GATE PSUs

State Engg. Exams

MADE EASY WORKBOOK 2025

Detailed Explanations of Try Yourself *Questions*

Chemical Engineering

Heat Transfer

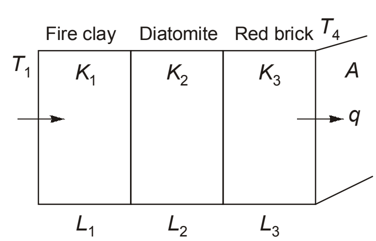
MADE EASY PUBLICATIONS

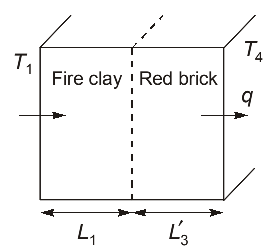
1 Conduction

Detailed Explanation of Try Yourself Questions

T1 : Solution

(Ans : 57.3 cm)





$$q = \frac{T_1 - T_4}{\frac{L_1}{k_1A} + \frac{L_2}{k_2A} + \frac{L_3}{k_3A}};$$

$$q = \frac{T_1 - T_4}{\frac{L_1}{k_1A} + \frac{L'_3}{k_2A}}$$

$$\frac{T_1 - T_4}{\frac{L_1}{k_1A} + \frac{L_2}{k_2A} + \frac{L_3}{k_3A}} = \frac{T_1 - T_4}{\frac{L_1}{k_1A} + \frac{L'_3}{k_2A}}$$

$$\frac{1}{\frac{0.11}{0.94} + \frac{0.06}{0.13} + \frac{0.25}{0.7}} = \frac{1}{\frac{0.11}{0.94} + \frac{L'_3}{0.7}}$$

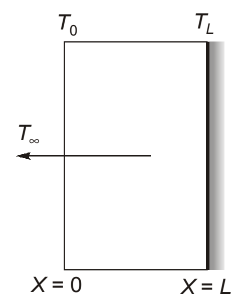
$$L'_3 = 0.573 = 57.3 \text{ cm}$$

T2 : Solution

t = 150 mm, k = 15 W/mK

(i)
$$\dot{q} = \frac{h(T - T_\infty)}{0.150} = \frac{500 \times (100 - 20)}{0.150}$$
$$= 0.267 \times 10^6 \text{ W/m}^3$$
$$T(X) = a + bx + cx^2$$
$$X = 0$$
$$T(0) = T_0 = 100°\text{C},\ T_\infty = 20°\text{C},$$
$$h = 500 \text{ W/m}^2\text{-K}$$

at
$$X = 0,$$
$$T_0 = 100°\text{C}$$
$$100 = a + 0 + 0, \qquad (a = 100)$$



$$\left.\frac{dT}{dX}\right|_{x = L} = 0$$
$$b + 2cx = 0$$
$$b + 2c(0.15) = 0$$
$$b + 0.3c = 0$$

(ii) For steady state,
$$-\left[-k\left.\frac{dT}{dX}\right|_{x=0}\right] = h(T - T_\infty)$$
$$15 \times b = 500 \times (100 - 20)$$
$$b = 266.67 \times 10$$
$$b = 2.67 \times 10^3 \text{ k/m}$$

(iii) $2.67 \times 10^3 + 0.3c = 0$
$$c = -8.9 \times 10^3 \text{ k/m}^2$$

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2 Transient Heat Conduction and Fins

Detailed Explanation of Try Yourself Questions

T1 : Solution

(8 watt)

Given:
$$Q = 6 \text{ watt}$$
$$\text{Effectiveness} = 3$$
$$\text{Efficiency} = 0.75$$

Now, as we know,
$$\eta = \frac{Q_{actual}}{Q_{max}} = \text{Efficiency}$$

$\therefore$ Q_{max} = When the entire fin surface is maintained at base temperature

$$0.75 = \frac{6}{Q_{max}} \rightarrow Q_{max} = 8 \text{ watt}$$

T2 : Solution

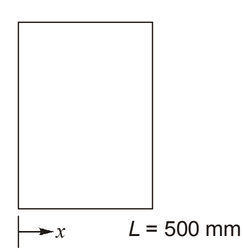
(Ans : 0.333 m)

$$T = 120 - 100x + 24x^2 + 40x^3 - 30x^4$$

$$\frac{\partial^2 T}{\partial x^2} + 0 + 0 + 0 = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}$$

Rate of heating or cooling,

$$\frac{\partial T}{\partial \tau} = \alpha \frac{\partial^2 T}{\partial \tau}$$



Location for maxima.

$$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial \tau}\right) = 0$$

$$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial \tau}\right) = \alpha \frac{\partial^3 T}{\partial x^3}$$

$$\alpha \frac{\partial^3 T}{\partial x^3} = 0$$

$$\frac{\partial^3 T}{\partial x^3} = 0 - 0 + 0 + 240 - 720x$$

$$240 - 720x = 0$$

$$x = \frac{240}{720} = 0.333 \text{ m}$$

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3 Radiation

Detailed Explanation of Try Yourself Questions

T1 : Solution

(806) [805 to 807] W/m^2

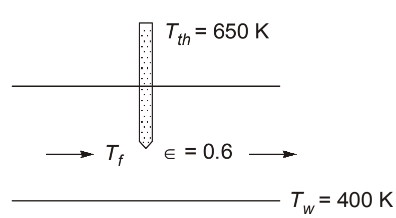
$$\dot{q}_{12,\text{ one shield}} = \frac{Q_{12,\text{ one shield}}}{A}$$

$$= \frac{\sigma\left[T_1^4 - T_2^4\right]}{\left(\frac{1}{\epsilon_1}+\frac{1}{\epsilon_2}-1\right)+\left(\frac{1}{\epsilon_{31}}+\frac{1}{\epsilon_{32}}-1\right)} = \frac{(5.67\times10^{-8})(800^4-500^4)}{\left[\frac{1}{0.2}+\frac{1}{0.7}-1\right]+\left[\frac{1}{0.1}+\frac{1}{0.1}-1\right]}$$

$$\dot{q}_{12} = 806\text{ W/m}^2$$

T2 : Solution

(715) (714 to 716) K



$$T_f = T_{th} + \frac{\epsilon\sigma\left(T_{th}^4 - T_w^4\right)}{h}$$

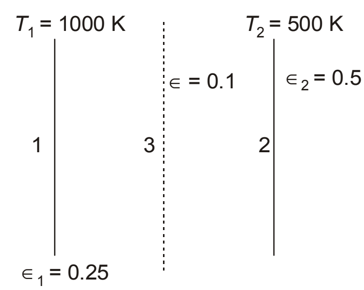
$$T_f = 650 + \frac{0.6\times5.67\times10^{-8}\times(650^4-400^4)}{80}$$

$$T_f = 715\text{ K}$$

T3 : Solution

(Ans : (a) 10.63 kW/m^2, (b) 2.21 kW/m^2, (c) 837.59 K)

(a)



$$\frac{\dot{q}}{A} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\epsilon_1}{\epsilon_1} + \frac{1}{F_{12}} + \frac{1-\epsilon_2}{\epsilon_2}}$$

$$= \frac{5.67 \times 10^{-8} \times \left(1000^4 - 500^4\right)}{3+1+1}$$

$$\frac{q}{A} = 10631.25 \text{ W/m}^2 = 10.631 \text{ kW/m}^2$$

(b)
$$\frac{\dot{q}}{A} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\epsilon_1}{\epsilon_1} + \frac{1}{F_{13}} + \left(\frac{1-\epsilon}{\epsilon}\right) + \left(\frac{1-\epsilon}{\epsilon}\right) + \frac{1}{F_{23}} + \frac{1-\epsilon_2}{\epsilon_2}}$$

$$\left(\frac{\dot{q}}{A}\right) = \frac{5.67 \times \left(1000^4 - 500^4\right) \times 10^{-8}}{3+1+9+9+1+1}$$

$$\frac{q}{A} = 2214.843 \text{ W/m}^2$$

or
$$\frac{q}{A} = 2.214 \frac{\text{kW}}{\text{m}^2}$$

(c)
$$\frac{\dot{q}}{A} = \frac{\sigma\left(T_1^4 - T^4\right)}{\frac{1-\epsilon_1}{\epsilon_1} + \frac{1}{F_{23}} + \frac{1-\epsilon}{\epsilon}}$$

$$2214.84 = \frac{5.67 \times 10^{-8} \times \left(1000^4 - T^4\right)}{3+1+9}$$

$$T = 837.59 \text{ K}$$

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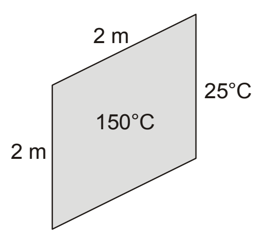
4 Convection

Detailed Explanation of Try Yourself Questions

T1 : Solution

(Ans : 9820 W)

Grashoff's number, $$Gr = \frac{L^3(\beta g \Delta T)}{\nu^2}$$



$$T_{mean} = 87.5°C$$
$$L = 2 \text{ m}$$
$$\nu = 1.6 \times 10^{-5} \text{ m}^2/\text{sec}$$
$$\beta = \frac{1}{T_{mean}} = \frac{1}{360.5} = 2.77 \times 10^{-3}/\text{K}$$
$$\Delta T = 150 - 25 = 125°C$$
$$Gr = \frac{2^3 \times 2.77 \times 10^{-3} \times 9.81 \times 125}{(1.6 \times 10^{-5})^2} = 1.061 \times 10^{11}$$
$$Nu = 0.15\,(Gr\,Pr)^{1/3}$$
$$\frac{hL}{K} = 0.15\,(1.061 \times 10^{11} \times 0.69)^{1/3} = 627.59$$
$$h = \frac{627.59 \times 3.13 \times 10^{-2}}{2} = 9.82 \text{ W/m}^2\text{-K}$$

Assuming heat transfer from both sides of the plate.

$$\text{Heat transfer rate} = h\,(2A)\,\Delta T = 9.82 \times (2 \times 4) \times 125 = 9820 \text{ W}$$

T2 : Solution

(Ans: 1553.76 W)

Given: Height, L = 1.5, Width, W = 1 m, Plate temp, t_s = 150°C, Surrounding temp,

$$t_\infty = 30°C,$$

$$\text{Average temp } t_{avg} = 90°C$$

for

$$\rho = 0.946 \text{ kg/m}^3,\ k_a = 0.0313 \text{ W/mK}$$

$$\nu = 22.10 \times 10^{-6} \text{ m}^2\text{/s},$$

$$C_p = 1.009 \text{ kJ/kg-K}$$

So,

$$G_r = \frac{g\beta\Delta t L^3}{\nu^2}$$

$$= \frac{9.81 \times \dfrac{1}{273+90} \times 120 \times 1.5^3}{(22.10 \times 10^{-6})^2}$$

[As $\beta = \dfrac{1}{273 + t_{avg}}$]

$$\text{Gr} = 2.24095 \times 10^{10}$$

Prandtl number, $\text{Pr} = \dfrac{\rho\gamma C_p}{k} = 0.67395$

$$R_{a_L} = \text{Gr} \times \text{Pr} = 1.51 \times 10^{10}$$

As given $N_{u_L} = 0.59\,(R_{a_L})^{0.25}$

$$\frac{hL}{k_a} = 50.562 \times 0.59 = 206.832$$

$$h = 4.316 \text{ W/m}^2\text{K}$$

So rate of heat transfer from both the surfaces,

$$'Q' = 2 \times h \times A \times (t_s - t_\infty) = 1553.76 \text{ W}$$

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5 Heat Exchanger and Condensation, Boiling and Evaporation

Detailed Explanation of Try Yourself Questions

T1 : Solution

(54.06°C)

Given:

$$\dot{m}_c = 7500 \text{ kg/h}, \quad \dot{m}_h = 8000 \text{ kg/h}$$

$$t_1 = 15°\text{C} \quad T_1 = 105°\text{C}$$

$$t_2 = ? \quad T_2 = ?$$

Here, $C_{p\,\text{water}} = 4.182$ kJ/kg K, $C_{p\,\text{air}} = 1.001$ kJ/kg K

Can be taken.

As the case is of counter flow, thus

$$\text{NTU} = \frac{U \cdot A}{(mC_p)_{\min}} = \frac{145 \times 20}{\left(\frac{8000}{3600}\right)(1001)} = 1.304$$

$$\in = \frac{\text{NTU}}{1+\text{NTU}} = \frac{1.304}{2.304} = 0.566$$

Now,

$$\in = \frac{(mC_p)_{\text{air}}(105-T)}{(mC_p)_{\text{air}}(105-15)} = 0.566$$

$$105 - T = 0.566 \times 90$$

$$T = 54.06°\text{C}$$

T2 : Solution

(i) 0.898 (ii) 60.73 m^2

Mass balance: Let us denote flow rates of feed as F, vapour as V, concentrated product as P, steam as S, mass fraction of solute as X.

Overall mass balance

$$F = V + P$$

Balance on solute

$$F \cdot X_F = P \cdot X_P$$

$$P = \frac{10 \times 0.05}{0.2} = 2.5 \text{ kg/S}$$

$$V = F - P$$

$$= 10 - 2.5 = 7.5 \text{ kg/S}$$

Energy balance:

$$FH_F + S\lambda_S = VH_V + PH_P$$

Thus,

$$10 \times 80 + 2000 \text{ S} = 7.5 \times 2200 + 2.5 \times 700$$

$$\text{S} = 8.35 \text{ kg/S}$$

$$\text{Steam economy} = \frac{V}{S} = \frac{7.5}{8.35} = 0.898$$

For area:

$$Q = S\lambda_S$$

$$= 8.35 \times 2000 = 16700 \text{ kJ/sec}$$

$$Q = U \cdot A \cdot (\Delta T)$$

$$A = \frac{16700 \times 1000}{5000(380 - 325)} = 60.73 \text{ m}^2$$

T3 : Solution

(1.256 (W/m^2))

$$\text{Frequency} = 20\left[\frac{\text{Bubbles}}{\text{Second}}\right]$$

$$n = 120\left(\frac{\text{Nucleation site}}{\text{m}^2}\right)$$

$$\lambda = 1000 \text{ kJ/kg},\ \rho_v = 1 \text{ kg/m}^3$$

$$d_b = 10^{-3} \text{ m}$$

$$\text{Heat flux} = (120)(20) \times 1 \times \frac{\pi}{6}(10^{-9}) \times 1000 \times 1000$$

$$q = 1.256 \text{ (W/m}^2\text{)}$$

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