Course: Technologies of Renewable Energy Sources

Module-2:Thermal Energy Collectors

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Solar Energy Collectors

- A solar collector is a device for collecting solar radiation and transfer the energy to a fluid passing in contact with it.
- Utilization of solar energy requires solar collectors.
- These are general of two types:
  - (i) Non concentrating or flat plate type solar collector.
  - (ii) Concentrating (focusing) type solar collector.
- The solar energy collector, with its associated absorber, is the essential component of any system for the conversion of solar radiation energy into more usable form (e.g., heat or electricity).

- In the non-concentration type, the collector area (i.e., the area that intercepts the solar radiation) is the same as the absorber area (i.e., the area absorbing the radiation).
- On the other hand, in concentrating collectors, the area intercepting the solar radiation is greater, sometimes hundred of times greater than the absorber area.
- By means of concentrating collectors, much higher temperatures can be obtained than with the non-concentrating type.
- Concentrating collectors may be used to generate medium pressure steam. They use many different arrangements of mirrors and lenses to concentrate the sun's rays on the boiler.
- This type shows better efficiency than the flat plate type. For best efficiency, collectors should be mounted to face the sun as it moves through the sky.

Physical Principles of the Conversion of Solar Radiation into Heat

- The fundamental process now in general use for heat conversion is the green house effect.
- The name come from its first use in green houses, in which it is possible to grow exotic plants in cold climates through better utilization of the available sunlight.
- Most of the energy we receive from the sun comes in the form of light, a shortwave radiation, not all of which is visible to the human eye.
- When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy; the material becomes warm and stores the heat, conducts it to surrounding materials (air, water and other solids or liquids) or reradiates it to other materials of lower temperature.

- Fig. 2.1 shows how temperature on earth is affected by the ***'green house effect'.***
- Visible sunlight is absorbed on the ground at a temperature of 20°C, for example emits infra-red light at a wavelength of about 10 μm, but CO_2 in atmosphere absorbs light of that wavelength and back radiates part of it to earth. (CO_2 does not absorbs the incoming sunlight which has a shorter wavelength).
- Hence the green house effect brings about an accumulation of energy of the ground.

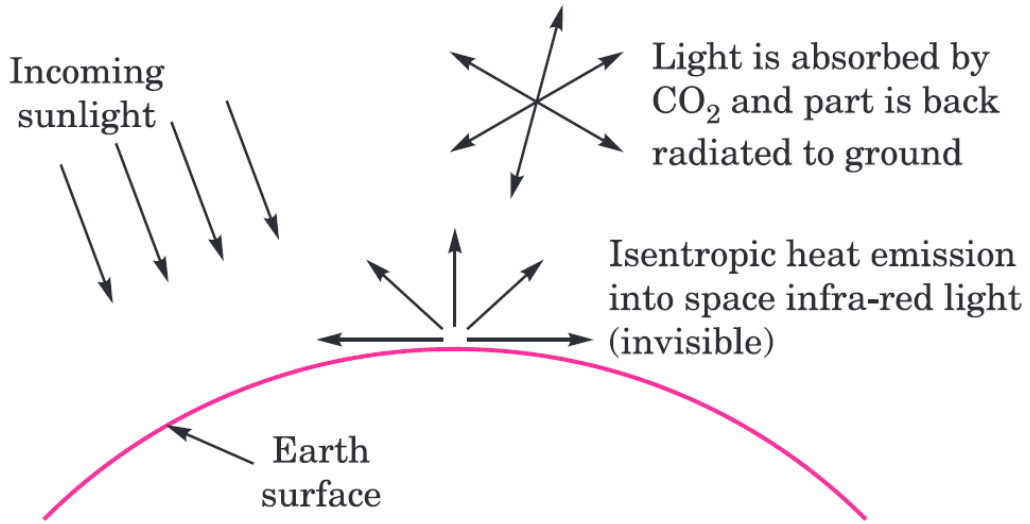


Fig. 2.1

The green house effect radiated to the CO_2 content of the atmosphere.

- Glass easily transmits short-wave radiation, which means that it poses little interference to incoming solar energy, but it is a very poor transmitter of long wave radiation.
- Once the sun's energy has passed through the glass windows and has been absorbed by some material inside, the heat will not be reradiated back outside.
- Glass therefore, act as a heat trap, a phenomenon which has been recognized for sometime in the construction of green houses, which can get quite warm on sunny days, even in the middle of winter; this has come to be known in fact, as the ***"green house effect".***

Solar collectors for home heating usually called flat plate collectors, almost have one or more glass covers, although various plastic and other transparent materials are often used instead of glass.

Flat-plate solar collectors

- Flat-plate solar collectors may be divided into two main classifications based on the type of heat transfer fluid used.
- Liquid heating collectors are used for heating water and non-freezing aqueous solutions and occasionally for non-aqueous heat transfer fluids.
- Air or gas heating collectors are employed as solar air heaters.
- The principal difference between the two types is the design of the passages for the heat for the transfer fluid.

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

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

(ii) Tubes, fins, passages or ***channels*** are integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.

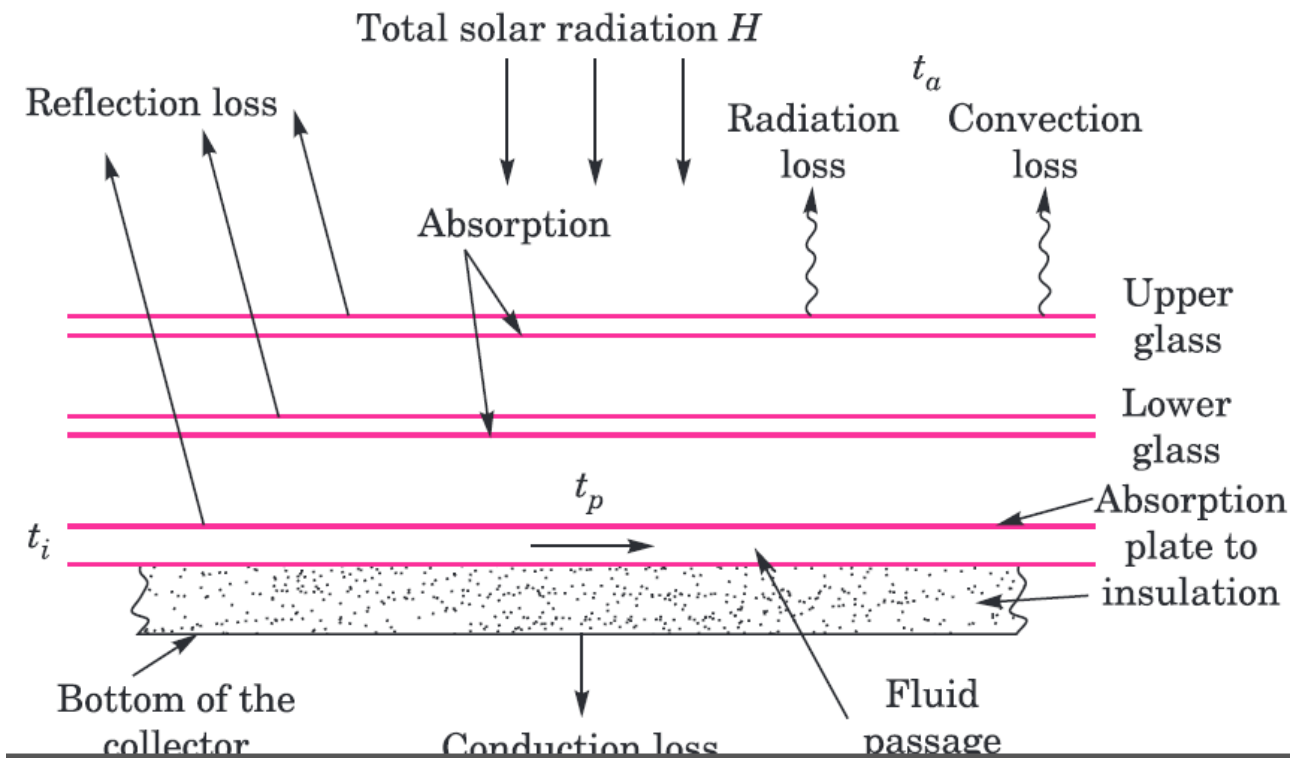
(iii) The ***absorber plate***, normally metallic or with a black, surface, although a wide variety of other materials can be used with air heaters.

(iv) ***Insulation***, which should be provided at the back and sides to minimize the heat losses. Standard insulating materials such as fiber glass or styro-foam are used for this purpose.

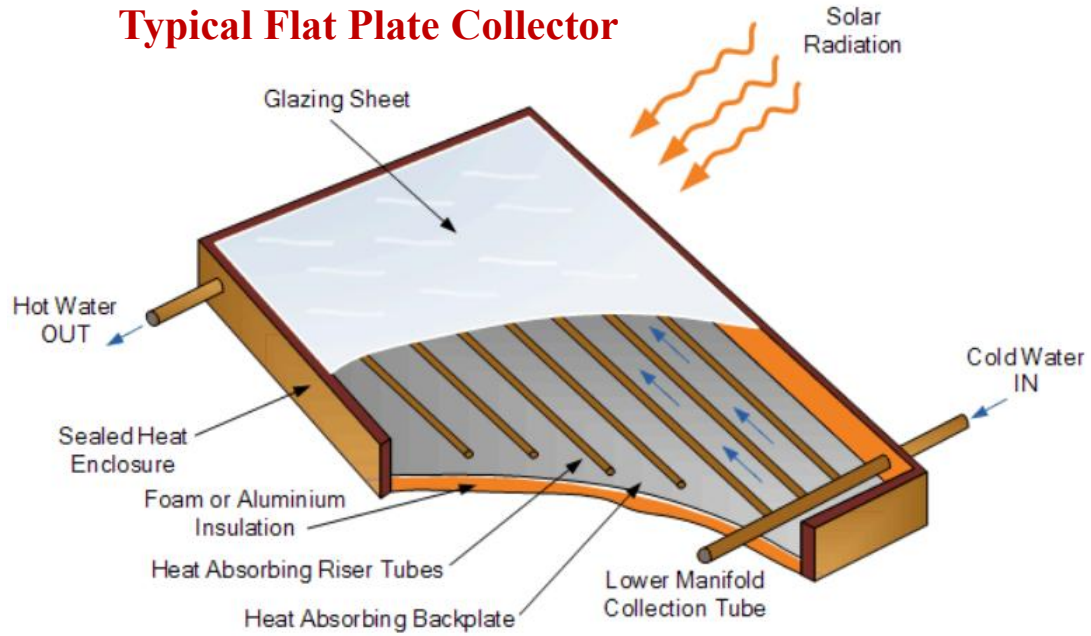
(v) ***The casing*** or container which enclose the other components and protects them from the weather.

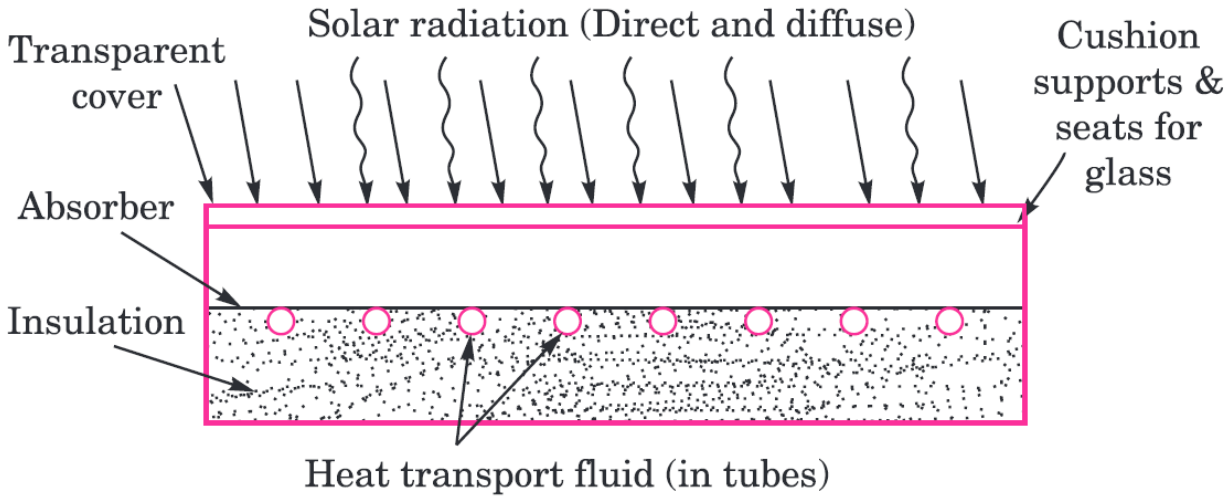
Flat Plate Air Collector

- When solar energy is passed through the transparent surface a portion of energy is absorbed by the absorber and transferred to the transport medium in the fluid tube and carried away for use or storage.
- The transparent cover will reduce the conventional losses.
- The flat plate air collector has a air has a heat transport medium. It is usually used for the purpose of space heating.
- Absorber can be of any material. Air is passed through the absorber by fan or convection method.
- Its efficiency is less then liquid fluid.



Typical Flat Plate Collector





CONFIGURATION OF CERTAIN PRACTICAL SOLAR THERMAL COLLECTOR

1. **Flat Plate Collector:** used for solar water and space heating system. These collector heat liquid or air less than 90°C.it is a insulated metal box with glass or plastic cover with dark colored absorber.

   Liquid Flat plate Collector: the fluid can be oil, water antifreeze, thermal oil etc. it is used for the purpose of water heating and swimming pool heating.

   Air flat Plate Collector: used of solar space heating, ventilation, air heating, crop drying purpose. Absorber can be metal or non metallic material.
2. **Glazed Flat Plate Collectors:** liquid based and air based collector. Moderate temperature application of 30°C to 70°C. used for commercial and domestic heating system.
3. **Unglazed Flat Plate Collectors:** Because they are not insulated it is best suited for low temperature < 30°C. it application are heating of water, fish farming, swimming pool etc. Since they are not glazed large portion of sun energy is absorbed since not insulated energy is lost.

4. **Unglazed Perforated plate Collectors:** In this type of collector are perforated with many holes of 2-4 cm. the air flow through the collector to provide preheated fresh air for ventilation. Application are like ventilation crop drying.
5. **Back pass Solar Collectors:** Air based collector use solar energy to heat air for space heating.
6. **Flat Plate Solar thermal Collectors:** Reflector plate coated with glazing is placed over a tank surface. Storage surface and the absorber act as a single unit so there is no need of other components.
7. **Flat Plate Collector With Flat reflector:** Addition of reflector on collector will increase thermal efficiency of 44% in winter and 15% in summer. When reflector are placed at the edges aperture angle is larger.

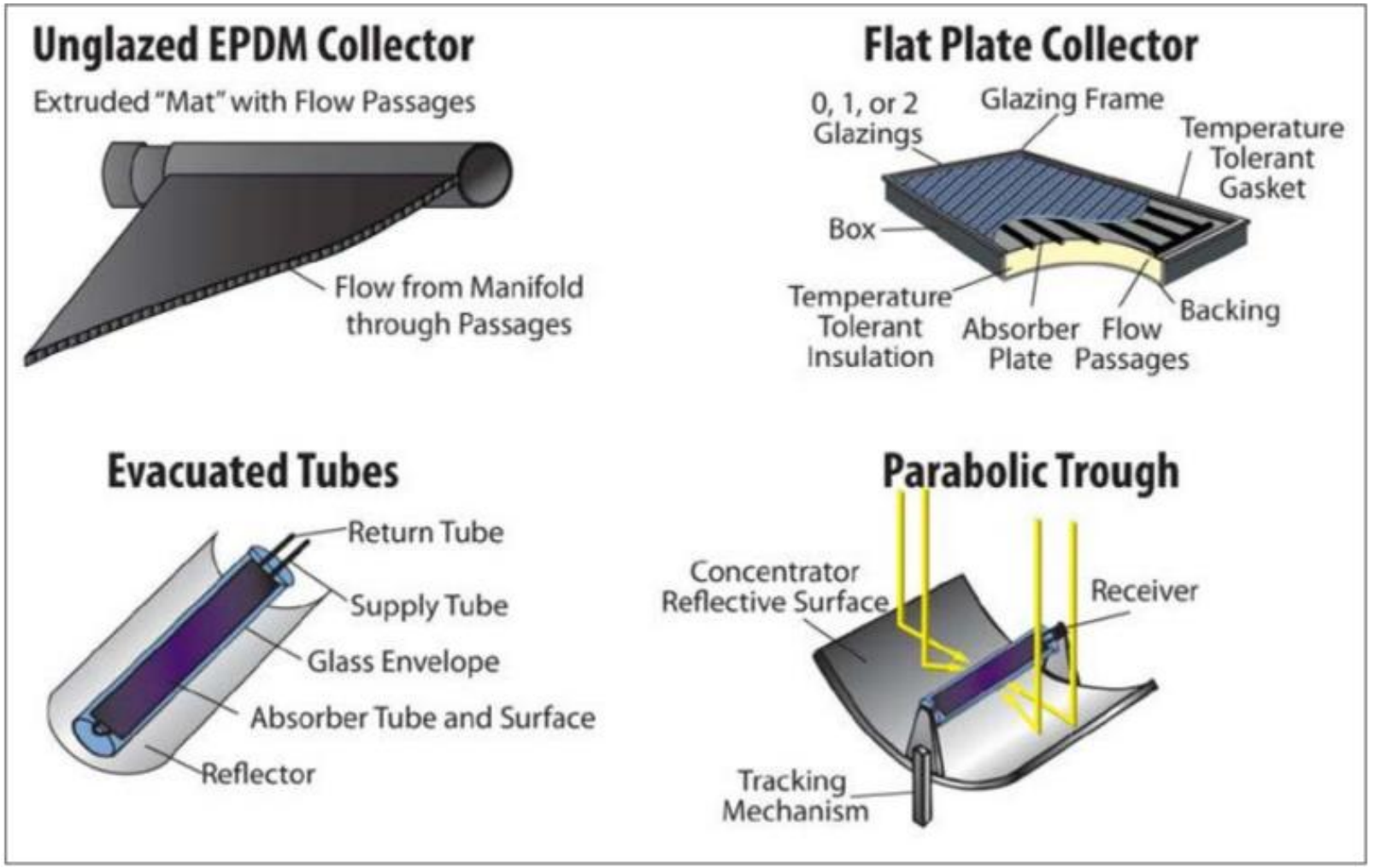


Fig. 2.2 : Solar thermal technologies, with unique characteristics shown, Illustration by Jim Leyshon, NREL

7. Evacuated Tube Collectors:

- These types of collector are used when climate is cold, cloudy and windy days.
- During such condition performance of other collector are reduced.
- Evacuated solar collector consists of heat pipe inside a vacuum sealed tube. There are 2 transparent glasses placed parallel.
- Each tube consists of glass outer tube and absorber tube attached to fin.
- The fin is covered with coating that absorbs solar energy.
- Air is removed by two glasses placed in parallel to remove air and create vacuum, which reduces losses This can achieve high temperature around 75°C to 180°C.
- These types of tube are more expensive.
- Applications are as heating of domestic and commercial hot water, building, swimming pools.

MATERIAL ASPECTS OF SOLAR COLLECTORS

1. Absorber

- Flat, grooved, fins, tubes are attached to the absorber
- Cu, Al, Cu with integrated water passage , cu tube, Iron, steel, plastic

Absorptive Coating

- Coating is done to increase absorptive
- It must not degrade up to 200’C, withstand low and high humidity,.
- It should not fade or chip.
- Should not be thick coating

2. Glazing

- Glass sheet or radiation transmitting material is used as coating.
- It reduces radiative heat losses from the absorber and protects absorber from the UV radiation.

Material used should have good resistance to UV radiation, thin and tempered glass should not be used, plastic material of low tensile strength should not be used, should be resistant to temperature shock, should have good thermal stress.

Practical application of Glazing

- High Cost
- Longevity
- Black chrome coating
- Absorptive 92% - 95% (Visible) 10-20% (IR)

Glazing Materials

Glass, Fiber, tedlar with fiber glass, fiber glass, optical rating must not change in service period.

3. Insulation Shell

- Solar flat plate collector must be insulate on its back side and edges to reduce heat losses.
- Withstand high temperature (200'C), should not shrink, it should not melt or evaporate.

Concentrating Collector: Focusing Type

Introduction:

- Focusing collector is a device to collect solar energy with high intensity of solar radiation on the energy absorbing surface.
- Such collectors generally use optical system in the form of reflectors or refractors.
- A focusing collector is a special form of flat-plate collector modified by introducing a reflecting (or refracting) surface (concentrator) between the solar radiations and the absorber.
- These type of collectors can have radiation increase from low value of 1.5 to 2 to high values of the order of 10,000.
- In these collectors radiation falling on a relatively large area is focused on to a receiver (or absorber) of considerably smaller area.
- As a result of the energy concentration, fluids can be heated to temperatures 500°C or more.

- An importance difference between collectors of the ***non-focusing*** and ***focusing types*** in that the latter concentrate only direct radiation coming from a specific direction, since diffuse radiation arrives from all directions, only a very small proportion is from the direction for which focusing occurs.

Types of concentrating collectors:

Concentrating or focusing collectors may be considered in two general categories:

Line focusing and point focusing types.

- In practice, the line is a collector pipe and the point is a small volume through which the heat transport fluid flows.
- Because the sun has a finite size, focusing does infact occur over a small area or volume rather than a line or point.

As per the number of concentrating collector geometries, the main-types of concentrating collectors are:

(a) Parabolic trough collector
(b) Mirror strip reflector
(c) Fresnel lens collector
(d) Flat plate collector with adjustable mirrors
(e) Compound parabolic concentrator (C.P.C.).

Line Focusing Collectors: Parabolic Trough Reflector.

- The principle of the parabolic trough collector, which is often used in concentration collectors, is shown by the cross-section in Fig. 2.3.
- Solar radiation coming from the particular direction is collected over the area of the reflecting surface and is concentrated at the focus of the parabola, if the reflector is in the form of a trough with parabolic cross-section, the solar radiation is focused alone a line.
- Mostly cylindrical parabolic concentrators are used, in which absorber is placed along focus axis.

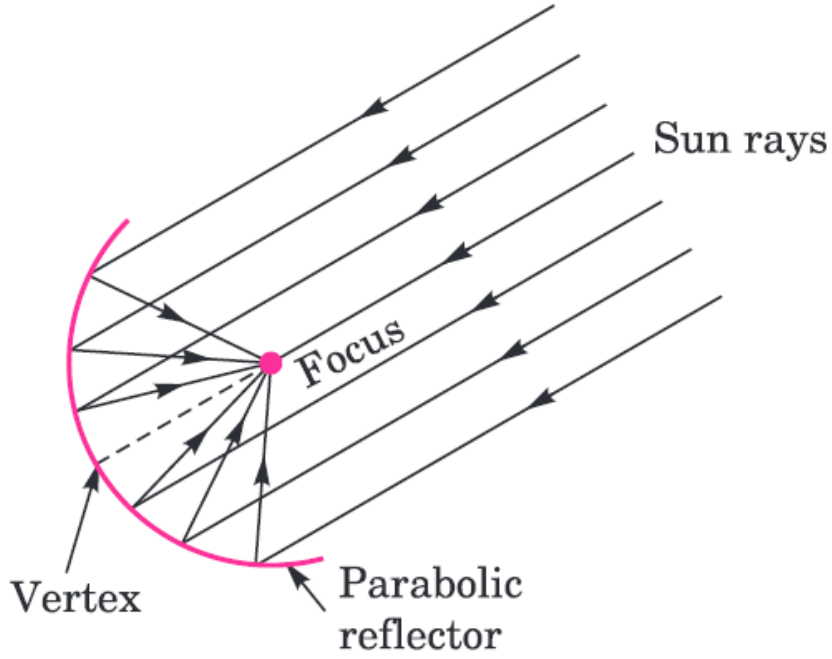
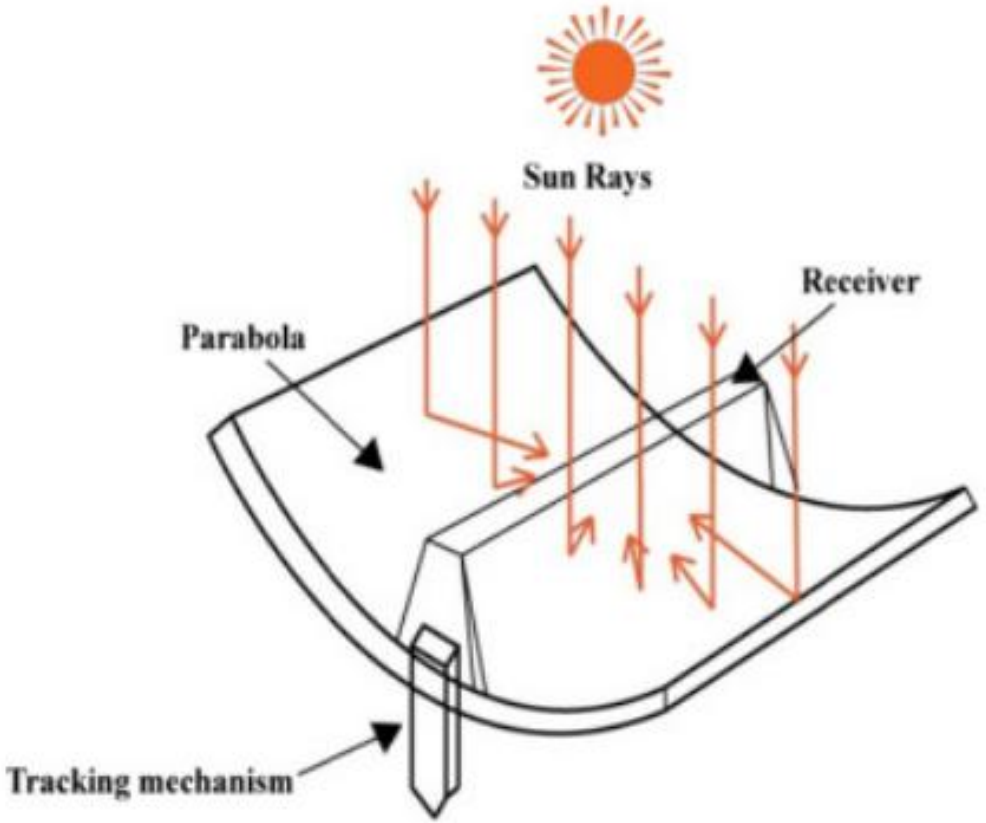


Fig. 2.3: Cross-section of parabolic-trough collector.

- The collector pipe, preferably with a selective absorber coating, is used as an absorber.



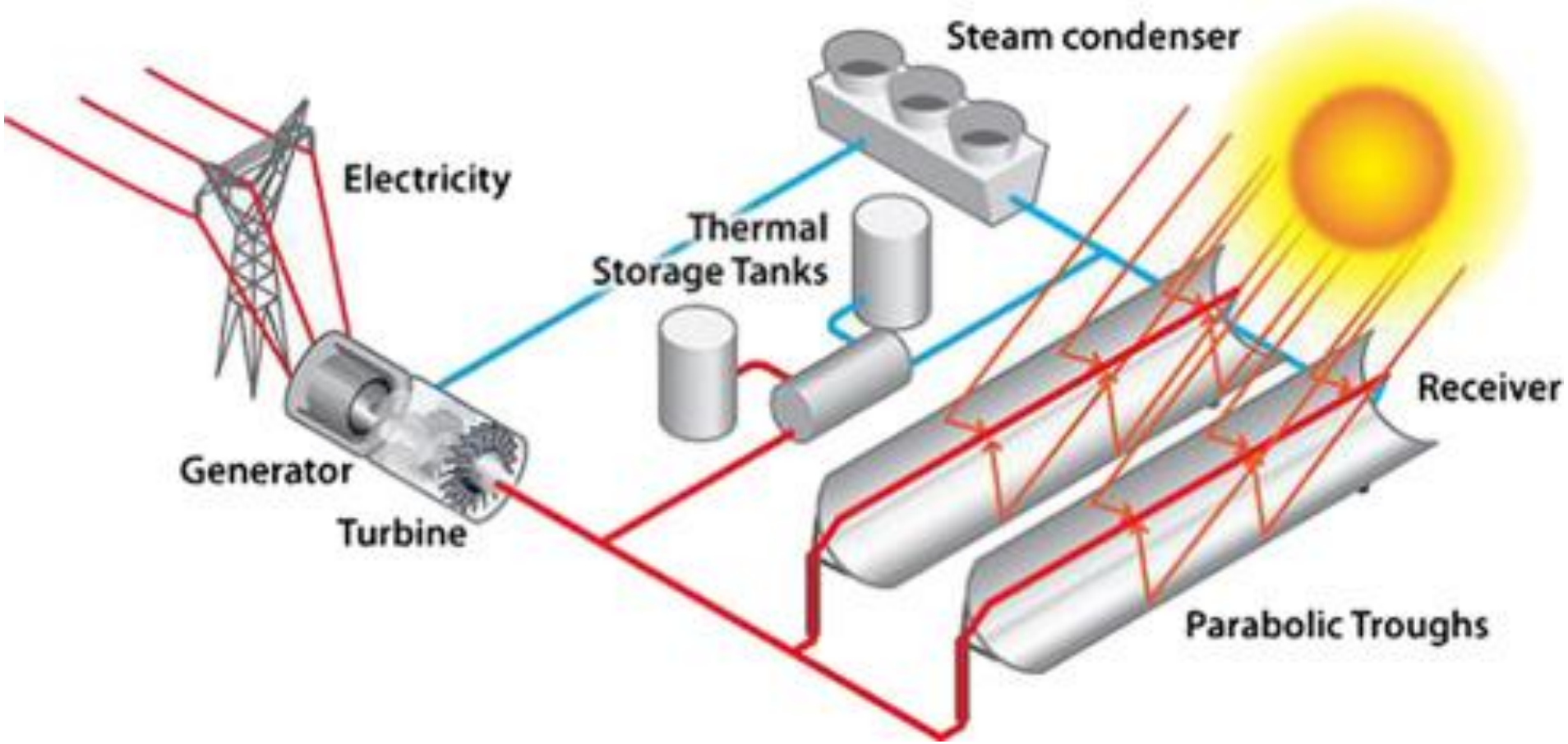


Fig 2.4: Parabolic Trough Generation Systems

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 (Fig. 2.5).
- 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.

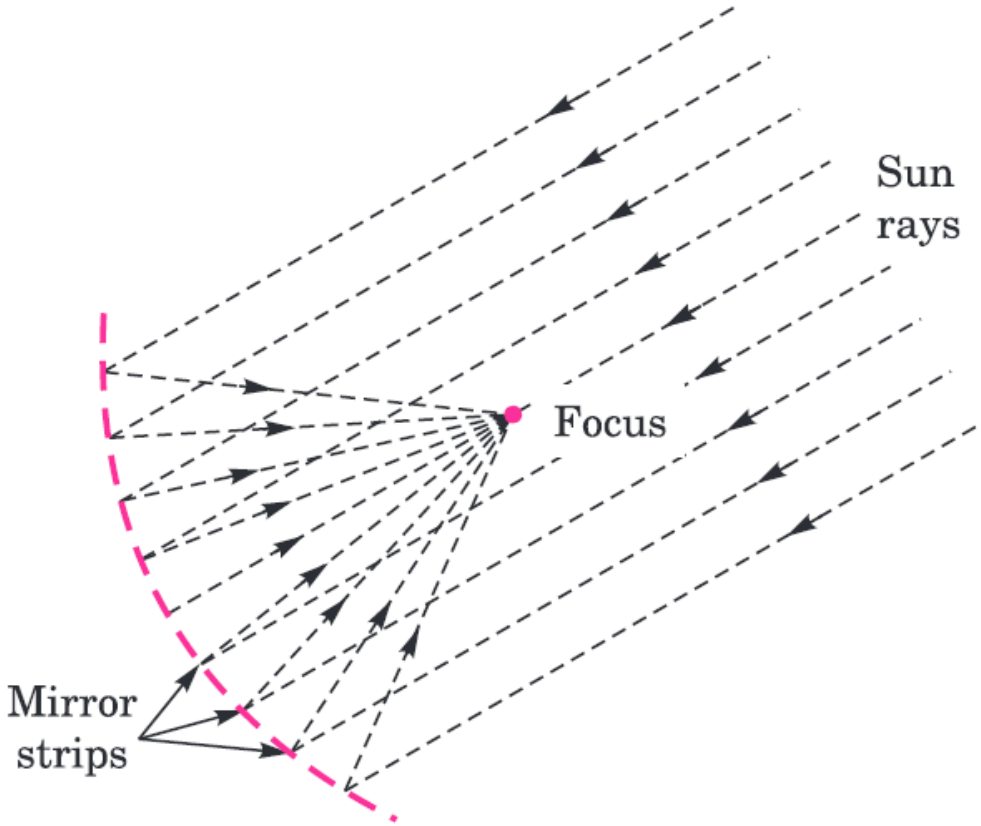
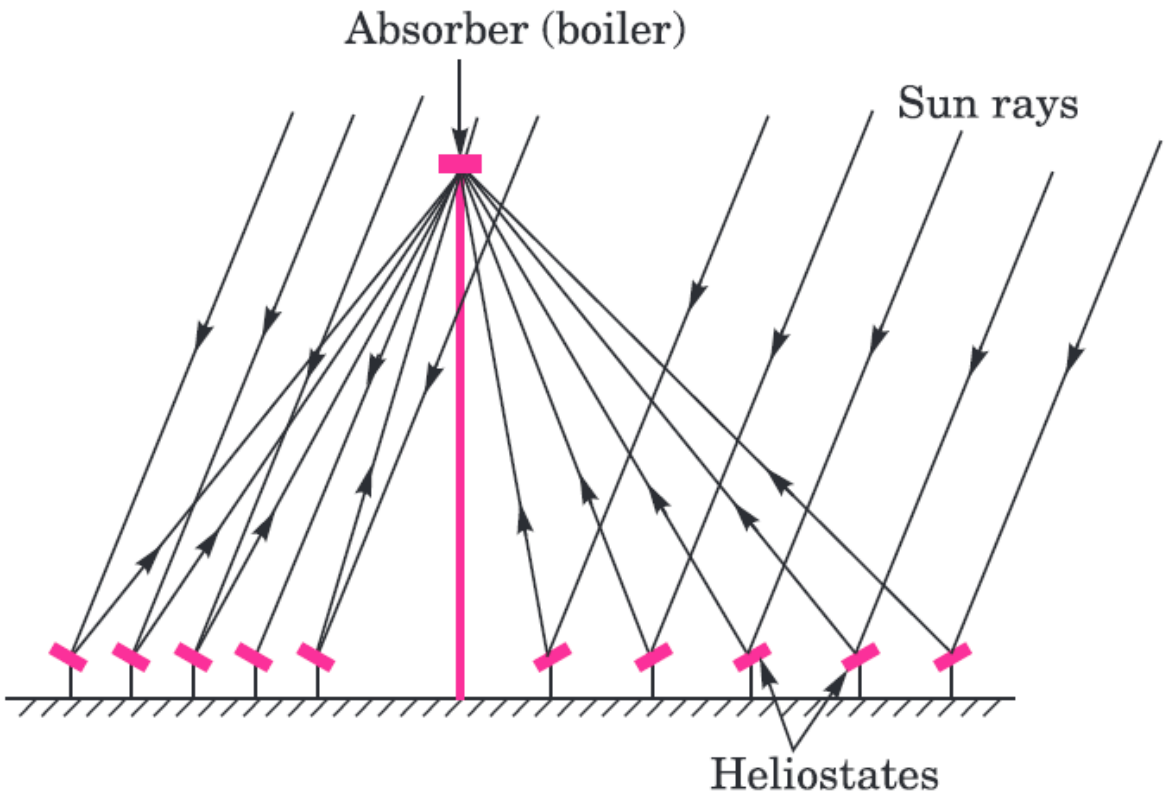


Fig 2.5: Mirror-Strip Solar Collector

Fig 2.5 (B) Linear Fresnel

Fig 2.5 (C) Parabolic Dish.

Heliostat Field Solar Collector



Distributed Heliostat Point Focusing Reflector (Central Receiver)

Fig 2.5 (D) Tower or Central Receiver

- Heliostat is mirror based, point focusing type. It uses two axis solar tracking flat mirror reflector.
- The collected solar energy is converted in electrical energy.
- **Application:** Domestic Heating, Lighting and Electricity.
- Flat plate collector has low efficiency but use of glazing has increased the efficiency.
- Heliostat is used for the generation of power, it has large mirror placed side of a tower and concentrate the energy at the receiver point placed on top of tower.

Advantages and Disadvantages of Concentrating Collectors over Flat Plate Type Collectors

Advantages:

The main advantages of concentrator systems over flat-plate type collectors are:

1. 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.
2. The absorber area of a concentrator system is smaller than that of a flat-plate system for same solar energy collection and therefore the insolation intensity is greater.
3. Because of the area from which heat is lost to the surroundings per unit of the solar energy collecting area is less than that for flat-plate collector and because the insulation on the absorber is more concentrated, the working fluid can attain higher temperatures in a concentrating system than in a flat-plate collector of the same solar energy collecting surface.

4. Owing to the small area of absorber per unit of solar energy collecting area, selective surface treatment and/or vacuum insulation to reduce heat losses and improve collector efficiency are economically feasible.
5. 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.
6. Because the temperature attainable with concentrating collector system is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems than for flat-plate collectors.
7. 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.

8. 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

1. Out of the beam and diffuse solar radiation components, only beam component is collected in case of focusing collectors because diffuse component can not be reflected and is thus lost.
2. In some stationary reflecting systems it is necessary to have a small absorber to track the sun image; in others the reflector may have to be adjustable more than one position if year round operation is desired; in other words costly orienting systems have to be used to track the sun.
3. Additional requirements of maintenance particular to retain the quality of reflecting surface against dirt, weather, oxidation etc.

4. Non-uniform flux on the absorber whereas flux in flat-plate collectors is uniform.
5. Additional optical losses such as reflectance loss and the intercept loss, so they introduce additional factors in energy balances.
6. High initial cost.

Stirling Engine

- Stirling engine is unique in its sense that it uses only two pistons for its operation to produce motoring action unlike the conventional motors.
- A Stirling engine is basically a heat engine that operates by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work.
- This solar powered Stirling engine is coupled with a generator to produce power.
- The generator is usually a linear alternator which helps in reducing the number of moving parts and linkages that are required in a conventional generator arrangement.
- Moreover, the gas bearings provide a non-contact frictionless surface for the piston, thus eliminating the need of maintenance.
- Provision for storage of solar heat using salt storage system is implemented to make use during its absence.
- The Stirling engine is noted for its high efficiency (up to 40%), quiet operation, and the ease with which it can use almost any heat source.

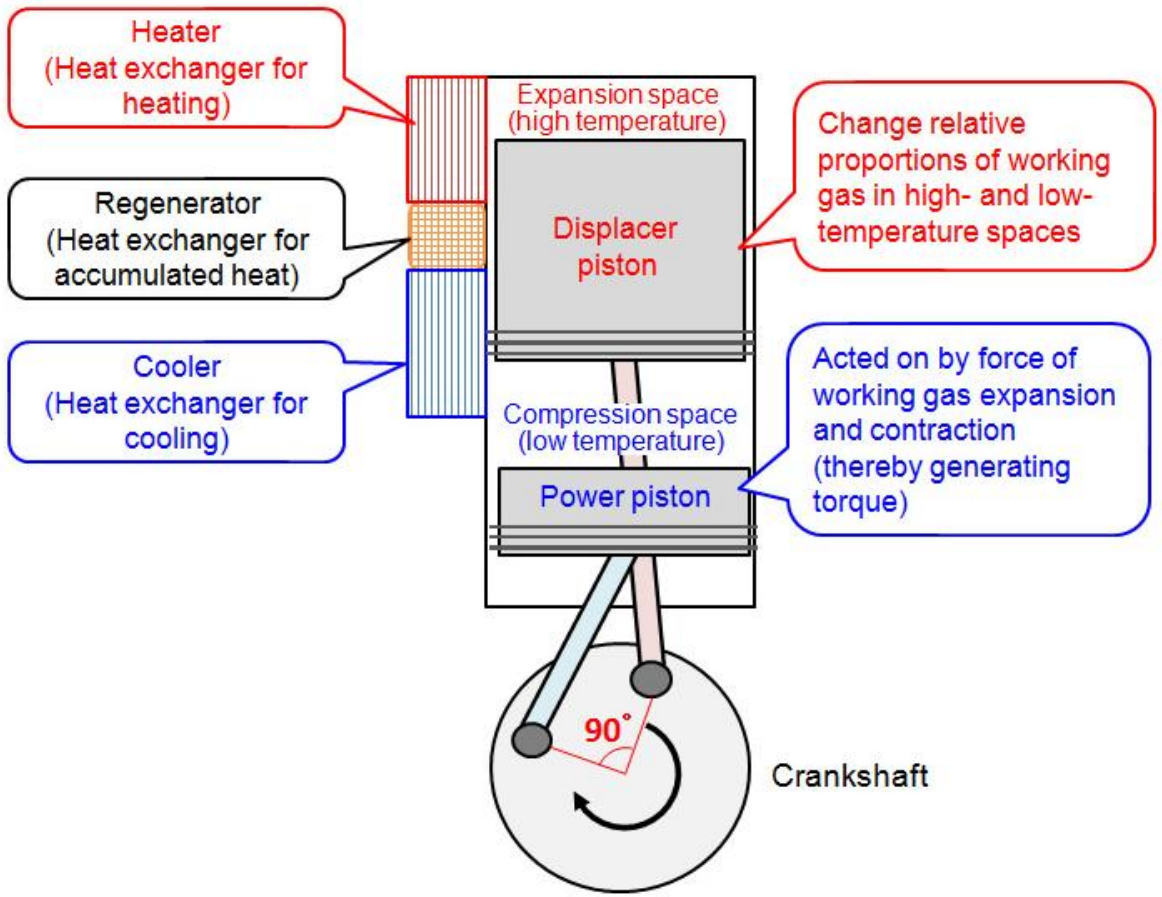
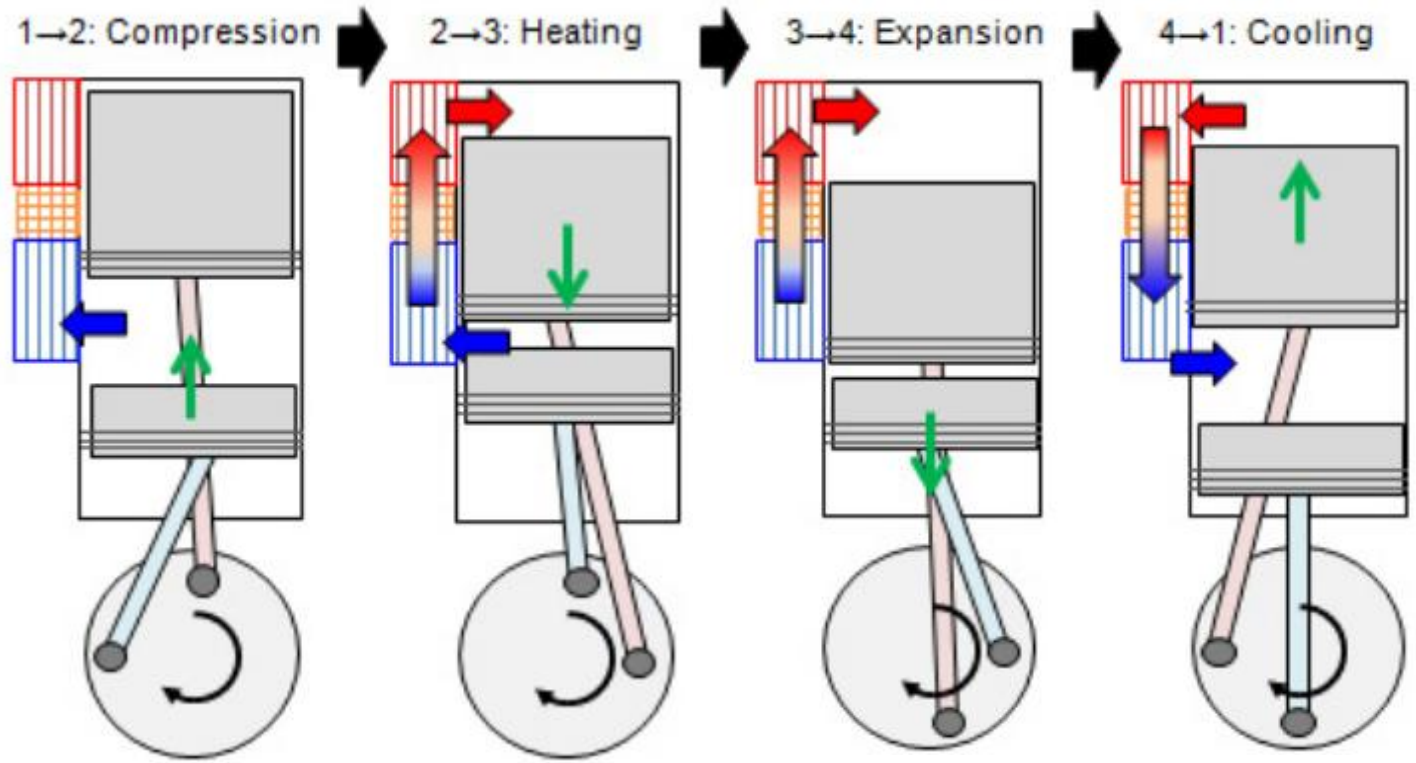


Fig 2.6 Basic Mechanism of β Stirling Engine

- It has the ability to utilize effectively any burnable fuel, such as wood, rice husk, straw, agricultural waste and other readily available and cheap combustibles.
- This compatibility with alternative and renewable energy sources has become increasingly significant as the price of conventional fuel rise.
- This method of power production has no pollution, no noise.
- Incredibly, the absorber in the concentrator is very small (10″ × 10″) but has the ability of providing 10kW per hour.
- This is proven to be the most efficient way to convert solar energy to electric power.



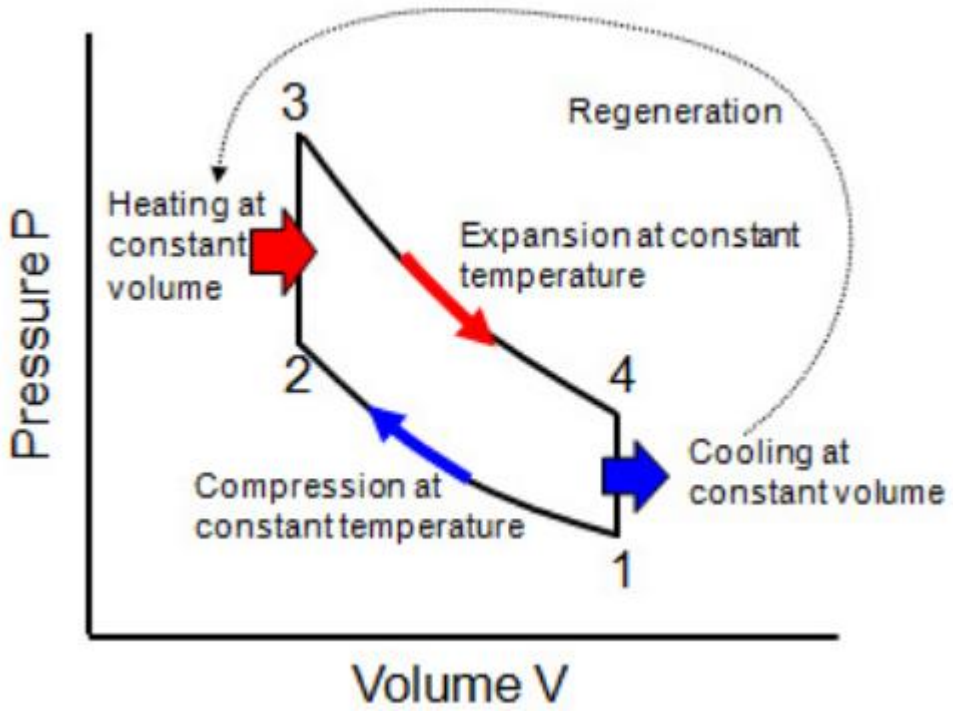


Fig 2.7: Principle of Operation of Stirling Engine

WORKING OF PARABOLIC DISH STRILING OR BRAYTON ENGINE SYSTEM

- Array of mirrors focuses the sunlight.
- This heats up the working fluid to temperatures of around 750°C within the receiver.
- This high temperature working fluid is then used in either a Stirling or Brayton heat engine cycle to produce mechanical power via rotational kinetic energy.
- As the electric generator is coupled to the engine, electricity is produced.

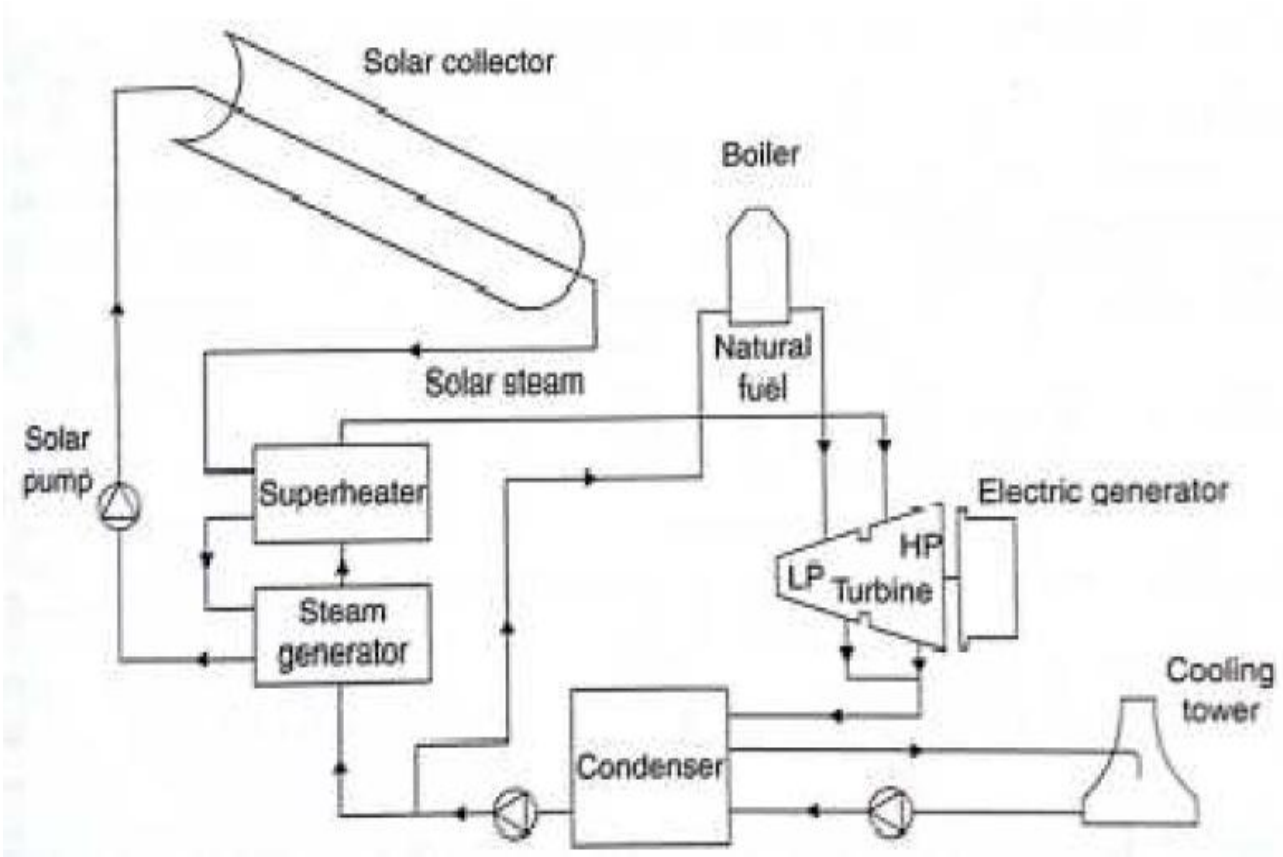


Fig. 2.8 Schematic Solar Electric Generation

- As shown in the Fig 2.8, Brayton cycle is used to produce electricity by concentrating the sun using parabolic dish collector.
- Concentrated sunlight heats up the compressed working fluid, in the combustion chamber for power generation.
- Hot compressed air is then expanded through a turbine to produce rotational KE, which is converted into electricity using alternator.
- A recuperator is used to capture waste heat from turbine to preheat the compressed air.

Solar Collector Systems into Building Services

Solar Heating of Building

- Many different concepts have been proposed (and tested) for using solar in space heating of buildings.
- There are two primary categories into which energy virtually all solar heating systems may be divided.
- The first is ***passive systems***, in which solar radiation is collected by some element, of the structure itself, or admitted directly into, building through large, south facing windows.
- The second is the ***active systems*** which generally consists of

  (a) Separate Solar Collectors, which may heat either water or air,

  (b) Storage devices which can accumulate the collected energy for use at nights and during inclement days and,

  (c) A backup system to provide heat for protected periods of bad weather.

- Passive heating systems operate without pumps, blowers, or other mechanical devices; the air is circulated past a solar heated surface (or surface) and through the building by convection (i.e., less dense, cooler air tends to rise while more dense, cooler air moves downward).
- In active heating systems, fans and pumps are used to circulate the air and often a separate heat absorbing fluid.
- In principle, it should be possible to provide all the heating (and cooling) needs of a building by solar energy.
- However, to do this, the heating system would have to be designed for minimum sunshine conditions and hence would be over designed for the majority of the situations.
- In most cases, solar-energy systems provide roughly 50 to 75 percent of the annual heating requirements.
- The remaining is supplied by an auxiliary-heating systems using gas, oil, or electricity.

Solar Cooling of Building

- The major current interest is in mechanical cooling (or air conditioning) systems that depend on solar heat for their operation and are unaffected by atmospheric humidity.
- The two most common refrigeration techniques are ***vapor compression*** and ***absorption*** and, in principle, both could be adopted for use with solar energy, although the temperatures required are higher than those adequate for space heating.
- In the former procedure, solar heated water could vaporize ***propane or ammonia*** at a moderate pressure.
- The vapour could then drive a turbine which would inturn, operate a vapor compression cooling unit.
- Such a low pressure vapor turbine, however, would inevitably have a very low efficiency.

- Further-more, propane is highly flammable whereas ammonia forms a noxious gas.
- Absorption cooling with solar energy, which is regarded as more practical, is possible with current technology although improvements in design would be desirable.

SOLAR WATER HEATING SYSTEM

The two main parts of a water heating system are a solar collector and a storage tank. There are two types: an active system (which relies on a pump to move liquid from the collector and storage tank) and a passive system (which relies on gravity to circulate water).

Active Solar Water Heating System

Five major components in active solar water heating systems:

- Collector(s) to capture solar energy.
- Circulation system to move a fluid between the collectors to a storage tank.
- Storage tank.
- Backup heating system.
- Control system to regulate the overall system operation.

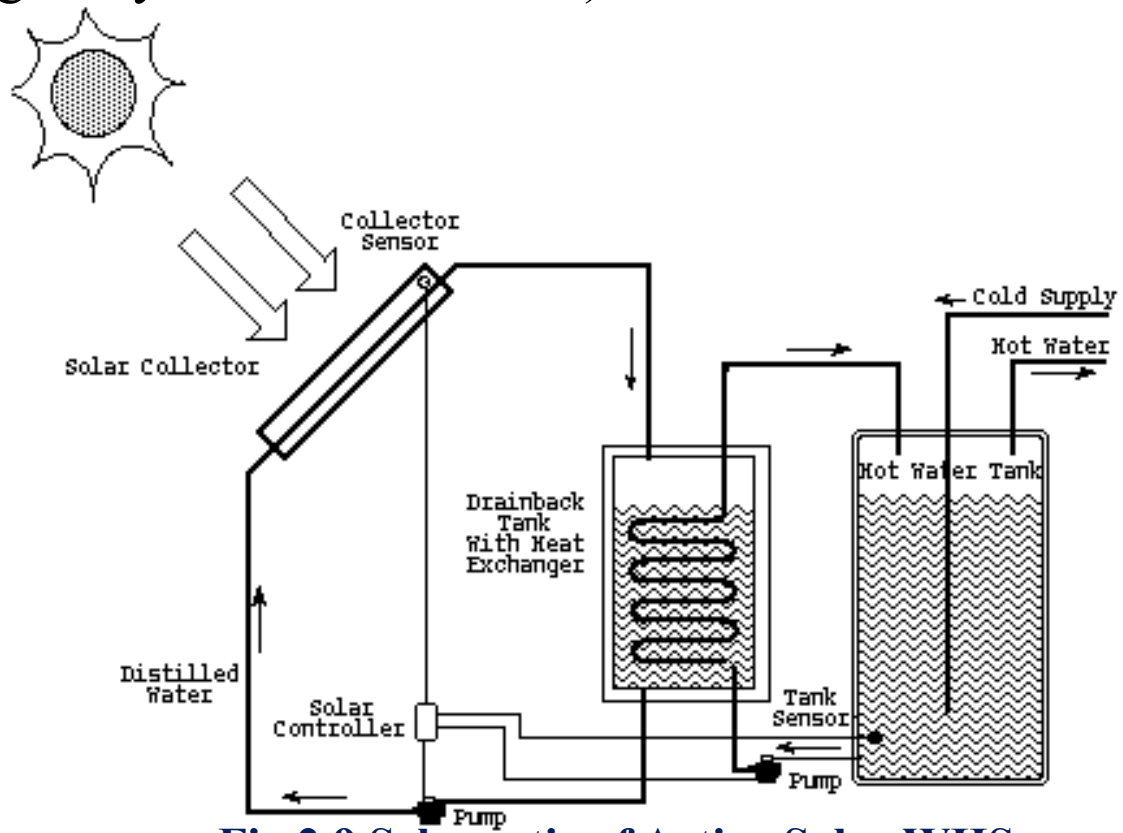


Fig.2.9 Schematic of Active Solar WHS

- The fluids that are circulated into the collectors are separated from the heated water that will be used in the home by a double-walled heat exchanger.
- A heat exchanger is used to transfer the heat from the fluids circulating through the collectors to the water used in the home.
- The fluids that are used in the collectors can be water, oil, an antifreeze solution, or refrigerant.
- The heat exchangers should be double-walled to prevent contamination of the household water.
- The controller in these systems will activate the pumps to the collectors and heat exchanger when design temperature differences are reached.
- The heat exchanger may be separate from the storage tank or built into it.

Passive Solar Water Heating System

- A passive solar water heating system uses natural convection or household water pressure to circulate water through a solar collector to a storage tank or to the point of use.
- Active systems employ pumps and controllers to regulate and circulate water.
- Although passive system are generally less efficient than active systems, the passive approach is simple and economical.

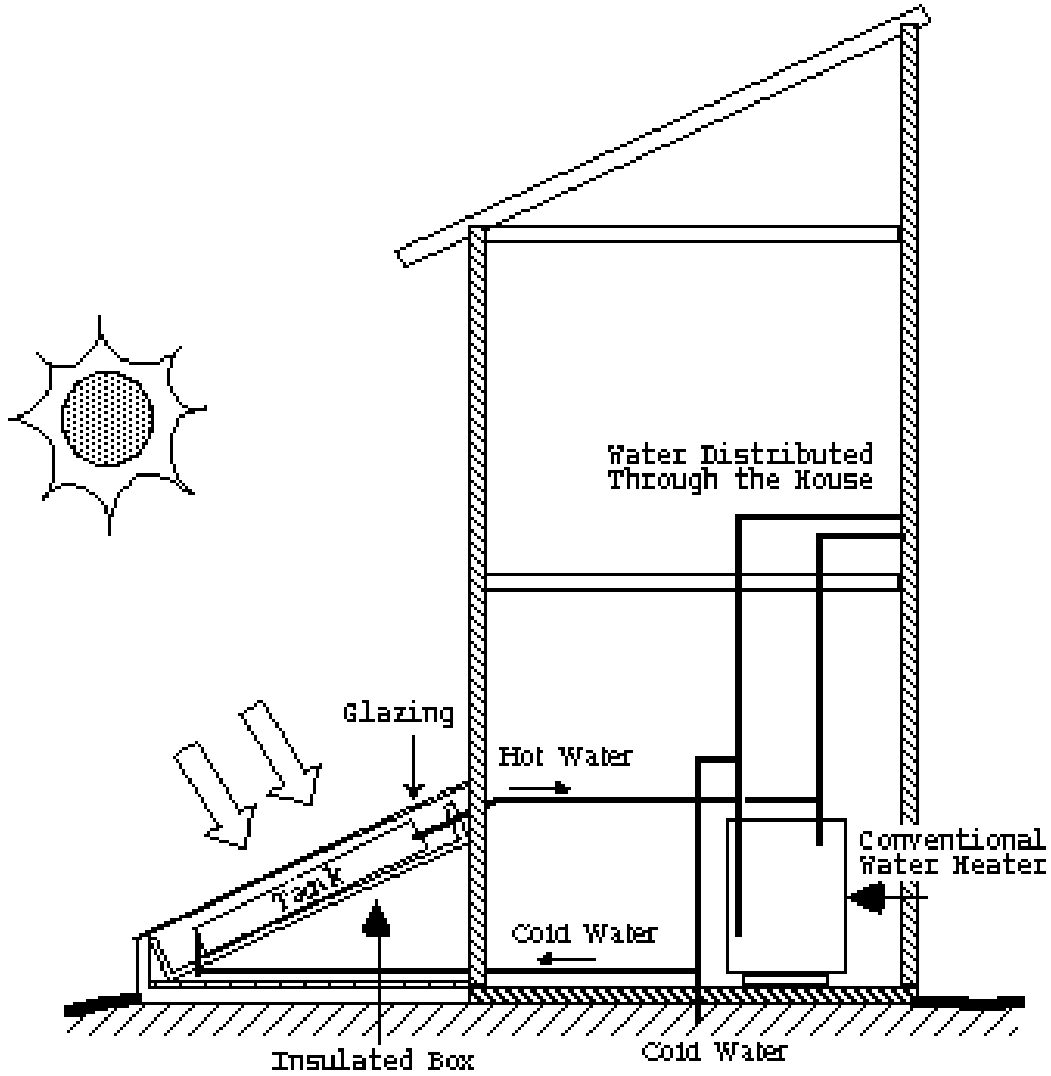


Fig.2.10 Schematic of Passive Solar WHS

Batch Type Solar Water Heating Systems

- The batch system is the simplest of all solar water heating systems.
- It consists of one or more metal water tanks painted with a heat absorbing black coating and placed in an insulating box or container with a glass or plastic cover that admits sunlight to strike the tank directly.
- The batch system's storage tank is the collector as well.
- These systems will use the existing house pressure to move water through the system.
- Each time a hot water tap is opened, heated water from the batch system tank is removed and replaced by incoming cold water.
- The piping that connects to and from the batch heater needs to be highly insulated.
- On a cold night when no one is drawing hot water, the water in the pipes is standing still and vulnerable to freezing.

Solar Distillation

- Fresh water is a necessity for the sustenance of life and also the key to man's prosperity.
- In areas where solar energy is plentiful and can be used for converting saline water into distilled water.
- The pure water can be obtained by distillation in the simplest solar still, generally known as the ***"basin type solar still".***
- It is shown schematically in Fig. (2.11). Such solar stills have been operated for farm and community use in several countries.
- It consists of a blackened basin containing saline water at a shallow depth, over which is a transparent air tight cover that encloses completely the space above the basin and It has a roof-like shape.
- The cover, which is usually glass, may be of plastic, is sloped towards a collection trough.
- Solar radiation passes through the cover and is absorbed and converted into heat in the black surface.

- Impure water in the basin or tray is heated and the vapour produced is condensed to purified water on the cooler interior of the roof.
- The transparent roof material, (mainly glass) transmits nearly all radiation falling on it and absorbs very little; hence it remains cool enough to condense the water vapour.
- The condensed water flows down the sloping roof and is collected in troughs at the bottom.
- Saline water can be replaced in the operation by either continuous operation or by batches.
- The basin type solar still has produced distilled water at a cost per unit.

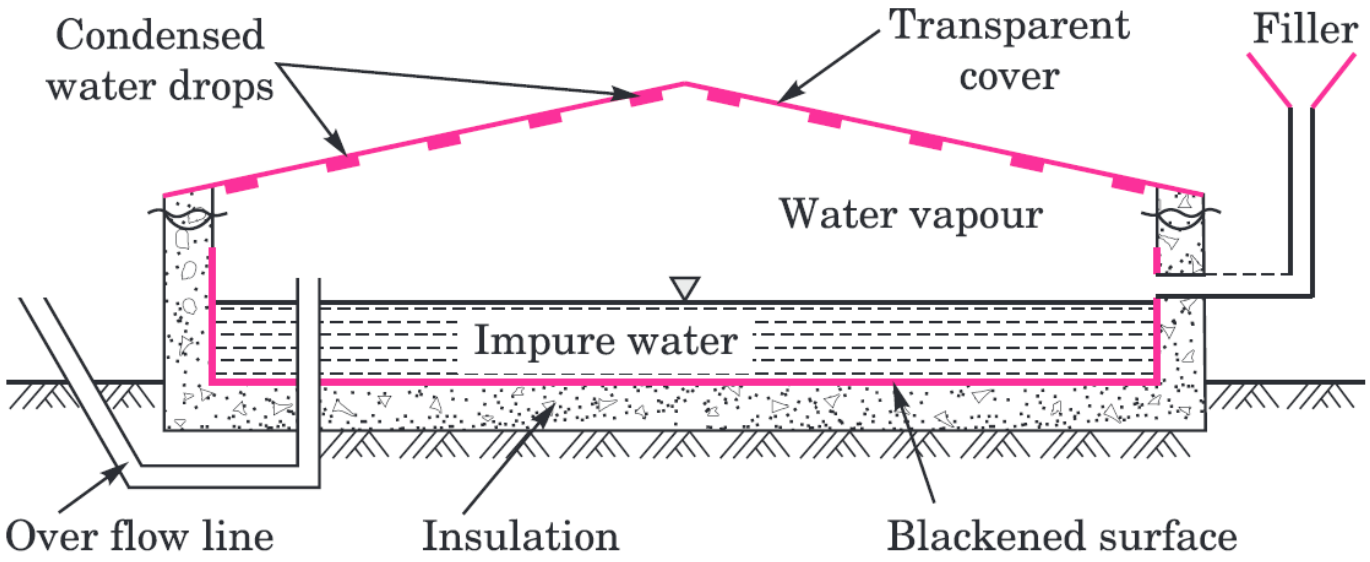


Fig.2.11 Solar Water Still

Principle of Working Solar Furnace

- The principle of the solar furnace is outlined in Fig. (2.12). A number of heliostats (turnable mirrors) are arranged in terraces on a slopping surface (e.g., on a hill side) so that, regardless of the sun's position, they always reflect solar radiation in the same direction onto a large paraboloid (or spherical) reflecting collector made up of many fixed mirrors) attached to the face of a structure.
- The collector then brings the radiation to a focus within a small volume (receiver).
- In figure a heliostat type furnace with horizontal optical axis is shown which is comparatively convenient and widely used in large furnaces.

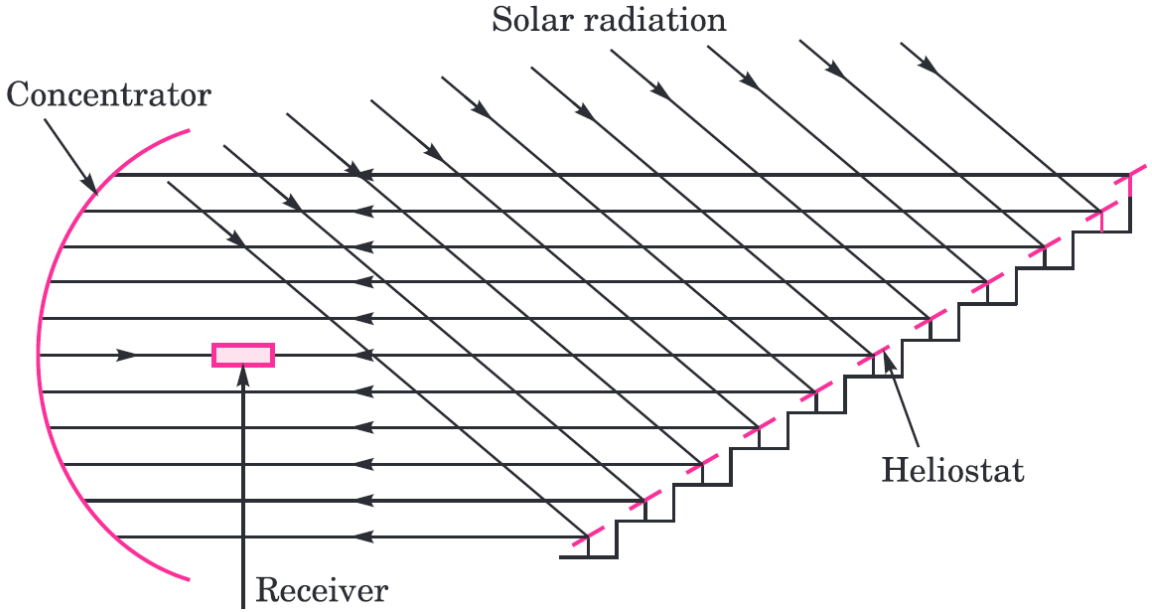


Fig.2.12 Solar Furnace

- The most desirable mirror is that obtained by grinding and polishing a glass plate into an optical flat, aluminizing or silvering by vacuum evaporation, and cooling with a suitable film.
- The change of elevation and that of azimuth can be obtained by the rotation of frame about a horizontal axis and about a vertical axis respectively.
- In order to rotate the frame, hydraulic or electric driving is used which is coupled with a servo system or a time system for sun following.
- The other method is to use many heliostats to convey the solar radiation into a concentrator.

Solar Cooker

Basically there are three designs of solar cooker:

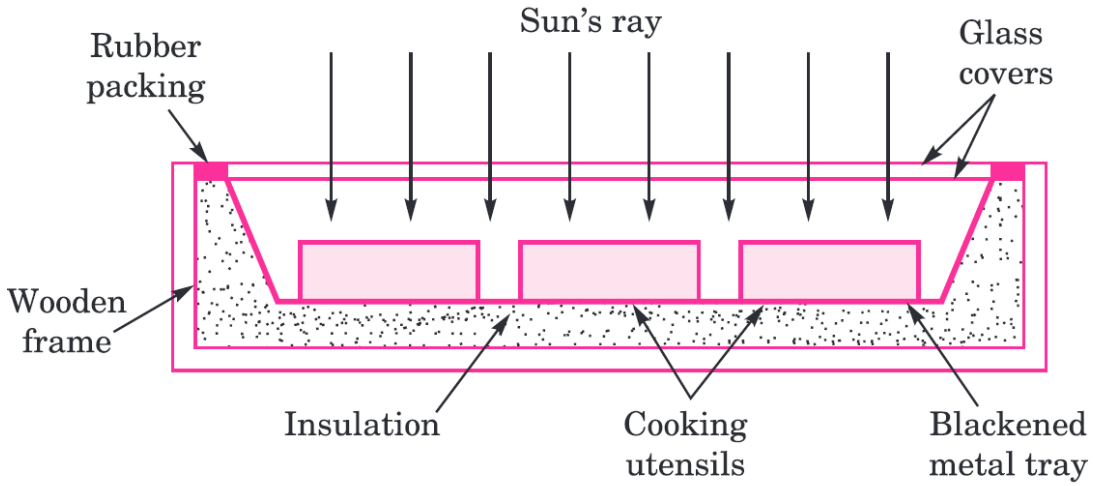
(i) Flat plate box type solar cooker with or without reflector.

(ii) Multi reflector type solar oven.

(iii) Parabolic disc concentrator type solar cooker.

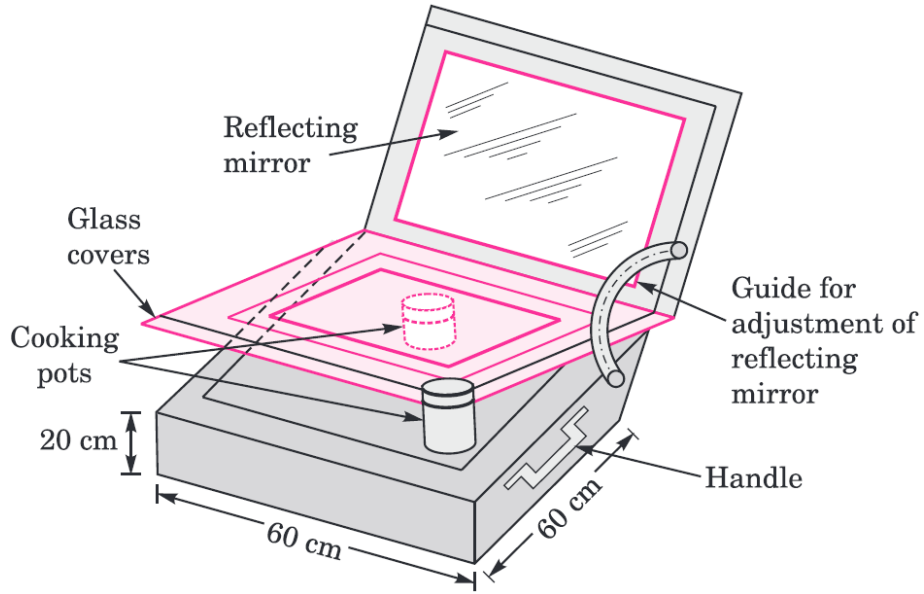
Design Principle and Constructional Details of A Box Type Solar Cooker

- The principle of operation of box type solar cooker is illustrated in Fig. (2.12) (a).
- The solar rays penetrate through the glass covers and absorbed by a blackened metal tray kept inside the solar box.

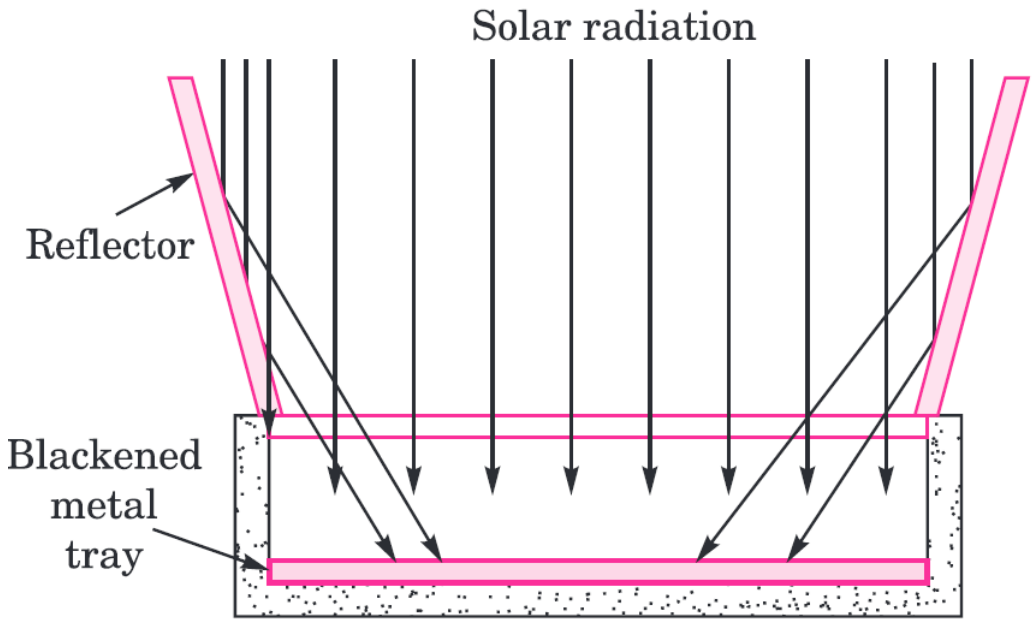


(a) Principle of box type cooker.

Fig.2.12 Solar Cooker

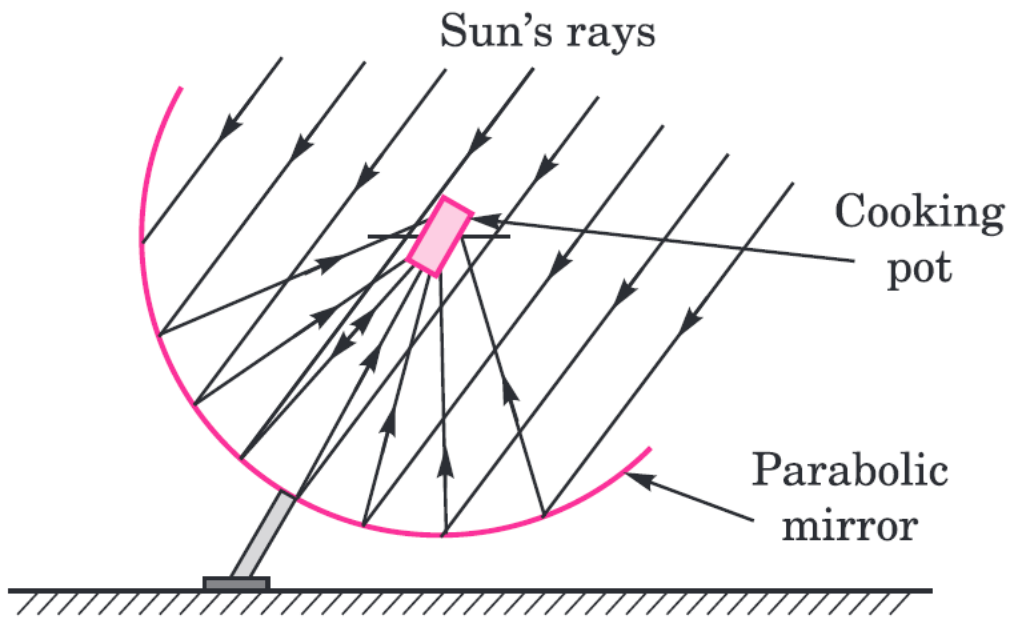


- The solar radiation entering the box are of short wavelength.
- The higher wavelength radiation is not able to pass through the glass cover i.e. reradiation from absorber plate to outside the box is minimized by providing the glass cover.
- Two glass covers are provided to minimize the heat loss.
- The loss due to convection is minimized by making the box air tight by providing a rubber strip all round between the upper lid and the box.
- Insulating material like glass wool, paddy husk, saw dust or any other material is filled in the space between blackened tray and outer cover of the box, This minimizes heat loss due to conduction.
- With this type of cooker is placed in the sun, the blackened surface starts absorbing sun rays and temperature inside the box starts rising.
- The cooking pots, which are also blackened are placed inside with food material, get heat energy and food will be cooked in a certain period of time depending upon the actual temperature attained inside.



(*b*) Reflector type solar cooker.

Multi Reflector type Solar Oven



(*c*) Principle of concentrating type cooker.

Parabolic disc concentrator type Solar Cooker

Solar Photovoltaics

Introduction:

- The direct conversion of solar energy into electrical energy by means of the photovoltaic effect, that is, the conversion of light (or other electromagnetic radiation) into electricity.
- The photovoltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation.
- Energy conversion devices which are used to convert sunlight to electricity by the use of the photovoltaic effect are called solar cells.
- A single converter cell is called a solar cell or, more generally, a photovoltaic cell, and combination of such cells; designed to increase the electric power output is called a ***solar module or solar array.***
- Photovoltaic cells are made of semiconductors that generate electricity when they absorb light.

- As photons are received, free electrical charges are generated that can be collected on contacts applied to the surfaces of the semiconductors.
- Because solar cells are not heat engines, and therefore do not need to operate at high temperatures, they are adopted to the weak energy flux of solar radiation, operating at room temperature.

A PV (Photo-Voltaic) system consists of:

(i) Solar cell array (ii) Load leveler

(iii) Storage system (iv) Tracking system (where necessary).

Solar Cell Principles:

- The photovoltaic effect can be observed in nature in a variety of materials, but the materials that have shown the best performance in sunlight are semiconductors.
- When photons from the sun are absorbed in a semiconductor, they create free electrons with higher energies than the electrons which provide the bonding in the base crystal.
- Once these electrons are created, there must be an electric field to induce these higher-energy electrons to flow out of the semiconductor to do useful work.
- The electric field in most solar cells is provided by a junction of materials which have different electrical properties.

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

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

For completing the above processes, a solar cell consists of:

(a) Semiconductor in which electron hole pairs are created by absorption of incident solar radiation.

(b) Region containing a drift field for charge separation, and

(c) Charge collecting front and back electrodes.

Conversion Efficiency and Power Output

A solar cell usually uses a p-n junction, Current and voltage relationship is given by

$$j_i = j_o \left[\exp\left(\frac{Ve}{KT} \right) - 1 \right]$$

j_o = Saturation current also called the dark current and is obtained when a large negative voltage is applied across the diode.

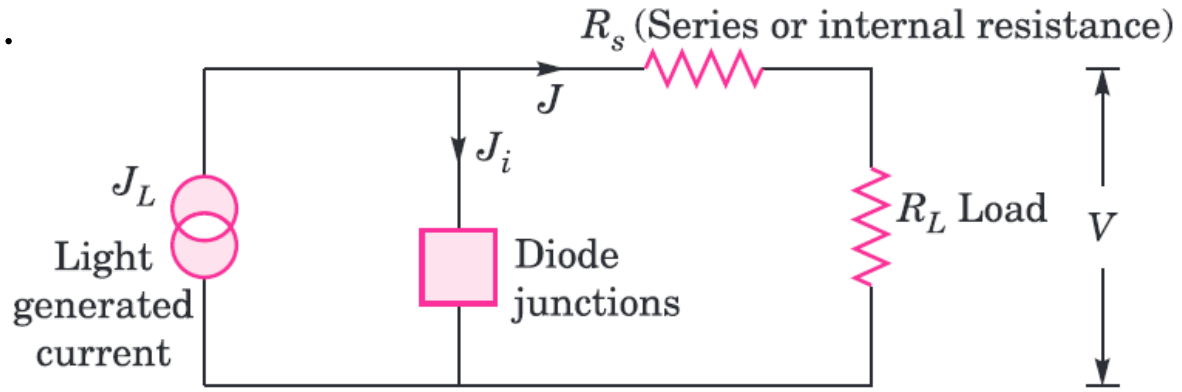
V = The voltage across junction

e = The electronic charge

k = Boltzmann's constant

T = The absolute temperature

when light impinges on the junction, electron hole pairs are created at a constant rate providing an electrical current flow across the junction, the net current is thus the difference between the normal diode current and light generated current J_L. Simplified equivalent circuit for the cell is shown in Figure.



The net current J is given by

$$J = J_L - J_i = J_L - J_0 \left[\exp\left(\frac{Ve}{kT}\right) - 1 \right]$$

The internal voltage drop in a cell can usually be minimized, and for ideal cell R may be assumed equal to zero i.e., R = 0. Therefore Open circuit voltage Voc for the ideal cell is then given by

$$V_{OC} = \left(\frac{kT}{e}\right) \ln\left[\frac{J_L}{J_0} + 1\right] \quad \text{.... (i)}$$

$J_L >> J_o$, the 1 in the equation can be neglected. Then open circuit voltage is

$$V_{OC} = \frac{kT}{e} \ln \frac{J_L}{J_0} \qquad \text{.... (ii)}$$

In practice the open circuit voltage of the cell decreases with increasing temperature.

The maximum power that can be derived from the device is given by

$$P_{max} = V_{mp}.J_{mp} \qquad \text{.... (iii)}$$

where V**mp** and J**mp** are the voltage and current at maximum power point. It can be seen that the maximum efficiency for the cell is obtained by dividing V**mp** J**mp** by the total power density of the sunlight P**sun**

$$\eta = \frac{V_{mp}\, J_{mp}}{P_{sun}} \qquad \text{.... (iv)}$$

$$= \left(\frac{J_L E_g}{e P_{sun}}\right)\underbrace{\left(\frac{J_{mp} V_{mp}}{J_L V_{0C}}\right)}_{\text{Fill factor}}\underbrace{\left(\frac{e V_{0C}}{E_g}\right)}_{\text{Voltage factor}}$$

[where E_g = Forbidden energy gap]

The fill factor (FF) for a solar cell is defined as the ratio of two areas shown.

$$FF = \frac{J_{mp} V_{mp}}{J_L \times V_{0C}}$$

Solar cell designers, strive to increase the fill factor values, to minimize internal losses. Maximum power can be defined in terms of V_{0C} and J_L and is given by

$$P_{max} = J_L \times V_{0C} \times FF$$

A typical value of the fill factor for a good silicon cell is about 0.8.

A Basic Photovoltaic System for Power Generation

- A basic photovoltaic system integrated with the utility grid is shown in Fig. 2.13.
- It permits solarly generated electrical power to be delivered to a local load.

It consists of:

(i) Solar Array:

Large or small, which converts the insolation to useful DC electrical power.

(ii) A Blocking Diode:

Which lets the array-generated power flow only toward the battery or grid. Without a blocking diode the battery would discharge back through the solar array during times of no insolation.

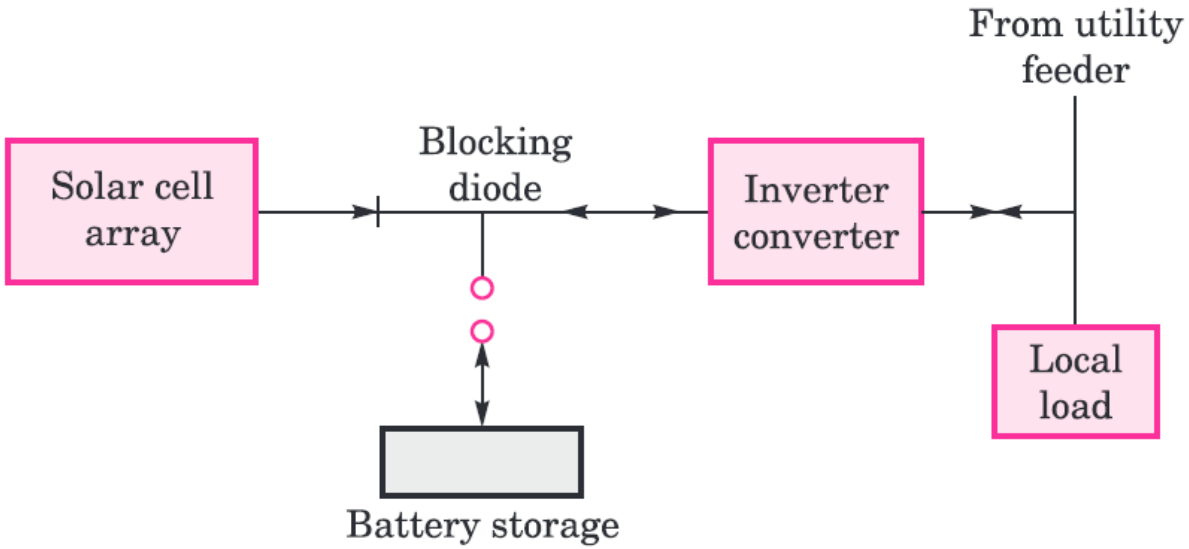


Fig.2.13 Basic Photovoltaic System for Power Generation

(iii) Battery Storage: In which the solarly generated electric energy may be stored.

(iv) Inverter/converter:

- Usually solid state which converts the battery bus voltage to AC of frequency and phase to match that needed to integrate with the utility grid.
- Thus it is typically a DC or AC inverter. It may also contain a suitable output step up transformer, perhaps some filtering and power factor correction circuits and perhaps some power conditioning, i.e., circuitry to initiate battery charging and to prevent over charging.
- Power conditioning may be shown as a separate system functional block.
- This block may also be used in figure shown to function as a rectifier to charge the battery from the utility feeder when needed and when no insolation was present.

(v) Appropriate Switches and Circuit Breakers:

To permit isolating parts of the system, as the battery. One would also want to include breakers and fusing protection between the inverter output and the utility grid to protect both the photovoltaic system and the grid.

Factor limiting the efficiency of the cell

Cable Thickness

- We generally have electrical appliances working at 220V which is significantly higher compared with the usual PV system DC voltages of 12V, 24V or 48V.
- For the same wattage much higher currents are involved in the PV systems. This brings into picture resistance losses in the wiring.

Shading

- Ideally solar panels should be located such that there will never be shadows on them because a shadow on even a small part of the panel can have a surprisingly large effect on the output.
- The cells within a panel are normally all wired in series and the shaded cells affect the current flow of the whole panel.

Inverter Efficiency

- When the solar PV system is catering to the needs of the AC loads an inverter is needed.

Battery Efficiency

- Whenever backup is required batteries are needed for charge storage.

Applications of Solar Photovoltaic System

The terrestrial applications of these include provision of power supply to:

- Water pumping sets for micro irrigation and drinking water supply.
- Radio beacons for ship navigation at ports
- Community radio and television sets.
- Cathodic protection of oil pipe.
- Weather monitoring.
- Battery charging lines
- Railway signaling equipment.
- Street lighting.

The major application of photovoltaic systems lies in water pumping for drinking water supply and irrigation in rural areas. The photovoltaic water pumping system essentially consists of: (a) A photovoltaic (PV) array, (b) Storage battery, (c) Power control equipment, (d) Motor pump sets, and (e) Water storage tank

Advantages and Disadvantages of Photovoltaic Solar Energy Conversion

Advantages:

- Direct room temperature conversion of light to electricity through a simple solid state device.
- Absence of moving parts.
- Ability to function unattended for long periods as evidence in space programme.
- Modular nature in which desired currents, voltages and power levels can be achieved by mere integration.
- Maintenance cost is low as they are easy to operate.
- They do not create pollution.
- They have a long effective life.
- They are highly reliable.
- They consume no fuel to operate as the sun's energy is free

- They have rapid response in output to input radiation changes; no long time constant is involved, as on thermal systems, before steady state is reached.
- They have wide power handling capabilities from microwatts to kilowatts or even megawatts when modules are combined into large area arrays.
- Solar cells can be used in combination with power conditioning circuitry to feed power into utility grid.
- They are easy to fabricate, being one of the simplest of semi conductor devices.

Their *principal disadvantages* are their high cost, and the fact that, in many applications, energy storage is required because of no insolation at night.

Efforts are being made world-wide to reduce costs through various technological innovations.

THANK YOU