CLASS TEST

S.No. : 01_JP_ME_04092025

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HEAT TRANSFER

MECHANICAL ENGINEERING

Date of Test : 04/09/2025

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)**

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

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

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

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

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

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

3. **(b)**

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

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

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

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

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

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

4. **(a)**

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

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

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

5. (b)

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

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

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

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

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; $\in = \sqrt{\dfrac{Pk}{hA}}$

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

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

8. (c)

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

Where, $n = 0.4$ For heating of fluid

$n = 0.3$ For cooling of fluid

9. (c)

Given: T_w = 27°C, D = 120 mm, R = 60 mm = 0.060 m, K = 2 W/m^{2}K, q_g = 10000 W/m^3.

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

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

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

10. (a)

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

$\text{Re} > 2200$

$\Rightarrow$ Flow is turbulent.

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

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

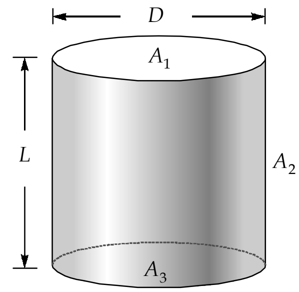
$$\Rightarrow \quad \frac{h \times 0.040}{0.6} = 0.023 \times (114285.7143)^{0.8} (4.9)^{0.4}$$

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

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

11. (b)

From summation rule,



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

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

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

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

From reciprocal theorem,

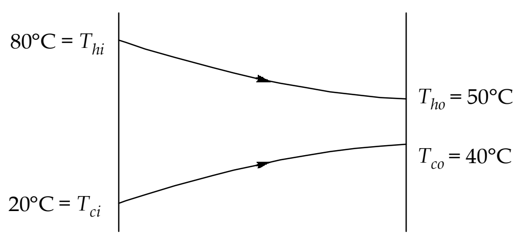
$$A_2 F_{21} = A_1 F_{12}$$

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

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

12. (b)

As per given data,

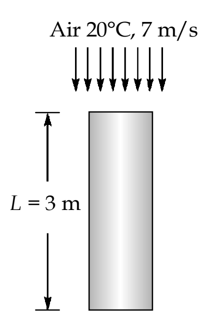


$$\Delta T_1 = 80°C - 20°C = 60°C$$

$$\Delta T_2 = 50°C - 40°C = 10°C$$

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

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,

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

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

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

14. **(b)**

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

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

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

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

$$Nu_2 = Nu_1$$

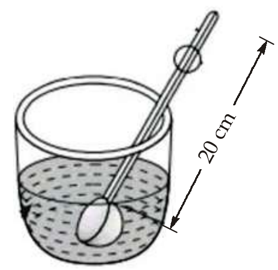
$$\frac{h_1 L_{C_1}}{K} = \frac{h_2 L_{C_2}}{K}$$

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

Heat flux from the second airfoil

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

15. (b)



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

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

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

$$mL = 32 \times 0.20 = 6.4$$

$$mL > 5 \text{(So can assume infinitely long fin)}$$

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

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

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

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)

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

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

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

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

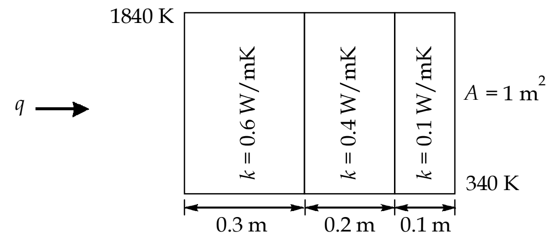
$$= \sqrt{32 \times \left(\frac{hr}{k}\right) \times \left(\frac{L}{d}\right)}$$

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

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

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

18. **(d)**



$$q = \frac{T_1 - T_2}{\sum R_{th}}$$
$$= \frac{1840 - 340}{\frac{0.3}{0.6 \times 1} + \frac{0.2}{0.4 \times 1} + \frac{0.1}{0.1 \times 1}} = 750 \text{ W}$$

19. **(b)**

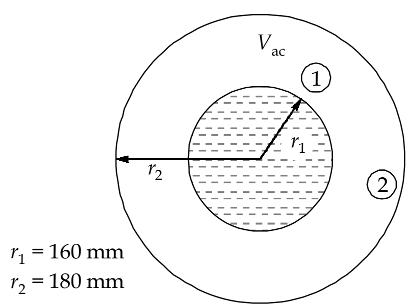
From Wien's displacement law,

$$\lambda_m T = 2897.6 \text{ µm-K}$$

where, λ_m = wavelength at which E_{b_λ} is maximum

$$\lambda_m = \frac{2897.6}{390} = 7.43 \text{ µm}$$

20. **(b)**



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

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

$$T_1 = (-153 + 273) \text{ K} = 120 \text{ K}$$
$$T_2 = (27 + 273)\text{K} = 300 \text{ K}$$
$$A_1 = 4\pi r_1^2$$

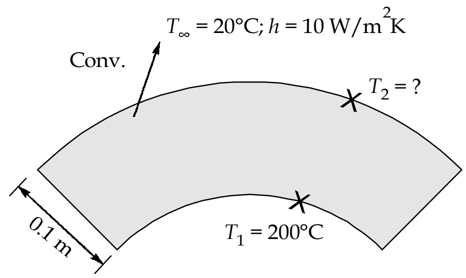
Substituting, $(q_{1\text{-}2})_{net}$ = –2.446 Watt

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)



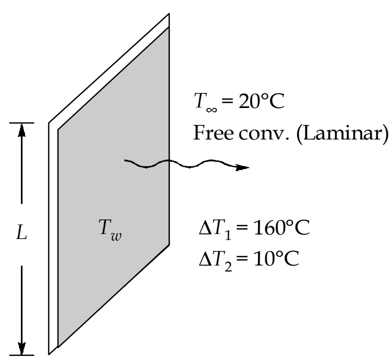
For steady state conditions,

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

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

$\therefore$ $T_2 = 28.1936°C$

22. (c)



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

In laminar flow,

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

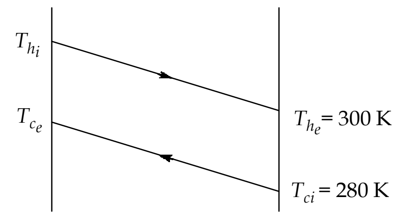
$$\text{Gr} = \frac{g\beta\Delta T L^3}{v^2}$$

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

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

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

23. (b)



$$T_{he} = 300\text{ K};\ T_{ci} = 280\text{ K}$$

$$\Delta T_i = \Delta T_e = 20\text{ K}$$

$$T_{hi} - T_{he} = T_{ce} - T_{ci}$$

$$T_{hi} - 300 = T_{ce} - 280$$

$$T_{hi} = T_{ce} + 20 \quad \text{...(i)}$$

$$\text{NTU} = \frac{UA}{(\dot{m}c_p)_{small}} = \frac{20 \times 20}{0.4 \times 1000} = 1$$

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

From equation (i),

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

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

24. (b)

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

$\Rightarrow$ Flow is laminar

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

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

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

25. (d)

When no radiation shield placed, heat flux:

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

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

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

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

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

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 = 100W/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, $F = 0$

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

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

$$Q \propto U$$

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

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.

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

$$\Rightarrow \qquad \ln(0.01) = \frac{-(200)t}{9000\times(0.002)\times\left(0.3\times10^3\right)}$$

$$\Rightarrow \qquad t = 124.3396\text{s} \approx 124\text{s}$$

29. (d)

By reciprocity theorem:

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

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

By summation rule,

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

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

$$\Rightarrow \qquad F_{13} = 0.9$$

Also, $F_{21} + F_{22} + F_{23} = 1$

$$0.375 + 0 + F_{23} = 1 \qquad [\because F_{22} = 0]$$

$$\Rightarrow \qquad F_{23} = 0.625$$

By reciprocity theorem:

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

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

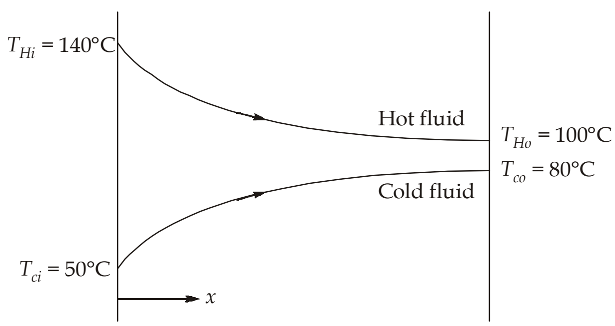
By summation rule:

$$F_{31} + F_{32} + F_{33} = 1$$

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

30. (d)

For parallel flow heat exchanger:



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

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

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