SNS COLLEGE OF TECHNOLOGY

Coimbatore-35
An Autonomous Institution

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DEPARTMENT OF FOOD TECHNOLOGY

UNIT 1 – CONDUCTION

Topic 1 Basic concepts

HEAT TRANSFER

✓ Any matter which is made up of atoms and molecules has the ability to transfer heat

✓ According to thermodynamic systems, heat transfer is defined as

"The movement of heat across the border of the system due to a difference in temperature between the system and its surroundings."

❑ Mechanism of heat transfer

✓Heat can travel from one place to another in several ways. The different modes of heat transfer include:

- Conduction
- Convection
- Radiation

CONDUCTION

❖Conduction

- Heat transfer occurs via two mechanisms
  1. Molecules at high energy level (Temperature exchange energy to the adjacent molecules at lower energy by the kinetic motion or direct impact of molecules
  2. By the drift of free electron in metallic solids
- Conduction eg : - Ironing of clothes, Heat transfer from hands to ice cube

Conduction

Physical law for heat transfer by conduction given by Fourier in 1822.

– Rate of heat conduction $\propto$ to the area measured normal to the direction of heat flow and to the temp gradient in that direction.

$$Q = -KA\frac{\partial T}{\partial n} \quad \text{or} \quad q = -K\frac{\partial T}{\partial n}.$$

K – coeff of thermal conductivity.

– ability of a substance to conduct heat

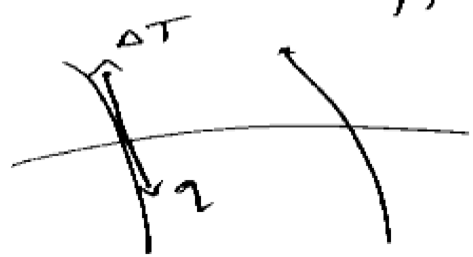
CONDUCTION

- Quantity of heat flux transferred per unit time / unit area of isothermal surface – heat flux

$$q = -n_i k \frac{\partial T}{\partial n}$$

heat flux normal to isothermal surface, +ve in the direction of ↓ temp. acc to 2^{nd} law of thermodynamics heat flows from hot to cold one.

Vectors grad T and q are both normal to isothermal but even in opp direction.



greatest heat flow rate – along the lines normal to isothermal surfaces.

$$Q_x = -k_x A \frac{\partial T}{\partial x} \quad \text{or} \quad q_x = \frac{Q_x}{A} = -k_x \frac{\partial T}{\partial x}$$

$$Q_y = -k_y A \frac{\partial T}{\partial y} \quad \text{or} \quad q_y = \frac{Q_y}{A} = -k_y \frac{\partial T}{\partial y}$$

$$Q_z = -k_z A \frac{\partial T}{\partial z} \quad \text{or} \quad q_z = \frac{Q_z}{A} = -k_z \frac{\partial T}{\partial z}$$

CONDUCTION

heat tran. eqn $\Rightarrow \dot{Q}_x = -KA \frac{\partial T}{\partial x}$.

$Q_x \int_0^L dx = -KA \int_{T_0}^{T_L} dT$ or $Q_x = \frac{KA}{L}(T_0 - T_L)$

L – thickness of plane wall

T_0 & T_L – on its two sides

– k – W/m°C or W/mK.

heat flux, q – W/m² – temp gradient = °C/m.

– Pure metals have highest values of thermal conductive where gases and vapours – lowest.

insulating mat → in b/w metals & gases.

– Insulating mat – ↓ condu – bcz – in building mat – they have porous structure with some fluid in air trapped – it's a bad conductor.

Convection

- The movement of fluid molecules from higher temperature regions to lower temperature regions.
- When a fluid flows inside a duct or over a solid body and the temperatures of the fluid and the solid surfaces are different, heat transfer between the fluid and solid surface will takes place.
    1. Natural convection – If the fluid motion is set up by the buoyancy effects resulting from the density variation caused by the temperature difference in the fluid, heat transfer happens
    2. Forced convection – When the fluid motion is artificially created
- Convection is always accompanied by conduction
- Convection eg: Boiling of water, Blood circulation

Convection

- For a fluid flowing at a mean temp T_∞ over a surface at a temp T_s heat convection eqn

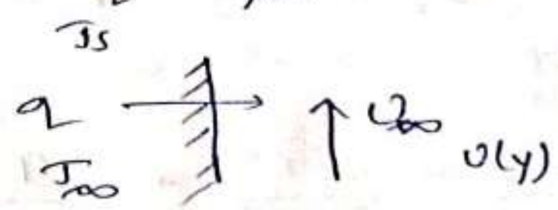
$$q = Q/A = h(T_s - T_\infty) = h\,\Delta T \quad \text{——— (1)}$$

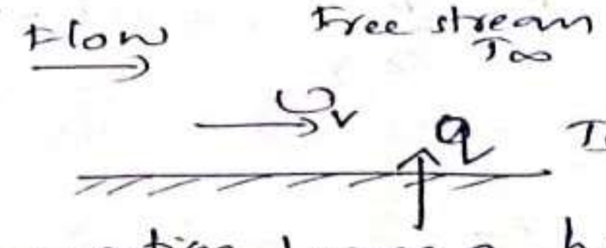
Newton's law of cooling

q - heat flux at wall. h - heat transfer coefficient

h - unit - $W/m^\circ C$ or W/mK.

$q - W/m^2$





convection from a heated plate

- $U_v = 0$, bcz no slip condition
  - The v wrt surface is 0
- Temp gradient is dependent upon the rate at which fluid carries the heat away, which in turn depend on v, other thermal ppty

$$h = \frac{K}{T_s - T_\infty} \left.\frac{\partial T}{\partial y}\right|_{y=0}$$

$$\frac{Q}{A} = h(T_s - T_\infty)$$

$$= \frac{K\,\partial T}{\partial y} = h(T_s - T_\infty)$$

$$h = \frac{K}{T_s - T_\infty} \left.\frac{\partial T}{\partial y}\right|_{y=0}$$

Pblm

A flat plat of length 1 m and width 0.5 m is placed in an air stream at 30°c blowing parallel to it. The convective heat transfer coefficient is 30 W/m^2K. Calculate the heat transfer if the plate is maintained at a temperature of 300°c.

$$Q = hA(T_s - T_\infty)$$

$l = 1m$

$w = 0.5m.$

$$= 30(1.0)(0.5)(300-30)$$

$$= 4.05 \text{ KW}$$

$= 4050 W$

$= 4.05 KW$

Thermal Radiation

Acc to stefan Boltzmann law, the radiation energy emitted by a body is proportional to the fourth power of it's absolute temperature

$$Q = \sigma A T_1^4$$

σ – stefan Boltzman constant $= 5.6697 \times 10^{-8} W/m^2K^4$

T_1 – surface temp

– Consider a black body (a perfect emitter and perfect absorber) of surface area A_1, and at an absolute temperature T_1, exchanging radiation with another black body at a temp T_2.

Net heat exchang is $\propto$ to diff in T^4

$$Q = \sigma A_1 (T_1^4 - T_2^4)$$

- if it is a polished metal plate, do not radiate as mu[ch] energy as black body., introducing a factor ϵ_1. called emissivity. which relates gray and black bod[y] at same temp
- gray body - imperfect black body - partially absorbs

$$Q = \sigma A_1 \epsilon_1 (T_1^4 - T_2^4)$$

While considering, geometry, and orientation of 2 black bod surfaces exchanging radiation.

$$Q = \sigma A_1 \epsilon_1 F (T_1^4 - T_2^4)$$

F - view factor - depend on geometry.

Pblm

A radiator in a domestic heating system operates at a surface temp of 55°c. Determine the rate at which it emits radiant heat per unit area if it behaves as a black body.

- $\frac{Q}{A} = q = \sigma T^4 = 5.6697 \times 10^{-8} (273+55)^4 = 0.66\ kW/m^2$

Driving potential

Fourier's eqn can also be written as.

$$Q_x = \frac{KA}{L} \Delta T = \frac{\Delta T}{L/KA}$$

Now consider, heat transfer rate as flow and (L/KA) as resistance to the flow.

$$\text{Heat flow} = \frac{\text{Thermal potential diff}}{\text{Thermal resistance}}$$

$$Q = \frac{\Delta T}{R_{th}}$$

$$\frac{1}{R_{th}} = K \text{ (thermal conductance)}$$

= equal to the amount of heat conducted through a solid of area A, L, ΔT

$$K = \frac{KA}{L}$$

Convection, $Q = hA\Delta T = K_c \Delta T = \frac{\Delta T}{R_c}$

Where $R_c = 1/hA$, $K_c = hA$

Radiation, $Q = \sigma A_1 \epsilon_1 F(T_1^4 - T_2^4) = K_r \Delta T = \frac{\Delta T}{R_r}$

where

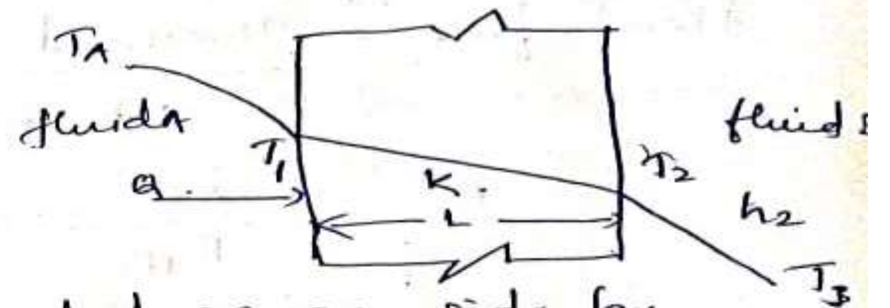
$$K_r = \frac{\sigma A_1 F(T_1^4 - T_2^4)}{\Delta T}, \quad R_r = \frac{\Delta T}{\sigma A_1 \epsilon_1 F(T_1^4 - T_2^4)}.$$

Combined Mechanisms of Heat Transfer

- Steam generating tubes of a boiler recieve heat from the pdts of combustion by all three modes of heat transfer.

$Q = UA\Delta T$ U- Overall heat transfer coef

- U -



In case of plane wall, heated on one side by hot fluid A and cooled on other side by cold fluid B heat transfer rate is given by

$$Q = h_1 A (T_A - T_1) = \frac{KA}{L}(T_1 - T_2) = h_2 A (T_2 - T_B)$$

$$T_A - T_1 = \frac{Q}{h_1 A} \quad \text{—— (1)}$$

$$T_1 - T_2 = \frac{Q}{\frac{KA}{L}} \quad \text{—— (2)}$$

$$T_2 - T_B = \frac{Q}{h_2 A} \quad \text{—— (3)}$$

* Governing by the equation Fick's law

$$N = D \frac{dc}{dn}.$$

N - Rate of mass flux of the diffusing component measured in moles per second per unit area

D - coeff of molecular diffusion or diffusivity

dc/dn - local concentration gradient of the diffusing component.

- if c expressed in mol / v - then D - m^2/s

- Mass transfer may also take place due to convection between a moving fluid and a surface & between 2 relatively immiscible liquids / fluids both under natural and forced convection.

- Convective Mass transfer ; $N = h_m \Delta C$

h_m - convective mass transfer coefficient

ΔC - concentration gradient b/w the boundary surface conc^n & avg conc^n of the diffusing fluid stream.

SI Units

1) Force = mass x acceleration

1 Newton Force = 1 kg m/s^2.

2) Work, 1 J = 1 kg m^2/s^2. = 1 Nm

3) Power, 1 W = 1 J/s = 1 kg m^2/s^3

4) Pressure ; 1 bar = $10^5 N/m^2$ = 10^5 kg/ms^2.

1 atm = 1.013 bar.

5) Thermal conductivity, - W/mK.

6) Heat transfer coefficient - W/m^2K.

7) Specific heat - J/kg K.

8) Heat flux - W/m^2.