CLASS TEST

S.No. : 01SPME_HIJKLM_270724

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HEAT TRANSFER

MECHANICAL ENGINEERING

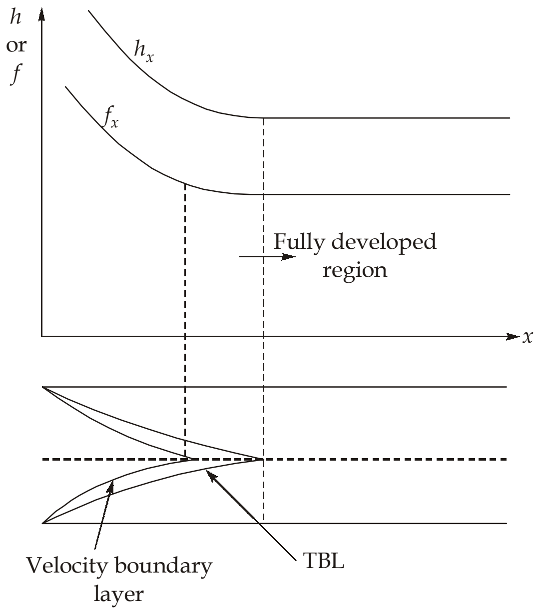
Date of Test : 27/07/2024

ANSWER KEY

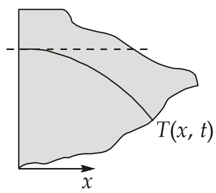
1.	(a)	7.	(b)	13.	(b)	19.	(b)	25.	(b)
2.	(c)	8.	(c)	14.	(b)	20.	(a)	26.	(a)
3.	(d)	9.	(b)	15.	(c)	21.	(b)	27.	(b)
4.	(d)	10.	(d)	16.	(b)	22.	(c)	28.	(a)
5.	(c)	11.	(c)	17.	(c)	23.	(a)	29.	(c)
6.	(b)	12.	(b)	18.	(a)	24.	(b)	30.	(d)

DETAILED EXPLANATIONS

1. (a)



2. (c)



As $\left.\frac{\partial T}{\partial x}\right|_{x=0} = 0$, the boundary is an adiabatic or insulated surface.

3. (d)

$$(Q)_{x=1} = -kA\left(\frac{dT}{dx}\right)_{x=1}$$

$$= -25 \times 0.005 \times (-150 + 20x)_{x=1}$$

$$= 16.25 \text{ W}$$

4. (d)

$$d = 5 \text{ mm}$$
$$p = \pi d = \pi \times 0.005 = 0.0157 \text{ m}$$
$$T_0 = 100°\text{C}$$
$$h = 100 \text{ W/m}^2\text{K}$$
$$k = 398 \text{ W/mK}$$
$$T_\infty = 25°\text{C}$$

Assume infinite length of rod

$$Q = \sqrt{hpkA_c}\,(T_0 - T_\infty)$$

$$= \sqrt{100 \times 0.0157 \times 398 \times \frac{\pi \times (0.005)^2}{4}}(100 - 25)$$

$$= 8.3 \text{ W}$$

5. (c)

In case of natural convection,

$$Nu = C(GrPr)^m$$

6. (b)

For parallel flow heat exchanger,

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

Put $C = 0$,

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

$$\varepsilon = 1 - \exp(-NTU)$$

For counter flow heat exchanger,

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

Put $C = 0$,

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

$$\varepsilon = 1 - \exp(-NTU)$$

So, expression:

$$\varepsilon = 1 - \exp(-NTU)$$

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

7. (b)

Temperature of body, $T = 2000$ K

From Wien's Displacement law:

$$\lambda_m T = 2898 \ \mu\text{m-K}$$

$$\lambda_m \times 2000 = 2898$$

$$\lambda_m = 1.449 \ \mu\text{m}$$

$$\lambda_m \simeq 1.45 \ \mu\text{m}$$

8. (c)

Minimum heat capacity rate,

$$C_{min} = \dot{m}_c c_{pc} = 3 \times 4.2 = 12.6 \text{ kW/K}$$

Overall heat transfer coefficient, $U = 1600$ W/m^2°C

Heat transfer area, $A = 12$ m^2

$$NTU = \frac{UA}{C_{min}} = \frac{1600 \times 12}{12.6 \times 1000} = 1.5238$$

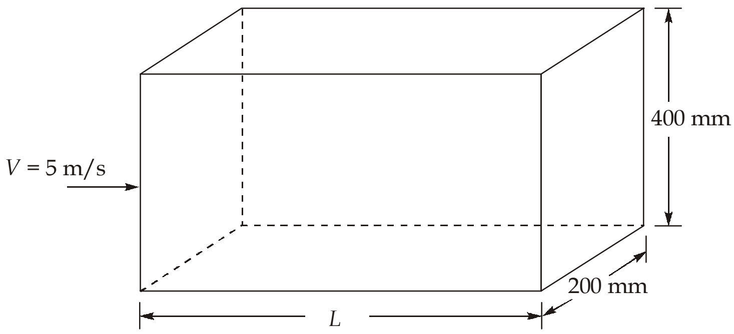
Effectiveness, $\varepsilon = 1 - e^{-NTU} = 1 - e^{-(1.5238)} = 0.782$

9. (b)

$$F_{12} = 1.0$$
$$A_2F_{21} = A_1F_{12}$$
$$F_{21} = \frac{A_1}{A_2}\times 1 = \frac{2R\times L}{\frac{3}{4}\times(2\pi RL)}\times 1.0 = \frac{4}{3\pi} = 0.424$$

10. (d)

11. (c)



Hydraulic diameter, $D_h = \frac{4A}{P} = \frac{4\times 200\times 400}{2(200+400)}$

$$D_h = 266.667 \text{ mm}$$

Reynolds number, $\text{Re} = \frac{VD_h}{\nu} = \frac{5\times 0.266667}{15.06\times 10^{-6}} = 88.535\times 10^3 > 2000$

So, flow is turbulent,

Prandtl number, $\text{Pr} = \frac{\nu}{\alpha} = \frac{15.06\times 10^{-6}}{7.71\times 10^{-2}/3600} = 0.7032$

For heating of fluid case,

$$\text{Nu} = 0.023(\text{Re})^{0.8}(\text{Pr})^{0.4}$$
$$= 0.023(88.535\times 10^3)^{0.8}(0.7032)^{0.4}$$
$$\text{Nu} = 181.239$$

$$\Rightarrow \quad \frac{h\times D_h}{k} = 181.239$$

$$\frac{h\times 0.266667}{0.026} = 181.239$$

$$\Rightarrow \quad h = 17.671 \text{ W/m}^2\,°\text{C}$$

Heat transfer rate per unit length per unit temperature difference,

$$Q = h(PL)(\Delta T)$$
$$\frac{Q}{L\Delta T} = 17.671\times 2(0.2+0.4)$$
$$\frac{Q}{L\Delta T} = 21.205 \text{ W/m°C}$$

12. (b)

$$q_{net} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2} + \frac{1}{A_1 F_{12}}}$$

Since, $F_{12} = 1$

$$q_{net} = \frac{5.67 \times 10^{-8} \times [(40+273)^4 - (250+273)^4]}{\frac{1}{A_2}\left[\frac{1-0.25}{0.25 \times A_1} \times A_2 + \frac{1-0.7}{0.7 \times 1} + \frac{A_2}{A_1}\right]}$$

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

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

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

13. (b)

Effectiveness is lowest when capacity ratio is 1.

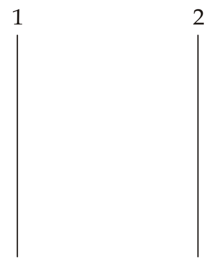
So, $$\varepsilon = \frac{1 - \exp\{-NTU(1+C)\}}{1+C}$$

$$= \frac{1 - \exp\{-NTU(1+1)\}}{1+1} = \frac{1 - \exp\{-3.5(2)\}}{2} = 0.4995 \simeq 0.5$$

14. (b)

Without shield

Radiation heat transfer rate,

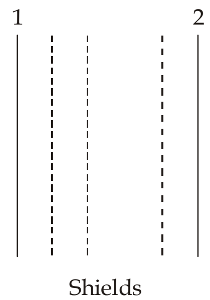


$$q = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

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,

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

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

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

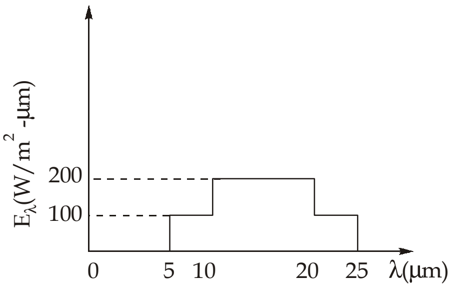
$$\frac{\left(\frac{1}{0.8}+\frac{1}{0.6}-1\right)+N\left(\frac{2}{0.29}-1\right)}{\left(\frac{1}{0.8}+\frac{1}{0.6}-1\right)} = 10$$

Number of shields, $N = 2.925$

$N \simeq 3$

15. (c)

Refer figure,

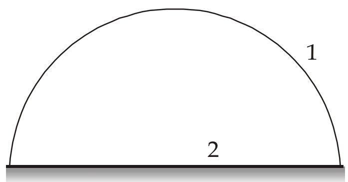


$$E = \int_0^\infty E_\lambda d\lambda = \text{Area under the spectral intensity curve}$$

$$= 100 \times (25 - 5) + 100 \times (20 - 10)$$

$$= 3000 \text{ W/m}^2 \text{ or } 3 \text{ kW/m}^2$$

16. (b)



$$q_{12} = A_1 F_{12}\sigma(T_1^4 - T_2^4)$$

$$A_1 = 2\pi r^2$$

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

$$= 1\times\frac{\pi r^2}{2\pi r^2} = 0.5$$

$$q_{12} = 2 \times \pi \times (0.5)^2 \times 0.5 \times 5.67 \times 10^{-8}(1100^4 - 330^4)$$

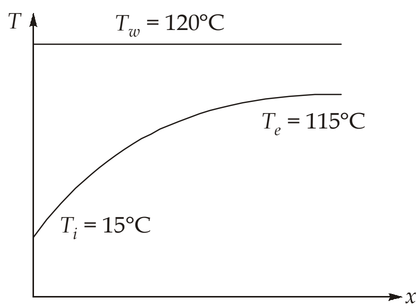
$$= 64.7 \text{ kW} \simeq 65 \text{ kW}$$

17. (c)

The rate of heat transfer (θ) is calculated as,

$$Q = \dot{m}c_p(T_e - T_i)$$

$$= 0.3 \times 4.187 \times (115 - 15) = 125.61 \text{ kW}$$



$$\Delta T_i = T_w - T_i = 120 - 15 = 105°\text{C}$$

$$\Delta T_e = T_w - T_e = 120 - 115 = 5°\text{C}$$

$$\Delta T_m = \frac{\Delta T_e - \Delta T_i}{\ln\left(\frac{\Delta T_e}{\Delta T_i}\right)} = \frac{5-105}{\ln\left(\frac{5}{105}\right)} = 32.845°\text{C}$$

$$Q = hA_w \, \Delta T_m$$

$$\Rightarrow \quad 125.61 \times 10^3 = 800 \times \pi \times 2.5 \times 10^{-2} \times L \times 32.845$$

$$L = 60.866 \text{ m} \simeq 61 \text{ m}$$

18. (a)

$$\frac{1}{U} = \frac{1}{h_i} + R_i + \frac{1}{h_o} + R_o$$

$$= \frac{1}{500} + 0.0002 + \frac{1}{2500} + 0.0004 = 0.003 \text{ m}^2\text{°C/W}$$

$$\therefore \quad U = 333.33 \text{ W/m}^2\text{°C}$$

19. (b)

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

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

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

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

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

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

20. (a)

$$\eta_{\text{fin}} = \left(\frac{\tanh mL}{mL}\right) = 0.7$$

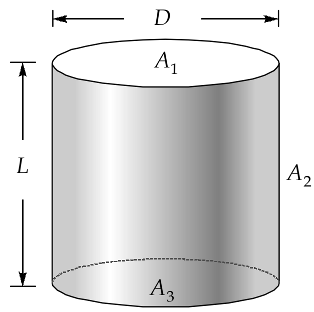
$$\varepsilon_{\text{fin}} = \tanh mL\sqrt{\frac{kP}{hA}} = \frac{\tanh mL}{m} \times \frac{P}{A}$$

$$\frac{\varepsilon_{fin}}{\eta_{fin}} = \frac{L \times P}{A}$$

$$\text{Effectiveness} = \frac{3 \times \pi \times 0.6 \times 0.7}{\frac{\pi}{4}(0.6)^2} = 14$$

21. (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,

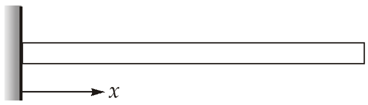
$$A_2F_{21} = A_1F_{12}$$

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

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

22. (c)

$$T(x) - T_\infty = e^{-mx}\,(T_b - T_\infty)$$



Heat transfer through fin, $q_{x=0}$

$$= -kA\left.\frac{dT}{dx}\right|_{x=0} = -kA(-m)\left(T_b - T_\infty\right)e^{-mx}\Big|_{x=0}$$

$$= kA\sqrt{\frac{hP}{kA}}\left(T_b - T_\infty\right) = \sqrt{hPkA}\left(T_b - T_\infty\right)$$

23. (a)

Given: $\alpha = \in = 0.8$ (for gray surface)

$T = 150°\text{C} = 150 + 273 = 423\ \text{K}$

$G = 1200\ \text{W/m}^2$

For opaque body, $\tau = 0$, $\alpha + \rho = 1$

$\rho = 1 - \alpha = 1 - 0.8 = 0.2$

Radiosity, $J = E + \rho G = \in E_b + \rho G = \in \sigma T^4 + \rho G$

$$= 0.8 \times 5.67 \times \left(\frac{423}{100}\right)^4 + 0.2 \times 1200$$

$$= \mathbf{1692.227\ W/m^2}$$

24. (b)

Given:

The heat release is uniform along the rod. Maximum temperature occurs at the centre is given by,

$$T_{max} = T_s + \frac{\dot{q}R^2}{4k} \qquad (T_s = \text{Surface temperature})$$

$$T_{max} - T_s = \frac{\dot{q}R^2}{4k} \qquad \text{... (i)}$$

$$\therefore\ \dot{q}\ \text{(Heat generated/m}^3) = \frac{0.25\times10^6}{\pi R^2 L} = \frac{0.25\times10^6}{\pi R^2\times 6}$$

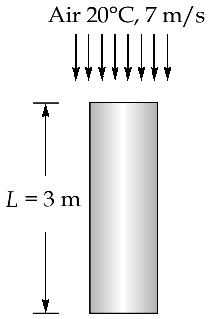
$$= \frac{13262.91}{R^2}\ \text{W/m}^3$$

Now from equation (i)

$$T_{max} - T_s = \frac{13262.91}{R^2}\times\frac{R^2}{4\times30}$$

$$= \mathbf{110.52°C}$$

25. (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,

$$A = 2\times w\times L$$

$$= 2\times2\times3 = 12\ \text{m}^2$$

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

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

$$C_f = \frac{F_f}{\frac{1}{2}\rho A_s V^2} = \frac{0.86}{1.204\times12\times\frac{1}{2}\times(7)^2} = 0.00243$$

From Reynolds Analogy,

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

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

$$h = 0.00149\times1.204\times7\times1007$$

$$= 12.64\ \text{W/m}^2\text{K}$$

26. (a)

$$\text{Reynolds, number, Re} = \frac{\rho VL}{\mu} = \frac{996.6\times0.2\times1}{0.854\times10^{-3}} = 2.33\times10^5$$ (< 5×10^5, So laminar flow)

$$\text{Nusselt number, Nu} = 0.664\ \text{Re}^{1/2}\ \text{Pr}^{1/3}$$

$$\frac{hL}{k} = 0.664\ (2.33\times10^5)^{1/2}\times(5.85)^{1/3}$$

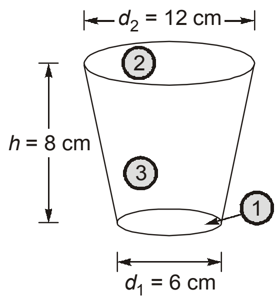
$$= 577.516$$

$$h = 577.516 \times 0.61 = 352.28 \text{ W/m}^2\text{K}$$

Heat transfer, $Q = hA\Delta T = 352.28 \times (1 \times 1) \times (40 - 10)$

$$= 10568.4 \text{ W} = 10.56 \text{ kW}$$

27. (b)



Given: $F_{21} = 0.2$

$\therefore$ $F_{21} + F_{22} + F_{23} = 1$ $(F_{22} = 0)$

$$F_{21} + F_{23} = 1$$

$$F_{23} = 1 - F_{21} = 1 - 0.2 = \mathbf{0.8}$$

28. (a)

$$\frac{T_L - T_\infty}{T_0 - T_\infty} = \frac{1}{\cos hmL}$$

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{250 \times 0.11}{20 \times 6 \times 10^{-4}}}$$

$$m = 47.87 \text{ per meter}$$

$$mL = 47.87 \times 0.05 = 2.39$$

$$\dot{Q} = \sqrt{hPkA}\theta_0 \tanh mL$$

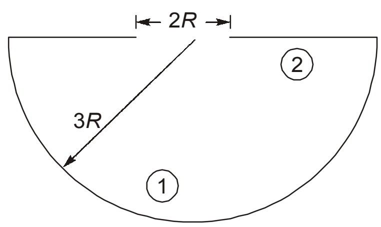
$$= \sqrt{250 \times 0.11 \times 20 \times 6 \times 10^{-4}} \times [1200 - 300] \times \tan h(2.39)$$

$$Q = 517 \times 0.983$$

$$Q = 508 \text{ W}$$

29. (c)

F_{12} needs to be found;



$$A_1 = 2\pi \times (3R)^2 = 18\pi R^2$$

$$A_2 = \pi \times (3R^2) - \pi R^2 = 8\pi R^2$$

$$F_{21} + F_{22} = 1$$

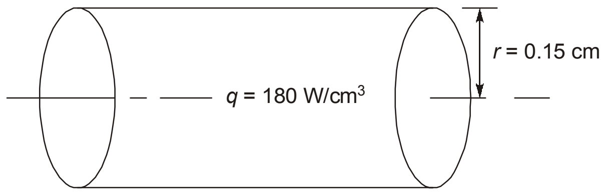
$$\Rightarrow \quad F_{21} = 1$$

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

$$\Rightarrow \quad 18\pi R^2F_{12} = 8\pi R^2 \times 1$$

$$\Rightarrow \quad F_{12} = 0.44$$

30. (d)



Applying energy conservation

Heat generated in the cylinder = Heat conduction at $x = r$

$$q \times \text{volume} = Q = -kA\frac{dT}{dx}$$

$$Q = \left(180\times\frac{\pi}{4}\times 0.3^2\times L\right) \text{ W}$$

$$\text{Heat flux} = \frac{Q}{A} = \frac{180\times\frac{\pi}{4}\times 0.3^2\times L}{\pi\times 0.3\times L} = 13.5 \text{ W/cm}^2$$

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