CLASS TEST

S.No. : 01 PT_ME_ABC_250822

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HEAT TRANSFER

MECHANICAL ENGINEERING

Date of Test : 30/08/2022

ANSWER KEY

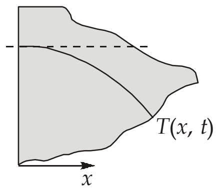
1.	(b)	7.	(b)	13.	(b)	19.	(c)	25.	(b)
2.	(c)	8.	(c)	14.	(b)	20.	(a)	26.	(a)
3.	(a)	9.	(c)	15.	(c)	21.	(a)	27.	(b)
4.	(c)	10.	(d)	16.	(b)	22.	(c)	28.	(d)
5.	(c)	11.	(c)	17.	(b)	23.	(a)	29.	(c)
6.	(b)	12.	(b)	18.	(a)	24.	(b)	30.	(d)

DETAILED EXPLANATIONS

1. (b)

According to the kinetic theory of gases, the thermal conductivity is directly proportional to the density of the gas, the mean molecular speed, and the mean free path of the gas molecules. Because density and mean free path are directly and inversely proportional to the gas pressure, respectively, the thermal conductivity is independent of pressure in a wide range of pressure encountered in practice.

2. (c)



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

3. (a)

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

5. (c)

In case of natural convection,

$$\text{Nu} = C(\text{GrPr})^m$$

6. (b)

For parallel flow heat exchanger,

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

Put $C = 0$,

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

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

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.

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

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

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

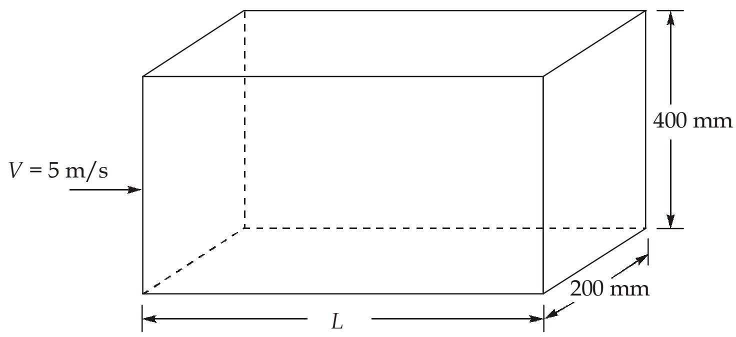
9. (c)

For maximum rate of heat transfer by radiation, surface must be blackbody (i.e., $\varepsilon = 1$)

$$\text{Emissive power, } E_b = \sigma T_1^4$$
$$= 5.67 \times 10^{-8} \times (150 + 273)^4 = 1815.28 \text{ W/m}^2$$

10. (d)

11. (c)



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

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

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

So, flow is turbulent,

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

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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)

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

Since, $F_{12} = 1$

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

$$\frac{q_{net}}{A_2} = \frac{-3697.9847}{\dfrac{0.75}{0.25} \times \dfrac{\pi D_2^2}{\pi D_1^2} + \dfrac{0.3}{0.7} + \dfrac{\pi D_2^2}{\pi D_1^2}}$$

$$= \frac{-3697.9847}{\dfrac{0.75}{0.25} \times \left(\dfrac{1}{0.3}\right)^2 + \dfrac{0.3}{0.7} + \left(\dfrac{1}{0.3}\right)^2}$$

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

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.

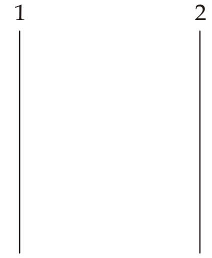
So, $$\varepsilon = \frac{1 - \exp\{-NTU(1+C)\}}{1+C}$$

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

14. (b)

Without shield

Radiation heat transfer rate,

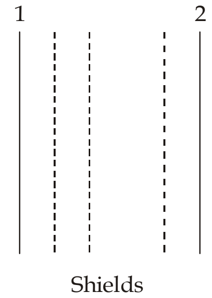


$$q = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

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,

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

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

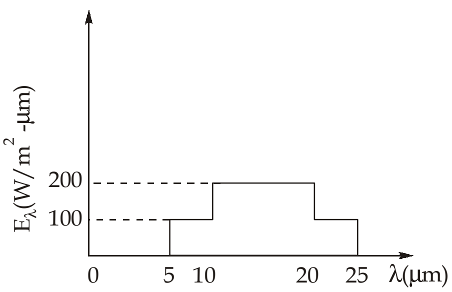
$$\frac{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right) + N\left(\frac{2}{\varepsilon} - 1\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)} = 10$$

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

Number of shields, $N = 2.925$

$$N \simeq 3$$

15. (c)



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

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

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

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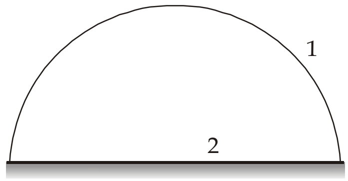
16. (b)



$$q_{12} = A_1F_{12}\sigma(T_1^4 - T_2^4)$$
$$A_1 = 2\pi r^2$$
$$F_{12} = F_{21}\frac{A_2}{A_1}$$
$$= 1\times\frac{\pi r^2}{2\pi r^2} = 0.5$$
$$q_{12} = 2 \times \pi \times (0.5)^2 \times 0.5 \times 5.67 \times 10^{-8}(1100^4 - 330^4)$$
$$= 64.7 \text{ kW}$$

17. (b)

$$T = 150x^2 - 30x$$
$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$
$$\frac{\partial^2 T}{\partial x^2} = 300 > 0$$
$$\therefore \quad \frac{\partial T}{\partial t} > 0$$

Temperature is rising with time i.e. heating.

Heat flux at $x = 20$ cm

$$q'' = -k\frac{\partial T}{\partial x} = -0.02(300 \times 0.2 - 30) = -0.6 \text{ W/m}^2$$

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. (c)

For constant heat flux is

$$\frac{q}{A} = -k_1\frac{(T_2 - T_1)}{\delta_1} = -k_2\frac{(T_3 - T_2)}{\delta_2}$$

here $\delta_1 = b,\ \delta_2 = 2b$

and $k_1 = k;\ k_2 = 2k$

$$\Rightarrow \quad -k\frac{(T - 327)}{b} = -2k\frac{(27 - T)}{2b}$$
$$\Rightarrow \quad 2T = 354\text{°C}$$
$$T = 177\text{°C}$$

20. (a)

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

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

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

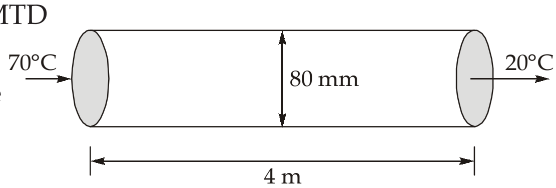
$$\text{Effectiveness} = \frac{3 \times \pi \times 0.6 \times 0.7}{\frac{\pi}{4}(0.6)^2} = 14$$

21. (a)

Heat transfer rate, $q = h(\pi dl)\text{LMTD}$

$\Rightarrow$ $520 = 25 \times (\pi \times 0.08 \times 4) \times \text{LMTD}$

$\text{LMTD} = 20.69°\text{C}$



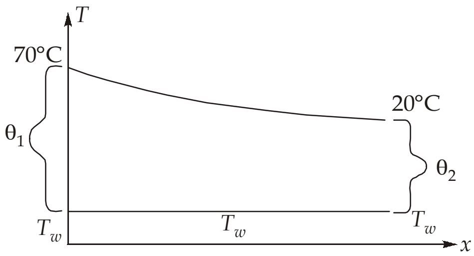
Let, T_w = Tube wall temperature

$\theta_1 = 70 - T_w$

$\theta_2 = 20 - T_w$

$$\text{LMTD} = \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)} = \frac{(70 - T_w) - (20 - T_w)}{\ln\left(\frac{70 - T_w}{20 - T_w}\right)} = 20.69°\text{C}$$

$$\frac{50}{\ln\left(\frac{70 - T_w}{20 - T_w}\right)} = 20.69°\text{C}$$



$$\left(\frac{70 - T_w}{20 - T_w}\right) = 11.2079$$

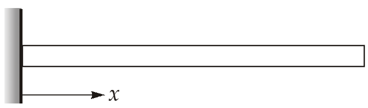
$$70 - T_w = 224.1596 - 11.2079T_w$$

$$10.2079T_w = 154.1596$$

$$T_w = 15.10°\text{C}$$

22. (c)

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



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

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

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

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23. (a)

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

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

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

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

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

$$\text{Radiosity, } J = E + \rho G = \epsilon E_b + \rho G = \epsilon \sigma T^4 + \rho G$$

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

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

24. (b)

Given:

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

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

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

$$\therefore\ \dot{q}\ (\text{Heat generated/m}^3) = \frac{0.25 \times 10^6}{\pi R^2 L} = \frac{0.25 \times 10^6}{\pi R^2 \times 6}$$

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

Now from equation (i)

$$T_{max} - T_s = \frac{13262.91}{R^2} \times \frac{R^2}{4 \times 30}$$

$$= \mathbf{110.52°C}$$

25. (b)

$$Q = kA\frac{dT}{dx}$$

$$Q \propto \frac{k}{dx}$$

As Q is same in both cases,

$$\frac{k_1}{(dx)_1} = \frac{k_2}{(dx)_2}$$

$$\frac{0.5}{15} = \frac{0.1}{(dx)_2}$$

$$(dx)_2 = \frac{0.1 \times 15}{0.5} = 3 \text{ cm}$$

26. (a)

$$\text{Reynolds, number, Re} = \frac{\rho VL}{\mu} = \frac{996.6 \times 0.2 \times 1}{0.854 \times 10^{-3}} = 2.33 \times 10^5 \qquad (< 5 \times 10^5, \text{ So laminar flow})$$

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

$$\frac{hL}{k} = 0.664\ (2.33 \times 10^5)^{1/2} \times (5.85)^{1/3}$$

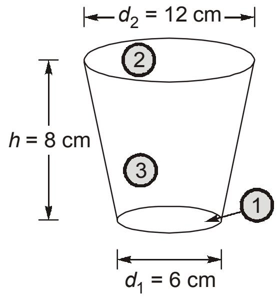
$$= 577.516$$

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

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

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

27. (b)



Given: $F_{21} = 0.2$

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

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

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

28. (d)

$$\text{Pr} = \frac{\nu}{\alpha} = \frac{0.65 \times 10^{-4}}{7.2 \times 10^{-8}} = 902.77$$

also $\quad \dfrac{\delta_t}{\delta} = \dfrac{1}{1.026}(\text{Pr})^{-1/3}$

$\Rightarrow \quad \dfrac{\delta_t}{0.4031} = \dfrac{1}{1.026}(902.77)^{-1/3}$

$\Rightarrow \quad \delta_t = 0.0406\ \text{m} = 40.74\ \text{mm}$

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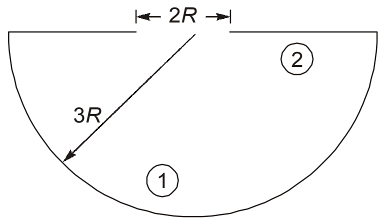
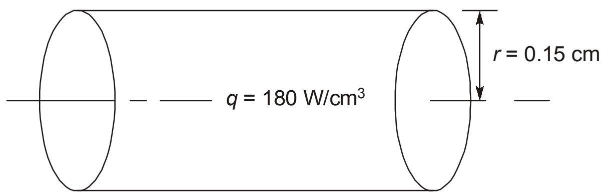
29. (c)

F_{12} needs to be found;



$$A_1 = 2\pi \times (3R)^2 = 18\pi R^2$$
$$A_2 = \pi \times (3R^2) - \pi R^2 = 8\pi R^2$$
$$F_{21} + F_{22} = 1$$
$$\Rightarrow \quad F_{21} = 1$$
$$A_1 F_{12} = A_2 F_{21}$$
$$\Rightarrow \quad 18\pi R^2 F_{12} = 8\pi R^2 \times 1$$
$$\Rightarrow \quad F_{12} = 0.44$$

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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