Name:	
Enrolment No:	

UPES
End Semester Examination, May 2023

Course: Heat and Mass Transfer — **Semester: IV**
Program: B.Tech Food Technology — **Time : 03 hrs.**
Course Code: MECH2037 — **Max. Marks: 100**

Instructions: Read all the questions carefully. Assume suitable value of parameters/variables if it is not given.

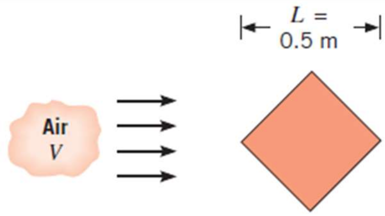
SECTION A
(5Qx4M = 20Marks)

S. No.		Marks	CO
Q 1	Explain governing forces and important non-dimensional numbers used in forced and free convection analysis. Why convective heat transfer coefficient is different for entrance and fully developed regions of the internal forced convection?	**4**	**CO1**
Q 2	10 kg of water at 15°C is converted in to steam at atmospheric condition. What is the value of sensible heat and latent heat added to the steam? (The specific heat capacity of water = 4.20 kJ/(kg K), Latent heat of vaporization of water = 2250 kJ/kg)	**4**	**CO2**
Q 3	When is a heat exchanger classified as being compact? What are the heat transfer mechanisms involved during heat transfer in a liquid-to-liquid heat exchanger from the hot to the cold fluid?	**4**	**CO1**
Q 4	Explain the Log mean temperature difference (LMTD) and effectiveness-NTU methods used in the analysis of heat exchangers.	**4**	**CO1**
Q 5	What is a blackbody? Does a blackbody actually exist? Consider a surface at a uniform temperature of 800 K. Determine the maximum rate of thermal radiation that can be emitted by this surface, in W/m^2. (Stefan Boltzmann constant: 5.67×10^{-8} $W/m^2 \cdot K^4$)	**4**	**CO2**

SECTION B
(4Qx10M = 40 Marks)

Q 6	What is the driving force for mass diffusion? Explain Fick's law of mass diffusion and differentiate between diffusion and convection mass transfer phenomena? Pressurized hydrogen gas is stored at 358 K in a 1.2-m-outer-diameter cylindrical container made of nickel. The shell of the container is 6 cm thick.	**5+5**	**CO2**

	The molar concentration of hydrogen in the nickel at the inner surface is determined to be 0.087 kmol/m^3. The concentration of hydrogen in the nickel at the outer surface is negligible. Determine the mass flow rate of hydrogen by diffusion through the nickel container. Assume mass diffusion is steady and one-dimensional and the binary diffusion coefficient for hydrogen in the nickel at the specified temperature is 1.2×10^{-12} m^2/s.		
Q 7	An electrical water heater uses natural convection to transfer heat from a 1-cm-diameter by 0.65-m-long, 110 V electrical resistance heater to the water. During operation, the surface temperature of this heater is 120°C while the temperature of the water is 35°C, and the Nusselt number (based on the diameter) is 5. Calculate the current passing through the electrical heating element. (Thermal conductivity of water, k = 0.61 W/m-K)	**10**	**CO4**
Q 8	In the final stages of production, a pharmaceutical is sterilized by heating it from 25 to 75ºC as it moves at 0.2 m/s through a straight thin-walled stainless steel tube of 12.7-mm diameter. A uniform heat flux is maintained by an electric resistance heater wrapped around the outer surface of the tube. If the tube is 10 m long, what is the required heat flux? If fluid enters the tube with a fully developed velocity profile and a uniform temperature profile, what is the surface temperature at the tube exit? (Fluid properties may be approximated as Cp = 4000 J/kg K, μ = 2x10^3 kg/m-s, ρ = 1000 kg/m^3, k = 0.8 W/m-K)	**10**	**CO4**
Q 9	During air cooling of oranges, grapefruit, and tangelos, the heat transfer coefficient for combined convection, radiation, and evaporation for air velocities of 0.11 < V < 0.33 m/s is determined experimentally and is expressed as $h = 5.05\, k_{air} Re^{1/3}/D$, where the diameter D is the characteristic length. Oranges are cooled by refrigerated air at 5°C and 1 atm at a velocity of 0.2 m/s. Determine (*a*) the initial rate of heat transfer from a 7-cm-diameter orange initially at 15°C with a thermal conductivity of 0.50 W/m-K, and (*b*) the value of the Nusselt number. (Thermal conductivity of air = 0.025 W/m-K) **OR** Experimental measurements of the convection heat transfer coefficient for a square bar in cross flow yielded the following values: h_1 = 50 W/m^2 K when 20 m/s and h_2 = 40 W/m^2 K when 15 m/s	**10**	**CO4**

	 Assume that the functional form of the Nusselt number is: $Nu = C\,Re^{m}\,Pr^{n}$, where C, m, and n are constants. What will be the convection heat transfer coefficient for a similar bar with L = 1 m when V = 15 m/s?		
SECTION-C **(2Qx20M = 40 Marks)**			
Q 10	A liquid food is being conveyed through an uninsulated pipe at 90°C. The product flow rate is 0.25 kg/s and has a density of 1000 kg/m^3, specific heat of 4 kJ/(kg K), viscosity of 8×10^{-3} Pa-s, and thermal conductivity of 0.55 W/(m-K). Assume the viscosity correction is negligible. The internal pipe diameter is 20 mm with 3 mm thickness made of stainless steel (k = 15 W/[m-K]). The outside temperature is 15°C. If the outside convective heat-transfer coefficient is 18 W/(m^2 K), calculate (a) the internal convective heat transfer coefficient and rate of heat transfer at tube lengths (i) L = 0.75 m and (ii) L = 3 m (b) If flow rate is increased to 1.25 kg/s, what would be the value of convective heat transfer coefficient in fully developed regions of the flow. Use Nusselt number correlations provided at the end, as per requirement.	**20**	**CO5**
Q 11	Hot water (c_{ph} = 4.18 kJ/kg-K) with mass flow rate of 2.5 kg/s at 100°C enters a thin-walled concentric tube counterflow heat exchanger with a surface area of 23 m^2 and an overall heat transfer coefficient of 1000 W/m^2-K. Cold water (c_{pc} = 4.18 kJ/kg-K) with mass flow rate of 5 kg/s enters the heat exchanger at 20°C, determine (*a*) the heat transfer rate for the heat exchanger and (*b*) the outlet temperatures of the cold and hot fluids. After a period of operation, the overall heat transfer coefficient is reduced to 500 W/m^{2}K, determine (*c*) the fouling factor that caused the reduction in the overall heat transfer coefficient. Use *effectiveness-NTU* correlation provided below wherever required. **(*NTU* = *UA*$_s$/*C*$_{min}$)** Counter-flow $\quad \varepsilon = \dfrac{1 - \exp[-\mathrm{NTU}(1-c)]}{1 - c\exp[-\mathrm{NTU}(1-c)]}$ (for $c < 1$) $\varepsilon = \dfrac{\mathrm{NTU}}{1 + \mathrm{NTU}}$ (for $c = 1$) **OR**	**20**	**CO5**

	In a parallel flow heat exchanger, hot fluid enters the heat exchanger at a temperature of 150°C and a mass flow rate of 3 kg/s. The cooling medium enters the heat exchanger at a temperature of 30°C with a mass flow rate of 0.5 kg/s and leaves at a temperature of 70°C. The specific heat capacities of the hot and cold fluids are 1.15 kJ/kg·K and 4.18 kJ/kg·K, respectively. The convection heat transfer coefficient on the inner and outer side of the tube is 300 $W/m^2 \cdot K$ and 800 $W/m^2 \cdot K$, respectively. For a fouling factor of 0.0003 $m^2 \cdot K/W$ on the tube side and 0.0001 $m^2 \cdot K/W$ on the shell side, determine (a) the overall heat transfer coefficient, (b) the exit temperature of the hot fluid and (c) surface area of the heat exchanger.		

Nusselt number correlations:

Fully developed laminar flow in tube:	*Circular tube, laminar* ($\dot{q}_s$ = constant): $\text{Nu} = \frac{hD}{k} = 4.36$ *Circular tube, laminar* (T_s = constant): $\text{Nu} = \frac{hD}{k} = 3.66$
Entry region laminar flow in tubes:	$\text{Nu} = 1.86\left(\frac{\text{Re Pr } D}{L}\right)^{1/3}\left(\frac{\mu_b}{\mu_s}\right)^{0.14}$
Fully developed turbulent flow in tube (Dittus-Boelter correlation):	$\text{Nu} = 0.023\ \text{Re}^{0.8}\ \text{Pr}^n$ $\quad \frac{L}{D} \gtrsim 10 \quad Re_D \gtrsim 10{,}000$ n = 0.4 for heating and 0.3 for cooling