Heat transfer. 17/9/18

Modes of Heat transfer.

1) **Conduction** – Flow of Heat due to exchange of energy between molecules having higher temp. (high K.E.) and lower temp. (low K.E.)

Solid – occurs due to ~~lattice~~ vibration of molecules

- Solids with crystalline structure have high conductivity than amorphous due to vibration motion of the crystal lattice as a whole.
- Amorphous ~~solid~~ has k of the order of liquids ~~0.1~~
- Electronic conductivity also plays important role in high k in metals.

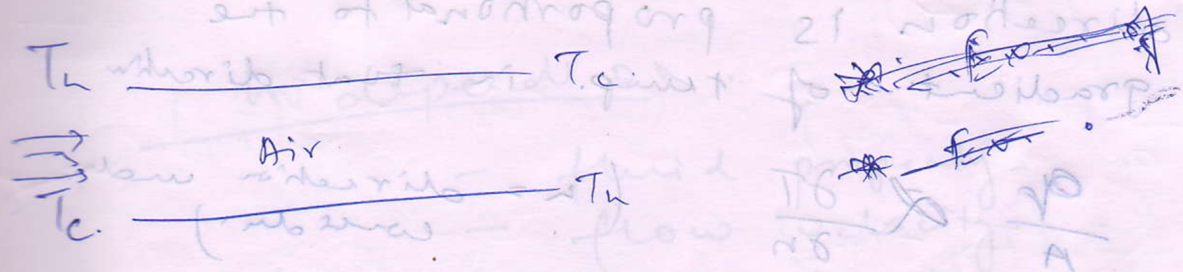
Liq. & Gases – occurs due to ~~vibration~~ transmission of energy due to molecular motion and collision.

K → depends on
- chemical composition
- phase (solid, gas, liq.) (Mercury, vap. – 0.034, liq – 8, solid – 48) W/(m·K)
- crystalline structure (Carbon, Charcoal – 0.084, Graphite – 168, Diamond – 1000, Cu – 401) (1950 – 517)
- Orientation

- temp. → dec. for metal.
  → inc. for other solid / liq. / gas
  → is also for stainless steel / Al.
- Pressure → ~~inc. with pr.~~ (gas) negligible effect on Solid / liq.
  → gas — ↑ with pr. → weak dep.
  — irregular for steam.

Convection — due to bulk motion of molecules
— liq / gas only.

- free / natural convection
- forced convection.



Radiation — all physical matter in the solid / liq / gas emits 'thermal radiation' in the form of EMW because of vibrational / rotational movements of molecules / atoms which make up the matter.

The rate of emission increases with temp.

$$\frac{q}{A} = \sigma T^4.$$

All matter also absorbs the radiation in diff. capacity and radiation passing through it gets 'attenuated'.

Laws of heat transfer.

- Cons. of mass
- " " energy
-

- Fourier's law of heat conduction

- States that in a material in which temp. diff. exists, the heat flux due to conduction in any direction is proportional to the gradient of temp. in that direction.

$$\therefore \frac{q}{A} \propto \frac{\partial T}{\partial n} \quad (n = \text{direction under consider.})$$

$$\therefore \left.\frac{q}{A}\right|_n = -K \frac{\partial T}{\partial n}$$

$$\left.\frac{q}{A}\right|_y = -K \frac{\partial T}{\partial y}, \quad \left.\frac{q}{A}\right|_z = -K \frac{\partial T}{\partial z},$$

$$\therefore \left(\frac{q}{A}\right) = -K \nabla T$$

$K = W/m°C$

$W/(m \cdot °C)$

- Newton's law for conv. heat flow. - It states

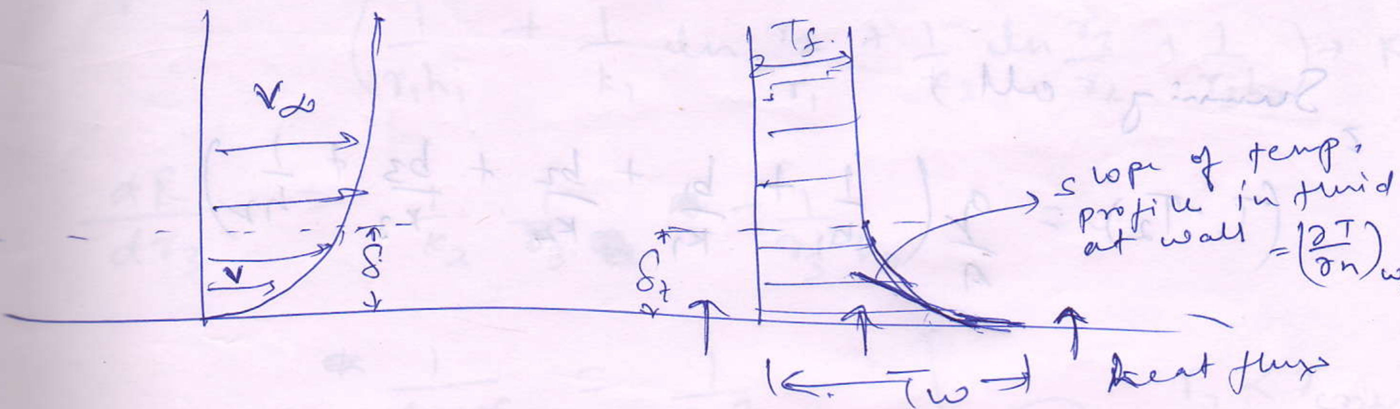
That when a fluid at a temp. T_f is in contact with a solid surface at a diff. temp. (T_w), the heat flux from the surface to the fluid is proportional to the temp. diff. ~~betwe~~ bet. surface & so[...]

$$\frac{q}{A} = h\,(T_w - T_f).$$

$$\left(\underset{\substack{\downarrow \\ \text{heat transfer coeff}}}{h} = \frac{W}{m^2 K} \right)$$

h depends on.

- fluid property.
- flow velocity.
- type of flow (laminar / turbulent.)
- shape ~~of sol~~ / orientation of surface
- phase change (highest 'h' value) encountered.



$$h = \frac{\left(\frac{q}{A}\right)}{(T_w - T_f)} = \frac{-k_f \left(\frac{\partial T}{\partial n}\right)_{wf}}{(T_w - T_f)}$$

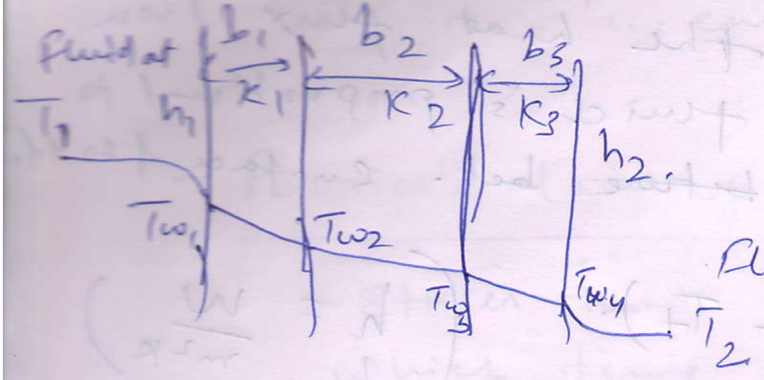
* ~~e~~ examples of 2 glass layer

* Solar pond.

* Varying orientation of hot plates.

18/9/18

Concept of thermal resistance and composite slab



$$\frac{q}{A} = h_1 (T_1 - T_{w_1}) \Rightarrow (T_1 - T_{w_1}) = \frac{q}{A h_1}$$

$$= \frac{k_1}{b_1}(T_{w_1} - T_{w_2}) \Rightarrow (T_{w_1} - T_{w_2}) = \frac{q}{A}\left(\frac{b_1}{k_1}\right)$$

$$= \frac{k_2}{b_2}(T_{w_2} - T_{w_3})$$

$$= \frac{k_3}{b_3}(T_{w_3} - T_{w_4})$$

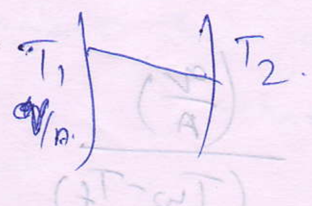
$$= h_2 (T_{w_4} - T_2) \Rightarrow (T_{w_4} - T_2) = \frac{q}{A h_2}$$

Summing all,

$$(T_1 - T_2) = \frac{q}{A}\left(\frac{1}{h_1} + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \frac{b_3}{k_3} + \frac{1}{h_2}\right)$$

Thermal resistance

$$\frac{q}{A} = \frac{k}{b}(T_1 - T_2)$$



Potential → $(T_1 - T_2)$

Current → q

Resistance → $\left(\frac{T_1 - T_2}{q}\right) = \left(\frac{1}{k/b}\right)\left(\frac{1}{A}\right)$

In series of composite slab.

$$R_{th} = \frac{1}{A}\left[\frac{1}{h_1} + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \frac{b_3}{k_3} + \frac{1}{h_2}\right].$$

Overall heat transfer coefficient.

$$q = UA\,(T_1 - T_2).$$

where, $U = \dfrac{1}{\left(\dfrac{1}{h_1} + \dfrac{b_1}{k_1} + \dfrac{b_2}{k_2} + \dfrac{b_3}{k_3} + \dfrac{1}{h_2}\right)}$

Critical Radius

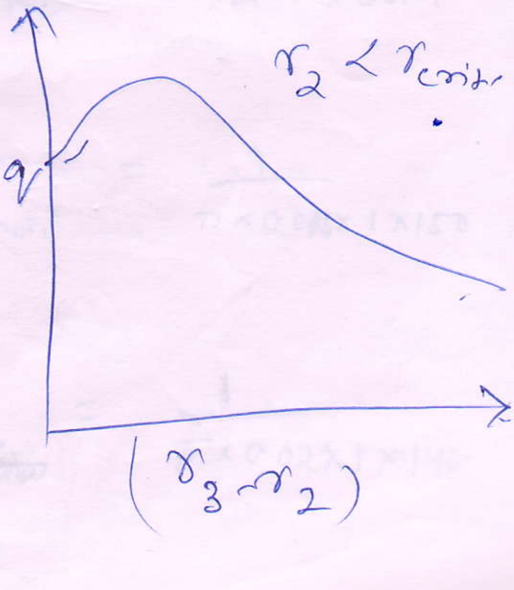
for a cylindrical pipe,

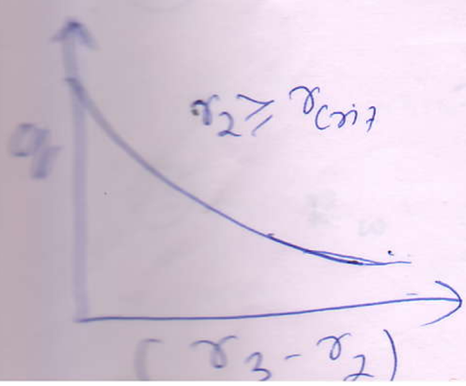
$$q = \frac{2\pi L\,(T_i - T_0)}{\left(\dfrac{1}{r_1 h_i} + \dfrac{1}{k_1}\ln\dfrac{r_2}{r_1} + \dfrac{1}{k_2}\ln\dfrac{r_3}{r_2} + \dfrac{1}{r_3 h_0}\right) \rightarrow R}$$

$$\frac{dR}{dr_3} = \frac{1}{k_2}\cdot\frac{1}{r_3} - \frac{1}{r_3^2 h_0} = 0.$$

$$\frac{1}{k_2 r_3} = \frac{1}{r_3^2 h_0}$$

$$\Rightarrow \boxed{r_{3,crit} = \frac{k_2}{h_0}}$$





Cylindrical pipe.

$$\left(\frac{q}{A}\right)_r = -k\frac{dT}{dr}$$

$$\frac{q}{A} = -k\int\frac{dT}{dr}$$

$$\therefore \cancel{\int\frac{q}{A}\,dr}$$

$$\Rightarrow \frac{q}{2\pi r L} = -k\frac{dT}{dr}$$

$$\Rightarrow \frac{q}{2\pi L}\int_{r_i}^{r_o}\frac{dr}{r} = -k\int_{T_i}^{T_o} dT$$

$$\Rightarrow \frac{q}{2\pi L}\ln\left(\frac{r_o}{r_i}\right) = -k\left(T_o - T_i\right)$$

$$\Rightarrow q = \frac{2\pi L k\left(T_i - T_o\right)}{\ln\left(\frac{r_o}{r_i}\right)}$$