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Internal Assessment Test 2 – July. 2022

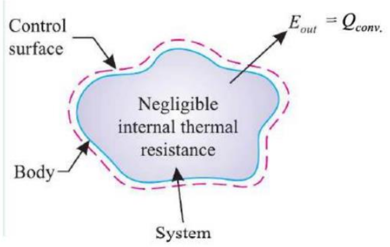
Sub:	HEAT TRANSFER	Sub Code:	18ME63	Branch:	ME
Date:	09.07.2022	Duration:	90 min	Max Marks:	50
Sem / Sec:	VI/A&B	OBE			

Answer All the Questions
Use of Heat Transfer Data handbook is permitted

		MARKS	CO	RBT
1	Derive the expressions for temperature variation, instantaneous rate of heat transfer and total heat flow for a lumped body.	[10]	CO3	L3
2	Derive an expression for LMTD for a counter flow heat exchanger.	[10]	CO5	L3
3	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	L3
4	A concrete wall initially at 30°C is exposed to gases at 900°C with h = 85W/m²K. The thermal diffusivity is 4.92 X 10^{-7} m²/s and k = 1.28 W/mK. Determine the temperature of the surface and temperatures at 1 cm depth and at 5 cm depth after 1 hr. Also estimate the heat flow.	[10]	CO3	L3
5	An aluminium sphere weighing 6 kg and initially at temperature of 350°C is immersed in a fluid at 30°C with convection coefficient of 60 W/m²K. Estimate the time required to cool the sphere at 100°C. Take the thermophysical properties as c= 900 J/kgK, density = 2700 kg/m³, k = 205 W/mK	[10]	CO3	L3

CI CCI HOD

1)



At t = 0, T = T_i
For t>0, T = f(t)

$$E_{out} = Qconv$$

$$-\rho V c \frac{\partial T}{\partial t} = hA_s(T - T_\infty)$$

$$-\rho V c \frac{dT}{dt} = hA_s(T - T_\infty)$$

$$\int \frac{dT}{(T - T_\infty)} = -\frac{hA_s}{\rho V c}\int dt$$

$$\ln(T - T_\infty) = -\frac{hA_s}{\rho V c}t + C$$

At t = 0, T = T_i
Therefore,

$$\ln(T_i - T_\infty) = C$$

Hence,

$$\ln(T - T_\infty) = -\frac{hA_s}{\rho V c}t + \ln(T_i - T_\infty)$$

$$\ln\left(\frac{T - T_\infty}{T_i - T_\infty}\right) = -\frac{hA_s}{\rho V c}t$$

$$\left(\frac{T - T_\infty}{T_i - T_\infty}\right) = exp\left(-\frac{hA_s}{\rho V c}t\right)$$

$$\left(\frac{T - T_\infty}{T_i - T_\infty}\right) = exp\left(-\frac{hA_s}{\rho V c}t\right)$$

$$(T - T_\infty) = (T_i - T_\infty)exp\left(-\frac{hA_s}{\rho V c}t\right)$$

$$T = T_\infty + (T_i - T_\infty)exp\left(-\frac{hA_s}{\rho V c}t\right)$$

$$\frac{dT}{dt} = -\frac{hA_s}{\rho V c}(T_i - T_\infty)exp\left(-\frac{hA_s}{\rho V c}t\right)$$

Q_i – instantaneous rate of heat transfer in the lumped body

$$Q_i = \rho V c \frac{dT}{dt}$$

$$Q_i = \rho V c\left[-\frac{hA_s}{\rho V c}(Ti - T_\infty)exp\left(-\frac{hA_s}{\rho V c}t\right)\right]$$

$$Q_i = -hA_s(T_i - T_\infty)exp\left(-\frac{hA_s}{\rho V c}t\right)$$

Unit for Q_i : Watts

Q_t – Total Heat Flow

$$Q_t = \int Q_i\, dt$$

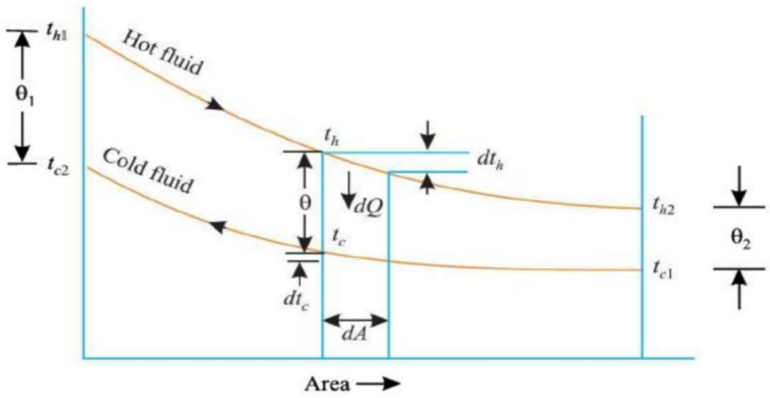
$$Q_t = \int_0^t \left[-hA_s(T_i - T_\infty)exp\left(-\frac{hA_s}{\rho V c}t\right)\right]dt$$

$$Q_t = -hA_s(T_i - T_\infty)\left[-\frac{\rho V c}{hA_s}\right]\left[exp\left(-\frac{hA_s}{\rho V c}t\right) - exp\left(-\frac{hA_s}{\rho V c}0\right)\right]$$

$$Q_t = \rho V c(T_i - T_\infty)\left[exp\left(-\frac{hA_s}{\rho V c}t\right) - 1\right]$$

2)

COUNTER FLOW HEAT EXCHANGERS (LMTD)



The total heat flow is calculated using,

$Q = m_h c_h (T_{h1} - T_{h2}) = m_c c_c (T_{c2} - T_{c1}) = UA\theta_m$

$Q = C_h (T_{h1} - T_{h2}) = C_c (T_{c2} - T_{c1}) = UA\theta_m$

m : mass flow rate, NOT MASS
c : specific heat
C = mc : Heat capacity

Consider a small area dA and let the heat flow through the area be dQ.

$dQ \quad = -C_h dTh = -C_c dTc = UdA(T_h - T_c)$

Let, $T_h - T_c = \theta$
$dT_h - dT_c = d\theta$

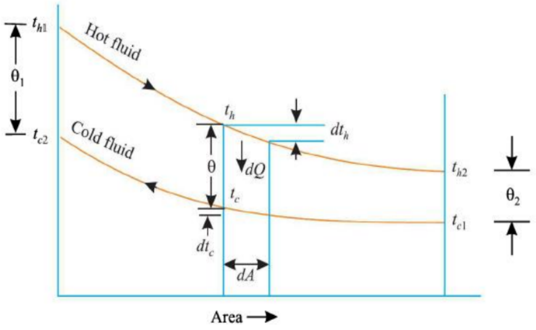
(The –ve sign indicates temperature drop.)

Now, $dT_h = \frac{-dQ}{C_h} = \frac{-UdA\theta}{C_h}$

and $dT_c = \frac{-dQ}{C_c} = \frac{-UdA\theta}{C_c}$

$dT_h - dT_c = \frac{-UdA\theta}{C_h} - \frac{-UdA\theta}{C_c}$

$d\theta = -UdA\theta\left[\frac{1}{C_h} - \frac{1}{C_c}\right]$



$$\int_{\theta 1}^{\theta 2} \frac{d\theta}{\theta} = -U\left[\frac{1}{C_h} - \frac{1}{C_c}\right]\int_0^A dA$$

$$ln\left(\frac{\theta 2}{\theta 1}\right) = -UA\left[\frac{1}{C_h} - \frac{1}{C_c}\right]$$

$Q = C_h (T_{h1} - T_{h2}) = C_c (T_{c2} - T_{c1})$

$\frac{1}{C_h} = \frac{(Th_1 - Th_2)}{Q}$

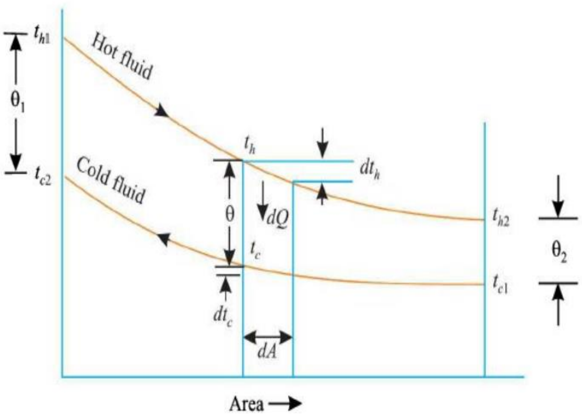
$\frac{1}{C_c} = \frac{(Tc_2 - Tc_1)}{Q}$

$$ln\left(\frac{\theta 2}{\theta 1}\right) = -UA\left[\frac{(Th_1 - T_{h2})}{Q} - \frac{(Tc_2 - T_{c1})}{Q}\right]$$

$$ln\left(\frac{\theta 2}{\theta 1}\right) = -UA\left[\frac{(Th_1 - Tc_2) - (T_{h2} - T_{c1})}{Q}\right]$$

$$ln\left(\frac{\theta 2}{\theta 1}\right) = -UA\frac{\theta 1 - \theta 2}{Q}$$

$$\mathbf{Q} = UA\frac{\theta 2 - \theta 1}{ln\left(\frac{\theta 2}{\theta 1}\right)}$$



3)

(*i*) The number of tubes required, *N* :

Heat lost by vapour = Heat gained by water

$$\dot{m}_h \times h_{fg} = \dot{m}_c \times c_{pc} \times (t_{c2} - t_{c1})$$

$$8.33 \times 600 = 60 \times 4.18 \times (t_{c2} - 13)$$

$$\therefore \quad t_{c2} = \frac{8.33 \times 600}{60 \times 4.18} + 13 = 32.9°C$$

Logarithmic mean temperature difference (*LMTD*) is given by,

$$\theta_m = \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)} = \frac{(82 - 13) - (82 - 32.9)}{\ln[(82 - 13)/(32.9 - 13)]}$$

$$= \frac{69 - 49.1}{\ln(69/49.1)} = 58.5°C$$

Heat transfer rate is given by,

$$Q = \dot{m}_h \times h_{fg} = U A \theta_m = U (\pi d_o L N) \times \theta_m$$

$$8.33 \times 600 \times 10^3 = 475 \times (\pi \times 0.025 \times 4.87 \times N) \times 58.5$$

$$\therefore \quad N = 470 \text{ tubes}$$ **(Ans.)**

(*ii*) The number of tube passes, *p* :

The cold water flow mass passing through each pass (assume *p* are number of passes) is given by,

$$\dot{m}_c = \left(\frac{\pi}{4} d_i^2 \times V \times \rho\right) \times N_p$$

where, N_p = Number of tubes in each pass ($N = p \times N_p$)

$$60 = \frac{\pi}{4} \times (0.021)^2 \times 2 \times 1000 \times N_p$$

$$\therefore \quad N_p = \frac{60 \times 4}{\pi \times (0.021)^2 \times 2 \times 1000} = 95.5$$

Number of passes, $p = \frac{N}{N_p} = \frac{470}{95.5} = 4.91 = \mathbf{5}$ **(Ans.)**

4)

Solution. *Given :* $t_i = 25°C$, $t_a = 340°C$, $\alpha = 1.6 \times 10^{-3}$ m²/h, $k = 0.94$ W/m°C, $\tau = 8h$, $x = 80$ mm = 0.08 m.

(*i*) The temperature at a point 0.08 m from the surface :

$$\frac{t - t_a}{t_i - t_a} = erf\left[\frac{x}{2\sqrt{\alpha\tau}}\right]$$

or,
$$t = t_a + erf\left[\frac{x}{2\sqrt{\alpha\tau}}\right](t_i - t_a)$$

where,
$$erf\left[\frac{x}{2\sqrt{\alpha\tau}}\right] = erf\left[\frac{0.08}{2\sqrt{1.6\times10^{-3}\times8}}\right] = erf\ (0.353) \simeq 0.37$$

$\therefore$
$$t = 340 + 0.37\ (25 - 340) = \mathbf{223.45°C\ (Ans.)}$$

(*ii*) The instantaneous heat flow rate, (Q_i) at the specified plane :

$$Q_i = -kA\ (t_i - t_a)\ \frac{e^{[-x^2/(4\alpha\tau)]}}{\sqrt{\pi\alpha\tau}}$$

$$= -0.94\times1\times(25-340)\ \frac{e^{[-0.08^2/(4\times1.6\times10^{-3}\times8)]}}{\sqrt{\pi\times1.6\times10^{-3}\times8}}$$

$$= -296.1\times\frac{0.8825}{0.2005} = \mathbf{-1303.08\ W}\ \textbf{per m}^2\textbf{ of wall area (Ans.)}$$

The negative sign shows the *heat lost from the wall.*

Heat flow rate at the surface itself, $Q_{surface}$:

$$Q_{surface} = -\frac{kA\ (t_i - t_a)}{\sqrt{\pi\ \alpha\ \tau}}$$

$$= -\frac{0.94\times1\times(25-340)}{\sqrt{\pi\times1.6\times10^{-3}\times8}} = \mathbf{(-)\ 1476.6\ W\ per\ m^2\ of\ wall\ area\ (Ans.)}$$

5)

Solution. *Given* : $R = \frac{120}{2} = 60$ mm = 0.06 m, $\rho = 990$ kg/m³, $c = 4170$ J/kg°C, $k = 0.58$ W/m°C, $t_i = 25°C$, $t_a = 6°C$, $h = 5.8$ W/m² °C, $\tau = 2$ hours or 7200 s.

The chracteristic length,
$$L_c = \frac{\frac{4}{3}\pi R^3}{4\pi R^2} = \frac{R}{3} = \frac{0.06}{3} = 0.02\ \text{m}$$

Biot number,
$$B_i = \frac{h L_c}{k} = \frac{12.8\times0.02}{0.58} = 0.441$$

Since $B_i > 0.1$, a lumped capacity approach is inappropriate. Further as $B_i < 100$ Heisler charts can be used to obtain the solution of the problem.

The parametric values for the spherical apple are :

$$\frac{1}{B_i} = \frac{1}{0.441} = 2.267$$

$$F_o = \frac{\alpha\tau}{R^2} = \left(\frac{k}{\rho c}\right)\frac{\tau}{R^2} = \left(\frac{0.58}{990\times4170}\right)\times\left(\frac{7200}{0.06^2}\right) = 0.281$$

$$\frac{r}{R} = 0\ \text{(midplane or centre of the apple)}$$

Corresponding to the above values, from the chart for a sphere (Fig. 4.13), we read

$$\frac{t_o - t_a}{t_i - t_a} = 0.75$$

or,
$$\frac{t_o - t_a}{25 - 6} = 0.75$$

or,
$$t_o = 6 + 0.75\ (25 - 6) = \mathbf{20.25°C\ (Ans.)}$$