SLOT: F1+TF1
REG.NO.:

Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

SCHOOL OF MECHANICAL ENGINEERING
CONTINUOUS ASSESSMENT TEST (CAT) -II
WINTER SEMESTER 2024-2025

Programme Name & Branch	**: B. Tech & Mechanical Engineering**
Course Code	**:BMEE402L**
Course Name	**: Heat and Mass Transfer**
Faculty Name(s)	**: Prof. Mohan C.G; Prof. Govindha Rasu N ; Senthil Kumar M, Prof Balaji K; Prof Praveen Kumar G**
Class Number(s)	**: VL2024250503589; 3588; 4091; 3587; 4024**
Date of Examination	**: 21-03-2025**
Exam Duration	**: 90 minutes** **Maximum Marks: 50**

General instruction(s):

- Answer All Questions
- M - Max mark; CO – Course Outcome; BL – Blooms Taxonomy Level (1 – Remember, 2 – Understand, 3 – Apply, 4 – Analyse, 5 – Evaluate, 6 – Create)
- Course Outcomes Statements:
- CO. 1: Solve the steady and unsteady heat conduction problems for simple geometries
- CO. 2: Analyse the natural and forced convective heat transfer processes

Q. No	Question	M	CO	BL
1.	A piece of aluminium weighing 6 kg and initially at a temperature of 300°C is suddenly immersed in a fluid at 20°C. The convection heat-transfer coefficient is 58 W/m²°C. Taking the aluminium as a sphere having the same weight as that given, estimate the time required to cool the aluminium to 90°C.	10	1	4
2.	A 120 mm diameter orange (ρ = 990 kg/m^3, cp = 4170 J/kg°C, k = 0.58 W/m°C), approximately spherical in shape, is taken from a 35°C environment and placed in a refrigerator where the temperature maintained at 4°C. The average convective heat transfer coefficient over the orange surface is 12.8 W/m^2°C. Determine the temperature at the centre of the orange after 2 hours.	10	1	4
3.	During the manufacturing process of hot steel pizza trays, the trays undergo a quenching process to rapidly cool them down for improved material properties. In this process, water at 10°C flows over a 1 m x 1 m hot steel pizza tray plate maintained at 90°C, with a flow velocity of 2 m/s. Determine two key aspects: (a) the length of the plate over which the flow remains laminar, and (b) the total rate of heat transfer from the entire plate surface.	10	2	3

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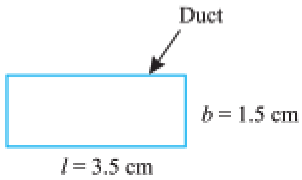
4.	 Determine the length of this duct needed to heat water flowing at 1.2 m/s from an inlet temperature of 40°C to an outlet temperature of 75°C, with the tube wall maintained at a constant temperature of 85°C.	10	2	4
5.	In a dairy processing plant, a heat exchanger is used to cool heated milk before packaging. The system consists of a tube bundle where chilled water flows inside the tubes, and the cooled air crosses over them to extract heat from the milk. A tube bundle transfers heat, where water flows inside the tubes and air crosses over them. The staggered tube arrangement has an outside diameter of 16.4 mm, longitudinal pitch 34.3 mm, and transverse pitch 31.3 mm. The airflow passes over 8 horizontal rows and 7 vertical columns in a staggered arrangement. The cylinder surface temperature is 70°C, while the air upstream temperature and velocity are 15°C and 6 m/s, respectively. Determine the air-side convection coefficient and the rate of heat transfer for the tube bundle.	10	2	4

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Q. No	Question
1.	$m = \rho V \qquad \rho = 2707 \ \mathrm{kg/m^3} \qquad c = 896 \ \dfrac{\mathrm{J}}{\mathrm{kg \cdot ^\circ C}} \qquad h = 58$ $\dfrac{4}{3}\pi r^3(2700) = 6 \qquad r = 0.0807 \ \mathrm{m}$ $A = 4\pi r^2 = 0.0822 \ \mathrm{m^2}$ $\dfrac{hA}{\rho c V} = \dfrac{(58)(0.0822)}{(6)(896)} = 8.87 \times 10^{-4}$ $\dfrac{90-20}{300-20} = \exp(-8.87 \times 10^{-4}\tau) = 0.25$ $\tau = 1563 \ \mathrm{sec}$

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2.	The chracteristic length, $L_c = \dfrac{\frac{4}{3}\pi R^3}{4\pi R^2} = \dfrac{R}{3} = \dfrac{0.06}{3} = 0.02$ m Biot number, $B_i = \dfrac{h L_c}{k} = \dfrac{12.8 \times 0.02}{0.58} = 0.441$ 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 : $\dfrac{1}{B_i} = \dfrac{1}{0.441} = 2.267$ $F_o = \dfrac{\alpha \tau}{R^2} = \left(\dfrac{k}{\rho c}\right)\dfrac{\tau}{R^2} = \left(\dfrac{0.58}{990 \times 4170}\right) \times \left(\dfrac{7200}{0.06^2}\right) = 0.281$ $\dfrac{r}{R} = 0$ (midplane or centre of the apple) Corresponding to the above values, from the chart for a sphere (Fig. 4.13), we read $\dfrac{t_o - t_a}{t_i - t_a} = 0.75$ or, $\dfrac{t_o - t_a}{25 - 6} = 0.75$ or, $t_o = 6 + 0.75\ (25 - 6) =$ **20.25°C (Ans.)**
3	$\mathrm{Re}_c = 500,000 = \dfrac{u_\infty x_c}{\nu}$ Properties of water at 50°C are Density = 988.1°C, Kine Vis= 0.556 *10^{-6} m2/s, Pr = 3.54 and k = 0.648 W/mK

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$$x_c = \frac{500,000 \times 0.556 \times 10^{-6}}{2} = 0.139 \text{ m}$$

The length of plate up to which the flow is laminar is 0.139 m. *Ans*. (a)

Laminar Part:

$$\begin{aligned}
\text{Nu}_c &= 0.664\,(\text{Re}_c)^{1/2}\,(\text{Pr})^{1/3} \\
&= 0.664\,(500,000)^{1/2}\,(3.54)^{1/3} \\
&= 715.08 = \frac{h_m x_c}{k}
\end{aligned}$$

$$h_m = \frac{715.08 \times 0.648}{0.139} = 3333.6 \text{ W/m}^2\text{K}$$

$$\begin{aligned}
Q_{\text{laminar}} &= h_m A(T_\omega - T_\infty) \\
&= 3333.6 \times 0.139 \times 1 \times (90 - 10) \\
&= 37069.6 \text{ W} = 37.07 \text{ kW}
\end{aligned}$$

Turbulent Part

$$\frac{h_m(L - x_c)}{k} = 0.036[(\text{Re}_L)^{0.8} - (\text{Re}_C)^{0.8}]\text{Pr}^{1/3}$$

where $\text{Re}_L = \frac{U_\infty L}{v} = \frac{2 \times 1 \times 10^6}{0.556} = 3.597 \times 10^6$

and $(\text{Re}_L)^{0.8} = 175,692$

$(\text{Re}_c)^{0.8} = (500,000)^{0.8} = 36239$

$\text{Pr}^{1/3} = (3.54)^{1/3} = 1.523$

$$\therefore \quad \frac{h_m(1 - 0.139)}{0.648} = 0.036\,(175692 - 36,239) \times 1.523 = 7645.93$$

$$\therefore \quad h_m = 5754.4 \text{ W/m}^2\text{K}$$

$$\begin{aligned}
Q_{\text{turbulent}} &= 5754.4 \times 0.861 \times 1 \times (90 - 10) \\
&= 396365 \text{ W} = 396.365 \text{ kW}
\end{aligned}$$

$$\begin{aligned}
\therefore \quad Q_{\text{total}} &= Q_{\text{lam.}} + Q_{\text{turb.}} \\
&= 37.07 + 396.37 \\
&= 433.44 \text{ kW}
\end{aligned}$$

Ans. (b)

4. Heat transfer. $Q = mC_p\Delta T = hA(\Delta T)_m$

[ ] 1.5cm
3.5cm

Tube, surface are. $A_s = 2(l+b)\times L$
$= 2(0.035+0.015)\times 1$
$= 0.1\ m^2$

$v = 1.2\ m/s$

$m = A_c \times V\rho = (0.035\times 0.015)\times 1.2\times 985.5$
$= 0.621\ kg/s$

85°C

75°C

40°C

$(\Delta T)_m = \dfrac{(85-40)-(85-75)}{\ln\left(\dfrac{85-40}{85-75}\right)}$

$= 23.3°C$

@57.5°c water.
$\simeq 60°C$
$\rho = 985\ kg/m^3$
$\nu = 0.478\times10^{-6}\ m^2/s$
$k = 0.651$
$C = 4.18\ kJ/kgK$

$Nu = \dfrac{hL_c}{k}$

$L_c = \dfrac{4A_c}{P} = \dfrac{4(l\times b)}{2(l+b)}$

$= \dfrac{4(0.035\times 0.015)}{2(0.035+0.015)}$

$= 0.021\ m$

$Re = \dfrac{VL_c}{\nu}$

$= \dfrac{1.2\times 0.021}{0.478\times10^{-6}}$

$= 0.487\times10^{5}$

$Pr = \dfrac{\mu C_p}{k} = \dfrac{\rho\nu . C_p}{k} = \dfrac{985.8\times 0.478\times10^{-6}\times 4.18\times10^{3}}{0.651}$

$= 3.27$

$Nu = 0.023\ Re^{0.8}\ Pr^{0.33}$

$= 191.23$

$$h = \frac{Nu \cdot k}{L_c} = \frac{191.23 \times 0.653}{0.021}$$

$$= 5946.3 \ W/m^2 C$$

$$mC_p\Delta T = hA \cdot (\Delta T)_M$$

$$0.021 \times 4.19 \times 10^3 \times (75 - 40) = 5946.3 \times 0.1L \ (29.3)$$

$$L = 6.57 \ m$$

5. $\overline{Nu} = \frac{\bar{h} D}{k} = C \cdot Re^m \, Pr^{0.36} \left(\frac{Pr}{Pr_w} \right)^{0.25}$

Staggered $V_{max} = \left(\frac{S_T}{S_T - D} \right) V$

$= \frac{0.0313}{(0.0313 - 0.0164)} \times 6 = 12.6 \, m/s$

$Re_{D,max} = \frac{V_{max} \cdot D}{\nu}$

$= \frac{12.6 \times 0.0164}{14.82 \times 10^{-6}}$

$= 13943$

$C = 0.32$

$m = 0.6$

$n = 0.36$

$\overline{Nu} = 0.32 \cdot (13943)^{0.6} \cdot (0.71)^{0.36} \left(\frac{0.71}{0.705} \right)$

$= 87.9$ (or)

$Nu = C \cdot Re^n$

$\frac{S_T}{D} = \frac{0.0313}{0.0164} = 1.908$

$S_L/D = \frac{0.0343}{0.0164} = 2.091$

$C = 0.482, \; n = 0.556$

$(Nu)_{7 row} = 0.482 \cdot (13943)^{0.556} = 97.12$

Air

$T_\infty = 15°C$

$\rho = 1.217 \, kg/m^3$

$C_p = 1007 \, J/kg°C$

$\nu = 14.82 \times 10^{-6} \, m^2/s$

$k = 0.0253 \, W/m \, K$

$Pr = 0.71$

Air

$T_s = 70°C$

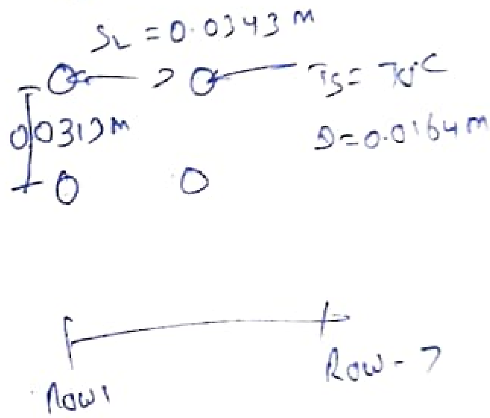
$Pr = 0.694$

$T_f = 45°C$

$\nu = 17.4 \times 10^{-6} \, m^2/s$

$k = 0.0274 \, W/m \, K$

$Pr_w = 0.705$ (wall prop. to)



For 7 tubes

staggered, $CF = 0.97$

$(Nu)_{7 row} = 0.97 \times 97.12$

$= 94.204$

$Nu = \frac{\bar{h} D}{k}$

$\bar{h} = \frac{94.2 \times 0.0253}{0.0164} = 145 \, W/m^2 K$

$T_s - T_0$

Total heat transfer area,

$A = N \cdot \pi D L$

$$\dot m C_p \, dT = h \, dA \, (T_s - T)$$

$$\int_{T_i}^{T_0} \frac{dT}{T_s - T} = \int_0^A \frac{h \cdot dA}{\dot m C_p}$$

$\rho \, Vol$

$\rho \dot V$

$$\ln(T_s - T)\Big|_{T_i}^{T_0} = \frac{hA}{\dot m C_p}$$

$$\ln\left(\frac{T_s - T_0}{T_s - T_i}\right) = -\frac{\pi D N L \cdot h}{\dot m C_p}$$

$$\frac{T_s - T_0}{T_s - T_i} = \exp\left(\frac{-\pi D N \bar h}{\rho V N_T S_T C_p}\right)$$

$$\frac{T_s - T_0}{70 - 15} = \exp\left(\frac{-\pi \cdot (0.0164) \times 56 \times 145}{1.217 \times 6 \times 8 \times 0.0313 \times 1007}\right) = \frac{\pi D N \bar h}{\rho V N_T S_T C_p}$$

q

$$T_s - T_0 = 44.5^\circ C$$

$$(\Delta T)_{lm} = \frac{(T_s - T_i) - (T_s - T_0)}{\ln\left(\frac{T_s - T_i}{T_s - T_0}\right)} = \frac{55 - 44.5}{\ln\left(\frac{55}{44.5}\right)}$$

$$= 49.6^\circ C$$

$$q = N(\bar h \pi D (\Delta T)_{lm})$$

$$= 56 \times 145 \pi \times 0.0164 \times 49.6$$

$$= 19.4 \text{ kW/m}.$$