THERMAL CONDUCTION THROUGH COMPOUND MEDIA

BODIES IN SERIES

Let us consider a compound slab made of three different materials A, B and C of thickness d_1, d_2 and d_3 as shown in fig. Let K_1, K_2 and K_3 be their thermal conductivities respectively. Let the temperatures of the faces be $\theta_1, \theta_2, \theta_3$ and θ_4 respectively and heat flows from A to C. If Q is the quantity of heat flowing through each material per second and A is the surface area then,

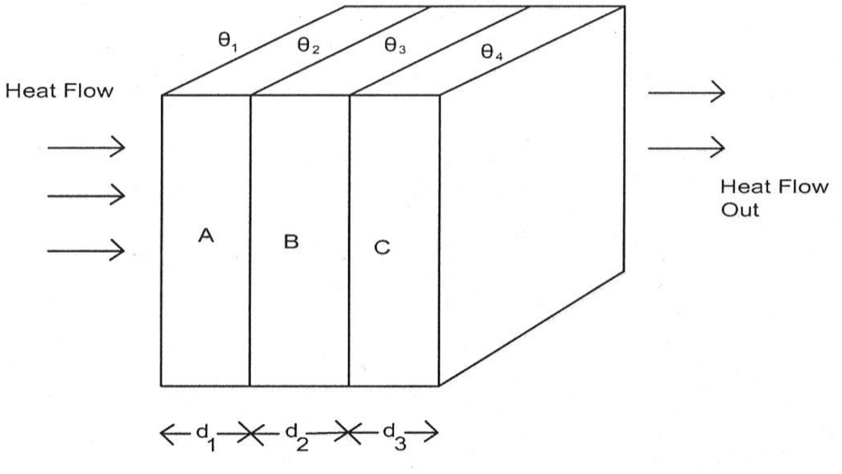


Fig. Bodies in series

$$Q = \frac{K_1 A(\theta_1 - \theta_2)}{d_1} = \frac{K_2 A(\theta_2 - \theta_3)}{d_2} = \frac{K_3 A(\theta_3 - \theta_4)}{d_3}$$

$$\theta_1 - \theta_2 = Q \frac{d_1}{K_1 A} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

$$\theta_2 - \theta_3 = Q \frac{d_2}{K_2 A} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2)$$

$$\theta_3 - \theta_4 = Q \frac{d_3}{K_3 A} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (3)$$

Adding (1), (2) & (3)

$$\theta_1 - \theta_4 = \frac{Q}{A}\left[\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Quantity of heat conducted per unit time is given by

$$Q = \frac{A(\theta_1 - \theta_4)}{\left[\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}\right]}$$

If there are *n* different materials in series with θ_1 and θ_{n+1} as the temperature of first and last face then quantity of heat conducted per unit time is given by

$$Q = \frac{A(\theta_1 - \theta_{n+1})}{\sum\left(\frac{d}{K}\right)}$$

Note: The amount of heat flowing through the material A, B and C is equal under steady state conditions.

BODIES IN PARALLEL

Let us consider a compound slab made of three different materials A, B & C of cross sectional areas A_1, A_2 and A_3 all with thickness *d* stacked together in parallel as shown in fig. Let K_1, K_2 & K_3 be their thermal conductivities respectively. Let θ_1 and θ_2 be the temperatures of two faces and heat flows from face at temperature θ_1 to face at temperature θ_2.

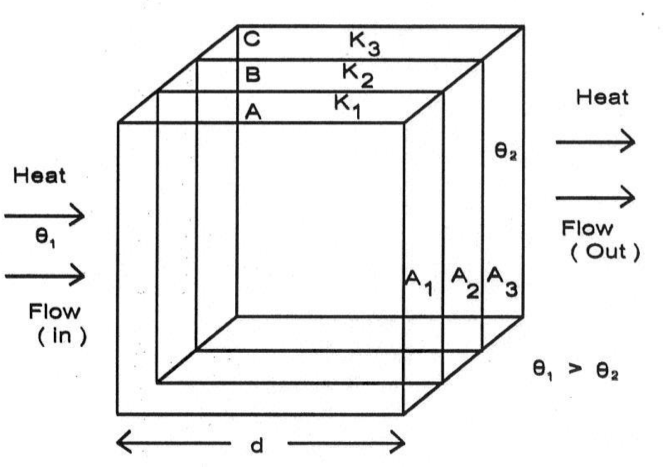


Fig . Bodies in parallel

Let Q_1 be the quantity of heat flowing through material A per second, then

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

Similarly considering materials B & C

$$Q_2 = \frac{K_2 A_2 (\theta_1 - \theta_2)}{d}$$

$$Q_3 = \frac{K_3 A_3 (\theta_1 - \theta_2)}{d}$$

Hence total heat flow/sec is given by

$$Q = Q_1 + Q_2 + Q_3$$

$$Q = \frac{(K_1 A_1 + K_2 A_2 + K_3 A_3)(\theta_1 - \theta_2)}{d}$$

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

This is applicable when all materials are of the same thickness 'd'. But in practice it may vary. For example when we consider the Walls of our houses, the entire wall is not of concrete. The wall may have glass panel or wooden panel etc. In such cases when the thickness of the materials vary, then

$$Q=\left[\frac{K_1 A_1}{d_1}+\frac{K_2 A_2}{d_2}+\frac{K_3 A_3}{d_3}\right](\theta_1-\theta_2)$$

3.2 Expansion joints

An expansion joint or movement joint is an assembly designed to safely absorb the heat- induced expansion and contraction of construction materials, to absorb vibration, to hold parts together, or to allow movement due to ground settlement or earthquakes. They are commonly found between sections of buildings, bridges, sidewalks, railway tracks, piping systems, ships, and other structures.

Building faces, concrete slabs and pipelines expand and contract due to warming and cooling from seasonal variation or due to other heat sources. Before expansion, joint gaps were built into these structures and they would crack under the stress induced.

We know, the Young's Modulus

$$Y = \frac{Longituinal\ Stress}{Longitudinal\ Strain} \quad \text{------------------(1)}$$

$$\text{Longitudinal stress} = \frac{F}{A} \quad \text{-----------------(2)}$$

We know that, coefficient of thermal expansion is

$$\alpha = \frac{dl}{l\theta}$$

From this, we can write longitudinal strain is

$$\text{longitudinal strain} = \frac{dl}{l} = \alpha\theta \quad \text{------------------(3)}$$

Substituting equation (2) and (3) in equation (1) we get

$$Y = \frac{F/A}{\alpha\theta}$$

$$\frac{F}{A} = Y\alpha\theta$$

$$F = Y\alpha\theta A \text{ ------------------(4)}$$

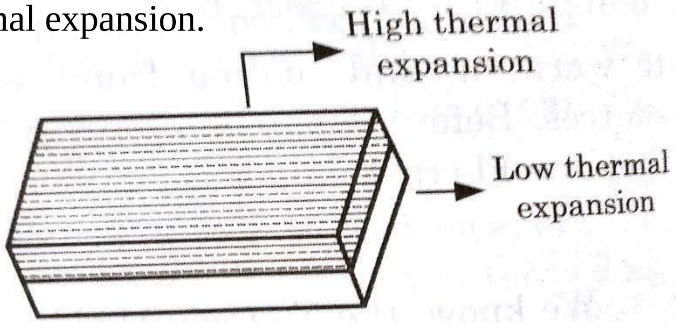
From equation (4) we can see that if the Area is less, then the force required to restore the material to its original position is less. Suppose, if the area is large then the restoring force should also be more, which is quite impossible. Hence, to avoid this problem, while constructing a large area of beams, gap is provided and these gaps are called expansion joints.

Examples

1. It is provided even in the construction of buildings. However, the joints area well packed and are not visible.
2. It is provided while laying the railway lines.

Bimetallic strips

Bimetallic strips are made up of two thin metal strips with different co-efficient of thermal expansion.

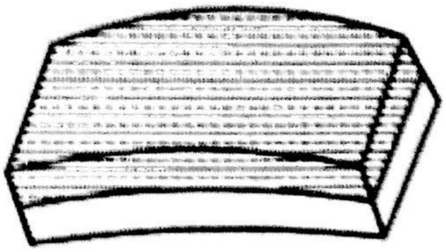


3.2.1 Bimetallic strips

Let us consider two metals are having (Brass) high co-efficient of thermal expansion and low co- efficient of thermal expansion (steel) are welded as shown in figure. This arrangement is known as bimetallic strips.

While Heating:

When the bimetallic strip is heated then the strip will start expanding and therefore the brass, which has large co-efficient of thermal expansion

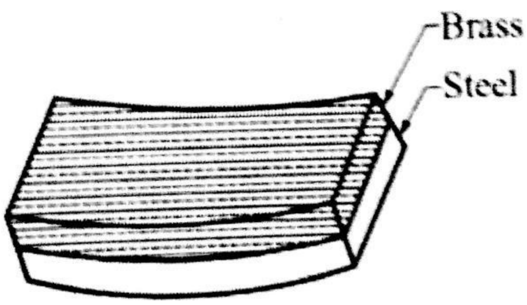


3.2.2 Bimetallic strips

expands more than the steel and hence the bimetallic strip bends like an arc as shown in figure.

While cooling:

Now, when the bimetallic strip is cooled then the strip will start contracting the therefore the brass which has large co-efficient of thermal expansion contacts more than the steel and bends like an arc as shown in figure.



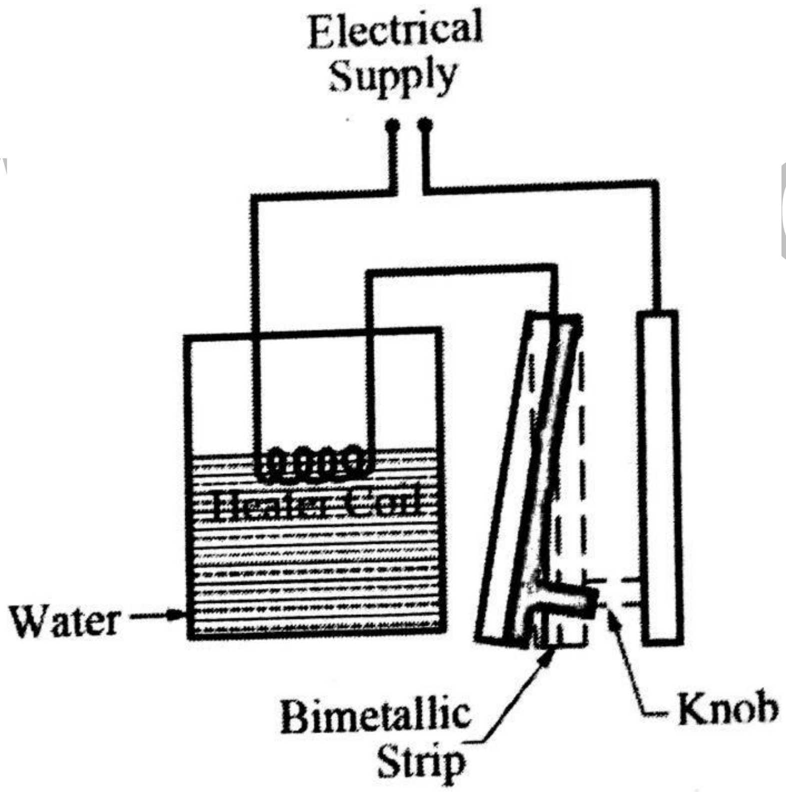
3.2.3 Bimetallic strips

Applications:

Bimetallic strips are commonly use in water heaters as temperature controller as detailed below. A water heater connected to the bimetallic strip as shown in figure. At room temperature, the bimetallic strip remains straight; the circuit is in the closed condition.

When the power supply is switched on die to increase in temperature of the water, the heater coil becomes hot and in turn, the bimetallic strip becomes hot. Now, due to thermal expansion, the bimetallic strip starts bending and at a particular temperature the knobs are detached and hence, the circuit becomes open.

Hence, the bimetallic strip acts as a temperature controller of the water heater.



3.2.4 Bimetallic strips

3.5 Thermal conductivity of good conductor Forbe's method

Metals are good conductors of both heat and electricity. To account for their heat conductor capacity, a quantity called "Thermal conductivity" is defined; higher the value of thermal conductivity more is the heat conduction. For example, copper is a very good conductor of heat followed by iron, aluminium etc. in decreasing order.

One of the oldest methods of determining the thermal conductivity of metals is being Forbes. In this method, a long rod of a metal with uniform cross section is heated at one of its ends. The entire length of the rod is left exposed to the surrounding air at the ambient room temperature.

As the rod gets heated up, it starts losing the acquired heat from its exposed surface to the surroundings. After a certain period a steady state is reached in, which

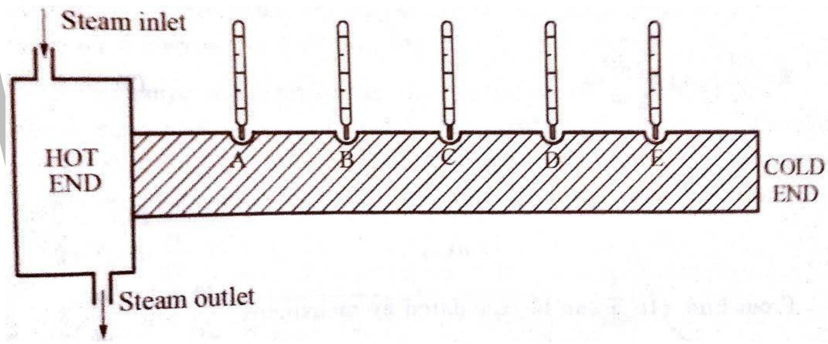


Fig 3.5 .1:Forbe's method

the entire heat supplied to the rod is lost to the surroundings. Let us consider cross section of the rod along its length at a distance 'x' from the heated end, as shown in figure.

Theory

Before steady state is reached, the amount of heat conducted through a particular point say B, per second can be written as,

$$Q_1 = KA\left(\frac{d\theta}{dx}\right)_B \text{------------------} (1)$$

Here K is the thermal conductivity of the material

A is the area of cross section of the material

$(\frac{d\theta}{dx})_B$ is the change in temperature per unit length of the rod at B

The total heat lost from the point B to E is, $Q_2 = \rho SA\int_B^E \frac{d\theta}{dt}dx$

S – Specific heat capacity,

ρ – Density

In a steady state condition, $Q_1 = Q_2$

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

Thermal conductivity

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

From equation (4), K can be calculated by measuring $\frac{d\theta}{dx}$ and $\frac{d\theta}{dt}$

Procedure:

- In the experimental set up, heater is switched on and the rod is allowed to rise to steady state temperature. At this state the temperature at points A, B, C, D etc. remains constant without any variation with time.
- The temperature at the points A, B, C, etc. are noted and tabulated. The distance of the points A, B, C, etc. from the hot end is also noted. A graph is plotted by taking distance alone *x*-axis and temperature along *y*-axis as shown in figure

To find $(\frac{d\theta}{dx})_B$:

Position	Distance from the hot end	Temperature θ (^{0}C)

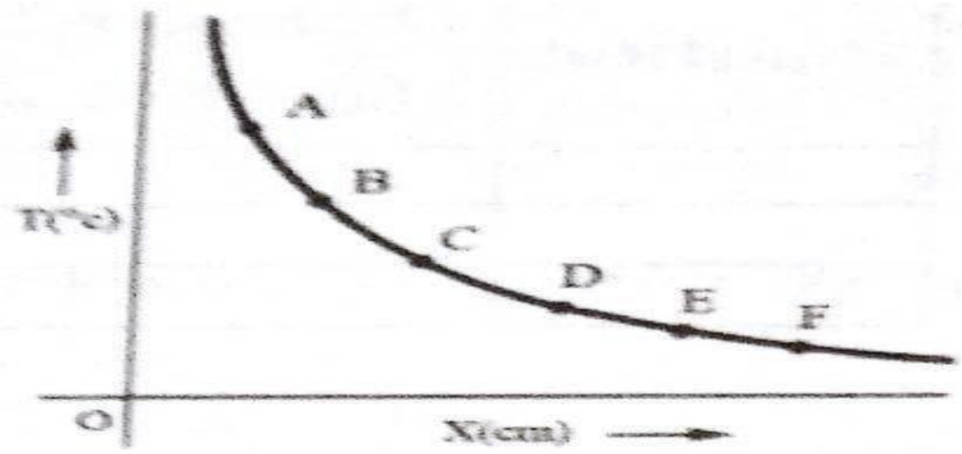


Fig 3.5.2 -To find $(\frac{d\theta}{dx})$

- Find the slope of the curve at any two points. From the slope $(\frac{d\theta}{dx})_B$ has been found.
- Heat the sample rod using a heater or boiling water bath for a sufficient time to reach a steady state. Take out the sample rod, hang it using a string and stand. Insert the thermometer into the groove as shown in figure.

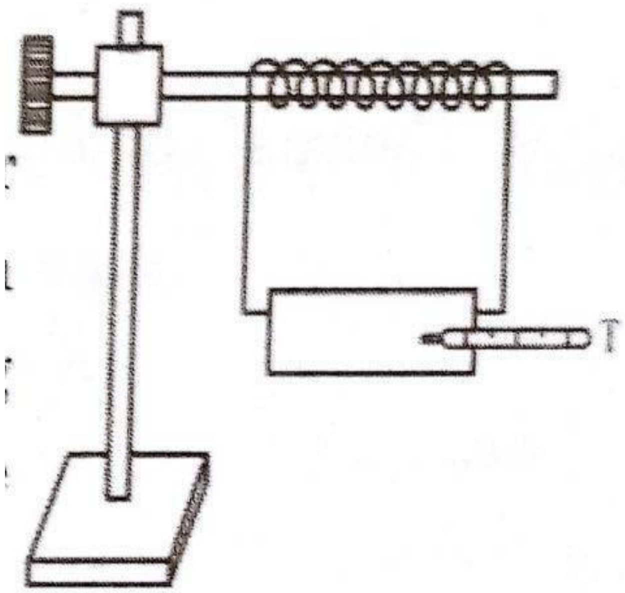


Fig 3.5.3- Set up to find temperature vs time

- Measure the temperature as a function of time at regular interval, using a stopwatch and the thermometer. Tabulate them as suggested in below table. A graph is plotted by taking time along *x*-axis and temperature along *y*-axis as shown in figure.
- To find $\frac{d\theta}{dt}$

Sl.No	Time	Temperature θ (^{0}C)

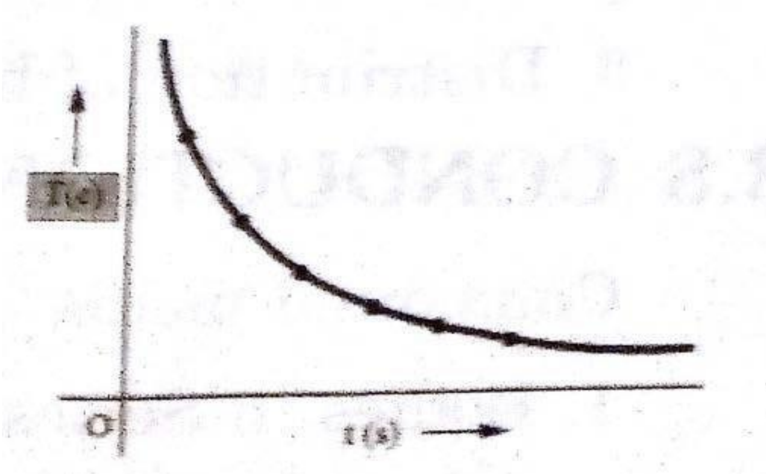


Fig 3.5.4-Graph to find $\frac{d\theta}{dt}$

- Find the slopes $\frac{d\theta}{dt}$ at the points A, B, C, D etc. from the figure.
- Now a graph is plotted by taking $\frac{d\theta}{dt}$ along *y*-axis and distance along *x*-axis as

shown in figure.

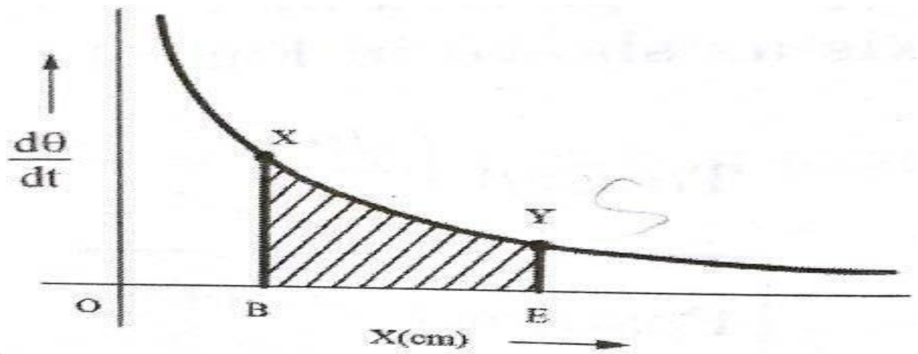


Fig 3.5.4-Graph to find Area ie $\frac{d\theta}{dt}$ vs x

- Mark two points x and y on the graph corresponding to the position B and E. Determine the area under the curve X, Y. BXYE in figure.

Area of $BXYE$ $= \int^{E} \frac{d\theta}{dt} dx$ -------------------- (5)

Thermal conductivity K can be calculated using equation (4) and (5).

$K = \frac{\rho S \text{Area of BXYE}}{(\frac{d\theta}{dx})_B}$ --------------------(6)

Note that instead of B and E, any two pair of points can be taken and accordingly the equation (6) can be modified.

Drawbacks:

1. Time consumption is long to complete the experiment.
2. It is bore to draw three graphs.
3. Distribution of heat is not the same all over the rod.

UNIT – 3 (THERMAL PHYSICS)

CONTENTS

3.4. Thermal conductivity of bad conductors – Lee's disc method

3.4.1 Principle

In the steady state, the quantity of heat flowing across the bad conductor in one second is equal to the quantity of heat radiated in one second from the lower face area and edge area of the metal disc in the Lee's disc apparatus.

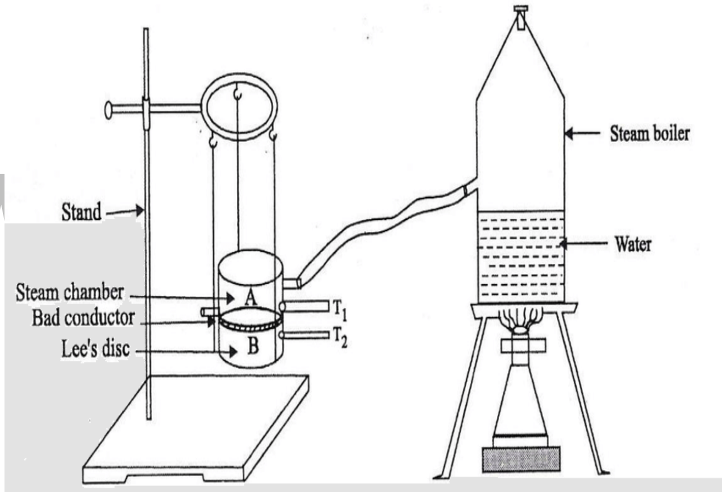


Fig 3.4.1 Lee's disc apparatus-

3.4.2.Apparatus

A flat cylindrical steam chamber 'S' and a disc D of equal diameters are arranged to sandwich the given bad conductor B taken in the form of a thin sheet of uniform thickness and having same diameter. There are holes in S and D into which thermometers T_1 and T_2 can be introduced. The bad conductor B is placed above the disc D and the steam chamber is placed above B. The whole set up is suspended by means of strings and a stand (figure3.4.1)

3.4.3.Experiment

Steam is passed through the steam chamber. The heat flows across the bad conductor from its upper surface to the lower surface. The upper surface of B is raised to the temperature of steam. Due to poor thermal conductivity of bad conductor, the lower surface will be at lesser temperature.

When the steady state is reached, the heat flowing across B is taken up by D and radiated away at the same rate from its lower face and its edges. When the thermometers show steady temperatures, theirreadings θ_1 and θ_2 are noted.

The heat flowing across the bad conductor 'B' in one second,

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

The heat radiated by metal disc 'D' in one second

$$Q' = (\pi r^2 + 2\pi r h)$$

In the steady state, $Q = Q'$

$$\frac{(\theta_1 - \theta_2)}{x} = (\pi r^2 + 2\pi r h)E$$

Since the area A of the bad conductor is πr^2, the same as that of D

$$\frac{(\theta\ \theta)}{x} \quad (\ )$$

$$= \frac{(r + 2h)}{(\theta_1 - \theta_2)} \ldots\ldots\ldots\ldots (1)$$

Now the steam chamber is lifted up and the bad conductor B is removed and the steam chamber is placed directly on the metal disc D. When the temperature of the disc D is 10^0C above itssteady state temperature, the steam chamber is removed and the disc D is allowed to cool. The time is noted for every 1^0C fall of temperature from about 5^0C above and below its steady state temperature T_2.

The emissivity is,

$$E = \frac{Rate\ of\ loss\ of\ heat}{Area\ of\ surfaces}$$

$$E = \frac{MS\frac{d\theta}{dt}}{2\pi r^2 + 2\pi r h}$$

Substituting the value of E in equation (1), we get

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

Where

K – Thermal conductivity of bad conductor BM – Mass of the disc D

S – Specific heat capacity of disc D

— – Rate of fall of temperature

x – Thickness of bad conductor B

r – Radius of the metallic disc D

h – Thickness of the metallic disc D

θ_1 – Steady temperature of steam chamber

θ_2 – Steady temperature of metallic disc D

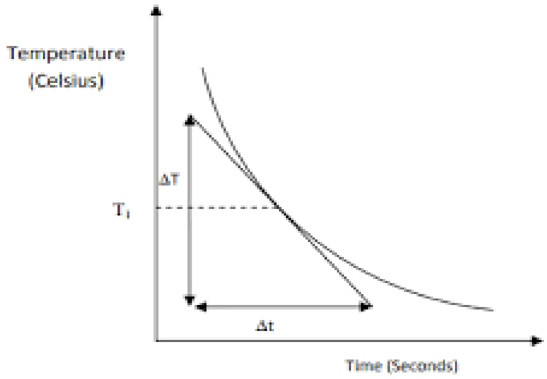


Fig 3.4.2 variation of temperature with time

A graph of temperature against time is drawn (figure) and the slope of graph at the temperature θ_2 is measured. Let it be — . Thus, substitute the above values in equation (2) we can find out the thermal conductivity of bad conductor.

3.8 MICROWAVE OVEN

PRINCIPLE:

High powered microwaves are generated and are allowed to fall on the food stuff. These waves heat the molecules in the food particles evenly and cook the food.

CONSTRUCTION

In consists of a microwave generator called a magnetron, which is used to take electricity from the power outlet and converts into high powered micro waves, as in fig

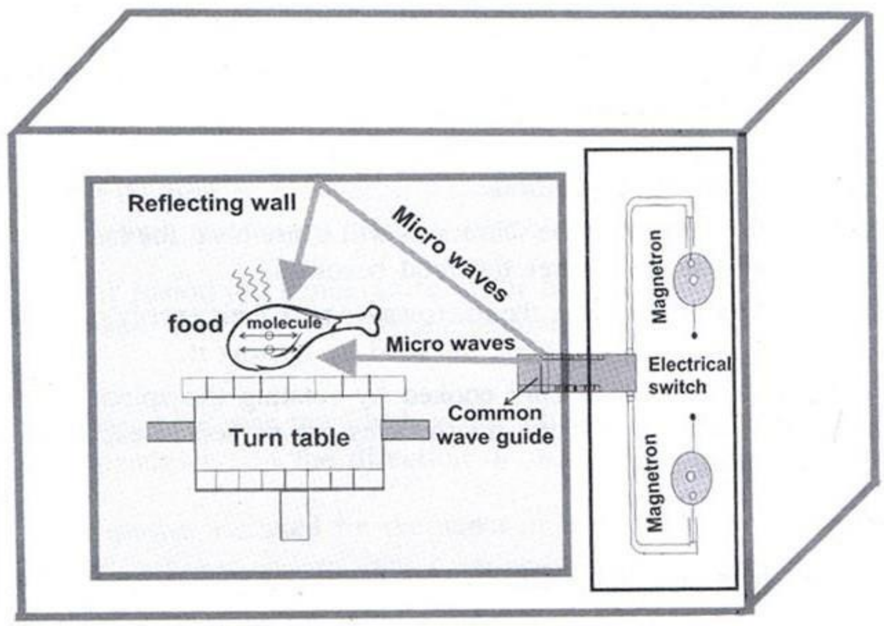


Fig 3.8.1 Microwave oven

The food compartment is made up of reflective metal walls, just like a mirror, to have effective focusing of microwaves onto the food particles. A rotating spinning arrangement, so called turn table is used to rotate the food stuff so as to cook the food evenly.

A channel ofcommon wave guide is used to transfer the microwaves from the magnetron to the food compartment.

The total setup is completely surrounded by strong metal boxes for safety.

A timer display is also provided in the modern microwave ovens to choose various options in cooking variety of food items like Grill,Tantoor etc.

WORKING:

- Food to be cooked is placed on the turn table and the electricity is switched ON.
- The magnetron converts the electrical energy into high powered radio waves,so called microwaves.
- The magnetron blasts these microwaves into the food compartment through a channel called a common wave guide.
- Microwave bounces back and forth between the reflective metal walls and reaches the food.
- This Micro wave penetrates inside the food and makes the molecules in the food to vibrate.
- The vibrations will cause heat then faster the molecules vibrate, the food becomes hotter.
- Thus in this way micro wave pass their energy onto the molecules in the food and cook the food by heating it.
- The food is evenly cooked by rotating the spinning or turn table slowly ,so that the micro waves are passed in each and every part of the food.

ADVANTAGES:

- It is portable,small in size.
- Easy and faster to cook, with high efficiency.
- Micro wave can penetrate more than two centimetres into the food.
- Cost of micro wave oven is less.

DISADVANTAGES

- Microwaves are dangerous and so there should not be any leakage.
- Every time the lock of the door should be checked properly
- We should not use cell phone in microwave oven cooking areas.
- Uneven heating (or) cooking of food is not good for health.

3.7 Refrigerators

Refrigeration 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. 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.

Refrigerator 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. The working fluid used in refrigerator is called refrigerant. Ex: Ammonia, Methyl chloride, Freon etc.

Parts of a Refrigerator and their functions

Evaporator: It is used to receive the liquid refrigerants from the condenser through throttle valve and to evaporate it. It is also called as cooling unit or freezing unit.

Compressor: It is used to draw the refrigerant from the evaporator through suction valve at low pressure and to force it to the condenser through exhaust valve at high pressure and temperature.

Condenser: It is used to condense the refrigerants at saturation temperature from vapour

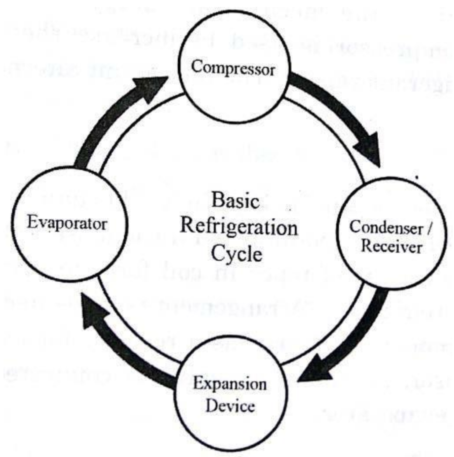


Fig 3.7.1- Condenser

to liquid by transferring its latent heat to the water.

Throttle (or) Expansion valve: It is used to control the rate of admission of refrigerants to the evaporator. As the refrigerant expands in the valve, it loses its pressure and temperature at its exit end and gets cooled.

Absorber (or) Receiver: It is a unit contains water. It is used to receive the refrigerant from the evaporator and to absorb it with water to become a strong solution of ammonia with an increase in temperature.

Pump: It is to pump the refrigerant from the absorber to the separator.

Separator: It is used to separate the refrigerant vapour from the strong solution using heat energy and then send it to condenser.

Based on the external work it mainly classified in to two types.

1. Using mechanical energy – vapour Compression Refrigeration
2. Using heat energy – vapour Absorption Refrigeration

Vapour Compression Refrigeration Principle

In this technique, the mechanical energy is utilized to achieve refrigeration. A compressor is used to increase the temperature and pressure of the refrigerant vapour. The refrigerant alternatively evaporates and condenses.

Construction

It consists of an evaporator is kept in a cold chamber. A compressor is connected in between an evaporator and a condenser. Both the condenser and the evaporator consist of pipes in coil form to provide more contact surface area for the refrigerant. Arrangement is made to circulate cold water or air around the condenser. A tray as a receiver for exit water is placed nearby the condenser. An expansion valve is connected in between the condenser and the.

Working

The unit completes one cycle with the following operations such as Suction, Compression, Condensation, Expansion and Vaporization.

Suction: The low-pressure vapour in dry state is drawn from the evaporator during in suction of the compressor through its inlet valve.

Compression: The pressure and temperature of the refrigerants increases inside the compressor and it is discharged through the exhaust valve and enters the condenser.

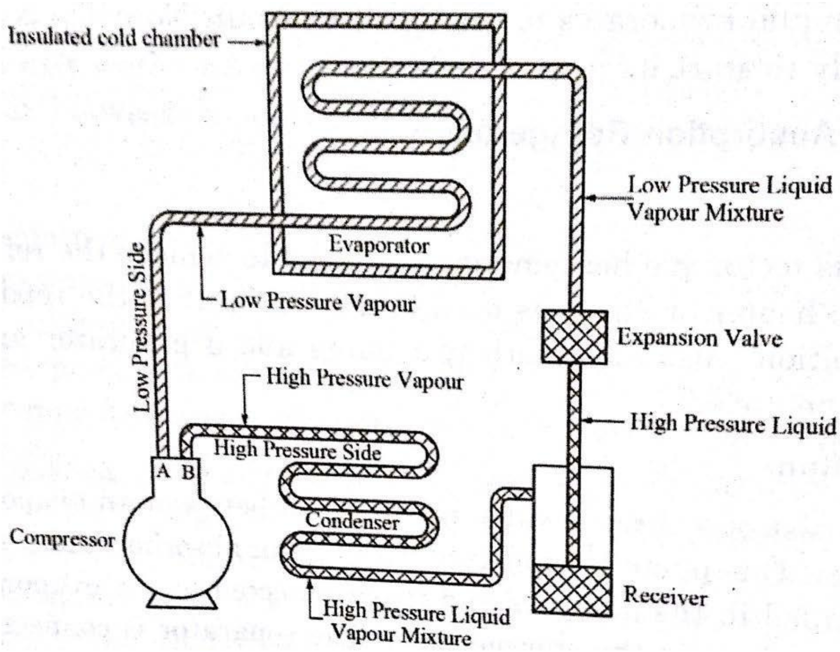


Fig 3.7.2- Refrigeration

Condensation: The condenser absorbs its heat. The heat now flows from condenser to the cooling water, which is circulated around it. As a result vapour is cooled and a return to liquid state. It is then made to exit through the expansion valve.

Expansion: The exit or expansion of the liquid result in decrease of its temperature and pressure to about -10^{0}C and enters the evaporator kept in the storage room.

Vaporization: As the temperature of the liquid is less than that of the storage room, the heat will be absorbed by it from the room. As the result the liquid evaporates to almost dry vapour. Now this is dry vapour and is ready to start its next cycle.

Vapour Absorption Refrigeration Principle

In this technique heat, energy is utilized to achieve the refrigeration. An electric heater or steam is used to add the heat to the refrigerant for its evaporation. In addition, an absorber, a pump and a generator are used to complete the cycle.

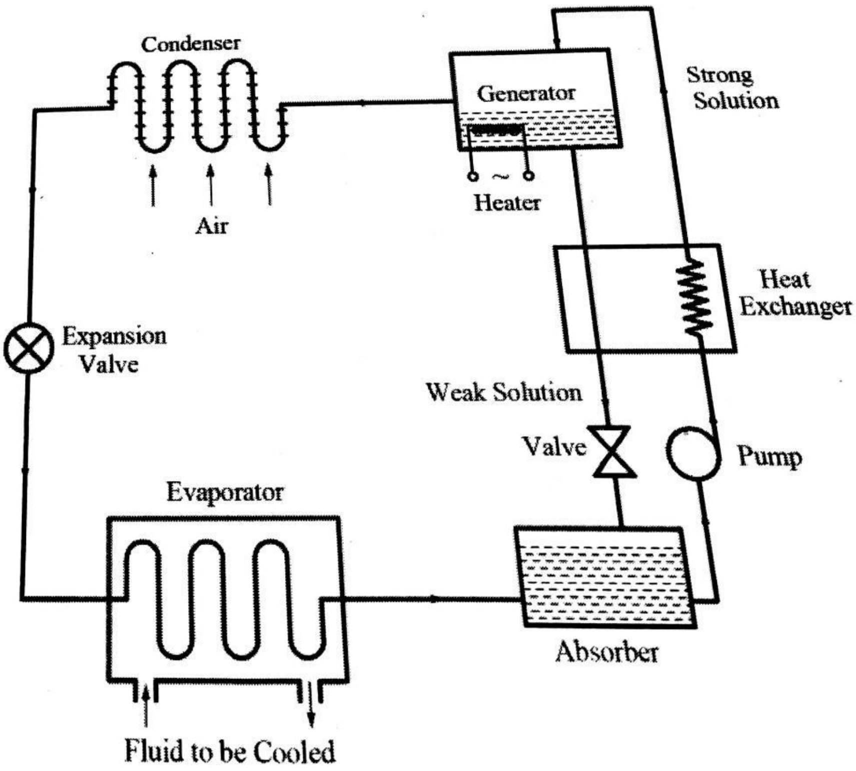


Fig 3.7.3- Refrigeration principle

Construction

It consists of a throttle valve is connected between an evaporator and a condenser. One pump is connected between an absorber and a separator. Water is filled in the absorber and it is connected to the evaporator. The evaporator is kept in the storage room. The separator is connected to the condenser. Both the condenser and evaporator consist of pipes in coil from to provide more contact surface area for the refrigerant. Arguments are made to circulate the cold water around the condenser and in the absorber. An electric heater is housed in the separator. Trays may be positioned to collect the exit water near by the absorber and condenser. A receiver is connected in between the condenser and the throttle valve.

Working

Dry ammonia vapour from the evaporator enters the absorber containing water it is absorbed by the water becomes a strong ammonia solution with an increase in temperature. The heat generated during this process is removed to some extent by circulating cold water through a pipe. Otherwise absorbing capacity reduces with hot water.

A pump to the generator now pumps the strong ammonia solution where it is heated by an electric coil. As result, ammonia vaporizes and separates out from the water. It is then driven out from the solution to the condenser where it is condensed and return to the liquid state.

The liquid ammonia is then collected in the receiver. The high-pressure liquid ammonia is then passed through the throttle valve where it is expanded with decrease in temperature and pressure. Later it enters the evaporator kept in the storage room.

Comparison between vapour compression and vapour absorption refrigeration

Vapour compression refrigeration	Vapour absorption refrigeration
Works using mechanical energy	Works using heat energy
Refrigeration capacity is less than 1000 tons.	Refrigeration capacity is greater than 1000 tons.
COP is much higher	COP is less.
Noisy due to compressor.	Pump noise is less.
Chances of leakage of refrigerant are more.	No leakage.
Maintenance and operating cost are high.	Less.
Smaller in size.	Larger
Wear and tear are more.	Wear and tear are less

Properties of good (ideal) refrigerants

An ideal refrigerant should have the following properties

1. Low viscosity
2. Low freezing point
3. Low boiling point
4. Low heat capacity
5. Low specific volume
6. Low saturation pressure
7. Odourless
8. High latent heat of vaporization
9. Good thermal conductivity.
10. High COP (Coefficient of performance = Output/input = Q/W)
11. Non inflammable and non-explosive.

12. High critical pressure and temperature.

Types of refrigerants

1. **Ammonia:** Ice plants, large cold storages, etc
2. **Carbon dioxide:** Marine refrigerators, dry ice making and air conditioning.
3. **Methyl chloride:** domestic and industrial refrigerators
4. **Fluorocarbon refrigerants:** Freon-11, 12, 13, 22, 113, 114, etc.

   These are used in domestic refrigerators, water coolers, air conditioning plants cold storages etc.
5. **Sulphur dioxide:** Domestic refrigerators

Uses of refrigeration

1. It is used make ice
2. It used to preserve food products and medicines.
3. It used in Air conditioning.
4. It used as a rocket fuels.
5. It used in transportation of foodstuffs, dairy products.
6. It used in special industrial processes.

Solar Water Heater

3.9. Solar Water Heater

3.9.1.Principle

3.9.2.Construction

3.9.3.Working

3.9.1.Principle

Solar water heater is based on the principle of converting solar energy into electrical energy and then into heat energy, using solar electric panels, so called solar cells or Photovoltaic cells.

3.9.2. Construction

It consists of a solar thermal panel in which collector is used to collect, capture and retain the heat radiations from the sun.

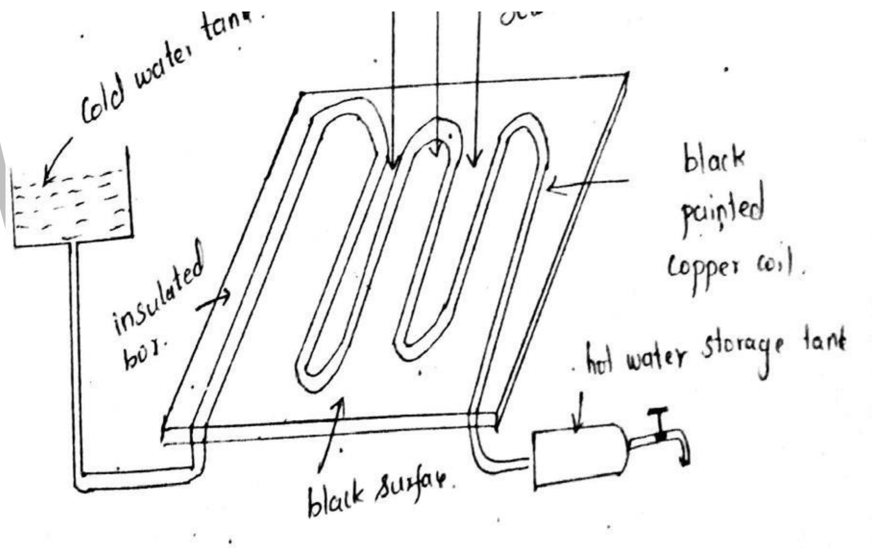


Fig 3.9.1 Solar heater

- The heat exchanger is made up of coil of copper pipes and is kept inside the water tank.
- Heat exchanger is used to transfer the heat energy from the hot water passing through the copper pipe in the heat exchanger to the cold water in the water tank.
- An electric pump is used to pump the cold water coming out from the heat exchanger to the collector of the thermal panel.
- The total system is controlled by the controller unit, which is used to

(i) Fill the water with Auto cut-off in the tank.

(ii) Switch on/off the electric pup, whenever required.

3.9.3. Working

1. With the help of the electric pump, cold is pumped to the collector in the solar thermal panel.
2. Now, due to the thermal radiations that fall on the thermal panel, the water in the collector is heated up.
3. This hot water is allowed to pass through the water tank with the help of the heat exchangers.
4. The heat exchanger, which is made up of coil of copper pipes, transfers the heat energy from the water inside the copper coils, to the water present in the water tank and therefore the water in the water tank becomes hot.
5. The water coming out from the heat exchanger, after transferring the energy, become cold water and enters into the electric pump again.
6. Thus we can run off hot water from the tank at any time without affecting the panel's operation.

Advantages

- Solar energy is free and abundant.
- Solar thermal panel occupies less space.
- Solar thermal panels are more efficient.
- We can save money by paying less electricity bill.
- It is a Eco-friendly way to heat water for the domestic need.

Disadvantages

- Capital investment and installation cost in high.
- Annual maintenance is required to check the working of pump, antifreezing etc.
- It occupies space and depends on the availability of direct sun light.
- It is not useful during rainy or foggy days.
- It will take about 10 to 15 years to get back the money we spent.

3.6 Heat exchangers

A 'heat exchanger' may be defined as an equipment, which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running costs.

In heat exchangers, the temperature of each fluid changes as it passes through the exchangers, and hence the temperature of the dividing wall between the fluids changes along the length of the exchanger.

Examples of heat exchangers:

(i) Intercoolers and pre heaters;

(ii) Condensers and boilers in steam plant;

(iii) Condensers and evaporators in refrigerator.

(iv) Automobile radiators;

(v) Oil coolers of heat engine;

(vi) Milk chiller of a pasteurising plant

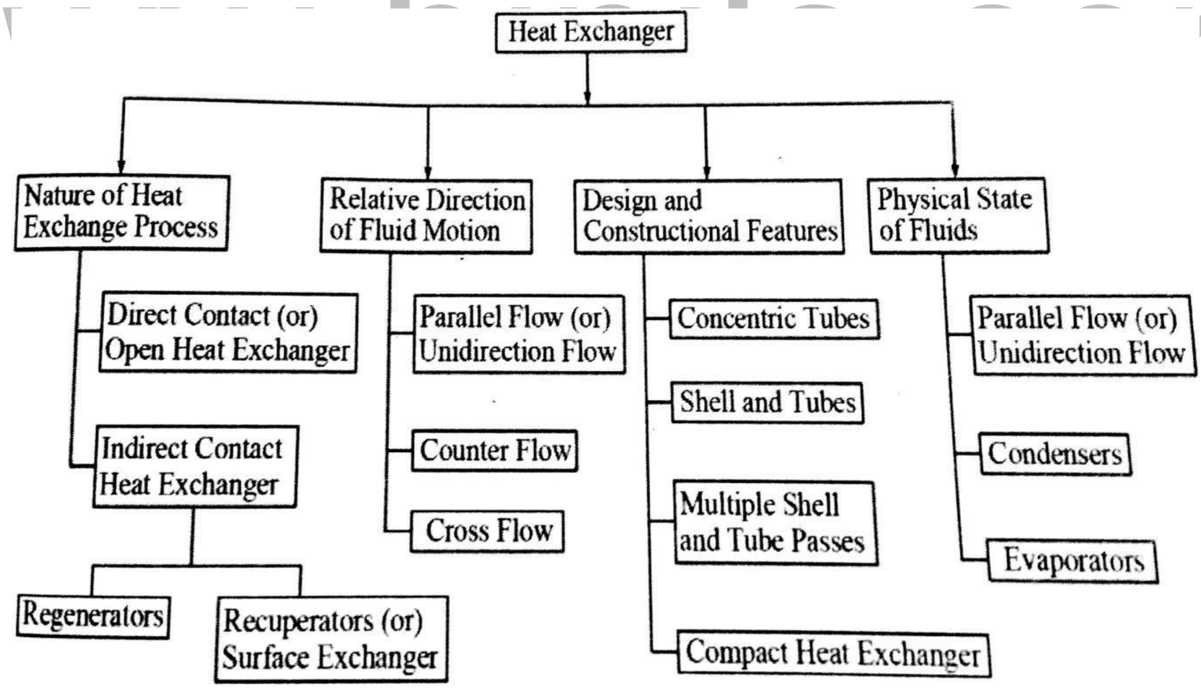


Fig-3.6.1 Types of Heat Exchangers

Types of Heat Exchangers

1. Nature of heat exchange process

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

i) Direct contact (or open) heat exchangers.

ii) Indirect contact heat exchangers

i) Direct contact heat exchangers

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 mass takes place simultaneously.The use of such units is made under conditions where mixing of two fluids is either harmless or desirable.

Ex: Cooling towers, Jet condensers, Direct contact feed heaters.

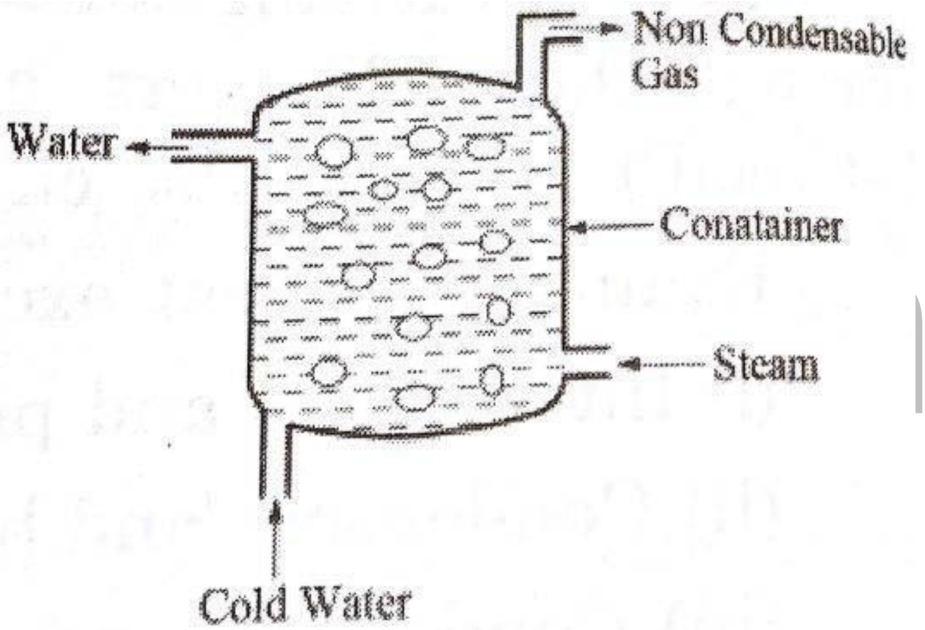


Fig-3.6.2- Heat Exchangers

ii) Indirect contact heat exchangers

In this type of heat exchangers, 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

b) Surface exchangers

a) Regenerators

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

Ex: I.C. engines and gas turbines, open hearth and glass melting furnaces, air heaters of blast furnaces.

The performance of these regenerators is affected by the following parameters:

i) Heat capacity of regenerating material.

ii) The rate of absorption, and

iii) The release of heat.

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 (in the form of pipes or tubes generally). These heat exchangers are used when two fluids cannot be allowed to mix i.e., when the mixing is undesirable.

Ex: Automobile radiators, Oil coolers, Intercoolers.

2. Relative direction of fluid motion

According to the relative directions of two fluid streams, the heat exchangers are classified into the following three categories:

i) Parallel – flow (or) uni-direction flow.

ii) Counter – flow

iii) Cross – flow

i) Parallel- flow heat exchangers

In a parallel-flow exchanger, as the name suggests, the two fluid streams (hot and cold) travel in the same direction. The two steams enter at one end and leave at the other end. Since this type of heat exchanger needs a large area of heat transfer, therefore, it is rarely used in practice.

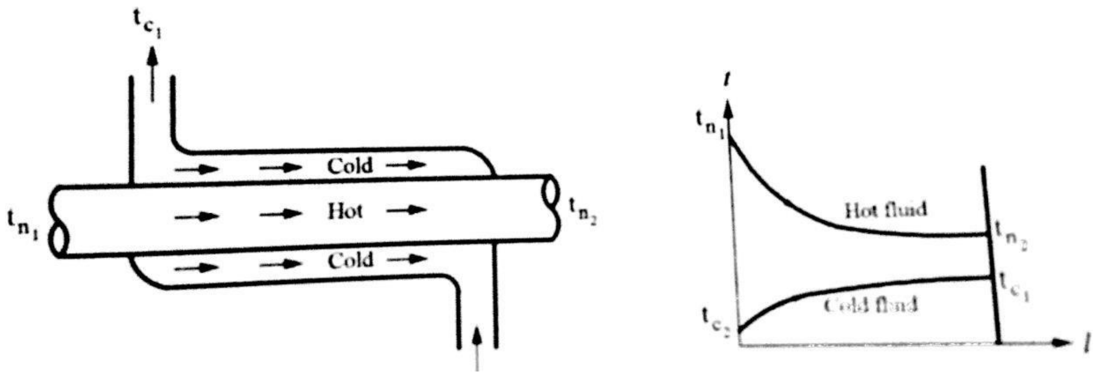


Fig-3.6.3- Parallel- flow heat exchangers

Ex: Oil coolers, oil heaters, water heaters etc.

As a wall separates the two fluids, this type of heat exchanger may be called parallel-flow recuperator or surface heat exchanger.

ii) Counter-flow heat exchangers

In a counter flow heat exchanger, the two fluids flow in opposite directions. The hot and cold fluids enter at the opposite ends. Due to counter flow, gives maximum rate of heat transfer for a given surface area. Hence, such heat exchangers are most favoured for heating and cooling of fluids.

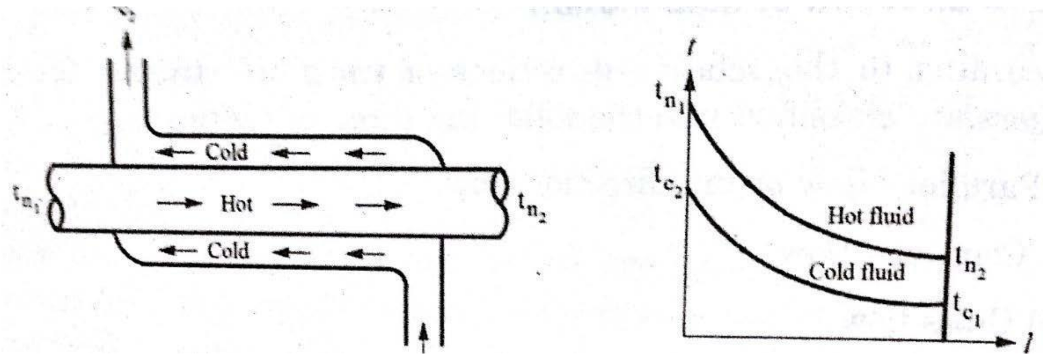


Fig-3.6.4- Counter-flow heat exchangers

i) Cross-flow heat exchangers

In cross-flow heat exchangers, the two fluids (hot and cold) cross one another in space, usually at right angles. Figure shows a schematic diagram of common arrangements of cross-flow heat exchangers.

Ex: The cooling unit of refrigeration system, automobile, radiators, etc.

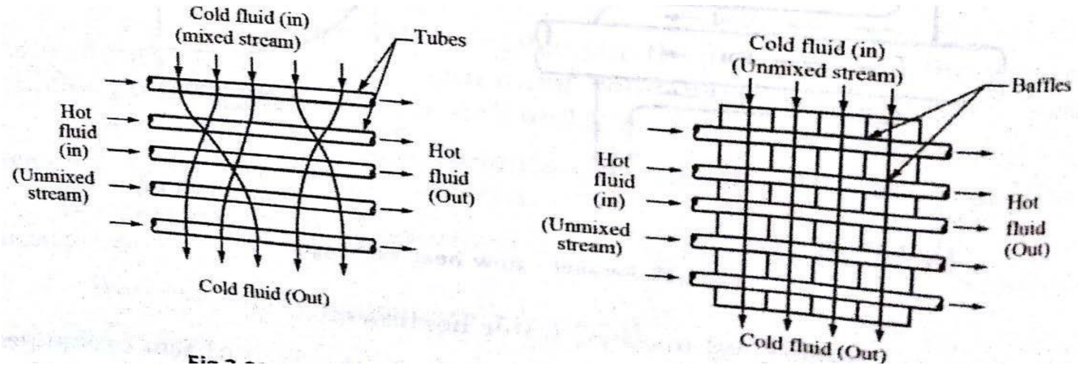


Fig-3.6.5- Cross-flow heat exchangers

3. Design and constructional features

Based on design and constructional features the heat exchangers are classified as under:

i) Concentric tubes

In this type, two concentric tubes are used, each carrying one of the fluids. This direction of flow may be parallel or counter as depicted in figure. The effectiveness of the heat exchanger is increased by using swirling flow.

ii) Shell and tube

In this type of heat exchanger, one of the fluids flows through a bundle of tubes enclosed by a shell. The other fluid is forced through the shell and it flows over the outside surface of the tubes. Such an arrangement is employed where reliability and heat transfer effectiveness are important. With the use of multiple tubes, heat transfer rate is amply improved due to increased surface area.

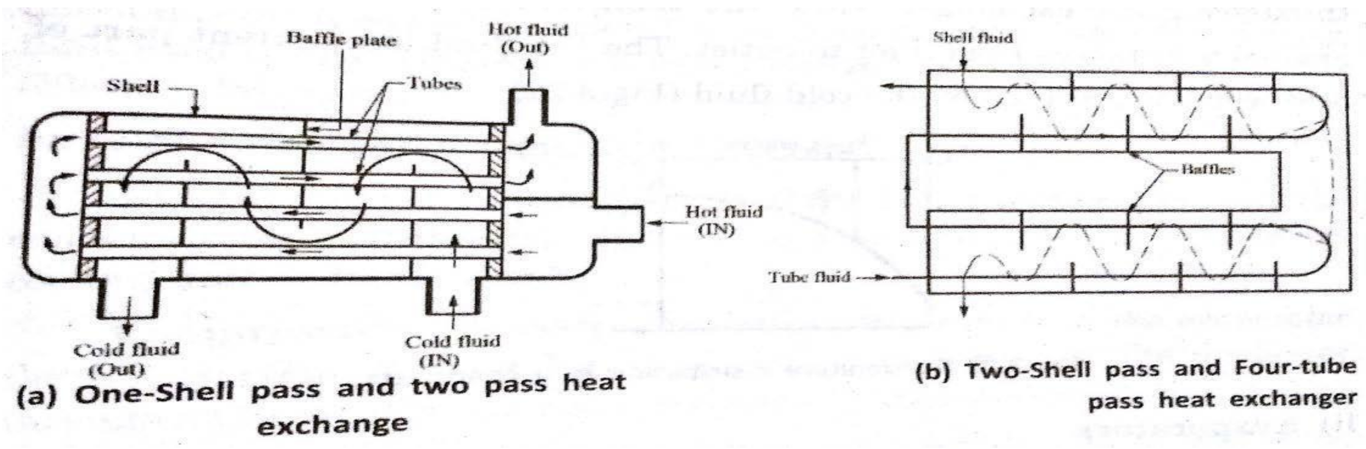


Fig-3.6.6- Shell and tube exchanger

i) Multiple shell and tube passes

Multiple shell and tube passes are used for enhancing the overall heat transfer. Multiple shell pass is possible where the fluid flowing through the shell is re-routed. The shell side fluid is forced to flow back and forth across the tubes by baffles. Multiple tube pass exchangers are those which re- route the fluid through tubes in the opposite direction.

ii) Compact heat exchangers

These are special purpose heat exchangers and have a very large transfer surface area per unit volume of the exchanger. They are generally employed when convective heat transfers sufficient associated with one of the fluids is much smaller than that associated with the other fluid.

Ex: Plate-fin, flattened fin tube exchangers etc.

4. Physical state of fluids

Depending upon the physical state of fluids the heat exchangers are classified as follows:

i) Condensers

ii) Evaporators

i) Condensers

In a condenser, the condensing fluid remains at constant temperature throughout the exchanger while the temperature of the colder fluid gradually increases from inlet to outlet. The hot fluid loses latent part of heat which is accepted by the cold fluid (figure).

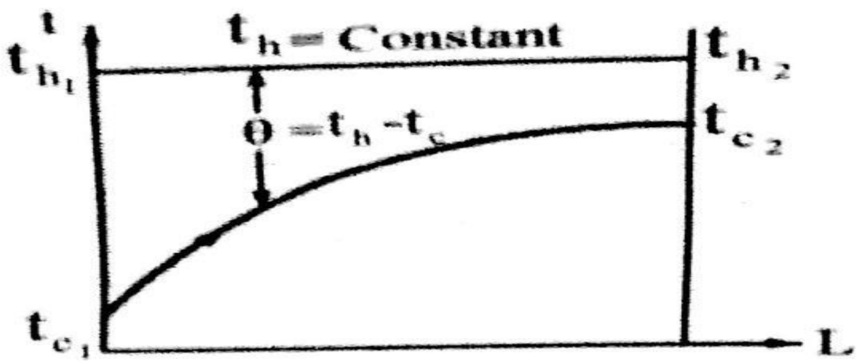


Fig-3.6.7- Condensers

i) Evaporators

In this case, the boiling fluid (cold fluid) remains at constant temperature while the temperature of hot fluid gradually decreases from inlet to outlet (figure).

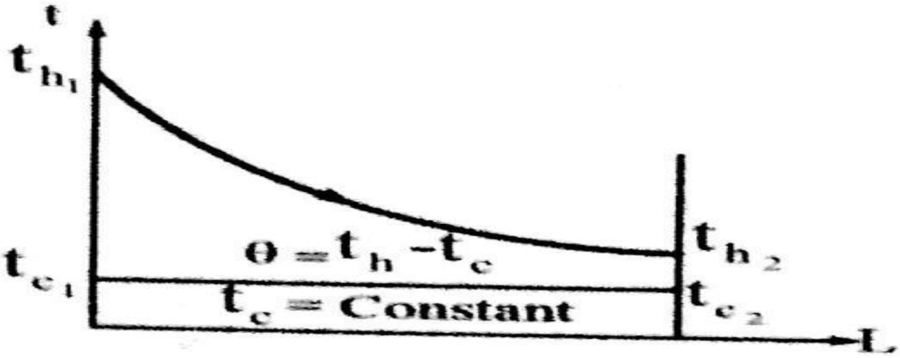


Fig-3.6.8- Evaporators

UNIT – 3 (THERMAL PHYSICS)

Introduction

Thermodynamic is the branch of science concerned with heat and temperature and their relation to energy and work. It states that the behavior of these quantities is governed by the four lawsof thermodynamics, .

3.1. Fundamental definition

3.1.1. Heat

Heat is a measurement of energy. The total energy of all the molecular motion inside theobject is known as heat. It is measured as calorie and Joule.

3.1.2. Temperature

Temperature is a measure of average heat or thermal energy of the molecule in a substance. Itis measured as Kelvin, Celsius and Fahrenheit.

3.1.3. Temperature gradient

The rate of fall of temperature with respect to the distance or thickness of the material iscalled temperature gradient.

3.1.4. Specific heat capacity

Specific heat capacity is defined as the amount of heat is required to raise the temperature ofunit mass of substance through one Kelvin.

3.1.5. Thermal diffusivity

The ratio of thermal conductivity to the thermal capacity per unit volume is known as thermaldiffusivity.

3.1.6. Thermal Conductivity

The quantity of heat conducted per second through unit area of the material when unittemperature gradient is maintained. Its unit is $Wm^{-1}K^{-1}$.

$$K = \frac{Qx}{(\theta_1 - \theta_2)t}$$

3.1.7. Laws of thermodynamics

- **Zeroth law of thermodynamics** – If two thermodynamic systems are each in thermalequilibrium with a third, then they are in thermal equilibrium with each other.
- **First law of thermodynamics** – Energy can neither be created nor destroyed. It can onlychange from one form to another form.
- **Second law of thermodynamics** – The entropy of an isolated system is always increasing.
- **Third law of thermodynamics** – As temperature approaches absolute zero, the entropy of asystem approaches a constant minimum.

Transfer of heat energy

Heat can be transferred from one place to the other place by three different ways. They are,

1. Conduction
2. Convection
3. Radiation

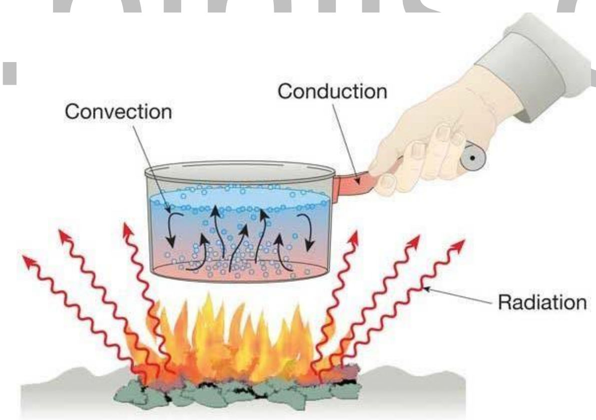


Figure 3.1.1 Transwer of heat energy

3.1.8. Conduction

Conduction is the process in which heat is transmitted from the hot end to the cold end of a body without the motion of the particles of the body.

If a metallic rod is heated form one end, we can see that the temperature of the other end also rises, which indicates that the heat is travelled from one end to the other end of the rod.

Due to the gain of heat energy, the amplitude of vibrating particles at the hot end increases. During this vibration, the vibrating particles collide with the adjacent particles and share their energy with them. This vibrational energy is passed from layer to layer towards the cold end. At the same time, each individual particle remains at its equilibrium position. This process of conduction is prominent in the case of solids.

3.1.9. Convection

Convection is the process in which heat is transmitted from one place to the other place by theactual movement of the heated particles.

In this mode of transmission, the particles themselves propagate the heat. Conduction is the normal mode of propagation of heat in liquids and gases. The regions of fluids, which are heated, expand and become less dense thereby carrying heat to the other regions.

3.1.10. Radiation

Radiation is the process in which heat is transmitted from one place to the other directly without the necessity of the intervening medium.

In this mode of propagation of heat, no material medium is required for the transmission of heat. If we are near to an open fire or we hold a hand near to a hot bath, we feel some hotness. In addition, the heat from the sun reaches us by this process.

Heat radiation can pass through vacuum and gas. Their properties are similar to lightradiations. Heat radiations are also from a part of the electromagnetic spectrum.

Thermal expansion

The property involves the increase in the length or area or volume of a matter as the temperature increases. The temperature of a body causes expansion or contraction of that body. All three states of matter (solid, liquid and gas) expand on heating and contract on cooling. This is called thermal expansion. Thermal expansion is the basic principle that a thermometer works on.

3.1.11. Thermal expansion of solids

When a solid is heated, its atoms vibrate faster about their fixed points. The relative increase in the size of solids when heated is therefore small. Metal railway tracks have small gaps so that when the sun heats them, the tracks expand into these gaps and do not buckle. The stress developed inside the metal to regain its original position is called thermal stress.

Explanation

Let us consider a metal rod of length '*l*' at a temperature T. When the rod is heated to the temperature from T to T + θ, then the length of the rod increases, linearly from *l* to *l* + *dl* as shown in figure.

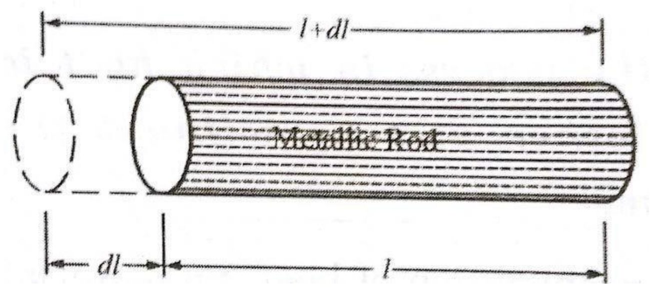


Fig 2.1.2 Expansion of solid

The co-efficient of the thermal expansion

$$\alpha = \frac{dl}{l\theta} \quad \ldots\ldots\ldots\ldots (1)$$

If θ = 1, then

$$\alpha = \frac{dl}{l}$$

Thus, the co-efficient of thermal expansion can be defined as the ratio between the changes inlength to the original length per unit rise of temperature.

The coefficient of thermal expansion describes how the size of an object changes with changein temperature. Specifically, it measures the fractional change in size per degree change in temperature at a constant pressure.

3.1.12. Thermal Expansion of Liquids

Liquids do not have a definite shape. They take the shape of the container. Thus, we can specify a liquid by it is volume. Hence, we can speak of volume expansion This means that the container expands first, due to which the level of the liquid falls. When the liquid gets heated, it expands more and beyond its original level. We cannot observe the intermediate state. We can only observe the initial and the final levels.

This observed expansion of the liquid is known as the apparentexpansion of the liquid.

only for liquids. Expansion of liquids is much greater than that of solids.

Explanation

A liquid is heated in a container. Heat flows through the container to the liquid.

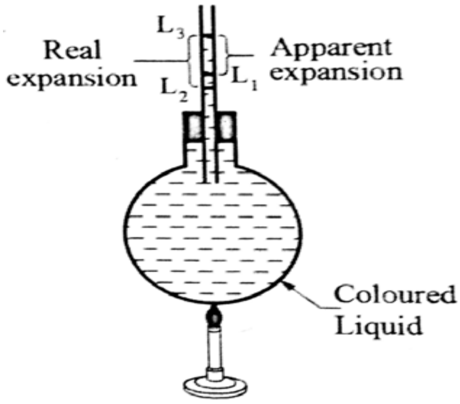


Fig 2.1.3 Expansion of liquid

If we consider the expansion of the container also and measure the total expansion in volume of the liquid, then the expansion is termed as the absolute expansion of the liquid.

When the liquid gets heated, it expands much more than the container and its level rises to L_3. We can only observe the increase in level from L_1 to L_3. Intermediate level L_2 goes unnoticed.

The expansion we measure is the apparent expansion of the liquid. The corresponding coefficient iscoefficient of apparent expansion.

The coefficient of apparent expansion is defined as the ratio of apparent increase in volume ofthe liquid to its original volume for every degree rise in temperature.

$$\text{coefficient of apparent expansion} = \frac{\text{increase in Volume}}{(\text{Original volume})(\text{increase in temperature})}$$

$$= \frac{\Delta v}{(t_2 - t_1)}$$