MADE EASY

Mechanical Engineering

Toppers Handwritten Notes

Heat And Mass Transfer

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H.T.

Conductive

↓ S, L, G.

Forier eqn.

$$q = -KA\frac{dT}{dx}$$

↓

solids.

- Metals
- Nonmetals

~~lattice vibration~~

- Metals:
  - lattice
  - electron flow,
- Nonmetals: lattice

Convection

↓ fluids

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

(fluids)

liquids & gases

↳ molecular collision

Thermal Radiation

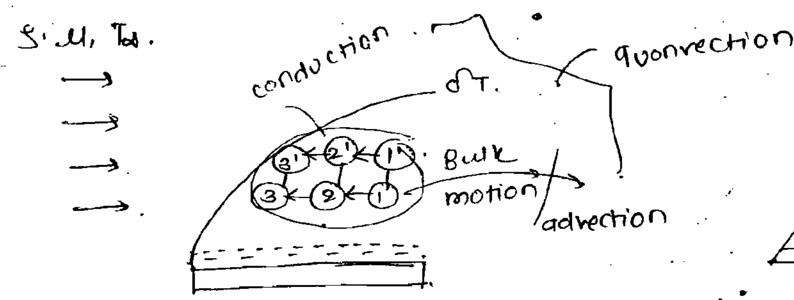
All medium / without medium.

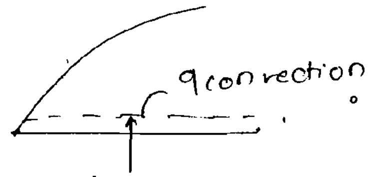
Stefan boltzman law

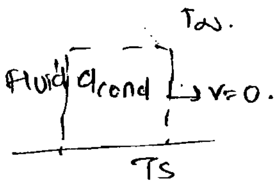
$$E_b = \sigma T^4$$

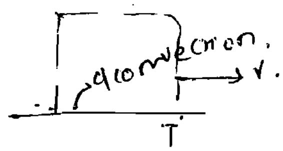
Energy transfer:-

- Energy transfer defined by rate of energy transfer known as heat transfer. rate.
- If it is due to temp. difference within the body or both bodies.
- The temp. of the body may be function of space & time
  $T = f(x, y, z, t)$. so HT rate is due either due to change of temp. within space or with time









$$Nu = \frac{(q_{conv})}{(q_{cond})_f}$$

conduction

$q_{adv} = 0$.

$q_{convection}$

$= q_{cond} + q_{adv}$

$$Nu = \frac{q_{cond} + q_{adv}}{q_{cond}} = 1 + \frac{q_{adv}}{q_{cond}}.$$

adv = 0 ⟶ cond^n.

∴ Nu = 1.

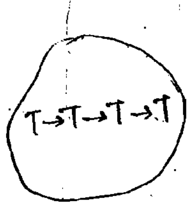
adv ≠ 0 ⟶ convection

Nu > 1.

$$Nu = \frac{hA(T_s - T_\infty)}{k_f A \frac{(T_s - T_\infty)}{L_c}} \quad \therefore Nu = \frac{hL_c}{k_f} \longrightarrow \text{fluid.}$$

<u>Note</u>:-

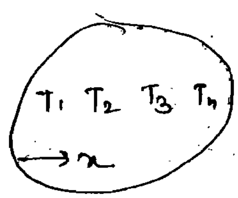
Unifor



$\frac{dT}{dx} = 0$

$T \neq f(x)$

Non uniform.



$\frac{dT}{dx} \neq 0$.

$T = f(x)$

$T = f(t)$

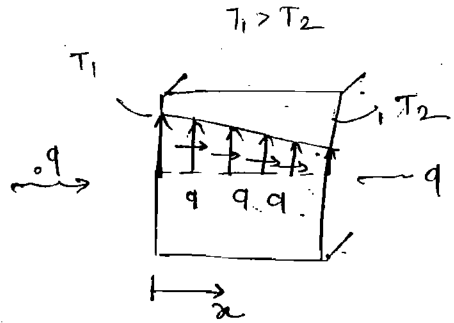
unsteady state

$\frac{\partial T}{\partial t} \neq 0$.

$T \neq f(t)$

steady state

$\frac{dT}{dt} = 0$.



Steady state $q \neq f(x)$

↓

$T \neq f(time)$

↓

$\frac{dT}{dt} = 0$

↓

$T = f(x)$ — Nonuniform

* Application of Heat Transfer:-

Condenser, evaporator, transformer, IC engine, electronic devices, Heat exchanger etc.

Thermodynamic	Heat Transfer.
① It is the science which ~~deals the heat transfer~~ (amount) from one equillibrium state to another without concerned with time.	① It defines the rate of the heat transfer

* Mechanism of Heat transfer:- (mode):-

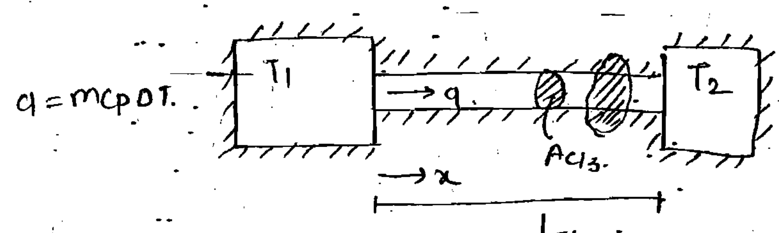
① conduction

② Convection

③ Radiation

① Conduction mechanism:- (Microscopic form of energy transfer)

- The conduction heat transfer occurs due to temp. difference within the medium (liquids, solids or gases) or betn different mediums. (due to direct physical contact)
- In solids, the conduction is due to lattice vibration and electron flow.
- In metals it is mainly due to electron flow. In nonmetals mainly due to lattice vibration.
- In gases it is due to molecular collision / also known as molecular diffusion.
- In liquids, conduction mechanism is similar to gases
- The conduction heat transfer is given by fundamental law known as fouriers law. ~~as per fouriers law~~
- As per fourier's law,



$q \propto (T_1 - T_2)$

$q \propto A_{c/s}$

$q \propto \frac{1}{L}$

$\therefore q \propto A_{c/s} \times \frac{(T_1 - T_2)}{L}$

$$\boxed{q = kA_{c/s}\frac{(T_1 - T_2)}{L}} \; W$$

$q = -kA\frac{dT}{dx}$

$\therefore k = \frac{q}{-A(dT/dx)}$

If $A = 1$, $\frac{dT}{dx} = 1$

$\therefore \boxed{k = q}$

$$k = \frac{q}{A_{cs}\frac{(T_1 - T_2)}{L}} = \frac{W}{m^\circ C} \text{ or } \frac{W}{mK}.$$

For temp. diffⁿ $\frac{W}{m^\circ C} = \frac{W}{mK}$.

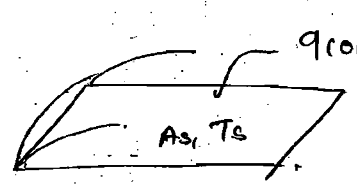
- k = Thermal conductivity of material.
- It is the property of material which defines the heat conduction rate.

② Convection heat transfer :- (Macroscopic form of energy transfer)

- When fluid flows over the ~~relative~~ solid surface (relative) the mode of heat transfer is known as convection heat transfer.
- The convection heat transfer is defined by conduction and advection heat transfer.
- It is given by newtons law of cooling & heating.
- The heat transfer coefficient (h) depends upon:-
  1. Velocity of flow (Forced conv)
  2. Property of fluid
  3. Geometry of surface.
  4. Type of fluid flow (laminar or turbulent)
  5. Orientation of surface in free convection.

q^* = heat flux.

$$q^* = \frac{q}{A} \quad \frac{W}{m^2}$$



$$q_{conv} = hA_s(T_s - T_\infty)$$

$$q_{conv} \propto (T_s - T_\infty)$$

$$q_{conv} = h(T_s - T_\infty) \; \frac{W}{m^2}$$

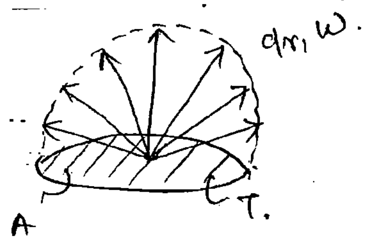
$$h = \frac{q_{conv}}{A_s (T_s - T_\infty)} = \frac{W}{m^2\,{}^\circ C} = \frac{W}{m^2 K}$$

$$Nu = f(Re, Pr)$$

↳ convective heat transfer coefficient.

③ Thermal radiation

- Unlike conduction & convection thermal radiation dose not require any medium.
- The radiation heat transfer is more effective in vaccum
- The radiation emitted by the black body above absolute zero temp. is given by a stefan boltzman law.

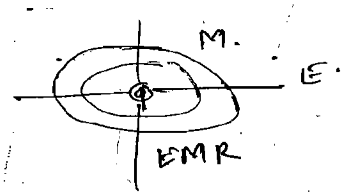


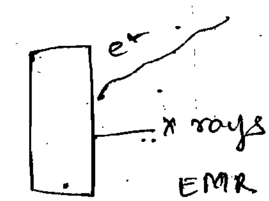
$$E_b = \frac{q_r}{A} = \frac{W}{m^2}$$

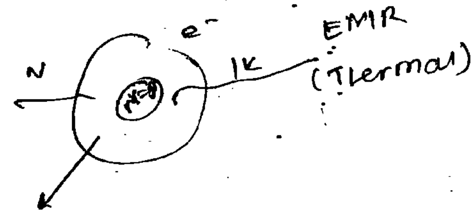
$$E_b \propto T^4$$

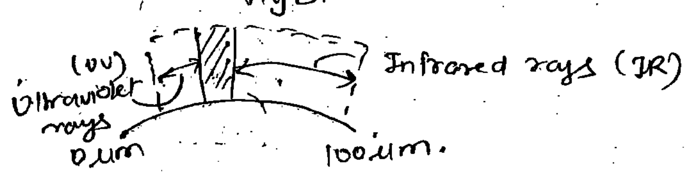
$$E_b = \sigma T^4$$

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

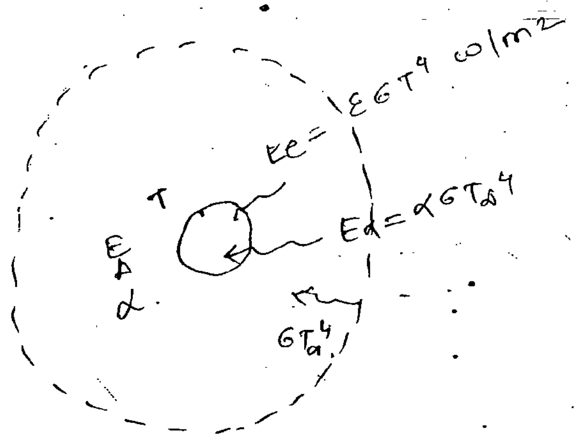








(1) Black body $E_b \propto T^4$



$q_{net} = E_e - E_a$

$q_{net} = \varepsilon \sigma T^4 - \alpha \sigma T_\infty^4 \longrightarrow (1)$

Kirchoffs law,

Small body in large enclosure

Thermal equillibrium $T = T_\infty$

$q_{net} = 0$

$\therefore 0 = \varepsilon \sigma T^4 - \alpha \sigma T^4$

$(\varepsilon - \alpha)\sigma T^4 = 0$

$\boxed{\varepsilon = \alpha}$

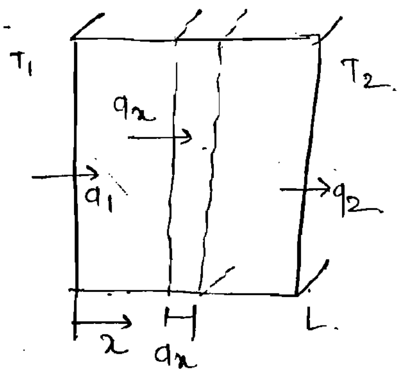
$\therefore$ By eqn (1).

$\frac{q_{net}}{A} = \varepsilon \sigma T^4 - \varepsilon \sigma T_\infty^4$

$\boxed{q_{net} = \varepsilon A \sigma (T^4 - T_\infty^4)}$

CONDUCTION HEAT TRASFER

* fourier's eq^n in differential form:-



$T_1 > T_2$

$T = f(x, t)$

As $x + dx > x$

$dx > 0$.

$T + dT < T$.

$dT < 0$.

$\frac{dT}{dx} < 0$ [where -ve sign shows heat flow from high temp to low temp]

$q_x'' \propto \left(\frac{dT}{dx}\right)$

+ve -(-ve).

$q_x'' = -k_x\left(\frac{dT}{dx}\right)$

$\frac{q_x}{A} = -k_x\left(\frac{dT}{dx}\right)$

$$q_x = -kA\left(\frac{dT}{dx}\right)$$

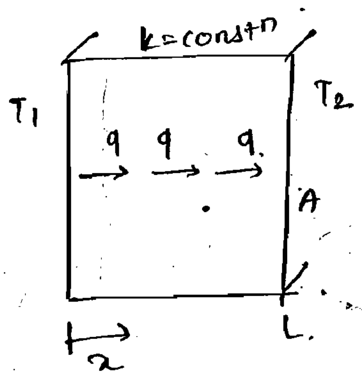
--- Generalized eq^n of fouriers law.

$\therefore q_1 = -kA\left.\frac{dT}{dx}\right|_{x=0}$.

$q_2 = -kA\left.\frac{dT}{dx}\right|_{x=L}$.

$q_1 > q_2$ = unsteady state

Now,



Assumption:-

① steday state $\therefore q \neq f(x)$

② $\dot{q}_g = 0$.

③ 1D heat conduction.

$\therefore q = -kA\frac{dT}{dx}$

$q\,dx = -kA\,dT$.

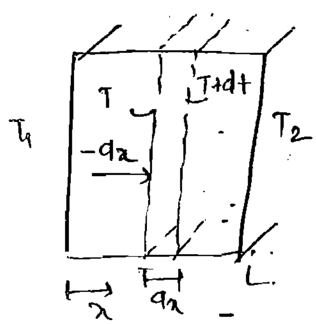
Integrating,

$$q\int_0^L dx = -kA\int_{T_1}^{T_2} dT.$$

$$qL = -kA(T_2 - T_1)$$

$$\boxed{q = \frac{kA(T_1 - T_2)}{L}}$$ — for steddy state

Case - II



$T_2 > T_1$

$$-q''_x \propto \frac{dT}{dx}.$$

$$q''_x \propto \left(\frac{-dT}{dx}\right)$$

$$\boxed{q''_x = -k_x \cdot A \cdot \frac{dT}{dx}}$$

$x + dx > x$

$dx > 0.$

$T + dT > T.$

$dT > 0.$

* Thermal conductivity :-

= It is the property of material which defines the ability of heat conduction.

- It is defined as heat conduction rate per unit area per unit temp. gradient.

$$q = -kA\frac{dT}{dx}$$

$k = q$ if $A = 1 m^2$

$\left(\frac{-dT}{dx}\right) = 1 k/m.$

- Conductivity (k) of vacum is zero.

Effect of temp. on conductivities :-

(1) Solids :-

(1) Pure metals :-

$k_{e^-} >>> k_l$

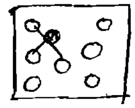
$k_T = k_{e^-}$

$T\uparrow - \delta\uparrow \rightarrow e^-$ flow $\downarrow - k_{e^-}\downarrow \rightarrow k_T\downarrow$

(δ : resistivity)

(2) Alloys :-

$k_T = k_{e^-} + k_l$

e^-  Fe-C

$k_{Cu} = 400$.

$k_{brass} = 100$.

$\therefore T\uparrow -$ stresses $\downarrow - k_T\uparrow$

(3) Nonmetals :-

$k_{e^-} <<< k_l$

$k_T = k_l$

$T\uparrow -$ lattice vibration $\uparrow \rightarrow k_l\uparrow \rightarrow k_T\uparrow$

k_{e^-} - electron flow

k_l = lattice vibration.

$k_{metal} > k_{alloy} > k_{nonmetal}$

(2) Gases :-

$k_{gas} \propto \frac{n V_{rms}}{\lambda}$

n = no. of molecules/volm

V_{rms} = root mean square velocity

λ = mean free path.

$KE = \frac{1}{2} m V_{rms}^2$

$KE = \frac{3}{2} kT$.

$\therefore \frac{1}{2} m V_{rms}^2 = \frac{3}{2} kT$.

$V_{rms} = \sqrt{\frac{3kT}{m}}$.

As $\frac{k}{m} = \frac{R}{M}$

$V_{rms} = \sqrt{\frac{3RT}{M}}$

$V_{rms} \propto \sqrt{T}$

$V_{rms} \propto \frac{1}{\sqrt{M}}$

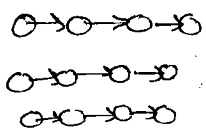
	M
H_2 —	2
He —	4
Air —	24
CO_2 →	44

↓ increasing ↑ k increasing.

③ Liquids :-

As temp. ↑ - intermolecular distance of liquid molecules ↑

so the collision ↓ - Conductivity (k) ↓



T↑ - ρ↓

T↓ - ρ↑

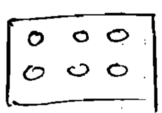
∴ T↑ - ρ↓ - k_{liquid} ↓

Exceptions :-

① ~~Nomentals~~ :- Nonmetals :-

- Some crystalize solids have high thermal conductivity than metals due to perfect crystalize structure like diamond, graphite, baryllium oxides, quartzs etc.

∴ Diamond = k = 2300 W/mk Nonmetal.



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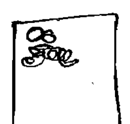

$0.5 \leq k \leq 10$ W/mk

Perpect structure.

Generally, Non prefect structure

k_{silver} = 437 W/mk.