CLASS TEST

S.No. 01SPME-ABCD-27072023

MADE EASY

India's Best Institute for IES, GATE & PSUs

Delhi | Bhopal | Hyderabad | Jaipur | Pune | Bhubaneswar | Kolkata

Web: www.madeeasy.in | **E-mail:** info@madeeasy.in | **Ph:** 011-45124612

HEAT TRANSFER

MECHANICAL ENGINEERING

Date of Test : 27/07/2023

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (d)

$$\eta = \frac{Q_{\text{actual}}}{Q_{\text{ideal}}} = \frac{\sqrt{hPkA}\,(T_b - T_\infty)}{hA_{\text{fin}}\,(T_b - T_\infty)} = \frac{\sqrt{hPkA}}{hPL} = \frac{1}{L}\sqrt{\frac{kA}{hP}}$$

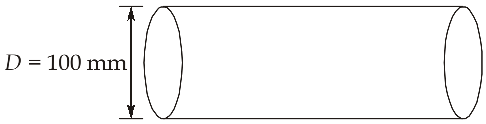
For circular fin

$$A = \frac{\pi}{4}d^2$$

$$P = \pi d$$

$$\eta = \frac{1}{L}\sqrt{\frac{kd}{4h}} = \frac{1}{2L}\sqrt{\frac{kd}{h}}$$

2. (d)



Diameter of steel pipe, D = 100 mm

Nusselt number, Nu = 20

Thermal conductivity, k = 0.06 W/mK

For horizontal pipe, $\text{Nu} = \frac{hD}{k}$

$$\Rightarrow \quad 20 = \frac{h \times 0.1}{0.06}$$

Heat transfer coefficient, h= 12 W/m^{2}K

3. (a)

$$\nu < \alpha$$

$$\text{Pr} = \frac{\nu}{\alpha}, \text{ so Pr} < 1$$

For Pr < 1, $\frac{\delta_t}{\delta_v} > 1$

$$\delta_t > \delta_v \text{ or } \delta_v < \delta_t$$

4. (d)

5. (d)

Critical radius of insulation, $r_c = \frac{k}{h_o}$

$$= \frac{0.5}{10} = 0.05 \text{ m} = 50 \text{ mm}$$

Maximum value of heat dissipation rate,

$$q_{max} = \frac{\Delta T}{\frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi kL} + \frac{1}{hA_o}} = \frac{100-25}{\frac{\ln(50/0.5)}{2\pi\times 0.5\times 1} + \frac{1}{2\pi\times\frac{50}{1000}\times 1\times 10}} = 42.036 \text{ W/m}$$

6. (a)

Heat transfer rate through composite structural wall, $q_1 = -k_1 A\frac{\Delta T}{\delta_1} = -0.2A\frac{\Delta T}{0.09}$

Heat transfer rate through masonry wall,

$$q_2 = -k_2 A\frac{\Delta T}{\delta_2} = -0.7A\times\frac{\Delta T}{\delta_2}$$

As per given condition,

$$q_2 = 0.6q_1$$

$$\Rightarrow \quad -0.7A\times\frac{\Delta T}{\delta_2} = 0.6\times\left(-0.2A\times\frac{\Delta T}{0.09}\right)$$

$$\delta_2 = 0.525 \text{ m} = 525 \text{ mm}$$

7. (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.

8. (a)

$$\frac{k_Q[100-T]A}{l} = \frac{k_P[T-0]A}{l}$$

$$k_P = 4\,k_Q$$

$$100 - T = 4T$$

$$5T = 100$$

$$T = 20°\text{C}$$

9. **(c)**

$$\text{Reflectivity, } \rho = 0.4$$

For opaque body,

$$\alpha + \rho = 1$$

$$\alpha + 0.4 = 1$$

$$\text{Absorptivity, } \alpha = 0.6 = \frac{G_{abs}}{G} = \frac{G_{abs}}{600}$$

Part of radiation absorbed,

$$G_{\text{abs}} = 0.6 \times 600 = 360 \text{ W/m}^2$$

10. **(d)**

For infinitely long fin,

$$\dot{q} = \sqrt{hPkA}\,(T_b - T_\infty)$$

$$\text{For circular fin, } P = \pi D$$

$$A = \frac{\pi}{4}D^2$$

So,

$$\dot{q} = \sqrt{h \times \pi D \times k \times \frac{\pi}{4}D^2}\,(T_b - T_\infty)$$

$$\dot{q} \propto \sqrt{k}D^{3/2}$$

$$\frac{\dot{q}_1}{\dot{q}_2} = \frac{\sqrt{k_1}}{\sqrt{k_2}}\frac{D_1^{3/2}}{D_2^{3/2}} = \left(\frac{400}{250}\right)^{1/2}\left(\frac{D}{0.4D}\right)^{3/2} = 5$$

11. **(b)**

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt}$$

$$\Rightarrow \quad \frac{\dfrac{T_i + T_\infty}{2} - T_\infty}{T_i - T_\infty} = e^{-bt}$$

$$\Rightarrow \quad \frac{1}{2} = e^{-bt}$$

Where

$$b = \frac{1}{\tau}$$

$$\text{Time required, } t = \frac{\ln 2}{b}$$

$$= \tau \ln 2 = 10 \times 0.693 = 6.93 \text{ s}$$

12. **(c)**

Mass flow rate of air, $\dot{m}_h = 1$ kg/s

Specific heat at constant pressure of air, $c_{ph} = 1.005$ kJ/kgK

$$\dot{m}_h c_{ph} = 1 \times 1.005 = 1.005 \text{ kW/K}$$

Mass flow-rate of water, $\dot{m}_c = 2$ kg/s

$$c_{pc} = 4.18 \text{ kJ/kgK}$$

$$\dot{m}_c c_{pc} = 2 \times 4.18 = 8.36 \text{ kW/K}$$

Since, $\dot{m}_h c_{ph} < \dot{m}_c c_{pc}$

$$C_{min} = \dot{m}_h c_{ph} = 1.005 \text{ kW/K}$$

Maximum heat transfer rate,

$$q_{max} = C_{min}(T_{hi} - T_{ci})$$
$$= 1.005 \times (80 - 15) = 65.325 \text{ kW}$$

13. (c)

Case I : $$Re_1 = \frac{V_1 L_1}{\nu_1} = \frac{100 \times 1}{\nu_1} = \frac{100}{\nu_1}$$

Case II : $$Re_2 = \frac{V_2 L_2}{\nu_2} = \frac{20 \times 5}{\nu_2} = \frac{100}{\nu_2}$$

For same fluid $\nu_1 = \nu_2$ and $Pr_1 = Pr_2$

We know that Nusselt number,

$$\text{Nu} = f(Re, Pr)$$

So, $$Nu_1 = Nu_2$$

$$\frac{h_1 L_1}{k_1} = \frac{h_2 L_2}{k_2}$$

$$h_2 = \frac{h_1 \times L_1}{L_2} \qquad (K_1 = K_2)$$

Case I : $$q''_1 = h_1(T_S - T_\infty)$$

$$\frac{20,000}{(400 - 300)} = h_1$$

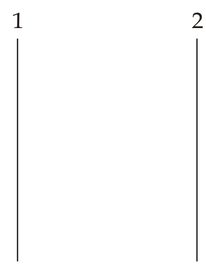
$$h_1 = 200 \text{ W/m}^2\text{K}$$

So, $$h_2 = \frac{200 \times 1}{5} = 40 \text{ W/m}^2\text{K}$$

14. (b)

Without shield

Radiation heat transfer rate,

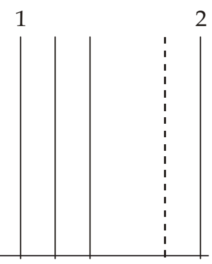


$$q = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Let number of shields be N.

With shield

Radiation heat transfer rate,



$$q' = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right) + N\left(\frac{2}{\varepsilon} - 1\right)}$$

Shields

As per the conditions,

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

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

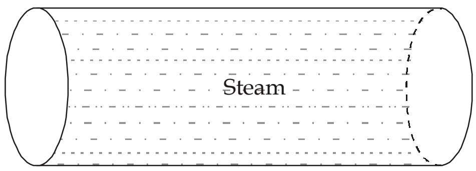
$$\frac{\left(\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1\right)+N\left(\frac{2}{\varepsilon}-1\right)}{\left(\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1\right)} = 10$$

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

Number of shields, $N = 2.925$

$$N \simeq 3$$

15. (a)



Heat transfer rate due to radiation,

$$q = \varepsilon\sigma(T_1^4 - T_2^4)$$
$$= 0.8 \times 5.67 \times 10^{-8} \times [(200 + 273)^4 - (25 + 273)^4] = 1912.7638 \text{ W/m}^2$$
$$= h_r(T_1 - T_2)$$

where, h_r = Radiation heat transfer coefficient

$\Rightarrow$ $1912.7638 = h_r \times (200 - 25)$

$$h_r = 10.93 \text{ W/m}^2\text{K}$$

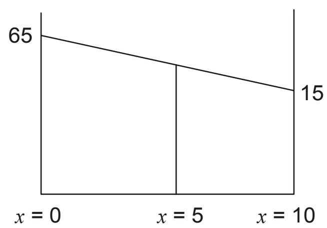
Convection heat transfer coefficient

$$h_c = 6 \text{ W/m}^2\text{-K}$$

So, combined heat transfer coefficient

$$= h_r + h_c = 10.93 + 6 = 16.93 \text{ W/m}^2\text{-K}$$

16. (b)



$$T - 65 = \frac{15-65}{10-0}[x-0]$$

$$T = 65 - \frac{50}{10}x$$

$$T = 65 - 5x$$

at $$x = 5 \text{ m}$$

$$T = 65 - 25 = 40°\text{C}$$

17. (b)

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

$$F_{21} = \frac{A_1}{A_2} \times F_{12} = \frac{\pi\left(0.75^2 - \left(\frac{0.25}{2}\right)^2\right)}{2\pi \times (0.75)^2} \times F_{12}$$

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

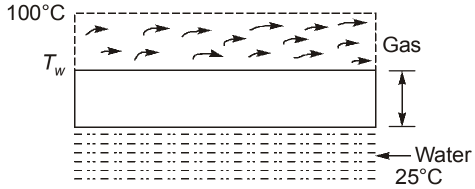
$$F_{1-1} = 0 \qquad \text{and } F_{1-3} = 0$$

$\therefore$ $$F_{12} = 1$$

$$F_{21} = \frac{\pi(0.75^2 - 0.125^2)}{2\pi \times 0.75 \times 0.75}$$

$$F_{21} = 0.486$$

18. (a)



$$\text{Rate of heat transfer} = \frac{T_g - T_w}{\Sigma R}$$

$$\Sigma R = \frac{1}{h_g} + \frac{L}{k} + \frac{1}{h_w} = \frac{1}{14500} + \frac{4 \times 10^{-3}}{95.5} + \frac{1}{2250}$$

$$\Sigma R = 5.553 \times 10^{-4} \text{ m}^2\text{K/W}$$

$$Q = \frac{100 - 25}{5.553 \times 10^{-4}} = 135063.4 \text{ W/m}^2$$

$$Q = (T_g - T_p)h_g$$

$$135063.4 = [100 - T_p]14500$$

$$T_p = 90.7°\text{C}$$

19. (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

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

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

20. (b)

For steady state, $$\frac{\partial T}{\partial t} = 0$$

$$\therefore \quad 0 = \frac{1}{r}\frac{\partial}{\partial r}\left(r \cdot \frac{\partial T}{\partial r}\right) + q$$

$$\frac{\partial}{\partial r}\left(r \cdot \frac{\partial T}{\partial r}\right) = -q \cdot r$$

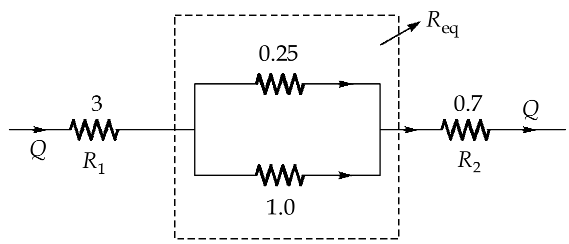
On integration,

$$r \cdot \left(\frac{\partial T}{\partial r}\right) = \frac{-qr^2}{2} + A$$

$$\frac{\partial T}{\partial r} = \frac{-qr}{2} + \frac{A}{r}$$

$$T(r) = \frac{-qr^2}{4} + A \ln r + B$$

21. (a)



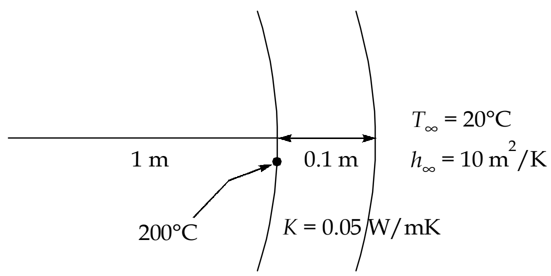
$$\frac{1}{R_{eq}} = \frac{1}{0.25} + \frac{1}{1}$$

$$R_{eq} = 0.2$$

$$R_{total} = R_1 + R_{eq} + R_2$$

$$R_{total} = 3 + 0.2 + 0.7 = 3.9$$

22. (b)



From steady state heat transfer,

$$\frac{200-T}{\dfrac{\ln\left(\dfrac{r_2}{r_1}\right)}{2\pi KL}} = \frac{T-20}{\dfrac{1}{h2\pi r_2 L}}$$

$$\frac{200-T}{\dfrac{\ln\left(\dfrac{1.1}{1}\right)}{2\pi\times 0.05}} = \frac{T-20}{\dfrac{1}{10\times 2\pi\times 1.1}}$$

$$T = 28.1936°C$$

23. (a)

$$\text{Initially, } T_H = 1850 + 273 = 2123 \text{ K}$$

$$Q = 25 \text{ W}, T_L = 500 + 273 = 773 \text{ K}$$

$$25 = \sigma\cdot A\left(T_H^4 - T_L^4\right)$$

$$25 = \sigma\cdot A\left(2123^4 - 773^4\right)$$

$$\sigma\cdot A = \frac{25}{(2123^4 - 773^4)}$$

$$\text{After some time, } T_H = 1500 + 273 = 1773 \text{ K}$$

$$T_L = 750 + 273 = 1023 \text{ K}$$

$$Q = \sigma_1 A\left(T_H^4 - T_L^4\right)$$

$$Q = \frac{25\left(1773^4 - 1023^4\right)}{(2123^4 - 773^4)} = 11 \text{ Watt}$$

24. (a)

We know that,

$$\text{Gr} = \frac{g\beta\Delta T L_c^3}{\nu^2}$$

$$\beta = \frac{1}{T_{avg}} = \frac{1}{161+273} = 2.304\times 10^{-3}\,\text{K}^{-1} \quad \left(T_{avg} = \frac{25+297}{2} = 161°\text{C}\right)$$

For horizontal plate:

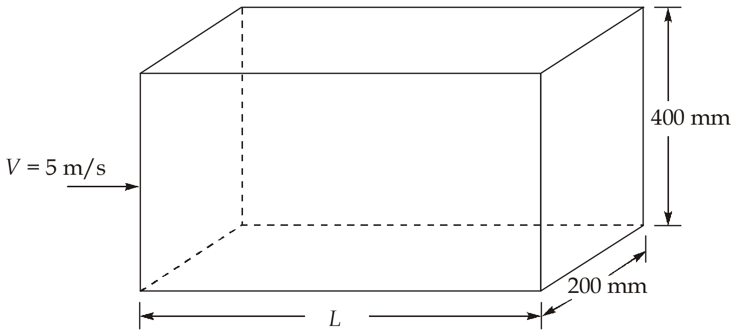
$$L_C = \frac{A_s}{p} = \frac{50\times 50}{4\times 50} = 12.5 \text{ cm or } 0.125 \text{ m}$$

So,

$$\text{Gr} = \frac{9.81\times(2.304\times 10^{-3})\times 272\times(0.125)^3}{(30\times 10^{-6})^2}$$

$$= 133.184\times 10^5$$

25. (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,

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

$$= 0.023(88.535 \times 10^3)^{0.8}(0.7032)^{0.4}$$

$$\text{Nu} = 181.239$$

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

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

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

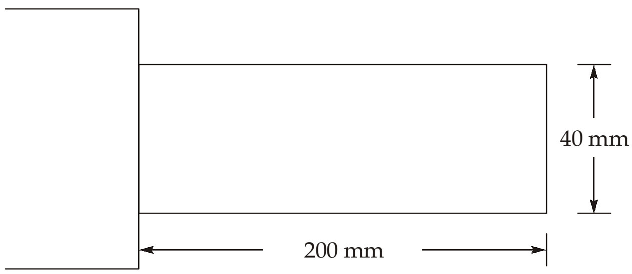
Heat transfer rate per unit length per unit temperature difference,

$$Q = h(PL)(\Delta T)$$

$$\frac{Q}{L\Delta T} = 17.671 \times 2(0.2 + 0.4)$$

$$\frac{Q}{L\Delta T} = 21.205 \text{ W/m°C}$$

26. (d)



Efficiency of fin, $\eta_{fin} = 40\%$

$$\text{Diameter of fin, } d = 40 \text{ mm}$$

$$\text{Cross-sectional area of fin, } A_b = \frac{\pi}{4}d^2$$

$$= \frac{\pi}{4}\times 0.04^2 = 1.2566 \times 10^{-3} \text{ m}^2$$

$$\text{Surface area of fin, } A_{fin} = \pi dl$$

$$= \pi \times 0.04 \times 0.2 = 0.02513 \text{ m}^2$$

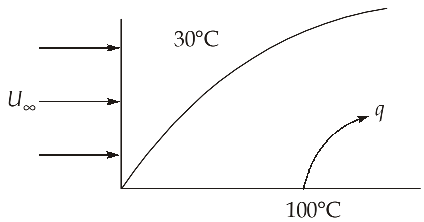
As we know,

$$\text{Effectiveness of fin, } \in_{fin} = \eta_{fin}\frac{A_{fin}}{A_b}$$

$$= 0.4\times\frac{0.02513}{1.2566\times 10^{-3}} = 7.99$$

27. **(a)**

$$\text{Velocity of air, } U_\infty = 30 \text{ m/s}$$



$$\text{Reynold number, Re}_L = \frac{U_\infty L}{\nu} = \frac{30\times L}{18.97\times 10^{-6}}$$

$$= 1.5814 \times 10^6 \text{ L} \quad \text{...(1)}$$

As we know,

$$\text{Drag force, } F_D = C_D \times \frac{1}{2}\rho U_\infty^2 A$$

$$10.5 = \frac{0.0742}{(1.5814\times 10^6 L)^{1/5}}\times\frac{1}{2}\times 1.06\times 30^2 \times L^2$$

$$10.5 = 2.0376L^{(2-0.2)}$$

$$L^{1.8} = 5.1532$$

$$L = (5.1532)^{1/1.8}$$

$$\Rightarrow \quad L = 2.486 \text{ m}$$

From eq. (1)

$$\text{Re}_L = 1.5814 \times 10^6 \times 2.486$$

$$= 3.9314 \times 10^6$$

$$C_D = \frac{0.0742}{(3.9314\times 10^6)^{1/5}} = 3.5604 \times 10^{-3}$$

By simple Reynolds analogy,

$$\overline{St} = \frac{C_D}{2}$$

$$\Rightarrow \qquad \frac{\bar{h}}{\rho U_\infty c_p} = \frac{C_D}{2}$$

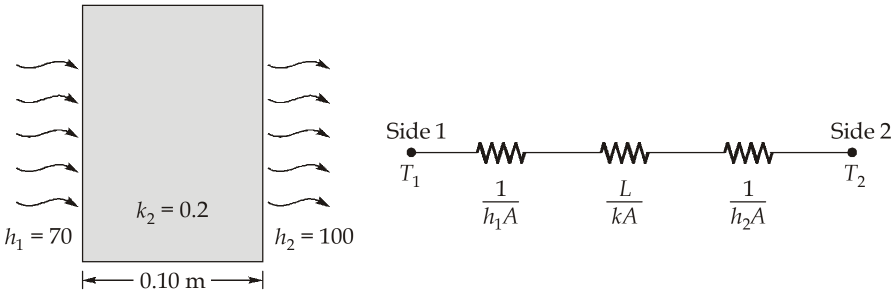
$$\Rightarrow \qquad \bar{h} = \frac{3.5604\times10^{-3}}{2}\times1.06\times30\times1.005\times1000$$

$$= 56.893 \text{ W/m}^2\text{K}$$

28. (c)

$$Q = \frac{\Delta T}{R} = \frac{T_1 - T_2}{R}$$

$$R = \frac{1}{h_1A}+\frac{1}{kA}+\frac{1}{h_2A} = \frac{1}{70}+\frac{0.1}{0.2}+\frac{1}{100} = 0.5242°\text{C/W}$$



$$T_1 - T_2 = Q \times R = 100 \times 0.5242$$

$$= 52.42°\text{C} \approx 52.4°\text{C}$$

29. (d)

$$Q_1 = A_1[F_{12}(J_1 - J_2) + F_{1-3}(J_1 - J_3)]$$

$$J_1 = \sigma\, 550^4 = 5188.4 \text{ W/m}^2\text{K}$$

$$J_2 = 7500 \text{ W/m}^2$$

$$J_3 = 3200 \text{ W/m}^2$$

$$Q = 9(0.2 \times (5188.4 - 7500) + 0.8 \times (5188.4 - 3200)) = 10.15 \text{ kW}$$

30. (c)

$$T_o = T_w + \frac{q_G R^2}{4k}$$

$$T_o = 100°\text{C} + \frac{3000}{\frac{\pi}{4}\times1.2^2\times5}\times\frac{0.6^2}{4\times62} = 100.64°\text{C}$$

■■■■