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Heat and Mass Transfer

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CLASS TEST 2019-2020

MECHANICAL ENGINEERING

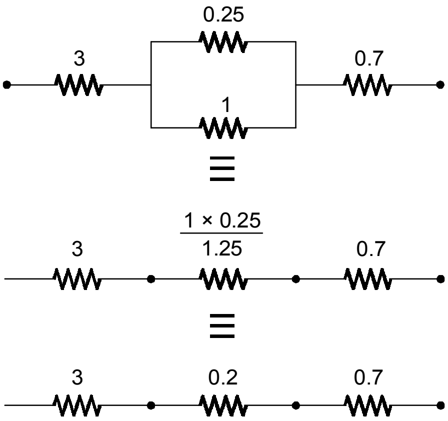
Date of Test : 20/09/2019

ANSWER KEY ➤ Heat and Mass Transfer

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

DETAILED EXPLANATIONS

3. (c)



$$R_{\text{overall}} = 3 + 0.2 + 0.7$$
$$= 3.9 \text{ K/W}$$

4. (c)

Nusselt equation for film-type condensation on a vertical plate is given as:

$$Nu_x = \frac{h_x x}{k} = \left[\frac{\rho_f(\rho_f - \rho_v) g h_{fg} x^3}{4\mu_f k_f \theta}\right]^{1/4}$$

As given, $\frac{Nu_2}{Nu_1} = \left(\frac{\theta_1}{\theta_2}\right)^{0.25}$ [Keeping other parameters constant]

$$\theta_1 = 100 - 10 = 90°\text{C or } 90 \text{ K}$$
$$\theta_2 = 100 - 55 = 45°\text{C or } 45 \text{ K}$$
$$\frac{Nu_2}{Nu_1} = \left(\frac{90}{45}\right)^{0.4} = (2)^{0.25} = 1.189 \approx 1.19$$

6. (b)

Material	Thermal conductivity, *k*(W/mK)
Copper	380
Aluminium, pure	225
Aluminium, alloy	156
Magnesium, pure	173
Steel	55
Stainless steel	14

9. (b)

General heat conduction equation in cylindrical coordinates is given as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q_G}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

For one-dimensional i.e., $T = T(r, t)$, the equation reduces to

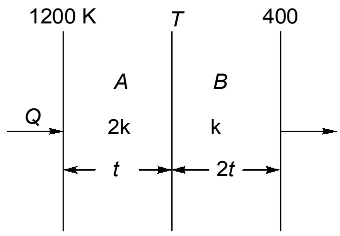
$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

We know that $\alpha = \dfrac{k}{\rho c_p}$ i.e., this equation can be re-written as

$$\rho c_p \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(rk\frac{\partial T}{\partial r}\right) \qquad \text{[Here, } n = 1\text{]}$$

11. (d)

For steady state condition:



$$\frac{-T+1200}{\left(\frac{t}{2k}\right)} = \frac{T-400}{\left(\frac{2t}{k}\right)}$$

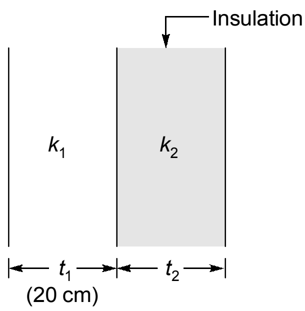
$$2(1200 - T) \times 2 = T - 400$$
$$4(1200 - T) = T - 400$$
$$4 \times 1200 - 4T = T - 400$$
$$5T = 4800 + 400 = 5200$$
$$T = 1040 \text{ K}$$
$$\Delta T_A = 1200 - 1040 = 160 \text{ K}$$

12. (b)

$$k_1 = 0.7 \text{ W/mK}$$
$$k_2 = 0.2 \text{ W/mK}$$

Heat transfer before insulation $\quad Q_1 = -k_1 A\dfrac{\Delta T}{t_1} = -k_1 A\left(\dfrac{\Delta T}{0.2}\right)$

After applying insulation, heat transfer decreases by 75%.



$$Q_2 = \frac{\Delta T}{\frac{0.2}{k_1 A} + \frac{t_2}{k_2 A}}$$

for unit area, $\quad A = 1 \text{ m}^2$

As given, $\quad Q_2 = 0.25\, Q_1$

$$\frac{\Delta T}{\frac{0.2}{0.7} + \frac{t_2}{0.2}} = \frac{\Delta T}{\left(\frac{0.2}{0.7}\right)} \times 0.25$$

$$\frac{t_2}{0.2} + \frac{0.2}{0.7} = \frac{8}{7}$$

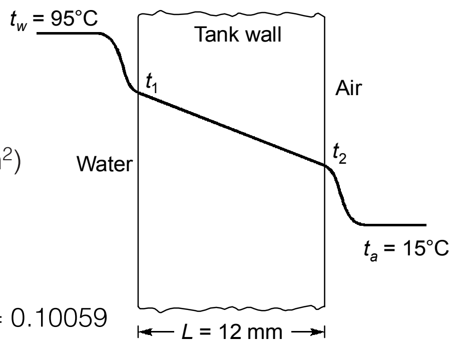
$$t_2 = \left(\frac{8}{7} - \frac{2}{7}\right)0.2 = \frac{6}{7} \times 0.2 = 0.17143 \text{ m or } 17.143 \text{ cm}$$

13. (c)

h_w (hot fluid) = 2850 W/m^2 K

h_a (cold fluid) = 10 W/m^{2}K

k (Thermal conductivity) = 50 W/mK



$$Q = U(t_w - t_a) \text{ (for } A = 1 \text{ m}^2)$$

$$\frac{1}{U} = \frac{1}{h_w} + \frac{L}{k} + \frac{1}{h_a}$$

$$= \frac{1}{2850} + \frac{0.012}{50} + \frac{1}{10} = 0.10059$$

$$U = \frac{1}{0.1006} = 9.9412 \text{ W/m}^2\text{K}$$

$$Q = 9.9412\,(95 - 15) = 9.9412 \times 80 = 795.3 \text{ W/m}^2$$

14. (a)

$$\text{Inner radius of pipe, } r_i = \frac{80}{2} = 40 \text{ mm} = 0.04 \text{ m}$$

$$\text{Outer radius of pipe, } r_o = \frac{100}{2} = 50 \text{ mm} = 0.05 \text{ m}$$

Temperature of hot gases, T_i = 160°C

Temperature of ambient, T_0 = 25°C

Thermal conductivity of pipe material, k = 180 W/mK

$$Q = \frac{\Delta T}{R_{th}} = \frac{T_i - T_0}{\frac{\ln(r_o / r_i)}{2\pi k L}} = \left[\frac{160 - 25}{\ln\left(\frac{0.05}{0.04}\right)}\right] \times 2\pi \times 180$$

$$= 684229 \text{ W} = 684.23 \text{ kW}$$

15. (c)

$$\text{Critical radius of insulation, } r_c = \frac{k}{h_a} = \frac{0.2}{15} \times 100 = 1.33 \text{ cm}$$

Critical thickness of insulation = 1.33 – 1 = 0.33 cm

16. (d)

General solution for the temperature distribution is

$$\theta = C_1 e^{-mx} + C_2 e^{mx}$$

where

$$m = \left(\frac{hP}{kA}\right)^{1/2}$$

At $x = 0$, $\theta = \theta_0$ and at $x = \infty$, $\theta = 0$

$$C_2 = 0, \; C_1 + C_2 = \theta_0$$

$$C_1 = \theta_0$$

$$\theta = C_1 e^{-mx} = \theta_0 e^{-mx}$$

Let l be the distance between the two points where the temperature are measured.

$$\theta_1 = \theta_0 e^{-mx_1} \text{ and } \theta_2 = \theta_0 e^{-mx_2}$$

$$\frac{\theta_1}{\theta_2} = e^{-m(x_1 - x_2)} = e^{m(x_2 - x_1)} = e^{ml}$$

$$\frac{130-25}{90-25} = \frac{105}{65} = 1.6154 = e^{ml}$$

$$ml = 0.4796$$

$$m = \frac{0.4796}{0.08} = 5.9946 = \left(\frac{hP}{kA}\right)^{1/2} = \left(\frac{h\pi d}{k\frac{\pi d^2}{4}}\right)^{1/2} = 2\times\sqrt{\frac{h}{kd}}$$

$$m^2 = 4\times\frac{h}{kd}$$

$$k = \frac{4h}{m^2 d} = \frac{4\times 23.36}{(5.9946)^2\times 0.025} = 104 \text{ W/mK}$$

17. (a)

Fin effectiveness is proportional to $\left(\frac{kP}{hA}\right)^{1/2}$

$\in_f \uparrow$ if $k\uparrow$

$\in_f \uparrow$ if $h\downarrow$

$\in_f \uparrow$ if $(P/A)\uparrow$

18. (b)

$$L = \frac{V}{A} = \frac{1}{6}\pi D^3 \times \frac{1}{\pi D^2} = \frac{D}{6}$$

$$\text{Biot number, } Bi = \frac{hL}{k} = \frac{hD}{6k} = \frac{400\times 0.8\times 10^{-3}}{6\times 20} = 2.67\times 10^{-3}$$

Here, $Bi < 0.1$. Therefore, lumped system analysis can be used

$$\frac{T-T_\infty}{T_i - T_\infty} = \exp\left[-\frac{hAt}{\rho CV}\right]$$

$$\frac{285-290}{25-290} = \exp\left[-\frac{400\times 6\times t}{8500\times 0.8\times 10^{-3}\times 400}\right]$$

$$0.018868 = \exp[-0.882353\, t]$$

$$\text{Time, } t = \frac{3.97}{0.882353} \approx 4.5 \text{ seconds}$$

19. (c)

Characteristic length of tube, L = diameter, D

$$\text{Nu} \propto \left[\frac{g\beta(T_W - T_\infty)L^3}{\nu^2}\right]^{0.25}$$

$$h \propto (L^{-1})(L^{0.75}) \qquad \left(\because Nu = \frac{hL}{k}\right)$$

$$h \propto L^{-0.25}$$

$$\propto D^{-0.25}$$

$$\frac{h_2}{h_1} = \left(\frac{D_2}{D_1}\right)^{-1/4} = \left(\frac{16}{4}\right)^{-1/4} = \frac{1}{\sqrt{2}}$$

$$h_2 = \frac{100}{\sqrt{2}} = 70.71 \text{ W/m}^2\text{K}$$

20. (b)

$$\text{Prandtl number, Pr} = \frac{\mu c_p}{k} = \frac{0.232 \times 10^{-4} \times 1005}{33.2 \times 10^{-3}} = 0.7023$$

$$T_{mean} = \frac{171 + 93.4}{2} = 132.2°\text{C} = 405.2 \text{ K}$$

$$\beta = \frac{1}{T_{mean}} = 2.47 \times 10^{-3} \text{K}^{-1}$$

$$\theta = T_W - T_\infty = 171 - 93.4 = 77.6°\text{C} = 77.6 \text{ K}$$

$$\rho = \frac{P}{RT} = \frac{101.325}{0.287 \times 405.2} = 0.8713 \text{ kg/m}^3$$

$$\nu = \frac{\mu}{\rho} = \frac{0.232 \times 10^{-4}}{0.8713} = 2.663 \times 10^{-5} \text{m}^2/\text{s}$$

$$\text{Gr} = \frac{g\beta\theta L^3}{\nu^2} = \frac{9.81 \times 2.47 \times 10^{-3} \times 77.6 \times (0.7)^3}{(2.663 \times 10^{-5})^2} = 9.0945 \times 10^8$$

$$\text{Nu} = 0.548\,(9.0945 \times 10^8 \times 0.7023)^{0.25} = 87.117$$

$$\frac{h_m L}{k} = 87.117$$

$$h_m = \frac{87.117 \times 33.2 \times 10^{-3}}{0.7} = 4.1318 \text{ W/m}^2\text{K}$$

21. (b)

$$\text{Reynolds number, Re} = \frac{\rho VD}{\mu} = \frac{950 \times 2 \times 0.035}{2.55 \times 10^{-4}} = 2.6 \times 10^5 > 2100 \text{ (for tube/pipe flow)}$$

So, the flow is turbulent.

$$\text{Nu} = \frac{hD}{k} = 0.023(\text{Re})^{0.8}(\text{Pr})^{0.4} = 0.023(2.6 \times 10^5)^{0.8}\left(\frac{2.55 \times 10^{-4} \times 4.23 \times 10^3}{0.685}\right)^{0.4}$$

$$= 0.023 \times 21529.065 \times 1.19916 = 593.786$$

$$h = \frac{593.786 \times 0.685}{0.035} = 11.62 \times 10^3 \text{ W/m}^2\text{K}$$

23. (b)

$$\text{Nu} = \frac{hD}{k} = 3.66 \quad \text{(for uniform wall temperature)}$$

$$h = 3.66\frac{k}{D} = \frac{3.66 \times 0.175}{0.006} = 106.75 \text{ W/m}^2\text{K}$$

24. (a)

$$Q = A_1 F_{12}(E_{b1} - E_{b2}) = \sigma A_1 F_{12}(T_1^4 - T_2^4)$$

$$= 5.67 \times 10^{-8} \times 1 \times 0.415\,[(900 + 273)^4 - (400 + 273)^4]$$

$$= 3.97 \times 10^4 = 39.7 \text{ kW}$$

25. (b)

$$A_1 F_{12} = A_2 F_{21}$$
$$F_{22} + F_{21} = 1 \Rightarrow F_{21} = 1 \quad (\text{because } F_{22} = 0)$$
$$F_{12} = \frac{A_2}{A_1} = \frac{4\pi a^2}{4\pi b^2} = \left(\frac{a}{b}\right)^2$$
$$F_{11} + F_{12} = 1$$
$$F_{11} = 1 - F_{12} = 1 - \left(\frac{a}{b}\right)^2$$

26. (b)

(i) Glass is transparent at short wavelengths

(ii) Thermal radiation wavelength range – 0.1 to 100 μm

27. (c)

The ratio of radiant energy transfer without and with shield is given by $\dfrac{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_s} - 1\right) + \left(\frac{1}{\epsilon_s} + \frac{1}{\epsilon_2} - 1\right)}$

We have $\epsilon_1 = \epsilon_2 = 0.5$, $\epsilon_s = 0.25$

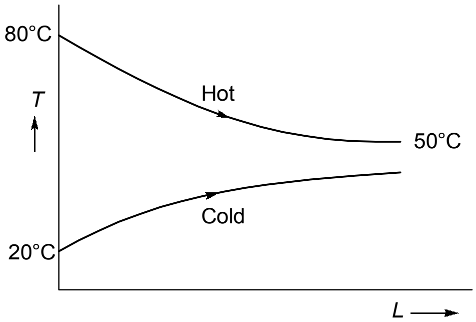
$$\frac{Q_1}{Q_2} = \frac{\left(\frac{1}{0.5} + \frac{1}{0.5} - 1\right)}{\left(\frac{1}{0.5} + \frac{1}{0.25} - 1\right) + \left(\frac{1}{0.5} + \frac{1}{0.25} - 1\right)} = \frac{3}{(2+4-1)+(2+4-1)} = \frac{3}{10}$$

28. (a)

$Q_H = 0.01$ m^3/min; $Q_C = 0.05$ m^3/min; $\rho_C = 800$ kg/m^3; $\rho_H = 1000$ kg/m^3; $c_{PC} = 2$ kJ/kgK = 2000 J/kgK

$c_{PH} = 4180$ J/kgK

For steady state heat balance:



$$\dot{m}_H c_{PH}(T_{H1} - T_{H2}) = \dot{m}_C c_{PC}(T_{C1} - T_{C2})$$
$$1000 \times 0.01 \times 4180\,(80 - 50) = 800 \times 0.05 \times 200\,(T_{C2} - 20)$$
$$T_{C2} = 35.675°\text{C}$$
$$\Delta T_1 = 80 - 20 = 60°\text{C}$$
$$\Delta T_2 = 50 - 35.675 = 14.325°\text{C}$$
$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{60 - 14.325}{\ln\left(\frac{60}{14.325}\right)} \approx 32°\text{C}$$

29. (b)

$$\frac{1}{U_o'} = \frac{1}{U_o} + R_f$$
$$\frac{1}{U_o'} = \frac{1}{400} + 0.0005$$
$$U_o' = 333.33 \text{ W/m}^2\text{K}$$

30. (b)

$$\epsilon = \frac{1 - \exp[-N(1-C)]}{1 - C\exp[-N(1-C)]}, \qquad \epsilon = \frac{N}{1+N} \text{ when } C = 1$$
$$\epsilon = \frac{0.6}{1.6} = 0.375$$

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