Heat and Mass Transfer [MEC 3210]

Assignment

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Q=1 A room is constructed for a multilayered wall, the material of which from inside are masonry brick ($k = 0.7$ w/mk) at the outside having thickness 0.25m, 0.025m, 0.1m & 0.013m, respectively. The room is maintained at 25°C when the outside air is at temp. of -7°C. assuming that the heat transfer coefficient of the air layer on the inside and outside of the composite are 6 w/m²k & 12 w/m² k, respectively find the overall heat transfer coefficient from the air on the interior to air at exterior of the wall, the overall thermal resistance per m², the rate heat transfer per m², and the temperature at the junction b/w the mortar and Lime stone.

Outside air $T_0 = -7°C$

$h_2 = 12\ w/m^2$

Solⁿ:-

$$R_i = \frac{1}{h_i A}$$

$$R_1 = \frac{L_1}{A k_1} = \left(\frac{0.25}{A \times 0.66}\right) \text{ k/w}$$

$$R_2 = \frac{L_2}{A k_2} = \left(\frac{0.025}{A \times 0.75}\right) \text{ k/w}$$

$$R_3 = \frac{L_3}{A k_3} = \left(\frac{0.1}{A \times 0.66}\right) \text{ k/w}$$

$$R_4 = \frac{L_4}{A k_4} = \left(\frac{0.013}{A \times 0.7}\right) \text{ k/w}$$

$$R_o = \frac{1}{h_o A} = \left(\frac{1}{12 A}\right) \text{ k/w}$$

Now $R_{Total} = R_i + R_{A1} + R_2 + R_3 + R_4 + R_o$

$$\Rightarrow \frac{1}{A}\left[\frac{1}{6} + 0.37 + 0.033 + 0.1515 + 0.0185 + \frac{1}{12}\right]$$

$$R_{Total} = \frac{0.8322}{A}$$

If $A = 1 m^2$ $\therefore R_{Total} = 0.8322 \ m^2 K/w$

overall heat transfer coefficient

$$U = \frac{1}{R} = 1.2 \ w/m^2 K$$

now consider multi layered wall, the heat transfer per m^2 can be given as

$$\frac{q}{A} = U(T_i - T_o)$$

$$= 1.2[25 - (-7)]$$

$$= 1.2 \times 32$$

$$= 38.4 \ w/m^2$$

Q=2 A 1·0m thick wall has its surfaces maintained constant at temperatures of 100°C & 60°C. If the thermal conductivity of this wall varies as ~~k=~~ : $k = 0.2(1 + 0.05\,T)$ where k is in W/mK and T is in °C find the location of wall where the temp. is 80°C. If the variation of thermal conductivity is ignored and taken as $k = 0.2$ W/mK. Calculate the new location in the wall where the temperature will be 80°C.

Solⁿ :-

⇒ using fourier's Law $\frac{\partial}{\partial x}\left(k \frac{\partial T}{\partial x}\right) = 0$

$$k = k_0(1 + \alpha T)$$

$$\frac{\partial}{\partial x}\left(k_0(1+\alpha T)\frac{\partial T}{\partial x}\right) = 0$$

or

$$\frac{d}{dx}\left[(1+\alpha T)\frac{dT}{dx}\right] = 0$$

Since k_0 is constant and not equal to zero

Integration will give $(1+\alpha T)\frac{dT}{dx} = C_1$

again $T + \frac{\alpha T^2}{2} = C_1 x + C_2$

$T = T_1$ at $x = 0$ will give, $T_1 + \frac{\alpha T_1^2}{2} = C_2$

& $T = T_2$ at $x = L$, ~~o~~

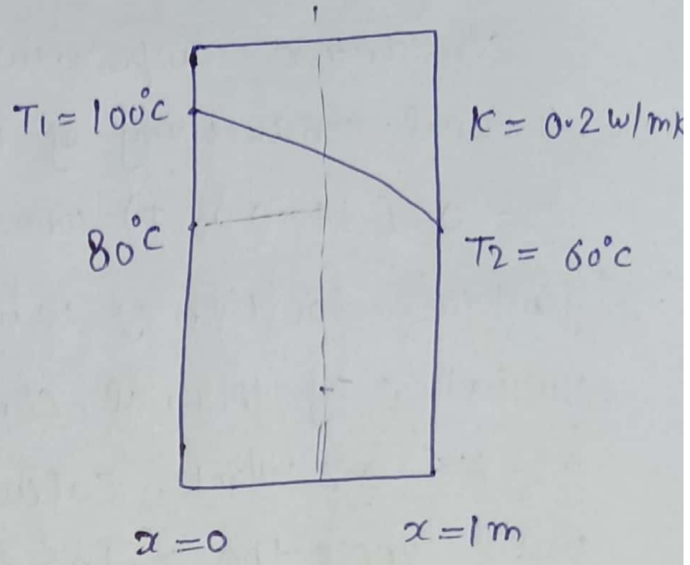
$$C_1 = \left[\left(T_2 + \frac{\alpha T_2^2}{2}\right) - C_2\right]\frac{1}{L}$$

Putting $T_1 = 100°C$

$T_2 = 60°C$

$\alpha = 0.05$

$L = 1 m$



$$C_2 = T_1 + \frac{\alpha T_1^2}{2}$$

$$C_2 = 100 + \frac{0.05 \times (100)^2}{2}$$

$$C_2 = 100 + 250$$

$$C_2 = 350 \quad \text{and} \quad C_1 = -150$$

Thus at $T = 80°C$ the following eqn $\left[T + \frac{\alpha T^2}{2}\right] = C_1 x + C_2$

gives $\boxed{X = 0.733 m}$.

Q=3 A 50 mm thick refractory Brick ($k = 2\ W/mK$) is placed b/w two 5 mm thick metallic ($k = 50\ W/mK$) plates. The Both faces of Brick adjacent to the plates have rough solid to solid contact over 20% of the area where the average height of asperities filled with air ($k = 0.02\ W/mK$) are 1mm. If the outer surface temp. of plates are 300°C and 100°C. find the rate of heat flow per unit area.

Solⁿ:- Thermal resistance offered by steel plates.

$$R_1 = \frac{L_1}{K_1 A} = \frac{5 \times 10^{-3}}{50 \times 1} = 1 \times 10^{-4}\ K/W$$

Thermal resistance offered by air in the cavity.

(80% of area A) : $R_a = \frac{L_a}{0.80\ K_a A} = \frac{1 \times 10^{-3}}{0.80 \times 0.02}$

$$= 0.0625\ K/W$$

Thermal resistance offered by concrete aspirites.

(20% of area A) :- $R_c = \frac{L_c}{0.20\ K_c A} = \frac{1 \times 10^{-3}}{0.2 \times 2}$

$$= 2.5 \times 10^{-3}\ K/W$$

effective thickness of concrete slab $(50 - 2) = 48\ mm$

$$\therefore R_3 = \frac{L_3}{K_3 A} = \frac{48 \times 10^{-3}}{2 \times 1} = 0.024\ K/W$$

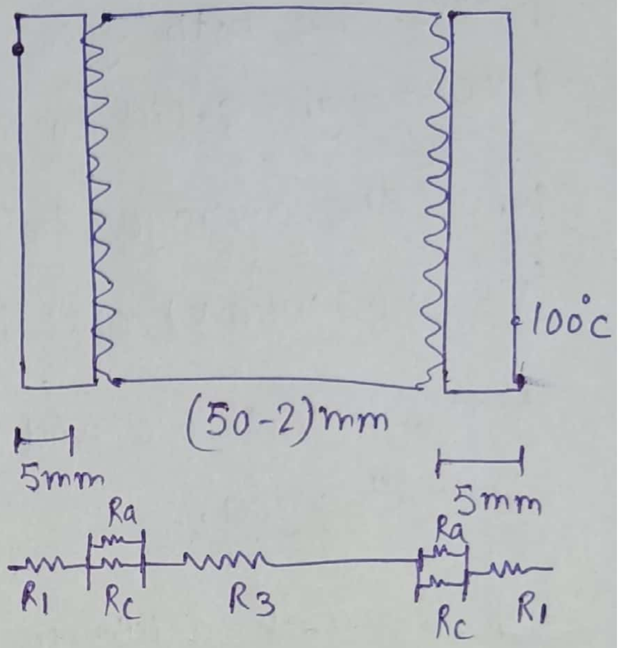
$$\frac{1}{R_2} = \frac{1}{R_a} + \frac{1}{R_c} = \frac{R_c + R_a}{R_a R_c}$$

$$R_2 = \frac{R_a R_c}{R_a + R_c}$$

$$R_2 = \frac{0.0625 \times 2.5 \times 10^{-3}}{(62.5 + 2.5) \times 10^{-3}}$$

$$R_2 = \frac{0.15625}{65}$$

$$R_2 = 2.403 \times 10^{-3} \text{ K/W}$$



Total resistance in the wall under consideration will be

$$\Sigma R = 2R_1 + 2R_2 + R_3$$

$$= 2 \times 10^{-4} + 2 \times 2.403 \times 10^{-3} + 2.4 \times 10^{-2}$$

$$\Sigma R = 0.029 \text{ K/W}$$

$$\therefore q = \frac{300 - 100}{\Sigma R} = \frac{200}{0.029}$$

$$\boxed{q = 6896.5 \text{ W}}$$

Q=4 Air flows at 120°C in a metallic tube ($k = 20 W/m°C$) having inner diameter as 25mm and wall thickness as 0.5mm If the tube is exposed to ambient air at 15°C calculate the overall heat transfer coefficient and the heat loss per meter length of the tube assume heat transfer coefficient of the inside air as $65 W/m^2 °C$ and that of ambient air is $6.5 W/m^2 °C$ estimate how much will be redn in heat Loss if an insulation of 10mm thickness is added on outer surface of tube.

Soln:- without insulation

$$\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{\ln(r_o/r_i)}{2\pi L K} + \frac{1}{h_o A_o}$$

$$\frac{1}{U_o} = \frac{A_o}{h_i A_i} + \frac{A_o \ln(r_o/r_i)}{2\pi L K} + \frac{A_o}{h_o A_o}$$

$$\Rightarrow \frac{r_o}{h_i r_i} + \frac{r_o \ln(r_o/r_i)}{K} + \frac{1}{h_o}$$

$$\frac{1}{U_o} = \frac{13}{65 \times 12.5} + \frac{0.013 \ln(0.013/0.0125)}{20} + \frac{1}{6.5}$$

$$\frac{1}{U_o} = 0.1690$$

$$\boxed{U_o = 5.91 \ W/m^2 K}$$

heat can ~~des~~ dissipate from the bare tube

$$q = U_o A_o (T_s - T_\infty) = 2\pi r_o h_o (120 - 15)$$

$\Rightarrow$

after adding an ~~is~~ insulation of 10mm thickness

~~ass~~ thermal conductivity of insulating material = 0.04 w/m

$$\frac{1}{U_{ins}} = \frac{A_{ins}}{h_i A_i} + \frac{A_{ins} \ln(r_o/r_i)}{2\pi L K} + \frac{A_{ins} \ln(r_{ins}/r_o)}{2\pi L K} + \frac{A_{ins}}{h_o A_{ins}} +$$

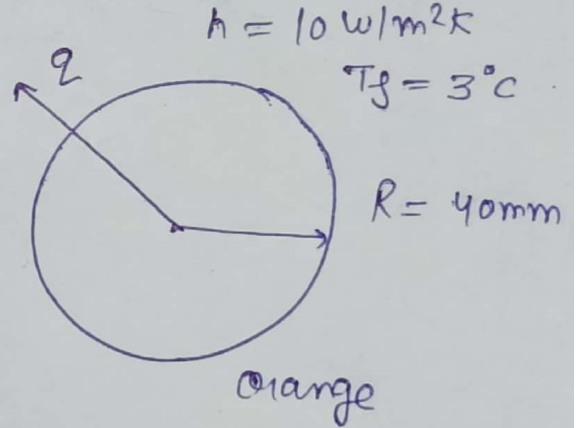
$$\frac{1}{U_{ins}} = \frac{r_{ins}}{h_i r_i} + \frac{r_{ins} \ln(r_o/r_i)}{K} + \frac{r_{ins} \ln(r_{ins}/r_o)}{K_{ins}} + \frac{1}{h_o}$$

Q=5 The energy released during ripening process of oranges is estimated to be 600 W/m³. assume that orange is a homogeneous sphere of dia. 80 mm with k = 0.15 W/mK. find temp. at the center of the orange and the heat flow from its outer surface.

(i) If the external surface temp. is 3°C

(ii) If instead of external surface temp. the ambient ($h = 10\ W/m^2K$) temp. is 3°C.

Soln:-



Considering the steady 1D heat conduction eqn for spherical body

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) + \frac{q}{k} = 0$$

$$\frac{dT}{dr} = \frac{-qr}{3k} + \frac{C_1}{r^2} \quad \text{and} \quad T = \frac{-qr^2}{6k} - \frac{C_1}{r} + C_2$$

applying Boundary conditions

$$T - T_s = \frac{qR^2}{6k}\left(1 - \frac{r^2}{R^2}\right)$$

(i) with $T_s = 3°C$

$$T_{r=0} = \frac{600 \times (0.04)^2}{6 \times 0.15} + 3$$

$$T_{r=0} = 4.066$$

$$q = 800 \times \frac{4}{3} \pi (0.04)^3$$

$$q = 0.1607 \ W$$

(ii) The ambient temp. at $3°C$ and $h = 10$, then at steady state

$$q = h(4\pi R^2)(T_s - T_f) = q \frac{4}{3} \pi R^3$$

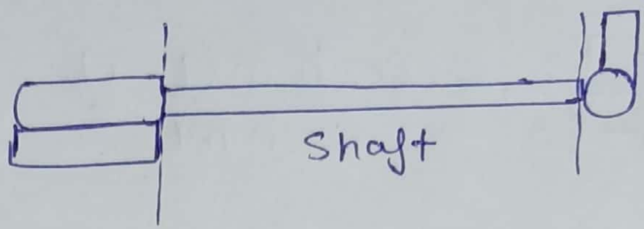
$$\cancel{(T_s - 3) = 600 \times \frac{4}{3} \times \pi \times}$$

$$T_s - 3 = \frac{600 \times 0.04}{3 \times 10}$$

$$\therefore T_s = 3.13°C$$

Q=6 A centrifugal pump ------------

Soln :-



Assuming that Shaft of motor is Behaving as insulated

$T_1 = 65^\circ C$ $\quad$ $T_2 = \cancel{400}\ 450^\circ C$

$h = 15\ W/m^2K$

$T_\infty = 25^\circ C$

$$\frac{\theta}{\theta_0} = \frac{\cosh m(L-x)}{\cosh mL}$$

$$\cancel{m = \sqrt{\frac{4\times 15}{40\times 0.02}}}$$

$$\cancel{m = 8.66}$$

$$\left.\frac{\theta}{\theta_0}\right|_{x=L} = \frac{T-T_\infty}{T_2-T_\infty} = \frac{65-25}{450-25} = \frac{40}{425}$$

$$\therefore \frac{40}{425} = \frac{1}{\cosh mL}$$

$$\cosh mL = 10.625$$

$$mL = 1.066$$

But $m = \sqrt{\frac{hP}{KA}} = \sqrt{\frac{4h}{Kd}}$

$$m = \sqrt{\frac{4\times 15}{40\times 0.02}} = 8.66$$

$$\because mL = 1.066$$

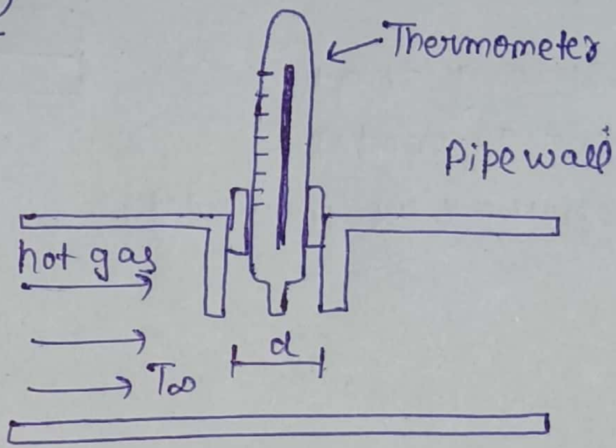
$$8.66\times L = 1.066$$

$$\underline{L = 0.123m}$$

Q=7 The Temperature of hot ~~gas~~ ---- ------

Sol^n:-

$$\frac{T-T_\infty}{T_0-T_\infty} = \frac{\cosh m(L-x)}{\cosh mL}$$



here $m = \sqrt{\frac{hP}{KA}}$

$= \sqrt{\frac{h\pi d}{K\pi d\delta}}$

$m = \sqrt{\frac{h}{K\delta}} = \sqrt{\frac{40}{43 \times 0.002}}$

$m = 21.5$

$$\frac{T-T_\infty}{T_0-T_\infty} = \frac{T_{x=L}-T_\infty}{T_{x=0}-T_\infty} = \frac{150-T_\infty}{80-T_\infty}$$

$$\Rightarrow \frac{1}{\cosh mL} = \frac{1}{\cosh(21.5 \times 0.1)} = \frac{1}{4.3507}$$

or $150 - T_\infty = 0.2298[80 - T_\infty]$

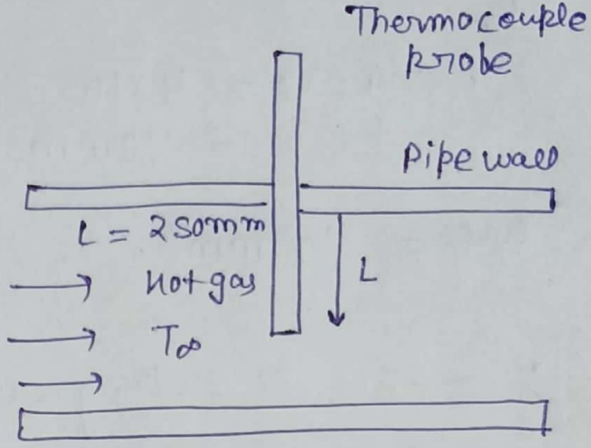
$\therefore$ Actual Temp. of gas is

$$\boxed{T_\infty = 170.87°C}$$

Q=8 A Thermo couple probe ---------

Soln :-

$$\frac{T - T_\infty}{T_0 - T_\infty} = \frac{\cosh m(L-x)}{\cosh mL}$$



$$m = \sqrt{\frac{hP}{KA}}$$

$$= \sqrt{\frac{10 \times 0.05}{145 \times 25 \times 10^{-6}}}$$

$$m = 11.74$$

$$\Rightarrow \frac{T - T_\infty}{T_0 - T_\infty} = \frac{390 - T_\infty}{T_{x=0} - T_\infty} = \frac{1}{\cosh mL} = \frac{1}{\cosh[11.74 \times 0.25]}$$

$$= 0.1133$$

$$\Rightarrow \frac{T - T_\infty}{T_0 - T_\infty} = \frac{350 - T_\infty}{T_{x=0} - T_\infty} = \frac{\cosh[11.74 \times 0.125]}{\cosh[11.74 \times 0.25]}$$

$$= \frac{2.2844}{9.437} \Rightarrow 0.242$$

$$\Rightarrow \frac{390 - T_\infty}{0.1133} = \frac{350 - T_\infty}{0.242}$$

$$\therefore T_\infty = 425.21^\circ C$$

Now $350 - T_\infty = 0.242 [T_0 - T_\infty]$

$$\therefore \boxed{T_0 = 20.21^\circ C}$$

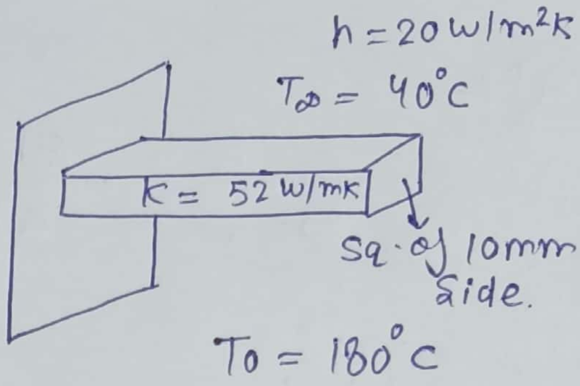
Q=9 A long square rod ------------

Soln :-

Perimeter $= 4 \times 10$

$= 40mm$

area $= 100mm^2$



Since this is a long rod so treated as an extended surface of infinite length.

using, $$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-mx}$$

$$\Rightarrow \frac{100 - 40}{180 - 40} = e^{-mx}$$

$$\Rightarrow \frac{60}{140} = e^{-mx} \quad \text{--- (1)}$$

$$m = \sqrt{\frac{hP}{KA}} = \sqrt{\frac{20 \times 0.04}{52 \times 100 \times 10^{-6}}} = 17.54$$

from eqn (1)

$$0.4285 = e^{-17.54x}$$

$\therefore x =$ ~~0.3117~~ $0.064 m$

where temp. is 80°C

Temperature at 80 mm from base.

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-mx} \quad \text{or} \quad \frac{T - 40}{180 - 40} = e^{-17.54 \times 0.3117}$$

$$\Rightarrow \frac{T-40}{180-40} = e^{-5.467}$$

$$T-40 = 140 \times 4.22 \times 10^{-3}$$

$$T = 40.59^\circ C$$

Temperature at mid Location, $L = 0.1\ mm$

$$T - T_\infty = (80-40)\frac{\sinh(17.54 \times 0.1)}{\sinh(13.86 \times 0.2)} + (180-40) \times \frac{\sinh(13.86 \times 0.1)}{\sinh(13.86 \times 0.2)}$$

$$T_{x=0.1m} = 86.485^\circ C$$

using $\dfrac{T_2 - T_\infty}{T_1 - T_\infty} = \dfrac{\cosh m(L - x_{min})}{\cosh m x_{min}}$