

GATE PSUs

State Engg. Exams

MADE EASY
WORKBOOK 2024



**Detailed Explanations of
Try Yourself *Questions***

Chemical Engineering

Heat Transfer



1

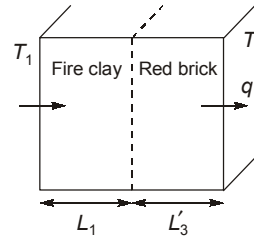
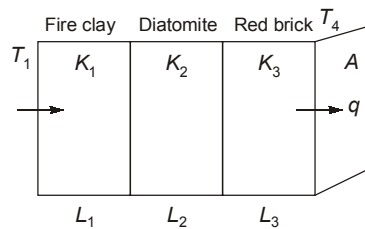
Conduction



Detailed Explanation of Try Yourself Questions

T1 : Solution

(Ans : 57.3 cm)



$$q = \frac{T_1 - T_4}{\frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{L_3}{k_3 A}};$$

$$q = \frac{T_1 - T_4}{\frac{L_1}{k_1 A} + \frac{L'_3}{k_2 A}}$$

$$\frac{\frac{T_1 - T_4}{\frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{L_3}{k_3 A}}}{\frac{T_1 - T_4}{\frac{L_1}{k_1 A} + \frac{L'_3}{k_2 A}}} = \frac{T_1 - T_4}{\frac{L_1}{k_1 A} + \frac{L'_3}{k_2 A}}$$

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

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

T2 : Solution

$$t = 150 \text{ mm}, k = 15 \text{ W/mK}$$

$$(i) \quad \dot{q} = \frac{h(T - T_{\infty})}{0.150} = \frac{500 \times (100 - 20)}{0.150}$$

$$= 0.267 \times 10^6 \text{ W/m}^3$$

$$T(X) = a + bx + cx^2$$

$$X = 0$$

$$T(0) = T_0 = 100^\circ\text{C}, T_{\infty} = 20^\circ\text{C},$$

$$h = 500 \text{ W/m}^2\text{-K}$$

at

$$X = 0,$$

$$T_0 = 100^\circ\text{C}$$

$$100 = a + 0 + 0, \quad (a = 100)$$

$$\left. \frac{dT}{dX} \right|_{x=L} = 0$$

$$b + 2cx = 0$$

$$b + 2c(0.15) = 0$$

$$b + 0.3c = 0$$

(ii) For steady state,

$$-\left[-k \frac{dT}{dX} \right]_{x=0} = h(T - T_{\infty})$$

$$15 \times b = 500 \times (100 - 20)$$

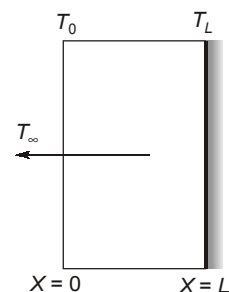
$$b = 266.67 \times 10$$

$$b = 2.67 \times 10^3 \text{ k/m}$$

$$(iii) 2.67 \times 10^3 + 0.3c = 0$$

$$c = -8.9 \times 10^3 \text{ k/m}^2$$

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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, $\eta = \frac{Q_{\text{actual}}}{Q_{\text{max}}} = \text{Efficiency}$

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

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

T2 : Solution

(Ans : 0.333 m)

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

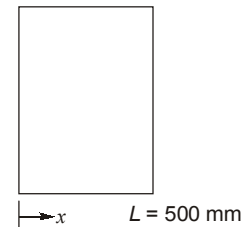
$$\frac{\partial^2 T}{\partial x^2} + 0 + 0 + 0 = \frac{1}{\alpha} \frac{\partial T}{\partial \tau}$$

Rate of heating or cooling,

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

Location for maxima.

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



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

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

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

$$240 - 720x = 0$$

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

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3

Radiation



Detailed Explanation of Try Yourself Questions

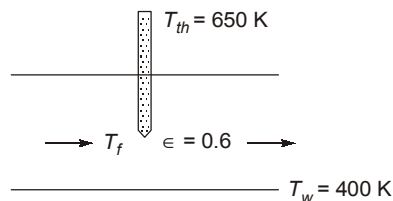
T1 : Solution

(806) [805 to 807] W/m²

$$\begin{aligned}\dot{q}_{12, \text{ one shield}} &= \frac{Q_{12, \text{ one shield}}}{A} \\ &= \frac{\sigma [T_1^4 - T_2^4]}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1 \right) + \left(\frac{1}{\epsilon_{31}} + \frac{1}{\epsilon_{32}} - 1 \right)} = \frac{(5.67 \times 10^{-8})(800^4 - 500^4)}{\left[\frac{1}{0.2} + \frac{1}{0.7} - 1 \right] + \left[\frac{1}{0.1} + \frac{1}{0.1} - 1 \right]} \\ \dot{q}_{12} &= 806 \text{ W/m}^2\end{aligned}$$

T2 : Solution

(715) (714 to 716) K

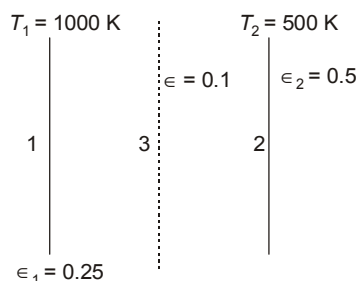


$$\begin{aligned}T_f &= T_{th} + \frac{\epsilon \sigma (T_{th}^4 - T_w^4)}{h} \\ T_f &= 650 + \frac{0.6 \times 5.67 \times 10^{-8} \times (650^4 - 400^4)}{80} \\ T_f &= 715 \text{ K}\end{aligned}$$

T3 : Solution

(Ans : (a) 10.63 kW/m², (b) 2.21 kW/m², (c) 837.59 K)

(a)



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

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

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

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

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

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

or

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

(c)

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

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

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

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Convection

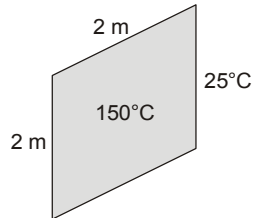


Detailed Explanation of Try Yourself Questions

T1 : Solution

(Ans : 9820 W)

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



$$T_{\text{mean}} = 87.5^\circ\text{C}$$

$$L = 2 \text{ m}$$

$$\nu = 1.6 \times 10^{-5} \text{ m}^2/\text{sec}$$

$$\beta = \frac{1}{T_{\text{mean}}} = \frac{1}{360.5} = 2.77 \times 10^{-3}/\text{K}$$

$$\Delta T = 150 - 25 = 125^\circ\text{C}$$

$$Gr = \frac{2^3 \times 2.77 \times 10^{-3} \times 9.81 \times 125}{(1.6 \times 10^{-5})^2} = 1.061 \times 10^{11}$$

$$Nu = 0.15 (Gr Pr)^{1/3}$$

$$\frac{hL}{K} = 0.15 (1.061 \times 10^{11} \times 0.69)^{1/3} = 627.59$$

$$h = \frac{627.59 \times 3.13 \times 10^{-2}}{2} = 9.82 \text{ W/m}^2\text{-K}$$

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, $t_s = 150^\circ\text{C}$, Surrounding temp,

$$t_\infty = 30^\circ\text{C},$$

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

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

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

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

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

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

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

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

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

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

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



Detailed Explanation of Try Yourself Questions

T1 : Solution

(54.06°C)

Given:

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

$$t_1 = 15^\circ\text{C}, \quad T_1 = 105^\circ\text{C}$$

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

Here,

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

Can be taken.

As the case is of counter flow, thus

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

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

Now,

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

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

$$T = 54.06^\circ\text{C}$$

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6

Condensation, Boiling and Evaporation



Detailed Explanation of Try Yourself Questions

T1 : Solution

(i) 0.898 (ii) 60.73 m²

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

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

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

$$\begin{aligned} V &= F - P \\ &= 10 - 2.5 = 7.5 \text{ kg/S} \end{aligned}$$

Energy balance:

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

Thus,

$$\begin{aligned} 10 \times 80 + 2000 S &= 7.5 \times 2200 + 2.5 \times 700 \\ S &= 8.35 \text{ kg/S} \end{aligned}$$

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

For area:

$$\begin{aligned} Q &= S\lambda_S \\ &= 8.35 \times 2000 = 16700 \text{ kJ/sec} \end{aligned}$$

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

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

T2 : Solution

(1.256 (W/m²))

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

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

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

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

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

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

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