Topic 3: Solar Energy

Introduction

Solar energy is a clean, cheap and abundantly available renewable energy. Solar energy can be used in two ways: (a) directly as thermal energy and (b) indirectly using solar photovoltaic cells to convert it to electricity. Solar energy can be used either in solar power plant or in solar photovoltaic (SPV) cells for (i) domestic lighting, (ii) solar water heating, (iii) street lighting, (iv) village electrification, (v) railway signals, (vi) desalination of saline water, (vii) water pumping, (viii) space heating, (ix) solar cooking, (x) space cooling, (xi) solar greenhouse and (xii) powering of remote telecommunication stations.

Learning Outcomes of Topic 3

Upon completion of this study unit, you should be able to:

1. discuss solar collectors and classification of solar collectors
2. discuss solar energy storage and classification of solar energy storage system, sensible heat storage
3. discuss some applications: solar water heater, solar thermal pump, solar passive heating, solar refrigeration and cooling system, solar cookers, solar distillation, solar thermal power plants solar greenhouse

SOLAR ENERGY

3.2 SOLAR COLLECTORS

- **Why is a solar collector needed?**

Solar energy reaching earth's surface has small intensity of about 5–7.5 kWh/m^2. Hence, for any worthwhile application, sufficient solar energy should be collected from a large ground area with the help of many solar collectors. Solar collector is a device for collecting solar radiation and then transferring the absorbed energy to a fluid passing through it. A solar collector absorbs solar energy in the form of heat and simultaneously transfers this heat to a fluid so that the heat can be transported by the fluid. The transport fluid takes this transferred heat from the collector and delivers it to a thermal storage tank, boiler or heat exchanger so that it can be utilized in a solar thermal system. Hence, solar collector is essential and it forms the first basic unit in a solar thermal system.

3.2.1 Classification of Solar Collectors

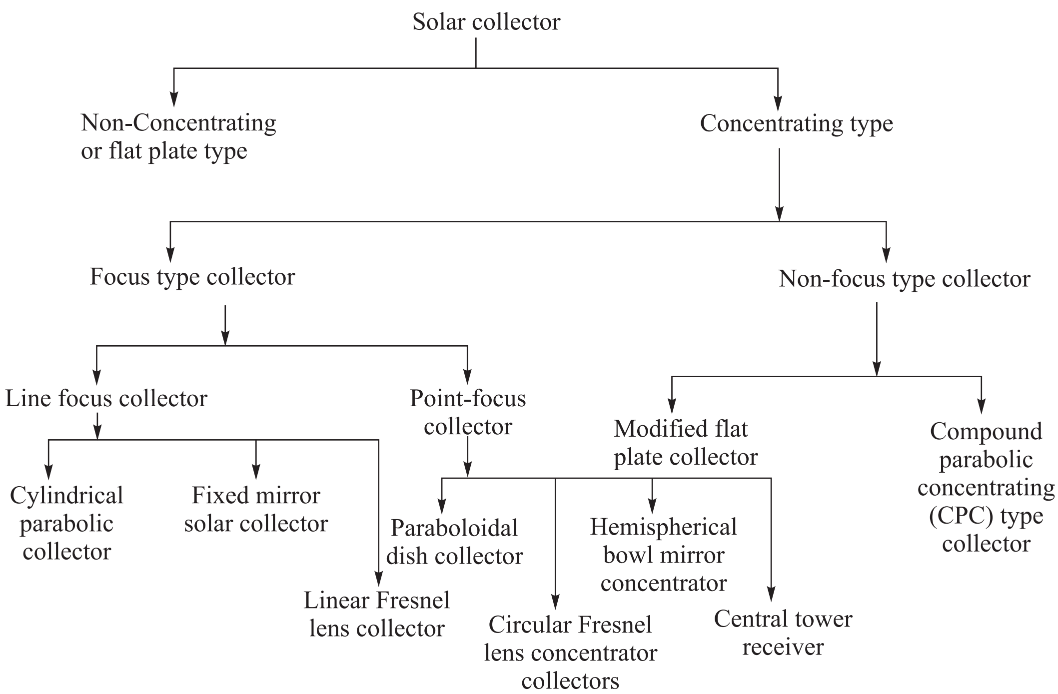
- **How are solar collectors classified? What are the important features of a solar collector?**

or

- **Explain (i) collector efficiency, (ii) concentration ratio and (iii) temperature range.**

or

- **Enumerate different types of concentrating solar collectors.**



Additional questions

1. What is a flat plate solar collector? or Explain the principle of conversion of solar energy to heat.
2. Describe briefly a cylindrical parabolic concentrator.
3. Write short notes on linear Fresnel Reflectors and paraboloidal dish collector.
4. Explain fixed mirror solar concentrator.
5. What do you understand by central tower receiver collector?

The important features of a solar collector are as follow:

- Collector efficiency
- Concentrating ratio (CR)
- Temperature range

Collector efficiency

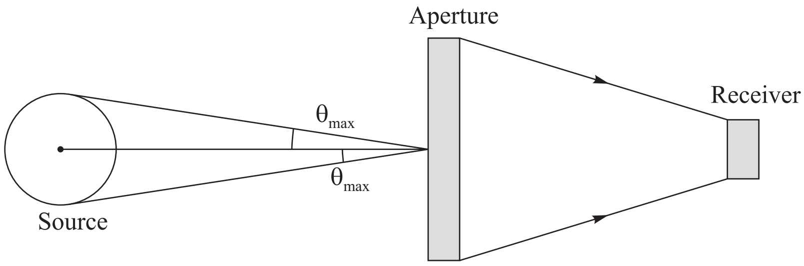
It is defined as the ratio of energy actually absorbed by the collector to the energy incident on the collector. The absorbed energy by a collector is the solar energy which is transferred to the transport fluid as heat energy.

$$\eta = \frac{\text{Energy absorbed}}{\text{Solar incident energy}}$$

Concentrating ratio

It is defined as the ratio of the area of aperture of the collector system to the area of the receiver. The aperture of the system is the projected area of collector facing or normal to the sun as shown in Figure 3.2. The radiation is incident on an aperture area A_o which is then concentrating on a smaller area on receiver or absorber plate given by A_r. The concentration ratio is

$$\text{CR} = \frac{A_o}{A_r} \text{ and } \text{CR}_{\text{max}} = \frac{1}{\sin \theta_{\text{max}}}$$



Temperature range

It is the range of temperature to which the heat transporting fluid is heated up by the collector. The temperature range depends upon the concentration ratio. The flat plate collectors have concentration ratio of unity as no focussing or optical concentration system is utilised in them to concentrate the solar radiation. This is the reason why the temperature range of flat collectors is less than 100°C. Line focus collectors have concentration ratio up to 100 and these collectors can have temperature range on the order of 150–300°C. Point focus collectors have very high concentration ratio (CR > 1000) and these collectors have temperature range in the order of 500–1000°C.

- **In a collector, the aperture area is 2m^2 while it has absorber area of 100 cm^2. Find its concentration ratio.**

$$\mathbf{CR} = \frac{A_a}{A_r} = \frac{2}{100 \times (100)^{-2}} = 200$$

- **A parabolic collector of length 2m has angle of acceptance (2θ) as 15°. Find the concentration ratio of the collector.**

$$\text{CR} = \frac{1}{\sin \theta_{\text{max}}}$$

But $2\theta_{\text{max}}$ = angle of acceptance = 15

$$\therefore \quad \theta_{\text{max}} = \frac{15}{2} = 7.5°$$

3.3 SOLAR ENERGY STORAGE

- **What do you understand by solar energy storage?**

or

- **Why is the storage of solar energy necessary?**

The solar energy is generally transformed into thermal or electric energy using solar devices. The solar energy is, however, available during sunshine hours, and the demand of thermal or electric energy may also exist during non-sunshine hours. Also, the maximum availability of solar energy may not coincide exactly with the demand of thermal or electric energy. The availability of solar energy is sometimes low for several days due to cloudy days, resulting in the substantial lowering of the output of thermal and electric energy from the solar radiation. Hence, it is essential to store energy output (thermal and electric) from solar devices during high insolation (in = incident, sol = solar and ation = radiation) times which is used afterwords to meet the thermal and electric load demand during peak demand times. During low insolation times, solar energy storage system enables delivery of more power than what is generated by the solar electric or thermal plant, and so it enables to match the generation of energy with the load demand.

3.3.1 Classification of Solar Energy Storage System

- **How can classification of solar energy storage systems be done? Explain them briefly.**

The solar energy storage systems can be classified as follows:

- Thermal energy storage system
- Chemical energy storage system
- Electrical energy storage system
- Hydrogen energy storage system
- Electromagnetic energy storage system
- Biological storage system

Thermal energy storage

Thermal energy storage can be (i) sensible heat storage by the virtue of heat capacity and the change in temperature of the material and (ii) latent heat storage by the virtue of latent heat necessary to change the phase of the storage medium.

Chemical energy storage

Lead acid batteries are the most commonly used means in chemical energy storage system. The advantages are (i) good working efficiency (up to 80%), (ii) low cost, (iii) rapid change from charging to discharging mode and (iv) slow discharge rate. A storage battery takes electrical energy generated by solar radiation and stores it as chemical energy. It later supplies electric energy by converting this stored energy.

Electrical energy storage

A capacitor is used to store electrical energy in an electrostatic field when it is charged. The capacitor of large capacity is required to store a significant amount of energy.

Hydrogen energy storage

The electrical energy is used to decompose water by the electrolysis reaction into hydrogen and oxygen. These substances can be recombined to release the stored energy when required.

Electromagnetic energy storage

The electrical energy is used to store energy in a magnetic field. The resistance of the coil wire is made almost negligible so that the stored energy in the coil is not dissipated out and stored energy in the magnetic field can be maintained indefinitely. The electromagnetic energy storage requires the use of superconducting materials. These materials develop almost zero resistance to electricity flow when cooled below a critical or transition temperature. This method of storing electromagnetic energy is also called super conducting magnetic energy storage (SMES). The electric energy can be recovered when coil is discharged.

Biological storage

The solar energy is stored in plants by a process known as photosynthesis. Photosynthesis is the process in which organic compounds are formed in green plants using carbon from atmospheric carbon dioxide in the presence of sunlight. The plants on decaying form biomass which can be converted into various types of solid, liquid and gaseous fuels.

3.3.2 Sensible Heat Storage

- **What are the main advantages and disadvantages of sensible heat storage with water as storage media? Compare them with those of solid media storage.**

Sensible heat storage

Thermal energy is stored in this types of storage by virtue of heat capacity and temperature difference developed during charging and discharging. The temperature of the storage material rises when thermal energy is absorbed and temperature drops when thermal energy is taken out. In this storage, the charging and discharging can be performed reversibly for an unlimited number of times. The sensible heat storage can be liquid media storage and solid media storage. Water is considered as the most suitable media for storage below 100°C. Liquids such as oils, liquid metals and molten salts are also used as liquid media storage.

The water thermal energy storage can be short term and long term. A short-term thermal energy storage system has a well-insulated storage tank as shown in Figure 3.14. The storage in such tank is economical for few days only as heat losses over long duration make the storage uneconomical. Long-term sensible heat storage by water is possible in underground reservoirs having special insulation. In this system, water is heated in charging mode by passing it through a heat exchanger and then it is stored in an underground reservoir. In the discharge mode, the hot water is made to flow back through the heat exchanger, where it releases the stored energy as shown in Figure 3.15 but with reverse circulation.

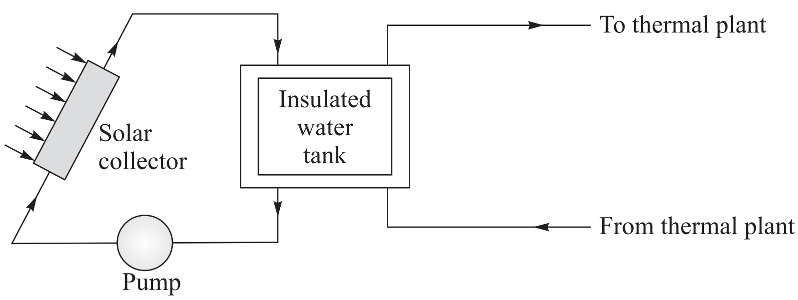


Figure 3.14 Short-term sensible heat storage by water.

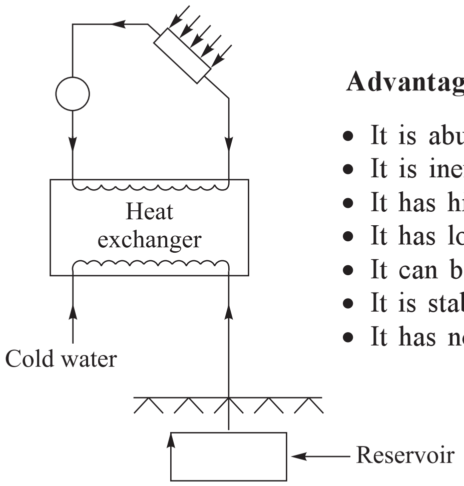


Figure 3.15 Long-term sensible heat storage by water.

Advantages. Water has the following advantages:

- It is abundantly available.
- It is inexpensive.
- It has high specific heat which enables to store more heat per unit mass.
- It has low viscosity requiring less energy to pump through the pipe system.
- It can be used for both storage and working medium.
- It is stable.
- It has no harmful effect.

Disadvantages. Water has the following disadvantages:

- It has limited temperature range of 0–100°C.
- It results in the corrosion of pipes.
- It can leak easily as it has low surface tension.

Solid media storage or packed media storage

This type of storage has a bed of loosely packed solid materials such as rocks, sand, concrete, pebbles and metals to store sensible heat. A fluid such as air is circulated through the bed to add or remove heat from the storage. This type of solid media storage has no limitations such as (i) low temperature due to freezing and (ii) high temperature due to vapourizing as applicable in the case of liquid media storage. A typical packed bed storage unit is shown in Figure 3.16. It consists of a container, a screen to support the bed, inlet duct and outlet duct. The charging or adding of heat is done by passing hot air through the bed in one direction and the removable of heat is done by passing the normal air through the bed in the opposite direction.

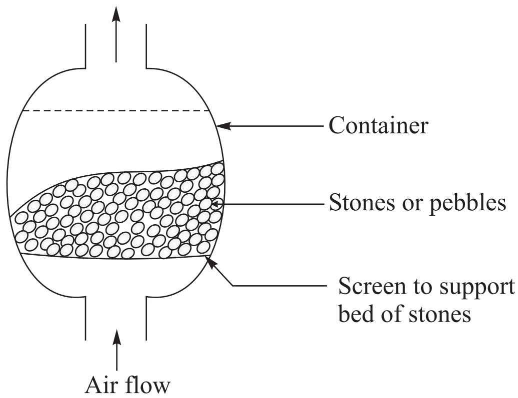


Figure 3.16 Solid media storage.

Advantages. The advantages of solid media storage are as follows:

- Stones or pebbles are abundantly available
- Low cost
- Non-combustible
- Easy to handle
- Possibility of high storage temperature
- No freezing point during heat removal
- No corrosion problem
- No requirement of heat exchanger

Disadvantages. The disadvantages are as follows:

- The size of the storage container should be large
- Simultaneously charging and discharging of energy is impossible
- Large pressure drop needs high capacity air blower

SOME APPLICATIONS

3.5 SOLAR WATER HEATER

- **With the help of a neat sketch, explain the working of a solar water heater.**

  or
- **Describe a solar water heating system.**

A small capacity water heating system with natural circulation is as shown in Figure 3.19. It is suitable to supply hot water for domestic purposes. It has two main components which include (i) flat plate collector to convert solar radiation into heat energy and (ii) water storage tank to store hot water. The tank is located above the level of collector. Heat is transferred to the water in the solar collector and hot water rises to flow in the water tank. The hot water enters the top of the water tank and cold water from the water tank moves out from the bottom of the tank so as to enter the inlet of the collector. The natural circulation of water is established from the collector to water tank and then from water tank to the collector. The hot water for use is withdrawn from the top of tank, which is replaced by cold water entering at the bottom of the tank. Water heating system is also provided with an auxiliary heating system so that the system can also work during cloudy and rainy days when sufficient solar radiation is unavailable.

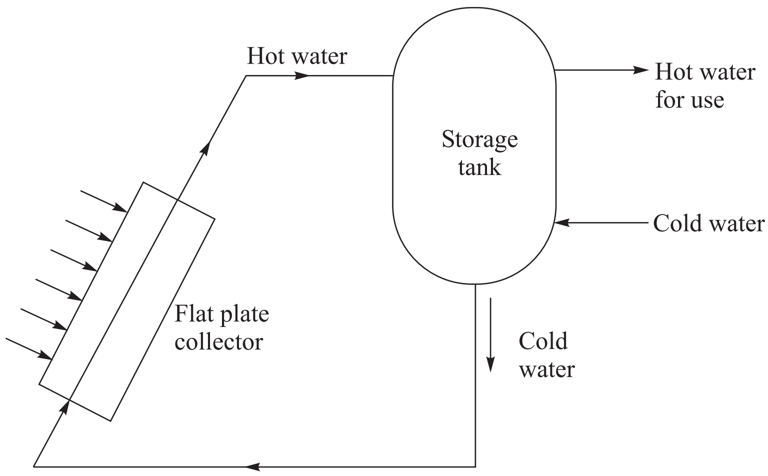


Figure 3.19 Small capacity water heating system with natural circulation.

3.6 SOLAR THERMAL PUMP

- **Explain the working of the solar thermal water pump with the help of a neat sketch.**

or

- **What are the features of solar energy which make it attractive for water pumping in irrigation?**

or

- **Explain the working of solar pumping.**

Solar pumping utilizes the mechanical power generated by the solar radiation to run the water pump. Solar energy offers several beneficial features which make its utilisation in irrigation pumping quite attractive. The features are as follows:

(i) The need for pumping arises most during the summer months when solar radiation is intense.
(ii) Pumping can be carried out intermittently without any problem.
(iii) Surplus pumped water can be stored in a reservoir or tank.
(iv) The requirement of water decreases during periods of low radiations when solar pumping decreases. Evaporation losses reduce during cloudy days. Rainwater is also available during rainy days.
(v) There is relatively inexpensive running and maintenance cost.

The solar pump is similar to solar heat engine working in low-temperature range. The source of heat is a solar collector. The heat is transported to a heat exchanger where heat is transferred to a refrigerant of low boiling point. The refrigerant evaporates and high-pressure vapour is taken to a turbine to do useful mechanical work by running the solar pump as shown in the Figure 3.20. The outlet refrigerant vapour from turbine is condensed and taken to heat exchanger using feed pump for reuse.

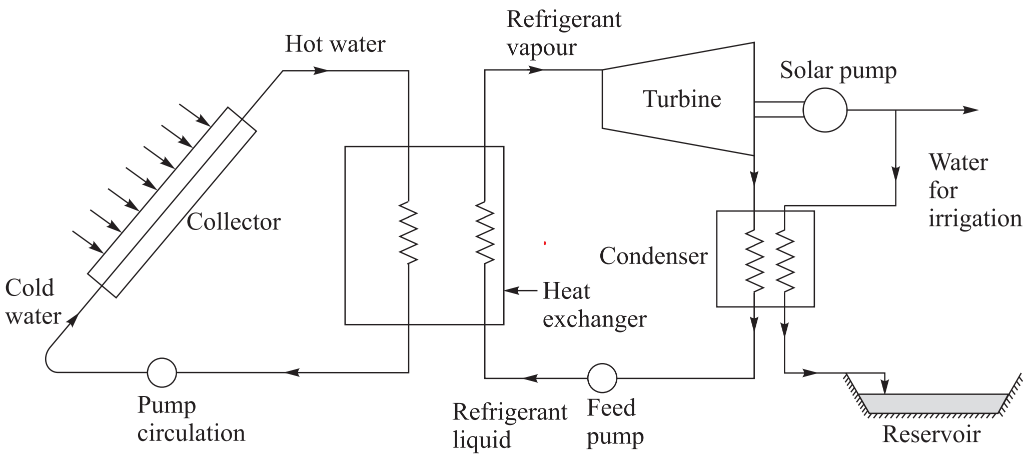


Figure 3.20 Solar water pump.

3.8 SOLAR PASSIVE HEATING

- **What do you understand by solar passive heating?**

or

- **How is passive heating assured by building design?**

or

- **Write briefly about the solar house.**

Solar energy can be used for passive heating of buildings to maintain comfortable temperature inside the buildings. Passive heating of buildings does not require any mechanical device. This heating consists of natural processes such as convection, radiation and conduction which are used to transport heat in the space. The heating necessitates a suitable building design to ensure natural flow of heat in the space inside building. Such specially designed building is called solar house.

In the northern hemisphere, the sun rays come from south direction. Hence in order to achieve solar passive heating in cold regions, south facing wall is made thick using concrete or stones to store the maximum heat energy from the incident solar radiation. The entire south wall is further provided with a plastic or glass sheet covering with an air gap in between the wall and the sheet covering. The incident solar radiation after passing through the sheet covering is absorbed by the thermal storage wall. The warm air in air gap rises and enters into the space inside the building to be heated as shown in Figure 3.22. The warm air enters into the space from the upper inlet vents and cold air is removed from the space from the lower outlet vents.

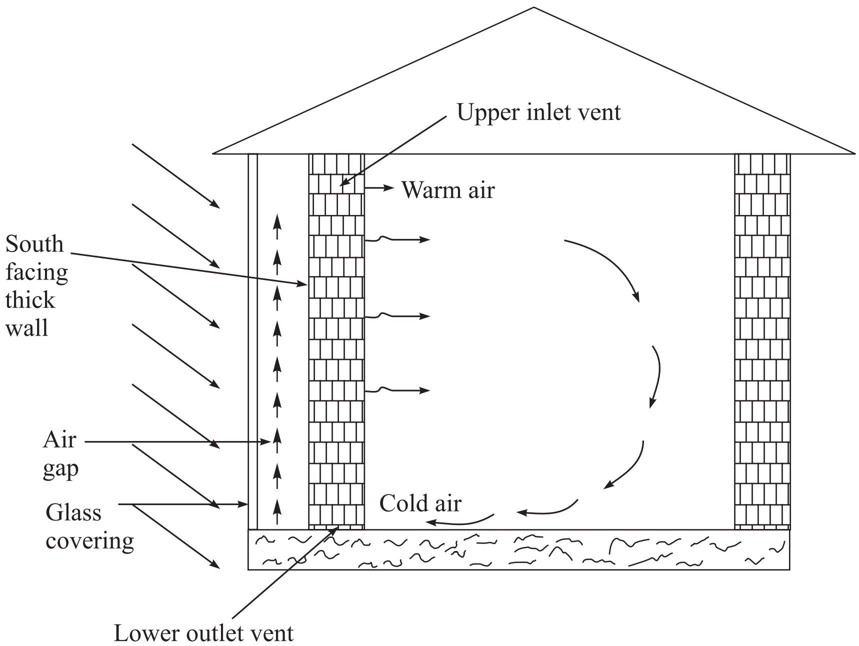


Figure 3.22 Solar passive space heating.

There is another method to provide solar passive space heating, which is shown in Figure 3.23. In this method, a flat plate collector is provided to face south. The collector is provided with rock bed type storage system. During sunshine hours, the collector transfers and stores heat energy from incident solar radiation into the rock bed storage system. The available stored energy in the rock bed is used later at night when air is passed through the rock bed, and so warm air enters into the space to be heated.

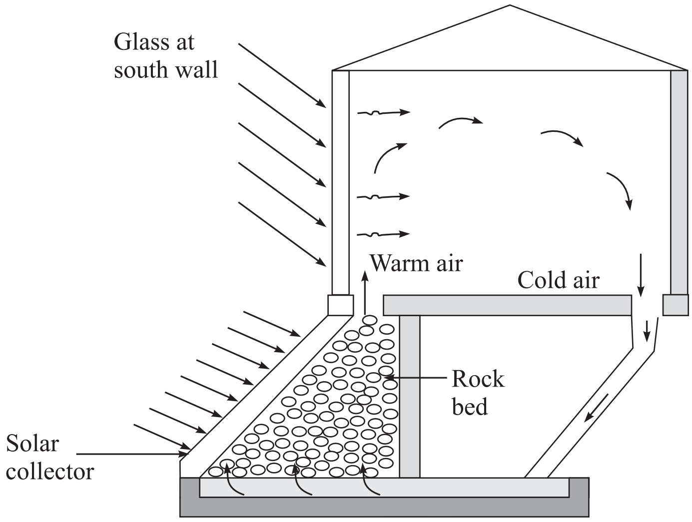


Figure 3.23 Passive solar heating using solar collector.

3.10 SOLAR REFRIGERATION AND COOLING SYSTEM

- **Explain a method of active cooling of a space by solar radiation.**

or

- **Explain solar vapour absorption system for cooling.**

A simple solar operated absorption refrigeration system to cool a space is as shown in Figure 3.25. The hot water transported from a flat plate collector is passed through a generator

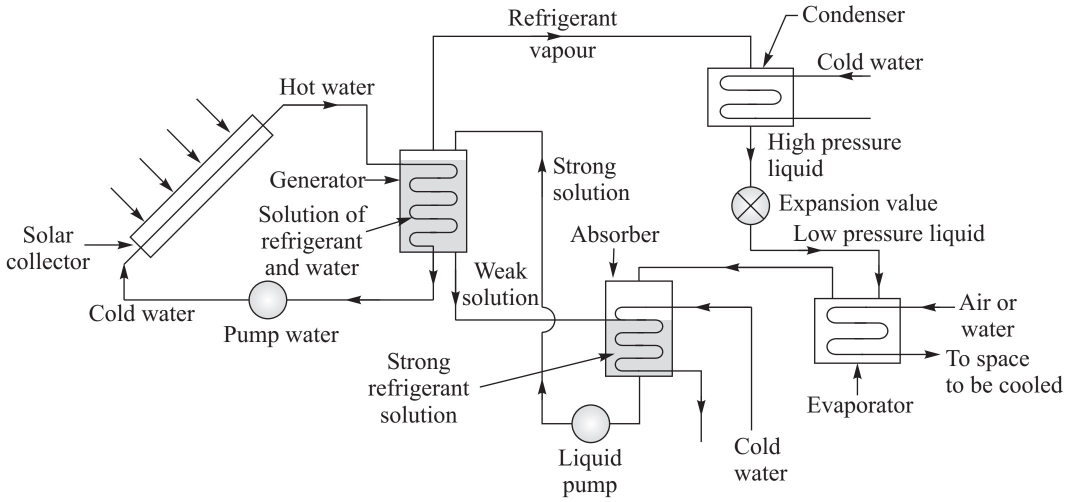


Figure 3.25 Solar absorption refrigeration system.

which is a heat exchanger. The heat is transferred to a refrigerant and absorber solution. The refrigerant can be ammonia or water while absorber is water or lithium bromide which generates refrigerant vapours at high pressure. The high-pressure vapours are condensed into high-pressure liquid in the condenser. The high-pressure refrigerant liquid is throttled to low pressure and temperature by an expansion valve. The low pressure refrigerant takes heat from the evaporator and vapouries, thereby cooling air or water which can be used for cooling the space inside the building. The refrigerant vapour is ultimately absorbed into the weak solution taken from generator to the absorber, thereby converting it into strong solution of the refrigerant. The strong solution is pumped from the absorber to the generator for the repeat of the refrigeration cycle.

3.12 SOLAR COOKERS

- **Describe solar cooker.**

or

- **What is the main advantage of using a glass cover in a box-type cooker?**

A solar cooker consists of (i) an insulated box of blackened aluminium in which utensils with food materials can be kept, (ii) reflector mirror hinged to one side of the box so that the angle of reflector can be adjusted and (iii) a glass cover consisting of two layers of clear window glass sheets which also serves as the box door as shown in Figure 3.27.

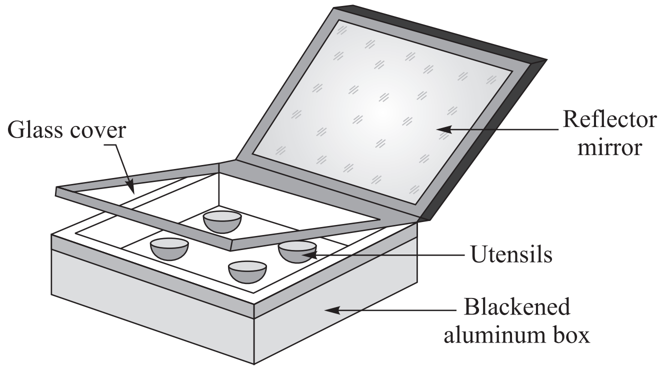


Figure 3.27 Solar cooker.

The box is kept in such a way that solar radiation falls directly on the glass cover and reflector mirror is also adjusted in such a way that additional solar radiation after mirror reflection is also incident on glass cover. The glass cover traps heat owing to the greenhouse effect, that is, short-wavelengths radiation can pass inside the box but long-wavelengths radiation coming out from the box is entrapped in the box, thereby providing more heating effect. The air temperature obtained inside the box ranges from 140 to 160°C. This provides sufficient heat for boiling and cooking purposes.

3.13 SOLAR DISTILLATION

- **What do you understand by solar distillation?**

The process to convert saline water into pure water using solar radiation is called solar distillation. A solar device used for this purpose is called solar still. A solar still consists of a shallow blackened basin filled with saline or brackish water to be distilled. It is covered with sloping transparent roof as shown in Figure 3.28. The sun rays can pass through transparent roof and these rays are absorbed by the blackened surface of the basin, thereby increasing

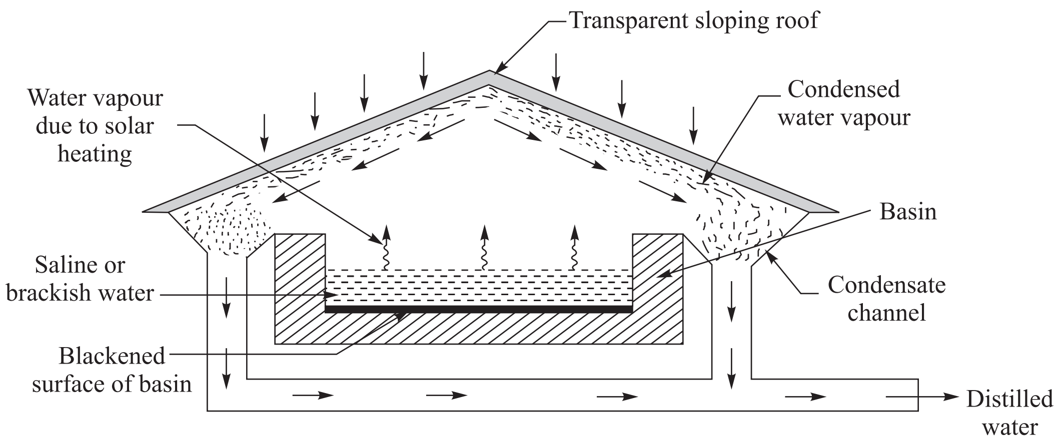


Figure 3.28 Working of a solar still.

the temperature of water. The water in basin evaporates due to solar heat and rises to the roof. The water vapour cools down and condenses at the undersurface of the roof. The water drops or condensed water slip down along the sloping roof. The condensed water is collected by the condensate channel and drained out from the solar still.

3.14 SOLAR THERMAL POWER PLANTS

- **Describe the working of a solar power plant.**

The solar thermal power plants can use different systems, such as

(i) Low temperature solar power plant using flat plate collectors
(ii) Low temperature solar power plant using solar pond
(iii) Medium temperature solar power plant using focussing collectors
(iv) High temperature solar power plant which can be

- Distributed collector system called solar farms
- Central receiver system or tower power plant

The principle of these plants is the same, which involves transportation of heat generated by the absorption of solar radiation. In medium and high temperature solar plants, steam is generated which is made to run a turbine with a generator coupled to it. In a low temperature solar system, transported heat is used to (i) generate vapour of low boiling point refrigerant using a heat exchanger and (ii) to run a turbine coupled with generator using refrigerant vapour. A central tower receiver solar power plant is shown in Figure 3.29.

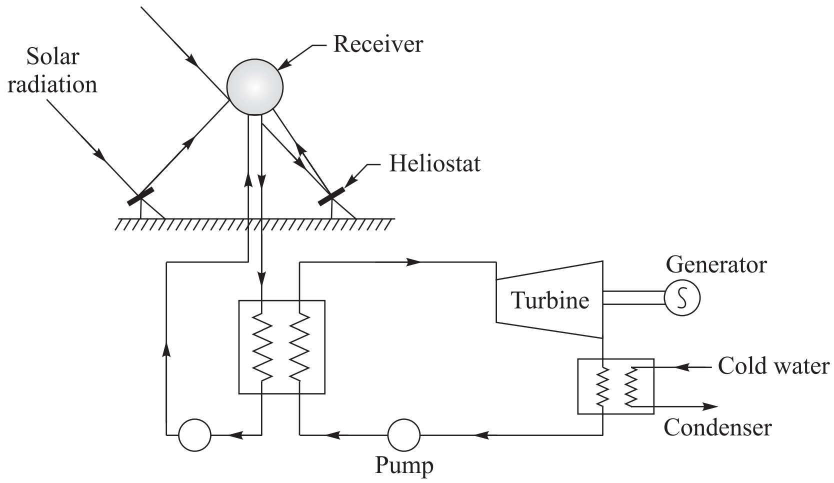


Figure 3.29 The working of a central tower receiver power plant.

3.15 SOLAR GREENHOUSE

- **What is a greenhouse?**

or

- **How is adequate supply of carbon dioxide maintained in a greenhouse?**

or

- **What is the purpose of using double layers of transparent glass sheet in a greenhouse?**

A greenhouse is a shed or enclosure in which a proper environment is provided to enable the growth and production of vegetables and flowering plants even during adverse and severe climatic conditions prevailing outside. Any vegetable or flowering plants can be grown throughout the year if suitable environmental conditions are provided.

In a greenhouse, visible light, carbon dioxide and water are provided as required for photosynthesis process. The photosynthesis process can be given as

$$\text{Light energy} + CO_2 + \text{water} = \text{Carbohydrate} + O_2$$

The carbohydrate produced in photosynthesis is used by plants during resporation process for growth. The respiration process can be given as

$$\text{Carbohydrate} + O_2 = CO_2 + \text{energy} + \text{water}$$

A typical greenhouse is shown in Figure 3.30. To ensure enough sunlight inside the greenhouse, sufficient glass or transparent plastic sheet is provided in roof and walls in the greenhouse facing the sun. For roof, two layers of glass or plastic sheets are provided with small air gap in between to obtain proper thermal insulation. The air gap helps in entrapping the solar radiation inside the greenhouse as it prevents the passing out of long-wavelength radiation from inside of the greenhouse to the atmosphere. Adequate presence of carbon dioxide is ensured by (i) supplying outside air (ii) using organic manure (iii) combustion of sulphur-free fossil fuels and (iv) carbon dioxide gas.

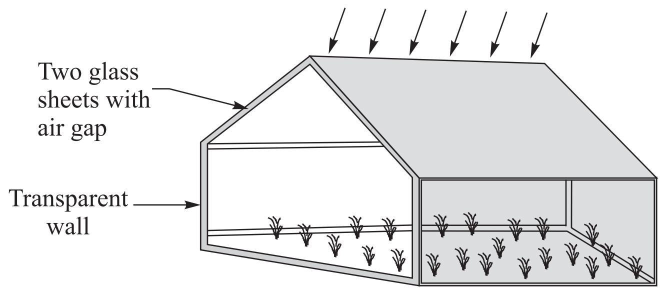


Figure 3.30 Greenhouse for cold climate.

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