Chapter 2

Photothermal Applications

2.1 Liquid flat plate collector, construction and working, Energy balance equation:

A solar collector is a device which absorbs incident solar radiation and transfer the energy to fluid in contact with it. Generally, there are two types of collector viz.

l. Flat plate collector

2. Concentrating collector.

Flat plate collector is divided into two types depending -upon fluid used. These two types are:

(a) Liquid flat plate collector

(b) Air collector.

The flat plate collector has five main components as follows:

(i) A transparent cover which may be one or two sheets made of glass, plastic film.

(ii) Tubes, passage or channels with collector absorber plate.

(iii) The black absorber plate made of metal.

(iv) Insulation which is provided to minimise heat loss due to conduction.

(v) Casing or container which encloses the other component and protects them from the weather.

1. Liquid flat plate collector:

Fig. 2.1.1 is a schematic diagram of liquid flat plate collector. It is also called as plate and tube collector. It consists of a flat surface with high absorptivity for solar- radiation, Such surface is called absorbing surface or absorber plate. Absorber plate is made of metal usually of copper, steel or aluminium material.

The absorber plate painted with black colour is in contact with copper tubing's. The tubes are having diameter from 1 to 1.5 cm. They are soldered, brazed, welded or pressure

bonded to the bottom of absorber plate.

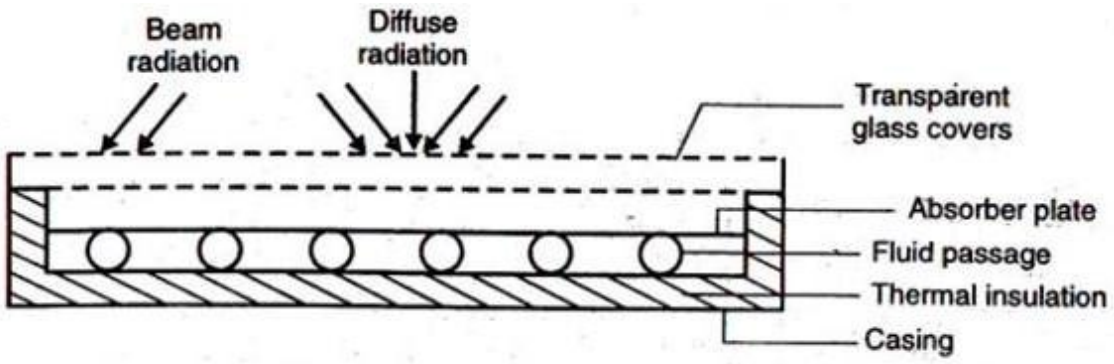


Figure 2.1.1 is a schematic diagram of liquid flat plate collector.

The solar radiation falls on absorber plate after coming through one or more transparent covers. The transparent cover helps in reducing the losses of convection radiation. The absorbed radiation is transferred to liquid flowing through the tubes fixed to absorber plate. The thermal insulation on back side helps in reducing the conduction heat loss. Liquid flat plate collector is held tilted in a fixed position on a supporting stri1cture.

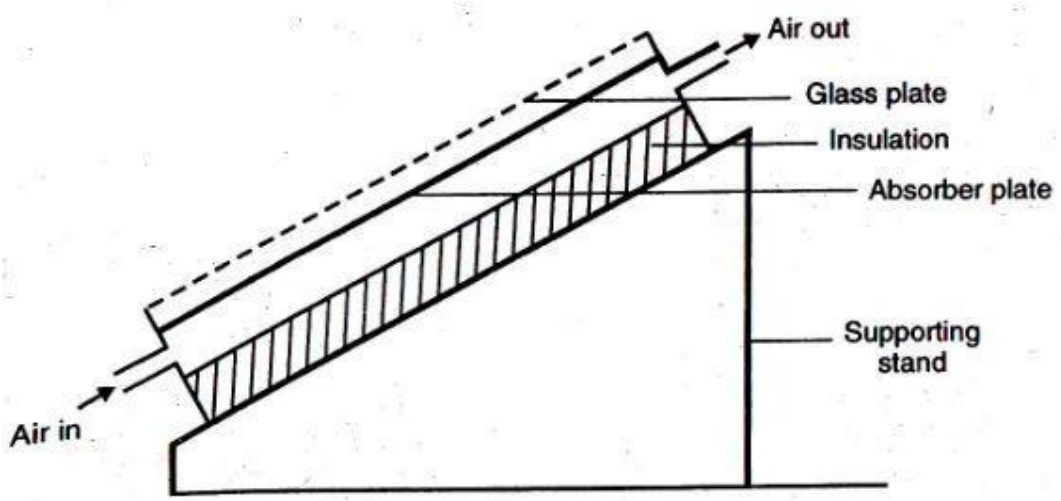
Flat plate collector is very simple to design. It has no moving parts and it requires low maintenance. It can be used for variety of applications in which temperature ranging from 40°C to about 100°C are required. The main disadvantage of flat plate collector is that because of the absence of optical concentration, the area from required which heat is collected is large. Hence collection efficiency (ratio of heat gain to radiation incident on it is low.

2. Air flat plate collector (or Solar air heater):

The construction of air flat plate collector is similar to that of flat plate collector except for passage through which air flows. These passages have to be made larger in order to keep the pressure drop across the collector within manageable limit. Air collector or air heater is used in heating building, green houses, and drying agricultural products. It consists of an absorber plate with a parallel plate below forming a passage through which the air to be heated flows. The transparent cover system is provided above absorber plate. A container filled with insulation is provided at the bottom and sides. (Fig. 2.1.2).

Like liquid flat plate collector, solar air heater requires low maintenance. As fluid does not freeze it has advantage of not requiring any special attention at temperature below O°C. Corrosion and leakage problems are also less. But value of heat transfer between

absorber plate and air is low, the efficiency of solar air heater is also low.



2.2 Concentrating collectors, advantages and disadvantages:

We have seen that a temperature of fluid ranging from 40°C to 100°C can be obtained from flat plate collector. When temperatures higher than 100°C are required, it becomes necessary to concentrate the radiation. This is achieved by using, focussing or concentrating collector.

Concentration of solar radiation is achieved by using reflecting arrangement of mirrors or refracting arrangement of lenses. Such optical system concentrates the solar radiation on absorber usually surrounded by glass or transparent cover. Due to optical system certain losses are introduced. These are reflection and absorption losses in mirror or lenses and losses due to geometrical imperfection in optical system. These optical losses are compensated by concentrating incident flux on absorber plate of smaller area.

Designing and maintenance of solar concentrator is not as simple as that of flat plate collector. Due to optical system, concentrator has tracking arrangement so that beam is concentrated on absorber surface. The method of tracking adopted and the precision with which it has to be done varies considerably. For a collector having a low degree of concentration only one or two adjustments are needed every day. But for a collector having high degree of' concentration, user has to make continuous adjustments of a collector orientation. All these factors add to the cost. Another disadvantage is that much of diffuse radiation is lost because it does not gets focussed.

There are various types of concentrating collectors. They are-reflecting type utilizing mirrors or of refracting type using Fresnel lenses. The reflecting surfaces may be parabolic, spherical or flat. They may be continuous or segmented.

Concentrators are also classified on the following criteria:

(i) based on formation of image.

(ii) based on concentration ratio (ratio of effective area of aperture to surface area of absorber)

(iii) based on type of tracking adopted.

Types of Concentrating Collector:

Fig. 2.2.1 shows number of concentrating collector geometries.

Fig. 2.2.1 (a) is a flat plate collector with adjustable mirror at edge. The mirror reflects radiation on the absorber plate. It has concentration ratio (ratio of effective aperture area to

absorber tube area) little above unity. It is useful to obtain temperature about 20°C to 30°C

higher than those obtained by flat plate collector. Instead of one mirror, we can use two or

more mirrors to obtain higher temperature Fig. 2.2.1 (b) shows geometry of a cylindrical parabolic collector. In such collector' image is formed on focal axis of parabola where absorber tube is located. The absorber tube is made of mild steel or copper. It is coated with

black paint and surrounded by concentric glass cover with gap of 1 or 2 cm. For high performance, absorber plate is' coated with black chrome and space between the tube and

glass cover is evacuated. The liquid heated in the collector depends upon temperature required by user. The reflecting surface is curved back silvered glass. The reflector is fixed on a light weight structure.

Fig. 2.2.1 (c) shows compound parabolic concentrator. The concentrator is made of parts of two parabolas. This collector is also non-imaging like flat plate collector with plane surface. The concentration ratio generally ranges between 3 to 10. Such concentrator requires occasional tracking.

Fig. 2.2.1 (d) shows collector with fixed circular concentrator and moving receiver.

The concentrator is array of long, narrow flat mirror strips fixed along the cylindrical

surface. As sun moves, the mirror strip produces a narrow line image on absorber. The receiver (absorber) has to move along the circular path in order to track the sun.

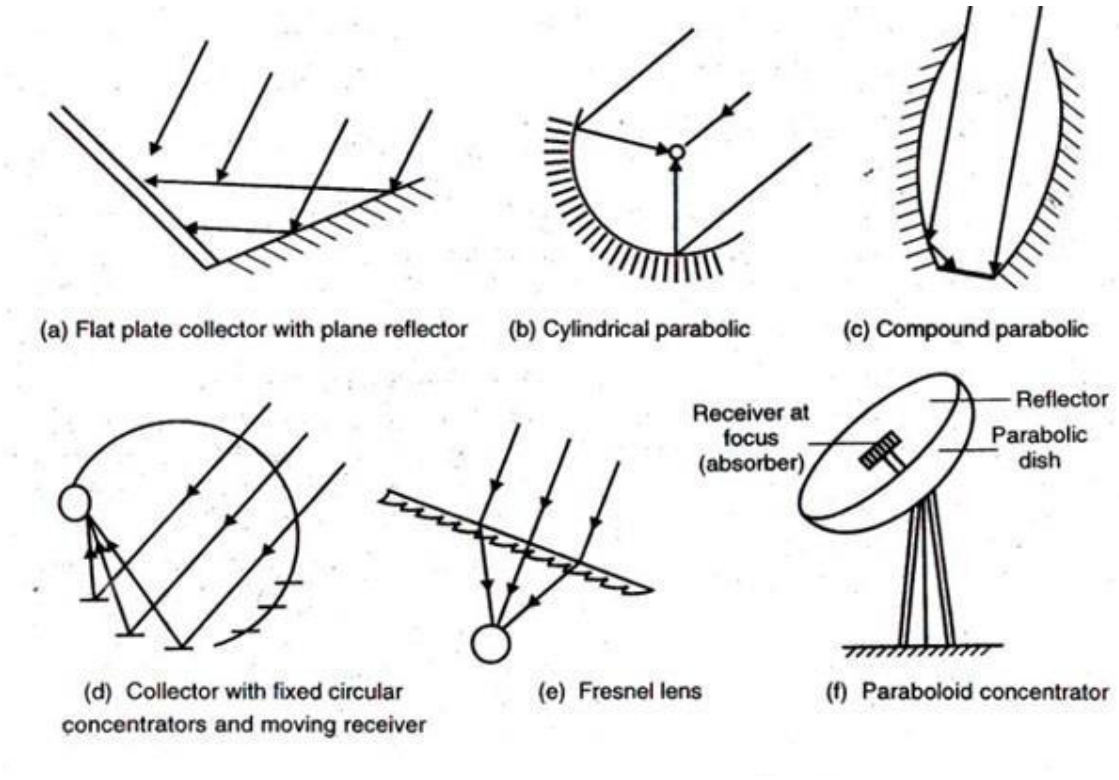


Fig. 2.2.1 Types of concentrating collectors (Geometric shapes)

The concentration is also achieved by Fresnel lens as shown in Fig. 2.2.1 (e). Fresnel lens is thin sheet, flat on one side and with fine longitudinal grooves on the other. The angle of grooves is such that radiation is brought to line focus. The lens is usually made of extruded acrylic plastic sheets. Line focussing collector as shown in Fig. 2.2.1 (b), (d), (e) has concentration ratio between 10 to 80. Such system yields temperature between 150° and 400°C.

If we want higher concentration ratio and temperature, one should have point focussing rather than line focussing. The point focussing can be done by using paraboloid concentrating collector as shown Fig. 2.2.1 (f). Such collector has concentration ratio above 100 and have yielded temperature up to 2000°C.

The main **advantages** of concentrator system over flat plate collector are as follows:

1. Reflecting surface requires less material and structurally simpler than flat plate collector. For a concentrator, cost per unit area of system is low.

2. The absorber, area of concentrator is smaller than that of flat plate collector, hence isolation intensity is greater.

3. Due to small area, heat lost per unit area' of concentrator is low than that of flat plate collector. Hence working fluid in concentrator can attain higher temperature.

4. Because of higher temperature attained in concentrator, heat stored per unit volume is larger. Hence heat storage cost is less than that of flat plate collector.

5. Concentrating system can be used for electric power generation when not used for cooling or heating. The total useful time in a year can be larger for concentrating system than flat plate collectors.

But concentrator has some limitations (disadvantages). These limitations are as follows:

1. Only beam radiation is collected. Diffused beam cannot be reflected.

2. Due to reflecting system and small absorber, tracking is required in Concentrator.

3. Additional requirement of maintenance to retain quality of reflecting surface against dirt, weather, and oxidation is required.

4. The flux is non-uniform on absorber plate.

5. Additional optical losses such as reflectance loss and the intercept loss are introduced in the system.

2.3 Solar distillation:

In many small communities, the natural supply of fresh water is inadequate in comparison to the availability of brackish or saline water. Solar distillation can prove to be an effective way of supplying drinking water to such communities. The principle of solar distillation is simple and can be explained with reference to Fig. 2.3.1, in which a conventional basin type solar still is shown. The still consists of a shallow air-tight basin lined with a black, impervious material which contains the saline water. As sloping transparent cover is provided at the top. Solar radiation is transmitted through the cover and is absorbed in the black lining. lt thus heats up the water by about 10 to 20°C and causes it to evaporate. The resulting vapour rises, condenses as pure water on the underside of the cover and flows into condensate collection channels on the sides. An output of about 3 litres / m^2 with an associated efficiency of 30 to 35 per cent can be obtained in a well-designed still on a good sunny day.

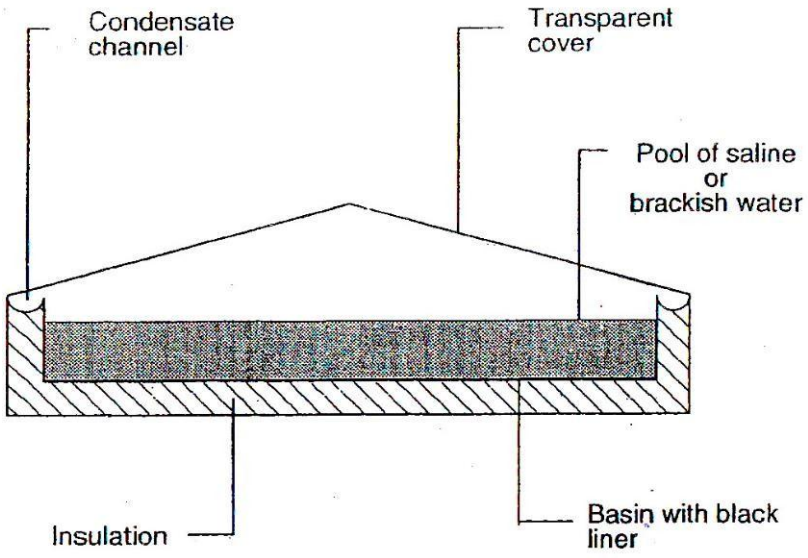


Fig. 2.3.1 Schematic diagram of solar distillation

A number of basin-type solar-still plants having areas greater than 100 m^2 are in operation in many parts of the world. In India, a plant having a capacity of 5000 litters a day was built in the village of **Awania near Bhavnagar in 1978**. A few other plants having similar capacities have also been subsequently, the total areas of all the plants built in India so far being about 10,000 m^2.

2.4 SOLAR DRYER:

Traditionally, solar energy has been used for drying agricultural products. The solar drying process is used to remove the moisture, which helps in preservation of agricultural products. The main disadvantage of traditional drying is that process is very slow. Also dust and insects get mixed with products. The product is also exposed to wind and rain. In which solar dryer causes spoilage and losses. These disadvantages can be removed by using solar dryer in which drying is done faster and quality of product can be improved.

The research work in solar drying has been oriented in two directions. First, in direct drying the material is exposed to solar radiation. By energy absorption and air circulation, the moisture is vapourised and thrown out in the atmosphere. Secondly drying is indirectly done by solar air heater.

A cabinet type dryer (Fig: 2.4.1) is used for small scale use of dehydration of vegetables and fruits. It has a chamber (cabinet) with glass plate (single or double) at the top. Sun light passes through glass and falls on product to be dried kept on perforated trays. The radiation is absorbed by product itself and surrounding the internal surface of enclosure. The air gets heated and the

moisture is removed from product. The vapours escape through opening on top of cabinet and fresh air enters through a opening at bottom-by natural convection.

The air flow thus started continuously removes moisture from the product. Temperatures ranging from 50°C to 80°C are usually attained by such drier and product is dried within 4 or 5 days. The products like dates, apricots, chillies can be dried by such dryer.

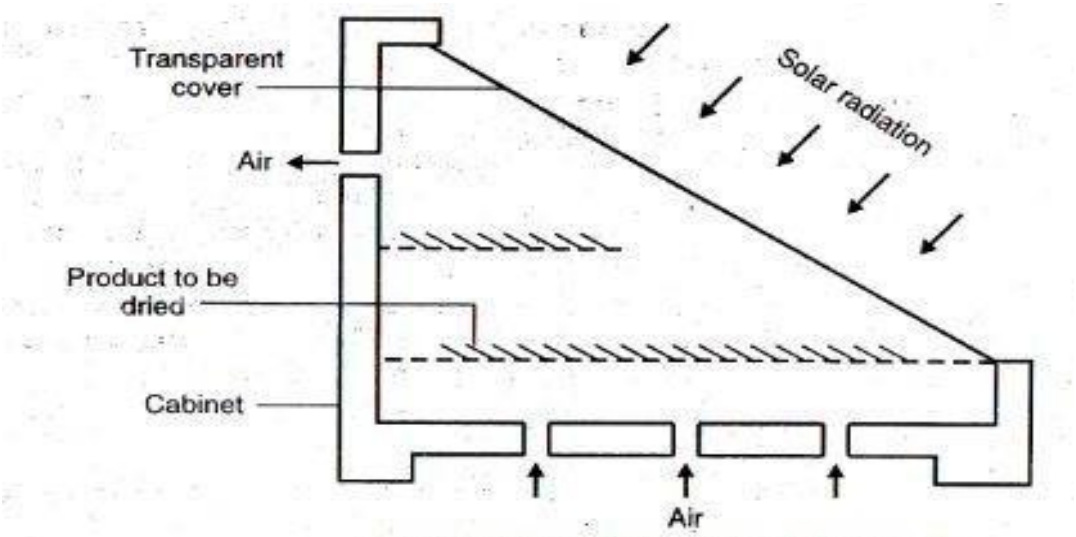


Figure 2.4.1 Cabinate type solar dryer

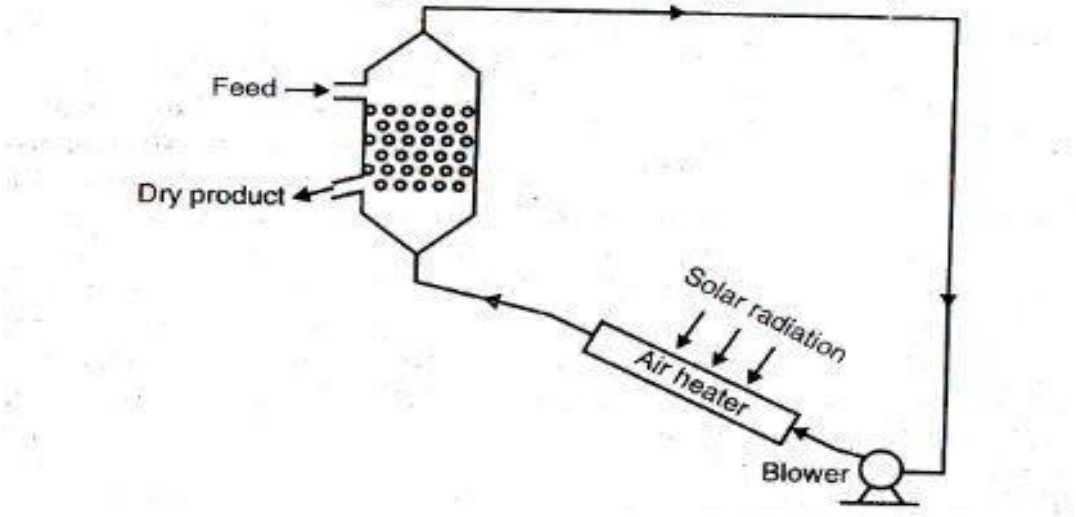


Figure 2.4.2 forced circulation dryer

For large scale drying instead of natural circulation, active device with forced circulation is used (See Fig: 2.4.2). Here air is heated separately by solar air heater, and then it is pushed in chamber in which the product to- be dried is stored. Such dryers are used for drying of food grains and products like tea and tobacco.

2.5 Solar cooker (Box type):

An important domestic thermal application is that of cooking. Over the past forty years, a number of designs of solar cookers have been developed, a few of which are described here.

Solar cooker designs generally fall into one of two categories. One category is the box-type cooker which essentially consists of a rectangular enclosure insulated on the bottom and sides, and having one or two glass covers on the top. Solar radiation enters through the top and heats up the enclosure in which the food to be cooked is Placed in shallow vessels. A typical size available has an enclosure about 50cm square and 12 cm in deep. Temperatures around 100°C can be obtained in these cookers on sunny days and pulses, rice, vegetables, etc., can be readily cooked. The time taken for cooking depends upon the solar radiation and varies from half to 2 and half hours.

A single glass reflector whose inclination can be varied is usually attached to the box-type cooker. A sketch of such a cooker is shown in Figure 2.5.1.

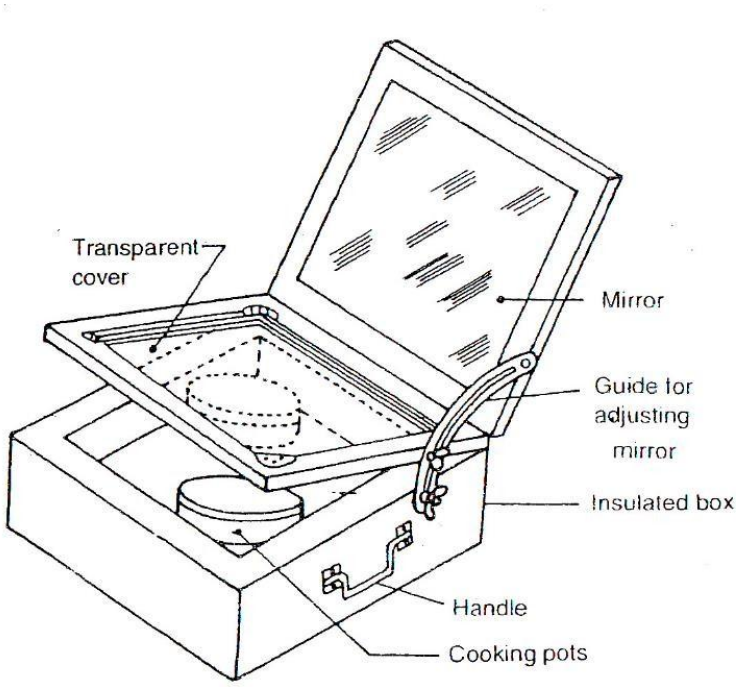


Figure 2.5.1 Box-type Solar Cooker

The addition of the mirror helps in achieving enclosure temperatures which are higher by about 15 to 20°C. As a result, the cooking time is reduced. Cookers with reflectors on all four edges have also been built.

Bon-type cooker with no reflector or with one reflector are simple to use and require little attention. As a result, they have found the maximum acceptance amongst all the designs developed. The item to be cooked has only to be placed inside and taken out, so that with some experience, the operator does not have to spend much time in the sun. However, the disadvantage is that they cannot be used for cooking items chapatis and purees, since these require higher temperatures.

Box-type solar cooker are being made by many organization in India. The cost of a typical good quality cooker with a mirror and having the dimensions given earlier ranges between Rs. 800 to 1000. With central and state government subsidies, the cooker is available for Rs.500 to 600. In most. places in India, such solar cookers can be used for at least 250 days in the year and it is estimated cost fuel saved would be about Rs 200 per year. Thus, a box-type cooker pay for itself in a period of two to three years. Because of the relatively low payback period, solar cookers have become fairly popular in many states. More than 2,50,000 cookers have been sold so far and the number is growing at the rate of about 20,000 every year.

Recently a new design of a solar cooker which can serve the needs of a community has been developed. It consists of a flat plate collector with booster mirrors used for heating oil, a pebble bed filled storage vessel, hot plates, interconnecting tubes and a set of three valves, the unit works on the thermosyphon principle and can operate in three modes.

The advantage of this cooker is that it yields a higher temperature than the box-type cooker because of the use of a selective surface and booster mirrors in the flat-plate collector. It can therefore be used for cooking a larger variety of items. In addition, the cooking area can be at a small distance from the collector and need not be in the sun. Cooking is also possible in the evening because of the inclusion of a storage vessel. The second category of solar cookers developed are those in which the radiation is concentrated by a paraboloid reflecting surface. The cooking vessel is placed at the focus of the paraboloid mirror and is thus directly heated. These cookers require some form of tracking. Temperatures well above 200°C can be achieved in such cookers. Various types of reflecting surfaces have been used.

These include glass mirrors, aluminium sheet and aluminium foil. The main disadvantage with these cookers is that although they can cook all types of food items, they require continuous attention, as a result of which the operator has to be in the sun most of the time. Another disadvantage is that except for glass, the reflectivity of all other surfaces decreases with the passage of time.

Following are the some **merits** of a solar cooker:

1. No attention is needed during cooking as in other devices
2. No fuel is required
3. Negligible maintenance cost
4. No pollution
5. No problem of charring of food and no over flowing
6. Vitamins of the food are not destroyed and food cooked is nutritive and delicious with natural taste.

Following are some **demerits** of a solar cooker:

1. One has to cook according to the sun shine, the menu has to be preplanned.
2. One cannot cook at short notice and food not be cooked in the night or during cloudy day.
3. It takes comparatively more time.
4. Chapatis are not cooked because high temperature for baking is required and also needs manipulation at the time of baking.

2.6 Solar water heating system:

Domestic solar water heater:

Solar water heater is the direct use of solar energy that is most extensively used. It is most viable in all low temperature solar energy applications.

A simple, small capacity and natural circulation system is suitable for domestic purpose. The system has two main components. These are liquid flat plate and insulated storage tank. The storage tank is located above level of solar collector.

The Water in flat plate collector is heated by solar energy as discussed earlier. Hot water automatically to the top of water tank. It is replaced by cold water at the bottom of tank, When required hot -water is withdrawn from tank, cold water automatically enters at bottom. Such process is also called as thermosyphon process as shown in fig. 2.6.1.

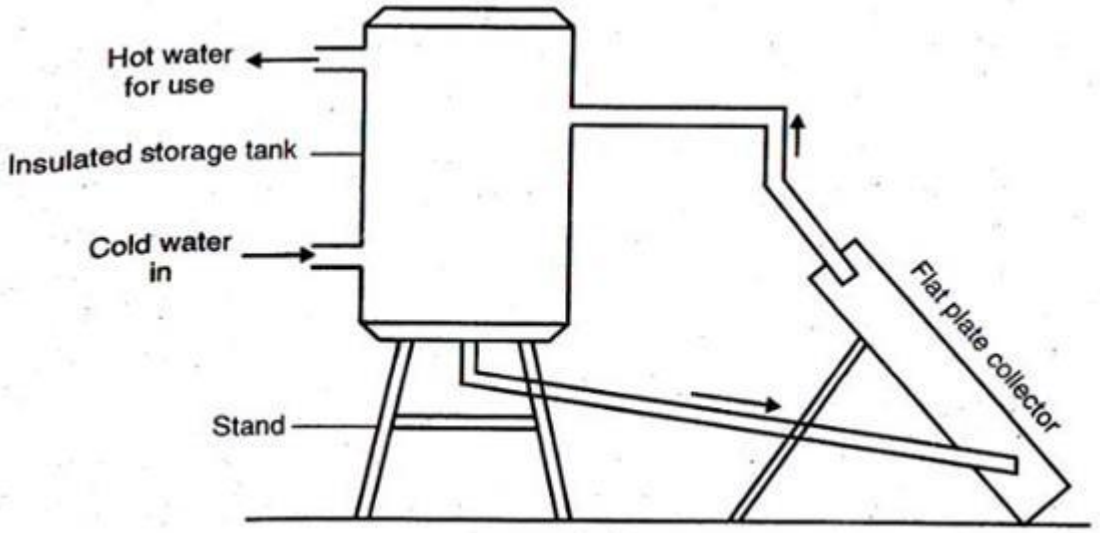


Fig. 2.6.1 Natural circulation water heater system

In such solar water system, there is possibility of matching the temperature required for the use. Due to this matching the thermodynamic efficiency based on consideration of available energy is higher than in case of water heating system than heating system than heating using natural gas or electricity. The temperature of hot water delivered by such domestic solar water heater ranges from 50°C to 80°C.

Solar water heater of natural circulation (thermosyphon) is largely used in many countries. In India, the market of solar water system has been steadily growing in the last decade.

Small capacity domestic water heaters are also available. It has simpler design. In such water heater, function of the collector and storage tank are combined in one unit.

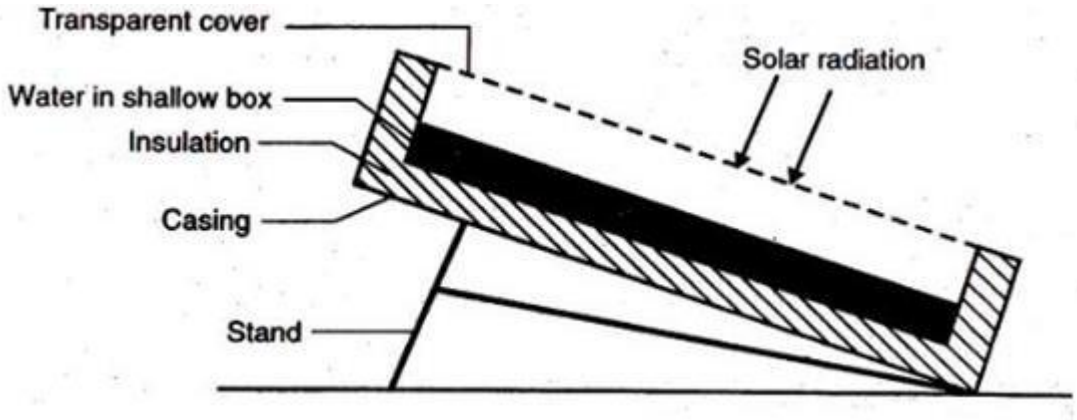


Fig. 2.6.2 shows collector cum storage type solar water heater.

Collector cum storage water system consists of a closed shallow rectangular box made of metal sheet. The box is contained in housing which supports glass cover. The box is, insulated at bottom and around the side. When the box is filled with the water in morning and water is withdrawn at evening, the water is heated up through a day. The collector cum storage type solar heater has lesser efficiency and yields slightly lower temperature. It is cheaper than natural-circulation water system.

When a large amount of hot water is required, natural circulation system is not suitable. In such case, large array of flat plate collectors are used. By using water pump, forced circulation is maintained. Water is pumped through collector array, where it is heated and then flows back in to storage tank. Storage tank is at the level of collector array. Whenever hot water is withdrawn, its place is replaced by cold water because of/ball float control. The water pump is operated by on off controller with a temperature sensor which detect temperature difference of water at exit and point inside storage tank. The pump is switch on when temperature difference of water at exit and point in tank exceeds certain value and off when it falls below the value. Such system is useful in hospital, factories, hotels, etc.

Solve Problem

1. Calculate efficiency of flat plate collector.

   Given: Q_k = 400 k cal / hr , Ac = 2 m^2, I = 500 Kcal / hr-m^2.

   Solution : Q_k = 400 k cal /hr = 400 x 1000 cal / hr , Ac = 2 m^2,

   I= 500 Kcal / hr-m^2.= 500 x 1000 cal / hr

$$\eta = \frac{\text{(Useful net gain)}}{\text{(Radiation Incident)}}$$

$$\eta = \frac{Q_k}{(Ac \times I)}$$

$$\eta = \frac{400 \times 1000}{2 \times 500 \times 1000}$$

$$= 0.4 \text{ or } 40\%$$

QUESTIONS AND EXAMPLES

1. Discuss flat plate collector in details.
2. Give limitations of concentrating collectors.
3. What are principle component of solar dryer?
4. Explain how a Water of required temperature is obtained from domestic water heater.

3. Write a short note on :

   (a) Solar dryer

   (b) Solar concentrator

4. What are advantages and disadvantages of solar concentrator over flat plate collector ?

5. Explain various solar drier design. What are the applications of solar drier?
6. Describe the construction and working of solar air heater and solar water heater (Natural circulation type).
7. Describe the construction and working of solar air heater and solar water heater (Natural circulation type).
8. Write the energy balance equation of flat plate collector.
9. Define efficiency of 'flat plate collector'.
10. Write applications of solar air heater.
11. What is the principle of solar dryer?
12. Describe the box type solar cooker with neat diagram.