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HEAT TRANSFER

MECHANICAL ENGINEERING

Date of Test : 10/02/2025

ANSWER KEY ➤

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

DETAILED EXPLANATIONS

1. **(d)**

Heat transfer effectiveness,

$$\varepsilon = \frac{\dot{Q}}{Q_{max}} = \frac{\text{Actual heat transfer rate}}{\text{Maximum possible heat transfer rate}}$$

2. **(d)**

- Biot number (Bi) = $\dfrac{\text{Internal thermal resistance of a solid}}{\text{Boundary layer thermal resistance}}$

$$Bi = \frac{h \cdot s}{k_{solid}}$$

- Grashof number (Gr) = $\dfrac{\text{Bouyancy force}}{\text{Viscous force}}$

$$= \frac{g\,\beta\left(T_W - T_\infty\right)L^3}{v^2}$$

Schmidt number, S_c = $\dfrac{\text{Momentum diffusivity}}{\text{Mass diffusivity}}$

$$S_c = \frac{v}{D}$$

3. **(b)**

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

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

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

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

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

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

4. **(a)**

Grashoff number, $Gr = \dfrac{g\beta\Delta T L^3}{v^2}$; $\qquad T_f = \dfrac{250+30}{2} = 140°C$ or 413 K; $\beta = \dfrac{1}{T_f}$

$$= \frac{9.81 \times \left(\dfrac{1}{413}\right)(250-30)\times 2^3}{(27.8\times 10^{-6})^2}$$

$$= 0.054 \times 10^{12}$$

5. (b)

$$\left(\frac{q}{A}\right)_{\text{net with 'n' shields}} = \left(\frac{1}{n+1}\right)\left(\frac{q}{A}\right)_{\text{without any shield}} \qquad \text{[Provided all } \in^s \text{ are same]}$$

$$\therefore \qquad \frac{1}{5}\left(\frac{q}{A}\right)_{\text{without}} = \frac{1}{n+1}\left(\frac{q}{A}\right)_{\text{without}}$$

$$\therefore \qquad \frac{1}{5} = \frac{1}{n+1}$$

$$\therefore \qquad n = 4 \text{ shields}$$

6. (c)

$$\in_{\text{balanced counter}} = \frac{NTU}{1+NTU} = \frac{0.5}{1+0.5} = 0.33$$

7. (d)

Fin effectiveness for long fin; $\in = \sqrt{\dfrac{Pk}{hA}}$

$$\Rightarrow \qquad \frac{\in_2}{\in_1} = \sqrt{\left(\frac{P_2}{P_1}\right)\times\left(\frac{K_2}{K_1}\right)\times\left(\frac{h_1}{h_2}\right)\times\left(\frac{A_1}{A_2}\right)}$$

$$\Rightarrow \qquad \frac{\in_2}{\in_1} = \sqrt{1\times 2\times\frac{1}{2}\times 1} = 1$$

8. (c)

$$\text{Nu} = 0.023\,\text{Re}^{0.8}\,\text{Pr}^n$$

Where, $\qquad n = 0.4 \quad$ For heating of fluid

$\qquad\qquad\quad n = 0.3 \quad$ For cooling of fluid

9. (c)

Given: $T_w = 27°C$, $D = 120$ mm, $R = 60$ mm $= 0.060$ m, $K = 2$ W/m²K, $q_g = 10000$ W/m³.

For a solid sphere with internal heat generation, the temperature at the centre is:

$$T_o = \frac{q_g\cdot R^2}{6K} + \frac{q_g\cdot R}{3h} + T_\infty = \frac{q_g\cdot R^2}{6K} + T_w$$

$$= \frac{10000\times(0.060)^2}{6\times 2} + 27 = 30°C$$

10. (a)

Reynolds number, $\quad \text{Re} = \dfrac{\rho VD}{\mu} = \dfrac{1000\times 2\times 0.040}{\left(7\times 10^{-4}\right)} = 114285.7143$

$$\text{Re} > 2200$$

$\Rightarrow$ Flow is turbulent.

Nusselt number for turbulent flow through pipe for heating of fluid:

$$\text{Nu} = \frac{hD}{k_f} = 0.023\,\text{Re}^{0.8}\,\text{Pr}^{0.4}$$

$$\Rightarrow \qquad \frac{h \times 0.040}{0.6} = 0.023 \times (114285.7143)^{0.8} (4.9)^{0.4}$$

$$\Rightarrow \qquad h = 7249.2167 \text{ W/m}^2\text{K}$$

$$\approx 7249.22 \text{ W/m}^2\text{K}$$

11.   (b)

From summation rule,

$$\cancel{F_{11}}^{0} + F_{12} + F_{13} = 1$$
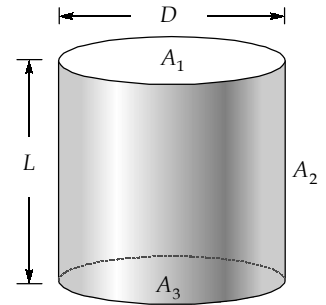
$$F_{12} = 1 - F_{13}$$

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

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

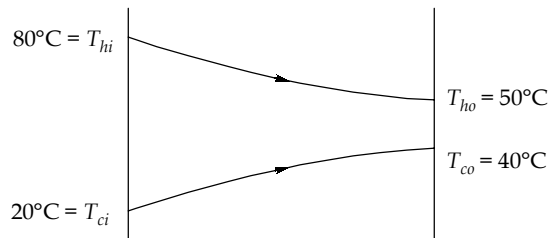From reciprocal theorem,

$$A_2 F_{21} = A_1 F_{12}$$

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

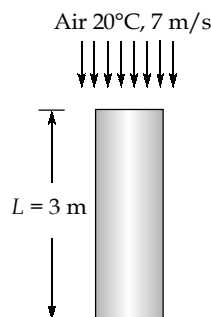$$F_{21} = \frac{\sqrt{2} - 1}{2}$$

12.   (b)

As per given data,

$$\Delta T_1 = 80°C - 20°C = 60°C$$
$$\Delta T_2 = 50°C - 40°C = 10°C$$

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

13.   (b)

The flow is along 3 m side of the plate, and thus the characteristic length is $L = 3$ m. Both sides are exposed to air flow,

$$A = 2 \times w \times L$$
$$= 2 \times 2 \times 3 = 12 \text{ m}^2$$

For flat plates, drag force is equivalent to friction force.

$$F_f = C_f A_s \frac{\rho V^2}{2}$$

$$C_f = \frac{F_f}{\frac{1}{2}\rho A_s V^2} = \frac{0.86}{1.204 \times 12 \times \frac{1}{2} \times (7)^2} = 0.00243$$

From Reynolds Analogy,

$$St \times (Pr)^{2/3} = \frac{C_f}{2} = \frac{0.00243}{2}$$

$$St = \frac{h}{\rho V c_p}$$

$$h = 0.00149 \times 1.204 \times 7 \times 1007$$
$$= 12.64 \text{ W/m}^2\text{K}$$

14.   (b)

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

$$Nu \propto (Re)^m$$

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

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

$$Nu_2 = Nu_1$$

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

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

Heat flux from the second airfoil

$$= h_2(T - T_\infty)$$
$$= 60 \times (80 - 15)$$
$$= 3900 \text{ W/m}^2$$

15. **(b)**

Given : $h = 16$, $k = 15$, $P = 2 \times (0.25 + 1.25) = 3$ cm

$$A = 0.25 \times 1.25 \text{ cm}^2$$

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{16}{15} \times \frac{3 \times 100}{0.25 \times 1.25}} = 32$$

$$mL = 32 \times 0.20 = 6.4$$
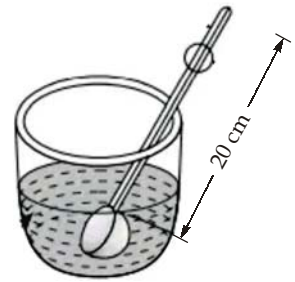
$mL > 5$ (So can assume infinitely long fin)

$$\frac{T_L - T_\infty}{T_0 - T_\infty} = e^{-mL}$$

$$\frac{T_L - 25}{70} = e^{-6.4}$$

$$\Rightarrow \qquad T_L = 25 + 70\, e^{-6.4}$$

Temperature difference across the exposed surface

$$T_0 - T_L = 95 - (25 + 70\, e^{-6.4})$$
$$= 70(1 - e^{-6.4})$$

16. **(c)**

$$Q = -kA\left(\frac{dT}{dx}\right)_{x=0}$$

$$\frac{dT}{dx} = 10x - 4$$

$$\left(\frac{dT}{dx}\right)_{x=0} = -4$$

$$Q = -0.15 \times 3 \times (-4) = 1.8 \text{ W}$$

17. **(c)**

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

$$mL = L\sqrt{\frac{hP}{kA_{cs}}} = \sqrt{\frac{hL^2 P}{kA_{cs}}}$$

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

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

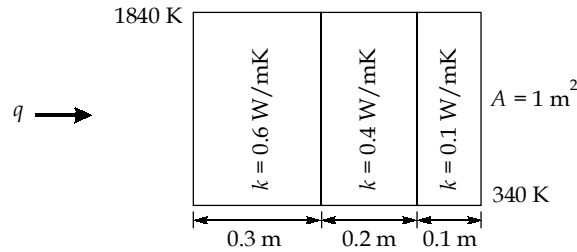$$= \sqrt{32 \times \left(\frac{hr}{k}\right) \times \left(\frac{L}{d}\right)}$$

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

$$= \sqrt{32 \times 0.04 \times 4} = 2.262$$

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

18.   (d)

$$q = \frac{T_1 - T_2}{\sum R_{th}}$$

$$= \frac{1840 - 340}{\dfrac{0.3}{0.6 \times 1} + \dfrac{0.2}{0.4 \times 1} + \dfrac{0.1}{0.1 \times 1}} = 750\ \text{W}$$
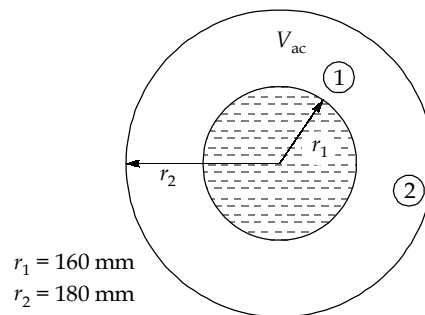
19.   (b)

From Wien's displacement law,

$$\lambda_m T = 2897.6\ \mu\text{m-K}$$

where, λ_m = wavelength at which $E_{b\lambda}$ is maximum

$$\lambda_m = \frac{2897.6}{390} = 7.43\ \mu\text{m}$$

20.   (b)

$$(q_{1\text{-}2})_{\text{net}} = \frac{\sigma\left(T_1^4 - T_2^4\right) A_1}{\dfrac{1}{\epsilon_1} + \dfrac{A_1}{A_2}\left(\dfrac{1}{\epsilon_2} - 1\right)}\ \text{Watt}$$

$$\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2}; \quad \epsilon_1 = \epsilon_2 = 0.03$$

$$T_1 = (-153 + 273)\ \text{K} = 120\ \text{K}$$
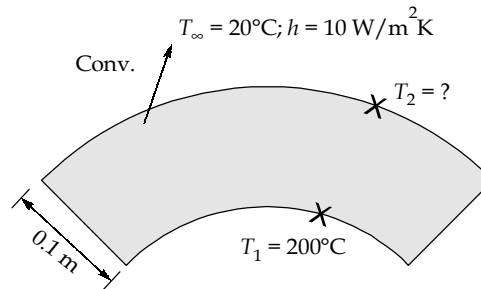$$T_2 = (27 + 273)\text{K} = 300\ \text{K}$$

$$A_1 = 4\pi r_1^2$$

Substituting, $\quad (q_{1\text{-}2})_{\text{net}} = -2.446\ \text{Watt}$

Rate of evaporation of liquid,

$$O_2 = \frac{q_{1-2} \text{ in J/sec}}{L.H. \text{ in J/kg}} \times 3600$$

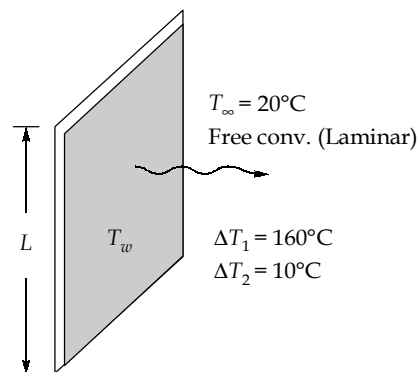$$= 0.042 \text{ kg/hr}$$

21.   (b)

For steady state conditions,

The rate of conduction heat transfer between T_1 and T_2 = The rate of convection heat transfer between T_2 and ambient

$$\frac{200 - T_2}{\dfrac{\ln\left(\dfrac{r_2}{r_1}\right)}{2\pi kL}} = \frac{T_2 - 20}{\dfrac{1}{2\pi r_2 L \times h}}$$

∴ $T_2 = 28.1936°C$

22.   (c)

$$\Delta T = T_w - T_\infty$$

In laminar flow,

$$\text{Nu} \propto \text{Gr}^{1/4}$$

$$\text{Gr} = \frac{g\beta\Delta T L^3}{v^2}$$

⇒ $\text{Nu} \propto (\Delta T)^{1/4}$

⇒ $\dfrac{Nu_2}{Nu_1} = \left(\dfrac{10}{160}\right)^{1/4}$

⇒ $\text{Nu}_2 = 48\left(\dfrac{1}{16}\right)^{1/4} = 24$

23. **(b)**

$$T_{he} = 300 \text{ K}; T_{ci} = 280 \text{ K}$$
$$\Delta T_i = \Delta T_e = 20 \text{ K}$$
$$T_{hi} - T_{he} = T_{ce} - T_{ci}$$
$$T_{hi} - 300 = T_{ce} - 280$$
$$T_{hi} = T_{ce} + 20 \qquad\qquad\qquad\qquad\qquad ...(i)$$
$$\text{NTU} = \frac{UA}{(\dot{m}c_p)_{small}} = \frac{20 \times 20}{0.4 \times 1000} = 1$$
$$\in_{\text{balanced counterflow}} = \frac{NTU}{1 + NTU} = 0.5$$

From equation (i),

$$\in = \frac{T_{c_e} - T_{c_i}}{T_{h_i} - T_{c_i}} = \frac{T_{c_e} - 280}{T_{c_e} + 20 - 280} = 0.5$$

$$\therefore \qquad\qquad T_{c_e} = 300 \text{ K}$$

24. **(b)**

If $\qquad\qquad\qquad \text{Re}_{x = L} < 5 \times 10^5$

$\Rightarrow$ Flow is laminar

$$\Rightarrow \qquad\qquad\qquad \text{Nu}_x = \frac{h_x x}{k} = 0.332 \, \text{Re}_x^{1/2} \, P_r^{1/3}$$

$$\text{Re}_x = \frac{V_\infty x \rho}{\mu}$$

$$\therefore \qquad\qquad\qquad h_x \propto x^{-1/2}$$

25. **(d)**

When no radiation shield placed, heat flux:

$$q_o = \frac{\sigma(T_1^4 - T_2^4)}{\left(\frac{2}{\in} - 1\right)}$$

For *n* radiation shields placed,

$$q_n = \left(\frac{1}{n+1}\right) q_o$$

Initially there was only 1 radiation shield plate,

$$q_1 = \left(\frac{1}{1+1}\right) = \frac{q_o}{2}$$

when there are 2 radiation shields

$$q_2 = \left(\frac{1}{2+1}\right) = \frac{q_o}{3}$$

$$\Rightarrow \qquad q_2 = \frac{q_o}{3} = \frac{2}{3}q_1$$

$$\% \text{ reduction in } q = \frac{q_1 - q_2}{q_1} \times 100 = 33.33\%$$

26. **(a)**

Given: $T_{ci} = 5°C$, $\dot{m}_c = 1$ kg/s, $C_c = 4.2$ kJ/kgK, $T_{hi} = 80°C$, $\dot{m}_h = 2$ kg/s, $C_h = 4.2$ kJ/kgK, $U = 250$ W/m^{2}K and $A = 25$ m^2.

$$C = \frac{(\dot{m}c)_{\min}}{(\dot{m}c)_{\max}} = \frac{\dot{m}_{\min}}{\dot{m}_{\max}} = 0.5$$

$$\text{NTU} = \frac{UA}{(\dot{m}c)_{\min}} = \frac{250 \times 25}{\left(1 \times 4.2 \times 10^3\right)} = 1.488$$

$$\in = \frac{1 - e^{-(1-C)NTU}}{1 - Ce^{-(1-C)NTU}} = \frac{1 - e^{-(1-0.5)(1.488)}}{1 - (0.5)e^{-(1-0.5) \times 1.488}} = 0.688$$

27. **(b)**

Given: $h_i = 100$ W/m^{2}K, $h_o = 1000$ W/m^{2}K, $F = 0.0004$ m^{2}K/W.

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} + F = \frac{1}{100} + \frac{1}{1000} + 0.0004$$

$$U_1 = 87.719 \text{ W/m}^2\text{K}$$

After removing the dirt, $F = 0$

$$\frac{1}{U_2} = \frac{1}{100} + \frac{1}{1000}$$

$$\Rightarrow \qquad U_2 = 90.909 \text{ W/m}^2\text{K}$$

$$Q \propto U$$

$$\% \text{ increase in } Q = \frac{U_2 - U_1}{U_1} \times 100 = \frac{90.909 - 87.719}{87.719} \times 100 = 3.6366\%$$

28. **(c)**

$$\text{Characteristic length, } L_c = \frac{V}{A} = \frac{\frac{4}{3}\pi R^3}{4\pi R^2} = \frac{R}{3} = \frac{D}{6} = \frac{0.012}{6} = 0.002 \text{ m}$$

$$\text{Biot number, Bi} = \frac{hL_c}{k_s} = \frac{200 \times (0.002)}{40} = 0.01$$

Bi < 0.1, so lumped system analysis is valid.

$$\frac{T - T_\infty}{T_o - T_\infty} = e^{-\frac{hA}{\rho VC}t} = 0.01$$

$$\Rightarrow \quad \ln(0.01) = \frac{-(200)t}{9000 \times (0.002) \times (0.3 \times 10^3)}$$

$$\Rightarrow \quad t = 124.3396s \approx 124s$$

29. **(d)**

By reciprocity theorem:

$$A_1 F_{12} = A_2 F_{21}$$

$$\Rightarrow \quad F_{21} = \frac{A_1}{A_2} \times F_{12} = \frac{300}{80} \times (0.1) = 0.375$$

By summation rule,

$$F_{11} + F_{12} + F_{13} = 1$$
$$0 + 0.1 + F_{13} = 1 \qquad [\because F_{11} = 0]$$
$$\Rightarrow \quad F_{13} = 0.9$$

Also, $\quad F_{21} + F_{22} + F_{23} = 1$
$$0.375 + 0 + F_{23} = 1 \qquad [\because F_{22} = 0]$$
$$\Rightarrow \quad F_{23} = 0.625$$

By reciprocity theorem:

$$F_{32} = \frac{A_2}{A_3} \times F_{23} = \frac{80}{500} \times 0.625 = 0.1$$

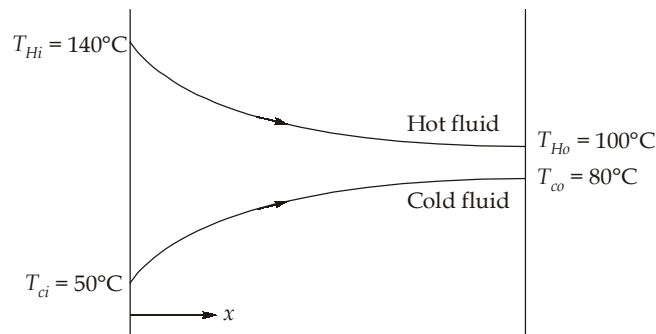$$F_{31} = \frac{A_1}{A_3} \times F_{13} = \frac{300}{500} \times 0.9 = 0.54$$

By summation rule:

$$F_{31} + F_{32} + F_{33} = 1$$
$$\Rightarrow \quad F_{33} = 1 - F_{31} - F_{32} = 1 - (0.54) - (0.1) = 0.36$$

30. **(d)**

For parallel flow heat exchanger:

For cold fluid: $\quad \dfrac{dT}{dx} > 0$

For hot fluid: $\quad \dfrac{dT}{dx} < 0$

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