USN :

CMR Institute of Technology, Bangalore
DEPARTMENT OF MECHANICAL ENGINEERING
III - INTERNAL ASSESSMENT

Semester: 6-CBCS 2018
Subject: HEAT TRANSFER (18ME63)
Faculty: Mr Shashank Dubey

Date: 30 Jul 2021
Time: 09:00 AM - 10:30 AM
Max Marks: 50

Instructions to Students :

- **Instructions:**
- **Each question carries 10 Marks**
- Attempt all 5 questions
- Use of heat transfer data hand book is permitted
- **Max Marks: 50**
- **Duration: 1 hr 30 mins**

Answer All Questions

Q.No		Marks	CO	PO	BT/CL
1	Explain the following terms: • Biot Number • Fourier Number • Thermal Time Constant • Lumped Body	10	CO2	PO1,PO2	L1
2	A 10 mm diameter mild steel sphere (k=42W/mK) is exposed to cooling airflow at 20°C resulting in the convective coefficient h = 120 W/m²K. For mild steel take: ρ=7850 kg/m³, α=0.045 m²/h, c=475 J/kgK. Determine: • Time required to cool sphere from 550°C to 90°C. • Instantaneous heat transfer rate 2 minutes after the start of cooling • Total energy transferred from the sphere during the first two minutes.	10	CO2	PO1,PO2	L5
3	A thick concrete wall fairly large in size initially at 30°C suddenly has its surface temperature increased to 600°C by an intense fire which lasted for 25 minutes. The material will disintegrate upto a depth where the temp. reaches 400°C. Determine the thickness which may disintegrate. The thermal diffusivity is 4.92 × 10^-7 m²/s; k = 1.28 W/mK. Also determine the total heat flow/m² during the time.	10	CO2	PO1,PO2	L5
4	A simple heat exchanger consisting of two concentric flow passages is used for heating 1110 Kg/h of oil (specific heat =2.1 kJ/kg-K) from a temperature of 270°C to 49°C. Oil flows through the inner pipe made of copper (O.D = 2.86cm, I.D = 2.54cm) and the surface heat transfer coefficient on the oil side is 635 W/m²K. The oil is heated by hot water supplied at the rate of 390 kg/h and at an inlet temperature of 93°C. The water side heat transfer coefficient is 1270 W/m²K. Take the thermal conductivity of copper to be 350 W/mK and the fouling factors on the oil and water sides to be 0.0001 and 0.0004 m²K/W respectively. What is the length of the heat exchanger for: • Parallel flow arrangement • Counter flow arrangement	10	CO5	PO1,PO2	L5
5	A heat exchanger has an effectiveness of 0.5 when the flow is counter and the thermal capacity of one fluid is twice that of the other fluid. Calculate the effectiveness of the heat exchanger if the direction of one of the fluids is reversed with the same mass flow rates as before.	10	CO5	PO1,PO2	L5

1

Biot Number - The biot number is the ratio of the internal resistance of the body to heat conduction to its external resistance to heat convection. Therefore a small Biot number represents small resistance to heat conduction and thus small temperature gradients within the body.

$$Bi = \frac{hL}{k}$$

Thermal time constant - Thermal time constant is a measurement of time required for the thermistor to respond to a change in the ambient temperature.

It is denoted by 't'

$$\frac{hAs}{\rho Vc} t = Bi \cdot Fo$$

Fourier Number - It is the measure of heat conducted through a body relative to heat stored. It signifies the degree of penetration of heating or cooling effect through a solid

$$Fo = \frac{\alpha t}{Lc^2}$$

Lumped body - The interior temperatures of some bodies remain essentially uniform at all times during heat transfer process.

Temperature of such bodies are a function of time $T = T(t)$.

The heat transfer analysis based on this idealization is called lumped system analysis

Q2) $D = 10 \times 10^{-3}\ m$

$k = 42\ W/m^2\ ^\circ C$

$T = 20^\circ C$

$h = 120\ W/m^2\ ^\circ C$

$T_i = 550^\circ C$, $T = 90^\circ C$.

$Q_{total} = ?$, $\delta = 7850\ kg/m^3$

$C_p = 475\ J/kg\ ^\circ C$, $\alpha = 0.045\ m^2/h$.

$$L_c = \frac{V}{A} = \frac{R}{3} = \sim 1.66 \times 10^{-3} m.$$

~~3.14 × 10^{-4} m~~

$$B_i = \frac{h L_c}{k} = \frac{120 \times 3.14 \times 10^{-4}}{42} = 0.0047$$

~~0.97 × 10^{-4}~~

Time taken for cooling

$$F_o = \frac{\alpha t}{L_c^2} = \frac{0.045 \times t}{(3.14 \times 10^{-4})^2}.$$

$$= 456407.96t.$$

Now $\frac{T - T_\infty}{T_i - T_\infty} = e^{-B_i F_O}$

~~$= \frac{90-20}{550-20} = e^{-7.14 \times 10^{-3} \times 456407.96t}$~~

~~$= 0.132 = e^{-3258.75t}$~~

~~$\log_e 0.132 = e^{-3258.75t}$~~

~~$\log_e 0.132 = -3258.75t \log_e$~~

~~$-2.025 = -3258.75t \times 1$~~

~~$t = 0.000621$ hr~~

$$= \frac{90-20}{550-20} = e^{\frac{-120t}{7850 \times 1.66 \times 10^{-3} \times 475}}$$

$$t = 104.41\ sec.$$

2) $Q_i = -hA\delta\,(T_i - T_\infty)\, e^{-\frac{hAC}{\delta VC} t}$.

$t = \text{min} = 120 s$

$Q_i = -120 \times 4 \times \pi \times (5 \times 10^{-3})^2 \times (550 - 20)$

$\cdot\, e^{\frac{-120 \times 120}{7850 \times 1.66 \times 10^{-3} \times 475}}$

$Q_i = -1.950$ Watt

3) $Q_t = \rho VC\,(T_1 - T_\infty)\left(e^{-\frac{hA\delta}{\rho VC}} - 1\right)$

$Q_t = 7850 \times \frac{4}{3} \times \pi \times (5 \times 10^{-3})^3 \times (550 - 20)$

$\left[e^{-\frac{120 \times 120}{7850 \times 1.66 \times 10^{-3} \times 475}}\right]$

$\boxed{Q_t = -1.965\,W}$

... called lumped system analysis

Q3) Given $T_i = 30°c$, $t = 25 min = 1500 Sec$.

$T_\infty = 600°c$. $T_0 = 400°c$.

$\alpha = 4.92 \times 10^{-7} m^2/s$.

$k = 1.28 W/mk$.

Using data hand book.

$$\frac{T_0 - T_\infty}{T_i - T_\infty} = erf\left(\frac{x}{2\sqrt{\alpha t}}\right)$$

$$= \frac{400 - 600}{30 - 600} = 0.3508$$

Z	erf (Z)
0.32	0.34913.
2	0.3508
0.33	0.3592

$Z = 0.321$

$$\therefore 0.321 = \frac{x}{2\sqrt{4.92 \times 10^{-2} \times 1500}}.$$

$x = 0.0174 m$.

∴ Total heat flow during the time

$$q_x = \frac{k(T_0 - T_i)}{\sqrt{\pi \alpha t}} \exp\left(-\frac{x^2}{4\alpha t}\right)$$

$$q_x = \frac{1.28(400-300)}{\sqrt{\pi \times 4.92\times10^{-7}\times1500}} \exp\left(\frac{-0.0174^2}{4\times4.92\times10^{-7}\times150}\right)$$

$$\underline{q_x = 8877.01\ W/m^2}$$

Q4)
Q.) <u>Given data</u>

$m_c = 1110\ kg/hr = 0.3083\ kg/s.$

$R_{fi} = 0.0001\ m^2 k/w$

$m_b = \frac{390}{3600} = 0.01083\ kg/s.$

$T_{ci} = 27°c$, $T_{co} = 49°c$, $k = 350\ w/mk$

$h_i = 635\ w/m^2k$, $C_{ph} = 4200\ kJ/kg\ k$

$T_{hi} = 93°c$, $h_o = 1270\ w/m^2k.$

$R_{fo} = 0.0004\ m^2 k/w$, $d_i = 2.54\times10^{-2}\ m$

Overall heat transfer

$$\frac{1}{u_o} = \frac{r_o}{r_i}\frac{1}{h_i} + \frac{r_o}{r_i}R_{fi} + \frac{r_o}{k}\log_e\frac{r_o}{r_i} + R_{fo} + \frac{1}{h_e}$$

$$= \frac{0.0286}{0.0254}\times\frac{1}{635} + \frac{0.0286}{0.0254}\times0.0001$$

$$+ \frac{0.0286}{350}\log\frac{0.0286}{0.0254} + 0.0004 + \frac{1}{1270}$$

$u_o = 325\ W/m^2k.$

$Q = m_c C_{pc}(T_{co}-T_{ci}) = 0.3083\times2100(49-27)$

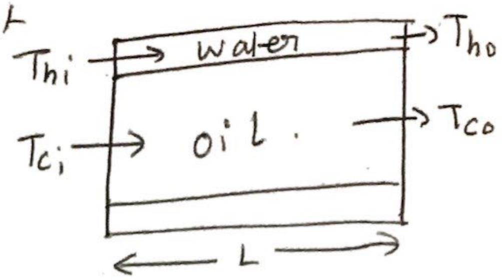
$= 14243.5\ W.$

$Q = m_h C_{pc}(T_{hi}-T_{ho})$

$14243.5 = 0.1083\times4200(93-T_{ho})$

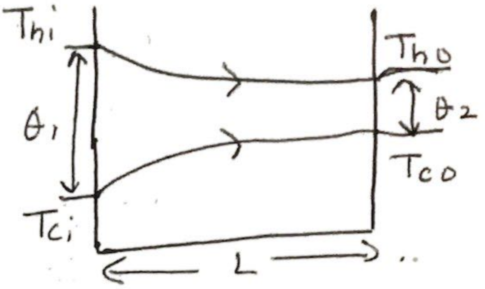
$T_{ho} = 61.7°c.$

1) parallel flow arrangement



$\theta_1 = T_{hi} - T_{ci}$

$= 93 - 27 = 66°c$



$\theta_2 = T_{ho} - T_{co}$

$= 61.7 - 49 = 12.7°c$

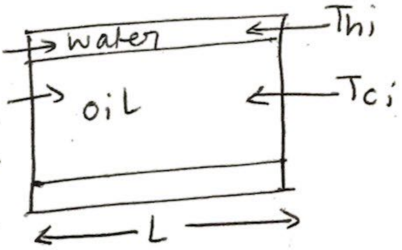
$$\theta m = \frac{\theta_1 - \theta_2}{\log \theta_1/\theta_2}$$

$$= \frac{66 - 12.7}{\log 66/12.7} = 32.24°c$$

$Q = U_o A_s \theta m$

$14248.5 = 325\pi \times 0.028 \times 32.34 \times L$

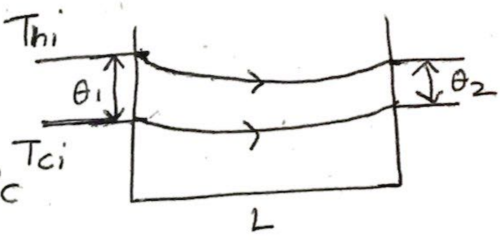
$L = 15.1 \, m$



2) counter flow arrangement.

$\theta_1 = T_{hi} - T_{co}$

$= 93 - 49 = 44°c$.



$\theta_2 = T_{ho} - T_{ci}$

$= 61.7 - 27 = 34.7°c$

$$\theta m = \frac{\theta_1 - \theta_2}{\log\left(\frac{\theta_1}{\theta_2}\right)} = 39.2°c.$$

$Q = U_o A_s \theta m$

$14243.5 = 325 \times \pi \times 0.286 \times L \times 39.2$

$L = 12.5 \, m$

85) Given $E_{gf} = 0.5$ $\quad E_{PF} = ?$

$C_{min} = 1$ $\quad \therefore \dfrac{C_{min}}{C_{max}} = 0.5$

$C_{max} = 2$

$$E_g = \frac{1 - e^{-N(1-c)}}{1 - ce^{-N(1-c)}} = \frac{1 - e^{-N(1-0.5)}}{1 - 0.5e^{-N(1-0.5)}}$$

$$0.5 - 0.25e^{-0.5N} = 1 - e^{0.5N}$$

$$e^{-0.5N} - 0.25e^{-0.5N} = 1 - 0.5$$

$$0.75e^{-0.5N} = 0.5$$

$$e^{-0.5N} = \frac{0.5}{0.75} = 0.667$$

$$e^{-0.5N} = 0.667 \quad \text{—— (1)}$$

Take ln on both sides

$$\ln e^{-0.5N} = \ln(0.667)$$

$$-0.5N = -0.4049$$

$$N = 0.809$$

__For__ PF

$$\varepsilon_{pf} = \frac{1 - e^{-N(1+c)}}{1+c} = \frac{1 - e^{-309(1+0.5)}}{1.5}$$

$$\varepsilon_{pf} = 0.4686$$