UNIVERSITI SAINS MALAYSIA

First Semester Examination
2012/2013 Academic Session

January 2013

EKC 217 – Mass Transfer
[Pemindahan Jisim]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains FIVE printed pages and TWO printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi LIMA muka surat yang bercetak dan DUA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] You have recently joined ABC Sdn. Bhd. as a chemical engineer. In the company, there is currently a five (5) stages counter-current absorption tower that is not in used. In order to utilized the tower, your superior has instructed you to assess the possibility of using it to recover acetone from a gas containing 1.0 mol% acetone in air using pure water. The amount of gas that must be treated is 30 kgmol/hr and the water inlet piping to the tower can accommodate up to a maximum flow rate of 90 kgmol H_2O/h. The process is to be operated isothermally at 300 K and a total pressure of 101.3 kPa. The equilibrium relation for the acetone in the gas-liquid is y=2.53x. Estimate what is the maximum amount of acetone (in percentage) that can be recovered using the tower.

Anda baru sahaja bekerja dengan syarikat ABC Sdn. Bhd. sebagai jurutera kimia. Di syarikat tersebut, terdapat satu turus penyerapan berlawanan-arus lima (5) peringkat yang kini tidak digunakan. Bagi menggunakan semula turus tersebut, penyelia anda telah mengarahkan anda untuk menilai kemungkinan untuk menggunakan turus tersebut bagi memulihkan semula aseton daripada gas yang mengandungi 1.0% mol aseton menggunakan air tulen. Kuantiti gas yang perlu dirawat adalah 30 kg mol/jam dan sistem paip suapan air ke turus boleh menampung kadar aliran air maksimum sebanyak 90 kgmol H_2O/jam. Proses tersebut beroperasi secara isoterma pada 300 K dan pada tekanan 101.3 kPa. Hubungan keseimbangan bagi aseton dalam gas-cecair adalah y=2.53x. Anggarkan kuantiti maksimum aseton (dalam peratus) yang boleh dipulihkan menggunakan turus tersebut.

[20 marks/markah]

[b] Can the operating line of an absorption process be below the equilibrium line? Please justify your answers clearly.

Bolehkah garis operasi bagi proses penyerapan berada di bawah garis keseimbangan? Berikan justifikasi kepada jawapan anda.

[5 marks/markah]

2. [a] Define a leaching process and list down three different activities that you do on a daily basis that involves leaching.

Takrifkan proses pengurasan dan senaraikan tiga aktiviti berlainan yang anda lakukan pada setiap hari yang melibatkan pengurasan.

[4 marks/markah]

[b] Describe three factors that may influence a leaching process.

Terangkan tiga faktor yang boleh mempengaruhi proses pengurasan.

[3 marks/markah]

[c] What do you understand when equilibrium is achieved in a leaching process?

Apakah yang anda faham apabila keseimbangan dicapai dalam proses pengurasan?

[3 marks/markah]

[d] A countercurrent extraction system is used to extract the sludge from the reaction:

Satu sistem penyarian berlawanan-arus digunakan untuk menyari enapcemar daripada tindak balas berikut:

$$Na_2CO_3 + CaO + H_2O \rightarrow CaCO_3 + 2NaOH$$

The $CaCO_3$ carries with it 1.5 times its weight of solution in flowing from one unit to another. It is desired to recover 99% of the NaOH by using 3.4 kg of pure water (H_2O) as the solvent. The products from the reaction enter the extraction system with no excess reactants but with 0.6 kg of H_2O per kg of $CaCO_3$. Assuming equilibrium is attained in each stage and on the basis of 1 kg of solid ($CaCO_3$), how many theoretical stages are required for the process? Use the calculation method to solve this problem.

$CaCO_3$ membawa bersama-samanya 1.5 kali berat larutan apabila mengalir daripada satu unit ke unit lain. Anda dikehendaki untuk memulihkan 99% NaOH dengan menggunakan 3.4 kg air tulen (H_2O) sebagai pelarut. Produk daripada tindak balas di atas memasuki sistem penyarian tanpa bahan tindak balas lebihan tetapi dengan 0.6 kg H_2O per kg $CaCO_3$. Anggap keseimbangan dicapai dalam setiap peringkat dan dengan menggunakan asas 1 kg pepejal ($CaCO_3$), berapakah peringkat teori yang diperlukan bagi proses di atas? Gunakan kaedah pengiraan bagi menyelesaikan masalah ini.

Given: Molecular weight (g/mol) of : Water – 18
Diberi: Jisim moleku (g/mol) bagi: Air – 18
Na_2CO_3 – 106
CaO – 56
$CaCO_3$ – 100
NaOH – 40

[15 marks/markah]

3. [a] Ethanol vapor is being absorbed from a mixture of alcohol vapor and water vapor by means of non-volatile solvent in which alcohol is soluble but water is not. The temperature is 80°C and the total pressure is 760 mmHg. The alcohol vapor can be considered to be diffusing through a film of alcohol-water vapor mixture 0.5 mm thick. The mole percent of the alcohol in the vapor at the outside of the film is 70%, and that on the inside, next to the solvent is 15%. The volumetric diffusivity of alcohol-water vapor mixtures at 25°C and 1 atm is 0.15 cm^2/s. Calculate the rate of diffusion of alcohol vapor in kilograms per hour if the area of the film is 15 m^2.

Wap etanol telah diserap daripada campuran wap alkohol dan air melalui pelarut tidak-meruap, yang mana alkohol adalah boleh larut tetapi tidak bagi air. Suhu ialah 80°C dan jumlah tekanan ialah 760 mmHg. Wap alkohol boleh dianggap meresap melalui filem campuran wap alkohol-air berketebalan 0.5 mm. Peratus mol wap alkohol pada bahagian luar filem ialah 70%, dan di bahagian dalam bersebelahan dengan pelarut ialah 15%. Kemeresapan isipadu bagi campuran wap alkohol-air pada 25°C dan 1 atm ialah 0.15 sm^2/s. *Kirakan kadar resapan wap alkohol dalam kilogram per jam jika keluasan filem ialah 15* m^2.

The relationship of diffusivity with temperature and pressure is
Hubungkait kemeresapan dengan suhu dan tekanan ialah

$$D_{AB} \propto \frac{T^{1.75}}{P}$$

Molecular weight of ethanol = 46 kg/kmole
Berat molekul etanol = 46 kg/kgmol

[13 marks/markah]

[b] An air-H_2S mixture is flowing in a wetted-wall column by a film of water that is flowing as a thin film down a vertical plate. The H_2S is being absorbed from the air to the water at a total pressure of 760 mmHg and 35°C. A value for k_c' of 9.567 x 10^{-4} m/s has been predicted for the gas-gas mass transfer coefficient. At a given point the mole fraction of H_2S in the liquid at the liquid-gas interface is 3.5 x 10^{-5} and partial pressure, p_A of H_2S in the gas is 0.08 atm. By assuming that point 1 is the interface and point 2 is the gas phase, calculate the rate of absorption of H_2S.

Campuran udara H_2S *mengalir di dalam turus dinding basah di sebelah filem air yang mengalir ke bawah plat menegak sebagai filem nipis.* H_2S *diserap daripada udara kepada air pada tekanan jumlah 760 mmHg. dan 35°C. Nilai* k_c' *sebagai 9.567 x* 10^{-4} *m/s telah dijangkakan bagi pekali pemindahan jisim gas-gas. Pada suatu titik, pecahan mol* H_2S *dalam cecair pada antaramuka cecair-gas ialah 3.5 x* 10^{-5} *dan tekanan separa,* p_A *bagi* H_2S *dalam gas ialah 0.08 atm. Dengan mengandaikan bahawa titik 1 ialah antaramuka dan titik 2 ialah fasa gas, kirakan kadar serapan* H_2S.

Henry's law equilibrium relation: $p_A = 609x_A$
Hubungkait keseimbangan Hukum Henry:

[12 marks/markah]

4. A methanol (A) – water (B) solution containing 50 wt% methanol is to be continuously enriched at a rate of 5000 kg/h to provide a distillate containing 95 wt% methanol and a residue (bottom product) containing 1.0 wt% methanol. The feed enters the column is liquid at its boiling point. Use the McCabe-Thiele method to compute the followings, assuming a uniform pressure of 1 atm throughout the column:

Larutan metanol (A) – air (B) mengandungi 50 berat % metanol akan dikayakan secara berterusan pada kadar 5000 kg/jam untuk memberikan hasil sulingan mengandungi 95 berat % metanol dan baki (produk bawahan) mengandungi 1.0 berat % metanol. Suapan yang memasuki turus ialah cecair pada takat didihnya. Gunakan kaedah McCabe-Thiele untuk mengira yang berikut, dengan mengandaikan tekanan seragam 1 atm di sepanjang turus:

[a] Moles per hour of distillate and bottom product.
Mol per jam hasil sulingan dan produk bawahan. *[7 marks/markah]*

[b] Number of theoretical trays required at total reflux.
Bilangan dulang teori yang diperlukan pada refluks jumlah. *[2 marks/markah]*

[c] Minimum reflux ratio, R_{min}.
Nisbah refluks minimum, R_{min}. *[4 marks/markah]*

[d] Number of theoretical trays required for $R = 3.5\ R_{min.}$
Bilangan dulang teori yang diperlukan untuk $R = 3.5\ R_{min}$. *[8 marks/markah]*

[e] Optimal location of the feed stage.
Lokasi optimum peringkat suapan. *[2 marks/markah]*

[f] Actual number of trays if the overall tray efficiency is 80%.
Bilangan dulang sebenar jika kecekapan dulang keseluruhan ialah 80%.
[2 marks/markah]

The relation between the mole fraction of methanol in liquid and in vapor is given in Table Q.4.[a]:
Hubungkait antara pecahan mol metanol dalam cecair dan wap diberikan dalam Jadual S.4.[a].

Table Q.4.[a]: VLE data for methanol-water system at 1 atm
Jadual S.4.[a].: Data keseimbangan wap-cecair bagi sistem metanol-air pada 1 atm.

x	0.0	0.0321	0.0523	0.075	0.154	0.225	0.349	0.813	0.918	1.0
y	0.0	0.1900	0.2940	0.352	0.516	0.593	0.703	0.918	0.963	1.0

<u>Data given:</u>
Molecular weight of methanol = 32.04 kg/kmole
Molecular weight of water = 18.02 kg/kmole

<u>Data yang diberi:</u>
Berat molekul metanol = 32.04 kg/kmol
Berat molekul air = 18.02 kg/kmol

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Appendix

Formulae and General Data

Atomic weights: H = 1, C = 12, N = 14, O = 16, S = 32, Cl = 35:5
Gas constant: R = 8.312 J/mol.K= 0.08206 L.atm/mol.K = 62.36 L.mmHg/mol.K
Pressure: 101324 Pa = 1 atm = 760 mm Hg
Acceleration due to gravity: g = 9.81 m/s^2
Properties of water (unless otherwise stated): ρ = 1000 kg/m^3, μ = 1.00 mPa.s

Diffusion

Fick's Law:

$$J_A = -D_{AB}\frac{dc_A}{dz} \qquad J_A = -cD_{AB}\frac{dx_A}{dz} \qquad J_A = \left(-D_{AB}\cdot\frac{P_T}{RT}\right)\frac{dy_A}{dz}$$

General equation for diffusion plus convection:

$$N_A = -cD_{AB}\frac{dx_A}{dz} + \frac{c_A}{c}(N_A + N_B)$$

Equimolar counter diffusion:

$$J_A = \frac{D_{AB}c}{z_T}(x_{Ai} - x_A)$$

$$J_A = \frac{D_{AB}}{z_T}(c_{Ai} - c_A)$$

$$J_A = \frac{D_{AB}(p_{A1} - p_{A2})}{RT(z_2 - z_1)}$$

Unimolecular diffusion:

$$N_A = -cD_{AB}\frac{dx_A}{dz} + x_A N_A$$

$$N_A = \frac{D_{AB}c}{z_T}\ln\frac{1 - x_A}{1 - x_{Ai}}$$

$$N_A = \frac{D_{AB}P_T}{RT(z_2 - z_1)p_{BM}}(p_{A1} - p_{A2})$$

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

$$N_A = \frac{D_{AB}\rho_M}{(z_2 - z_1)y_{BM}}(y_{A1} - y_{A2})$$

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

Molecular diffusion of solute in liquids:

$$J_A = \frac{D_{AB} c_{av}}{z_T}(x_{Ai} - x_A) = \frac{D_{AB}}{z_T}(c_{Ai} - c_A)$$

$$N_A = \frac{D_{AB}}{(z_2 - z_1) x_{BM}} \left(\frac{\rho}{M}\right)_{av} (x_{A1} - x_{A2})$$

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

Film theory (bulk flow effect is not negligible):

$$N_A = \frac{cD_{AB}}{\delta} \ln\left[\frac{1 - x_{A_b}}{1 - x_i}\right] = \frac{cD_{AB}}{\delta (1 - x_A)_{LM}}(x_{Ai} - x_{A_b})$$

$$(1 - x_A)_{LM} = (x_B)_{LM} = \frac{x_{A_i} - x_{A_b}}{\ln\left[(1 - x_{A_i})/(1 - x_{A_b})\right]}$$

Mass transfer coefficients:

Turbulent mass transfer with constant concentration:

$$J_{A1} = k_c'(c_{A1} - c_{A2})$$

$$k_c' = \frac{D_{AB} + \overline{\varepsilon_M}}{z_2 - z_1}$$

Turbulent mass transfer with equimolar counter diffusion:

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

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

Turbulent mass transfer with unimolecular diffusion:

$$N_A = \frac{k_c'}{x_{BM}}(c_{A1} - c_{A2}) = k_c(c_{A1} - c_{A2})$$

$$= \frac{k_x'}{x_{BM}}(x_{A1} - x_{A2}) = k_x(x_{A1} - x_{A2})$$

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

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

Overall mass transfer:

$$N_A = K_y(y_{A,G} - y_A^*)$$

$$\frac{1}{K_y} = \frac{1}{k_y} + \frac{m'}{k_x}$$

$$N_A = K_x(x_A^* - x_{A,L})$$

$$\frac{1}{K_x} = \frac{1}{k_x} + \frac{1}{m'' k_y}$$