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Heat and Mass Transfer

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CLASS TEST 2019-2020

MECHANICAL ENGINEERING

Date of Test : 16/09/2019

ANSWER KEY ➤ Heat and Mass Transfer

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

DETAILED EXPLANATIONS

1. (a)

$$NTU = \frac{UA}{C_{min}} = \frac{1000 \times 5}{10000} = 0.5$$

$$\in = 1 - \exp(-NTU)$$
$$= 1 - \exp(-0.5) = 0.39347$$

4. (b)

$$\lambda T = 2898\ \mu mK$$

$$\lambda = \frac{2898}{T} = \frac{2898}{1000} = 2.898\ \mu m$$

5. (a)

$$\eta_f = \frac{\sqrt{PhkA}(t_0 - t_a)\tanh(ml)}{hPl(t_0 - t_a)}$$

$$\in_f = \frac{\sqrt{PhkA}(t_0 - t_a)\tanh(ml)}{hA_C(t_0 - t_a)}$$

$$\Rightarrow \quad \in_f = \eta_f\left(\frac{Pl}{A_C}\right) = \eta_f\left(\frac{\text{Surface area}}{\text{Cross– section area}}\right)$$

$$\therefore \quad \in_f = 0.7 \times \left[\frac{\pi \times 1 \times 8}{\left(\frac{\pi \times 1^2}{4}\right)}\right] = 22.4$$

6. (a)

$$Nu_x = 0.035\, Re_x^{0.8}\, Pr^{1/3}$$

$$\Rightarrow \quad \frac{h_x x}{k} = 0.035.\left(\frac{Vx}{\nu}\right)^{0.8} Pr^{1/3}$$

$$\Rightarrow \quad h_x \propto x^{-0.2}$$

$$\Rightarrow \quad h_x = cx^{-0.2}$$

$$\frac{\bar{h}}{h_{x=L}} = \frac{1/L \int_{x=0}^{L} h_x dx}{h_{x=L}} = \frac{1/L \int_{x=0}^{L} cx^{-0.2} dx}{cL^{-0.2}}$$

$$= \frac{1/L\left[x^{-0.2+1}\right]_0^L}{L^{-0.2}[-0.2+1]}$$

$$= \frac{1}{L} \times \frac{L^{0.8}}{0.8 \times L^{-0.2}} = \frac{1}{0.8} \times \frac{L^{0.8+0.2}}{L} = \frac{1}{0.8} = 1.25$$

7. (b)

As outlet temperature of cold fluid is more than outlet temperature of hot fluid, so it will be counterflow heat exchanger.

9. (b)

From energy balance, $C_h \Delta T_h = C_c \Delta T_c$

$$\Rightarrow \quad C_h(250-175) = C_c(170-30)$$

$$\frac{C_c}{C_h} = 0.5357 \simeq 0.54$$

10. (b)

$$\text{Prandtl number, Pr} = \frac{\mu c_p}{k} = \frac{0.004 \times 2000}{1} = 8$$

$$\Rightarrow \quad \frac{\delta}{\delta_{th}} = (\text{Pr})^{1/3}$$

$$\Rightarrow \quad \delta_{th} = \frac{1}{2} = 0.5 \text{ mm}$$

11. (a)

From energy balance of copper bar,

$$I^2 R = h(\pi d l)\Delta t$$

$$\Rightarrow \quad I \propto \sqrt{h} \qquad ...(1)$$

Now, from given relation

$$\Rightarrow \quad h \propto \sqrt{\text{Re}} \propto \sqrt{V} \qquad ...(2)$$

where V is velocity of air.

From (1) and (2) we get,

$$\Rightarrow \quad I \propto (V)^{1/4}$$

Now,

$$I' = I\left(\frac{V'}{V}\right)^{1/4} = I \times 3^{1/4}$$

$$= 100 \times 3^{1/4} = 131.6 \text{ Amp.}$$

12. (d)

$$Q = \dot{m}_h C_h \left(T_{h_1} - T_{h_2}\right) = \dot{m}_c C_c \left(T_{c_2} - T_{c_1}\right)$$

$$Q = 0.02 \times 1880(350-300) = 0.015 \times 4175 \times (T_{c2} - 280)$$

$$1880 = 0.015 \times 4175 \times (T_{c2} - 280)$$

or

$$T_{c2} = 310 \text{K}$$

$$\text{LMTD} = \frac{40-20}{\log_e\left(\frac{40}{20}\right)} = 28.85 \text{ K}$$

$$Q = U_0 A_0 (\text{LMTD}) = U_0 (\pi d_0 L)(\text{LMTD})$$

$$\Rightarrow \quad L = \frac{1880}{640 \times \pi \times 0.02 \times 28.85} = 1.62 \text{ m}$$

13. (c)

Heat generated due to current flow,

$$= I^2 R$$

$$= 1000^2 \times \frac{0.08}{1000} \text{ W/m} = 80 \text{ W/m}$$

Heat dissipated to surrounding,

$$= hA\Delta t$$

$$= 15 \times (\pi \times 0.01)(t_w - 40) \text{ W/m}$$

where t_w is wire temperature.

Under steady condition,

$$\Rightarrow \quad 80 = 15(\pi \times 0.01)(t_w - 40)$$

$$\Rightarrow \quad t_w = 209.77°C$$

14. (b)

Given: $\mu = 1.967 \times 10^{-5}$ kg/ms, $k = 0.02792$ W/mK, $Pr = 0.713$, $m = 75$ kg/hr

$$\text{Reynolds number, Re} = \frac{\rho V d}{\mu} = \frac{md}{A\mu}$$

$$\Rightarrow \quad \text{Re} = \frac{4\text{m}}{\pi d\mu} = \frac{4\left[\frac{75}{3600}\right]}{\pi \times 0.1 \times 1.967 \times 10^{-5}}$$

$$\Rightarrow \quad \text{Re} = 13485$$

$\therefore$ Flow is turbulent

$$\therefore \quad Nu = 0.023\,[13485]^{0.8}\,(0.713)^{0.4} = 40.44$$

Now,

$$h = Nu \times \frac{k}{d}$$

$$= 40.44 \times \frac{0.02792}{0.1}$$

$$\Rightarrow \quad h = 11.290 \text{ W/m}^2\text{ K}$$

15. (c)

Given: $\theta_m = 60°C$, $m_h = 10$ kg/s, $h_{fg} = 500$ kJ/kg

Now,

$$m_h h_{fg} = UA\theta_m$$

$$\Rightarrow \quad m_h h_{fg} = U(\pi d_0 l \times n \times p)\theta_m$$

$$\Rightarrow \quad 10 \times 500 \times 10^3 = 500[\pi \times 0.025 \times 5 \times n \times p] \times 60$$

$$\Rightarrow \quad n \times p = 424.41$$

Let the mass flow rate of cold fluid in each pass and number of tubes in each pass be m_c and n respectively

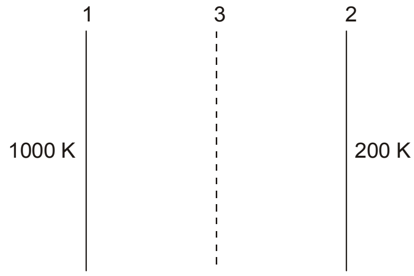
$$\Rightarrow \quad m_c = \left[\frac{\pi}{4} d^2 \times v \times \rho\right] n$$

$$\Rightarrow \quad 60 = \frac{\pi}{4} \times (0.025)^2 \times 3 \times 1000 \times n$$

$$\Rightarrow \quad n = 40.7$$

$$\text{Number of passes} = \frac{424.41}{41} = 10.35 \simeq 11$$

16. (a)



Heat flow from plate 1 to sheet per unit Area,

$$\Rightarrow \quad Q_{13} = (F_g)_{13}\,\sigma(T_1^4 - T_3^4)$$

Now
$$F_{g13} = \frac{1}{\frac{1}{\epsilon_1}+\frac{1}{\epsilon_3}-1} = \frac{1}{\frac{1}{0.6}+\frac{1}{0.2}-1} = 0.1765$$

$$\Rightarrow \quad Q_{13} = 0.1765\,\sigma(1000^4 - T_3^4) \qquad \text{...(1)}$$

Heat flow per unit area from sheet to plate 2,

$$\Rightarrow \quad Q_{32} = (F_g)_{32}\,\sigma\left(T_3^4 - T_2^4\right)$$

$$\Rightarrow \quad F_{g32} = \frac{1}{\frac{1}{\epsilon_3''}+1-1} = 0.1 \qquad (\epsilon_3'' = 0.1)$$

$$\frac{1}{\frac{1}{0.1}+1-1} = \frac{1}{10+1-1} = \frac{1}{10} = 0.1$$

$$\Rightarrow \quad Q_{32} = 0.1\ \sigma\left[T_3^4 - 200^4\right] \qquad \text{...(2)}$$

Equating equation (1) and (2) we get,

$$\Rightarrow \quad 0.1765\ \sigma\left[1000^4 - T_3^4\right] = 0.1\,\sigma\left[T_3^4 - 200^4\right]$$

$$\Rightarrow \quad T_3 = 894\text{ K}$$

17. (b)

$$m = \sqrt{\frac{hP}{kA_c}} = \sqrt{\frac{h\times\pi d}{K\times\frac{\pi d^2}{4}}} = \sqrt{\frac{4h}{Kd}}$$

$$= \sqrt{\frac{4\times 60}{30\times 0.02}} = 20\text{ m}^{-1}$$

Now,
$$\frac{\theta}{\theta_0} = \frac{t-t_a}{t_0-t_a} = \frac{\cos hm[l-x]}{\cos h\,ml}$$

$$x = 0.03;\ l = 0.1,\ t_a = 300\text{ K},\ t_0 = 400\text{ K}$$

$$\Rightarrow \quad \frac{t-300}{400-300} = \frac{\cos h\left[20(0.1-0.03)\right]}{\cos h(20\times 0.1)}$$

$$\Rightarrow \quad \frac{t-300}{100} = \frac{\cos h1.4}{\cos h2} = 0.5717$$

$$\Rightarrow \quad t = 357.17\text{ K}$$

18. (c)

Heat lost with existing insulation,

$$Q_1 = \frac{2\pi k l\,(t_1 - t_2)}{\log_e \frac{r_2}{r_1}}$$

Heat lost with additional insulation

$$Q_2 = \frac{2\pi k l\,(t_1 - t_2)}{\log_e \frac{r_2 + x}{r}}$$

Given $$Q_2 = \frac{Q_1}{5}$$

$$\Rightarrow \quad \frac{2\pi l k[t_1 - t_2]}{\log_e\left[\frac{r_2 + x}{r_1}\right]} = \frac{1}{5}\frac{2\pi k l\,(t_1 - t_2)}{\log_e\left(\frac{r_2}{r_1}\right)}$$

$$\Rightarrow \quad \frac{r_2 + x}{r_1} = \left(\frac{r_2}{r_1}\right)^5$$

Given $$r_1 = \frac{6\text{ cm}}{2} = 3\text{ cm}$$

$$r_2 = 3 + 1 = 4\text{ cm}$$

$$\Rightarrow \quad \frac{4 + x}{3} = \left(\frac{4}{3}\right)^5$$

$$\Rightarrow \quad x = 8.64\text{ cm}$$

19. (b)

$$\text{Resistance of wire, } R = 0.1\ \Omega \text{ per cm length}$$

$$= 10\ \Omega \text{ per m length}$$

$$\text{Heat generated, } Q = I^2 R$$

$$= 5^2 \times 10 = 250\text{ W/m}$$

$$Q = \frac{2\pi k l\,(t_1 - t_2)}{\log_e\left(\frac{r_2}{r_1}\right)}$$

$$\frac{Q}{l} = 250 = \frac{2\pi \times k \times 140}{\ln\left(\frac{1}{0.05}\right)} = 0.8514\text{ W/m-K}$$

20. (a)

$$k_m = 0.065\left(1 + 15 \times 10^{-4}\left(\frac{300 + 60}{2}\right)\right)$$

$$= 0.08255\text{ W/m-deg}$$

The heat flow through the cylinder with radii r_1 and r_2 is given by,

$$Q = \frac{2\pi k l (t_2 - t_1)}{\ln\left(\frac{r_2}{r_1}\right)} = \frac{2\pi \times 0.08255 \times 2 \times 240}{\ln\left(\frac{20.5}{12.5}\right)}$$

$$= 503.268\text{ W}$$

21. (b)

Taking

$$L = 1\text{ m}$$
$$A_1 = 2\pi r_1 L = 2\pi \times 0.025 \times 1 = 0.157\text{ m}^2$$
$$A_3 = 2\pi r_3 L = 2\pi \times 0.0575 \times 1 = 0.361\text{ m}^2$$
$$R_{conv,\,1} = \frac{1}{h_1 A_1} = \frac{1}{60 \times 0.157} = 0.106°\text{C/W}$$
$$R_{pipe} = \frac{\ln(r_2/r_1)}{2\pi k_1 L} = \frac{\ln(2.75/2.5)}{2\pi \times 80 \times 1} = 1.8961 \times 10^{-4}°\text{C/W}$$
$$R_{insulation} = \frac{\ln(r_3/r_2)}{2\pi k_2 L} = \frac{\ln(5.75/2.75)}{2\pi \times 0.05 \times 1} = 2.35°\text{C/W}$$
$$R_{conv,\,2} = \frac{1}{h_2 A_3} = \frac{1}{18 \times 0.361} = 0.154°\text{C/W}$$
$$R_{total} = 2.61°\text{C/W}$$
$$\Rightarrow \quad Q = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}} = \frac{320 - 5}{2.61} = 120.69\text{ W}$$

22. (d)

$$Gr_L = \frac{g\beta(T_\omega - T_\infty)}{\nu^2} L^3 = \frac{9.81 \times 3 \times 10^{-4}(60 - 20) \times (0.2)^3}{(0.658 \times 10^{-6})^2}$$
$$= 21.75 \times 10^8$$
$$Ra_L = Gr_L . Pr = 21.75 \times 10^8 \times 4.34$$
$$= 9.44 \times 10^9$$

∴ The flow is turbulent

$$\Rightarrow \quad \frac{\bar{h}L}{k} = 0.1(Gr\,Pr)^{1/3}$$
$$\bar{h} = \frac{0.628}{0.2} \times 0.10 \times (9.44 \times 10^9)^{1/3}$$
$$= 663.62\text{ W/m}^2\text{K}$$

∴ The rate of heat transfer $= \bar{h}A(T_\omega - T_\infty) = 663.62 \times 0.2 \times 0.2(60 - 20) \times 2$

$$= 2123.58\text{ W} = 2.123\text{ kW}$$

23. (a)

Lumped parameter solution for transient conduction.

$$\frac{T - T_a}{T_i - T_a} = \exp\left[-\frac{hA}{\rho Vc}\tau\right]$$

Now, $$\frac{A}{V} = \frac{2\pi r(r + l)}{\pi r^2 l} = \frac{2(r + l)}{\pi l} = \frac{2 \times [5 + 25]}{5 \times 25} = 0.48\text{ cm}^{-1}$$

Now, $$\frac{hA}{\rho VC} = \frac{k}{\rho C} \times \frac{h}{k} \times \frac{A}{V} = \alpha \times \frac{h}{k} \times \frac{A}{V}$$
$$= (0.45 \times 10^{-5}) \times \frac{100}{25} \times (0.48 \times 100) = 8.64 \times 10^{-4}$$

$$\therefore \quad \frac{1260 - 830}{1260 - 90} = \exp[-8.64 \times 10^{-4}\tau]$$

$$\Rightarrow \quad \exp[8.64 \times 10^{-4}\,\tau] = \frac{1260-90}{1260-830} = 2.7209$$

$$\Rightarrow \quad 8.64 \times 10^{-4}\tau = \log_e[2.7209]$$

$$\Rightarrow \quad \tau = 1158.53 \text{ s}$$

Required ingot velocity, $V = \dfrac{\text{furnace length}}{\text{Time}} = \dfrac{5}{1158.53} = 4.32 \times 10^{-3}$ m/s $= 4.32$ mm/s

24. (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 $k_1 = k;\ k_2 = 2k$

$$\Rightarrow \quad -k\frac{(T-327)}{b} = -2k\frac{(27-T)}{2b}$$

$$\Rightarrow \quad 2T = 354°C$$

$$T = 177°C$$

25. (b)

Temperature distribution for the above condition is given by

$$\left[\frac{T_o-T}{T_o-T_w}\right] = \left[\frac{x}{L}\right]^2$$

Putting values

$$\Rightarrow \quad \frac{200-T}{200-50} = \left(\frac{0.5}{1}\right)^2$$

$$200 - T = \frac{150}{4},\ T = 162.5°C$$

26. (a)

- In dropwise condensation rate of heat transfer is higher as compared to film wise condensation.
- In film condensation the liquid condensate wets the solid surface, spreads out and forms continuous film over the entire surface. So in this rate of heat transfer is less than that in dropwise condensation.

27. (b)

$$C_{gas} = C_1 = m_g \times c_{pg} = 2 \times 1.25 = 2.5 \text{ kJ/K}$$

$$C_{water} = C_2 = 1.5 \times 4 = 6 \text{ kJ/K}$$

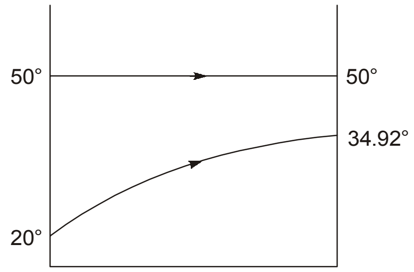
$$\Rightarrow \quad \text{Effectiveness} = \frac{C_{gas}\left(300-T_{ge}\right)}{C_{min}\left(300-40\right)} = 0.6$$

$$\Rightarrow \quad T_{ge} = 144°C$$

28. (a)

- Snow behaves as a black body. So its absorptivity will be high. Absorptivity of snow is around 0.985.
- The absorptivity of grey surface in necessarily below unity, but it remains constant over the entire range of temperature and wavelength of incident radiation.

30. (a)



Given heat exchanger is a condenser,

$$C_h = C_{max} = \infty$$

$$C_{min} = C_c$$

$$\text{Effectiveness} = \frac{C_c}{C_{min}}\frac{[t_{c2} - t_{c1}]}{[t_{h1} - t_{c1}]}$$

$$= \frac{t_{c2} - t_{c1}}{t_{h1} - t_{c1}} \qquad [\because C_{min.} = C_c]$$

$$= \frac{35.95 - 20}{50 - 20} = 0.5317$$

Effectiveness of condenser.

$$\in = 1 - \exp[-NTU] \qquad \text{(Since } C = 0\text{)}$$

$$\Rightarrow \quad 0.5317 = 1 - \exp[-NTU]$$

$$\Rightarrow \quad \exp[-NTU] = 1 - 0.5317 = 0.4683$$

$$\Rightarrow \quad -NTU = \log_e 0.4683 = -0.7586$$

$$\Rightarrow \quad NTU = 0.7586$$

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