Radiation And Heat Transfer

1. Introduction

- We already know that heat is the energy transferred from from one systm to another or from one part of the system to its another part , arising due to temperature difference.
- Heat can be transferred from one place to other by through three different modes conduction,convection & radiation.

2. Thermal Conduction

- Conduction of heat takes place in a body when diffrent part of body are at diffrent temperature.
- To notice conduction of heat put one end of metal rod on flame and another end on your hand. After some time you will feel hotness in your hand also.
- Here heat transfer takes place from hot end on flame to cold end in your hand through conduction.
- How heat transfers through conduction is given in steps below
  1)Molecules at hot end of the rod begin to vibrate as there is an increase in the energy of vibration as temperature of the end of rod on flame increases.

  2)These vibrating molecules then collides with the nearest neighbour sharing their energy with them and increasing their energy.

  3)These neighbouring molecules further pass their energy to molecules on colder end of the rod i.e farther from the end put on flame.

  4)This way energy of thermal motion is passed along from one molecule to the next keeping their original position fixed.
- Metals are good conducters of electricty as well as heat.

3. Thermal Conductivity

- Ability of Material to conduct heat is measured by thermal conductivity of that material.
- Consider a slab of uniform crossection A and length L also one face of slab is kept at Temperature T_1 and another at T_2 and remaining surface area is covered with a non conducting material to avoid transfer of heat.

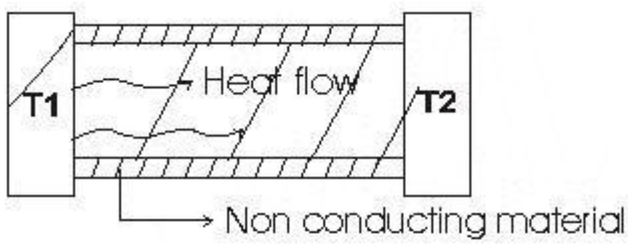

Figure 1

- After sufficient time slab reaches steady state temperarure at every point will remain unchanged.

- In steady state, rate of flow of the heat through any crosssection of slab is
  a) directly propertional to area A
  b) directly propertional to temperature diffrence (T_2-T_1)
  c) inversely propertional to length

- Thus if H is the quantity of heat flowing through slab per unit time then

$$H \propto \frac{A(T_2 - T_1)}{L}$$

$$H = \frac{kA(T_2 - T_1)}{L}$$

- where k is a constant whose numerical value depends on the material and is called thermal conductivity of the material.

- S.I. unit of thermal conductivity is $Js^{-1}m^{-1}K^{-1}$.

- For small amount of heat dQ flowing between two faces of slab in small time interval dt,

$$dQ = \frac{kA(T_2 - T_1)dt}{L}$$

- Materials for which K is large are good conductors of heat, while small value of K for a material implies material is poor conductor of heat.

4. Convection

- Convection is transfer of heat by actual motion of matter
- If material is forced to move by a blower or pump the process is called forced convection.

- If the material flows due to difference in density for example that caused by thermal expansion then the process is called natural of free convection.

- Meahanism of heat transfer in human body is forced convection. Here heart serves as the pump and blood as the circulating fluid.

5. Radiation

- Radiation process does not need any material medium for heat transfer.
- Term Radiation refers to the continous emission of energy from surface of all bodies and this energy is called radient energy.

- Radiant energy is in the form of Electro Magnetic waves.
- Radiant energy emitted by a sunface depends on the temperature and nature of the surface.

- All bodies whether they are solid, liquid or gas emit radiant energy.
- EM radiations emitted by a body by virtue of increased temperature of a body are called thermal radiation.

- Thermal radiation falling on a body can partly be absorbed and partly be reflected by the body and this absorption and reflection of radiation depends on the color of body.

- Thermal radiation travels through vacuum on straight line and with the velocity of light.

- Thermal radiations can be reflected and refracted.

6. Black Body Radiation

- A body that absorbs all the radiation falling on it is called a black body.

- Radiation emitted by black body is called Black Body radiation.

- A black body is also called an ideal radiator.

- For practical purpose black body can be considered as an enclosure painted black from inside and a small hole is made in the wall.

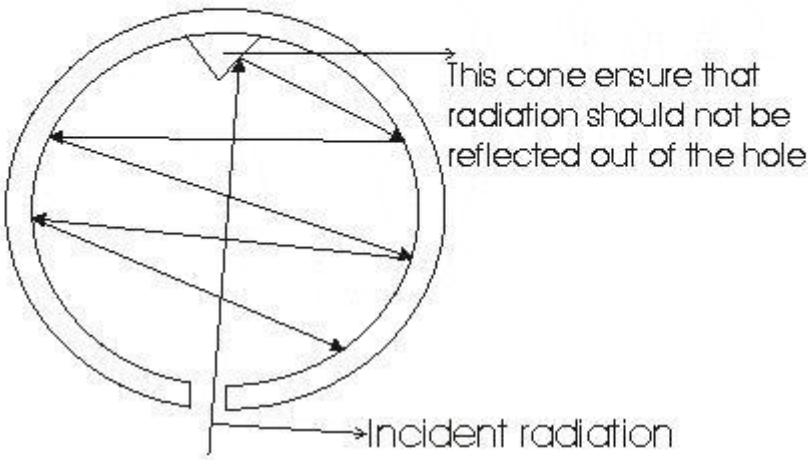

Figure 2

- Once radiation enters the enclosure it has very little chance to come out of the hole and it gets absorbad after multiple refrections inside thenclosure.

7. Stefan Boltzmann law

- The rate u_{rad} at which an object emits energy via EM radiation depends on objects surface area A
  and temperature T in kelvin of that area and is given by
  $u_{rad} = \sigma\varepsilon A T^4$ (2)
  Where
  $\sigma = 5.6703\times10^{-8}\ W/m^2K^4$
  is stefan boltzmann constant and ε is emissivity of object's sunface with value between 0 and 1.

- Black - Body radiator has emissivity of 1.0 which is an ideal limit and does not occuer in nature.

- The rate u_{abs} at which an object absorbs energy via thremal radiation from its environment with temperature T_{env} (in kelvin) is
  $u_{abs} = \sigma\varepsilon A(T_{env})^4$ (3)
  Where ε is same as in equation 2

- Since an object radiate energy to the enviornment and absorbe energy from environment its net energy enchange due to thermal radiation is
  $u = u_{abs} - u_{rad}$
  $= \sigma\varepsilon A\{(T_{env})^4 - T^4\}$ (4)

- u is positive if net energy is being absorbed via radiation and negative if it is being lost via radiation.

8. Nature of thermal Radiation

- Radiation emitted by a black body is a mixture of waves of different wavelengths and only a small range of wanelength has significant countribution in the total radiation.
- A body is heated at different temperature and Enegy of radiation is plotted agains wavelength is plotted for different temperature we get following curves.

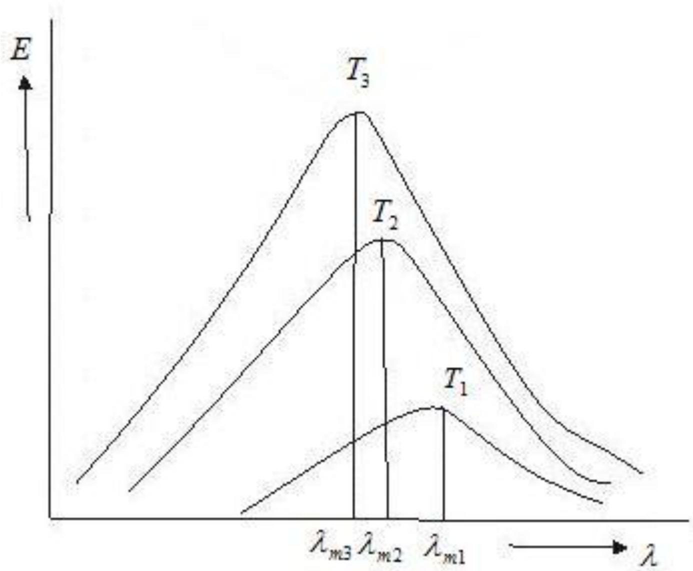

Figure 3

- These curves show
  (i) Energy is not uniformly distributed in the radiation spectreum of black body.

  (ii) At a given temperature the intensity of radiations increases with increase in wavelength, becoms maximum at particular wavelength and further increase in wavelngth leads to decrease in intensity of heat radiation.

  (iii) Increase in temperature causes increase in energy emission for all wavelengths.

  (iv) Increase in temperature causes decrease in λ_m, where λ_m is wavelenght corresponding to highest intersity. This wavelength λ_m is inversily properational to the absolute temperature of the emitter.

  $\lambda_m T = b$ (5)

  Where b is a constant and this equation is known as Wein's displacement law.

  $b=0.2896\times10^{-2}$ mk for black body and is known as Wien's constant.

9. Kirchoff's law

- Good absorbers of radiation are also good radiaters this statement is quantitatively explained by Kirchoff's law.

  (i) Emissive Power -

  Emissive power denotes the energy radiated per unit area per unit solid angle normal to the area.

E = Δu/ [(ΔA) (Δω) (Δt)]
where, Δu is the energy radiated by area ΔA of surface in solid angle Δω in time Δt.

(ii) Absorptive Power -
Absorptive power of a body is defined as the fraction of the incident radiation that is absorbedby the body
a(absorptive power) = energy absorbed / energy incident

(iii) Kirchoff's Law
"It status that at any given temperature the ratio of emissive power to the absorptive power is constant for all bodies and this constant is equal to the emissive power of perfect B.B. at thesame temperature.
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10. Newton's Law of Cooling

- Consider a hot body at temperature T_1 is placed in surrounding at temperature T_2.

- For small temperature difference between the body and surrounding rate of cooling is directly proportional to the temperature difference andsurface area exposed i.e.,
  $dT/dt = - bA (T_1 - T_2)$

- This is known a Newton's law of cooling.

  b depends on nature of surface involved and the surrounding conditions. Negative sign is to indicate that $T_1 > T_2$, dT/dt is negative and temperature decreases with time
- According to this law, the rate of cooling is directly prospertional to the excess of temperature.