UNIT – II

SOLAR RADIATON

The solar radiation that penetrates the earth's atmosphere and reaches the surface differs in both amount and character from the radiation at the top of the atmosphere.

Beam radiation: Solar radiation that reaches the ground directly from the sun is called direct radiation or Beam radiation.

Diffuse radiation: Solar radiation received from the sun after its direction has been changed by reflection and scattering by the atmosphere.

Insolation: 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).

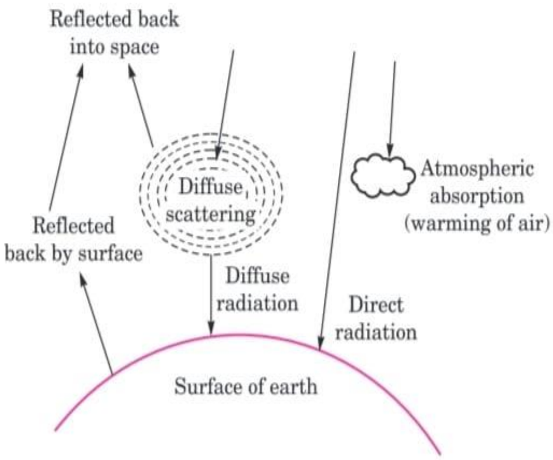


Fig.1 Direct, diffuse and total radiation

SOLAR RADIATION MEASUREMENT

Measurements of solar radiation are important because of the increasing number of solar heating and cooling applications, and the need for accurate solar irradiation data to predict performance. Experimental determination of the energy transferred to a surface by solar radiation required instruments which will measure the heating effect of direct solar radiation and diffuse solar radiation. Measurements are also made of beam radiation, which respond to solar radiation received from a very small portion of the circum solar sky. A total radiation type of instrument may be used for measuring diffuse radiation alone by shading the sensing element from the sun's direct rays.

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

(1) **Pyrheliometer -** It collimates the radiation to determine the beam intensity as a function of incident angle, and

(2) **Pyranometer -** It measures the total hemispherical solar radiation. The pyranometer measurements are the most common.

SOLAR RADIATION DATA

Solar radiation data are available in several forms and should include the following information.

1. Whether they are instantaneous measurement or values integrated over some period of time (usually hour or day)
2. The time or time period of the measurements.
3. Whether the measurements are of beam, diffuse or total radiation and the instrument used.
4. The receiving surface orientation (usually horizontal, it may be inclined at a fixed slope or normal)
5. If averaged, the period over which they are averaged (e.g, monthly average of daily radiation)

Most of the data on solar radiation received on the surface of the earth are measured by solarimeter which gives readings for instantaneous measurements at rate throughout the day for total radiation on a horizontal surface.

SOLAR ENERGY COLLECTORS

A solar collector is a device for collecting solar radiation and transformer the energy to a fluid passing in contact with. These are general of two types:

1. **Non Concentrating or flat plate type solar collector:**

   In this collector areas (i.e. area that intercepts the solar radiation) is the same as the absorber area (i.e. area absorbing the radiation). These collectors are convenient where temperature below 90 degree is required. They are made in rectangular panels. They can be collect and absorb both direct and diffuse solar radiation. These are divided into two main classification based on type of heat transfer fluid used.

   (a) Liquid heating collector:

   The majority of flat-plate collectors have five major components as follows:

   - A transparent cover which may be one or more sheets of glass or plastic film or sheet
   - Tubes, fins, passages or channels are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.
   - The absorber plate, normally metallic or with a black surface, although a wide variety of other materials can be used with air heaters
   - Insulation, which should be provided at the back and sides to minimize the heat losses. Standard insulating materials such as fiber glass or styro-foam are used for this purpose.
   - The casing or containers which enclose the other components and protect them from the weather.

Liquid collector is the plate and tube type collector used for heating water and non-freezing aqueous solutions and occasionally for non aqueous heat transfer fluids.

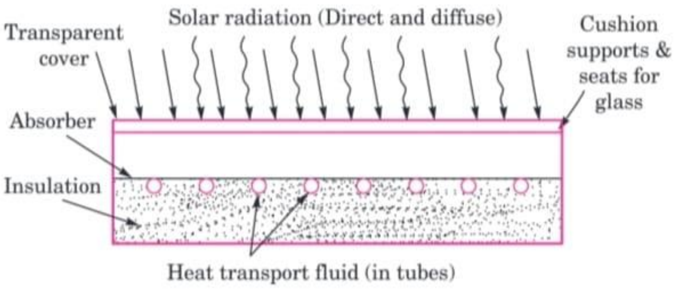


Fig.2 Selection through typical flat-plate collector

It basically consists of a flat surface with high absorptivity for solar radiation, called the absorbing surface. The absorber plate is usually made from a metal sheet 1 to 2 mm in thickness, while the tubes, which are also of metal, and range in diameter from 1 to 1.5 cm. They are soldered, brazed or clamped to the bottom of the absorber plate. The methods of bonding and clamping tubes to flat sheet are bond, tie and clamp.

Heat is transferred from the absorber plate to a point of use by circulation of fluid (usually water) across the solar heated surface. Thermal insulation of 5 to 10 cm thickness is usually placed behind the absorber plate to prevent the heat losses from the rear surface. Insulation materials are generally mineral wool or glass wool or fiberglass. The front covers are transparent to incoming solar radiation and opaque to the infrared re-radiation from the absorber. The glass covers act as a convection shield to reduce the losses from the absorber plate beneath.

Water is a very effective heat-transport medium, but it suffers from certain drawbacks, one is the possibility of freezing in the collector tubes in cold climates during cold nights. Ethylene glycol is added to prevent freezing, but this generally adds to the complexity of the heating system. Another problem is corrosion of metal tubes by water which can be minimized using a tube.

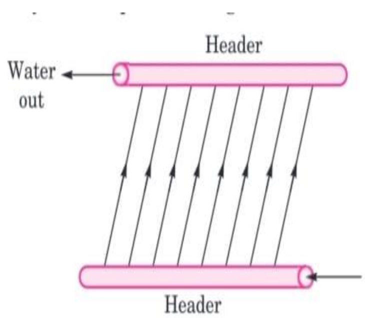


Fig. 3 Water flow in flat plate collector

(B) Solar Air Heater

In this an air stream is heated by the back side of the collector plates. Fins attached to the plate increase the contact surface. The back side of the collector is heavily insulated with mineral wool or some other material the most favorable orientation, of a collector, for heating only is facing due south at an inclination angle to the horizontal equal to the latitude plus 15 degree.

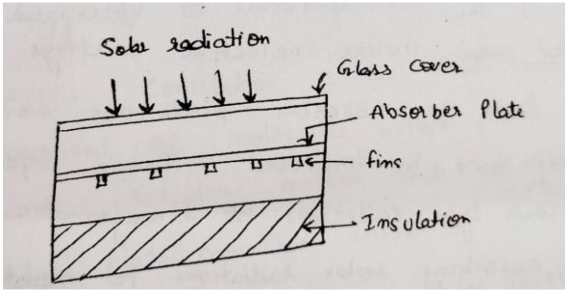


Fig. 4 Schematic flat-plate collector

Air as a heat transport medium in solar collectors has some advantages over water. Air as heat transport eliminates both freezing and corrosion problems and small air leaks are of less concern than water leaks.

The drawbacks are that transfer of heat from air to water in a hot water supply system is inefficient. Another drawback is that layers duct sizes & higher flow rates with increased pumping power are required for air than water as transport medium.

Basically air heaters are classified in the following two categories.

- The first type has a non-porous absorber in which the air stream does not flow through the absorber plate. Air may flow above and or behind the absorber plate.
- The second type has a porous absorber that includes slit and expanded metal.

The main drawback of the non-porous absorber plate is the necessity of absorbing all incoming radiation over the projected area from a thin layer over the surface, which is in the order of a few microns. Unless selective coatings are used, radioactive losses from the absorber plate are excessive; therefore the collection efficiency cannot be improved.
These defects are eliminated in porous type collectors in two ways:

- By absorbing solar radiation to greater depths depending on matrix density
- Pressure drop for the matrix is usually lower than the Non-porous absorber.

Applications

- Heating buildings
- Drying agricultural produce and lumber
- Heating green houses

Advantages

- They have the advantages of using both beam and diffuse solar radiation
- They do not require orientation towards the sun.
- They require little maintenance
- They are mechanically simpler

PERFORMANCE /ENERGY BALANCE EQUATION

The performance of solar collector is described by an energy balance that indicates the distribution of incident solar radiation into the useful energy gain and various losses. Thermal losses can be separated into three components:

Conductive losses: An overall heat transfer coefficient value of less than 0.69 $Wm^{2} \circ K$ is suggested to minimize back losses.

Convection losses: Convection is the heat transfer due to bulk movement of molecules within fluids such as gases & liquids, including molten rock. Convection losses between glass plates can be inhibited if a honeycomb type structure is placed between absorber & outer window plate.

Radioactive losses: Radiation is the emission of energy in the form of waves or particular through space. Radioactive losses can be reduced by the use of coatings having high absorptance of about 0.9 in the solar spectrum and low emittance of about o.1 in the solar infrared spectrum.

The energy balance equation on whole collection:

$$A_c \left[\{ HR(\tau \cdot \alpha)_b + HR(\tau \cdot \alpha)_d \} \right] = Q_u + Q_l + Q_s$$

where,

Q_u = rate of useful heat transfer to a working fluid in the solar heat exchanger.

Q_l = rate of energy losses from the collector to the surroundings by radiation, convection & conduction.

Q_s = rate of energy storage in the collector

A_c = Collector area, m^2

HR = Solar energy received on upper surface of the collector W/m^2 or $Kcal/hr\ m^2$

H : rate of incident beam or diffuse radiation on a unit area of surface of any orientation

R : Factor to convert beam or diffuse radiation to that on the plane of collector.

τ = Fraction of incoming solar radiation that reaches absorbing surface, transmissivity (dimensionless)

α = fraction of solar energy reaching the surface i.e absorbed, absorptivity (dimensionless)

$(\tau \cdot \alpha)_b$ for beam radiation $(\tau \cdot \alpha)_d$ for diffuse radiation

→ Collector efficiency η_c, is the collector performance and is defined as the ratio of useful gain over any time period to the incident solar energy over the same time period.

$$\eta_c = \frac{\int Q_u \, d_T}{\int HR \, d_T}$$

CONCENTRATING COLLECTOR: FOCUSING TYPE

A focusing collector is a special form of flat-plate collector modified by introducing a reflecting (or refracting) surface (concentrator) between solar radiation and the absorber. In these collectors, radiation falling on a large area is focused onto a receiver (absorber) of considerably smaller area. As a result of the energy concentration, fluids can be heated to temperature of 500 degree or more.

Types of concentrating collectors: Two general categories are considered:

1. **Line focusing collectors:** In this, line is the collector pipe.

Parabolic trough collector: Solar radiations coming from a particular direction is collected over the area of reflecting surface and is concentrated at the focus of the parabola. The collector pipe with selection absorber coating is used as an absorber placed along focus axis.

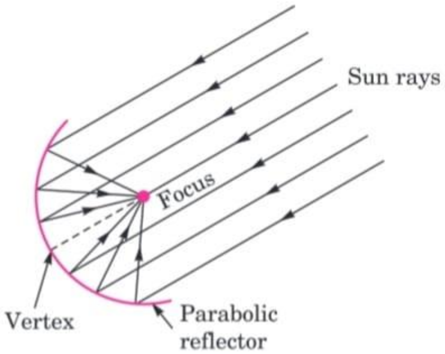


Fig. 5 Cross-section of parabolic trough collector

Parabolic trough reflectors have been made of highly polished aluminium of silvered glass on a firm base. Instead of having continuous form, reflector may be constructed from a number of long flat strips on a parabolic base.

Since the elevation of the sun is always changing, either the reflector trough or collector pipe must be turn continuously about its long axis to maintain the required orientation. General orientation is in east-west or north-south directions.
North-south orientation permits more solar energy to be collected than east west orientation except around winter equinox.

Mirror strip reflector: In another kind of focusing collector, a number of plane or slightly curved (concave) mirror strips are mounted on a flat base. The angles of the individual mirrors are such that they reflect solar radiation from a specific direction on to the same focal line. The angles of the mirrors must be adjusted to allow for changes in the sun's elevation while the focal line (for collector pipe) remains in a fixed position.

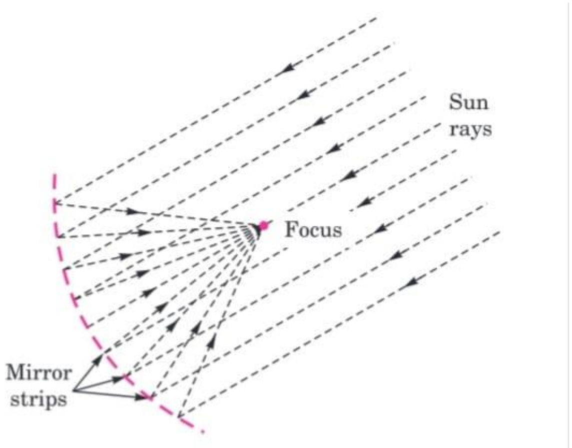


Fig. 6 Mirror strip solar collector

Fresnel lens collector: It is a refraction type of focusing collector which utilizes focusing effect of a Fresnel lens.

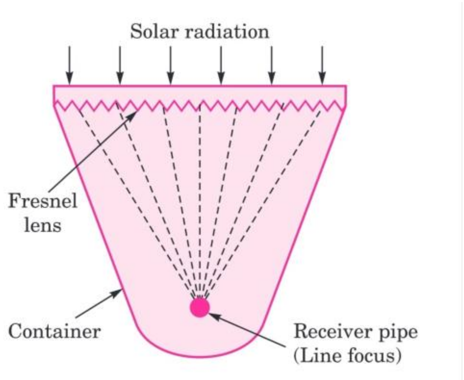


Fig. 7 Cross-section of Fresnel lens through collector

The lens is a rectangle about 4.7m in length & 0.95 m in width made in sections from acrylic plastic. The rounded triangular trough serves only as container & plays no role in concentrating solar energy.

Receiver Pipe/ Collector Pipe of line focusing collector: It has same general as flat plate collector. The solar radiation absorber is a central steel pipe with a treated surface (such as black chrome).

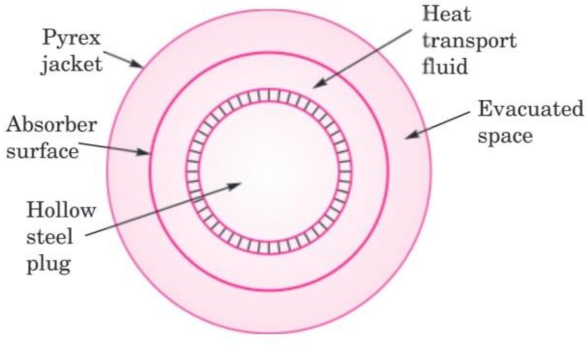


Fig. 8 Cross-section of solar energy pipe receiver

A hollow steel plug within the absorber pipe restricts the flow or the heat-transfer fluid to a narrow annular region. This results in a high flow velocity of the fluid and consequently a high rate of heat transfer from the absorber.

The absorber pipe is usually enclosed in a glass (Pyrex) jacket in order to decrease thermal losses by convection and radiation. The space between the pipe and the jacket is sometimes evacuated to reduce convection losses. The diameter of the glass jacket may be about 5 cm and that of the absorber pipe about 3 cm. The annulus between this pipe and the plug may be as little as 2.5 mm wide.

2. **Point focusing collector:** A point is a small volume through which heat transport fluid flows.

Paraboloidal Type : A paraboloidal dish collector brings solar radiation to a focus at a point actually a small central volume. A dish 6.6 m in, diameter has been made from about 200 curved mirror segments forming a paraboloidal surface. The absorber, located at the focus, is a cavity made of a zirconium copper alloy with a black chrome absorber selective coating. The heat transport focus fluid flows into and out of the absorber cavity through pipes bonded to the interior.

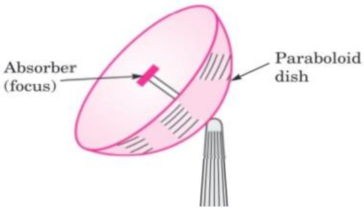


Fig. 9

The concentration ratios (concentration ratio is the ratio of the area of the concentrator aperture to the energy absorbing area of the receiver, it determines the effectiveness of a concentrator), are very high in the case of parabolic system and therefore can be used where high temperatures are required.

A broad classification of such collector is:

- The linear focus collector in the form of a parabolic through or the one employing faceted mirror strips.
- Spherical and conical mirror (Axicon) with aberrated foci.
- Central receiver collector Such as the paraboloidal mirror and the tower power plant using heliostat mirrors.

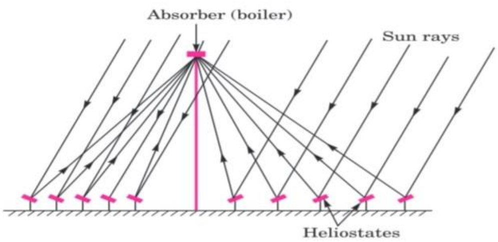


Fig. 10 Distributed heliostat point-focusing reflector (Central-Receiver)

Flat plate collector with adjustable mirror- It consists of a flat plate facing south with mirrors attached to its north and south edges. If the mirrors are set at the proper angle, they reflect solar radiation on to the absorber plate. Thus, the latter receive radiation in addition to that normally falling on it.

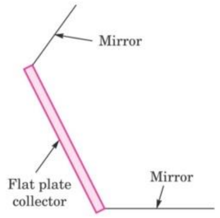


Fig. 11 Flat- Plate collector augmented with mirrors

In order for the mirrors to be effective, the angles should be adjusted continuously as the sum's attitude changes. For these reasons, they can provide only a relatively small increase in the solar radiation falling on the absorber; flat-plate collectors with mirrors are not widely used.

Compound Parabolic Concentrator (CPC): The CPC or winston collector is a trough like arrangement of two facing parabolic mirrors. CPC is non-focusing but solar radiation from many directions is reflected towards the bottom of the trough. It is possible to concentrate solar (direct & diffuse) radiation by a factor of 10 without diurnal tracking, using this type of collector.

CPC reflectors can be designed for any absorber shapes.
For example:

- Flat one sided absorber
- Flat two sided absorbers (fin),
- Wedge-like absorbers
- Tubular absorbers

CPC are capable of competitive performance at high temperature of about 300 degree Celsius required for power generation, if they are used with selectively coated, vaccum enclosed receivers which decrease thermal losses from the collector.

Advantages and Disadvantages of concentrating collectors over flat plate type collectors

Advantages:

- Reflecting surfaces required less material and are structurally simpler than flat-plate collectors. For a concentrator system the cost per unit area of solar collecting surface is therefore potentially less than that for flat-plate collectors.
- The absorber area of a concentrator system is smaller than that of a flat- plate system tor same solar energy collection and therefore the insolation intensity are greater.

- Focusing or concentrating systems can be used for electric power generation when not used for heating or cooling. The total useful operating time per year can therefore be large for a concentrator system than for a flat-plate collector and the initial installation cost of the system can be regained by saving in energy in a shorter period of time.
- In solar heating and cooling applications, the higher temperature of the working fluid attainable with a concentrating system makes it possible to attain higher efficiencies, in the cooling cycle and lower cost for air conditioning with concentrator systems than with flat-plate collectors
- Little or no anti-freeze is required to protect the absorber in a concentrator system whereas the entire solar energy collection surface requires anti –freeze protection in a flat-plate collector.

Disadvantages

- Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component cannot be reflected and is thus lost.
- High initial cost
- Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation, etc.

PERFORMANCE ANALYSIS OF A CYLINDRICAL PARABOLIC CONCENTRATING COLLECTOR

Energy balance is used to describe performance. Heat gain per unit aperture Area q_u is obtained by energy balance at x P.u. aperture area.

$$q_u = \frac{H_b R_b \rho \gamma (\tau.\alpha) A_a}{A_a} - \frac{U_L A_r (T_{r,x} - T_a)}{A_a}$$

$H_b R_b$ = beam radiation on the plane of the aperture P.u. time P.u. area.

ρ = specular reflectance of the reflector surface.

γ = intercept factor

$\tau.\alpha$ = Transmittance absorptance Product

A_a/A_r = ratio of effective area of aperture to area of solar energy absorber, concentration ratio.

U_L : Surface (receiver) loss coefficient

$T_{r,x}$ = receiver surface temp. at x T_a = ambient temp.

SOLAR ENERGY STORAGE SYSTEMS

1. **Thermal Storage:** Storage by causing a material to rise in temperature is called sensible heat storage. Storage by phase change, the transition from solid to liquid or from liquid to vapour is another mode of thermal storage known as the latent heat storage.

Thermal energy storage is essential for both domestic water and space heating applications and for the high temperature storage systems needed for thermal power applications. Storage is also required in the process industries and horticultural. The choice of the storage material depends on the particular application and for many domestic applications, water and/or rock storage systems have been developed. Water and rock are typical examples of material which store energy as specific heat (sensible heat), but their use is limited by their comparatively low specific heats. The heat of fusion (latent heat) which is involved when a substance changes state from a solid to a liquid, provides an attractive method of storing a given amount of heat within a much smaller volume. Glauber's salt (Na, SO.10H_2O) is the least expensive and most readily available salt hydrate.

(a) **Sensible heat storage:** The basic equation for an energy storage and unit over a finite temperature difference is:

$$\mathbf{Q_S = (mC_p)_s\,(T_1 - T_2)}$$

where,

Q_S = Total thermal energy
T_1, T_2 = Temperature
C_p = Specific heat
m =weight of storage medium

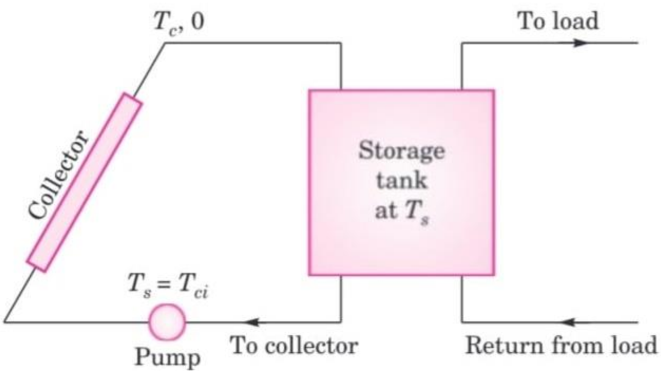


Fig. 12 Water tank storage unit

Water Storage: The most common heat transfer fluid for a solar system is water, and the easiest way to store thermal energy is by storing the water directly in a well insulated tank The optimum tank size for at-plate collector system is usually about 70 kg/m (2 gal/ft). Water has the following characteristics for storage medium.

- It is inexpensive, readily available and useful material to store sensible heat.
- It has high thermal Storage capacity
- Energy addition and removal from this type of storage is done by medium itself, thus eliminating any temperature drop between transport fluid and storage medium.
- Pumping cost is small

Packed Bed Exchanger Storage: For sensible heat storage with air as the energy transport mechanism, rock, gravel, or crushed stone in a bin has the advantage of providing a large, cheap heat transfer surface. It is thermal capacity, however, is only about half that of water and the bin volume will be about 3 times the volume of a water tank, that is heated same temperature interval. Water is superior because of its lower material cost and lower volume required per unit of energy stored. Rock does have the following advantages over water:

- Rock is more easily contained than water
- Rock acts as its own heat exchanger, which reduces total system cost.
- It can be easily used for thermal storage at high temperatures, much higher than 100°C; storage at high temperature where water cannot be used in liquid form without an experience, pressurized storage tank.
- The heat transfer coefficient between the air and solid is high.
- The cost of storage material is low.
- The conductivity of the bed is low when air flow is not present.

Essential features of a packed bed storage unit are a container, porous structure to support the bed and air distributors. In operation the flow is maintained through the bed in one direction during addition of heat and in the opposite direction during removal of heat. In this system, the heat addition and removal from the storage cannot be carried out simultaneously. Pebble bed exchanger has good heat transfer characteristics between air & solids of the bed. This type of storage system has been used in the solar houses or with hot air collector system.

b) Latent heat storage (Phase change energy storage):

In this system, heat is stored in a material when it melts and extracted from the material when it freezes. Materials that undergo a change of phase in a suitable temperature range may be useful for energy storage if the following criteria can be satisfied:

- The phase change must be accompanied by high latent heat effect.

- The phase change must be reversible over a very large number of cycles without degradation.
- The phase change must occur with limited super cooling
- Means must be available to contain the material and transfer heat into it and out of it.
- The cost ot materials and its containers must be reasonable.
- Its phase change must occur close to its actual melting temperature.
- The phase change must have a high latent heat effect, that is, it must store large quantities of heat.
- The material must be available in large quantities

There are several materials that undergo a change of phase. Glauber's salt ($Na_2SO_4.10H_2O$), water, Fe $(NO_3)_2 6H_2O$ and salt Eutectics are mostly used.

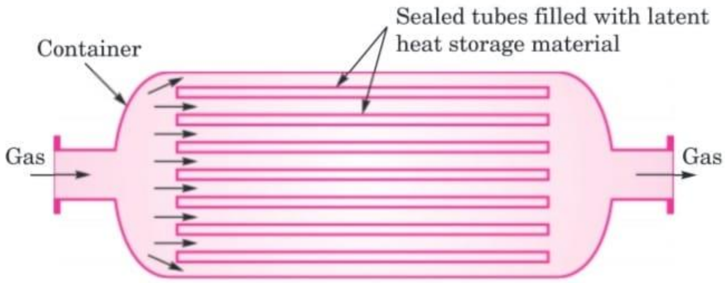


Fig. 13 A typical latent heat storage arrangements

An advantage of this storage system is that it is more compact than a sensible heat system. Its drawback is higher cost.

2. ELECTRICAL STORAGE:

Capacitors could store large amount of electrical

energy, Energy stored is , $H_{cap}= ½ \times V\varepsilon E^2$

- V is Volume of dielectric

  ε is constant

  E is Electric field strength
- Electric energy storable in dielectric (material-mica) is limited
- Capacitive storage is economical for times no longer than 12 hours
- Capacitors store electrical energy at high voltage and low current.

Inductor storage is at low voltage and high current

• $H_{ind}= ½ V\mu H_m$

• μ is permeability of material

• H_m is magnetic flux density

• For H_{ind} to be large both μ and H_m should be large

•High magnetic fields are required

• Reverse operation in case of inductor can discharge stored energy

Battery is combination of individual cells

- Cell is the combination of material and electrolyte where energy is stored electrochemically. This energy is regained as electrical energy
- Secondary batteries are important for solar application because they are rechargeable batteries
- Example – lead-acid , nickel-cadmium, iron-air, nickel hydrogen, sodium-suplhur etc

3. **CHEMICAL STORAGE:**

   Chemical storage in the form of fuel

- To store in battery by photochemical reaction brought about by solar radiation
- This battery is charged photo chemically and discharged electrically whenever needed

Thermo chemical energy storage are suitable for medium or high temp. applications

- Forward reaction takes place with absorption of heat from solar energy (Heat is stored)
- Reverse reaction caused to liberate heat.

4. **MECHANICAL STORAGE:**

   Pumped hydroelectric storage

- In hydroelectric power plants, once the water has been run downhill to turn the turbines it flows out to sea; pumped hydro lets us pump that water back up hill, to re-use for power generation again and again.

Compressed air energy storage

- A compressor/wind turbine is used to store compressed air in pressurized storage tank.
- Later this compressed air is used to drive turbine which will generate electricity when there is demand.

Flywheel storage

- Flywheel is driven by electric motor during off peak hours stores mechanical energy
- The rotation of flywheel can be used to operate a generator to produce electricity when required

5. **Electromagnetic energy storage**

- Material suddenly loose all resistance to the flow of electricity when cooled below very low temperature
- If maintained below this can carry strong electric currents
- Superconducting materials like niobium titanium alloy at temp – 263 degree celcius
- Electromagnetic field produced by an electric current flowing through wire coil can store energy.

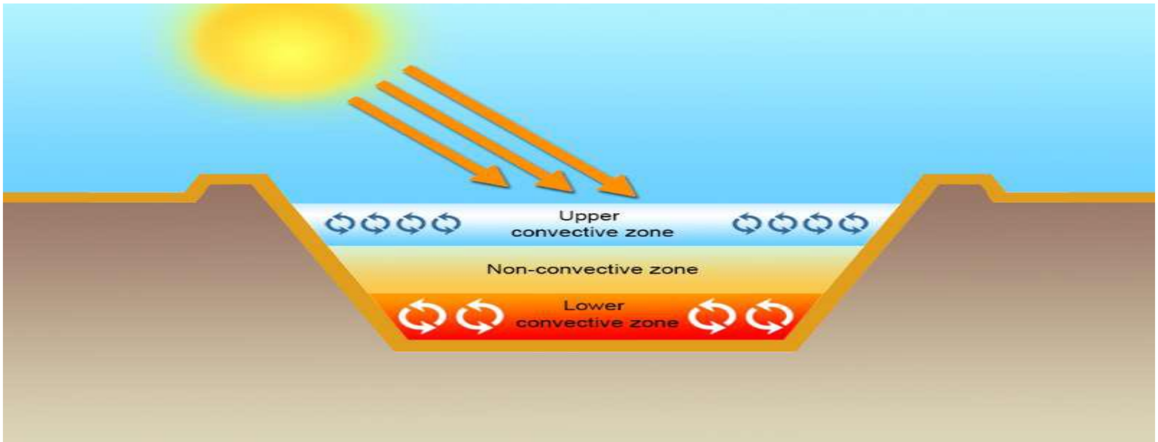
SOLAR POND:

- A solar pond is a body of water that collects and stores solar energy. Water warmed by the sun expands and rises as it becomes less dense. Once it reaches the surface, the water loses its heat to the air through convection, or evaporates, taking heat with it. The colder water, which is heavier, moves down to replace the warm water, creating a natural convective circulation that mixes the water and dissipates the heat. The design of solar ponds reduces either convection or evaporation in order to store the heat collected by the pond.
- A solar pond can store heat much more efficiently than the body of water of same size because the salinity prevents convectional current.
- The first solar pond in India (6000 m^2) was built at Bhuj. The project was sanctioned under the National Solar Pond Programme by the Ministry of Non-Conventional Energy Sources in 1987 and completed in 1993 after a sustained collaborative effort by TERI, the Gujarat Energy Development Agency, and the GDDC (Gujarat Dairy Development Corporation Ltd).
- The largest operating solar pond for electricity generation was the Beit Haarava pond built in Israel. It has an area of 210,000 m^2 and used to generate an electrical output of 5 MW.
- The 0.8-acre (3,200 m^2) solar pond powering 20% of Bruce Foods Corporation's operations in El Paso, Texas is the second largest in the U.S. It is also the first ever salt-gradient solar pond in the U.S.

Working principle of solar pond:

The solar pond normally consists of following three zones:-

1) Upper convective zone (UCZ) :- Adjacent to the surface there is a homogeneous convective zone that serves as a buffer zone between environmental fluctuations at the surface and conductive heat transport from the layer below.



2) **Intermediate gradient zone**:- A gradient which serves as the non convective zone which is much thicker and occupies more than half the depth of the pond. Salt concentration and temperature increase with depth.

3) **Lower convective zone(LCZ)**:- This is the highest salt concentration zone and where the high temperature are built up. Almost as thick as the middle non-convective zone.

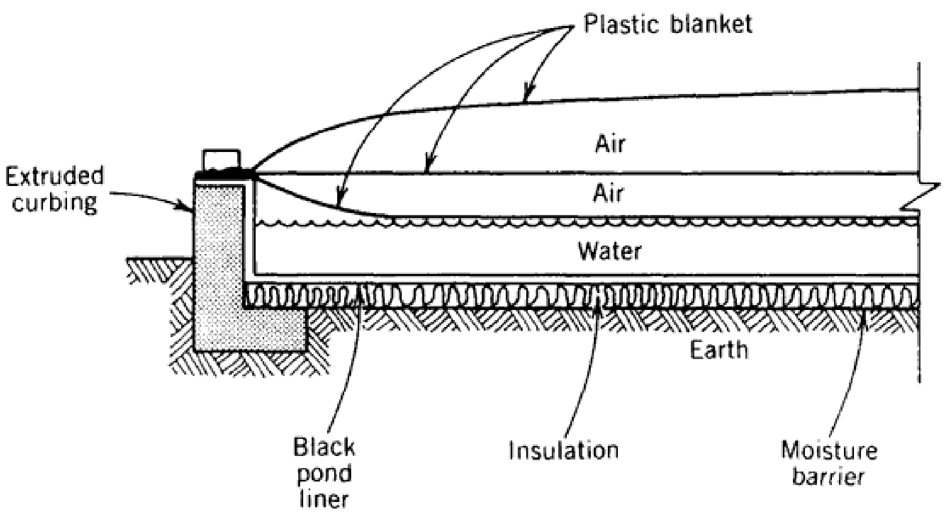
- To maintain a solar pond in this non-equilibrium stationary state, it is necessary to replace the amount of salt that is transported by molecular diffusion from the LCZ to the UCZ. This means that salt must be added to the LCZ, and fresh water to the UCZ whilst brine is removed.

- The surface area of the pond affects the amount of solar energy it can collect.The dark surface at the bottom of the pond increases the absorption of solar radiation. Salts like magnesium chloride, sodium chloride or sodium nitrate are dissolved in the water, the concentration being densest at the bottom (20% to 30%) and gradually decreasing to almost zero at the top.

TYPES OF SOLAR POND

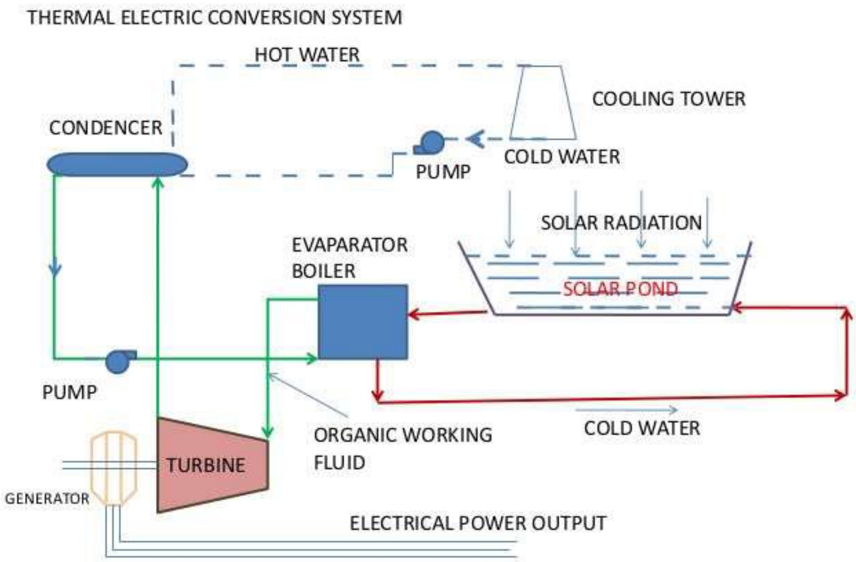
1. **CONVECTING SOLAR POND:**

- A well-researched example of a convecting pond is the shallow solar pond. This pond consists of pure water enclosed in a large bag that allows convection but hinders evaporation.
- The bag has a blackened bottom, has foam insulation below, and two types of glazing (sheets of plastic or glass) on top. The sun heats the water in the bag during the day. At night the hot water is pumped into a large heat storage tank to minimize heat loss. Excessive heat loss when pumping the hot water to the storage tank has limited the development of shallow solar ponds.



2. **NON CONVECTING SOLAR POND:**

- The main types of non convecting ponds are salt gradient ponds. A salt gradient pond has three distinct layers of brine (a mixture of salt and water) of varying concentrations. Because the density of the brine increases with salt concentration, the most concentrated layer forms at the bottom. The least concentrated layer is at the surface. The salts commonly used are sodium chloride and magnesium chloride. A dark-colored material usually butyl rubber lines the pond.
- As sunlight enters the pond, the water and the lining absorb the solar radiation. As a result, the water near the bottom of the pond becomes warm up to 93.3°C. Even when it becomes warm, the bottom layer remains denser than the upper layers, thus inhibiting convection. Pumping the brine through an external heat exchanger or an evaporator removes the heat from this bottom layer. Another method of heat removal is to extract heat with a heat transfer fluid as it is pumped through a heat exchanger placed on the bottom of the pond.



FLOW DIAGRAM OF SOLAR POND ELECTRIC POWER PLANT

EFFICIENCY

- The energy obtained is in the form of low grade heat of 70 to 80 °C compared to an assumed 20 °C ambient temperature. According to the second law of thermodynamics (Carnot cycle), the maximum theoretical efficiency of a cycle that uses heat from a high temperature reservoir at 80 °C and has a lower temperature of 20 °C is

$$\eta = 1 - \frac{T_C}{T_H} \qquad 1 - \frac{273+20}{273+80} = 17\%$$

Advantages

- Environment friendly energy – no pollution
- Renewable energy source
- It can be used for many purpose such as generation of electricity, heating of fluids
- No need of a separate collector for this thermal storage system
- Low maintenance costs.

Disadvantages

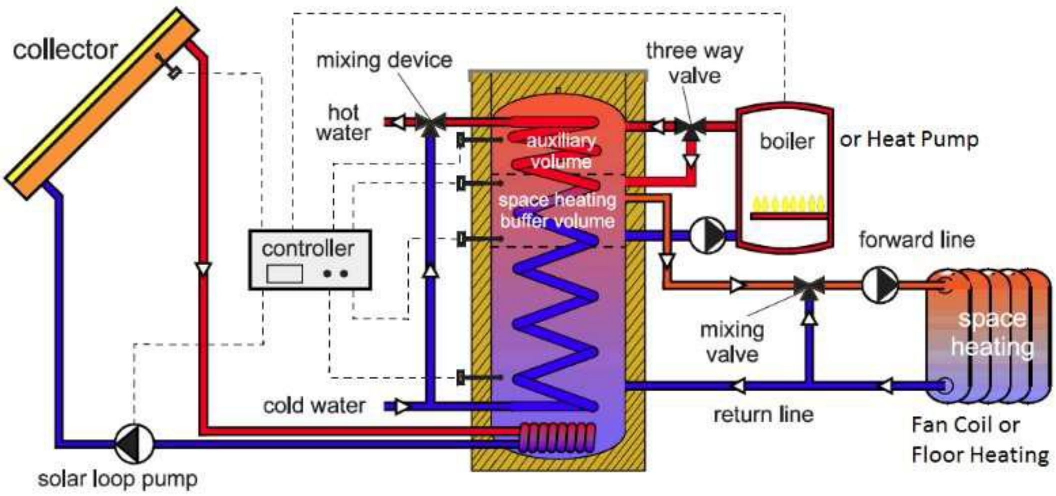
- Risk of contamination of ground with high salt levels from water in pond
- Excessive wind can blow water away or evaporate the top layer of water at high rate.
- Require a specific location that is not readily available in all areas.

Applications

- Salt production
- Aquaculture, using saline or fresh water
- Water supply(for desalination)
- Grain industry(for grain drying)
- Fruits and vegetable canning industry
- Dairy industry(to preheat feed water to boilers)

SOLAR HEATING AND COOLING SYSTEM (SHCS)

- Solar heating and cooling technology receive the thermal energy from sun and utilize this energy to provide hot water, space heating and pool heating for residential, commercial and industrial applications. These applications of SHCS reduce the dependency on electricity or natural fuels. The main function of solar system is to convert sun light into heat.
- The primary requirement of SHCS is to setup the light collectors with higher efficiency.



WHY WE NEED SHCS?

- Eliminating the need for electricity or natural gas.
- Instead collect and use free, clean thermal energy from the sun.
- An economical alternative to solar photovoltaic (PV) system.
- Solar heating and cooling systems simply eliminate the need for electricity to cool or heat the air and water in a home or business.

SOLAR HEATING METHODS

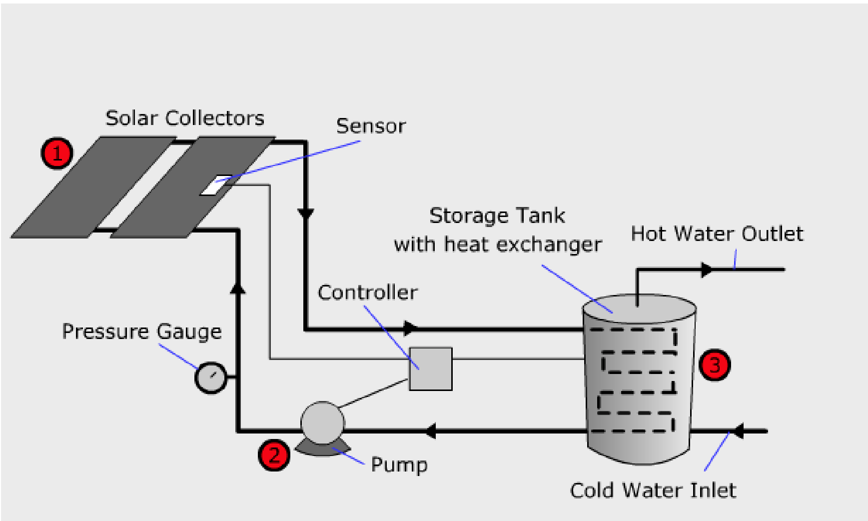
The term solar system mainly defines two types of system,

1. Active heating
2. Passive heating

1. **ACTIVE HEATING**

- Active solar heating systems use solar energy to heat a fluid -- either liquid or air and then transfer the solar heat directly to the interior space or to a storage system for later use. If the solar system cannot provide adequate space heating, an auxiliary or back-up system provides the additional heat.
- This system can be used as commercial hot water as well as space heat.
- A space heat application involves some additional connecting hardware for space heat distribution system.
- Active solar heating system involve following major components:

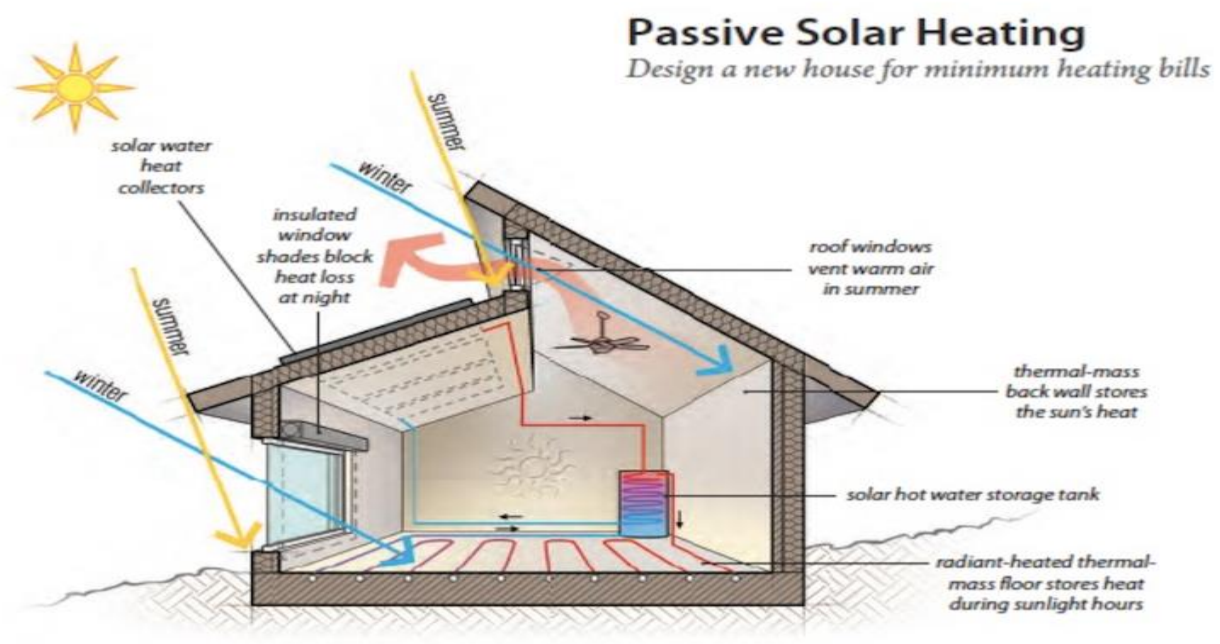
- Collectors to absorb energy
- Circulation system
- Storage tank
- Backup heating system
- Control system



2. **Passive heating**

Passive solar heating is the least costly technique to heat home space. The main aim of this system is to kept out heat in summer and kept in heat in winter from sun light.

Passive solar heating also depends on ventilation or windows provided in buildings or houses.



SOLAR COOLING

Solar cooling is a system that converts heat from the sun into cooling that can be used for refrigeration and air conditioning. A solar cooling system collects solar power and uses it in a thermally driven cooling process which is in turn used to decrease and control the temperature for purposes like generating chilled water or conditioning air for a building.

There are many different cooling cycle techniques using various different principals to function. Three of the most popular techniques include:

1. Absorption cycles
2. Desiccant cycles
3. Solar mechanical cycles

How solar cooling works

Regardless of the technique being used, a solar cooling system typically includes three core components:

- A solar collector, such as a solar panel, which is used to convert solar radiation into heat or mechanical work.

- A refrigeration or air conditioning plant that is used to produce the cooling.
- A heat sink that collects any rejected heat and radiates it away from the system.

While techniques used to achieve solar cooling vary, the end goal remains the same: utilize an external heat source, like a solar panel, to collect ambient temperature and then use that heat with a refrigerant to create pressure within a closed loop of refrigerant, thus enabling the solar cooling system to work.

A refrigerant is a substance or mixture that absorbs heat from the environment and can create refrigeration or air conditioning if it is combined with the other necessary components, like compressors and evaporators. In most cooling cycles, the refrigerant will transition from the liquid phase to the gas phase and then back again to achieve its cooling purpose.

1. **Absorption cycles**

In absorption cycles, the cooling process relies on the evaporative cooling of a refrigerant. Since vaporization requires energy input, the process takes heat from the system, leaving the remaining fluid cooler than before. Absorption cycles complete pressurization by dissolving a refrigerant in an absorbent, or something that soaks up liquid easily, instead of using a mechanical compressor.

Absorption cooling cycles possess four specific, major components: an absorber, a generator, a condenser and an evaporator. The evaporator is, essentially, the refrigeration or air conditioning plant used in all cooling systems since it is where the cooling occurs.

In an absorption cycle, the cooling process progresses as follows:

- The absorber holds an absorbent-refrigerant mixture that is delivered to the generator through a liquid pump.
- The generator takes the absorbent-refrigerant mixture and heats it up using the external solar energy that has been collected through a source such as a solar panel. The solution starts to boil in reaction to the heat, turning water into vapor which flows to the condenser.

- The condenser liquefies the water vapor, rejecting heat in the process which is collected by the heat sink. The new liquid condensate is then directed towards the evaporator through an expansion valve.
- Finally, evaporation of the refrigerant at low pressure causes the evaporator to absorb the heat from the cooled space, creating the cooling effect.

At the end, the vaporized refrigerant returns to the absorber and the cycle repeats. Solar power is responsible for driving this cycle.

2. **Desiccant cycles**

Desiccant cooling systems rely on cycling dehumidification-humidification processes. It uses substances and materials that readily attract water from their surroundings for dehumidification. These materials are known as desiccants. The desiccants are regenerated in the cycle by applying solar power.

Desiccant cooling systems can operate with both liquid and solid desiccants. The desiccant cooling process progresses as follows:

- Desiccants absorb the water vapor and remove the moisture from the process air in the dehumidification, or absorber, unit. A transfer results from the difference in vapor pressure, thus releasing heat due to the condensation of water and creating a heat exchange.
- The air is then introduced into the space or into an evaporative cooler for further cooling while the diluted desiccant is sent to the regenerator. However, before the diluted desiccant can enter the regenerator, it must pass through a liquid-liquid heat exchanger and a heating coil in order to raise its temperature.
- Once in the regenerator, the heated, diluted desiccant is exposed to regenerative air, causing moisture to transfer from the diluted solution to the air. This transfer is due to the created difference in vapor pressure.
- Next, the resulting, more concentrated desiccant passes through the liquid-liquid heat exchanger once again as well as a cooling coil and then moves back into the dehumidification unit, allowing the cycle to repeat.

3. **Solar mechanical cycles**
   It works very differently from the absorption and desiccant cycles. Instead of creating an entirely new system, solar mechanical cycles attempt to combine solar powered mechanics with conventional cooling systems. In this cycle, solar power is used to fuel the actual engine that produces the energy used to operate the entire cooling system instead fueling the absorption chiller, like it does in both the absorption and desiccant cycles.

Applications of solar cooling

Solar cooling is primarily intended for two main purposes: refrigerating food storage and space cooling, or air conditioning. Solar cooling can be seen in vehicles like RVs and campers which use the system for refrigeration. Vapor absorption refrigeration systems, which are used in industries where extremely low process temperatures are required as well as large thermal capabilities, also display the use of solar cooling.

Perhaps the most beneficial application of solar cooling is its ability to provide cooling systems to countries that otherwise would not be able to handle the total electric and energy cost and burden required by conventional cooling systems. Solar cooling greatly reduces the amount of energy required to refrigerate necessities such as vaccines and agricultural products, which, in turn, creates cost savings and benefits the environment by using renewable energy and reducing the use of ozone depleting materials.

SOLAR THERMAL ELECTRIC CONVERSION

The conversion of solar energy into electricity by way of thermal energy. Heat can be converted directly into electrical energy by solar cell or thermionic or thermoelectric methods, but these techniques may not be suitable for use with the sun-generated heat. The most practical thermal electric procedure for solar energy is to utilize the energy to heat a working fluid (eg, a gas, water or other volatile liquid). The heat energy is then converted into mechanical energy in a turbine and finally into electrical energy by means of a conventional generator coupled to the turbine. This mechanical power production system is called the solar thermal power production system.

Solar Power Generations

There are two main ways of generating energy from sun,

- **Photovoltaic (PV)** – Convert sunlight directly into electricity
- **Concentrating Solar thermal (CST)** – Generate electricity indirectly

Solar thermal systems:
There are two types of solar thermal systems:

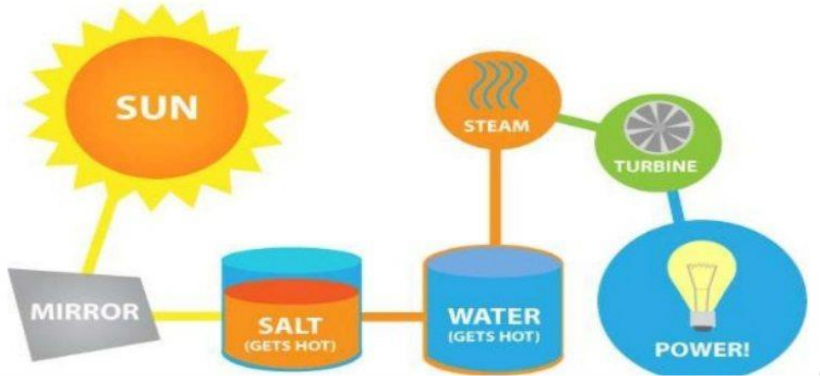
Passive: A passive system requires no equipment, like when heat builds up inside your car when it's left parked in the sun.

e.g. Thermal chimneys

Active: An active system requires some way to absorb and collect solar radiation and then store it.

e.g. Solar thermal power plants

Basic working principle:
Mirrors reflect and concentrate sunlight. Receivers collect that solar energy and convert it into heat energy. A generator can then be used to produce electricity from this heat energy.



Thermal energy storage (TES)

TES are high-pressure liquid storage tanks used along with a solar thermal system to allow plants to bank several hours of potential electricity.

- **Two-tank direct system:** solar thermal energy is stored right in the same heat-transfer fluid that collected it.
- **Two-tank indirect system:** functions basically the same as the direct system except it works with different types of heat-transfer fluids.
- **Single-tank thermocline system**: stores thermal energy as a solid usually silica sand.

TYPES OF SOLAR THERMAL POWER PLANTS

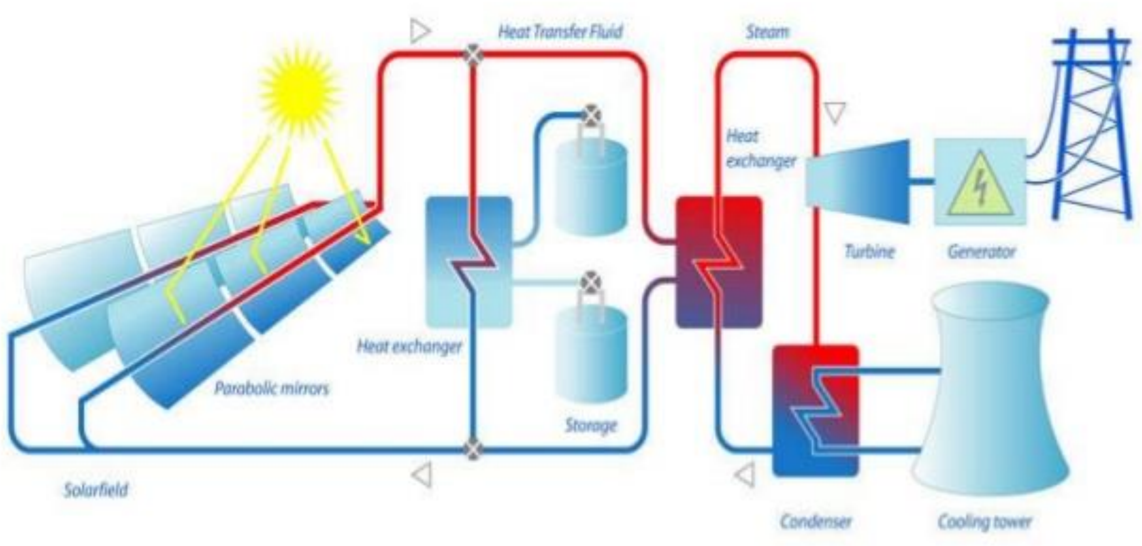
1. **Parabolic trough System**

- A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal tine.

- The receiver is a tube positioned directly above the middle of the parabolic mirror and filled with a working fluid.

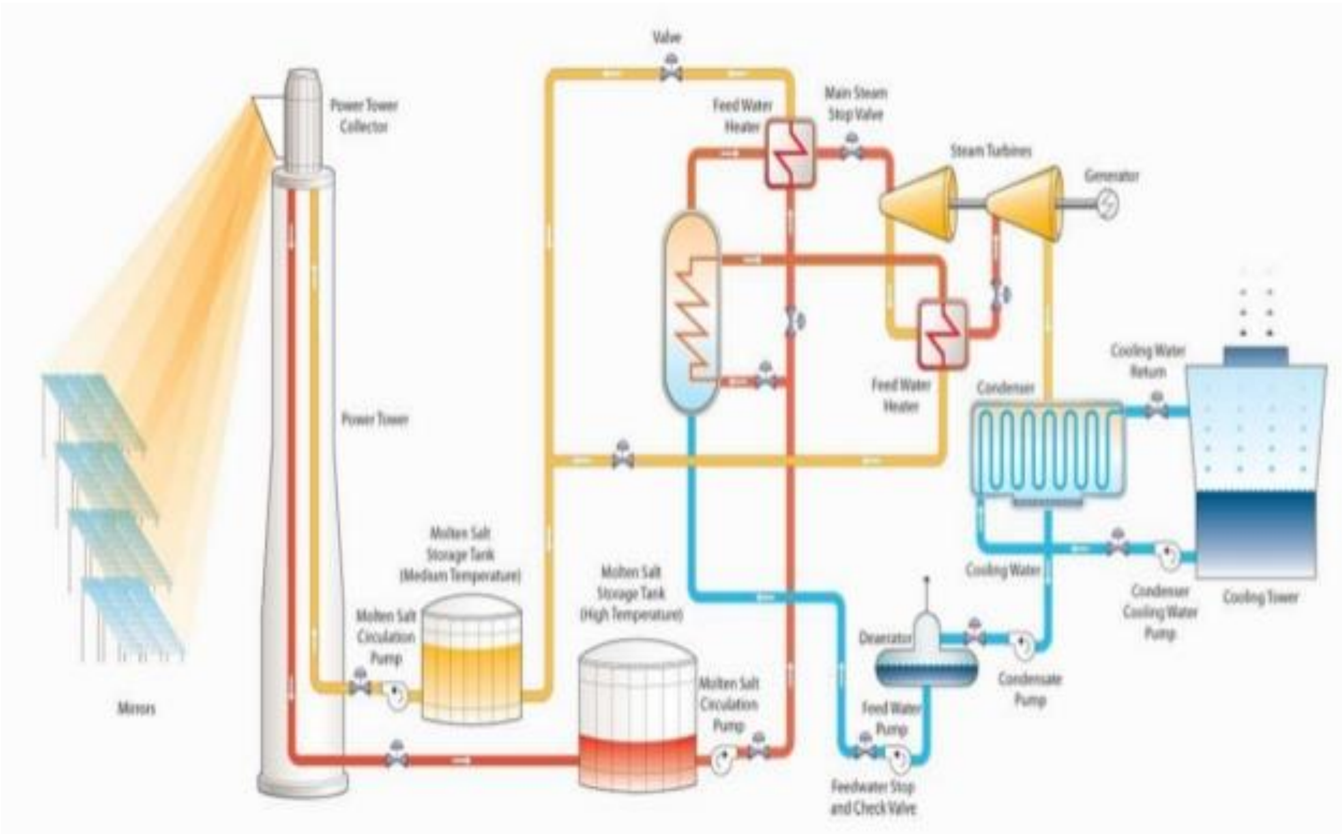
- The reflector follows the sun during the daylight hours by tracking along a Single axis

- A working fluid (e.g. molten salt) is heated to 150-350 °C (423-623 K(302-662 °F)) as it flows through the receiver and is then used as a heat source for a power generation system.

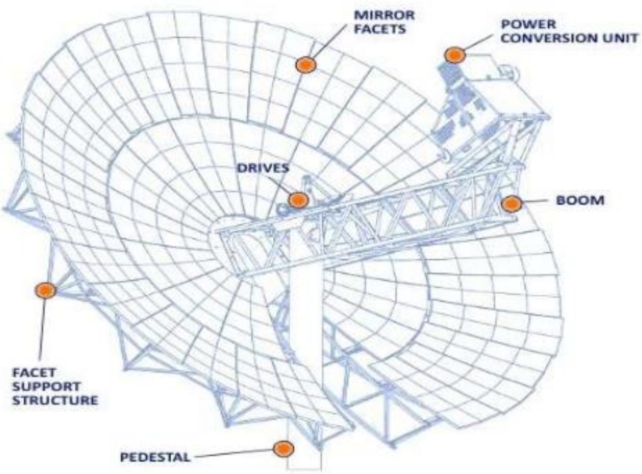


2. **Solar power tower systems**

- Power towers (also known as 'central tower power plants or "heliostat power plants).
- These designs capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in roughly a two square mile field.
- A tower resides in the center of the heliostat field. The heliostats focus concentrated sun light on a receiver which sits on top of the tower.
- Within the receiver the concentrated sunlight heats molten salt to over 1,000 "F (538 C).
- The heated molten salt then flows into a thermal storage tank where it is stored, maintains in g 98% thermal efficiency, and eventually pumped to a steam generator.
- The steam drives a standard turbine to generate electricity.



3. **Solar dish/engine system**
   - The system consists of a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point.
   - The working fluid in the receiver is heated to 250-700 °C (523-973 K (482-1,292 °F)) and then used by a Stirling engine to generate power
   - Parabolic-dish systems have the highest efficiency of all solar technologies provide solar-to-electric efficiency between 31-32%.



4. **Compact linear Fresnel reflector**

- Linear Fresnel reflectors use long, thin segments of mirrors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors.
- These mirrors are capable of concentrating the sun's energy to approximately 30 times its normal intensity.

- This concentrated energy is transferred through the absorber into some thermal fluid.
- The fluid then goes through a heat exchanger to power a steam generator.

5. **Enclosed parabolic trough**

   - The enclosed parabolic trough solar thermal system encapsulates the components within a greenhouse-like glasshouse.
   - The glasshouse protects the components from the elements that can negatively impact system reliability and efficiency
   - Lightweight curved solar-reflecting mirrors are suspended from the ceiling of the glasshouse by wires
   - A single-axis tracking system positions the mirrors to retrieve the optimal amount of sunlight.
   - The mirrors concentrate the sunlight and focus it on a network of stationary steel pipes, also suspended from glass house structure.
   - Water is pumped through the pipes and boiled to generate steam when intense sun radiation is applied by steel pipes, also suspended from the glasshouse structure.

Advantages of Solar Thermal Energy

- No Fuel Cost
- Predictable, 24/7 Power
- No Pollution and Global Warming Effects
- Using Existing Industrial Base

Disadvantages of Solar Thermal Energy

- High Cost
- Future Technology has a high probability of making CSP Obsolete
- Ecological and Cultural Issues
- Limited Locations and Size Limitations
- Long Gestation Time Leading to Cost Overruns