Heat Transfer

→ The heat or thermal energy in transit due to temperature difference.

q_x = rate of heat transfer along 'x' direction (J/s) or W

q'_x = " " " " " 'x' " per unit length (W/m)

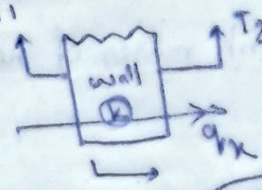
q''_x = rate of heat transfer along " " per unit area = Heat flux (W/m²)

q'''_x = rate of heat transfer along x direction a unit volume = (W/m³)

Conduction → due to Diffusion

Convection → Advection (Bulk movement of fluid particles) + Diffusion

Fourier's Law of Conduction



$T_1 > T_2$

(Conduction through)

(Fourier's Law of heat conduction)

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

q_x: W

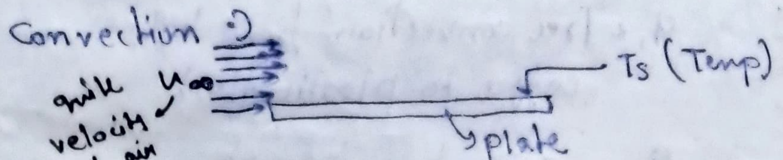
K: Thermal conductivity (W/m·K)

A: Area

$\frac{dT}{dx}$: Temp gradient (K/m)

(volumetric phenomenon)

Convection :



→ difference of density then Natural Convection

→ By some external fluid (fan) then Forced Convection

(Fluid Flow medium is mendatory)

(Convection from ____ to ____)

→ Newton's Law of cooling: $T_s > T_\infty$

$$q_{conv} = h\,A\,(T_s - T_\infty)$$

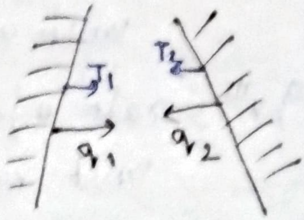
T_∞ → temp of air

h → convective heat transfer co-efficient ($W/m^2 \cdot K$)

A → Surface area of hot Plate

(Surface phenomenon)

→ For electromagnetic wave, Radiation will be happened.



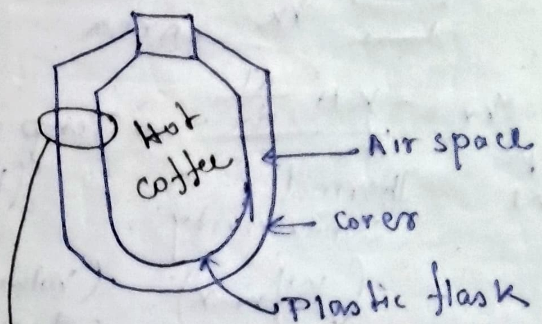
<u>Stephan Boltzmann eq^n:-</u>

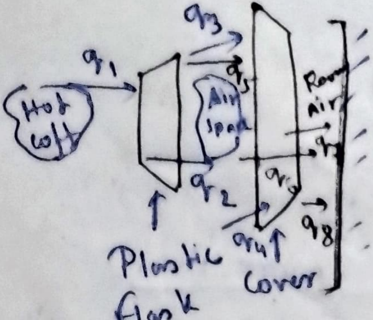
$$q_{rad} = \sigma A (T_1^4 - T_2^4)$$

σ → $8.716 \times 10^{-8} \frac{W}{m^2 \cdot K}$

$q_{rad} = q_1 - q_2$ → Net radiation exchange b/w surface '1' & '2'

<u>Identify the different modes of heat transfer:</u>





q_1 = free convection from hot coffee to plastic flask.

q_2 = Conduction through Plastic flask

q_3 = Free convection from flask to air

q_4 = free convection from air to cover.

q_5 = Net radiation exchange b/w outer surface of Plastic flask and inner surface of cover

q_6 = Conduction through cover

q_7 = free convection from cover to air

q_8 = Net radiation exchange b/w outer surface of cover and room air.

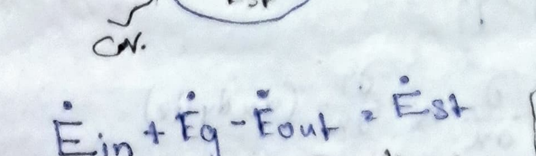
$$q_{loss} = \sum_{n=1}^{8} q_n$$

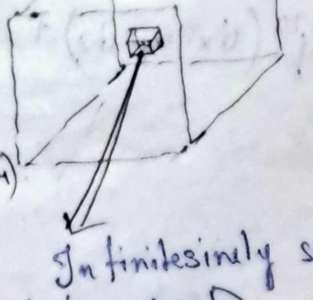
For minimize the q_{loss}:-

→ If we remove Air space & make it insulating material, then convection removed.

→ Polishing the plastic flask, then, radiation is removed.

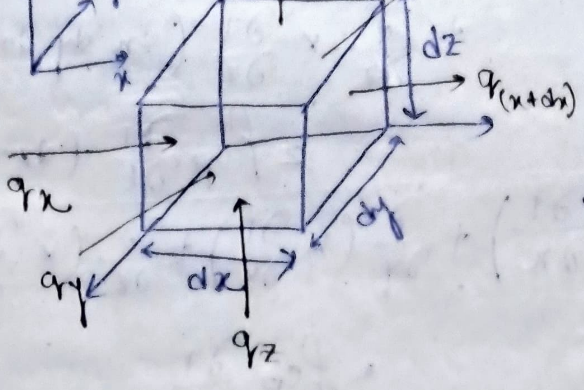
3-D Heat Conduction Eq^n in Cartesian Co-ordinate:-





$$\dot{E}_{in} + \dot{E}_g - \dot{E}_{out} = \dot{E}_{st}$$

⊛ Homogeneous body & no advection's



Infinitesimaly small c.v is selected

volume of c.v = dx.dy.dz

$$\dot{E}_{in} = q_x + q_y + q_z$$

$\dot{E}_{out}$ =

$$q_{x+dx} = q_x + \frac{\partial}{\partial x} q_x \cdot dx$$ [Taylor series Expansion & neglect the higher order terms]

$$q_{(y+dy)} = q_y + \frac{\partial}{\partial y} q_y \cdot dy$$

$$q_{(z+dz)} = q_z + \frac{\partial}{\partial z} q_z \cdot dz$$

$$\dot{E}_g = \underbrace{q'''}_{\text{Heat generation Per unit volume}} \cdot (dx \cdot dy \cdot dz)$$

$$\dot{E}_{st} = \underbrace{\rho \cdot C_p \cdot \frac{\partial T}{\partial t}}_{W/m^3} \times (dx \cdot dy \cdot dz)$$ [Unit → W]

(T → temp, t → time)

$$\underline{\cancel{q_x} + \cancel{q_y} + \cancel{q_z}} - \cancel{q_x} - \frac{\partial}{\partial x} q_x \cdot dx - \cancel{q_y} - \frac{\partial}{\partial y} q_y \cdot dy - \cancel{q_z} - \frac{\partial}{\partial z} q_z \cdot dz + \underline{q''' (dx \cdot dy \cdot dz)} = \underline{\rho c_p \frac{\partial T}{\partial t} (dx\, dy\, dz)}$$

$$\left[q_x = -k (dy \cdot dz) \frac{\partial T}{\partial x} \right]$$

$$\Rightarrow q''' (dx \cdot dy \cdot dz) + \frac{\partial}{\partial x} k \frac{\partial T}{\partial x} (dx\, dy\, dz) + \frac{\partial}{\partial y} k \frac{\partial T}{\partial y} (dx \cdot dy \cdot dz) + \frac{\partial}{\partial z} k \frac{\partial T}{\partial z} (dx\, dy\, dz) = \rho c_p \frac{\partial T}{\partial t} (dx \cdot dy \cdot dz)$$

$$\Rightarrow \boxed{q''' + \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) = \rho c_p \frac{\partial T}{\partial t}}$$

__Assumption__ → 3-D, variable k, uniform heat generation & unsteady state.

~~Heat Conduction eq~~

k = const

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q'''}{k} = \frac{\rho c_p}{k}\frac{\partial T}{\partial t}$$

$\frac{k}{\rho c_p} = \frac{1}{\alpha}$... α = Thermal diffusivity $= \frac{k}{\rho c_p}$

In solid

T↑ k↓

when we increase temp. larger the lattice vibration, as there is free e^-, for movement of free e^-, the k ↓

For gases

T ↑, k↑

→

$$\therefore \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q'''}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\alpha = \frac{k}{\rho c_p} = \frac{\text{Thermal conductivity}}{\text{Heat capacity}}$$

(m^2/s)

→ α is more, then, it is faster rates of heat transfer. & steady state is achieved faster.

→ In Solid, ρ↑, k↑, c_p↓

So, in solid k is more than the heat capacity.

→ In two dimensional with variable k, steady state, internal heat generation is there.

$$\cancel{\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{q'''}{k} = 0}$$

$$\rightarrow \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + q''' = 0$$

→ 3D, heat cond eqn with const k, no q_{gen},

steady state.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0 \quad \text{(Laplace eqn)}$$

$$\boxed{\nabla^2 T = 0}$$

∇^2 = Laplace operator.

if $\underline{\underline{1\text{-D}}}$

$$\frac{\partial^2 T}{\partial x^2} = 0$$

By Integrate

$$\frac{\partial T}{\partial x} = C_1$$

$$\rightarrow T = C_1 x + D_1 \longrightarrow \text{B.C's 2 needed.}$$

$$\rightarrow \frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k \frac{\partial T}{\partial z}\right) + q''' = \rho c_p \frac{\partial T}{\partial t}$$

6 B.C + 1 I.C

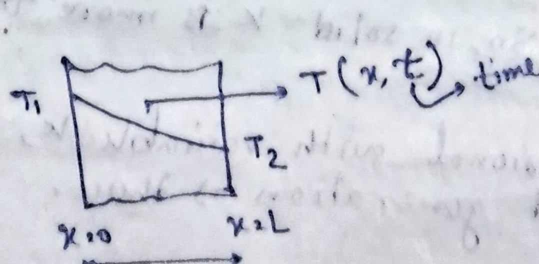
↳ Initial cond $[t=0 \Rightarrow T = T_i]$

→ Constant surface temp B.C / B.C of first kind :→

(Diritchlet B.C)

$T(0,t) = T_1$

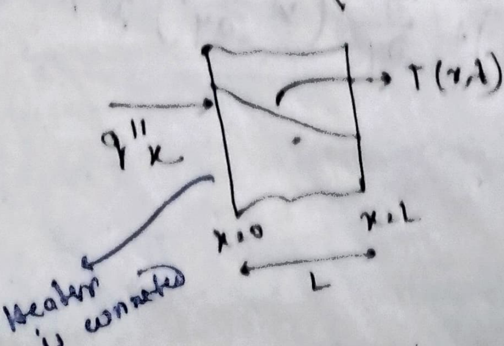
$T(L,t) = T_2$



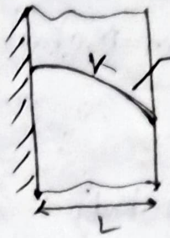
→ Constant heat flux / B.C of second kind :–

(Neumann B.C)

$$-k \left.\frac{dT}{dx}\right|_{x=0} = q''_x$$

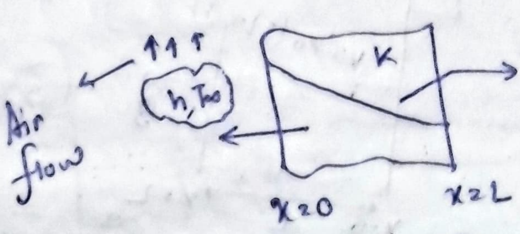


→ Special B.C (Insulated B.C)



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

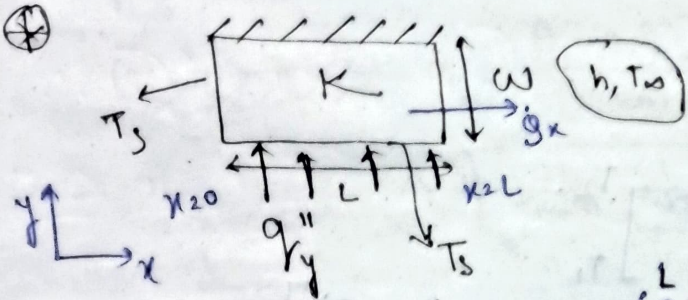
→ Convective B.C



$$-k \frac{dT}{dx}\Big|_{x=0} = h\left[T(0,t) - T_\infty\right]$$

⟶ in surface, $\underbrace{\text{Conduction} = \text{convection}}$.

⊛



$\cancel{\Rightarrow \text{(i)}\ T(0,y,t) = T_s}$

$\cancel{\text{(ii)}\ -k \frac{dT}{dy}\Big|_{y=0,\ x=L} = q''y}$

$\cancel{\text{(iii)}\ -k \frac{dT}{dx}\Big|_{x=L,\ y=\omega} = h\left[T(L,\omega,t) - T_\infty\right]}$

$\cancel{\text{(iv)}\ \frac{dT}{dy}\Big|_{y=\omega,\ x=L} = 0}$

$\Rightarrow$ (i) $T(L,\omega,t) = T_s$

(ii) $-k \frac{dT}{dy}\Big|_{y=0,\ x=L} = q''_y$

(iii) $-k \frac{dT}{dx}\Big|_{x=L,\ y=\omega} = h\left[T(L,\omega,t) - T_\infty\right]$

(iv) $\frac{dT}{dy}\Big|_{x=L,\ y=\omega} = 0$

α - Dependency :-

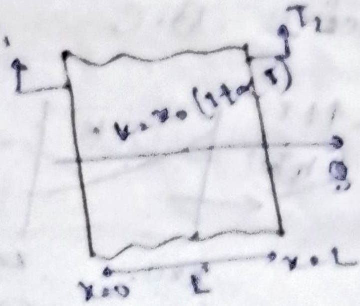
$k = f(t)$

$k = k_0 (1 + \alpha T)$ → thermal conductivity.

α - +ve (non metal)

$\alpha = 0$

α = -ve (Metal)



$T_1 > T_2$

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

$$q = -k_0 (1 + \alpha T) A \frac{dT}{dx}$$

$$q = k_0 (1 + \alpha T) A \frac{(T_1 - T_2)}{L}$$

$$qL = k_0 (1 + \alpha T) A (T_1 - T_2)$$

$$q\int_0^L dx = -k_0 \int_{T_1}^{T_2} (1 + \alpha T) A\, dT$$

$$\Rightarrow qL = -(k_0 A) \left[T + \frac{\alpha T^2}{2}\right]_{T_1}^{T_2}$$

$$\Rightarrow q = -\frac{k_0 A}{L}\left[(T_2 - T_1) + \frac{\alpha}{2}(T_2^2 - T_1^2)\right]$$

$$\Rightarrow q = -\frac{k_0 A}{L}(T_2 - T_1)\left[1 + \frac{\alpha}{2}(T_2 + T_1)\right]$$

$k_m = k_0 \left[1 + \frac{\alpha}{2}(T_1 + T_2)\right]$ → mean value of thermal conductivity of the A.M Temp.

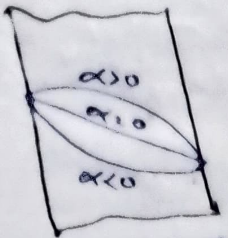
$$\Rightarrow q = -\frac{k_m A}{L}(T_2 - T_1)$$

$$\frac{dT}{dx} = \left[-\frac{q}{k_0(1 + \alpha T)}\right]$$

if $\alpha = 0 \Rightarrow k = k_0 \Rightarrow$ slop is cont

$\alpha > 0 \Rightarrow$ slope follows a (+ve) line along the material dirn.

$\alpha < 0$ ↳ slope follow a (-ve) line along the material dirn.

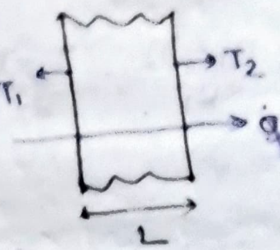


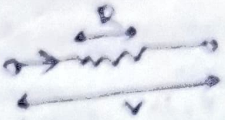
$\alpha > 0$, $\rightarrow k$ increases with α

$\alpha < 0$, $\rightarrow k$ decreases with α

Electrical analogy for heat transfer Problems:

Conduction





$R = \frac{V}{I}$ $\Rightarrow I = \frac{V}{R}$

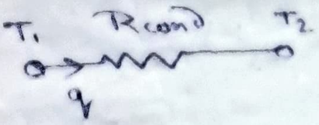
$q_{cond} \sim I$

$(T_1 - T_2) \sim V$

$L/kA \sim R$

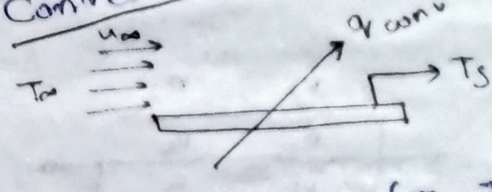
$q_{cond} = \frac{kA(T_1 - T_2)}{L}$

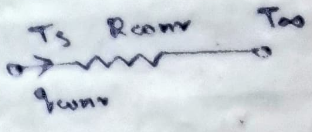
$\cancel{(T_1 - T_2) \ldots kA}$ $q_{cond} = \frac{(T_1 - T_2)}{(L/kA)}$



$\boxed{R_{cond} = \frac{L}{kA}}$ $\rightarrow$ only for plane wall.

Convection

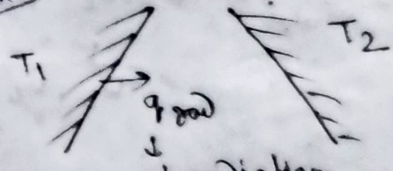




$q_{conv} = hA(T_S - T_\infty)$

$= \frac{(T_S - T_\infty)}{\left(\frac{1}{hA}\right)}$ $\therefore \boxed{R_{conv} = \frac{1}{hA}}$

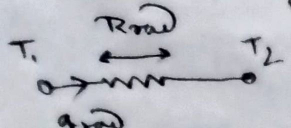
Radiation



$q_{rad} = \sigma A(T_1^4 - T_2^4)$

$= \frac{(T_1^2 - T_2^2)(T_1^2 + T_2^2)}{1/\sigma A}$

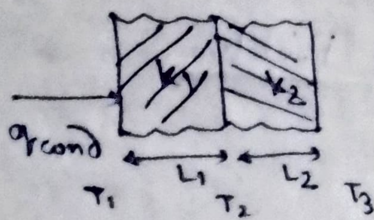
$= \frac{(T_1 - T_2)}{\frac{1}{(T_1 + T_2)(T_1^2 + T_2^2)\sigma A}}$



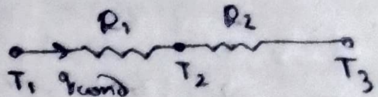
$\therefore \boxed{R_{rad} = \frac{1}{(T_1 + T_2).(T_1^2 + T_2^2).A.\sigma}}$

(8) **Composite wall :→**

Series



Area is same.

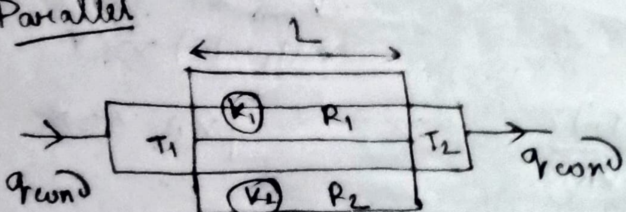


$$q_{cond} = \frac{T_1 - T_3}{R_1 + R_2}$$

$$= \frac{T_1 - T_2}{R_1} = \frac{T_2 - T_3}{R_2}$$

$$R_1 = \frac{L_1}{k_1 A}, \quad R_2 = \frac{L_2}{k_2 A}$$

Parallel



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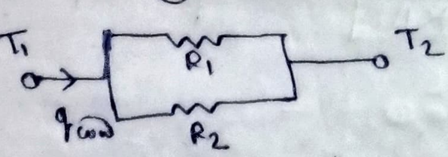
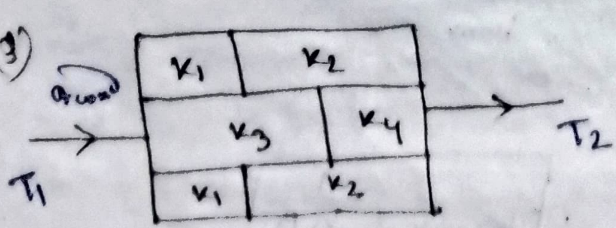
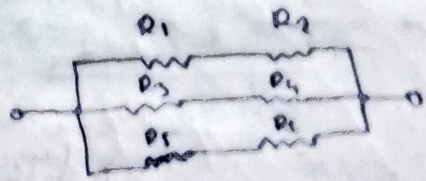


$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\therefore q_{cond} = \frac{T_1 - T_2}{R}$$

(3)





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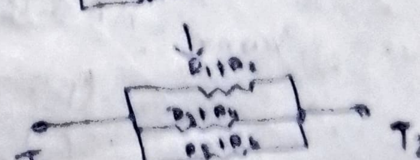
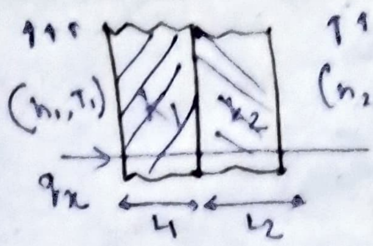
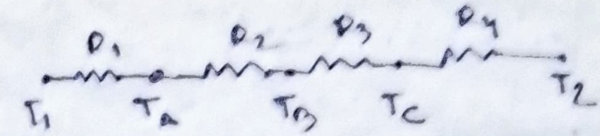


$$\therefore q_{cond} = \frac{T_1 - T_2}{R_{total}}$$

$$\frac{1}{R_{total}} = \frac{1}{R_1 + R_2} + \frac{1}{R_3 + R_4} + \frac{1}{R_5 + R_6}$$





$$R_1 = \frac{1}{h_1 A} \qquad R_2 = \frac{L_1}{k_1 A}$$

$$R_3 = \frac{L_2}{k_2 A}$$

$$R_4 = \frac{1}{h_2 A}$$

$$q_x = \frac{T_1 - T_2}{R_1 + R_2 + R_3 + R_4}$$

U = overall heat transfer co-eff. (W/m^2.K)

$$q = U A (T_1 - T_2)$$

$$= \frac{T_1 - T_2}{(1/UA)}$$

$$q_x = \frac{T_1 - T_2}{\frac{1}{h_1 A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{1}{h_2 A}}$$

$$\therefore \frac{1}{UA} = \frac{1}{h_1 A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{1}{h_2 A}.$$

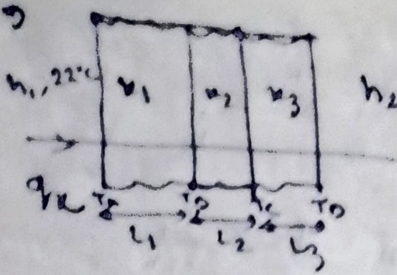
$$\boxed{\frac{1}{U} = \frac{1}{h_1} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{1}{h_2}}$$

(*) A cold storage room has walls made of 0.23 m. of brick on the outside, 0.08 m plastic foam & finally 1.5 cm of wood on the inside. The outside & inside air temp are 22°C & −2°C. If the inside & outside (h) are 29 & 12 W/m^2.°C. And K of brick, foam and wood are 0.98, 0.02 & 0.17 W/m °K. Determine

(i) The rate of heat removed by refrigeration if the total wall area is 90 m^2.

(ii) The temp of the inside surface of brick.

:)



$h_1 = 23$

$h_2 = 12$

$k_1 = 0.98$

$k_2 = 0.02$

$k_3 = 0.17$

$L_1 = 0.23$

$L_2 = 0.08$

$L_3 = 0.015$ m.

$T_1 = 22°C$

$T_2 = -2°C$

$$q_x = \frac{T_1 - T_2}{\frac{1}{h_1 A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{L_3}{k_3 A} + \frac{1}{h_2 A}}$$

$$\frac{1}{U} = \frac{1}{h_1} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} + \frac{1}{h_2} \Rightarrow \frac{1}{U} = 4.44$$

$\Rightarrow U = 0.2252$

$$q_x = \frac{T_1 - T_B}{R_1 + R_2}$$

$$\therefore q_x = \frac{295 - 271}{4.44 \times \frac{1}{90}}$$

~~= 486.94~~

$= 486.48\,W$

~~$T_B = 52$~~

$$486.48 = \frac{295 - T_B}{\frac{1}{23 \times 90} + \frac{0.23}{0.98 \times 90}}$$

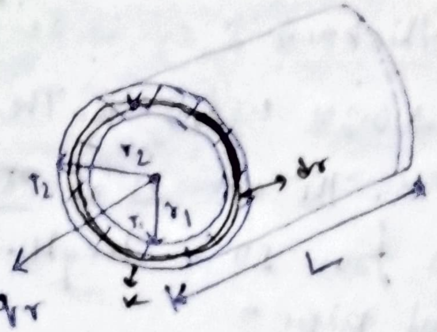
$$486.48 = \frac{295 - T_B}{0.00038 + 0.002}$$

$T_B = 295 - 1.45$

$= 293.55\,K$

$= 20.55\,°C.$

(4) Heat Conduction through hollow cylinder :-

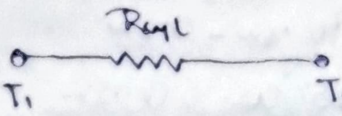


$$q_r = -kA\frac{dT}{dr}$$

$$q_r = -k(2\pi r L)\frac{dT}{dr}$$

$$A = 2\pi r L$$

$$\therefore q_r \int_{r_1}^{r_2}\frac{dr}{r} = -2\pi k L\int_{T_1}^{T_2} dT$$



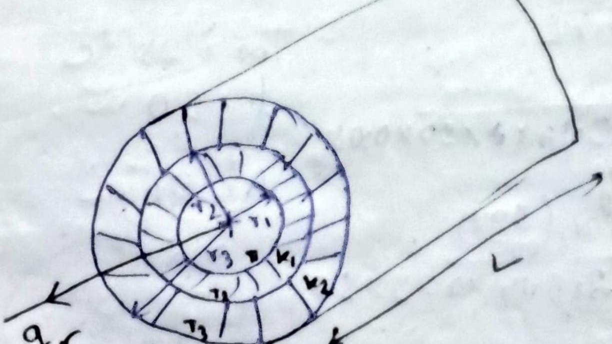
$$\Rightarrow q_r \ln\left[\frac{r_2}{r_1}\right] = -2\pi k L(T_2 - T_1)$$

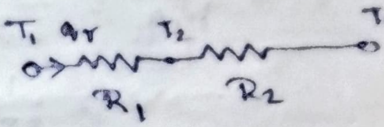
$$\boxed{R_{cyl} = \frac{\ln(r_2/r_1)}{2\pi k L}}$$

$$\Rightarrow q_r = \frac{2\pi k L(T_1 - T_2)}{\ln(r_2/r_1)}$$

$$\Rightarrow q_r = \frac{T_1 - T_2}{\frac{\ln(r_2/r_1)}{2\pi k L}} = \frac{T_1 - T_2}{R_{cyl}}$$

~~He~~ Composite Wall cylinder:





$$q_{r_1} = \frac{T_1 - T_2}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_1 L}}$$

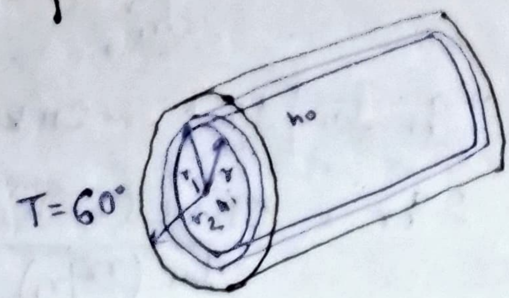
$$q_{r_2} = \frac{T_2 - T_3}{\frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi k_2 L}}$$

$$R_1 = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k_1 L} \qquad R_2 = \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi k_2 L}$$

If suppose thickness = difference of two consecutive radii.

(2) Hot Air at a temp of 60°C is flowing through a pipe of 10 cm Dia. The pipe is covered with two layers of diff insulating material of thickness 5 cm & 3 cm. Their corresponding k = 0.23 & 0.37 W/m °K. The atm is at 25°C h_i & h_o = 58 & 12 W/m².°K. The length of pipe 50 m. Find the rate of heat loss from 50 m length of pipe. Neglect the resistance of pipe?

⇒



$d = 10$ cm $= 0.1$ m

$r = 5$ cm $= 0.05$ m

$r_1 = 5 + 5$ cm $= 10$ cm $= 0.1$ m

$r_2 = 10 + 3 = 13$ cm $= 0.13$ m

$k_1 = 0.23$

$k_2 = 0.37$

$h_i = 58$

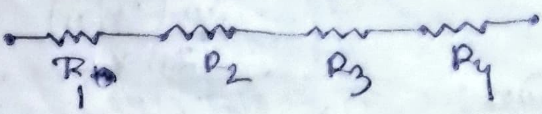
$h_o = 12$

$T_\infty = 25$ °C

$l = 50$ m.

$A = 2\pi r L$

$= 2$



$$R_1 = \frac{1}{h_i A_1} = \frac{1}{58 \times 2\pi r L}$$

$$= \frac{1}{58 \times 2 \times 3.14 \times 50 \times 0.05}$$

$$= 0.001$$

$$R_2 = \frac{\ln\left(\frac{r_1}{r}\right)}{2\pi k_1 l} = \frac{\ln\left(\frac{0.1}{0.05}\right)}{2 \times 3.14 \times 0.23 \times 50}$$

$$= 0.009$$

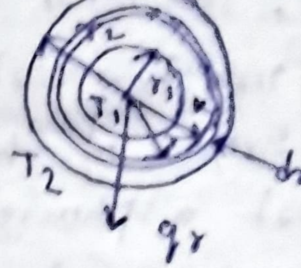
$$R_3 = \frac{\ln \frac{r_2}{r_1}}{2\pi k_2 l} = \frac{\ln \frac{0.13}{0.1}}{2 \times 3.14 \times 0.37 \times 50} = 0.0022$$

$$R_4 = \frac{1}{h_o A_2} = \frac{1}{12 \times 2 \times \pi \times r_2 \times l} = 0.002$$

$$\dot{Q}_x = \frac{T_1 - T_2}{R_{total}} = \frac{333 - 298}{0.001 + 0.009 + 0.0022 + 0.002}$$

$= 2464.78$ W

Heat transfer through a hollow sphere:-



$$q_r = -kA\frac{dT}{dr}$$

$$q_r = -k \times 4\pi r^2 \frac{dT}{dr}$$

$$\int_{T_1}^{T_2} dT = -\int_{r_1}^{r_2} \frac{q_r}{4k\pi}\frac{dr}{r^2}$$

$$(T_2 - T_1) = -\frac{1}{4\pi k} q_r \left[-\frac{1}{r}\right]_{r_1}^{r_2}$$

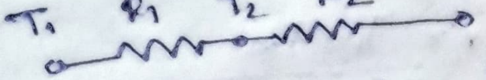
$$T_2 - T_1 = -\frac{q_r}{4\pi k}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$$

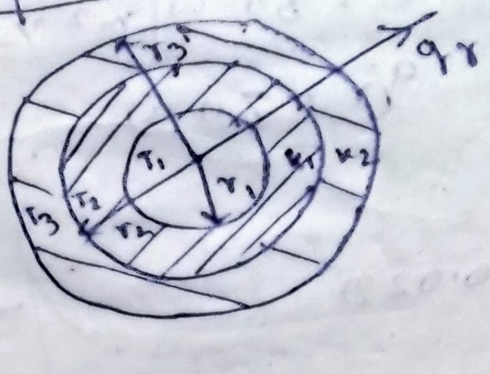
$$q_r = \frac{4\pi k(-T_2 + T_1)}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$$

$$q_r = \frac{(T_1 - T_2)}{\frac{1}{4\pi k}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$$

$$\boxed{R_{th} = \frac{1}{4\pi k}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$$

Composite wall sphere :→





$$R_1 = \frac{1}{4\pi k_1}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

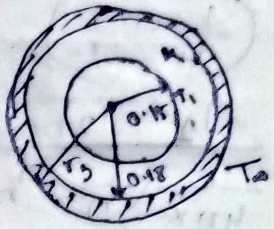
$$R_2 = \frac{1}{4\pi k_2}\left(\frac{1}{r_2} - \frac{1}{r_3}\right)$$

$$q_r = \frac{T_1 - T_3}{R_1 + R_2} = \frac{T_1 - T_2}{R_1}$$

$$= \frac{T_2 - T_3}{R_2}$$

(8) A Hollow Al sphere of thermal conductivity $230 \frac{W}{mK}$ with an electric heater in the center is used in tests to determine the k of insulating materials, the inner and outer radii of the sphere are 0.15 & 0.18 m. The testing is done under steady state with the inner surface of the Al maintain at 250°C in a particular test a spherical shell of insulation is cast on the outer surface of the sphere to a thickness of 0.12 m. The system is in a room for which the air temp is 20°C & h at the outer surface of insulation is 30 W/m²K. If 80 W is dissipated by the heater under steady state cond, what is k of insulation?

⇒



$k = 230 \ W/mK$

$r_i = 0.15 \ m$

$r_o = 0.18 \ m$

$T_1 = 250°C$

$r_3 = 0.18 + 0.12$

$= 0.3 \ m$

$T_\infty = 20°C$

$h = 30 \ W/m^2K$

$q_r = 80 \ W$

$$q_r = \frac{T_1 - T_\infty}{R_{total}}$$

$$R_3 = \frac{1}{hA}$$

$$= \frac{1}{30 \times 4\pi (0.3)^2} = 0.029 \quad \frac{K}{W}$$

$$R_2 = \frac{1}{4\pi k_2}\left(\frac{1}{r_2} - \frac{1}{r_3}\right)$$

$$= \frac{1}{4\pi k_2}\left(\frac{1}{0.18} - \frac{1}{0.3}\right) = \frac{0.177}{k_2}$$

$$R_1 = \frac{1}{4\pi k_1}\left(\frac{1}{0.15} - \frac{1}{0.18}\right) = 0.000038$$

$$80 = \frac{250-20}{0.00038 + \frac{0.177}{k_2} + 0.029}$$

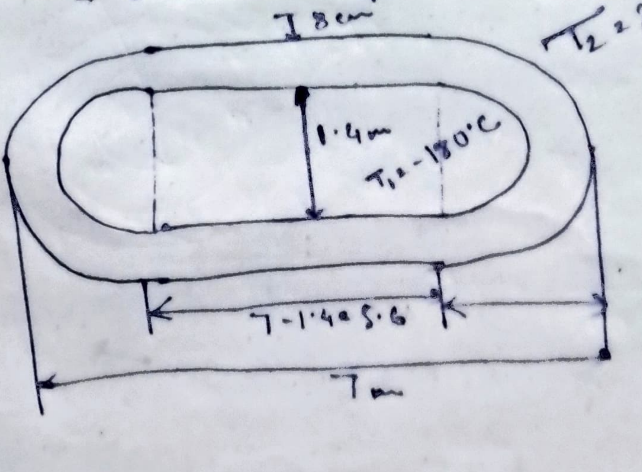
$$\left(\frac{230}{80} - 0.00038 - 0.029\right) = \frac{0.177}{k_2}$$

$$k_2 = \frac{0.177}{2.84} = 0.062$$

(*) A cylinderical liq. oxygen tank has a dia of 1.4 m, 7 m long and has spherical ends. The Boiling pt of liq. oxygen is −182°C & its latent heat of evaporation is 214 kJ/kg. The tank is insulated. In order to reduce the heat transfer to the tank in such a way that in steady state the rate of oxygen boiled off should not exceed 14 kg/hr. Calculate the k of insulating material, if its 8 cm thickness layer of insulation is applied and its outside surface is maintain at 30°C.

$$\Rightarrow \dot{q}_r = \overset{\dot{m} \times h_{fg}}{214 \times 14} \text{ kJ/hr} = 2996 \text{ kJ/hr}$$

$$= 0.832 \text{ kJ/s} = 832.2 \text{ W}$$



$k = ?$

$r_1 = 0.7$ m

$r_2 = 0.7 + 0.08$

$= 0.78$ m

$q = q_{cyl} + q_{sphere}$

$$832.2 = \frac{T_2 - T_1}{\frac{1}{2\pi k L} \ln \frac{r_2}{r_1}} + \frac{T_2 - T_1}{\frac{1}{4\pi k}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)} \Rightarrow 832.2 = \frac{210}{\frac{0.028}{k} \times 0.10} + \frac{210}{\frac{0.07}{k}(0.146)}$$

$$\Rightarrow \frac{832.2}{210} = \frac{210}{\frac{0.0503}{x}} + x \times 20547.94$$

$$\Rightarrow 3.96 = \cancel{399.3x +} 75{,}000x + 20547.94x$$

$$\Rightarrow x = 0.091$$