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HEAT TRANSFER

MECHANICAL ENGINEERING

Date of Test : 05/10/2025

ANSWER KEY

1.	(a)	7.	(a)	13.	(b)	19.	(b)	25.	(a)
2.	(d)	8.	(c)	14.	(d)	20.	(b)	26.	(a)
3.	(b)	9.	(c)	15.	(b)	21.	(b)	27.	(a)
4.	(d)	10.	(b)	16.	(b)	22.	(b)	28.	(d)
5.	(b)	11.	(c)	17.	(b)	23.	(b)	29.	(c)
6.	(b)	12.	(a)	18.	(d)	24.	(b)	30.	(b)

DETAILED EXPLANATIONS

1. (a)

Fourier number $\left(\frac{\alpha\tau}{l^2}\right)$ represents the dimensionless time.

2. (d)

$$\eta = \frac{Q_{\text{actual}}}{Q_{\text{ideal}}} = \frac{\sqrt{hPkA}\,(T_b - T_\infty)}{hA_{\text{fin}}\,(T_b - T_\infty)} = \frac{\sqrt{hPkA}}{hPL} = \frac{1}{L}\sqrt{\frac{kA}{hP}}$$

For circular fin

$$A = \frac{\pi}{4}d^2$$

$$P = \pi d$$

$$\eta = \frac{1}{L}\sqrt{\frac{kd}{4h}} = \frac{1}{2L}\sqrt{\frac{kd}{h}}$$

3. (b)

For infinitely long fin,

$$\dot{q} = \sqrt{hPkA}\,(T_b - T_\infty)$$

For circular fin, $P = \pi D$

$$A = \frac{\pi}{4}D^2$$

So,

$$\dot{q} = \sqrt{h \times \pi D \times k \times \frac{\pi}{4}D^2}\,(T_b - T_\infty)$$

$$\dot{q} \propto \sqrt{k}D^{3/2}$$

$$\frac{\dot{q}_1}{\dot{q}_2} = \frac{\sqrt{k_1}}{\sqrt{k_2}}\frac{D_1^{3/2}}{D_2^{3/2}} = \left(\frac{400}{250}\right)^{1/2}\left(\frac{D}{0.4D}\right)^{3/2} = 5$$

4. (d)

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt}$$

$$\Rightarrow \quad \frac{\frac{T_i + T_\infty}{2} - T_\infty}{T_i - T_\infty} = e^{-bt}$$

$$\Rightarrow \quad \frac{1}{2} = e^{-bt}$$

Where $b = \frac{1}{\tau}$

Time required, $t = \frac{\ln 2}{b}$

$$= \tau \ln 2 = 10 \times 0.693 = 6.93 \text{ s}$$

5. (b)

For parallel flow heat exchanger,

$$\varepsilon = \frac{1-\exp(-NTU(1+C))}{1+C}$$

Put $C = 0$,

$$\varepsilon = \frac{1-\exp(-NTU)}{1}$$

$$\varepsilon = 1 - \exp(-\text{NTU})$$

For counter flow heat exchanger,

$$\varepsilon = \frac{1-\exp\{-NTU(1-C)\}}{1-C\exp\{-NTU(1-C)\}}$$

Put $C = 0$,

$$\varepsilon = \frac{1-\exp\{-NTU(1-0)\}}{1-0\times\exp\{-NTU(1-0)\}}$$

$$\varepsilon = 1 - \exp(-\text{NTU})$$

So, expression:

$$\varepsilon = 1 - \exp(-\text{NTU})$$

is valid for all the heat exchangers having zero capacity ratio.

6. (b)

Temperature of body, $T = 2000$ K

From Wien's Displacement law:

$$\lambda_m T = 2898 \text{ μm-K}$$

$$\lambda_m \times 2000 = 2898$$

$$\lambda_m = 1.449 \text{ μm}$$

$$\lambda_m \simeq 1.45 \text{ μm}$$

7. (a)

Reflectivity, $\rho = 0.4$

For opaque body,

$$\alpha + \rho = 1$$

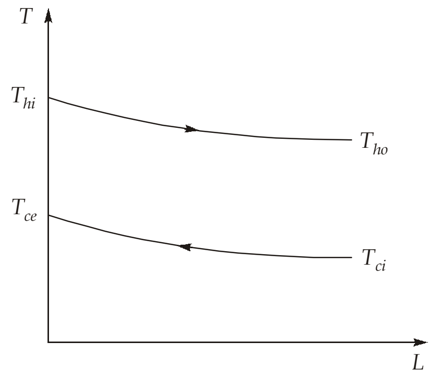
$$\alpha + 0.4 = 1$$

$$\text{Absorptivity, } \alpha = 0.6 = \frac{G_{abs}}{G} = \frac{G_{abs}}{600}$$

Part of radiation absorbed,

$$G_{abs} = 0.6 \times 600 = 360 \text{ W/m}^2$$

8. **(c)**



According to question:

$$T_{ce} - T_{ci} = T_{hi} - T_{he} = 0.7(T_{hi} - T_{ci})$$

For balanced counter flow heat exchanger,

$$C_{min} = \dot{m}_h c_{ph} = \dot{m}_c c_{pc}$$

$$\text{Effectiveness, } \varepsilon = \frac{Q}{Q_{max}} = \frac{\dot{m}_h c_{ph}(T_{hi} - T_{he})}{C_{min}(T_{hi} - T_{ci})} = \frac{T_{hi} - T_{he}}{T_{hi} - T_{ci}} = \frac{0.7(T_{hi} - T_{ci})}{T_{hi} - T_{ci}}$$

$$\varepsilon = 0.7 = \frac{NTU}{1 + NTU}$$

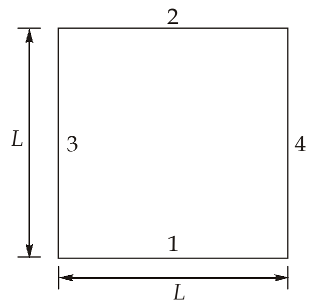
$$0.7 + 0.7\text{ NTU} = \text{NTU}$$

$$0.7 = 0.3\text{ NTU}$$

$$\text{NTU} = \frac{0.7}{0.3}$$

$$\text{NTU} = 2.333$$

9. **(c)**



$$F_{13} = 1 - \sin\frac{\alpha}{2} = 1 - \sin 45°$$

$$= 1 - \frac{1}{\sqrt{2}} \simeq 0.3$$

$$F_{14} = F_{13}$$

From summation rule,

$$F_{11} + F_{12} + F_{13} + F_{14} = 1$$

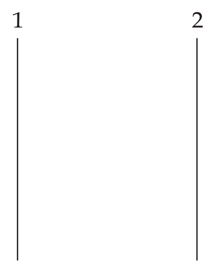
$$F_{12} = 0.4$$

So, $F_{12} > F_{13}$

10. **(b)**

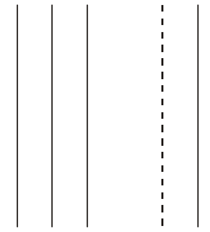
Without shield

Radiation heat transfer rate,



$$q = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Let number of shields be N.
With shield
Radiation heat transfer rate,



$$q' = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right) + N\left(\frac{2}{\varepsilon} - 1\right)}$$

As per the conditions,

$$q' = (1 - 0.9)q$$

$$\frac{q}{q'} = \frac{1}{0.1} = 10$$

$$\frac{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right) + N\left(\frac{2}{\varepsilon} - 1\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)} = 10$$

$$\frac{\left(\frac{1}{0.8} + \frac{1}{0.6} - 1\right) + N\left(\frac{2}{0.29} - 1\right)}{\left(\frac{1}{0.8} + \frac{1}{0.6} - 1\right)} = 10$$

Number of shields, $N = 2.925$

$N \simeq 3$

11. (c)

Wall thickness, $\delta = 10 \text{ mm} = 0.01 \text{ m}$

As given in question,

Thermal conductivity, $k = ax + b$

Heat flux, $q'' = -k\frac{dT}{dx}$

$$q'' = -(ax+b)\frac{dT}{dx}$$

$$\frac{q''}{ax+b}dx = -dT$$

On integrating,

$$q''\int_0^{\delta}\frac{dx}{ax+b} = -\int_{T_1}^{T_2} dT$$

$$\Rightarrow \quad \frac{q''}{a}\left[\ln|ax+b|\right]_0^{\delta} = -(T_2 - T_1)$$

$$\Rightarrow \quad \frac{q''}{a}\ln\left|\frac{a\delta + b}{a\times 0 + b}\right| = (T_1 - T_2)$$

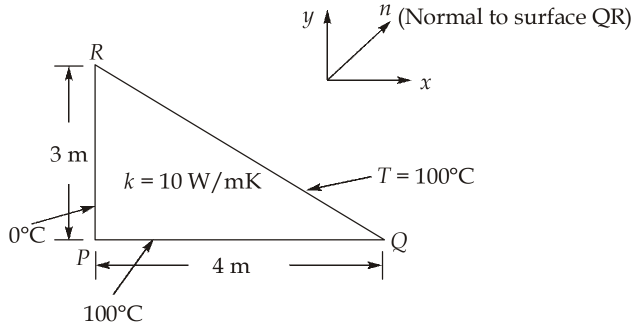
$$\Rightarrow \qquad \frac{q''}{a}\ln\left|\frac{a\delta+b}{b}\right| = (T_1 - T_2)$$

$$\frac{3.723\times10^6}{7\times10^4}\ln\left|\frac{7\times10^4\times0.01+200}{200}\right| = (100 - T_2)$$

$$T_2 = 20.0046°C$$

$$T_2 \simeq 20°C$$

12. (a)



At surface PQ

$$q_{PQ} = -k\times A\frac{\partial T}{\partial y} = -10\times4\times-30 = 1200 \text{ W/m}$$

At surface *R*Q

$$q_{RQ} = -k\times A\frac{\partial T}{\partial n} = -10\times5\times60 = -3000 \text{ W/m}$$

From energy balance,

$$q_{PQ} + q_{PR} = q_{RQ}$$

$$1200 + q_{PR} = -3000$$

$$q_{PR} = -4200 \text{ W/m} = -10\times3\times\frac{\partial T}{\partial x}$$

$$\frac{\partial T}{\partial x} = 140 \text{ K/m}$$

$$\frac{\partial T}{\partial y} = 0 \qquad (\because \text{Heat flows normal to surface})$$

13. (b)

$$q_{net} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1A_1}+\frac{1-\varepsilon_2}{\varepsilon_2A_2}+\frac{1}{A_1F_{12}}}$$

Since, $F_{12} = 1$

$$q_{net} = \frac{5.67\times10^{-8}\times[(40+273)^4-(250+273)^4]}{\frac{1}{A_2}\left[\frac{1-0.25}{0.25\times A_1}\times A_2+\frac{1-0.7}{0.7\times1}+\frac{A_2}{A_1}\right]}$$

$$\frac{q_{net}}{A_2} = \frac{-3697.9847}{\frac{0.75}{0.25}\times\frac{\pi D_2^2}{\pi D_1^2}+\frac{0.3}{0.7}+\frac{\pi D_2^2}{\pi D_1^2}} = \frac{-3697.9847}{\frac{0.75}{0.25}\times\left(\frac{1}{0.3}\right)^2+\frac{0.3}{0.7}+\left(\frac{1}{0.3}\right)^2}$$

$$\frac{q_{net}}{A_2} = -82.409 \text{ W/m}^2$$

Negative sign shows that there is net heat transfer from sphere 2 to sphere 1.

14. (d)

Mass flow-rate of air, $\dot{m}_a$ = 21 kg/s

c_{pa} = 1.005 kJ/kgK

Minimum heat capacity rate,

$$C_{min} = \dot{m}_a c_{pa}$$

$$= 21 \times 1.005$$

$$C_{min} = 21.105 \text{ kW/K}$$

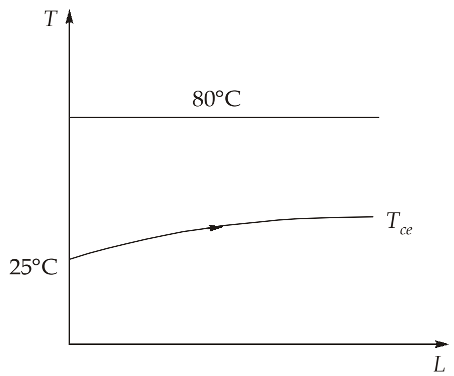
Overall heat transfer coefficient, U = 2.5 kW/m²K = 2500 W/m²K

Surface area, A = 2 m²

$$\text{NTU} = \frac{UA}{C_{min}} = \frac{2500\times 2}{21.105\times 1000} = 0.2369$$

Effectiveness, $\varepsilon = 1 - e^{(-\text{NTU})}$

$$= 1 - e^{(-0.2369)} = 0.2109$$



Also, $$\varepsilon = \frac{Q}{Q_{max}} = \frac{m_a c_{pa}(T_{ce}-25)}{C_{min}(80-25)}$$

$$= \frac{T_{ce}-25}{(80-25)} \qquad [\because C_{min} = \dot{m}_a c_{pa}]$$

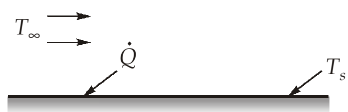
From (1) and (2)

$$\frac{T_{ce}-25}{55} = 0.2109$$

$\Rightarrow$ T_{ce} = 36.59°C

15. (b)

$$\dot{Q}_1 = -k_f \left.\frac{\partial T}{\partial y}\right|_{y=0}$$



$$\dot{Q}_2 = 2k_f\left(\frac{2\partial T}{\partial y}\bigg|_{y=0}\right) = 4\dot{Q}_1$$

$$\therefore \qquad \frac{\dot{Q}_2}{\dot{Q}_1} = 4$$

16. (b)

We know that,

$$\text{Gr} = \frac{g\beta\Delta T L_c^3}{\nu^2}$$

$$\beta = \frac{1}{T_{avg}} = \frac{1}{161+273} = 2.304\times10^{-3}\,\text{K}^{-1} \qquad \left(T_{avg} = \frac{25+297}{2} = 161°\text{C}\right)$$

For horizontal plate:

$$L_C = \frac{A_s}{p} = \frac{50\times50}{4\times50} = 12.5 \text{ cm or } 0.125 \text{ m}$$

So,

$$\text{Gr} = \frac{9.81\times(2.304\times10^{-3})\times272\times(0.125)^3}{(30\times10^{-6})^2} = 133.184\times10^5$$

17. (b)

$$\text{Heat generated} = \text{Heat convected}$$

$$\Rightarrow \qquad \dot{q}\times\pi r_0^2 L = h\times2\pi r_0 L\times(T_s - T_\infty)$$

$$\Rightarrow \qquad T_s = T_\infty + \frac{\dot{q}r_0}{2h} = 100 + \frac{16.4\times10^6\times0.6\times10^{-2}}{2\times3200}$$

$$= 115.375°\text{C}$$

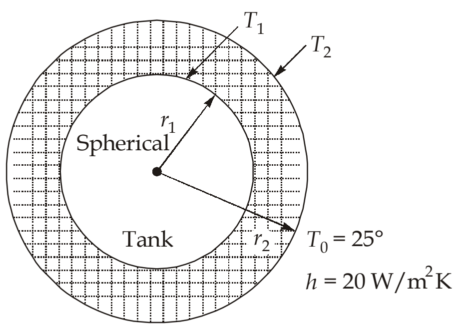
Temperature at the centreline of the wire (T_0)

$$T_0 - T_s = \frac{\dot{q}r_0^2}{4k} = \frac{16.4\times10^6\times(0.6\times10^{-2})^2}{4\times15.2} = 9.710$$

$$T_0 = 115.375 + 9.710 = 125.08°\text{C}$$

18. (d)

Given : $r_1 = \frac{D_1}{2} = 0.5$ m, $T_0 = 25°$C, $T_1 = 200°$C, $T_2 = 40°$C, $k = 0.026$ W/mK, $h = 20$ W/m^{2}K



For steady state:

Heat transfer through conduction = Heat transfer through convection

$$\Rightarrow \quad \frac{(T_1 - T_2)}{\frac{(r_2 - r_1)}{4\pi k r_1 r_2}} = hA_2(T_2 - T_0)$$

$$\Rightarrow \quad \frac{(200-40)\times 4\pi \times 0.026 \times 0.5 \times r_2}{r_2 - 0.5} = 20 \times 4\pi r_2^2 \times (40-25)$$

$$\Rightarrow \quad 2.08 = 300 r_2 (r_2 - 0.5)$$

$$\Rightarrow \quad r_2^2 - 0.5 r_2 - 6.933 \times 10^{-3} = 0$$

$$r_2 = 0.5135 \text{ m}$$

Thickness of insulation $= r_2 - r_1 = 0.5135 - 0.5 = 0.0135$ m
$= 13.5$ mm

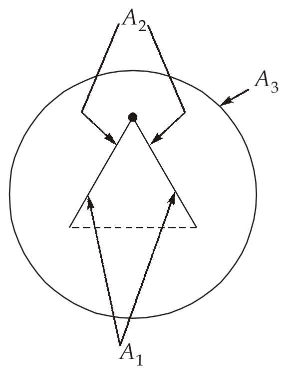
19. (b)

$$F_{12} = 1.0$$

$$A_2F_{21} = A_1F_{12}$$

$$F_{21} = \frac{A_1}{A_2} \times 1 = \frac{2R \times L}{\frac{3}{4} \times (2\pi RL)} \times 1.0 = \frac{4}{3\pi} = 0.424$$

20. (b)



Surface (3) can be represented by dashed line.
Because symmetry $F_{13} = 0.5$, $F_{23} = 1$
Now from reciprocity theorem,

$$A_3F_{31} = A_1F_{13}$$

$$A_3F_{31} = 2L \times 0.5 = 1 \text{ m}$$

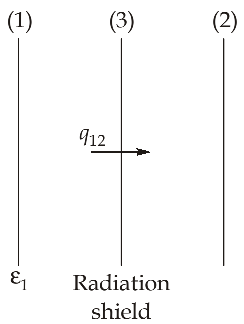
$$A_3F_{32} = A_2F_{23} = 2L \times 1 = 2 \text{ m}$$

The net radiation heat transfer

$$Q = A_3F_{31}\sigma\left(T_w^4 - T_p^4\right) + A_3F_{32}\sigma\left(T_w^4 - T_p^4\right)$$

$= 1 \times 5.67 \times 10^{-8} (1000^4 - 300^4) + 2 \times 5.67 \times 10^{-8} (1000^4 - 300^4)$
$= 3 \times 5.67 \times 10^{-8} (1000^4 - 300^4)$
$= 1.68 \times 10^5$ W/m

21. (b)



$$(q_{12})_{\text{without}} = \frac{A_1\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$(q_{12})_{\text{with}} = \frac{A_1\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} + \frac{2}{\varepsilon_3} - 2}$$

$$\frac{(q_{12})_{with}}{(q_{12})_{without}} = 0.1 = \frac{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} + \frac{2}{\varepsilon_3} - 2}$$

$$0.1 = \frac{\frac{1}{0.8} + \frac{1}{0.8} - 1}{\frac{1}{0.8} + \frac{1}{0.8} + \frac{2}{\varepsilon_3} - 2}$$

$$\varepsilon_3 = 0.1379 \simeq 0.14$$

22. **(b)**

$$q'' = h(T_w - T_\infty) = -K\left(\frac{dT}{dy}\right)_{y=0}$$

$$\frac{-dT}{dy} = \left(T_w - T_\infty\right)\left[\frac{a_1}{L} + 2a_2\frac{y}{L^2}\right]$$

$$\left(\frac{dT}{dy}\right)_{y=0} = -\left(T_w - T_\infty\right)\frac{a_1}{L}$$

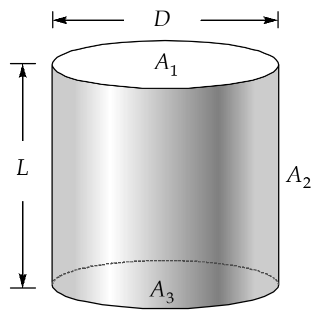
$$\Rightarrow \quad h(T_w - T_\infty) = K\frac{a_1}{L}\left(T_w - T_\infty\right)$$

$$\frac{hL}{K} = a_1$$

$$Nu = \frac{hL}{K} = a_1$$

23. **(b)**

From summation rule,



$$\cancelto{0}{F_{11}} + F_{12} + F_{13} = 1$$

$$F_{12} = 1 - F_{13}$$

$$= 1 - 3 + 2\sqrt{2}$$

$$= 2\left(-1 + \sqrt{2}\right)$$

From reciprocal theorem,

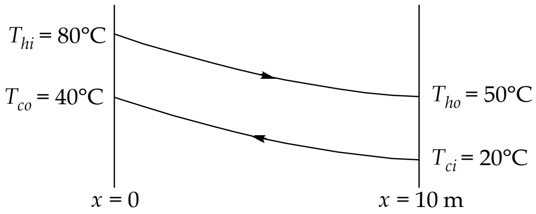
$$A_2F_{21} = A_1F_{12}$$

$$\pi D \times L \times F_{21} = \frac{\pi D^2}{4} \times 2\left(-1 + \sqrt{2}\right)$$

$$F_{21} = \frac{\sqrt{2} - 1}{2}$$

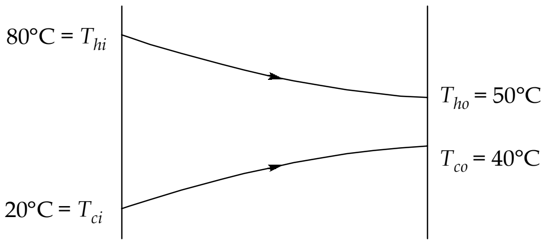
24. (b)

Assume counter,



$$\Delta T_1 = 80°C - 40°C = 40°C$$
$$\Delta T_2 = 50°C - 20°C = 30°C$$
$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{40°C - 30°C}{\ln\left(\frac{40}{30}\right)} = 34.7°C$$

Assume parallel,



$$\Delta T_1 = 80°C - 20°C = 60°C$$
$$\Delta T_2 = 50°C - 40°C = 10°C$$
$$(\text{LMTD})_{\text{parallel HE}} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{60°C - 10°C}{\ln\left(\frac{60}{10}\right)} = 27.9°C$$

25. (a)

$$\text{Fin efficiency} = \frac{\tan h\, \text{mL}}{\text{mL}}$$

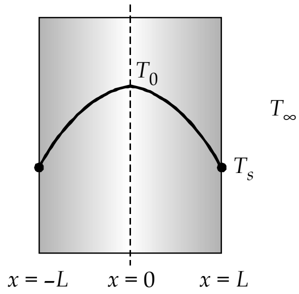
$$mL = L\sqrt{\frac{hP}{kA_{cs}}} = \sqrt{\frac{hL^2 P}{kA_{cs}}} = \sqrt{\frac{hL^2 \times \pi d}{k\frac{\pi}{4}d^2}} = \sqrt{\frac{hL^2}{k} \times \frac{4}{d}}$$

$$= \sqrt{\frac{hL}{k} \times 4 \times \left(\frac{L}{d}\right)} = \sqrt{\frac{h}{k} \times 4d \times 4 \times \left(\frac{L}{d}\right)} = \sqrt{32 \times \left(\frac{hr}{k}\right) \times \left(\frac{L}{d}\right)}$$

$$mL = \sqrt{32 \times (Bi) \times \left(\frac{l}{d}\right)} = \sqrt{32 \times 0.04 \times 4} = 2.262$$

$$\eta = \frac{\tan h\, \text{mL}}{\text{mL}} = \frac{0.9785}{2.262} = 0.4325 = 43.25\% = 43\%$$

26. (a)



Given: $T_s = 370\text{ K}, T_\infty = 300\text{ K}$

$$T(x=0) = \frac{\dot{q}L^2}{2K} + T_s$$

$$T_0 = T_s + \frac{\dot{q}L^2}{2K}$$

Heat generated = Heat convected

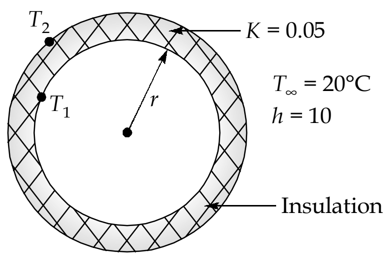
$$\Rightarrow \quad \dot{q} \times A \times 2L = h \times 2A \times (T_s - T_\infty)$$

$$T_s - T_\infty = \frac{\dot{q}L}{h} \times \frac{L/k}{L/k}$$

$$\frac{\dot{q}L^2}{K} = Bi \times (T_s - T_\infty) = 0.7 \times (370 - 300) = 49$$

$$T_0 = T_s + \frac{49}{2} = 370 + 24.5 = 394.5\text{ K}$$

27. (a)



Heat conducted = Heat convected

$$\frac{T_1 - T_2}{\dfrac{\ln\left(\dfrac{r_2}{r_1}\right)}{2\pi KL}} = h \times 2\pi r_2 \times L \times (T_2 - T_\infty)$$

$$r_1 = 1\text{ m}, r_2 = 1.1\text{ m}$$

$$\Rightarrow \quad \frac{(200 - T_2) \times 2\pi \times 0.05 \times L}{\ln(1.1/1)} = h \times \pi \times 2.2 \times L \times (T_2 - 20)$$

$$\Rightarrow \quad \frac{(200 - T_2)}{\ln(1.1/1)} \times 0.1 = h \times 2.2 \times (T_2 - 20)$$

$$\Rightarrow \quad 200 - T_2 = 2.097 \times 10 \times (T_2 - 20)$$

$$\Rightarrow \quad 200 - T_2 = 20.97 \times (T_2 - 20)$$

$$\Rightarrow \quad 200 - T_2 = 20.97T_2 - 419.4$$

$$\Rightarrow \quad T_2 = 28.19°C$$

28. (d)

$$\dot{m}_h = \frac{1000}{3600} = 0.277\text{ kg/s}$$

Hot fluid, $T_{hi} = 70°C$

$T_{ho} = 40°C$

$c_{ph} = 2\text{ kJ/kgK}$

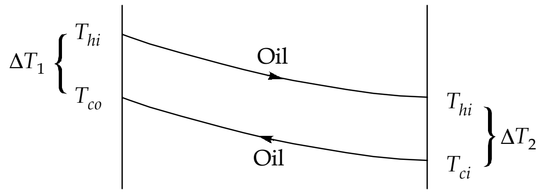
Cold fluid, $T_{ci} = 25°C$

$T_{co} = 40°C$

$c_{pc} = 4.2\text{ kJ/kgK}$

$U = 0.2\text{ kW/m}^2\text{K}$

Counter flow temperature profile



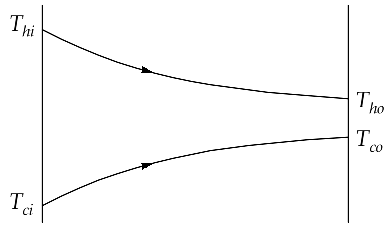
$$\Delta T_1 = 70°C - 40°C = 30°C$$
$$\Delta T_2 = 40°C - 25°C = 15°C$$
$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{30°C - 15°C}{\ln\left(\frac{30°C}{15°C}\right)}$$
$$\text{LMTD} = 21.64°C$$
$$\text{Heat transfer} = \dot{m}_h c_{ph}(T_{hi} - T_{ho}) = U.A(\text{LMTD})$$
$$10^3 \times 0.277 \times 2 \times (70 - 40) = 0.2 \times 1000 \times A \times 21.64$$
$$A = 3.84 \text{ m}^2$$

29. (c)

As per given condition,

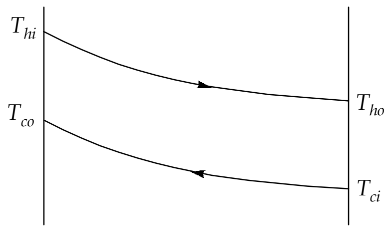
$$U_{\text{parallel}} = U_{\text{counter}}$$
$$(UA\Delta T)_{\text{parallel}} = (UA\Delta T)_{\text{counter}} \quad \text{...(i)}$$

For parallel,



$$T_{hi} = 80°C$$
$$T_{ho} = 50°C$$
$$T_{ci} = 30°C$$
$$T_{co} = 45°C$$
$$\Delta T_1 = T_{hi} - T_{ci}$$
$$= 80 - 30 = 50°C$$
$$(\Delta T_2) = T_{h_o} - T_{c_o} = 50°C - 45°C = 5°C$$
$$(\text{LMTD})_{\text{parallel}} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{50°C - 5°C}{\ln\left(\frac{50}{2}\right)}$$
$$(\Delta T)_{\text{parallel}} = 19.543°C$$

In counter flow



$$\Delta T_1 = T_{h_i} - T_{c_o} = 80°C - 45°C = 35°C$$
$$\Delta T_2 = T_{h_o} - T_{c_i} = 50°C - 30°C = 20°C$$
$$(\text{LMTD})_{\text{counter}} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{35°C - 20°C}{\ln\left(\frac{35}{20}\right)}$$
$$(\text{LMTD})_{\text{counter}} = 26.804°C$$

From equation (i),

$$(A \times 19.543)_{\text{parallel}} = (A \times 26.804)_{\text{counter}}$$

$$A_{\text{parallel}} = 1.3715\, A_{\text{counter}}$$

$$\text{Percentage saving in Area} = \left|\frac{A_{\text{counter}} - A_{\text{parallel}}}{A_{\text{parallel}}}\right| \times 100$$

$$= \left|\frac{1 - 1.3715}{1.3715}\right| \times 100 = 27.09\%$$

30. (b)

Since fluid properties will be same at same temperature so Prandtl number will be same

$$Nu \propto (\text{Re})^m$$

$$\frac{Nu_2}{Nu_1} = \frac{(VL_C)_2^m}{(VL_C)_1^m} = \left(\frac{V_2 L_{C_2}}{V_1 L_{C_1}}\right)^m$$

$$= \left(\frac{25}{50} \times \frac{12}{6}\right)^m = 1$$

$$Nu_2 = Nu_1$$

$$\frac{h_1 L_{C_1}}{K} = \frac{h_2 L_{C_2}}{K}$$

$$\Rightarrow \quad h_2 = \frac{h_1 L_{C_1}}{L_{C_2}} = \frac{120 \times 6}{12} = 60 \text{ W/m}^2\,°\text{C}$$

Heat flux from the second airfoil

$$= h_2 (T - T_\infty)$$

$$= 60 \times (80 - 15)$$

$$= 3900 \text{ W/m}^2$$

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