UNIT 2

SOLAR THERMAL SYSTEMS

Solar collectors:-

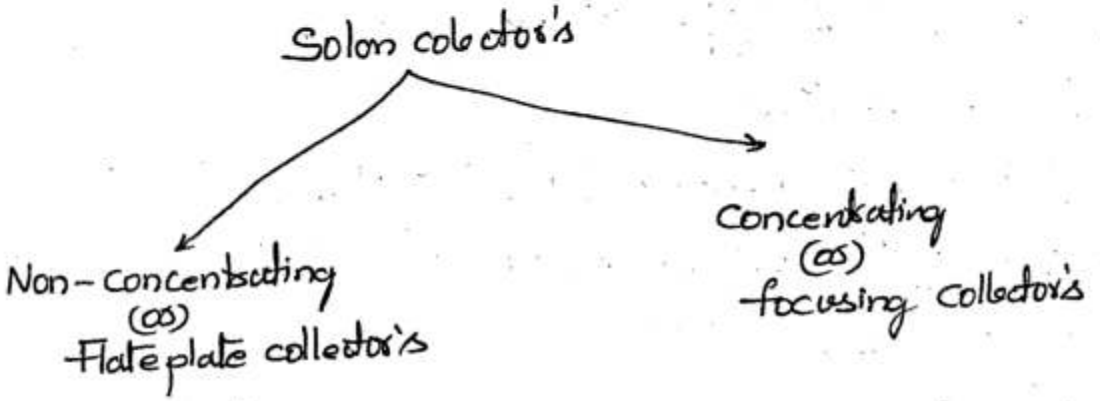
It is used to collect solar radiation on the surface of the earth which intern transfer's to working fluid to convert to other usable forms.

Applications:-

1) Solar heating
2) Solar cooling
3) Solar drying.
4) Space heating & cooling
5) Solar cooking etc.

It is the best & most effcent easy to convert solar energy to other usable form.

Solar collector's can be classified as

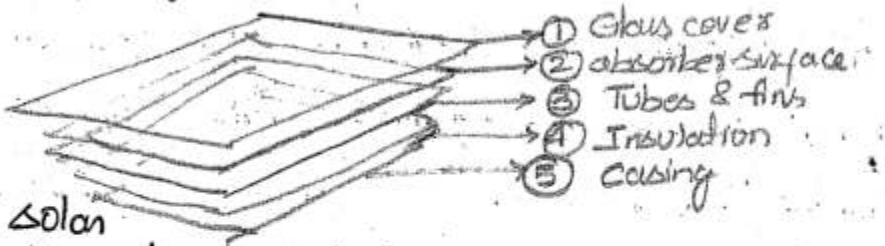


Flate plate collectors :

* This collectors have flat absorbing surface for collecting solar radiation.
* This collectors area is numerically same as absorbing area.
* These collectors are rectangular in shape ranging from 1.7m² to 2.9m² and most easy to instal & construct
* This collectors are able to collect solar energy of both direct & diffuse radiation.

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flate plate collectors essentially consists of 5 layers.



Layer1) Glass cover allows solar radiation to fall on the absorber surface.

Layer 2:- Absorber surface a thin sheet of metal made of aluminium, steel (or) copper.

Layer 3:-

Tubes & fins carriers absorbes fluid to extract the heat of the absorber. Generally this tubes are brazed and welded to the absorber plate.

Layer 4:-

To minimize the heat loss from collector, we use insulation layer. Generally we use fibre glass (or) styro-foam.

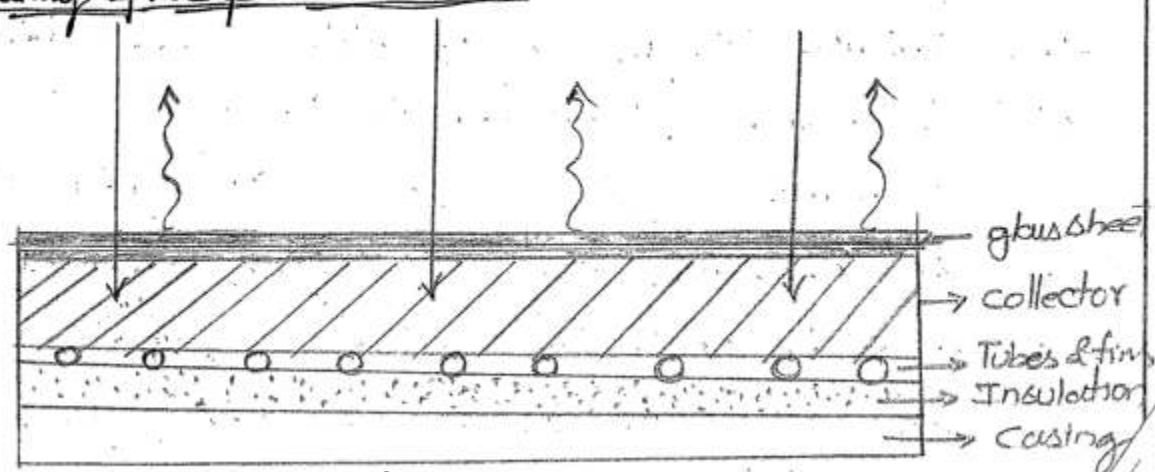
Layer 5:-

Casing houses all the components of flate plate collectors.

* Based on the absurbent fluid used, flate plate collectors can be classified as

a) Liquid flate plate collectors
b) Air (or) gas heating collectors.

a) Liquid heating flate plate collectors:-



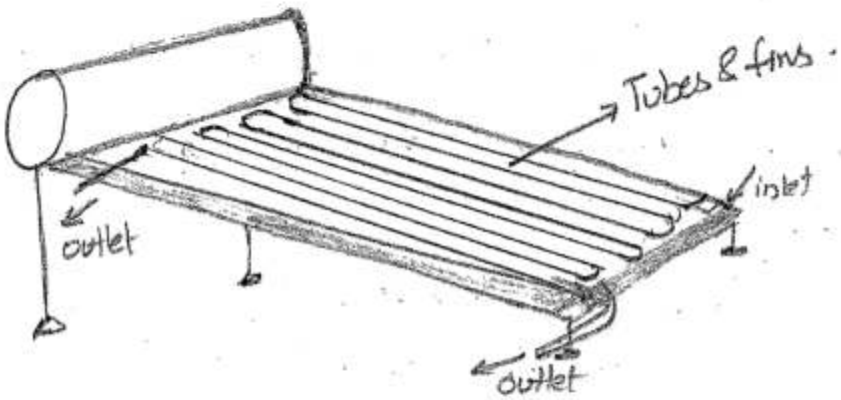
+ This collector's consists of flate absorbing surface to absorb solar radiation. The thickness of collector area may from 1mm to 2mm in thickness. This collector's are generally made of metallic sheet such as copper, aluminium (or) steel.

* Below the collector surface we have copper tubings with diameter ranging from 1.2cm to 1.5cm. This copper tubings are welded and brazed to the collector surface. The pitch of the copper tubings ranges from 5cm to 15cm.

To extract heat from the collector surface we circulate water along the surface of collector through this tubes.

* Below copper tubings lies insulation layer. The main perpose of insulation is to reduce (or) minimize heat loses from absorber surface. Generally mineral wool (or) glass wool (or) fiber glass is used.

*



Glass cover should have enhalf transpaency to allow solar radiation to fall on collector's surface. Ether 1 glass cover (or) 2 glass cover's can be used.

2 glass cover's are more beneficial due to following.

1) Air convection loses are reduced considerably
2) Loses in infra-red spectrum are minimized.

3rd glass cover can not be used since each each glass cover reflect's 15% of [illegible] on collector's surface.

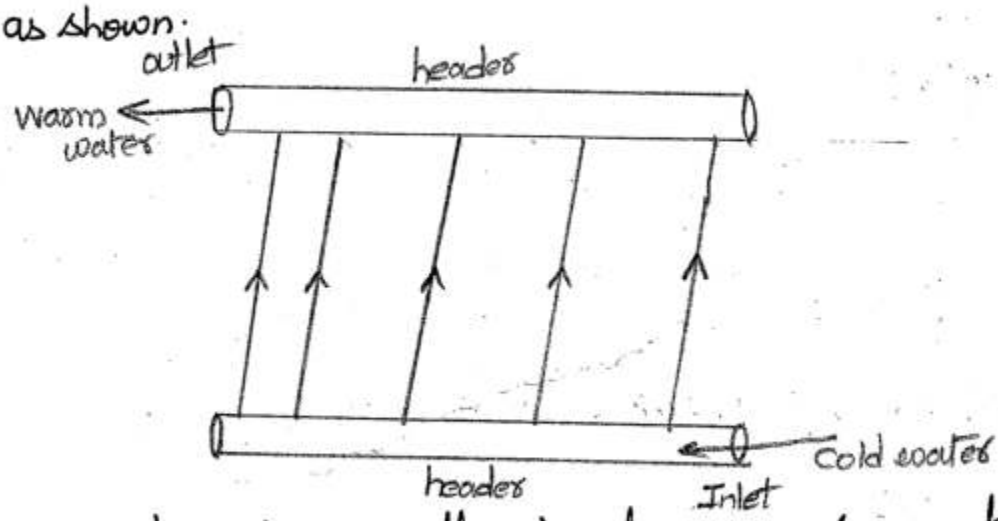
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However some part of radiation is lost from glass cover due to reflection and air convection loses.

further reflection can be minized by coating the glass with magnesium fluoride and Hydrafloosic acid.

Heat transport system

* Copper tubes are welded to the collector surface. This tubes can be rectangular (or) circular in shape.
* To collect heat from absorbeter surface water is circulated along the tubes.
* The copper tubes are attached to the common header's as shown.



* cold water is allowed to pass from bottom header. When water flows along tubes, water gets heated and can be collected from top header.

This is done to expose the surface to the solar radiation.

Difficulties in heat transport system:

* During freezing seasons the water in the tubes are subjected to freezing.
* Ethelyn glycol can be added to prevent freezing but add complexity to the system.
* Anti-freezing solutions can be used but extract's less

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heat from collector surface.

* Metal tubes may subject to corrosion due to flow of water. Hence it is better to use copper tubes.

* Leakage of water from tubes requires immediate attention.

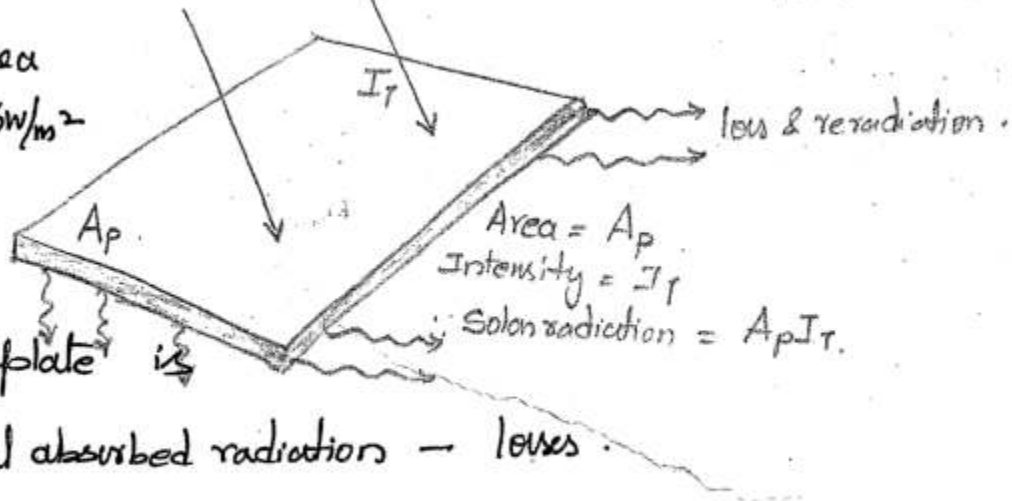
Performance of flate plate collector:

collection efficency of flate plate collector is given by η_i

$$\eta_i = \frac{\text{Useful heat gain}}{\text{Solar radiation incident on collector}} = \frac{q_u}{A_p I_T} \longrightarrow (1)$$

Where A_p = absorbing area

I_T = intensity in KW/m^2



Energy available at plate is given as

q_u = Total absorbed radiation − losses.

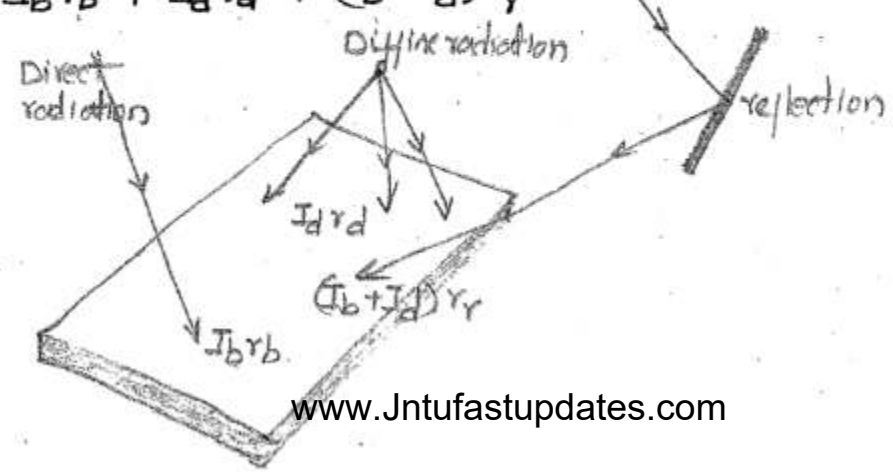
$\therefore q_u = A_p \cdot S - q_L \longrightarrow (2)$

where S → Solar flux absorbed at plate.

q_L → energy lost due to ① convention and reradiation
② convention and conduction from side and bottom surface.

flux incident on top cover is given by

$$I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r \longrightarrow (3).$$



To determine total solar flux ③ should be multiplied with transmissivity – absorptivity factor $(\tau\cdot\alpha)$.

$\therefore$ ③ $\times \tau\alpha \Rightarrow$

$$S = I_b r_b (\tau\alpha)_b + \left[I_d r_d + (I_d + I_b) r_r\right](\tau\alpha)_d \longrightarrow ④$$

"Transmissitivity - absurbtivity factor can be defined as the ratio of radiation absorbed in the absorber plate ~~and~~ to the radiation ~~received~~ incident on the coves system. It is denoted by $(\tau\alpha)$."

$(\tau\alpha)_b \longrightarrow$ T-A product of beam radiation

$(\tau\alpha)_d \longrightarrow$ T-A product of diffuse radiation.

Heat lost from collector surface interms of overall loss component is given by

$$q_L = U_L A_p [t_{pm} - t_a] \longrightarrow ⑤$$

$U_L \longrightarrow$ loss co-efficent

$t_{pm} \longrightarrow$ Mean temperature of collector

$t_a \longrightarrow$ temperature of surrounding air.

But heat lost from collector surface is the sum of heat lost from top, bottom and sides.

$$\therefore q_L = q_t + q_b + q_s \longrightarrow ⑥.$$

(q_t: top, q_b: bottom, q_s: sides.)

Now each of the loss components can be expressed with individual loss co-efficents.

$$q_t = U_t A_p [t_{pm} - t_a]$$

$$q_b = U_b \cdot A_p [t_{pm} - t_a]$$

$$q_s = U_s \cdot A_p [t_{pm} - t_a]$$

Where all of them expressed with common surface area A_p & t_{pm} & t_a.

Now overall loss co-efficent is given by

$$q_a = U_L = U_t + U_b + U_s \longrightarrow (5)$$

Now eq (2) can be written as

$$q_u = A_p S - U_L A_p [t_{pm} - t_a] \longrightarrow (6)$$

$$\therefore \boxed{q_u = F' \left[A_p S - U_L A_p (t_{pm} - t_a) \right]}$$

Where $F' \longrightarrow$ collector efficency factor (0.9 to 0.95).

It is the ratio of actual useful heat collection to useful heat collection

$$F' = \frac{\text{actual useful heat collection rate}}{\text{useful heat collection rate}}$$

* To calculate heat lost from collector it is necessary to know verge temperature of collector (or) average temperature of local fluid, which is Unknown.

By considering heat removal factor, a modified expression can be obtained

$$\boxed{q_u = F_R A_p \left[S - U_L (t_{fi} - t_a) \right]}$$

Where $F_R \longrightarrow$ collector heat removal factor defined as ratio of actual ~~heat~~ useful heat collection rate to the useful heat collection rate. It's range is 0 to 1.

also $$\boxed{F_R = \frac{\dot{m} c_p}{U_L A_p} \left(1 - e^{\left(- \frac{F' U_L A_p}{\dot{m} c_p} \right)} \right)}$$

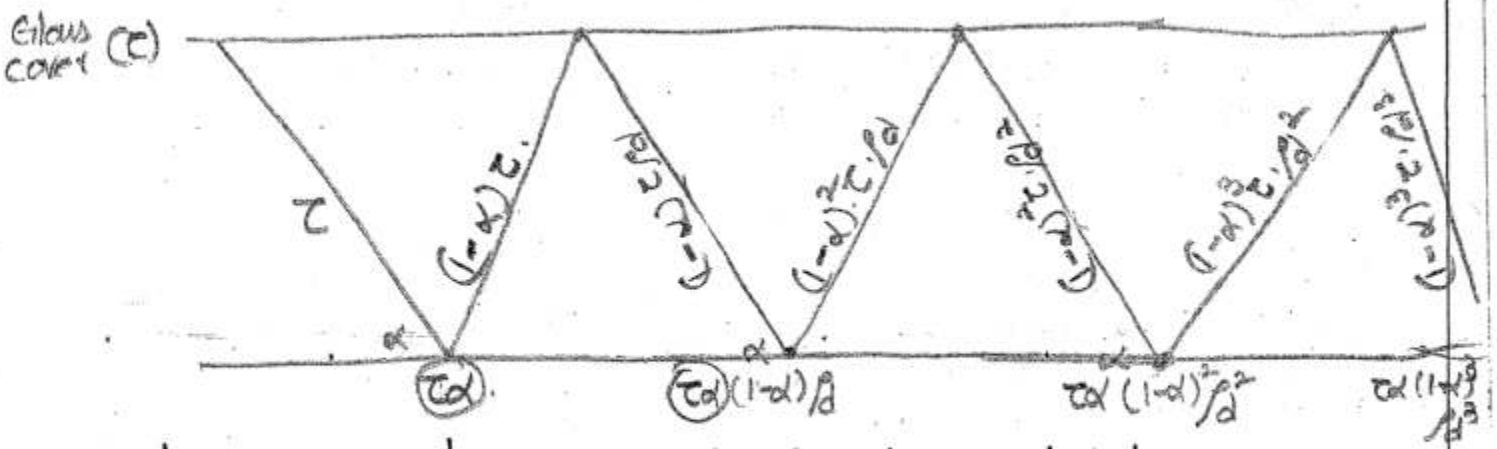
Transmissivity - Absorptivity product :-

Let τ be the transmissivity of the glass cover and
α be the absorptivity co-efficent of absorber plate.

The term $\tau\alpha$ is called transmissivity - absorptivity product.

Generally $\tau\alpha$ is absorbed by the plate and $(1-\alpha)\tau$ is ejected back to the glass cover as shown. This reflection from absorber surface is mostly diffuse radiation.

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* Again from glass cover $(1-\alpha)\cdot\tau\cdot\rho_d$ is reflected back to the absorber plate as shown.

$$\therefore \langle\tau\alpha\rangle = \tau\alpha + (1-\alpha)\tau\alpha\rho_d + (1-\alpha)^2\tau^2\alpha\cdot\rho_d^2 + (1-\alpha)^3\tau^3\alpha\cdot\rho_d^3 + \cdots$$

$$= \tau\alpha\left[1 + (1-\alpha)\rho_d + (1-\alpha)^2\rho_d^2 + \cdots\right]$$

$$\langle\tau\alpha\rangle = \tau\alpha + \tau\alpha(1-\alpha)\rho_d + \tau\alpha(1-\alpha)^2\rho_d^2 + \tau\alpha(1-\alpha)^3\rho_d^3 + \cdots\cdots$$

$$= \tau\alpha\left[1 + (1-\alpha)\rho_d + (1-\alpha)^2\rho_d^2 + (1-\alpha)^3\rho_d^3 + \cdots\right]$$

$$\boxed{\langle\tau\alpha\rangle = \tau\alpha\cdot\frac{1}{1-(1-\alpha)\cdot\rho_d}}$$

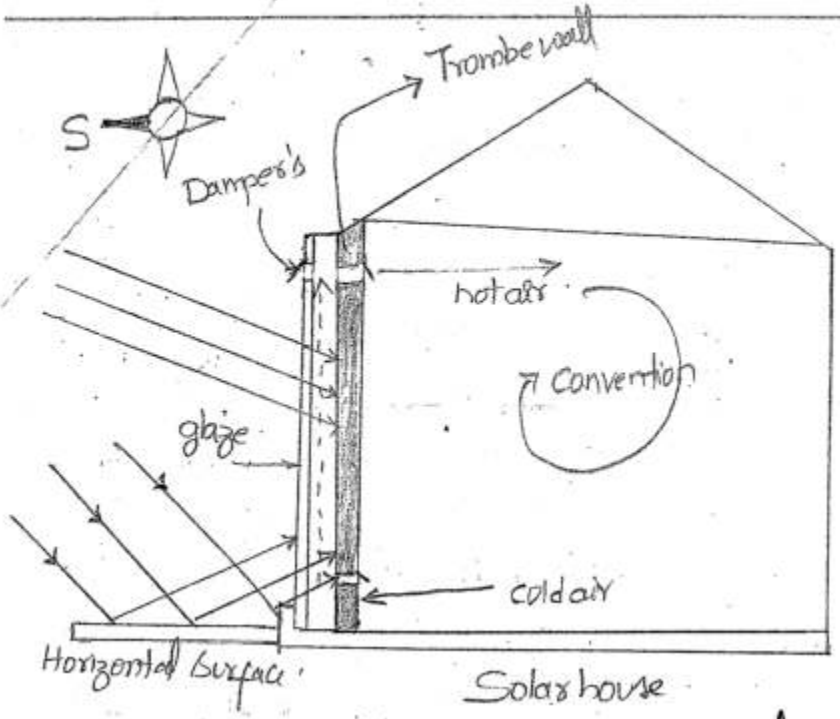
for inident radiation of 60°, ρ_d = 0.16, 0.24 & 0.29 for 1, 2, 3 glass covers respectively.

Solar air heaters:

* Solar energy can also be used for heating. Likewise traditional methods, this solar heaters does not require any mechanical devices.

* Solar heaters uses process like conduction, convention & radiation.

* Solar air heaters requires special house called solar house.



Solar house

* Solar house consists of special wall called Trombe wall which should face south direction only. This wall is made of either concrete, adobe, bricks (or) Sand. Some times this wall is painted with black to increase the heat absorbtivity.

* This trombe wall is entirely covered with either 1 (or) 2 layer's of glaze (or glass). Usually the gap between glaze and wall will range between 10cm - 15 cm so air could easily circulated in between them.

* When solar radiation fall's on glaze and can easily penetr-ate through it and strike the wall. In mean time the wall will store heat energy. When air is circulated between trombe wall and glaze, the air get's heated up and raises to up side and flow's through the top vent to the room.

* If we do not want heat any more in the room, a dampers can be opened so that entire heated air in the gap get's escaped to the environment.

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* Some times an tilted glaze can be provided for additional radiation as shown in figure.

Concentrating (or) focusing collectors :-

This collectors focus high intensity of solar radiation on an absorbing surface. This collectors are derived from flateplate collectors with little modification by replacing absorbing surface with small reflectors. Hence solar radiation on absorbing surface would increase to 1000 times.

* In concentrating collectors solar radiation will be collected in large areas and made to focus on absorbent surface. As a result, the absorber surface temperature could be increased to 500°c.

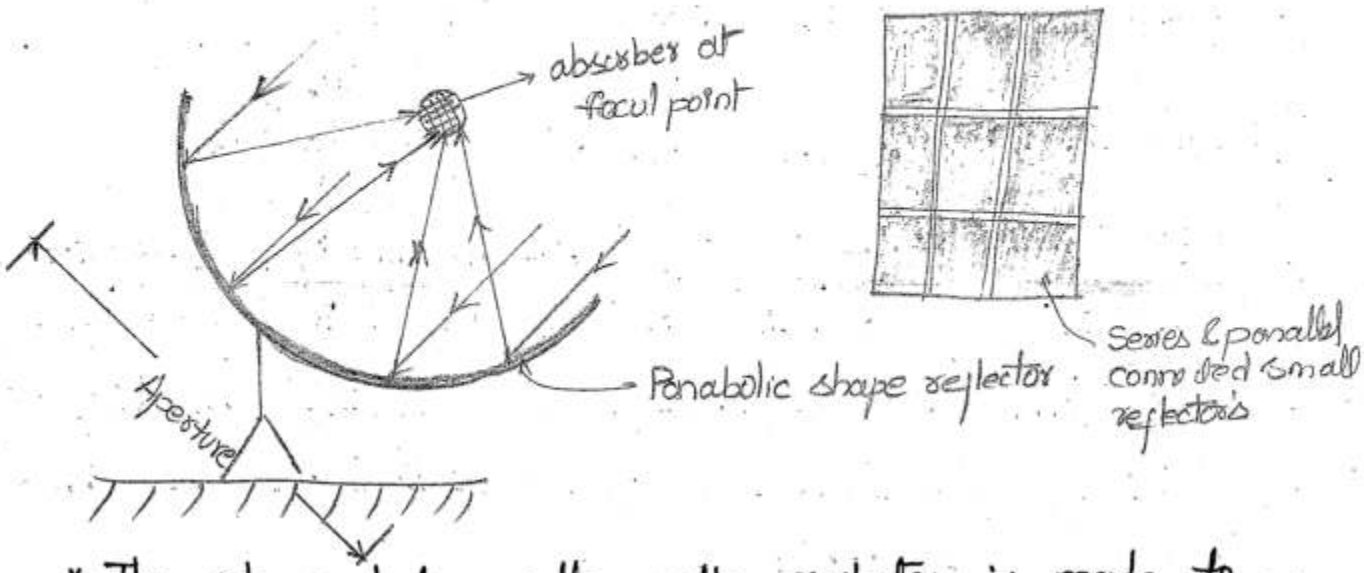
* This collectors can focus only direct radiation since diffuse radiation can be available in all directions.

Types of Concentrating collectors :

1) Parabolic trough collector
2) Mirror strip collector
3) Fresnel lense collector
4) Flate plate collectors with adjustable mirrors
5) Compound parabolic Collectors (CPC)
6) Parabolic dish collectors.

1) Parabolic trough collectors :

In this reflector is in the form of a trough, with parabolic cross section.



* The solar radiation falling on the reflectors is made to concentrate at the focal point where a absorber is installed. Due to concentrating of solar energy at the absorbes, the working fluid get's quickly heated up.

* This parabolic reflector consists of series and parallel connected reflectors. Parabolic reflectors are made up of highly polished aluminium, silvered glass (or) thin sheet of aluminized plastic.

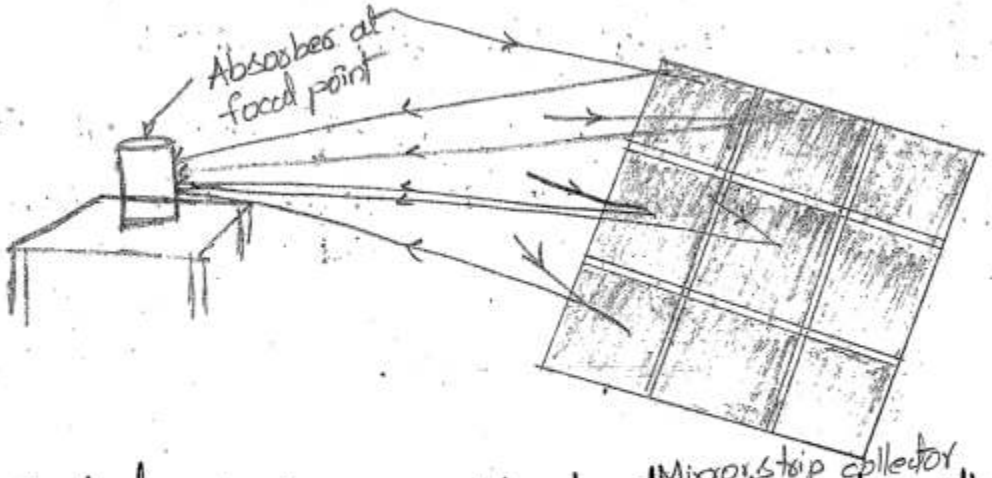
* At focus point pipes with coating can be used for absorbing the high intensity solar radiation.

* Parabolic collectors should orient towards sun direction. Since the sun direction will change continiously, the parabolic trough (or) pipes orientation should change accordingly.

* Always parabolic collectors are placed in east-west (or) north south direction.

2) Mirror strip collector:

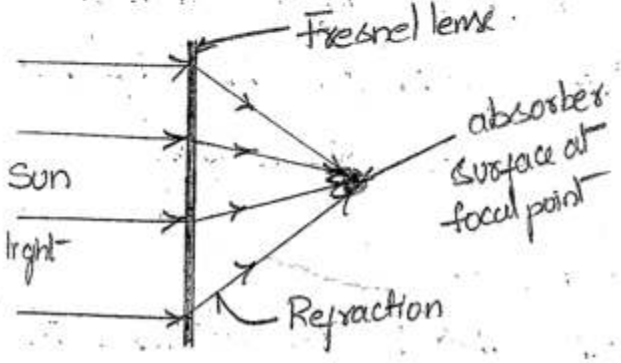
It consists of number of planes (or) slightly curved (or) concave mirror strip's which are mounted on a base.

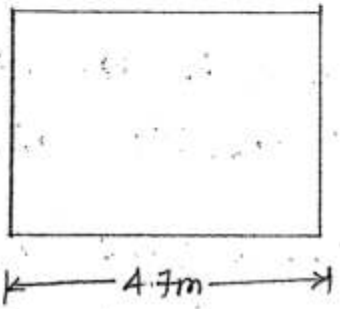


This individual mirrors are placed at such angles that the reflected solar radiation falls on the same focal line where pipe is located. In this system collector surface is rotated so that radiation on the absorbes remains focused with respect to changes in sun direction.

3) Fresnel lense collector :

* This collector works on the principle of refraction. This collector makes use of fresnel lense.



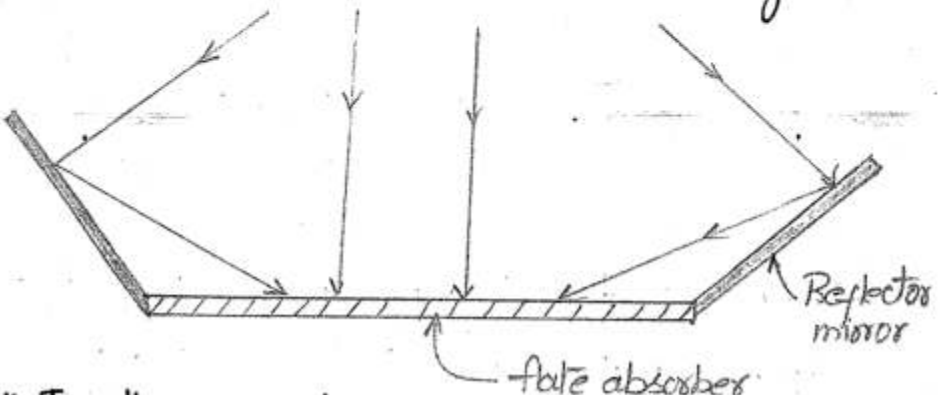


* This lenses can be installed to ponabolic collectors.
* The lense is rectangular in shape, 4.7M length & 0.05m width
* This lenses are made from acrylic plastic. This lenses are cheaper.

* The collector should orient along north-south direction, with slight slope on the north edge to expose the maximum area as sun's elevation decreases.

4) Flate plate collector with adjustable mirror's

It consists of a flate plate collector facing south, with mirror's attached to it's north-south edges.



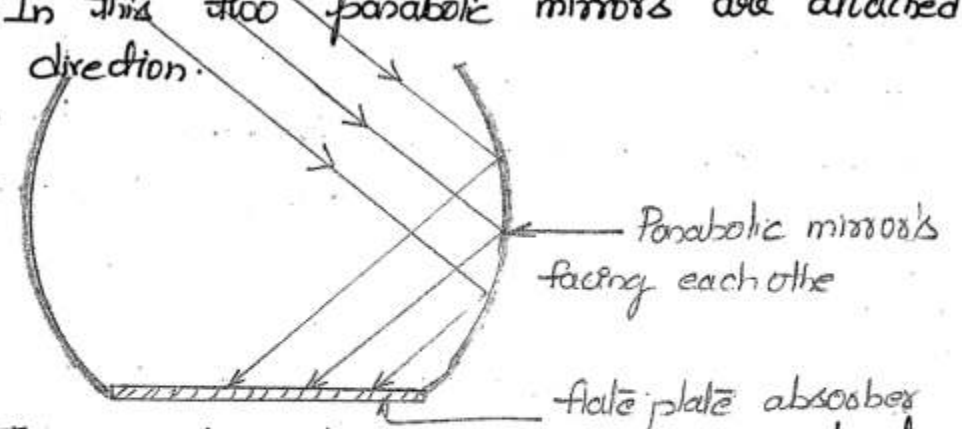
* If the mirror's are set at the proper angles, they reflect solar radiation on to the absorber plate. Thus, the flate plate absorber receives reflected radiation in addition to the normally radiation falling on it.

* In order to make the mirror's effective, the angles should be adjusted continiously as the sun's direction changes.

* Since the mirror's can provide only a relatively small increase in the solar radiation falling on the absorber, flate plate collector's with mirror's are not widely used.

5) Compound parabolic Concentrator (CPC):-

* In this two parabolic mirror's are attached in face to face direction.



* This mirror's reflect radiation in many directions to the bottom of the trough. Hence a large proportion of radiation including diffuse radiation is collected on a small area.

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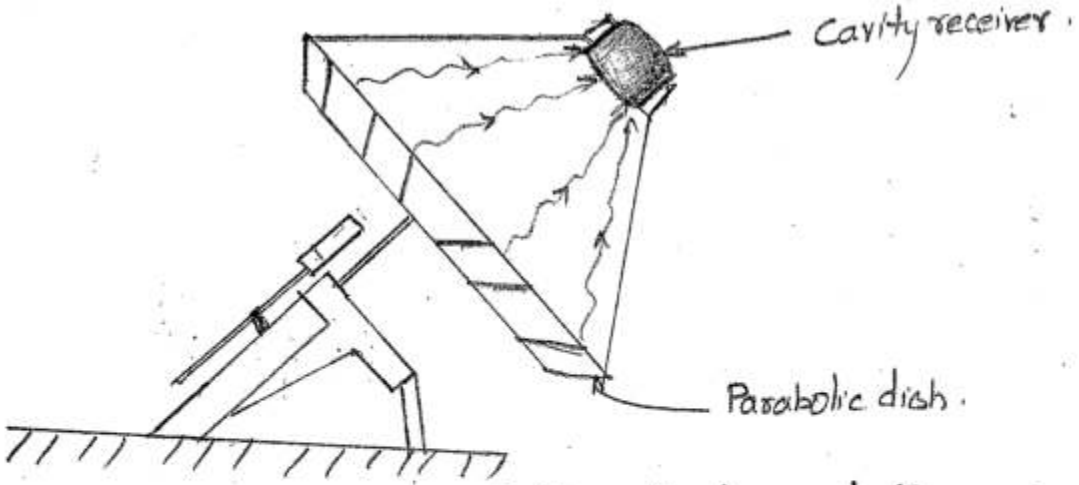
* This collectors give moderate concentration than other collectors. It is possible to concentrate solar radiation by a factor of 10.

* CPC collectors can be used to produce 300°c which can be utilized for power generation.

Advantages:-

* No sun tracking
* Acceptance of diffuse radiation
* Concentration ratio is higher

6) Parabolic dish collectors:



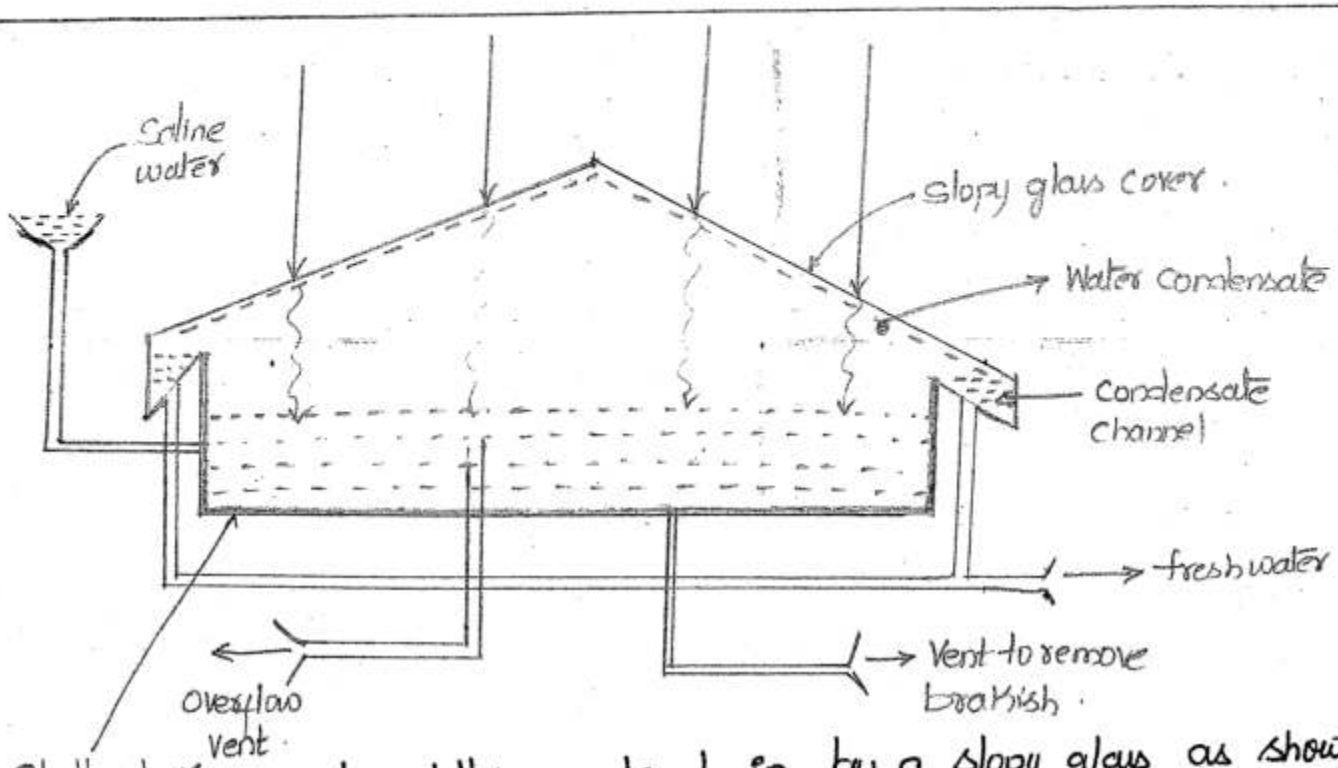
* In this collector all the radiations from the sun are focused at a point. This collector can generate temperatures upto 3000°c and concentration ratio's from 10 to few thousands.

* This diameter is of the range between 6 to 7m and can be commercially manufactured.

Solar Still (or) Solar Distillation:-

The need of fresh water is becoming scarcity due to increase of population and pollution. Under this circumstances solar still is a good idea.

It consists of a shallow blackened basin for storing saline (or) brakish water. The basin in lined with black surface for increasing heat absorptivity rate.



* Solar still is enclosed in by a slopy glass as shown.

* Solar energy could easily penetrate through glass surface and hits the saline water in the shallow basic. This basin slowly stores thermal energy and water get's heated up and slowly starts evaporating. This evaporated ~~air~~ water will reach glass surface and get's condensated on the surface of glass. When condensate is cooled down, becomes water and is collected at condensate channel as shown.

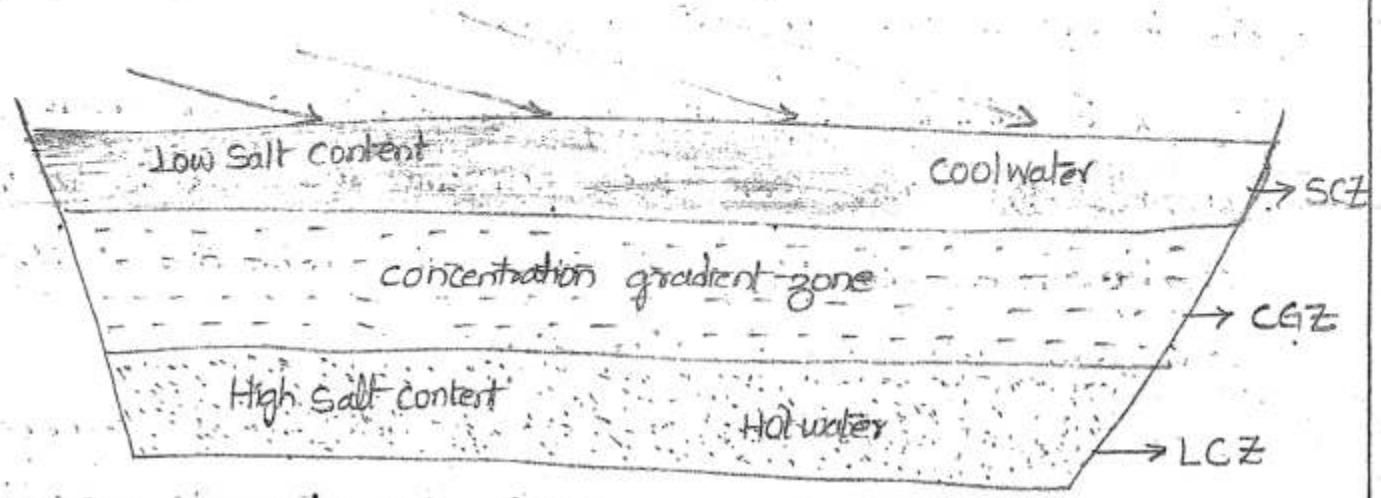
* The depth of the water ranges from 5cm to 100m. Generally saline (or) brakish water is can be pumped continiously (or) intermittenently. However saline water is pumped at a rate twice the fresh water collected.

Solar pond :-

* Solar pond also called as salt pond is an artificialy made pond that maintains different salt gra concentration gradient.

* Solar ponds are used for thermal storage and solar energy

Solar ponds eventially consists of 3 layer's of different concentration gradient of salt.



1) Surface convective zone (SCZ):-

This is first layer and lies at the top of the solar pond which is adjacent to the surface. This layer's acts as buffer zone between environmental fluctuations and ~~heat~~ conductive heat transport system. This layer has least concentration of salt. This layer is about 10cm - 20cm in thickness.

2) Lower convective zone (LCZ):-

This layer's lies at the bottom of solar pond. It has highest concentration of salt gradient. It is the layer where high temperatures are build up.

3) Intermediate gradient zone (CGZ):-

* This layer is also called as concentrative gradient zone which is inbetween SGZ & LCZ.

* This layer allows solar radiation to pass through it but does not allow heat loss from lower convective zone. Hence it acts as a excellent insulation layer.

→ To give solar pond non equilibirium stationary state, regularly salt has to be added to lower layer and fresh

water has to be supplied to the top layer.

* To minimize heat loss from top layer, a platic grid is spread over the top surface.

* To minimize infiltration of salt water to the nearby borewells and wells, the lower convective zone (LCZ) is provided with impermeable soil (or) plastic liner. This facilitation to solar pond adds huge cost to solar pond.

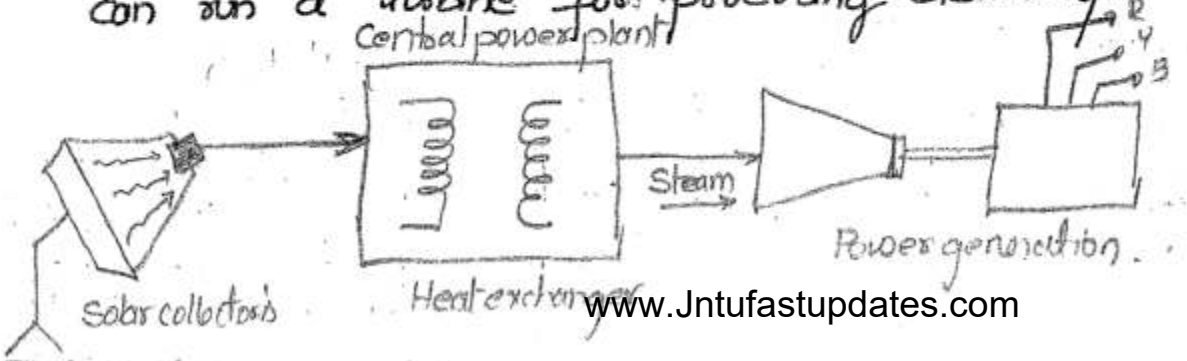
* Whenever LCZ reaches 60°c, the heat can be exchanged through heat exchanger and can be used to drive low tempe-rature turbine for producing electricity.

* Solar pond is a good collector for collecting both direct & diffuse radiation. Under normal conditions ponds absorption efficency can reach 50% of incomming solar radiation.

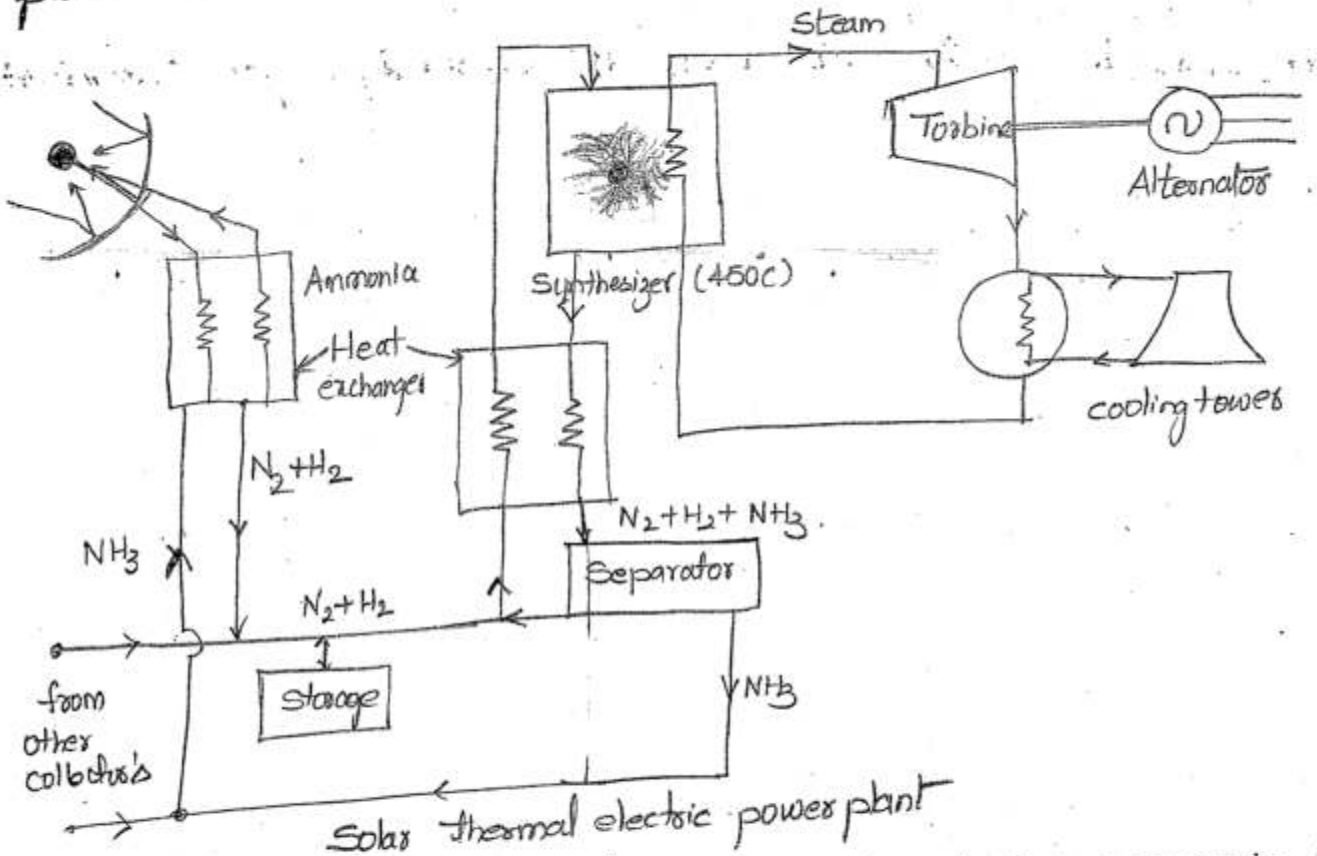
Solar thermal electric power plant:-

Principle:-

In this solar energy is collected from large sun-tracking collector's. The heat from collector's is transported to absorbent fluid. This high temperature absorbent fluid is send to central power station. At this point high temperature absorbent fluid exchanges heat with heat exchanger thus raises steam. This evolved steam can run a turbine for producing electricity.



The below figure shows distributed solar thermal electric power plant.



Solar thermal electric power plant

* In this absorbent fluid is used which is ammonia NH_3.

* Solar radiation is collected by several hundred collector and heat is transported to the absorbent fluid. This high temperature will dissociate ammonia into nitrogen N_2 and hydrogen H_2 which has gaseous state.

* This mixture (N_2+H_2) is sent to central power station and fed into synthesizer to recombine into ammonia using catylst. During recombination a large amount of heat is liberated which is used to raise steam. This steam is used to run turbine for electric power generation.

* Only a part of the mixture (N_2+H_2) is recombined into ammonia. The remaining part is left to cooling to liquify ammonia. This output of synthesizer is sent

to separator which separate liquid ammonia and N_2+H_2 (gas). Liquid ammonia is sent back to the collectors and mixture N_2+H_2 (gas) is again sent back to synthesizer for recombination.