HEAT TRANSFER (18ME73/17ME73)
IAT 2

Instructions:
Each question carries 10 Marks
Attempt all 5 questions
Use of heat transfer data hand book is permitted

Max Marks: 50
Duration: 1.5 hrs

1. A steel rod (k=32W/mK), 12mm in diameter and 60 mm long, with an insulated end, is to be used as a spine. It is exposed to surroundings with a temperature of 60 ^oC and a heat transfer coefficient of 55W/m^{2}K. The temperature at the base of fin is 95°C. Determine:
   I. The Fin efficiency
   II. The temperature at the edge of the spine
   III. The rate of heat transfer
   IV. Fin Effectiveness
2. A short fin with insulated tip of 0.08 m length and diameter 12 mm is exposed to air at 30°C. Thermal conductivity is 15 W/mK. The base temperature is 280°C. The heat dissipated by the fin is 7W. Determine the value of convection coefficient and also the tip temperature.
3. Saturated steam at 110^{0}C flows inside a copper pipe (k= 450 W/mK) having an internal diameter of 10 cm and external diameter of 12 cm. Convective heat transfer coefficient for steam side is 1200 W/m^{2}K and for outside surface of pipe is 18 W/m^{2}K. Determine the rate of heat loss in the pipe if it is located in space at 25^{0}C.
   Determine the % increase/decrease in rate of heat loss if the pipe is lagged with 5cm thick insulation (k= 0.22 W/mK).
4. A steel slab 16 cm thickness, has thermal conductivity k = 51 $(1 – 8.6 \times 10^{-4}$ T) k is the thermal conductivity at T °C in W/mK. The slab surfaces are maintained at 400°C and 180°C. Determine the heat flow rate, the temperature and temperature gradient at 4cm from the end at 400°C.
5. A wire of 8mm diameter at a temperature of 60^{o}C is to be insulated by a material having k = 0.174 W/mK. Heat transfer coefficient between surface and atmosphere is 8W/m^{2}K and ambient temperature is 25^{o}C. For maximum heat loss find the minimum thickness of insulation. Find % increase in heat dissipation due to insulation.

HT IAT - II

(1) Given, $k = 32\, W/mk$ $L = 60\times10^{-3} m$

$d = 12\times10^{-3} m$ $T_\infty = 60°$

$T_b = 95°$ $h = 55 w/m^2 k$

$$m = \sqrt{\frac{hp}{kA_c}} = \sqrt{\frac{4h}{kd}} = \sqrt{\frac{4\times55}{32\times12\times10^{-2}}}$$

$= 23.935$

i) $$\eta = \frac{Q_{fin}}{Q_{max}}$$

ii) At the edge of the spine temp →

$x = L$ at the edge of spine

$$\frac{T_L - T_\infty}{T_b - T_\infty} = \frac{\cos h[m(L-L)]}{\cos h(mL)}$$

$$\frac{T_L - 60}{95-60} = \frac{\cos h(0)}{\cos h(23.935\times60\times10^{-3})}$$

$$\boxed{T_L = 75.75°}$$

iii) Rate of heat transfer

$$Q_{fin} = \sqrt{hpkA_c}\;\theta_b \tanh(mL)$$

$$= \sqrt{55 \times \pi \times 12 \times 10^{-3} \times 32 \times \pi \times (6 \times 10^{-3})^2} \times (95 - 60) \times \tanh(23.935 \times 60 \times 10^{-3})$$

$$\boxed{Q_{fin} = 2.7 \text{ watt}}$$

∴ Efficiency

$$\eta = \frac{Q_{fin}}{Q_{max}} = \frac{\sqrt{hpkA_c}\;\theta_b \tanh(mL)}{h(pL)\,\theta_b}$$

$$= \sqrt{\frac{kA_c}{hp}} \times \frac{1}{l} \times \tanh(mL)$$

$$\frac{\tanh(mL)}{mL} = \frac{\tanh(23.935 \times 60 \times 10^{-3})}{23.935 \times 60 \times 10^{-3}}$$

$$\Rightarrow 0.6217 = 62.17\%$$

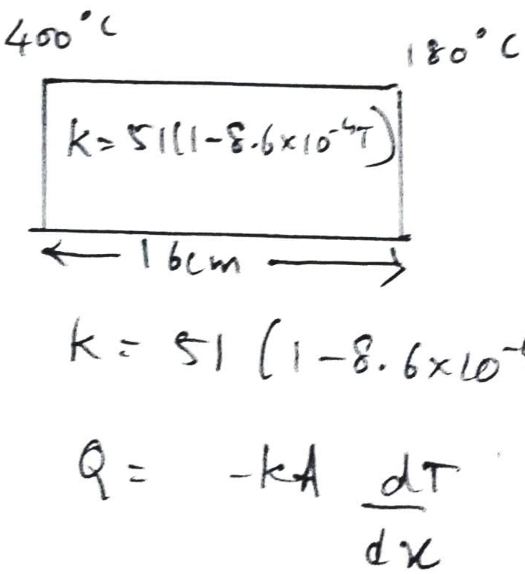
ii) Fin effectiveness $= \dfrac{Q_{with\ fin}}{Q_{without\ fin}}$

$Q_{without\ fin} = h A_c \theta_b$

Fin effectiveness $= \dfrac{2.7}{55 \times \frac{\pi \times (12\times10^{-3})^2}{4} (95-60)}$

Fin effectiveness $= 12.40$

(4)



Here $k = 51(1 - 8.6\times10^{-4} T)$

WKT $Q = -kA \dfrac{dT}{dx}$

$Q\,dx = -51(1-8.6\times10^{-4}T) A\,dT$

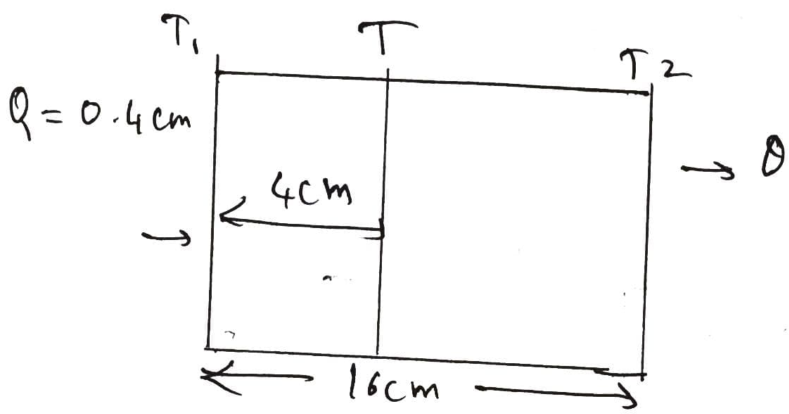
$Q \int_0^{0.16} dx = \int_{400}^{180} -51(1-8.6\times10^{-4}T) A\,dT$

$Q \int_0^{0.16} dx = -51A \int_{400}^{180} (1-8.6\times10^{-4}T)\,dT$

$$Q \times [0.16 - 0] = -51A\left[(180-400) - 8.6\times10^{-4}\left(\frac{180^2-400^2}{2}\right)\right]$$

$$\frac{Q}{A} = \frac{51}{0.16}\left[(400-180) - \frac{8.6\times10^{-4}(400^2-180^2)}{2}\right]$$

$$\boxed{\frac{Q}{A} = 52635.825 \, W/m^2}$$



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

$$\frac{Q}{A}dx = -51(1-8.6\times10^{-4}T)dT$$

$$52635.825\int_0^{0.04} dx = -51\int_{400}^{T}(1-8.6\times10^{-4}T)dT$$

$$52635.825[0.04-0] = -51\left[(T-400) - 8.6\times10^{-4}\frac{(T^2-400^2)}{2}\right]$$

$$52635.825 \times 0.04 = 51\left[(400-T) - 8.6\times10^{-4}\times\frac{(400^2-T^2)}{2}\right]$$

$$\frac{51\times8.6\times T^2}{2} - 51T + \left[51\times400 - \frac{51\times8.6\times10^{-4}\times400^2}{2} - 52635.825\times0.04\right] = 0$$

$$T = \begin{cases} 339.47^\circ C \\ 1986.1 \end{cases}$$

So, $\boxed{T = 339.47^\circ C}$

$\therefore \frac{Q}{A} = 52635.825\ w/m^2$

$T_{4cm} = 339.5^\circ C$

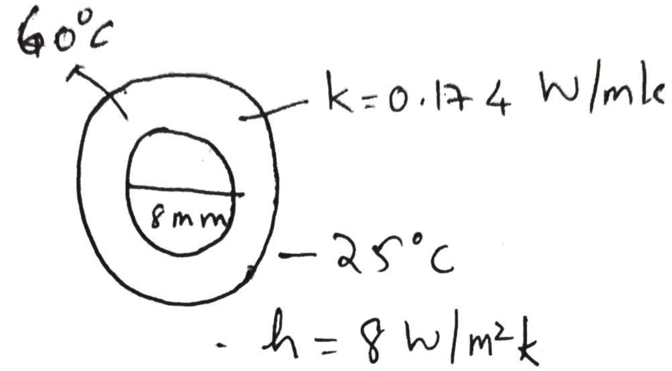
$$Q = -kA\frac{dT}{dx}$$

$$\frac{dT}{dx} = \frac{-Q}{kA} = \frac{-52635.825}{51(1-8.6\times10^{-4}T)}$$

$$\left.\frac{dT}{dx}\right|_{4cm^2} = \frac{-52635.825}{51(1-8.6\times10^{-4}\times339.5)}$$

$$\frac{dT}{dx} = -1457.17 \, k/m \text{ or } °C/m$$

(5)



$k = 0.174 \, W/mk$

$h = 8 \, W/m^2k$

$$r_c = \frac{k}{h} = \frac{0.174}{8} = 0.0218 \, m$$

$$t_c = r_c - r_1 = 0.0218 - 4 \times 10^{-3} = 0.0178 \, m$$

$t_c = 17.8 \, mm$

$$Q_w = \frac{T_1 - T_2}{\frac{1}{2\pi k l} \ln\left(\frac{r_c}{r_1}\right) + \frac{1}{2\pi r_c l \times h}}$$ → Case i → with insulation

$$\frac{Q_H}{l} = \frac{60 - 25}{\frac{1}{2\pi 0.174} \ln\left(\frac{0.0218}{4 \times 10^{-3}}\right) + \frac{1}{2\pi (0.0218) \times 8}}$$

Case ii → Without insulation

$$\frac{Q_{w/o}}{l} = \frac{T_1 - T_2}{\frac{1}{h(2\pi r_1 l)}} = \frac{60-25}{\frac{1}{8(2\pi(4\times10^{-3})}} = 7.037 \ W/m$$

% increase in heat dissipation

$$= \frac{14.2 - 7.037}{7.037} \times 100$$

$$= \boxed{101.88\ \%}$$

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(2)

$L = 0.08 \ m$

$d = 12\times10^{-3} \ m$ $\quad$ $T_\infty = 30°C$

$k = 15 \ W/mK$ $\quad$ $Q = 7 \ W$

$T_b = 280°C$

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

$$m = \sqrt{\frac{h\times\pi\times d \times 4}{k\times\pi\times d^2}}$$

$$m = \sqrt{\frac{h\times4}{k\times d}}$$

$$m^2 = \frac{h \times 4}{k \times d}$$

$$h = \frac{m^2 \times k \times d}{4}$$

$$h = \frac{m^2 \times 15 \times (12 \times 10^{-3})}{4}$$

$$\boxed{h = 0.045 m^2}$$

$$Q = \sqrt{h p \times A_c} \cdot \theta_b \tanh(mL)$$

$$Q = \sqrt{(0.045 m^2) \times (\pi \times 12 \times 10^{-3}) \times 15 \times \left(\frac{\pi (120 \times 10^{-3})^2}{4}\right)} \times (280 - 30) \times \tanh(m \times 0.08)$$

$$7 = m \, (1.696 \times 10^{-3}) \times (250) \times \tanh(0.08m)$$

$$7 = 0.4241 m \tanh(0.08m)$$

$$16.5044 = m \cdot \tanh(m 0.08)$$

$$\boxed{m = 18.3531 m}$$

Now, $h = (0.045)(18.353)^2$

$$\boxed{h = 15.157 \ W/m^2 k}$$

Tip temp, At $x = 0.08$

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

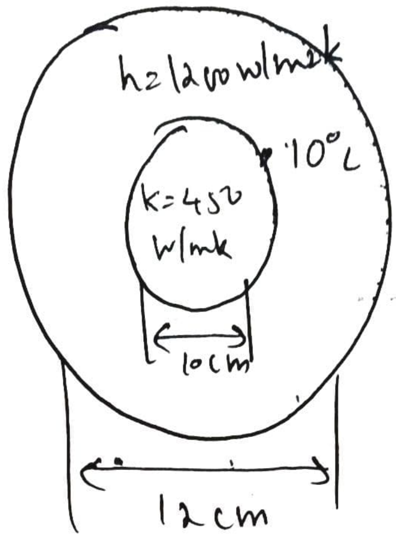
$$\frac{T - 30}{250} = \frac{\cosh(18.353(0.08 - 0.03))}{\cosh(18.353 \times 0.68)}$$

$$\frac{T - 30}{250} = \frac{\cosh[18.53(0.08 - 0.03)]}{\cosh(18.35m \times 0.68)}$$

$$\frac{T - 30}{250} = \frac{1}{2.2859}$$

$$\boxed{T = 139.36°C}$$

(3)



$h = 18\ w/m^2k$

$25°c$

$r_1 = 5\,cm$

$= 5\times10^{-2} m$

$r_2 = 12\,cm = 12\times10^{-2} m$

i) Q without insulation

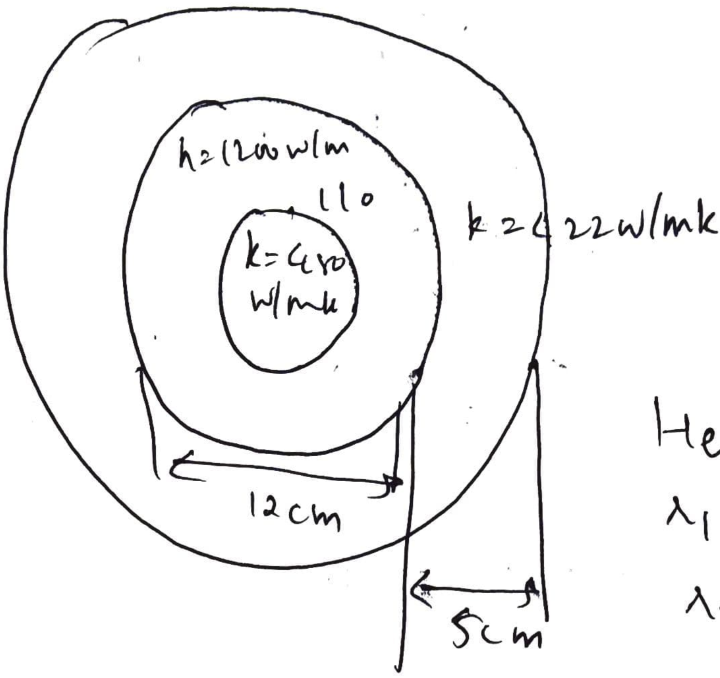
$$110 \quad \frac{1}{1200\times2\times\pi(5\times10^{-2})} \quad \frac{\ln\left(\frac{6\times10^{-2}}{5\times10^{-2}}\right)}{2\times\pi\times450} \quad \frac{1}{18\times2\times\pi\times0.6\times10^{-2}} \quad 25$$

$\frac{Q_{without}}{l}$

$$\frac{Q_{without}}{l} = \frac{110-25}{\frac{1}{2\times\pi\times5\times10^{-2}\times1200} + \frac{\ln\left(\frac{6\times10^{-2}}{5\times10^{-2}}\right)}{2\times\pi\times450} + \frac{1}{18\times2\pi\times0.6\times10^{-2}}}$$

$$\frac{Q_{without}}{l} = 57.57\ W/m$$

ii) <u>Without insulation</u>



Here
$r_1 = 5cm$
$r_2 = 6cm$
$r_3 = 11cm$

110 —W—W—W—W— 25

$$\frac{1}{1200\times2\times\pi\times5\times10^{-2}} \quad \frac{\ln\left(\frac{6\times10^{-2}}{5\times10^{-2}}\right)}{2\times\pi\times480} \quad \frac{\ln\left(\frac{11\times10^{-2}}{6\times10^{-2}}\right)}{2\times\pi\times0.22} \quad \frac{1}{1\times2\times\pi\times11\times10^{-2}}$$

$$\frac{Q_{with}}{l} = \frac{110-25}{\frac{1}{1200\times2\times\pi\times5\times10^{-2}} + \frac{\ln\left(\frac{6\times10^{-2}}{5\times10^{-2}}\right)}{2\times\pi\times480} + \frac{\ln\left(\frac{11\times10^{-2}}{6\times10^{-2}}\right)}{2\times\pi\times0.22} + \frac{1}{1\times2\times\pi\times11\times10^{-2}}}$$

$$\frac{Q_{with}}{l} = 162.96\,w/m$$

∴ Increase in heat transfer

$$\frac{162.96 - 57.57}{57.57} \times 100$$

$= 183.06\ \%$