UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2021/2022

COURSE NAME : MASS TRANSFER

COURSE CODE : BNQ 20303

PROGRAMME CODE : BNN

EXAMINATION DATE : JULY 2022

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 **TWELVE (12)** PAGES

Q1 (a) Siva has a problem 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) Sublimation is one part of diffusion mass transfer where the substance transition is directly from the solid to the gas state, without passing through the liquid state. Give **ONE (1)** example of a material that sublimes and recommend a suitable way to measure the sublimation rate of the material.

(5 marks)

(c) (i) The first step in the milk processing industry is to pre-concentrate the milk before proceed to the next step. Demonstrate a complete experiment with step-by-step procedures and illustrations to run this pre-concentration process.

(6 marks)

(ii) After the process in **Q1(c)(i)** is completed, the concentrated milk needs to undergo another process to eliminate the moisture, preserve the good properties and to make it easy for handling. Name this process and explain the procedure in detail.

(5 marks)

(d) 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. Propose a method for isolating the compounds and explain how the isolation process applies.

(5 marks)

Q2 Nitrogen gas is stored in the following storage with the properties of:

Temperature: 358 K
Spherical storage: Outside Diameter (OD) = 4.8 m (container + shell)
Shell thickness: 6 cm.
C_{A1}: 0.087 kmol/m^3
D_{AB}: 1.2x10^{-12} m^2/s
Mw of Nitrogen: 14 kg/kmol.

(a) Sketch and label in detail the situation mentioned above.
(5 marks)

(b) Calculate the diffusion rate of nitrogen through the container to the air.
(10 marks)

(c) Determine the mass flow rate of nitrogen that diffuses out from the container in **ONE (1)** year.
(5 marks)

(d) Discuss the factors that can slow down the diffusion of the gas in the spherical storage
(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)

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Q4 A very thick slab of clay has an initial moisture content of $c_o = 14$ kg mol/m^3. Air is passed over the top surface to dry the clay. Assume a relative resistance of the gas at the surface of zero. The equilibrium moisture content at the surface is constant at $c_1 = 3$ kg mol/m^3. The diffusion of the moisture in the clay can be approximated by a diffusivity of $D_{AB} = 1.29 \times 10^{-8}$ m^2/s. Assume that the clay is a semi-infinite solid.

(a) Sketch the aforementioned situation in a labelled schematic diagram.
(4 marks)

(b) By referring to **Figure Q4 (b)** and **Table Q4 (b)** determine the concentration of water at points after 1 hr of drying:

(i) 0.005 m below the surface.
(7 marks)

(ii) 0.01 m below the surface
(7 marks)

(iii) 0.02 m below the surface
(7 marks)

- END OF QUESTIONS-

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Unit Conversion

R value

$R = 8.31451\ \mathrm{J\ K^{-1}\ mol^{-1}} = 8.20578\times10^{-2}\ \mathrm{L\ atm\ K^{-1}\ mol^{-1}} = 8.31451\times10^{-2}\ \mathrm{L\ bar\ K^{-1}\ mol^{-1}}$
$= 8.31451\ \mathrm{Pa\ m^3\ K^{-1}\ mol^{-1}} = 62.364\ \mathrm{L\ Torr\ K^{-1}\ mol^{-1}} = 1.98722\ \mathrm{cal\ K^{-1}\ mol^{-1}}$

Liquid water properties at 4 °C (277.2 K)

Density (ρ) = 1000 kg/m^3
= 1 g/cm^3
= 62.43 lb$_m$/ft^3

Temperature

K = °C + 273.15
°F= 32 + 1.8(°C)
°R= °F + 459.67
100 °C = 212 °F + 373.15 K = 671.67 °R
0 °C = 32 °F = 273.15 K = 491.67 °R

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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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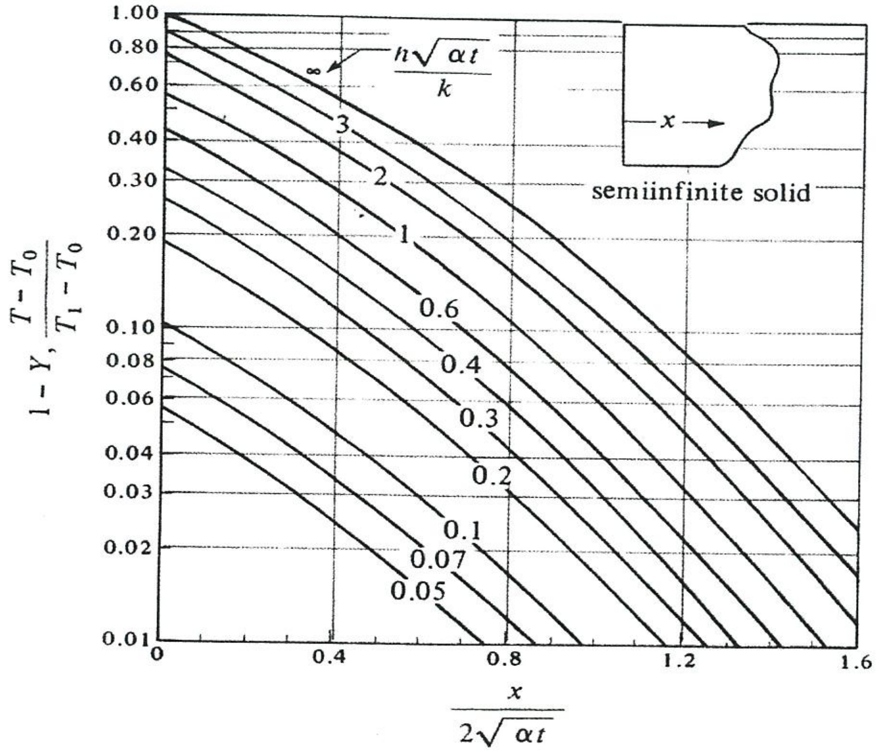

Figure Q4 (b) Unsteady-state conducted in a semiinfinite solid with surface convection

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

Diffusion in Spherical system

$$N_{A1} = 4\pi r_1 r_2 D_{AB} \frac{C_{A1} - C_{A2}}{r_2 - r_1}$$

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

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

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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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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 $\left(\text{m/s}\right)$

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

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