is still available.

→ The highest temperature ever recorded in a solar pond is 108°C.

→ The efficiency is twice as compared to flatplate collector.

→ Megnesium chloride & sodium chloride is added at the bottom.

→ It is necessary to add periodically concentrat solutions at the bottom, & wash the surface with fresh water to maintain the concentration gradie

(4) Hot brine is taken as out for the next stage of the thermal system. Hot brine is replaced with cold brine & it is continous process.

(5) Solar-pond Electric power plant :-

The black bottom serves as an absorber & the layer of salt water above it is used as an Insulator.

→ The salt concentration varies from 20-30% at the bottom to almost zero at the top.

→ Solar radiation penetrates through water up to the blackened bottom, where it gets absorbed & increases the temperature near the bottom.

→ the bottom layers of the brine reach 70-85°C while the top remains at 25°C.

→ The hot brine from the bottom is slowly withdrawn from the pond & used to evaporate an organic working fluid in a heat exchanger & returned to the pond.

→ heat is extracted by water flowing through a heat exchanger. The water is converted to steam that steam hits the turbine blade the turbine is connected to Electrical generator produces Electrical energy as outp

→ It is a Rankine cycle. The annual effecie i's 15 to 20%.

→ In India at Gujarat (KVJ) the solar pond electric power plant is installed in the ye 1995. with a capacity of 80,000 liters/day with a temperature of 75°C.

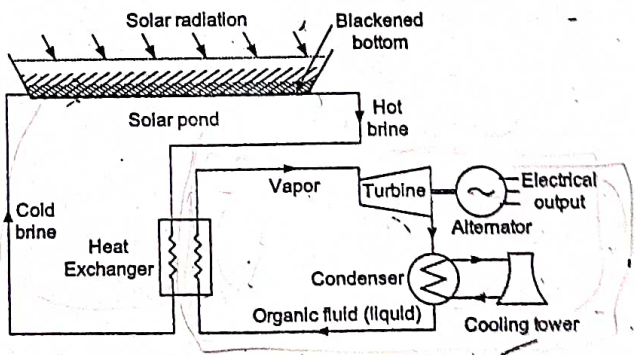


Fig. 5.38 Solar pond electric power plant

→ The steam is collected by the condenser & it is passing to the cooling tower, it is passed to the heat exchanger. It is a continous process.

⊛ solar water heater :-

→ A tilted flat-plate solar collector with water as a heat-transfer fluid is used.

→ A thermally Insulated hot-water storage tank is mounted above the collector.

→ The heated water of the collector rises up to the hot water tank & replaces an equal quantity of cold water, which enters the collector.

→ The cycle repeats, resulting in all the water of the hot water tank getting heated up.

→ When the hot water is taken out from the hot water outlet, the same is replaced by cold water. This scheme is known as passive heating system.

→ In average Indian climatic conditions, a solar water heater can be used for 300 days in a year & delivers water at 60-80°C. It has a life span of 10-12 years.

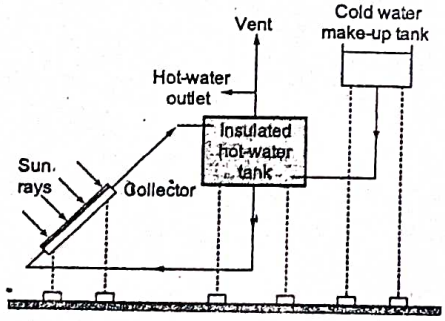


Fig. 5.18 *Solar water heater*

→ Insulation avoids the heat losses from the hot water.

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(11) Applications of solar pond :-

→ The various applications of solar pond are as follows.

① Heating & cooling of buildings
② Production of power
③ Industrial process heat
④ Desalination
⑤ Drying crops on farms
⑥ Heat for biomass conversion.

① Heating & Cooling of buildings :-

→ solar ponds are used for heating the houses during cloudy days. The amount of heat requir for heating house is calculated by the scientis From the calculations it has been found that a solar pond with 100m in diameter & 1m depth is capable of driving 50 houses in a community

② Production of power :-

It has wide application of generating electrici
→ The solar pond is suitable for generating the electricity of the areas, where there is sufficie solar Radiation.

→ The temperature ranges of the order of 70-10
→ It requires propane, sodium chloride, sodium nitr which usually increases the amount of heat Liberation.

③ Industrial process heat :-

Thermal energy is required in the industries for manufacturing & treatment of materials & goods.

→ scientists have found the applications of solar pond for supplying process heat in industries, which saves the using of oil, natural gas, electricity & coal.

→ It is used for Drying the paper.

④ Desalination :- Thermal energy also be used for purify the water for drinking & irrigation. It has been found that a solar pond of 0.3 ha area can be used to produce about 4700 m^3/day of distilled water.

⑤ Drying crops on farms :-

→ In Agricultural low grade heat can be used for drying crops & heat green houses.

⑥ Heat for Biomass conversion :-

→ solar ponds can also be used for conversion purposes like, the heat produced can be used for convert biomass to alcohol (or) methane

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