MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

DEPARTMENT OF BIOTECHNOLOGY

IV SEMESTER B.TECH. (BIOTECHNOLOGY)

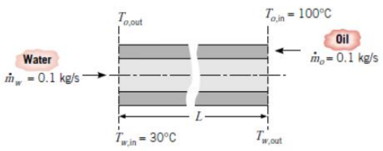
END SEMESTER EXAMINATIONS, MAY 2024

SUBJECT: PRINCIPLES OF HEAT AND MASS TRANSFER [BIO2224]

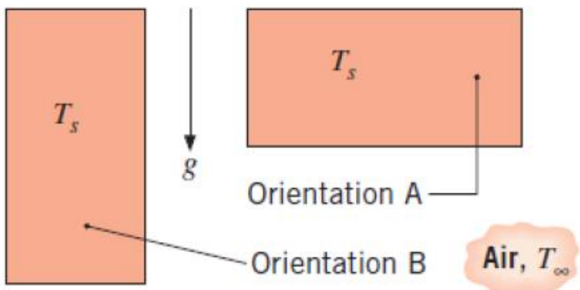
Time: 3 Hours **MAX. MARKS: 50**

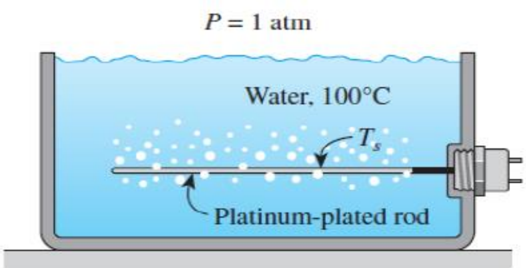
Instructions to Candidates:

- Answer **ALL** the questions.
- Any data not provided may be suitably assumed.

<table>
<tr><th>Q. No</th><th>Question</th><th>M</th><th>CO</th><th>PO</th><th>BL</th></tr>
<tr><td>1A</td><td>A block of ice with a temperature of 0 °C lies on the upper surface of 2400 cm^2 slab of stone of thickness 10 cm. The slab is steam-exposed on the lower surface at a temperature of 100 °C. Find the heat conductivity of stone in cal/cm.s, if 4000 g of ice is melted in one hour given that the latent heat of fusion of ice is 80 cal ⁄ gm.</td><td>3</td><td>1</td><td>1,2,3,4,
5,6,11,
12</td><td>3</td></tr>
<tr><td>1B</td><td>A concentric tube heat exchanger for cooling lubricating oil is comprised of a thin-walled inner tube of 25-mm diameter carrying water and an outer tube of 45-mm diameter carrying the oil. The exchanger operates in counterflow with an overall heat transfer coefficient of 60 W/m^2. K and the tabulated average properties. (a) If the outlet temperature of the oil is 60°C, determine the total heat transfer and the outlet temperature of the water. (b) Determine the length required for the heat exchanger. (4)


<table>
<tr><th>Properties</th><th>Water</th><th>Oil</th></tr>
<tr><td>ρ (kg/m^3)</td><td>1000</td><td>800</td></tr>
<tr><td>c_p (J/kg · K)</td><td>4200</td><td>1900</td></tr>
<tr><td>ν (m^2/s)</td><td>7×10^{-7}</td><td>1×10^{-5}</td></tr>
<tr><td>k (W/m · K)</td><td>0.64</td><td>0.134</td></tr>
<tr><td>Pr</td><td>4.7</td><td>140</td></tr>
</table></td><td>4</td><td>1</td><td>1,2,3,4,
5,6,11,
12</td><td>3</td></tr>
<tr><td>1C</td><td>The Boiler wall is made up of two layers, A & B. Thickness & Thermal conductivity of A are 240 mm and 0.2 W/m^0C respectively. For B, thickness & thermal conductivity are 525 mm and 0.3 W/m^0C respectively. Inner surface of A is maintained at 1000^0C and outer surface of B is maintained at 250^0C. If there is contact thermal resistance of $0.05^0C/W$ per unit area exists at the interface . Calculate,
i. the heat lost per m^2 area
ii. The temperature drop at the interface</td><td>3</td><td>1</td><td>1,2,3,4,
5,6,11,
12</td><td>3</td></tr>
</table>

2A	A 200W heater has a spherical casing of diameter 0.2m. The heat transfer coefficient for conduction and convection from the casing to the ambient air is obtained from $Nu = 2 + 0.6Re^{0.5}\ Pr^{0.333}$, with Re = 104 and Pr = 0.69. The temperature of the ambient air is 30^0 C and the thermal conductivity of air is k = 0.02 W/m.K. i. Find the heat flux from the surface at steady state. ii. Find the steady state surface temperature of the casing. Find the temperature of the casing at steady state for stagnant air. Why is this situation physically infeasible?	**3**	**2**	1,2,3,4, 5,6,11, 12	**3**
2B	Consider a vertical plate of dimensions 0.25mx0.5m with $T_S=100^0C$ in a quiescent temperature of $T_\infty = 20^0C$. In the interest of minimizing heat transfer from plate, which orientation A or B is preferred? What is the convective heat transfer (W) from the preferred orientation? Use properties $\nu=\mu/\rho= 1.92\times10^{-6}\ m^2/s$, k=0.0287W/mK, Pr=0.702, $\alpha=k/\rho C_p = 2.74\times10^{-6} m^2/s$. $Ra=GrPr=g\beta\Delta T\ L^3/\alpha\nu$; $\beta=1/T$; (4) $Nu = 0.68 + \frac{0.67 Ra^{1/4}}{\left[1+\left(\frac{0.492}{Pr}\right)^{9/16}\right]^{4/9}}$  	**4**	**2**	1,2,3,4, 5,6,11, 12	**3**

2C	Acetone at 56^0 C is being condensed on the inside surface of a horizontal tube of 3 m length and 50 mm OD, the flow rate of cooling water entering at 20^0 C and leaving at 40^0 C (flowing outside the tube), is 0.0644 kg/s. Average properties of condensate ρ=784 kg/m^3, k=0.161 W/mK, Cp=2172 J/kgK, μ=0.306mPa.s, λ=518kJ/kg Assume negligible tube thickness, water Cp=4200 J/kgK, Determine the tube surface temperature. $$\bar{h} = 0.555\left(\frac{\rho^2 k^3 g\lambda}{\mu D\Delta T}\right)^{0.25}$$	**3**	**2**	1,2,3,4, 5,6,11, 12	**3**
3A	A surface is at 200^0C and is exposed to surroundings at 60^0C and convects and radiates heat to the surroundings. The convection coefficient is 80W/m.K. If the heat is conducted to the surface through a solid of conductivity 12 W/m.K, determine the temperature gradient at the surface of the solid. σ= 5.67x10^{-8}W/m^2 K^4.	**3**	**3**	1,2,3,4, 5,6,11, 12	**3**
3B	Distinguish between (1) Red hot substance and white hot substance (2) Diffuse reflection and Specular reflection	**2**	**3**	1,2,3,4, 5,6,11, 12	**3**
3C	Water is boiled at atmospheric pressure by horizontal platinum coated wire with diameter 10 mm. If the surface temperature is at 110^0C, determine the nucleate boiling heat transfer coefficient, Heat transfer $q_{nucleate}$(W/m^2) is given by the below equation; h_{fg}=2257kJ/kg, ρ_l=957.9 kg/m^3,μ_l=0.282x10^{-3}kg/m.s, C_{pl}=4217 kJ/kg ^{0}C, Pr_l=1.75, ρ_v=0.6 kg/m^3, n=1, σ=0.0589 N/m; C_{sf}=0.013. $$\dot{q}_{\text{nucleate}} = \mu_l h_{fg}\left[\frac{g(\rho_l-\rho_v)}{\sigma}\right]^{1/2}\left(\frac{c_{pl}(T_s-T_{sat})}{C_{sf}h_{fg}\,\mathrm{Pr}_l^n}\right)^3$$ 	**5**	**3**	1,2,3,4, 5,6,11, 12	**3**

4A	When a certain sample of moist soap is exposed to air at 75^0C, 1 atm, the equilibrium distribution of moisture between soap and air is tabulated below I: 0, 2.40, 3.76, 4.76, 6.10, 7.83, 9.90, 12.63, 15.40, 19.02 II: 0, 9.66, 19.20, 28.40, 37.20, 46.40, 55.00, 63.20, 71.90, 79.50 where I = wt% moisture in soap; II= Partial pressure of water in air, mmHg Convert this data to kg moisture/kg dry soap (x) vs kg moisture/kg dry air (y) and plot.	**4**	**4**	1,2,3,4, 5,6,11, 12	**3**
4B	Given a 50% by volume ammonia gas diffusing across a 1cm long section of tubing with a diameter of 1cm , where the opposite end of the tubing has a 10% ammonia concentration, temperature is 295K, the pressure is atmospheric, and the diffusivity of ammonia in air under these conditions is 1.8×10^{-5} m^2/s. Estimate the rate of diffusion of ammonia through the section of tubing. R=8.315 J/molK. (2)	**2**	**4**	1,2,3,4, 5,6,11, 12	**3**
4C	The equilibrium relationship between mole fraction of an active component in liquid (x) and partial pressure in vapor (P_A, mm Hg), at total pressure of 1 atm, is given by $x=0.00154P_A$. If K_x=1.82 and K_y= 2.15, compute k_x and k_y, percentage of resistance offered by the liquid phase and vapor phase. Total pressure is atmospheric. (4) $\frac{1}{K_x}=\frac{1}{k_x}+\frac{1}{mk_y};\ \frac{1}{K_y}=\frac{1}{k_y}+\frac{m}{k_x}$ (3)	**4**	**5**	1,2,3,4, 5,6,11, 12	**3**
5A	Water flows through a thin tube, the walls of which are lightly coated with benzoic acid. The benzoic acid is dissolved very rapidly and so is saturated at the pipe's wall for negligible thickness. The water flows slowly, at room temperature and v cm/s. The pipe diameter (d=2R). Under these conditions the mass transfer coefficient varies along the pipe. $\frac{kd}{D}=1.62\left(\frac{d^2V}{DL}\right)^{\frac{1}{3}}$ where L is the length of the pipe (cm), k is the mass transfer coefficient for benzoic acid in water cm/s, v is average velocity in the pipe (cm/s), D=diffusivity of benzoic acid in water, Solubility of benzoic acid= C_{sat} (25°C) Assume uniform concentration (C) throughout cross section of the pipe at any particular length, L. Prove that	**4**	**5**	1,2,3,4, 5,6,11, 12	**3**

	$e^{C_{sat}} - e^{C_{sat}-C} = 3.85(\frac{DV^2L^2}{R^4})^{\frac{1}{3}}$				
5B	Define and explain the following dimensionless Mass Transfer numbers (i) Schmidt number (ii) Sherwood number (iii) Peclet number	**2**	**5**	1,2,3,4, 5,6,11, 12	**3**
5C	It is desired to reduce the ammonia content of 0.05 m^3/s (27°C/1 std. atm.) of an ammonia air mixture from 5.0 to 0.5% (by volume) by pure water scrubbing (absorption) i. Plot X-Y diagram and calculate G_S ii. What is the minimum rate of water required and the corresponding ammonia concentration in outlet water ? iii. If water flow rate is 1.5 times the minimum, what is the number of equilibrium tray required, and the ammonia concentration in outlet water? Data: At 27°C, y=1.5x ; R=8.314 J/molK (4)	**4**	**5**	1,2,3,4, 5,6,11, 12	**3**