MODULE-1

MECHANISM OF HEAT TRANSFER BY CONDUCTION , CONVECTION, RADIATION AND EVAPORATION

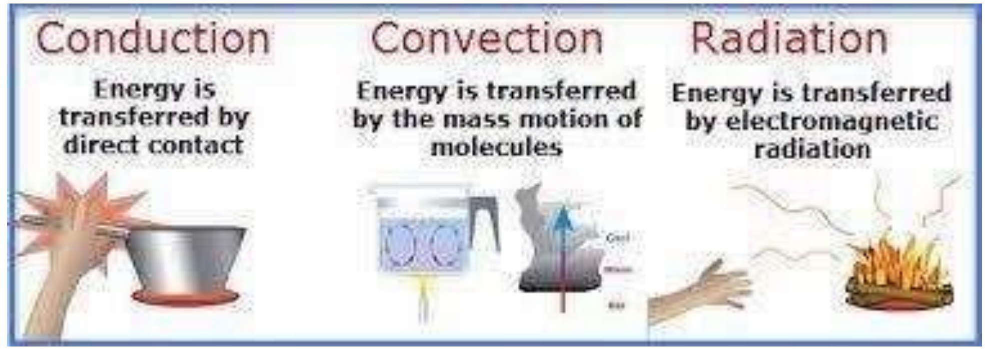
- Define conduction ,Convection, Radiation
- Define thermal conductivity and Fourier's law of thermal conduction
- Derivation of conduction equation for a plane wall
- Solve the simple problems based on Fourier's law and conduction in plane wall
- Derive the equation to calculate heat transfer through composite plane wall
- Derive the equation to calculate heat transfer through cylindrical wall
- Derive the equation to calculate heat transfer through spherical wall
- Solve the problems using the equation derived

- Explain the mechanism of natural convection
- Explain the heat transfer in boiling liquid and regimes of boiling
- An elementary idea of black body, gray body, emissivity, absorptivity, radiation laws and Stefan Boltzmann equation , Heat Transfer equipments
- An idea of parallel flow, counter current flow and cross flow heat exchangers
- Explain the working Shell and Tube Heat Exchanger and Double pipe heat exchanger with diagram
- Mention the various types of evaporators and the basis for classification
- Explain the working of horizontal, vertical and multiple effect evaporators

HEAT TRANSFER

- ✓ Deals with the study of rates at which exchange of heat takes place between a hot surface and a cold receiver.
- ✓ If two bodies at different temperatures are brought into thermal contact, heat flows from a hot body to a relatively cold body.
- ✓ The net flow of heat is always in the direction of decrease in temperature.
- ✓ Thus heat is defined as a form of energy which is in transit (transfer) between a hot source and a cold receiver.
- ✓ The transfer of heat depends upon the temperature of the bodies.

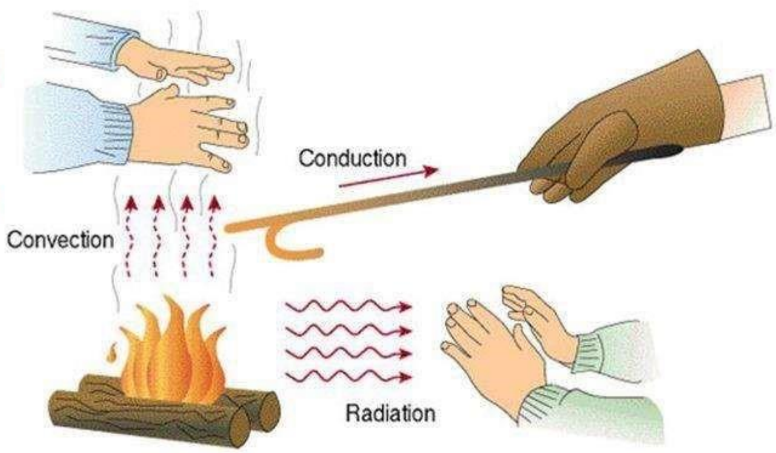
MODES OF HEAT TRANSFER



How is Heat Transferred?

There are THREE ways heat can move.

- **Conduction**
- **Convection**
- **Radiation**



MODES OF HEAT TRANSFER

HEAT TRANSFER

- Conduction is the transfer of heat from one part of a body to another part of the same body or from one body to another which is in physical contact with it.
- Convection is the transfer of heat from one point to another point within a fluid (gas or liquid) by mixing of hot and cold portions of the fluid. Convection is restricted to the flow of heat in fluids.
- Radiation refers to the transfer of heat energy from one body to another through space by electromagnetic waves

Different ways of heat transfer

CONDUCTION

- Conduction refers to the mode of heat transfer in which heat flow though the material medium occurs without actual migration of particles of the medium from a region of higher temperature to a region of lower temperature
- Heat conduction occurs by the migration of molecules and more effectively by the collision of the molecules vibrating around relatively fixed positions

STEADY STATE UNIDIRECTIONAL HEAT CONDUCTION IN SOLIDS

- Steady state heat flow means the temperature at any location along the heat flow path does not vary with time and the rate at heat transfer does not vary with time
- Temperature varies with location but not with time

FOURIERS LAW/ LAW OF HEAT CONDUCTION

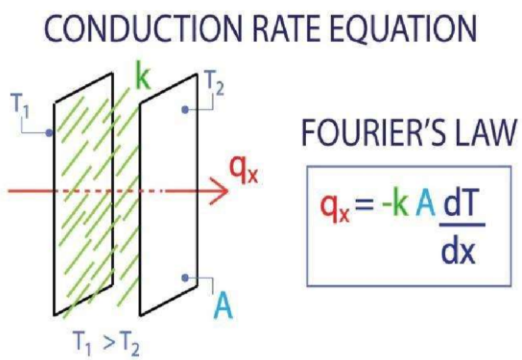
Fourier’s law states that “rate of heat flow by conduction through a uniform (fixed) material is directly proportional to the area normal to the direction of the heat flow and the temperature gradient in the direction of heat flow.

OR

Fourier’s law states that: “the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area.”

Temperature gradient: the rate of change of temperature with displacement in a given direction, here temp gradient is negative since with an increase in n there is a decrease in T, i.e. temperature decreases in the direction of heat flow

FOURIERS LAW/ LAW OF HEAT CONDUCTION



Where,

'Q' is the rate of heat flow/transfer by conduction (Watts, W)

'K' is the thermal conductivity of body material ($Wm^{-1}K^{-1}$)

'A' is the cross-sectional area normal to direction of heat flow (m^2)

'dT/dx' is the temperature gradient (Km^{-1})

Heat flux is defines as the rate of heat flow per unit area or amount of heat transfer per unit area per unit time in W/m^2 (heat flux, q = Q/A)

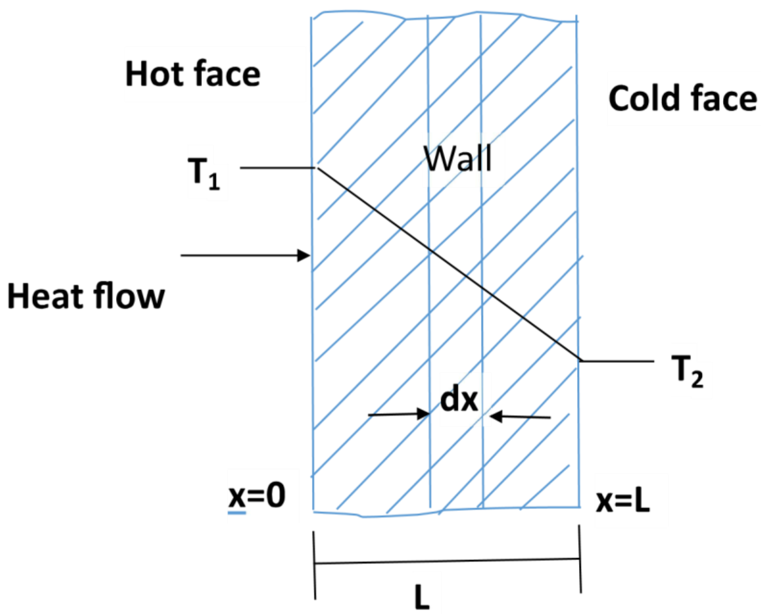
$$\boxed{\underline{q} = -k\,\nabla T}$$

THERMAL CONDUCTIVITY

- Measure of the ability of a substance to conduct heat.
- **Thermal conductivity is the quantity of heat passing through a quantity of material of unit thickness with unit heat flow area in unit time when a unit temperature difference is maintained across the opposite faces of material.**
- Thermal conductivity depends on the nature of material and its temperature.
- Larger the values of K, higher will be the amount of heat conducted by that substance.
- It is a characteristics/transport properties of a material through which heat is flowing and varies with temperature.
- Thermal conductivities of solids are higher than that of liquids and liquids are having higher thermal conductivities than gases. { Metals : good conductors of heat}
- Air-0.02 W/mK   Water-0.6 W/mK   Iron-80 W/mK

CONDUCTION THROUGH PLANE WALL

- Consider that the wall is made of a material of thermal Consider a plane / flat wall as in figure conductivity, K and is of uniform thickness (x) and constant cross sectional area (A).
- Assume that k is independent of temperature and area of wall is very large in comparison with the thickness so that heat losses from the edges are negligible.
- A hot face is at a temperature T_1 and cold face at a temperature T_2 and both are isothermal surfaces (Surface, at all points of which the temperature is the same).
- The direction of heat flow is perpendicular to the wall and T varies in the direction of x-axis.



CONDUCTION THROUGH PLANE WALL

As in steady state, Q is constant along the path of heat flow. The Fourier's law equation can be integrated over the entire path from =0 to x=L (total thickness of the wall)

$$\dot{Q}_{cond,wall} = -k\,A\,\frac{dT}{dx} \qquad \text{(Fourier's law of conduction)} \longrightarrow 1$$

The variables in (1) are x and T

$$\int_{x=0}^{x=L} \dot{Q}_{cond,wall}\,dx = -\int_{T_1}^{T_2} kA\,dT \qquad \dot{Q}_{cond,wall} = k\,A\,\frac{T_1 - T_2}{L} \longrightarrow 2$$

Rearranging the above equation

$$\boxed{\dot{Q}_{cond,wall} = \frac{T_1 - T_2}{\left(\frac{L}{kA}\right)}} \longrightarrow 3$$

$$\dot{Q}_{cond,wall} = \frac{T_1 - T_2}{(R_{wall})}$$

$$\boxed{\text{Thermal resistance, } R_{wall} = \left(\frac{L}{kA}\right)}$$

CONDUCTION THROUGH PLANE WALL

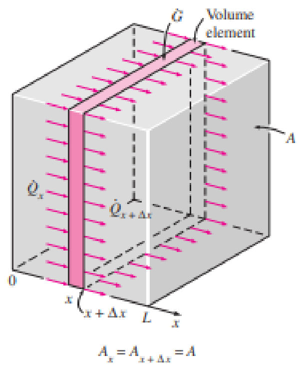
CONDUCTION THROUGH PLANE WALL

The reciprocal of resistance is called conductance, which for heat conduction is

Conductance = 1/ R = KA/L

Both the resistance and conductance depends upon the dimensions of a solid as well as on the thermal conductivity, a property of material.δ

ONE DIMENSIONAL HEAT CONDUCTION EQUATION



$$\begin{pmatrix}\text{Rate of heat}\\ \text{conduction}\\ \text{at } x\end{pmatrix} - \begin{pmatrix}\text{Rate of heat}\\ \text{conduction}\\ \text{at } x+\Delta x\end{pmatrix} + \begin{pmatrix}\text{Rate of heat}\\ \text{generation}\\ \text{inside the}\\ \text{element}\end{pmatrix} = \begin{pmatrix}\text{Rate of change}\\ \text{of the energy}\\ \text{content of the}\\ \text{element}\end{pmatrix}$$

$$\lim_{\Delta x \to 0} \frac{\dot{Q}_{x+\Delta x} - \dot{Q}_x}{\Delta x} = \frac{\partial \dot{Q}}{\partial x} = \frac{\partial}{\partial x}\left(-kA\frac{\partial T}{\partial x}\right)$$

Alpha : Thermal Diffusivity

Variable Conductivity

$$\frac{\partial}{\partial x}\left(k\,\frac{\partial T}{\partial x}\right) + \dot{g} = \rho C\,\frac{\partial T}{\partial t}$$

Constant Conductivity

$$\frac{\partial^2 T}{\partial x^2} + \frac{\dot{g}}{k} = \frac{1}{\alpha}\,\frac{\partial T}{\partial t}$$