KAMARAJ
COLLEGE OF ENGINEERING & TECHNOLOGY
(An Autonomous Institution - AFFILIATED TO ANNA UNIVERSITY, CHENNAI)
S.P.G.Chidambara Nadar - C.Nagammal Campus
S.P.G.C.Nagar, K.Vellakulam - 625 701, (Near Virudhunagar), Madurai District.

PH1171 - ENGINEERING PHYSICS

UNIT – III

Thermal Physics

S.No.	Contents	Page No.
1	Introduction	2
2	Thermal conductivity	3
3	Forbe's method	4
4	Lee's method	8
5	Conduction through compound media	11
6	Thermal expansion of Solid and Liquid	14
7	Thermal insulation	21
8	Applications:heatexchangers	24
9	Refrigerators	26
10	Oven	29
11	Solar water heater	32

UNIT - 3

Thermal Physics

Thermal conductivity – Forbe's and Lee's disc method - conduction through compound media (series andparallel) - thermal expansion of solids and liquids – thermalinsulation- Applications:heatexchangers,refrigerators, ovens and solar water heater

3.1 Introduction:

Thermal Physics is a field of science that deals with heat and temperature. The study of thermal physics is important because of its applications in various fields of engineering. In designs of internal and external combustion engines, refrigeration and air-conditioning plants, heat-exchangers, coolers, condensers, furnaces, preheaters, cooling system for motors, transformers and generators, Control of heat transfer in dams, structures, building and tunnels, in the application of heat transfer is in freezing, boiling, evaporation and condensation processes, etc.

Transfer of heat energy

(i) CONDUCTION: In this process heat is transmitted from one point to the other through the substance **without the actual motion of the particles**.

When one end of a brass rod is heated in flame the other end gets heated in course of time. In this case the molecules at the hot end vibrate with higher amplitude (K.E) and transmit the heat energy from one particle to the next and so on. Heat is said to be conducted through the rod. However, particles in the body remain in their position and so not move. Thus conduction is the transference of heat from the hotter part of a body to the colder part without the motion of the particles in thebody. Metals are good conductors of heat.

(ii) CONVECTION: It is the process in which heat is transmitted from one place to another bythe **actual movement of the heated particles**. It is prominent in the case of liquids and gases.

(iii) RADIATION: It is the process in which heat in transmitted from one place to theother directly **without anymedium**.

Example: We get heat radiations directly from the sun without affecting the intervening medium. Heat radiation can pass through vacuum.

Applications of heat radiations:

(1) White cloths are preferred in summer and dark colored clothes inwinter.

Reason: When heat radiations fall on white clothes, they are reflected back. No heat is absorbed by the clothes and a person does not get heat from outside in summer. Dark clothes in winter will absorb the heat radiations falling on them and keep the body warm.

(2) Polished reflectors are used in electric heaters to reflect maximum heat inthe room.

Co-efficient of thermal conductivity:

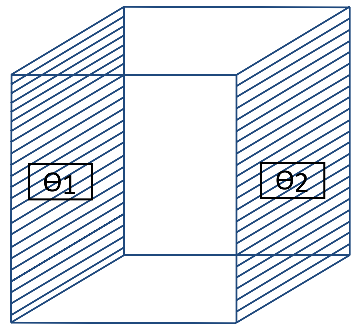


Fig. 3.1

Suppose there is a slab of material of area of cross-section A. Let the opposite faces be maintained at temperatures θ_1 and θ_2 C $\theta_1>\theta_2$)$_2$ Let 'x ' be the distance between the faces. It is found that the quantity of Q of heat conducted in a time t is directly proportional, to A to (θ_1-θ_2) to t (time) and inversely proportional tox.

Therefore,

$$Q \ \alpha \frac{A(\theta 1-\theta 2)t}{x}$$

$$Q = \frac{KA(\theta 1-\theta 2)t}{x}$$

Where, K is called the co- efficient of thermal conductivity of the material of the slab.

Definition: (Thermal Conductivity)

It is defined as the quantity of heat conducted in one second normally across unit area of cross-section, of the material per unit temperature difference per unit length.

Temperature gradient:

The quantity (θ_1-θ_2)/x represents the rate of fall of temperature with respect to distance. The quantity (dθ/dx) represents the rate of change of temperature with respect to the distance. As temperature decreases with increase in distance from the hot end, the quantity (dθ/dx) is negative and is called the temperaturegradient.

Newton's Law of Cooling statement:

It states that the rate at which a body loses heat is directly proportional to the temperature difference between the body and that of the surrounding.

The amount of heat radiated depends upon the area and nature of the radiating surface.

If'θ'isthetemperatureofthebodyatanyinstantand'θ_o'thetemperatureofthesurroundings, then according to Newton's law of cooling, heat lost is proportional to the difference of temperature between the body and surroundings i.e.(θ_1-θ_o)

If dQ is the quantity of heat lost in a small time dt, then

$$-\frac{dQ}{dt} \propto (\theta_1 - \theta_0)$$

$$-\frac{dQ}{dt} = k(\theta_1 - \theta_0)$$

Where k is the constant depending upon the area and the nature of the radiating surface. The negative sign indicates that there is decrease of heat with time.

3.2 Methods to determine thermal conductivity

The thermal conductivity of a material is determined by various methods.

1. Searle’s method – for good conductors like metallicrods.
2. Forbe’s method – for determining the absolute conductivity ofmetals.
3. Lee’s disc method – for badconductors.
4. Radial flow method – for bad conductors.

3.2.1 FORBE’S METHOD – THEORY AND EXPERIMENT

This is one of the earliest method to find the absolute thermal conductivity of metals.

Theory of the experiment

Consider a long rod. This rod is heated at one end and a steady state is reached after some time.

Amount of heat flowing per second across the cross-section A at the point B

$$= KA\left[\frac{d\theta}{dx}\right]_B \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where

K - thermalconductivity

A - cross sectionalarea

$\left[\frac{d\theta}{dx}\right]_B$ - temperature gradient at B.

This amount of heat flowing across the section B is equal to the heat lost by radiation by the rod beyond the section B.

Consider an element of thickness dx of the rod.

Mass of the element = (A dx)ρ

Where ρ is density of the rod

Heat lost by the element per second = Mass x specific heat capacity x rate of fall of temp.

$$= (Adx)\rho \times S \times \frac{d\theta}{dt} \text{--------}(2)$$

Where $\frac{d\theta}{dt}$ - rate of fall of temperature of the element

S – specific heat capacity of the rod

Total heat lost by the portion of the rod between section B and the end C

$$= \int_B^c (Adx)\rho \times S \times \frac{d\theta}{dt} \text{ -------------------------}(3)$$

Amount of heat flowing per second across the cross section at the point B = Heat lost by radiation by radiation by the rod beyond the section B.

$$KA \left(\frac{d\theta}{dx}\right)_B = \int_B^C (Adx)\rho \times S \times \frac{d\theta}{dt} \quad (3)$$

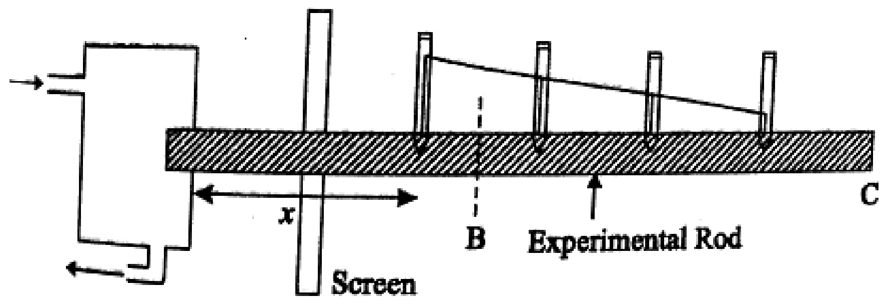
$$K = \frac{\rho\, S \int_B^C \frac{d\theta}{dt}\, dx}{\left(\frac{d\theta}{dx}\right)_B}$$

Experiment consists of two parts:

1. Static experiment tofind $\left(\frac{d\theta}{dx}\right)_B$
2. Dynamic experimentto find $\left(\frac{d\theta}{dx}\right)_B$ and $\int_B^C \frac{d\theta}{dt}\, dx$

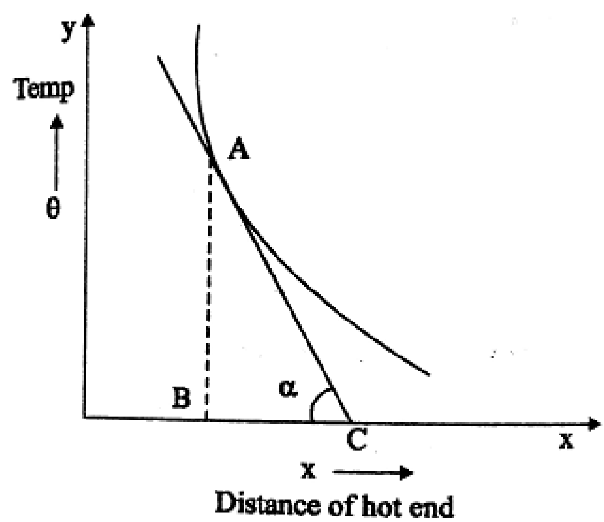
Static experiment

The specimen metal is taken in the form of a long rod. One end of this rod is heated by a steam chamber. The rod has a series of holes into which thermometers are fitted. These thermometers record temperatures at different points along the rod.



When the steady state is reached, the temperature shown by the thermometers of the rod and their respective distances from the hot end are noted.

A graph is drawn between the temperature and distance from the hot end.



The value of $\left(\frac{d\theta}{dx}\right)_B$ is obtained by drawing a tangent to the curve at a point B.

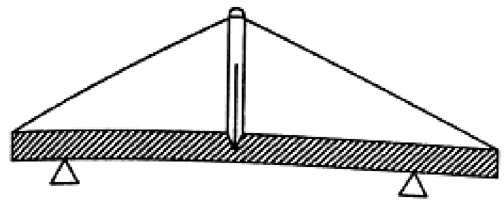
If this tangent makes an angle α with the x axis, then from the graph

$$\left(\frac{d\theta}{dx}\right)_B = \frac{AB}{BC} = \tan\alpha$$

1. **Dynamicexperiment**

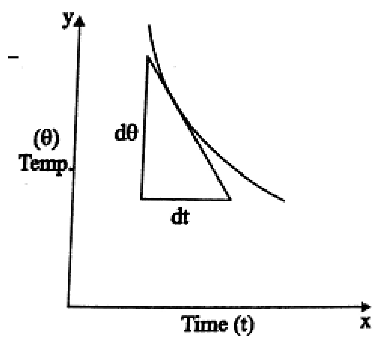
A piece of the original rod is heated to the same temperature as that of the hot end in the static experiment. The heated piece of the rod is suspended in air.

Now, it is allowed to cool. Its temperature is noted at regular intervals of time by a thermometer placed in a hole at the center.



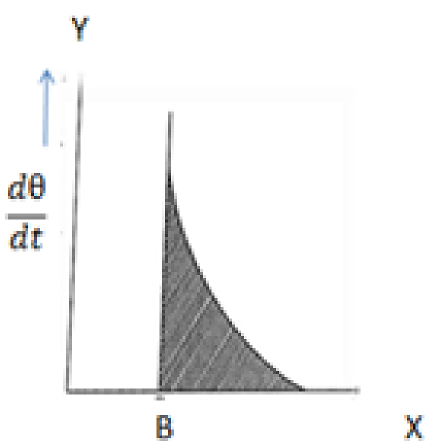
Forbe's method – Dynamic experiment

A graph is drawn between temperature and time.



From this graph, the value of $\frac{d\theta}{dt}$ for various values of θ are determined by drawing tangents at various points of the cooling curve.

From the graph between temperature θ and the distances of hot end x for various values of temperature θ are obtained. Now, third graph is drawn between $\frac{d\theta}{dt}$ and the corresponding valuesof x.



The area of the shaded portion is determined.

$$K = \frac{\rho S \int_B^C \frac{d\theta}{dt}}{(\frac{d\theta}{dx})_B}$$

Substituting the values in the above equating, we have

$$K = \frac{\rho S \times (Area\ of\ the\ shaded\ portion)}{\tan \alpha}$$

Hence, K is determined.

Merits

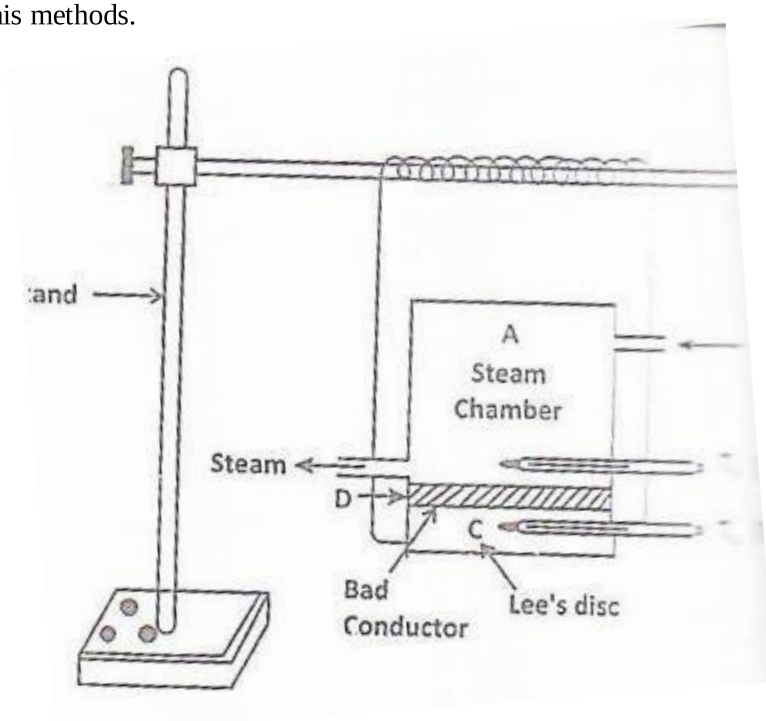
1. It is one of the earliest methodto determine theabsolute thermal conductivity of the material.
2. This method is based on the fundamental relation which defines thermalconductivity.

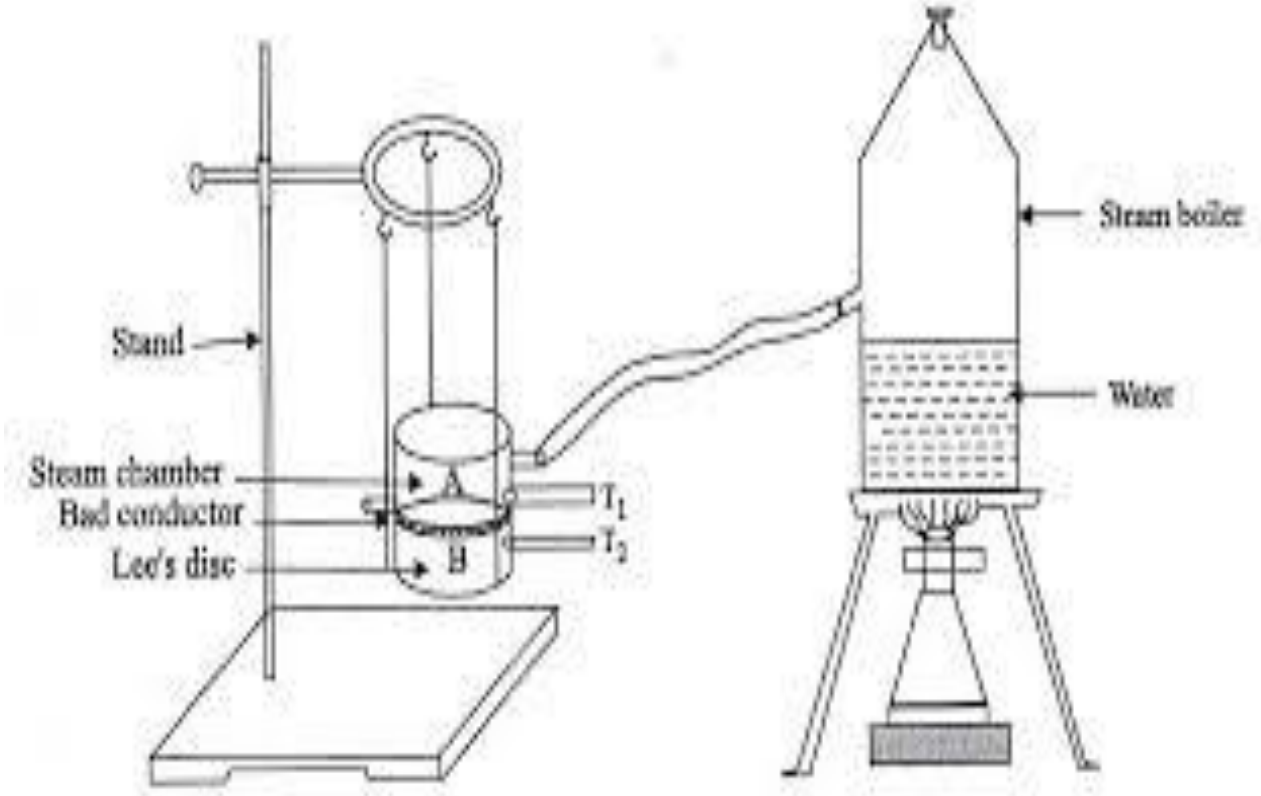
Demerits

1. It is tedious method and requires a lot of time for the completion of the experiment and drawing the threegraphs.
2. The specific heat capacity of the material of the rod does not remain constant at different temperatures asassumed.
3. The distribution of heat is not uniform along the bar in the two experiments. Therefore,this experiment is notaccurate.

3.2.2LEE'S DISC METHOD FOR BAD CONDUCTORS

The thermal conductivity o bad conductors like ebonite or card board is determined by this methods.





Description:

The apparatus consists of circular metal disc or slab C(Lee's Disc) by strings rom as stand. The given bad conductor (such as glass, ebonite) is taken in the form of the disc(D). This disc has the same diameter as that of the slab and is placed over it.

A cylindrical hollow steam chamber A having the same diameter as that of the slab is placed over the bad conductor. There are holes in the steam chamber and the slab through which thermometers T_1 and $T_2$are inserted to record the respective temperatures.

Working :

Steam is passed through the steam chamber until the temperatures in the chamber and the slab are steady. When the thermometer show steady temperatures, there reading $\theta_1$and $\theta_2$are noted. The radius(r) of the disc D and its thickness (d) are also noted.

Observation and Calculation

Thickness of the bad conductor = d meter

Radius of the bad conductor = r meter

Mass of the Slab (c) = M kg

Steady temperature in the steam chamber = θ_1

Steady temperature in the bad conductor = θ_2

Thermal conductivity o the bad conductor = K

Rate of cooling at θ_1= R

Specific heat capacity of the slab = S

Area of cross section A = πr^2

Amount of heat conducted through the specimen per second

$$Q = \frac{KA(\theta_1 - \theta_2)}{d} = \frac{K(\pi r^2)(\theta_1 - \theta_2)}{d} \longrightarrow \quad 1$$

At this stage, all the heat conducted through the bad conductor is completely radiated by the bottom flat surface and the curved surface of the Slab C.
Amount of heat lost per second by the Slab C
Q= Mass x Specific Heat Capacity x Rate of cooling

$$Q = MSR \longrightarrow \quad 2$$

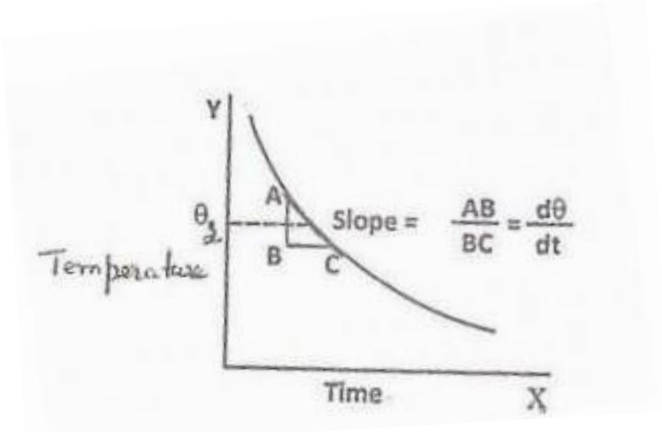
At steady state,
Heat conducted through bad conductor per second = heat lost [per second by the slab]
Hence the equation (1) and (2) are equal

$$\frac{K(\pi r^2)(\theta_1 - \theta_2)}{d} = MSR$$

$$\therefore K = \frac{MSRd}{\pi r^2(\theta_1 - \theta_2)} Wm^{-1}K^{-1} \longrightarrow \quad 3$$

Determination of Rate of Cooling R

The bad conductor is removed and the steam chamber is placed directly on the slab. The slab is heated to a temperature of about 5°C higher than θ_2.
The steam chamber is removed and the slab alone is allowed to cool.



As the slab cools, the temperatures of the slab are noted at regular intervals of half a minute until the temperature of the slab falls to about 5°C below θ_2. The time temperature graph is drawn as shown in the figure and the rate of cooling $d\theta/dt$ at the steady temperature θ_2 is determined.

During the first part of the experiment, the top surface of the slab is covered by the bad conductor.Radiationistakingplaceonlyfromthebottomsurfaceareaandcurvedsurfacearea.

In the second part of the experiment, heat is radiated from the top surface area, bottom surface area and the curved sides i.e. over an area.

Total area of $= \pi r^2 + 2\pi rh = \pi r(r+2h)$ where h is the height of C

$$\frac{R}{\frac{d\theta}{dt}} = \frac{\pi r(r+2h)}{2\pi r(r+h)} = \frac{r+2h}{2(r+h)}$$

$$R = \frac{d\theta}{dt} \cdot \frac{(r+2h)}{2(r+h)} \longrightarrow \quad 4$$

Substituting this value in equation 3 , we have

$$K = \frac{MS\frac{d\theta}{dt}d}{\pi r^2(\theta_1 - \theta_2)} \times \frac{(r+2h)}{(r+h)} \longrightarrow \quad 5$$

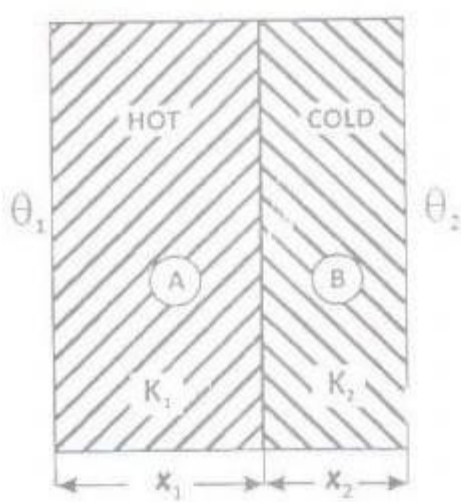
From which K is determined.

3.3 HEAT CONDUCTION THROUGH A COMPOUND MEDIA

3.3.1Bodies in Series

Let us consider a composite slab (or compound wall) of two different materials A and B with thermal conductivities K_1 and $K_2$and of thickness $x_1$andx_2.

The temperature of the outer faces of A and B are θ_1 andθ_2.



The temperature of the surface in contact is θ.

When the steady state is reached, the amount of heat flowing per second(Q) through every is same

Amount of heat flowing through the material(A) per second

$$Q = \frac{K_1 A(\theta_1 - \theta\ )}{x_1} \longrightarrow \quad 1$$

Amount of heat flowing through the material (B) per second

$$Q = \frac{K_2 A(\theta\ - \theta_2)}{x_2} \quad 2$$

Here , the equations 1 and 2 are equal $\longrightarrow$

$$\frac{K_1 A(\theta_1 - \theta_2)}{x_1} = \frac{K_2 A(\theta_1 - \theta_2)}{x_2} \longrightarrow \quad 3$$

$$K_1 A(\theta_1 - \theta)x_2 = K_2 A(\theta\ - \theta_2)x_1$$

$$K_1\theta_1 x_2 - K_1\theta x_2 = K_2\theta x_1 - K_2\theta_2 x_1$$

$$K_1\theta_1 x_2 + K_2\theta_2 x_1 = K_2\theta x_1 - K_1\theta x_2$$

$$K_1\theta_1 x_2 + K_2\theta_2 x_1 = \theta(K_2 x_1 + K_1 x_2)$$

$$\theta = \frac{K_1\theta_1 x_2 + K_2\theta_2 x_1}{K_2 x_1 + K_1 x_2} \longrightarrow \quad 4$$

This is the expression for interface temperature of two composite slabs

Substituting the value of θ inn equation 1 we have,

$$Q = \frac{K_1 A}{x_1}\left[\theta_1 - \left(\frac{K_1\theta_1 x_2 + K_2\theta_2 x_1}{K_2 x_1 + K_1 x_2}\right)\right]$$

$$Q = \frac{K_1 A}{x_1}\left[\left(\frac{K_2\theta_1 x_1 + K_1\theta_1 x_2 - K_1\theta_1 x_2 - K_2\theta_2 x_1}{K_2 x_1 + K_1 x_2}\right)\right]$$

$$Q = \frac{K_1 A}{x_1}\left[\left(\frac{K_2\theta_1 x_1 - K_2\theta_2 x_1}{K_2 x_1 + K_1 x_2}\right)\right]$$

$$Q = \frac{K_1 K_2 A}{x_1}\left[\left(\frac{\theta_1 x_1 - \theta_2 x_1}{K_2 x_1 + K_1 x_2}\right)\right]$$

$$Q = \frac{K_1 K_2 A}{x_1}\left[\left(\frac{x_1(\theta_1 - \theta_2)}{K_2 x_1 + K_1 x_2}\right)\right]$$

$$Q = K_1 K_2 A\left[\left(\frac{(\theta_1 - \theta_2)}{K_2 x_1 + K_1 x_2}\right)\right]$$

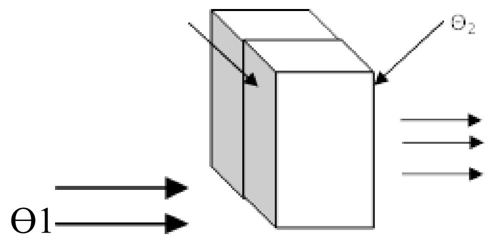
$$\frac{A(\theta_1 - \theta_2)}{\frac{K_2 x_1}{K_1 K_2} + \frac{K_1 x_2}{K_1 K_2}}$$

$$\frac{A(\theta_1 - \theta_2)}{\frac{x_1}{K_1} + \frac{x_2}{K_2}} \longrightarrow \quad 5$$

$$Q=\frac{A(\theta 1-\theta 2)}{\sum (x/K)}$$

3.3.2 Bodies in Parallel

Let us consider a composite slab (or Compound wall) of two different materials A and B with thermal conductivities K_1 and $K_2$and o thickness $x_1$and x_2. They are arranged in parallel as shown in the figure.



Let the faces of the material be at temperature $\theta_1$and the respective other end faces be at $\theta_2$temperature.

A_1 and A_2 be the areas of cross section of the materials

Amount of heat flowing through the first material (A) in one second

$$Q_1 = \frac{K_1 A_1(\theta_1 - \theta_2)}{x_1} \longrightarrow$$

1

Similarly the amount of heat flowing through the second material (B) in one second

$$Q_1 = \frac{K_2 A_2(\theta_1 - \theta_2)}{x_2}$$

The total heat flowing through these materials per second is the sum of these two heats Q_1 and Q_2

$$Q = Q_1 + Q_2$$

$$Q = \frac{K_1 A_1(\theta_1 - \theta_2)}{x_1} + \frac{K_2 A_2(\theta_1 - \theta_2)}{x_2}$$

$\therefore$ The amount of heat flowing per second

$$Q = (\theta_1 - \theta_2)\left(\frac{K_1 A_1}{x_1} + \frac{K_2 A_2}{x_2}\right)$$

In general

$$Q = (\theta_1 - \theta_2)\sum \frac{KA}{x}$$

3.4 Thermal expansion of solids

It is a common observation that nearly all substances expand on heating and contract on cooling. Types of expansion

A solid substance can undergo three types of expansion:

(i) Expansion in length is known as linearexpansion
(ii) Expansion in area is known as superficialexpansion
(iii) Expansion in volume is known as cubicalexpansion.

Coefficients of linear, superficial and cubical expansion of a solid:

(a) The coefficient of linear expansion of a solid is the increase in length of unit length of the solid when its temperature is raised by 1K. it is denoted by the letterα.
Thus if a rod having a length L_1 at T_1 K is heated to a temperature T_2 K its length increases to L_2.

$$\alpha = \frac{L_2 — L_1}{L_1(T_2 — T_1)} = \frac{\text{Increase in length}}{\text{Original length x Rise in temperature}}$$

(b) The coefficient of superficial expansion of a solid is the increase in area produced per unit area of the solid when the temperature is raised by 1 K. It is denoted by the letter β. Thus if a solid having area A_1 at T_1 K is heated to T_2K, its area increases toA_2.

$$\beta = \frac{A2 — A1}{A_1(T_2 — T_1)} = \frac{\text{Increase in area}}{\text{Original area x Rise in temperature}}$$

(c) Coefficient of cubical expansion of a solid is the increase in volume per unit volume of a solid for 1 K rise of temperature. It is denoted by the letter γ.
Thus if a solid having a volume V_1 at T_1 K is heated to a temperature T_2 K, let V_2 be its volume at T_2 K. Then,

$$\gamma = \frac{V_2 - V_1}{V_1(T_2 - T_1)} = \frac{\text{Increase in volume}}{\text{Original volume x Rise in temperature}}$$

Thermal Expansion of Liquids

Absolute and apparent expansion of a liquid:

A liquid has always been taken in a container and so when heat is given to the vessel, both the liquid and the container expand in volume.

The observed expansion of the liquid is only relative to the container. If we ignore the expansion of the container what we obtain is only apparent expansion.

To find the absolute expansion of the liquid we should take into account the expansion of the container.

(a) Coefficient of apparent expansion of aliquid:
It is the observed increase in volume of unit volume of the liquid per degree Kelvin rise of temperature. It is denoted by γ_a. Thus if $V_1$and V_2 be the observed volumes of a liquid at temperature T_1 K and T_2 K respectively then

$$y_a = \frac{V_2 - V_1}{V_1(T_2 - T_1)} = \frac{\text{Increase in volume ofliquid}}{\text{Original volume x Rise in temperature}}$$

(b) Coefficient of real or absolute expansion of aliquid:
It is the real increase in volume of unit volume of a liquid per degree Kelvin rise of temperature. It is denoted by γ_r.

If V_1 and V_2be the real volumes of a liquid at T_1K and T_2 K,then

$$y_r = \frac{V_2 - V_1}{V_2 (T_2 - T_1)} \quad \frac{\text{Real increase in volume ofliquid}}{\text{Original volume x Rise in temperature}}$$

Applications of expansion of solids

Expansion of solids plays an important role in numerous engineering applications.

1. Thermal expansion joints with gaps are provided in building concrete highways and bridges to compensate for change in dimension with temperaturevariations.
2. The length of the electric wire between two electric poles is kept slightly larger to compensate for its contraction during winterdays.
3. A gap is left at the joint of tworails.
4. One of the most important applications is expansion joints and bimetallic strip.

3.6 Thermal insulation

Thermal insulation is to resist the flow of heat to and from a body. It is a material that reduces the rate of heat flow.

General principles of thermal insulation

1. The thermal resistance of an insulating material is directly proportional to its thickness.
2. The provision of an air gap is a very important insulatingagent.
3. The thermal resistance of a building depends on its orientationalso.
4. Heat is energy that flows from one region to another because of a difference in temperature between the two regions. The heat is transferred by conduction, convection, radiation or any combination ofthem.

(i) Reducing heat transfer byconduction

- In a flat wall made of any solid material, if one face is at a higher temperature than the other, heat will flow through the wall byconduction.
- The rate at which heat will flow through the wall depends on thethermal conductivity of the wallmaterial.
- The higher the thermal conductivity of a material, the poorer its se asthermal insulation.

(ii)Reducing heat by convection

The mode of carrying heat from the warm to the cold side of the air space is called convection, and the air flows are called convection currents.

If the air space within the walls of a house is filled with a porous material, the air circulation will be impeded, and the rate of heat transfer due to convection will be greatly reduced.

(iii) Reducing heat transfer byradiation

- The transfer of heat by radiation does not requirethe presence of any matter.
- The rate at which heat is transmitted by radiation depends on various factors, includingthetemperaturesofthesurfacesandthekindsofsurfacesinvolved.

Thermal insulating materials

The materials which are used to insulate thermally are known as thermal insulating materials.

Thermal insulating materials are classified as

(a)Organicmaterials (b) Inorganicmaterials

(a) Organicmaterials

Cattle hair, Silk, Wool, Wood-pulp, Corkboard, Saw dust, Sugar-cane fiber, Cardboard, Paper, Leather.

(b) Inorganic insulatingmaterials

Still air, Mineral wool, Slag-wool, Glass wool, Charcoal, Gypsum powder, Slag, Coke powder, Asbestos.

Types of Thermal insulation

There are three types of thermal insulation. They are

1. House thermalinsulation
2. Industrial thermalinsulation
3. Building thermalinsulation

1. House thermalinsulation

- In a warm house during the winter, insulation in the walls, ceilings, and floors reduces the loss of heat from the warm interior to the colder outdoorair.
- In a cool house during the summer, the insulation reduces the entry of heat from the warmer out-doorair.
- Thermal insulation of house hold items are veryessential.

2. Industrial thermalinsulation

- In industry, thermal insulation is used for enclosing heating equipment, pipes thatcarry steam, and cold storagespaces.
- The insulation helps to conserve fuel or power or to maintain a uniform temperature in anenclosure.

3. Building thermalinsulation

Thermal insulation of exposed doors and windows

The doors and windows which are exposed to outside world transmit heat to a considerable extent.

Following methods are used to ensure thermal insulation of the exposed doors and windows.

- The insulating glass or double glass with air space may be provided for glassed doors and windows. This will reduce heat transmission through doors andwindows.
- In order to reduce incidence of solar heat, the protection in the form of

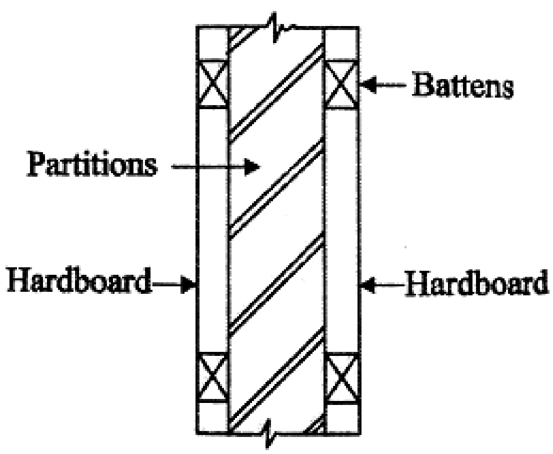
sunbreakers, weather sheds, projections curtains, may be provided on the exposed doors and windows.

- The flat roofs may be kept cool by water which may either be stored or sprayed at regular intervals. The surface temperature of the roof is reduced substantially by this method.
- The thermal insulation of flat roof may be provided by putting a layer of about 25 mm thickness of coconut pith or cementconcrete.

Thermal insulation of exposed walls

The following methods are adopted for the thermal insulation of exposed wall.

- The suitable thickness of wall may beprovided.
- The hollow wall or cavity wall construction may beadopted.
- For partitions, an air space may be created by fixing hardboards on battens, weather sheds, projections, curtains etc may be provided on the exposed doors and windows.



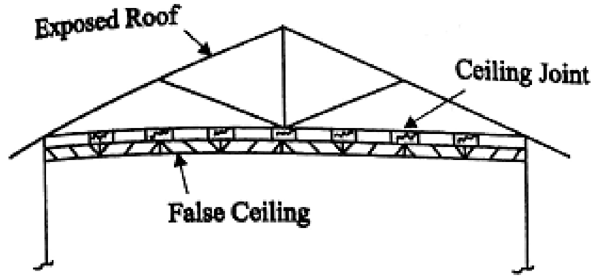
Thermal insulation of partition

Thermal insulation of exposed roofs

The thermal insulation of exposed roofs is achieved either by treating inside surface or outside surface.

Internal treatment:

- The false ceiling with an air gap may be provided. The ceiling is made of thermal insulating materials.
- The light insulating materials may be pasted by suitable adhesives to the insidesurfaces of the exposedroof.



Internal Treatment for pitched roof

Applications:

Heat Exchangers

Heat exchangers are devices used to transfer heat between two or more fluid steams at different temperatures.

Heat exchangers find widespread use in power generation, chemical processing, electronics, cooling, air-conditioning, refrigeration and automotive applications.

Examples for heat exchangers

(i) Intercoolers and preheaters
(ii) Condensers and boilers in steam plat
(iii)Condensers and evaporators in refrigerationunits
(iv) Regenerators
(v) Automobileradiators
(vi) Oil coolers of heat engine
(vii)Milk chiller of a pasteurizingplant

Types of heat exchangers

In order to meet the widely varying applications, several types of heat exchangers are developed. They are classified on the basis of nature of heat exchange process, relative direction of fluid motion, design and constructional features, and physical state of fluids.

1. Nature of heat exchangeprocess

Heat exchangers, on the basis of nature of heat exchange process, are classified as follows:

(i) Direct contact heatexchangers.
(ii) Indirect contact heatexchangers
 (a) Regenerator
 (b) Recuperators

2. Relative direction of fluidmotion

According to the relative directions of fluid motions the heat exchangers are classified into the following there categories:

(i) Parallel flow or unidirectionflow
(ii) Counter-
flow (iii)Cross-
flow

3. Design and constructionalfeatures

Based on design and constructional features, heat exchangers are classified as

(i) Concentrictubes
(ii) Shell andtube
(iii) Multiple shell and tubepasses
(iv) Compact heaterexchanger

4. Physical state offluids

Based on the physical state of fluids, heat exchangers are classified as

(i) Condensers
(ii) Evaporators

Direct contact heat exchanger

In a direct contact or open heat exchanger, the exchange of heat takes place by direct mixing of hot and cold fluids and transfer of heat and mass takes place simultaneously.

Indirect contact heat exchanger

In this type of heat exchanger, the heat transfer between two fluids could be carried out by transmission through wall which separates the two fluids.

This type includes the following:

(a) Regenerators

In a regenerator type of heat exchanger the hot and cold fluids pass alternately through a space containing solid particles, these particles providing alternately a sink and a source for heat flow.

Examples

(i) I.C. engines and gasturbines
(ii) Open hearth and glass
meltingfurnaces (iii)Air heaters or
blastfurnaces

(b) Recuperators

Recuperator is the most important type of heat exchanger in which the flowing fluids exchanging heat are on either side of dividing wall. These heat exchangers are used when two fluids cannot be allowed to mix.

Examples

(i) Automobile radiators
(ii) Oil coolers, inter coolers.
(iii) Milk chiller of pasteurizing plant
(iv) Evaporation of an ice plant.

3.7 Refrigeration

Definitions:

Refrigeration: It is the process of continuous cooling or extraction of heat to below that of the atmosphere from a substance with a help of the external work.

Principle of refrigeration: It is based on the second law of thermodynamics that the heat can made to flow from cold body to a hot body with the help of external source.

Refrigerant: It is the working fluid used in the refrigerator. Eg. Ammonia, Methyl chloride.

Ton of refrigeration:

It is the standard unit of the refrigerator. It is the freezing capacity of the one American short ton of water from 0ºC in 24 hrs.

One ton of the refrigeration = 3.5 kW = 3.5 kJ/s = 210 kJ/min.

Coefficient of performance: It is the measure of the performance of the refrigeration system. It is the ratio of the refrigerating effect to the input work required to produce the effect.

The value of the coefficient of performance may be less than the unity or greater than unity.

Relative Coefficient of performance: It is the ratio of the actual to the theoretical coefficient of performance.

Refrigerator

It is a machine which produces cold. It is used to remove heat from the refrigerated space and reject it to atmosphere. Hence, it maintains the temperature below the surrounding atmosphere.

Principle

A refrigerator works by passing a cool refrigerant gas around food items, which absorbs heat from them and then loses that heat to the relatively cooler surroundings on the outside.

Types of refrigeration systems

Mainly they are classified under two groups:

1. Based on the type of the externalwork Using mechanicalenergy:
   (a) Cold airrefrigeration
   (b) Vapors

   compressionrefrigeration Using

   heatenergy:

   (a) Simple vapour absorption refrigeration
   (b) Actual vapour absorption refrigeration
2. Based on theusage
   (a) Primaryrefrigeration
   (b) Secondaryrefrigeration

Parts and working of vapour compression refrigerator

A refrigerator consists of a few key components that play a vital role in the refrigeration process.

They are

1. Expansionvalve
2. Compressor
3. Evaporator
4. Condenser
5. Refrigerant

Expansionvalve

Also referred to as the flow control device, an expansion valve controls the flow of the liquid refrigerant into the evaporator. It is actually a very small device that is sensitive to temperature changes of the refrigerant.

Compressor

The compressor consists of a motor that sucks in the refrigerant from the evaporator and compresses it in a cylinder to make a hot, high-pressure gas.

Evaporator

This is the part that actually cools the stuff kept inside a refrigerator. It consists of finned tube that absorbs heat blown through a coil by a fan. The evaporator absorbs heat from the stuff kept inside, and a result of this heat, the liquid refrigerant turns into vapor.

Condenser

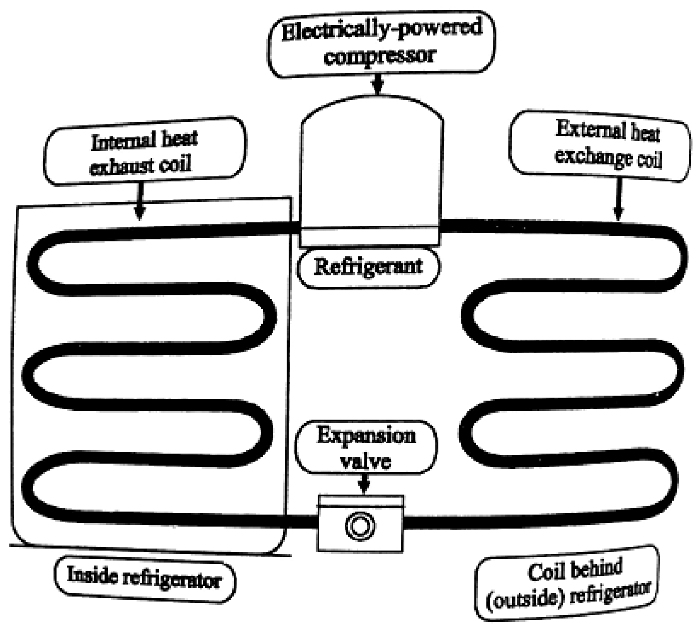
The condenser consists of a coiled set of tubes with external fins and is located at the rear of the refrigerator. It helps in the liquefaction of the gaseous refrigerant by absorbing its heat and subsequently expelling it to the surroundings.

As the heat of the refrigerant is removed, its temperature drops to condensation temperature, and it changes its state from vapor to liquid.

Refrigerant

Also commonly referred to as the coolant, it's the liquid that keeps the refrigeration cycle going.

It's actually a specially designed chemical that is capable of alternating between being a hot gas and a cool liquid.



Working

The refrigerant, which is now in a liquid state, passes though the expansion valve and turns into a cool gas due to the sudden drop in pressure.

As the cool refrigerant gas flows though the chiller cabinet, it absorbs the heat from the food items inside the fridge and vaporizes.

The refrigerant, which is now a gas, flows into the compressor, which sucks it inside and compresses the molecules together to make it into a hot, high-pressure gas.

Now, this gas transports to the condenser coils, where the coils help dissipate its heat so that it becomes cool enough to condense and convert back into its liquid phase.

After the condenser, the liquid refrigerant travels back to the expansion valve, where it experiences a pressure drop and once again becomes a cool gas. It then absorbs heat from the contents of the fridge and the whole cycle repeats.

3.8 Oven

An oven is a thermally insulated chamber used for heating, baking or drying of a substance and most commonly used for cooking

Kilns and furnaces are special purpose ovens, used in pottery and metalworking respectively.

Types of ovens

- Doubleoven
- Ceramicoven
- Gasoven
- Microwave oven
- Toasteroven
- Hot airoven

Hot Air Oven

The electrical device which is widely used in medical products industries, rubber industries, and for the process of sterilization using dry heat is known as hot air oven.

The instrument works on the basis of dry heat to sterilize the specimens and articles. The instrument can be operated at a temperature of 50ºC to 250ºC.

It is also known as the thermostat that controls the temperature. The device is provided with the digital panel to control the temperature digitally.

Operating Principle

It works on the principle of fine gravity air convection in a highly heated electrical chamber.

Description

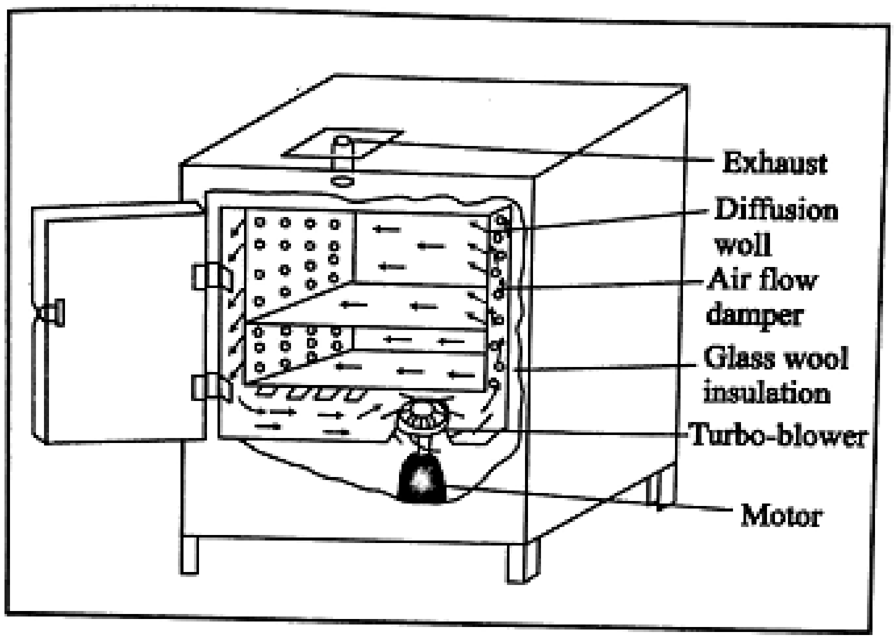
It consists of the following parts:

- An insulated chamber surrounded by an outer case containing electricheaters.
- A fan to circulate theair
- Shelves
- Thermocouples
- Temperaturesensor
- Door lockingcontrols

The apparatus consists of a large, rectangular, copper base and covered with asbestos sheets. It is also provided with a door and erected on a four-legged stand.

The roof is provided with a hole through which a thermometer is fitted inside for recording of temperature.

Dry of the instrument. There is a regulator of heater to control the inside temperature.



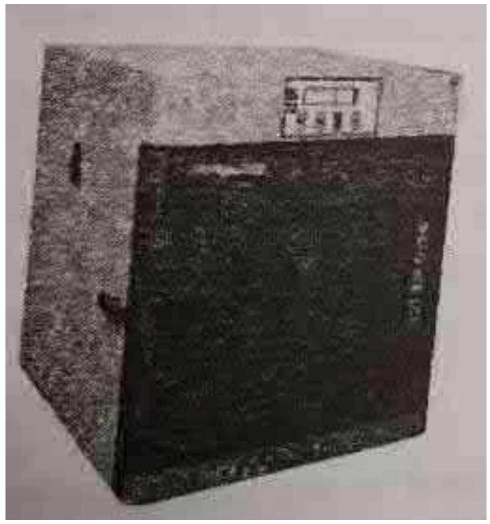
Hot air oven

Working

Before sterilization, the glassware are dried properly and wrapped ni brown paper and then exposed to hot air inside the oven.

After loading of glassware, the oven is switched on, the temperature will increase slowly up to the desired point (160ºC) where it will remain steady.

Then at 160ºC, the oven is kept for an hour. This is the appropriate temperature for sterilization of glassware. Then, gradually the temperature is brought down and there after sterilization is complete.



Hot air oven

Advantages

- This treatment kills the bacterial endotoxin, not all treatments can dothis.
- Dry heat sterilization by hot air oven does not leave any chemicalresidue.
- Eliminates „wet pack" problems in humidclimates.

Disadvantages

- Plastic and rubber items cannot be dry-heat sterilized because temperaturesused (160ºC - 170ºC) are too high for thesematerials.
- Dry heat penetrates materials slowly andunevenly.
- It requires a continuous source ofelectricity.

Safety Guidelines

- Before placing in Hot AirOven
  (i) Dry glasswares completely. (ii)Plug test tubes with cottonwools.
  (iii)Wrap glasswares in kraft papers. Do not overload the oven.Overloading alters heat convection and increases the time required tosterilize
- Allow free circulation of air between thematerials
- The material used for wrapping instruments and other items must be porous enough to let steam through but tightly woven enough to protect against dust particles and microorganisms.

Applications

- It is widely used to sterilize glassware in pharmaceutical industries such aspetri dishes, pipettes, bottles, test tubes, flasks, pestle,etc.

3.9 Solar Power

The energy obtained from the sun is called solar energy. Sun is the source of all energy. Sunlight containsinfraredradiationsinlargeproportion,andtheseinfraredraysheatsallobjects on which theyfall.

Every square meter of earth's upper atmosphere receives 1.36 kJ of energy per second. However, of this only 47%, i.e., 0.64 kJ of solar energy reaches every square metreof earth"s surface per second.

Harnessing solar energy

The solar energy falling on the earth is very much diffused, and scattered. In order touse solar energy for practical purposes, we have to collect and concentrateit.

The solar energy is harnessed by using the following two ways:

1. Directharnessing
2. Indirectharnessing

1. Directharnessing

The solar energy is either directly collected as heat or converted directly into electricity.

2. Indirectharnessing

Indirect harnessing is carried out by

- Converting solar energy into chemical energy inplants
- Harnessing the energy ofwind
- Utilizing the energy of sea wavesand
- Utilizingtheenergy duetothetemperaturedifferenceofthewateratdifferentlevels inoceans.

Conversation of Solar energy

Solar energy is converted into more useful forms of energies by two ways.

1. Thermalconversion
2. Photo-conversion

Thermal conversion

In thermal conversion, the heat from the direct rays of Sun is absorbed in the form of infrared radiation by surfaces, air or water and put to many uses.

Photo conversion

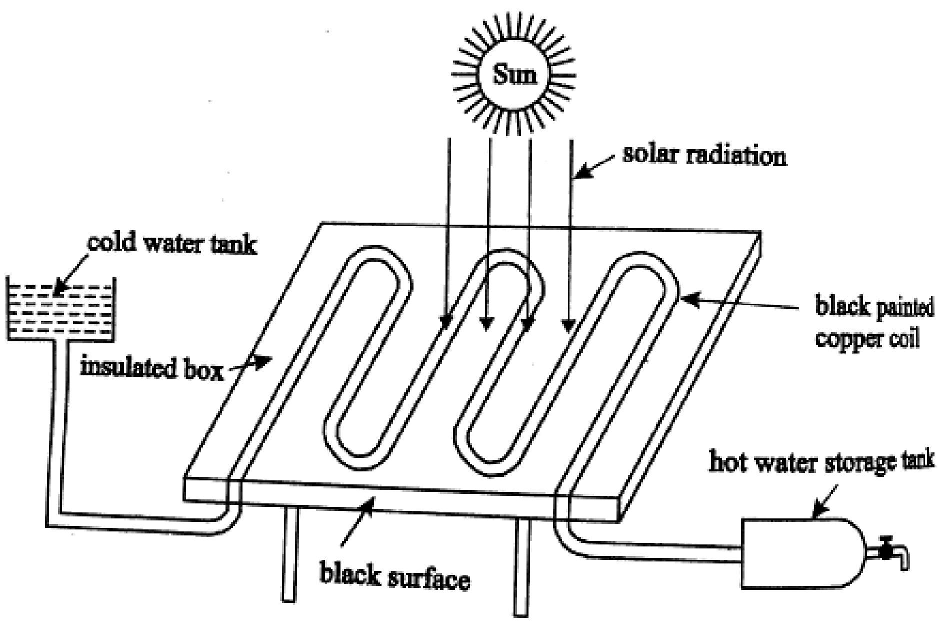
In photo conversion, when sunlight of short wavelength falls on the surface of a metal, it is absorbed and it is used to excite and eject electrons from the surface. This is known as photoelectric effect.

The ejected electrons move in a circuit in a direction opposite to that of conventional current and generate electric current. The photovoltaic or solar cells are designed based on this principle.

Solar Water Heater

It consists of an insulated box painted black from inside having a glass lid to receive and store solar heat as shown in figure. Inside the box it has black painted copper tube coil through which cold water is made to flow in.

Water gets heated and flows out into a storage tank. The hot water from the storage tank fitted on roof top is then supplied through pipes into buildings.



Solar water heater

Applications of Solar Power

- Traditional uses of solarenergy
  Drying clothes, drying fruits and vegetables, reducing moisture content in grins, and making salt from sea-water.
- Solarcells

Used in calculators, electronic watches, street lights, water pumps, radios and TVs.

- SolarBattery

  When a large number of solar cells are connected in series it forms a solar battery. It produces more electricity which is enough to run water pump.
- Solar heatcollector

  It is generally used in cold places, where houses are kept in hot condition using solar heat collectors.
- It is also helpful in cooking using solar cookers or to warm up water using solar water heaters.

Advantages of Solar Power

- Solar energy systems are maintenance free and will last fordecades.
- Once installed, there are no recurringcosts.

Environment friendly

- It's not affected by the supply and demand of fuel. Therefore, it is not subjected to the ever- increasing price ofgasoline.
- Solar energy is clean,renewable.
- It does not polluteair
- It does not contribute to the cost and problems of the recovery and transportation of fuel orthe storage of radioactivewaste.

Disadvantages of Solar Power

- The initial cost of purchasing and installing solar panels always ishigh.
- Solar energy is not available round theclock.
- Available solar energy isdiffused.
- Energy has not be stored inbatteries
- Air pollution and whether can affect the production ofelectricity.
- They need large area of land to produce more efficient powersupply.