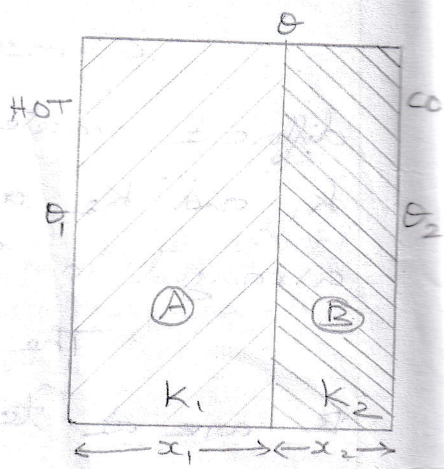
Unit-III Thermal Physics

1. Derive an expression for a heat conduction through a compound media.

Bodies in series

Let us consider a compound media of 2 different materials A and B with thermal conductivities K_1 and K_2 and thicknesses x_1 and x_2.

The temperatures of the outer faces of A and B are θ_1 and θ_2.



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

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

The amount of heat flowing through the materials A and B is equal in steady state conditions.

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

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

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

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

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

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

This is the expression for interface temperature of two composite slabs in series.

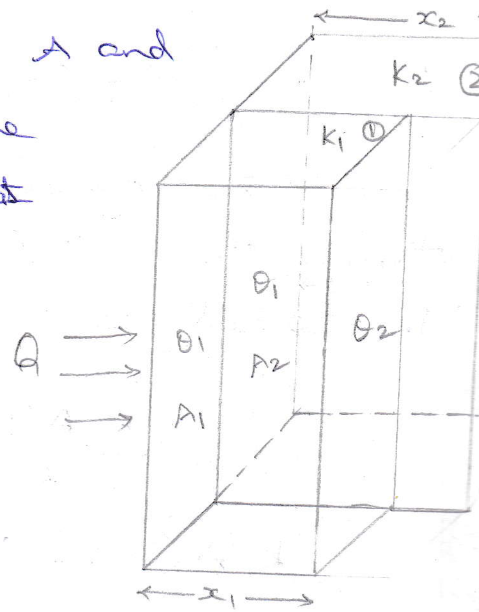
Substituting θ in eqn ①,

$$Q = \frac{A(\theta_1 - \theta_2)}{\frac{x_1}{k_1} + \frac{x_2}{k_2}} \quad - ⑤$$

$$Q = \frac{A(\theta_1 - \theta_2)}{\Sigma\left(\frac{x}{k}\right)}$$

Bodies in parallel

Consider a composite media of two different materials A and B with thermal conductivi[ties] k_1 and k_2 and thicknesses x_1 and x_2 they are arranged in Parallel.



The faces of the material A and B are at temperature θ_1 and the other end faces of A and B are at temperature θ_2.

$$Q_1 = \frac{k_1 A_1 (\theta_1 - \theta_2)}{x_1} \quad - ①$$

$$Q_2 = \frac{k_2 A_2 (\theta_1 - \theta_2)}{x_2} \quad - ②$$

$$Q = Q_1 + Q_2$$

$$= \frac{k_1 A_1 (\theta_1 - \theta_2)}{x_1} + \frac{k_2 A_2 (\theta_1 - \theta_2)}{x_2} \quad - ③$$

∴ Amount of heat flowing per second

$$Q = (\theta_1 - \theta_2)\left[\frac{k_1 A_1}{x_1} + \frac{k_2 A_2}{x_2}\right] \quad - ④$$

$$\Sigma Q = (\theta_1 - \theta_2) \frac{\Sigma kA}{x} \quad - ⑤$$

FORBES METHOD - Theory and 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 $= KA\left(\frac{d\theta}{dx}\right)_B$.

Consider an element of thickness dx of the rod.

Mass of the element $=(A\,dx)\rho$

ρ _ density of the rod.

Heat lost by the element per second;

= Mass x specific heat capacity x rate of fall of temperature.

$= (A\,dx)\rho \times S \times \frac{d\theta}{dt}$

Total heat lost $= \int_B^C (A\,dx)\rho\, s\, \frac{d\theta}{dt}$

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

$$\therefore KA\left(\frac{d\theta}{dx}\right)_B = \int_B^C (A\,dx\,\rho)\, s\, \frac{d\theta}{dt}$$

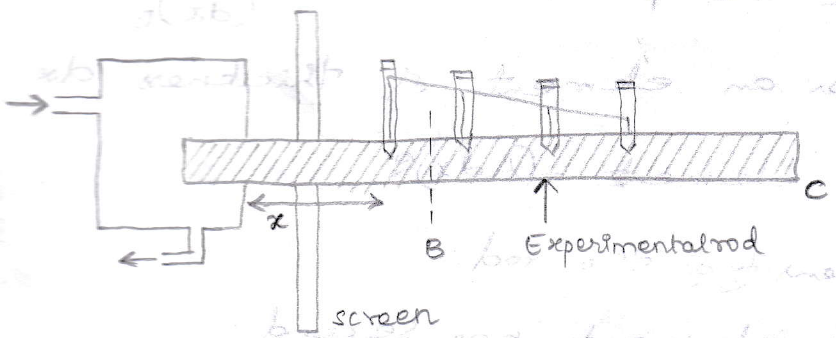
$$k = \frac{\rho s \int_B^C \frac{d\theta}{dt}\, dx}{\left(\frac{d\theta}{dx}\right)_B}$$

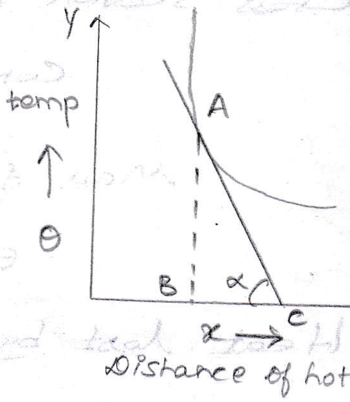
<u>Experiment Consist of two parts.</u>

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

1. Static Experiment

The specimen metal is taken in the for[m of] a long rod. One end of this rod is heated by a [steam] chamber. The rod has a series of holes into whi[ch] thermometers are fitted. These thermometers rec[ord] temperatures at different points along the rod.



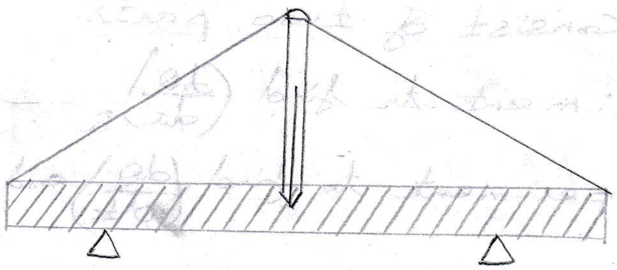


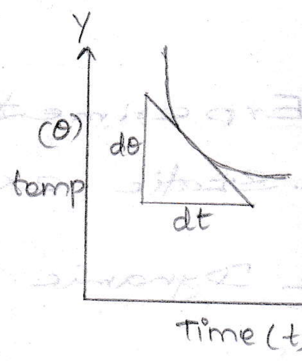
A graph is drawn between the temper[ature] and the distance (x) from the hot end.

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

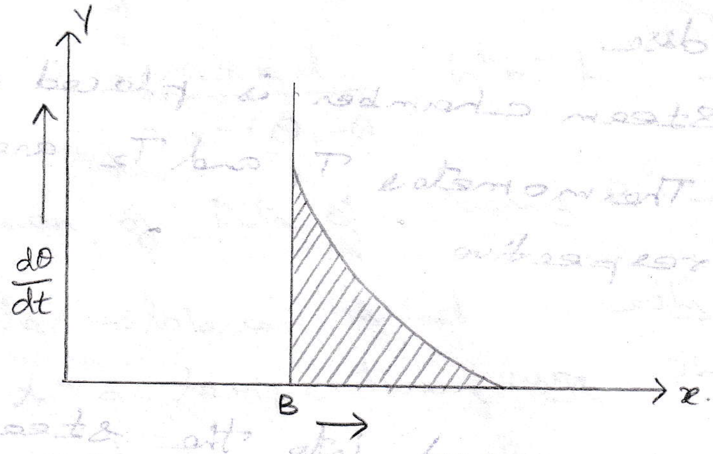
2. Dynamic experiment

The heated piece of the rod is suspend[ed] in air, it is allowed to cool. Its temperature i[s] noted at regular intervals of time by a thermometer placed in a hole at the centre.





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.



The area of the shaded portion is determined.

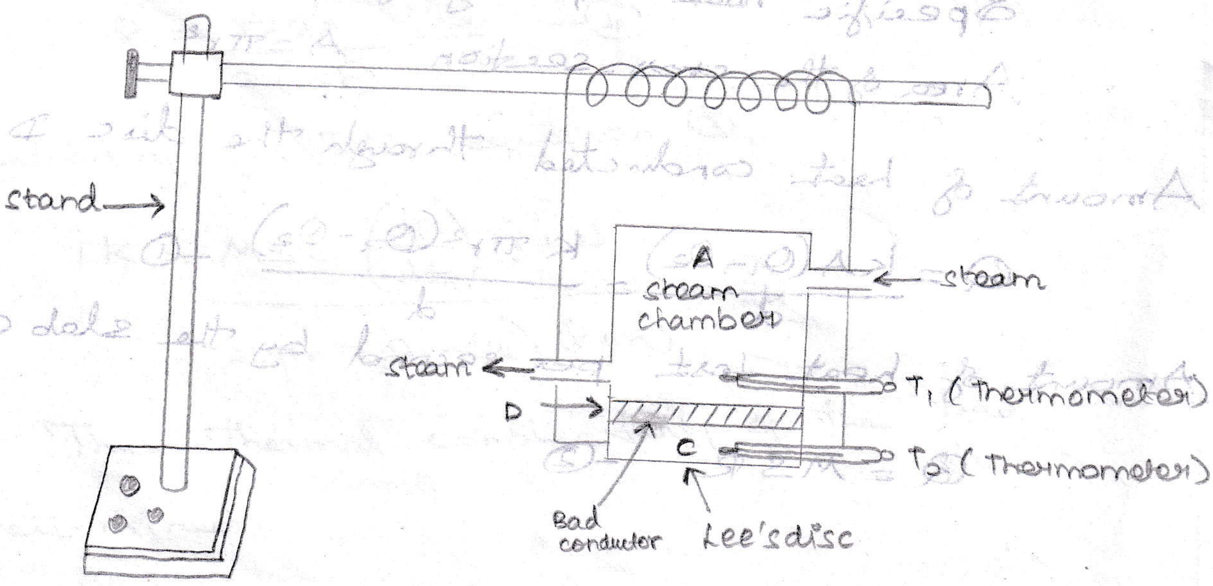
$$K = \frac{\rho s \int_B^C \left(\frac{d\theta}{dt}\right) dx}{\left(\frac{d\theta}{dx}\right)_B}$$

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

Hence K is determined.

3. Lee's Disc Method - Theory and Experiment.

The thermal conductivity of bad conductors like ebonite or card board is determined by this method.



Description:-

The apparatus consists of a circular metal

The given bad conductor (glass, ebonite) is taken in the form of a disc.

A steam chamber is placed on the bad conductor. Thermometers T_1 and T_2 are inserted to record the respective

Working:-

Steam is passed into the steam chamber until the temperatures in the chamber and the slab are steady, readings θ_1 and θ_2 are noted.

Observation and calculation:-

Thickness of the bad conductor $= d$

Radius of the bad conductor $= r$

Mass of the slab C $= M$

Steady temperature in the slab $= \theta_1$

Steady temperature in the steam chamber $= \theta_2$

Thermal Conductivity of the bad conductor $= K$

Rate of cooling of the slab at $\theta_2 = R$.

Specific heat capacity of the slab $= S$.

Area of the cross-section $A = \pi r^2$.

Amount of heat conducted through the disc D per sec

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

Amount of heat lost per second by the slab C

$$Q = MSR \quad -②$$

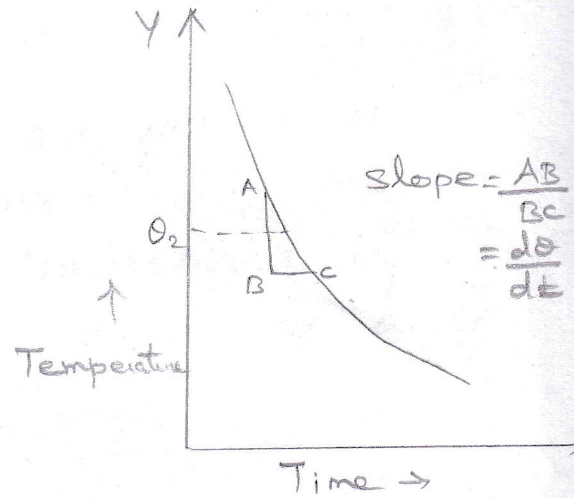
At steady state, the equations ① and ② are equal.

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

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

Determination of Rate of Cooling R :-

The slab is heated directly without bad conductor to a temperature higher than θ_2 and allowed to cool.



Total area $= \pi r^2 + 2\pi r h$
$= \pi r(r+2h)$

Orea entire surface area
$\pi r^2 + \pi r^2 + 2\pi r h = 2\pi r^2 + 2\pi r h$
$= 2\pi r(r+h)$

As the rate of cooling is directly proportional to the surfaces that are expose

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

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

Substituting for R in equation ③,

$$K = \frac{Msd\left(\frac{d\theta}{dt}\right)(r+2h)}{2\pi r^2(\theta_1-\theta_2)(r+h)} \quad -⑤.$$

Thus thermal conductivity of the bad conductor is determined.

4. Thermal Insulation and Heat Exchanger:-

THERMAL INSULATION:

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

GENERAL PRINCIPLES OF THERMAL INSULATION:

* Thermal resistance of an insulating material is directly proportional to its thickness
* Provision of an air gap is an important insulating agent.
* The heat is transferred by conduction, covection or radiation or any combination of them.

i) REDUCING HEAT TRANSFER BY CONDUCTION:

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 by conduction.

ii) REDUCING HEAT BY CONVECTION:

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 BY RADIATION:

The rate at which heat is transmitted by radiation depends on various factors. including the temperatures the surfaces and the kinds of surfaces inv

THERMAL INSULATING MATERIALS:

a.) Organic materials
b.) Inorganic materials

ORGANIC MATERIALS:

Cattle hair, silk, wool, wood-pulp, Paper.

INORGANIC MATERIALS:

Still air, slag, slag-wool, Glass-w

TYPES OF THERMAL INSULATION:

* HOUSE THERMAL INSULATION.
* INDUSTRIAL THERMAL INSULATION
* BUILDING THERMAL INSULATION.

HOUSE THERMAL INSULATION:

In a warm house during the winter, insulation in the walls, ceilings floors reduces the loss of heat from t warm interior to the colder outdoor air.

INDUSTRIAL THERMAL INSULATION:

In industry, thermal insulation used for enclosing heating equipment, p that carry steam, and cold storage spa

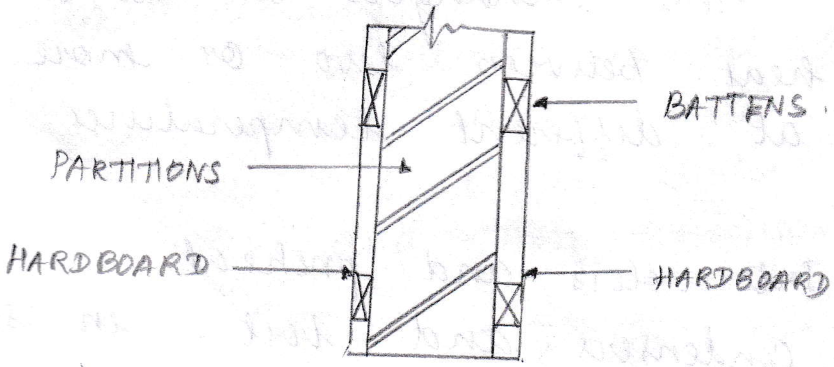
BUILDING THERMAL INSULATION:

The insulating glass or double glass with air space may be provided for glased doors and windows. This reduces heat transmission through doors and windows.

In order to reduce incidence of solar heat, the protection in the form of sun breakers, weathersheds, projections curtains, may be provided on the exposed doors and windows.

THERMAL INSULATION OF EXPOSED WALLS:

* The suitable thickness of wall may be provided
* The hollow wall or cavity wall construction may be adopted.
* For partitions, an air space may be created by fixing weathersheds, harboards on battens.



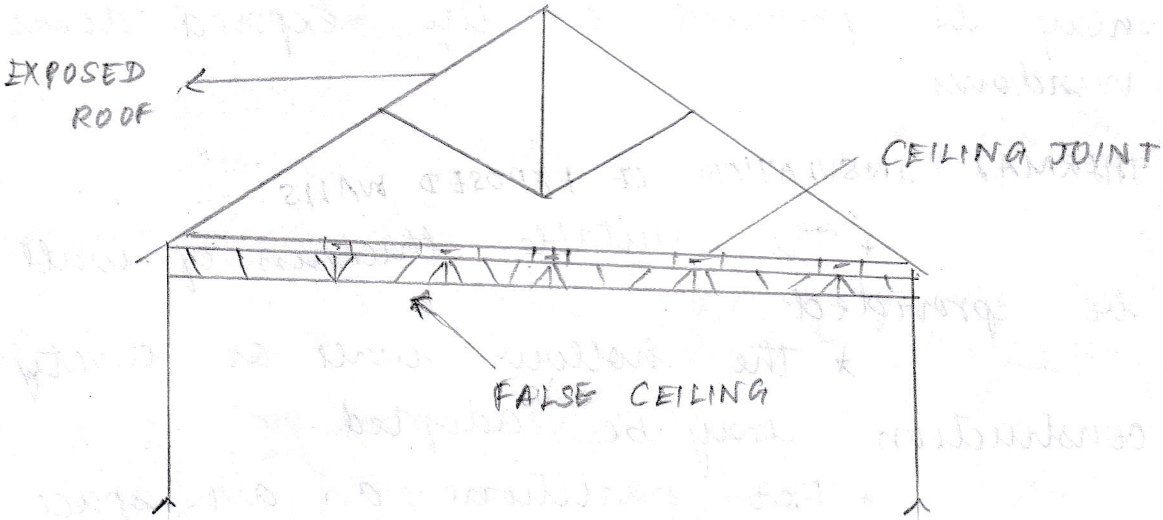
THERMAL INSULATION OF EXPOSED ROOFS:

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

INTERNAL TREATMENT:

* The false ceiling with an air ga[p] may be provided. The ceiling is made of thermal insulating materials.

* The light insulating materials m[ay] be pasted by suitable adhesives to the inside surfaces of the exposed roof.



HEAT EXCHANGERS:

Heat exchangers are devices used [to] transfer heat between two or more fluid streams at different temperatures

Examples:-

i) Intercoolers and preheaters

ii) Condensers and boilers in steam pla[nt]

TYPES OF HEAT EXCHANGERS:

NATURE OF HEAT EXCHANGE PROCESS:

i) Direct contact (or open) heat exchangers

ii) Indirect contact heat exchangers.

a.) Regenerators b.) Recuperators.

2. **RELATIVE DIRECTION OF FLUID MOTION:**

i) Parallel flow or unidirectional flow

ii) Counter flow

iii) Cross flow.

8. **DESIGN AND CONSTRUCTIONAL FEATURES:**

i) Concentric tubes

ii) Shell and tube

iii) Multiple shell and tupe passes.

A) **PHYSICAL STATE OF FLUIDS:**

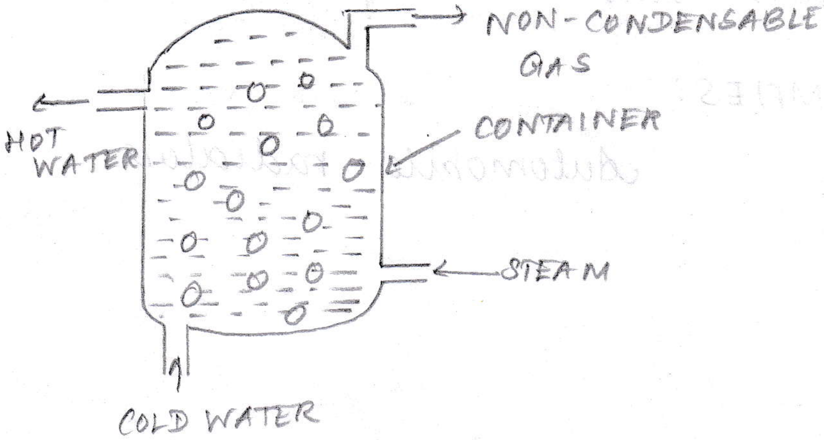
i) Condensers

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 fluid and transfer of heat and mass takes place simultaneously.

A direct contact heat exchanger in which steam mixes with cold water, gives its latent heat to water and gets condense. Hot water and non-condensable gases leave the container.



EXAMPLES

i) Cooling towers

ii) Jet condensers

iii) Direct contact feed heaters.

INDIRECT CONTACT HEAT EXCHANGER:

This type includes the following:

a.) Regenerators

b.) Recuperators or surface exchangers.

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 h flow.

Examples

i) I.C engines and gas turbines.

b.) RECUPERATORS:

These heat exchangers are used two fluids cannot be allowed to mi when the mixing is undesirable

EXAMPLES:

Automobile radiators.

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 remains the temperature below the surrounding temperature.

PRINCIPLE :-

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

DESCRIPTION :-

EXPANSION VALVE :-

An expansion valve controls the flow of the liquid refridgerant into the evaporator.

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 gas.

EVAPORATOR :-

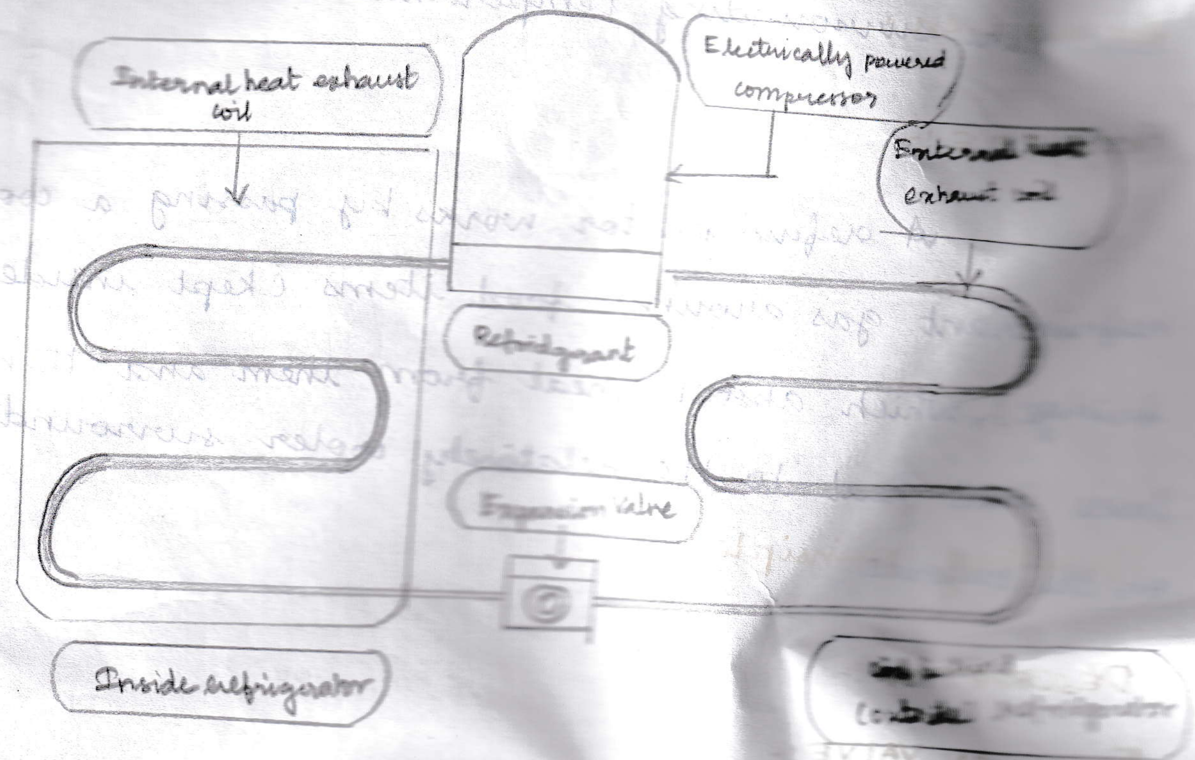
The evaporator absorbs heat from the stuff kept inside and as a result of this heat, the liquid refridgerant turns into vapour.

CONDENSER :-

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

REFRIDGERANT :-

Also commonly referred to as the coolant. It is liquid that keeps the refrigeration cycle going.



WORKING :-

The refrigerant (liquid) passes thro' expansion valve turns into gas. It is passed through chiller cabinet, it absorbs the heat from food item & vaporizes.

It flows into compressor, which suck and compresses the molecules together

gas transferred to the condenser coils, it dissipiates its heat so that it become cool and convert back into liquid phase.

The liquid refrigerant travel back to the expansion valve and once again becomes a cool gas

It absorbs heat from the contents of the fridge and whole cycle repeats.

OVEN :-

An Oven is a thermally insulated chamber used for heating, baking or drying of a substances and most uncommonly used for cooking.

Hot air Oven :-

The electrical device which is widely used in medical products industries, rubber industries, 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.

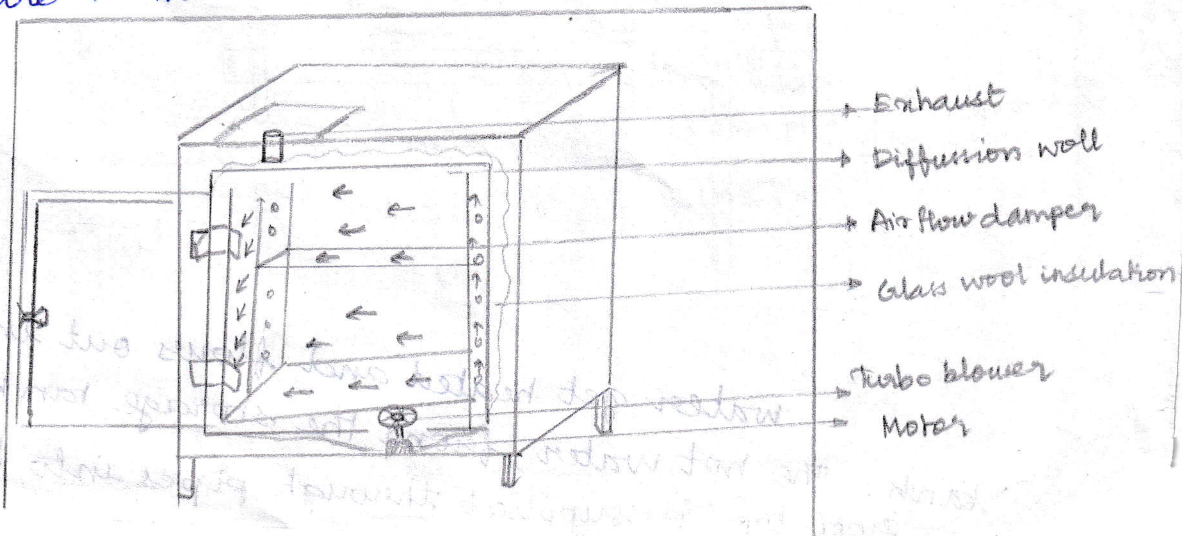
Operating principle :-

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

Description :-

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

The roof provided with a hole through which a thermometer is fitted inside for recording of temperature. The oven has two or three shelves.



Working :-

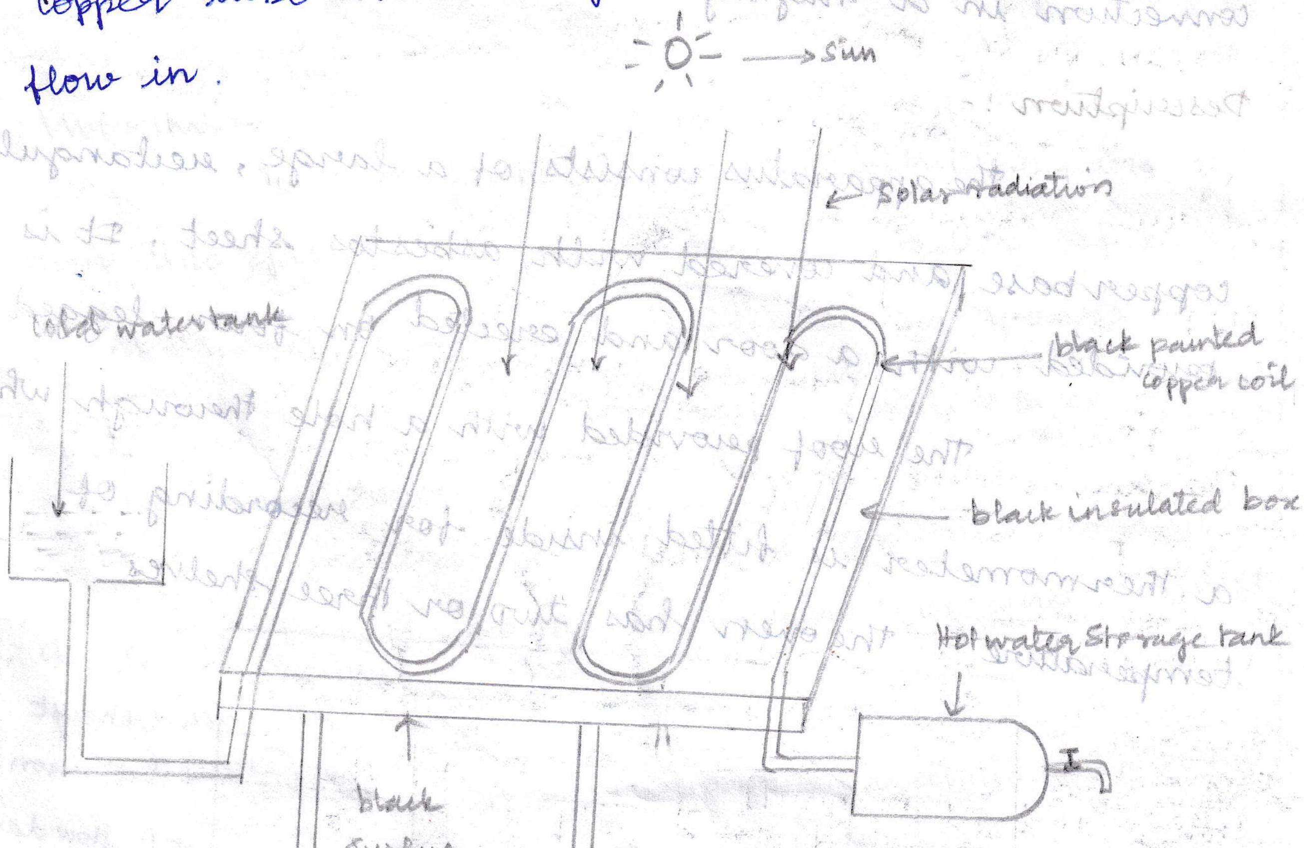
. After wrapp loading brownpaper wrapped glassware oven is switched on.

Temperature slowly increase upto desired point (160°C), the oven is kept for an hour.

This is the appropriate temperature for sterligation gradually temperature is brought down and thereafter sterligation is complete.

SOLAR WATER HEATER :-

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



water get heated and flows out into a storage tank. The hot water from the storage tank fitted on roof-top is supplied through pipes into building.