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CLASS TEST

MECHANICAL ENGINEERING

Date of Test : 07/10/2021

ANSWER KEY ➤ Heat Mass Transfer

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

DETAILED EXPLANATIONS

1. **(a)**

When internal resistance (due to conduction) is less than 10% of surface (convection) resistance.

i.e. $$Bi < 0.1$$

$$\frac{\text{Internal resistance}}{\text{Surface resistance}} < 0.1$$

i.e $$\text{Internal resistance} < 10\% \text{ of surface resistance}$$

2. **(a)**

$$\frac{\delta_t}{\delta} = \frac{1}{1.0246}(\text{Pr})^{-1/3}$$

$$\frac{\delta_t}{2} = \frac{1}{1.0246}(2.54)^{-1/3}$$

$$\delta_t = 1.43 \text{ mm}$$

3. **(d)**

Since, $\text{Re} < 2300$ i.e. flow is laminar in pipe

for laminar flow in a pipe with constant wall temperature.

$$\text{Nu} = 3.66$$

also $$\text{Nu} = \frac{hD}{k},\ h = \frac{Nu \cdot \text{k}}{D} = \frac{3.66 \times 5}{0.2} = 91.5 \text{ W/m}^2\text{K}$$

4. **(b)**

$$\in = \frac{mk}{h}$$

and if $$h > mk$$

$$\in < 1$$

5. **(c)**

Both conduction and convection resistance increases.

6. **(d)**

$$F_{11} = 0 \qquad [\therefore F_{12} = 1]$$

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

$$F_{21} = \frac{\pi d_1 l}{\pi d_2 l} = \frac{d_1}{d_2}$$

A = curved surface area, a = cross-sectional area

$$\frac{a_1}{a_2} = \left(\frac{d_1}{d_2}\right)^2$$

$$\left(\frac{100\pi}{625\pi}\right)^{1/2} = \frac{d_1}{d_2}$$

$$\frac{d_1}{d_2} = 0.4$$

also

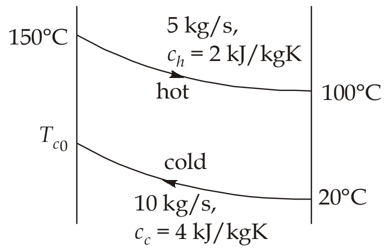
$$F_{21} + F_{22} = 1$$
$$F_{22} = 1 - 0.4 = 0.6$$
$$F_{22} = 0.6$$

7. (d)

$$\text{Space resistance} = \frac{1}{A_1 F_{12}}$$

Since shape factor is unit less i.e. unit of space resistance m^{-2}.

8. (d)



From energy balance,

$$Q_{hot} = Q_{cold}$$
$$m_h \cdot c_h \cdot (T_{hi} - T_{ho}) = m_c \cdot c_c \cdot (T_{co} - T_{ci})$$
$$5 \times 2 \times (150 - 100) = 10 \times 4 \times (T_{co} - 20)$$
$$T_{co} = 32.5°$$

9. (a)

Uses Wien's displacement law of radiation for temperature measurement.

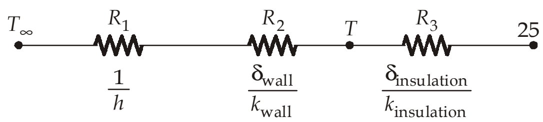
$$\lambda_{max.}\ T = 2900\ \mu\text{m K}$$

10. (a)

Heat transfer will take place between man and fire. Air is at less temperature from both fire and man but it has no effect on the radiation heat transfer between man and fire. Because air has transmissivity 1.

11. (a)

Let the interface temperature in T. So equivalent electric circuit



Since there is series convection between the thermal resistance so,

$$\frac{T_\infty - T}{R_1 + R_2} = \frac{T - T_{insulation}}{R_3}$$

$$\frac{700 - T}{\frac{1}{100} + \frac{0.2}{2}} = \frac{T - 25}{\frac{0.03}{0.008}}$$

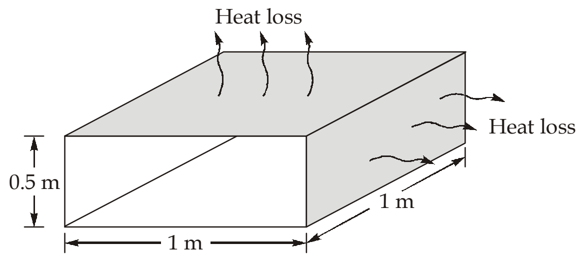
$$T = 680.76°\text{C}$$

12. (b)

$$\text{Equivalent length, } L = \frac{4A}{P} = \frac{4 \times 1 \times 0.5}{2(1+0.5)} = 0.667 \text{ m}$$

$$Re = \frac{\rho VL}{\mu} = \frac{1.2 \times 20 \times 0.667}{18 \times 10^{-6}} = 8.893 \times 10^5$$

Since $Re > 4000$



Flow is turbulent, $Nu = \frac{hL}{k} = 0.023\text{Re}^{0.8}\text{Pr}^{0.33}$

$$\frac{h \times 0.667}{0.025} = 0.023(8.893 \times 10^5)^{0.8} \times (0.73)^{0.33}$$

$$h = 44.64 \text{ W/m}^2\text{K}$$

$$Q = hA_{\text{side}} \times (T - T_\infty)$$

$$= 44.64 \times 2 \times (1 + 0.5) \times 1 \times (30 - 20)$$

$$Q = 1339 \text{ W}$$

13. (d)

In lumped analysis temperature variation is given by

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-\frac{hA}{\rho vc}\tau} \quad \text{...(i)}$$

Given equation, $T = A + Be^{C\tau}$

$$\frac{T - A}{B} = e^{C\tau} \quad \text{...(ii)}$$

Compare (i) and (ii)

$$A = T_\infty,\ B = T_i - T_\infty$$

$$C = \frac{-hA}{\rho vc}$$

Now time constant is given by

$$\tau^* = \frac{\rho vc}{hA}$$

$$\therefore \quad \tau^* = \frac{-1}{C}$$

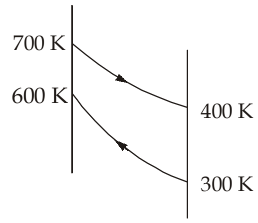
14. (c)

Since in a regeneration system of gas turbine there is same fluid (air) on both side with approximately same mass flow rate and specific heat,

$$C_h = C_c = C_{min}$$
$$C_h(T_{hi} - T_{ho}) = C_c(T_{co} - T_{ci})$$
$$700 - 400 = T_{co} - 300$$
$$T_{co} = 600\,\text{K} \qquad \text{(i.e. counter flow)}$$
$$\varepsilon = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}} = \frac{700 - 400}{700 - 300} = 0.75$$

Now,
$$\varepsilon = \frac{NTU}{1 + NTU}$$
$$0.75 = \frac{NTU}{1 + NTU}$$
$$\text{NTU} = 3$$

or
$$\frac{UA}{C_{min}} = \text{NTU} = 3$$
$$A = \frac{3 \times 1 \times 10^3 \times 0.1}{30} = 10\ \text{m}^2$$



Counter flow is choosen because cold fluid exit temperature (600 K) is greater than hot fluid exit temperature (400 K)

15. (a)

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{4h}{kd}} \qquad \text{(Cylinder)}$$
$$= \sqrt{\frac{4 \times 15}{50 \times 0.15}} = 2.83\ \text{m}^{-1}$$
$$L_c = L + \frac{d}{4} = 100 + \frac{15}{4} \Rightarrow 103.75\ \text{cm}$$
$$Q = mkA.\theta_0.\tanh(mL_c)$$
$$75 = 2.83 \times 50 \times \frac{\pi}{4} \times 0.15^2 \times (T - 25) \times \tan h(2.83 \times 103.75 \times 10^{-2})$$
$$T = 55.17°\text{C}$$

16. (a)

$$Ra = Gr.\text{Pr} = \frac{g\beta\Delta T \cdot L_e^3}{\nu^2} \cdot \text{Pr}$$
$$\beta = \frac{1}{T_f}, \qquad T_f = \frac{20 + 140}{2} = 80°\text{C}$$
$$\Delta T = 140 - 20 = 120°\text{C}$$

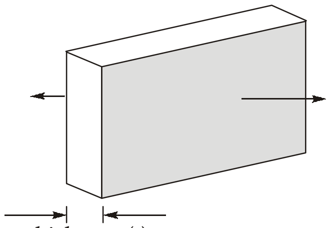
or
$$\beta = \frac{1}{80 + 273} \cdot K^{-1} = \frac{1}{353}$$

Now,
$$Ra = \frac{9.81 \times \frac{1}{353} \times 120 \times (0.15)^3}{(21.09 \times 10^{-6})^2} \times 0.692 = 17510650, < 10^9$$
$$\text{Nu} = 0.59 \times (17510650)^{1/4} = 38.17 = \frac{hL_c}{k}$$
$$h = \frac{38.17 \times 0.03}{0.15} = 7.63\ \text{W/m}^2\text{K}$$

So,
$$Q_c = h(2A)\Delta T = 7.63 \times (2 \times 0.15 \times 0.1) \times 120$$
$$Q_c = 27.48\ \text{Watt}$$

17. (d)

Characteristic length (s) = (V/A)



$$s = \frac{A \cdot t}{2A}$$

$$s = \frac{t}{2}$$

$\Rightarrow$ $$s = \frac{30}{2} = 15 \text{ mm}$$

Now, $$\frac{T - T_\infty}{T_i - T_\infty} = e^{\frac{-hA}{\rho vc}\tau} = e^{\frac{-h\tau}{\rho sc}}$$

$$\frac{50-25}{225-25} = e^{\frac{-320\times\tau}{2790\times15\times10^{-3}\times0.88\times10^{3}}}$$

$$\tau = 239.32 \text{ sec}$$

18. (c)

From Plank's law spectral emissive power,

$$E_{d\lambda} = \frac{C_1\lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right)-1}$$

where $C_1 = 2\pi c^2 h = 3.74 \times 10^8 \text{ W } (\mu\text{m})^4/\text{m}^2$

$$C_2 = \frac{hc}{k} = 1.439 \times 10^4 \ \mu\text{m-K}$$

here, $\lambda = 3 \ \mu\text{m}$, $T = 800$ K

$$E_{b\lambda} = \frac{3.74\times10^8 \left(W\mu\text{m}^4/\text{m}^2\right)\times(3\mu\text{m})^{-5}}{\exp\left(\frac{1.439\times10^4 \mu m - K}{(3\mu m)(800K)}\right)-1}$$

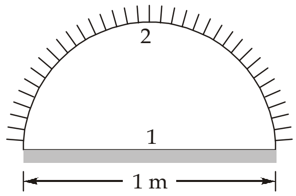
$$E_{b\lambda} = 3840 \text{ W/m}^2 - \mu\text{m}$$

Option (a) is not correct because

$$\text{W/m}^2 - \mu\text{m} \neq \text{MW/m}^3$$

19. (b)

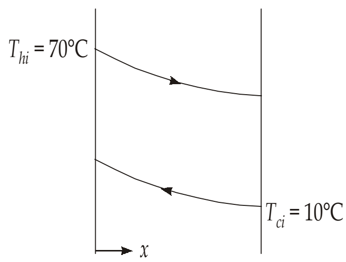
$$T_1 = 700 \text{ K} \qquad T_2 = 1000 \text{ K}$$
$$\epsilon_1 = 0.5 \qquad \epsilon_2 = 0.25$$
$$A_1 = \frac{\pi}{4}\times d^2 \qquad A_2 = \frac{\pi d^2}{2} \qquad [F_{12} = 1]$$
$$Q_{21} = \frac{\sigma(T_2^4 - T_1^4)}{\frac{1-\epsilon_1}{A_1\epsilon_1} + \frac{1-\epsilon_2}{A_2\epsilon_2} + \frac{1}{A_1F_{12}}} \text{ or } \frac{\sigma(T_2^4 - T_1^4)A_1}{\frac{1-\epsilon_1}{\epsilon_1} + \frac{A_1}{A_2}\left(\frac{1-\epsilon_2}{\epsilon_2}\right)+1}$$
$$\frac{A_1}{A_2} = \frac{\pi d^2/4}{\pi d^2/2} \Rightarrow \left(\frac{1}{2}\right)$$



$$A_1 = \frac{\pi}{4}\times 1^2 \Rightarrow 0.785 \text{ m}^2$$
$$Q_{21} = \frac{5.67\times10^{-8}(1000^4 - 700^4)\times 0.785}{\frac{1-0.5}{0.5} + \frac{1}{2}\left(\frac{1-0.25}{0.25}\right)+1}$$
$$= 9663 = 9.66 \text{ kW}$$

20. (b)

$$T_{hi} = 70°\text{C}, \ \dot{m}_h = 2 \text{ kg/s}, \ c_h = 4.18 \text{ kJ/kgK},$$
$$T_{ci} = 10°\text{C}, \ \dot{m}_c = 8 \text{ kg/s}, \ c_c = 4.18 \text{ kJ/kg-K}$$
$$C_h = \dot{m}_h \times c_h = 2 \times 4.18 = 8.36 \text{ kW/K}$$
$$C_c = \dot{m}_c \times c_c = 8 \times 4.18 = 33.44 \text{ kW/K}$$



Therefore, $C_{min} = C_h = 8.36 \text{ kW/K}$

Now $Q_{max} = C_h(T_{hi} - T_{ci}) = 8.36(70 - 10)$

$$Q_{max} = 501.6 \text{ kW}$$
$$Q_{max} = Q_h = Q_c = C_c(T_{co} - T_{ci})$$
$$501.6 = 33.44(T_{co} - 10)$$
$$T_{co} = 25°\text{C}$$

21. (b)

$$Bi = \left(\frac{hS}{k}\right)$$
$$s = \frac{t}{2} \qquad \text{[characteristic length for plate]}$$
$$Bi = \frac{500\times0.025}{60} = 0.2083$$
$$Bi > 0.1 \qquad \text{Lumped analysis is not valid.}$$
$$\frac{1}{Bi} = 4.8$$
$$Fo = \frac{\alpha\tau}{s^2} = \frac{1.5\times10^{-5}\times180}{(0.025)^2} = 4.32$$

from interpolation:

$$R = 0.5 + \frac{0.5-0.4}{4-5}(4.32-4)$$

$$R = 0.468$$

R = centerline temperature ratio

$$\frac{T_c - T_\infty}{T_i - T_\infty} = R$$

$$\frac{T_c - 25}{225-25} = 0.468$$

$$T_c = 118.6°C$$

22. (b)

$$\frac{\partial^2 T}{\partial x^2} + \frac{\dot{q}}{k} = \frac{1}{\alpha}\left(\frac{\partial T}{\partial \tau}\right)$$

$$\alpha = \left(\frac{k}{\rho c}\right) = \frac{40}{1600 \times 3000}$$

$$= 8.33 \times 10^{-6} \text{ m}^2/\text{s}$$

$$\left(\frac{\partial T}{\partial \tau}\right) = \alpha\left\{\frac{\partial^2 T}{\partial x^2} + \frac{\dot{q}}{k}\right\} = \alpha\left\{(-100) + \frac{1000}{40}\right\}$$

$$\left(\frac{\partial T}{\partial \tau}\right) = -75\alpha$$

Rate of change of internal energy $= mc\dfrac{\partial T}{\partial \tau}$

$= 1600 \times 1 \times 1 \times 3000 \times (-75\alpha)$

$= -1600 \times 3000 \times 75 \times 8.33 \times 10^{-6}$

$= -2998.8$ J/s per m^2 cross-section

$\simeq 3$ kJ/s (decreasing)

23. (c)

$$\lambda_1 T = 0.40 \times 5800 = 2320 \ \mu\text{m-K}$$

So, f_1 from interporation

$$f_1 = \frac{0.140256 - 0.100888}{200} \times (2320 - 2200) + 0.100888$$

$$f_1 = 0.124509$$

also $\lambda_2 T = 0.76 \times 5800 = 4408 \ \mu\text{m K}$

$$f_2 = 0.550049$$

fraction of visible radiation emitted by sun is

$$f = f_2 - f_1$$

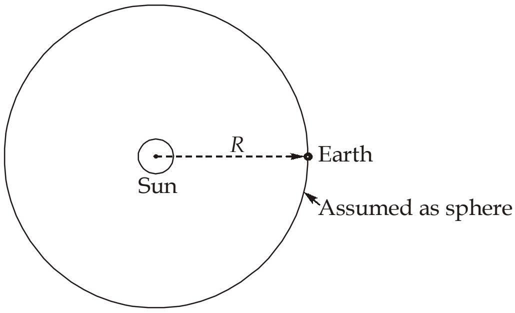
$$= 0.550049 - 0.124509$$

$$f = 0.4256$$

or $f_{\lambda 1 - \lambda 2} = 42.56\%$

24. (b)

$$Q_{sun} = 1.4 \times 4\pi R^2 \text{ kW}$$



Total radiation emitted by sun;

$$Q_{sun} = \sigma \times 4\pi r^2 . T^4 \text{ W} \qquad (r \text{ is the radius of sun})$$

So, $\sigma \times 4\pi r^2 . T^4 = 1.4 \times 4\pi R^2 \times 10^3$ W

$$T^4 = \left(\frac{R}{r}\right)^2 \times \frac{1.4}{\sigma} \times 10^3 = (216)^2 \times \frac{1.4 \times 10^3}{5.67 \times 10^{-8}}$$

$$T = 5825.9 \text{ K}$$

or $T = 5825.9 - 273 = 5552.9°\text{C}$

25. (a)

Given: d_0 = 30 cm, L = 170 cm, h = 8 W/m^{2}K, k = 7 W/mK

$$s = \frac{\pi r_0^2 L}{2\pi r_0 L + 2\pi r_0^2}$$

$$s = \frac{\pi \times 0.15^2 \times 1.7}{2\pi \times 0.15 \times 1.7 + 2\pi \times 0.15^2}$$

$$s = 0.0689 \text{ m}$$

$$Bi = \frac{hs}{k} = \frac{8 \times 0.0689}{7} = 0.0787$$

lumped analysis is valid,

$$\frac{ht}{\rho sc} = \ln\left[\frac{37-20}{26-20}\right]$$

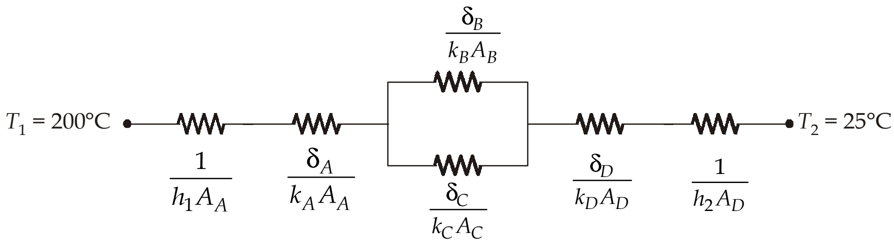
$$t = \frac{1.0414 \times 1000 \times 0.0689 \times 4180}{8} = 37492 \text{ second}$$

or t = 10.41 hours = 10 hours 25 minutes before

i.e. died at 12 : 00 – (10 : 25 – 6 : 00) PM = 7 : 35 pm yesterday

26. (a)

Equivalent electric circuit,



i.e.
$$R_{\text{thermal}} = \frac{1}{h_1 A_A} + \frac{\delta_A}{k_A A_A} + \frac{\delta_B}{k_B \times A_B + K_c \times A_c} + \frac{\delta_D}{k_D \times A_D} + \frac{1}{h_2 \times A_D}$$

$$= \frac{1}{50\times3} + \frac{0.05}{50\times3} + \frac{0.1}{(10\times1.5+1\times1.5)} + \frac{0.05}{50\times3} + \frac{1}{10\times3}$$

$$R_{\text{th}} = 0.0467 \text{ K/W per unit width}$$

So,
$$Q = \frac{\Delta T}{R_{\text{thermal}}} = \frac{200-25}{0.0467} = 3747 \text{ W/m} = 3.75 \text{ kW per unit width.}$$

27. (a)

Statement 1 is correct but statement 2 is incorrect, it depends on matter which type of phenomenon is taking place.

Volumetric phenomenon = gas, semi transparent solids

Surface phenomenon = solids and liquids

28. (a)

Given:
$$d = 30 \text{ mm}, L = 700 \text{ mm},$$
$$T_\infty = 25°C, T_0 = 600°C$$
$$h = 20 \text{ W/m}^2\text{K}, k = 132.3 \text{ W/mK}$$
$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{4h}{kd}} \qquad \text{(for cylinder)}$$
$$m = \sqrt{\frac{4\times20}{132.3\times0.03}} = 4.49$$

Steady state rate of heat lost,
$$q = \sqrt{hPkA} \times \theta_0 \times \tan h(\text{mL})$$
$$\sqrt{hPkA} = \sqrt{20\times(\pi\times0.03)\times132.3\times(\pi\times0.25\times0.03^2)} = 0.4199$$
$$\tan h(mL) = \tan h(4.49 \times 0.7) = 0.9963$$
$$\dot{q} = 0.4199 \times 0.9963 \times (600 - 25)$$
$$\dot{q} = 240.57 \text{ W}$$

Heat lost in one minute $= \dot{q}\,.t = 240.57 \times 60 \times 10^{-3} \text{ kJ} = 14.43 \text{ kJ}$

29. (a)

$$D = 20 \text{ mm}, \rho = 978 \text{ kg/m}^3, \mu = 4 \times 10^{-4} \text{ kg/m-s}, \text{Pr} = 2.54,$$

$$\text{Re} = \frac{\rho VD}{\mu} = \frac{978 \times 2 \times 0.02}{4 \times 10^{-4}} \Rightarrow \text{Re} = 97800$$

$\therefore$ Re > 2300 flow is turbulent

Using Dittus Boltier equation,

$$\text{Nu} = 0.023(\text{Re})^{0.8}(\text{Pr})^{0.4}$$

$$\frac{h_i d}{k} = 0.023(97800)^{0.8}(2.54)^{0.4}$$

$$h_i = 328.04 \times \frac{0.332}{0.02} = 5445.5 \text{ W/m}^2\text{K}$$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_0} = \frac{1}{5445.5} + \frac{1}{10000}$$

$$U = 3525.6 \text{ W/m}^2\text{K}$$

30. (a)

For solid sphere, with internal heat generation temperature at center in maximum and given by

$$T_{\max} = T_{\text{center}} = T_w + \frac{q}{6k}R^2 = 18 + \frac{5100}{6 \times 0.23} \times \left(\frac{0.090}{2}\right)^2$$

$$= 25.48°\text{C}$$

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