SLOT: F2+TF2

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

Programme Name & Branch	**: B.Tech & BME, BMA, BMM**
Course Code	**: BMEE402L**
Course Name	**: Heat and Mass Transfer**
Faculty Name(s)	**: TAPANO KUMAR HOTTA, CHIRANJEEVI C, KAMATCHI R, DEEPAKKUMAR R, ASHISH ALEX SAM**
Class Number(s)	**: VL2024250504090; 3593; 6122; 6612; 4023**
Date of Examination	**: 21-03-2025**
Exam Duration	**: 90 minutes** **Maximum Marks: 50**

General instruction(s):

- Use of the standard HMT data book is permitted
- 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.	The heat transfer coefficient for air flowing over a sphere is to be determined by observing the temperature–time history of a sphere made of pure copper. The sphere has a diameter of 12.7 mm and is initially at 66 °C before being inserted into an air stream at 27 °C. A thermocouple on the outer surface of the sphere records a temperature of 55 °C after 69 seconds. Assume, and then justify, that the sphere behaves as a space wise isothermal object and calculate the heat transfer coefficient. **Solution:**	10	1	4

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	Assumption : lumped system diameter, $d = 12.7$ mm $T_i = 66°c$ $T_\infty = 27°c$ $T = 55°C$ time, $t = 69s$ $\frac{T - T_\infty}{T_i - T_\infty} = e^{-bt}$. $\frac{55 - 27}{66 - 27} = e^{-bt}$; $b = 0.00478$ [2 Marks] Properties of Copper [1 Mark] density, $\rho = 8954$ kg/m^3 $\alpha = 112.34 \times 10^{-6}$ m^2/s Specific heat, $c = 383$ J/kg K thermal conductivity, $k = 386$ W/mK [1 Mark] $b = \frac{h A_s}{\rho V C}$ $0.00478 = \frac{h \times (\pi \times 0.0127^2) \times 6}{8954 \times 383 \times (\pi \times 0.0127^3)}$ $A_s = \pi d^2$ $V = \pi d^3/6$ [3 Marks] $h = 34.697$ W/m^2 K Characteristic length, $L_c = D_0/6$ Biot Number, $Bi = \frac{h L_c}{k}$ $= \frac{34.697 \times (0.0127)}{6 \times 386}$ $= 0.00019 < 0.1$ $\therefore$ Spatially isothermal assumption is reasonable. [3 Marks]			
2.	As part of a heat treatment process, cylindrical, 304 stainless steel rods of 100 mm diameter are cooled from an initial temperature of 500 °C by suspending them in an oil bath at 30 °C. If a convection coefficient of 500 W/m^{2}K is maintained by	10	1	4

circulation of the oil, how long does it take for the centerline of a rod to reach a temperature of 50 ℃, at which point it is withdrawn from the bath? If 10 rods of length L = 1 m are processed per hour, determine the required cooling load?

Solution:

Question 2

Properties of Stainless steel from data book

$\rho = 7900\ kg/m^3 \quad \alpha = 3.95\times10^{-6}\ m^2/s$

$c = 477\ J/kgK \quad k = 14.9\ W/mK$

Biot Number, $Bi = \dfrac{h\,(r_0/2)}{k}$

$h = 500\ W/m^2K$

$r = 50mm = 0.05m$

$Bi = \dfrac{500\times0.025}{14.9} = 0.838 > 0.1$ [1 Mark]

Lumped capacitance method not valid

Using Heisler charts

$T_0 = 50^\circ C$

$\dfrac{T_0 - T_\infty}{T_i - T_\infty} = \dfrac{50-30}{500-30} = 0.0426$

$\dfrac{hR_0}{k} = \dfrac{500\times0.05}{14.9} \approx 1.67$ [1 Mark]

From the chart

$\dfrac{\alpha\tau}{R_0^2} = 1.6$

$\tau = \dfrac{1.6\times(0.05)^2}{(3.95\times10^{-6})} = 1012$

$\approx$ 17 minutes [2 Marks]

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	Determine the cooling load $Q_0 = m c_p (T_i - T_\infty)$ $= V \rho c_p (T_i - T_\infty)$ $= \pi (0.05^2) \times 1 \times 7900 \times 477 \times (500-30)$ $= 1.39 \times 10^7$ J [2 Marks] From the heat flow - long cylinder chart $\frac{h^2 \alpha t}{k^2} = \frac{500^2 \times (3.95 \times 10^{-6}) \times 1012}{14.9^2}$ $= 4.5$ $\frac{h R_o}{k} = 1.67$ $Q/Q_0 = 0.98$ $Q = 0.98 Q_0 = 1.3622 \times 10^7$ J [2 Marks] Nominal cooling load for 10 rods $= \frac{10 \times 1.3622 \times 10^7}{1012} = 1.34 \times 10^5$ W $= 134$ kW [2 Marks]			
3.	Air at a pressure of 1 atm and a temperature of 40 °C is in parallel flow over the top surface of a flat plate that is heated to a uniform temperature of 100 °C. The plate has a length of 0.20 m (in the flow direction) and a width of 0.10 m. The Reynolds number based on the plate length is 40,000. What is the rate of heat transfer from the plate to the air? With the pressure remaining same, if the free stream velocity of the air is doubled, what is the rate of heat transfer? **Solution:**	10	2	3

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Question 3

Air at 1 atm and $T = 40°C$

Flow over flat plate $L = 0.2\,m$

$Re = 40{,}000$

$$T_f = \frac{40+100}{2} = 70°C$$

$\rho = 1029\ kg/m^3$

$\nu = 20.02 \times 10^{-6}\ m^2/s$

$\alpha = 28.556 \times 10^{-6}\ m^2/s$

$P_r = 0.694$ [1 Mark]

$c = 1009\ J/kg\,K$

$k = 0.02966\ W/mK.$

Since $Re = 4 \times 10^4$, flow is laminar

$$Nu_L = 0.664 \times Re_x^{0.5}\ P_r^{0.33}$$
$$= 0.664 \times (4 \times 10^4)^{0.5} \times (0.694)^{0.33}$$
$$= 117.9 \quad [3\ \text{Marks}]$$

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

$$h = \frac{Nu_L \times k}{L} = \frac{117.9 \times 0.02966}{0.2}$$

$$= 17.48\ W/m^2K \quad [1\ \text{Mark}]$$

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	$Q = hA\Delta T$ $= 17.48\,(0.2 \times 0.1) \times (100-40)$ $= \underline{20.98\ W}$ [1 Mark] (b) if velocity is doubled $Re = 8 \times 10^4$ Still the flow is laminar $Nu_L = 0.664 \times (8 \times 10^4)^{0.5} \times (0.694)^{0.33}$ $= \underline{166.479}$ [2 Marks] $h = \frac{Nu_L \times k}{L} = \frac{166.479 \times 0.0296}{0.2}$ $= \underline{24.638}$ [1 Mark] $Q = hA\Delta T = 24.638 \times (0.2 \times 0.1) \times 60$ $= \underline{29.56\ W}$ [1 Mark]			
4.	Air at 100 kPa and 30 °C enters a 4.0 mm diameter tube with a mass flow rate of 7×10^{-5} kg/s. A constant heat flux is imposed at the tube surface so that the tube wall temperature is 70 °C above the fluid bulk temperature. Calculate the exit air temperature for a tube length of 12 cm. **Solution:**	10	2	4

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Question 4

$T_m = \frac{30+70}{2} = 50^\circ C$

$\rho = 1.093\ kg/m^3$
$\nu = 17.95 \times 10^{-6}\ m^2/s$
$P_r = 0.698$
$c = 1005\ J/kg\,K$
$k = 0.02826\ W/mK$

diameter, $d = 4mm = 0.004\ m$

$\dot{m} = \rho A V$

Velocity $V = \frac{\dot{m}}{\rho A} = \frac{7 \times 10^{-5} \times 4}{1.093 \times \pi (0.004)^2}$

$= 5.096\ m/s$

$Re_D = \frac{VD}{\nu} = \frac{5.096 \times 0.004}{17.95 \times 10^{-6}}$

$= 1135.6 < 2300$. [2 Marks]

Flow is laminar

Hydrodynamic entry length

$x = 0.04\ D\ Re_D$
$= 0.04 \times 0.004 \times 1135.6$
$= 0.1817\ m$ [1 Mark]

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	Thermal entry length $x = 0.04 D Re_D \cdot Pr$ $= 0.1817 \times 0.698$ $= \underline{0.1268\ m}$ [1 Mark] Length of the tube is 12 cm = 0.12m Simultaneous development of hydrodynamic & thermal boundary layers. $Nu = 3.66 + \frac{0.104 (Re_D \cdot Pr \cdot D/x)}{1 + 0.16 (Re_D \cdot Pr \cdot D/x)^{0.8}}$ $= 3.66 + \frac{0.104 (1135.6 \times 0.698 \times 0.004/0.12)}{1 + 0.16 (1135.6 \times 0.698 \times 0.004/0.12)^{0.8}}$ $= 3.66 + 0.859 = \underline{4.52}$ [2 Marks] $Nu = \frac{hD}{k}$ $h = \frac{4.52 \times 0.02826}{0.004} = \underline{31.93\ W/m^2 K}$ [2 Marks] To find temperature at the exit. $h A (T_w - T_b) = \dot{m} C_p (T_e - T_i)$ $31.93 \times \pi \times (0.004) \times (0.12) \times 70$ $= 7 \times 10^{-5} \times 1005 \times (T_e - 27)$ $T_e - T_i = 47.91\ °C$ $T_e = 47.91 + 27 = \underline{74.91°C}$ [2 Marks]			
5.	A tube bank uses an in-line arrangement with $S_l = S_t = 1.9$ cm and 6.33-mm diameter tubes. Six rows of tubes are employed with a stack 50 tubes high. The surface temperature of the tubes is constant at 80 °C, and atmospheric air at 20 °C is forced across them at an inlet velocity of 4.5 m/s before the flow enters the tube bank. Calculate the total heat transfer per unit length for the tube bank. **Solution:**	10	2	4

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Question 5

$S_L/D = S_T/D = 1.9/0.633 = 3$

$V_\infty = 4.5 m/s$

$T_m = \frac{80+20}{2} = \underline{\underline{50^\circ C}}$

$\rho = 1.093 \ kg/m^3$

$\nu = 17.95 \times 10^{-6} \ m^2/s$

$Pr = 0.698$

$k = 0.02826 \ W/mK$

$V_{max} = V_\infty \left(\frac{S_T}{S_T - d} \right)$ [2 Marks]

$= \underline{\underline{6.75 m/s}}$

$Re = \frac{VD}{\nu} = \frac{6.75 \times 0.00633}{17.95 \times 10^{-6}}$ [1 Mark]

$= \underline{\underline{2380.36}}$

$C = 0.2860 \quad n = 0.608$

Correction factor, $f = 0.94$

$Nu = C \ Re^n$

$= 0.2860 \times (2380.36)^{0.608} \times 0.94$ [2 Marks]

$= \underline{\underline{30.373}}$

$h = \frac{Nu \ k}{D} = \frac{30.373 \times 0.02826}{0.00633}$

$= \underline{\underline{135.59 \ W/m^2 K}}$ [2 Marks]

$Q/L = 135.59 \times (\pi \times 0.00633) \times 6 \times 50 \times (80 - 20)$

$= 48.54 \ kW/m$ [3 Marks]

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