UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	MASS TRANSFER
COURSE CODE	:	BNQ 20303
PROGRAMME CODE	:	BNN
EXAMINATION DATE	:	JULY/AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **ALL** QUESTIONS 2.THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK.** 3.STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **ELEVEN (11)** PAGES

Q1 (a) Siva has difficulties to differentiate between molecular diffusion and convective mass transfer. Conduct a simple experiment to help Siva to understand better the differences between them.

(4 marks)

(b) There were two experiments in membrane separation laboratory. The first one was to determine the membrane resistance while the second one was to check the salt rejection for the selected membrane. Both experiments were conducted at various pressure differences. In your own words, explain your understanding for both experiments. The explanation should include the objective of the experiment and the outcome that you need to inspect.

(6 marks)

(c) In a spray dryer experiment, 100 g of milo powder was dissolved in 500 ml of hot water. The milo solution was inserted into the spray dryer unit at 200 °C. After 10 minutes, the solution was dried, and the final product collected was 65 g milo powder.

(i) Discuss why the product did not have the same amount as the initial milo powder (100 g).

(3 marks)

(ii) Calculate the efficiency of the spray dryer in percentage (%).

(2 marks)

(d) There are two methods to obtain salt from salt solution in crystallization experiment.

(i) State the two methods mentioned above.

(1 marks)

(ii) Draw a flow chart on how you conduct the experiment from weighing the salt until achieving the final product.

(4 marks)

(e) A final-year project student needs to extract bioactive compounds from selected plants. After the extraction process, he needs to isolate those compounds from plant matrices.

(i) Propose a method for isolating the compounds.

(1 mark)

(ii) Explain how the isolation process applies.

(4 marks)

Q2 A solution of n-propanol (A)-water (B) at 298 K is in contact with hexane. The n-propanol-water solution is stagnant with thickness of 5 mm. Propanol is soluble in hexane, while water is totally immiscible with hexane. Thus, propanol diffuses through the stagnant solution, and dissolves into the hexane layer. The concentration of n-propanol at the interface of solution-hexane is 6.0 wt% and the solution density at this point is 988.1 kg/m^3. At point 2, (5 mm away from the interface), the propanol concentration is 18 wt% and the solution density is 972.8 kg/m^3.

Additional Data:
n-propanol = C_3H_7OH, Water = H_2O,
C=12, H=1, O=16,
Water viscosity,μ_B = 0.8937 x 10^{-3} Pa.s,
Association parameter of water, φ=2.6,
Atomic molar volume of A, V_A=81.4x10^3 m^3/kg.mol.

(a) Calculate the average concentration (C_{av}) of the solution.

(15 marks)

(b) Calculate the diffusivity of the solution (D_{AB}) using Wilke-Chang Correlation equation.

(5 marks)

(c) Determine the steady state flux, N_A.

(5 marks)

Q3 Mercury (in liquid form) at 26.5 °C is flowing through a packed bed of lead spheres having a diameter of 2.096 mm with a void fraction of 0.499. The superficial velocity is 0.02198 m/s. The weight estimation of the lead and mercury is 1.721 kg and 98.279 kg respectively. The Schmidt number is 124.1, the viscosity of the solution is 1.577 x 10^{-3} Pa.s, and the density is 13530 kg/m^3. The molecular weight of lead is 207.19 kg/mol and 200.59 kg/mol for mercury.

(a) Draw and label the situation mentioned above.

(5 marks)

(b) Calculate the value of J_D.

(5 marks)

(c) Determine the value of k_c for the case of A diffusing through non-diffusing B by referring to **Table Q3(c)**.

(15 marks)

Q4 A very thick slab has a uniform concentration of solute A of c_o = 1.0 x 10^{-2} kg mol A/m^3. Suddenly, the front face of the slab is exposed to a flowing fluid having a concentration c_1 = 0.1 kg mol A/m^3 and a convective coefficient k_c = 2 x 10^{-7} m/s. The equilibrium distribution coefficient and the diffusivity in the solid are K= c_{Li}/c_i = 2.0 and D_{AB} = 4 x 10^{-9} m^2/s respectively. Assume that the slab is a semi-infinite solid.

(a) Draw and label the situation mentioned above.

(5 marks)

(b) By referring to **Figure Q4 (b)** and **Table Q4 (b)**, determine the concentration in the solid at the surface after t = 3 x 10^4 s at the following distance from the surface,

(i) x = 0 m

(10 marks)

(ii) x = 0.01 m

(10 marks)

- END OF QUESTIONS-

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Unit Conversion

Table 1: Unit Conversion Factors

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz
	1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 μm = 10^{10} Å
	1 m = 39.37 in = 3.2808 ft = 1.0936 yd = 0.0006214 mile
	1 ft = 12 in = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 liters = 10^6 cm^3 = 10^6 ml
	1 m^3 = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt
	1 ft^3 = 1728 in^3 = 7.4805 gal = 0.028317 m^3 = 28.317 liters = 28317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f
	1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bars
	1 atm = 1.01325×10^6 dynes/cm^2
	1 atm = 760 mmHg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/in^2 (psi)
	1 atm = 33.9 ft H_20 at 4°C = 29.921 inHg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h
	1 J = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 1.341×10^{-3} hp

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Table Q3 (c) Flux Equations and Mass Transfer Coefficients

Flux equations for equimolar counterdiffusion

Gases: $N_A = k'_c(c_{A1} - c_{A2}) = k'_G(p_{A1} - p_{A2}) = k'_y(y_{A1} - y_{A2})$

Liquids: $N_A = k'_c(c_{A1} - c_{A2}) = k'_L(c_{A1} - c_{A2}) = k'_x(x_{A1} - x_{A2})$

Flux equations for A diffusing through stagnant, nondiffusing B

Gases: $N_A = k_c(c_{A1} - c_{A2}) = k_G(p_{A1} - p_{A2}) = k_y(y_{A1} - y_{A2})$

Liquids: $N_A = k_c(c_{A1} - c_{A2}) = k_L(c_{A1} - c_{A2}) = k_x(x_{A1} - x_{A2})$

Conversions between mass-transfer coefficients

Gases:

$$k'_c c = k'_c \frac{P}{RT} = k_c \frac{p_{BM}}{RT} = k'_G P = k_G p_{BM} = k_y y_{BM} = k'_y = k_c y_{BM} c = k_G y_{BM} P$$

Liquids:

$$k'_c c = k'_L c = k_L x_{BM} c = k'_L \rho / M = k'_x = k_x x_{BM}$$

(where ρ is density of liquid and M is molecular weight)

Units of mass-transfer coefficients

	SI Units	*Cgs Units*	*English Units*
k_c, k_L, k'_c, k'_L	m/s	cm/s	ft/h
k_x, k_y, k'_x, k'_y	$\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{mol frac}}$	$\frac{\text{g mol}}{\text{s} \cdot \text{cm}^2 \cdot \text{mol frac}}$	$\frac{\text{lb mol}}{\text{h} \cdot \text{ft}^2 \cdot \text{mol frac}}$
k_G, k'_G	$\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{Pa}}$ (preferred) $\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{atm}}$	$\frac{\text{g mol}}{\text{s} \cdot \text{cm}^2 \cdot \text{atm}}$	$\frac{\text{lb mol}}{\text{h} \cdot \text{ft}^2 \cdot \text{atm}}$

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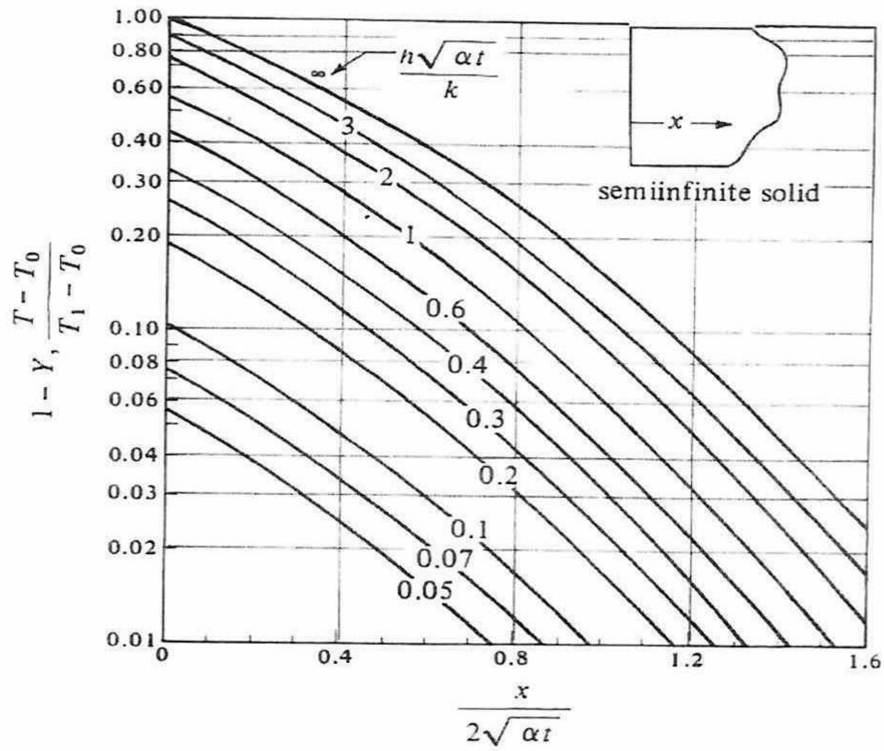

Figure Q4 (b) Unsteady-state conducted in a semiinfinite solid with surface convection

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Table Q4 (b) Relation between mass and heat transfer parameters for unsteady state diffusion

	Mass Transfer	
Heat Transfer	$K = c_L/c = 1.0$	$K = c_L/c \neq 1.0$
$Y, \dfrac{T_1 - T}{T_1 - T_0}$	$\dfrac{c_1 - c}{c_1 - c_0}$	$\dfrac{c_1/K - c}{c_1/K - c_0}$
$1 - Y, \dfrac{T - T_0}{T_1 - T_0}$	$\dfrac{c - c_0}{c_1 - c_0}$	$\dfrac{c - c_0}{c_1/K - c_0}$
$X, \dfrac{\alpha t}{x_1^2}$	$\dfrac{D_{AB}\,t}{x_1^2}$	$\dfrac{D_{AB}\,t}{x_1^2}$
$\dfrac{x}{2\sqrt{\alpha t}}$	$\dfrac{x}{2\sqrt{D_{AB}\,t}}$	$\dfrac{x}{2\sqrt{D_{AB}\,t}}$
$m, \dfrac{k}{hx_1}$	$\dfrac{D_{AB}}{k_c\,x_1}$	$\dfrac{D_{AB}}{Kk_c\,x_1}$
$\dfrac{h}{k}\sqrt{\alpha t}$	$\dfrac{k_c}{D_{AB}}\sqrt{D_{AB}\,t}$	$\dfrac{Kk_c}{D_{AB}}\sqrt{D_{AB}\,t}$
$n, \dfrac{x}{x_1}$	$\dfrac{x}{x_1}$	$\dfrac{x}{x_1}$

* x is the distance from the center of the slab, cylinder, or sphere; for a semiinfinite slab, x is the distance from the surface. c_0 is the original uniform concentration in the solid, c_1 the concentration in the fluid outside the slab, and c the concentration in the solid at position x and time t.

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FORMULA

1) Molecular Diffusion

Wilke-Chang Correlation

$$D_{AB} = 1.173\text{x}10^{-16}(\varphi M_B)^{1/2}\frac{T}{\mu_B V_A^{0.6}}$$

φ - Association parameter: 2.6 (water), 1.9 (methanol), 1.0 (benzene and other organic solvent)
V_A - atomic molar volume of A

$$x_{A1} = \frac{w_{A1}/M_A}{w_{A1}/M_A + w_{B1}/M_B}$$

$$x_{A2} = \frac{w_{A2}/M_A}{w_{A2}/M_A + w_{B2}/M_B}$$

$$M_1 = x_{A1}M_A + x_{B1}M_B$$
$$M_2 = x_{A2}M_A + x_{B2}M_B$$

$$c_{av} = \left(\frac{\rho_1}{M_1} + \frac{\rho_2}{M_2}\right)/2$$

$$x_{BM} = \frac{x_{A_1} - x_{A_2}}{\ln\left(\frac{1 - x_{A_2}}{1 - x_{A_1}}\right)}$$

$$N_A = \frac{D_{AB}c_{av}\left(x_{A_1} - x_{A_2}\right)}{\left(z_2 - z_1\right)x_{BM}}$$

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2) Mass Transfer to Packed Beds

For Reynold number between 10 - 10,000, in gas form,

$$J_D = \frac{0.4548}{\varepsilon} N_{RE}^{-0.4069}$$

Reynold Number

$$N_{RE} = \frac{D_P v' \rho}{\mu}$$

For Reynold number between 0.0016 - 55, in liquid form
No. Schmidt 165 - 70000

$$J_D = \frac{1.09}{\varepsilon} N_{RE}^{-2/3}$$

For Reynold number between 55 - 1500, in liquid form
No. Schmidt 165 - 10690

$$J_D = \frac{0.250}{\varepsilon} N_{RE}^{-0.31}$$

$$x_{BM} = \frac{x_{B2} - x_{B1}}{\ln(x_{B2}/x_{B1})}$$

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3) Unsteady State Mass Transfer

$$N_A = k_c\left(c_{L_1} - c_{L_i}\right)$$

where N_A = convective molar flux of A $\left(\text{kmol A/s.m}^2\right)$

k_c = mass-transfer coefficient (m/s)

c_{L_1} = the bulk fluid concentration $\left(\text{kmol A/m}^3\right)$

c_{L_i} = the concentration in the fluid next to the surface of the solid $\left(\text{kmol A/m}^3\right)$

c_i = the concentration in the solid at the surface

Equilibrium distribution coefficient, K

$$K = \frac{c_{L_i}}{c_i}$$