UNIVERSITI SAINS MALAYSIA

First Semester Examination
2016/2017 Academic Session

December 2016 / January 2017

EKC 217 – Mass Transfer
[Pemindahan Jisim]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of NINE pages of printed material and SIX pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN muka surat yang bercetak dan ENAM 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.]

Write your index number in the space provided on the question paper to be attached to answer sheet.

[Tulis nombor angka giliran dalam ruangan yang disediakan pada kertas soalan peperiksaan untuk dikepilkan bersama kertas jawapan.]

Answer ALL questions.

1. [a] Briefly explain the basic principle of mass transfer. *[3 marks]*

[b] Methane gas is diffusing in a straight tube with a length of 0.1 m containing helium at 298 K and the total pressure is 1 atm ($=1.01325 \times 10^5$ Pa). The partial pressure of methane is 1.40×10^4 Pa at one end and 1.35×10^3 Pa at the other end. Helium gas is insoluble in methane and it is non-diffusing. The diffusivity of methane-helium is 0.675×10^{-4} m^2/s. Calculate the flux of methane in $kmol/m^2 \cdot s$ at steady-state conditions.

[5 marks]

[c] A layer of benzene 1 mm thick lies at the bottom of an open tank 5 m in diameter. The tank temperature is 295 K and the diffusivity of benzene in air is 8.0×10^{-6} m^2/s at this temperature. If the vapor pressure of benzene in the tank is 13.3 kPa and diffusion may be assumed to take place through a stagnant air film 3 mm thick.

Calculate:

[i] the rate of diffusion of benzene in $kmol/m^2 \cdot s$ *[7 marks]*

[ii] the benzene evaporation time in second *[10 marks]*

Given : Density of benzene = 880 kg/m^3
Molecular weight of benzene = 78

2. [a] Figure Q.2.[a] shows the vapor-liquid phase equilibrium curves for constant values of relative volatility of component 1 with respect to component 2 in the binary system, $\alpha_{1,2}$.

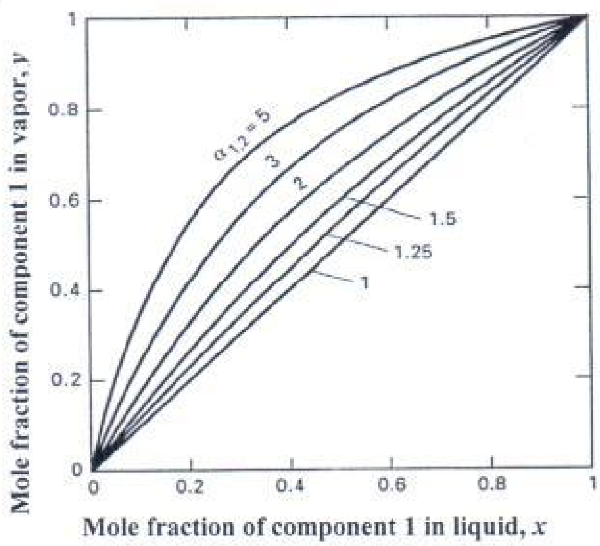


Figure Q.2.[a]: Vapor-liquid phase equilibrium curves for constant values of relative volatility

[i] Define relative volatility *[2 marks]*

Comment on the separation if :

[ii] $\alpha_{1,2} = 1$ *[1 mark]*

[iii] $\alpha_{1,2} < 1$ *[1 mark]*

[iv] Smaller $\alpha_{1,2}$ better separation, true or false? *[1 mark]*

Jawab SEMUA soalan.

1. [a] *Terangkan secara ringkas prinsip asas pemindahan jisim.* [3 markah]

[b] *Gas metana meresap ke dalam tiub lurus dengan panjang 0.1 m yang mengandungi helium pada 298 K dan jumlah tekanan 1 atm (=1.01325×10^5 Pa). Tekanan separa metana adalah 1.40×10^4 Pa pada satu hujung dan 1.35×10^3 Pa di hujung yang lain. Gas helium tidak larut dalam metana dan ia tak meresap. Kemeresapan metana-helium adalah 0.675×10^{-4} m^2/s. Kirakan fluks metana dalam $kmol/m^2 \cdot s$ pada keadaan mantap.* [5 markah]

[c] *Satu lapisan benzena berketebalan 1 mm berada di dasar satu tangki terbuka berdiameter 5 m. Suhu tangki adalah 295 K dan kemeresapan benzena di udara ialah 8.0×10^{-6} m^2/s pada suhu tersebut. Jika tekanan wap benzena dalam tangki ialah 13.3 kPa dan andaikan resapan berlaku melalui saput udara genang berketebalan 3 mm,*

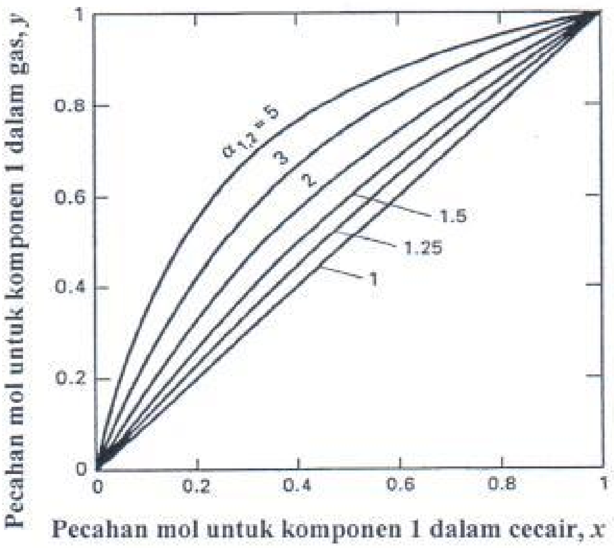
Hitungkan:

[i] *kadar resapan benzena dalam $kmol/m^2 \cdot s$* [7 markah]

[ii] *masa sejatan dalam saat untuk benzena* [10 markah]

Diberikan: Ketumpatan benzena = 880 kg/m^3
Berat molekul benzena = 78

2. [a] *Rajah S.2.[a] menunjukkan lengkung-lengkung keseimbangan fasa wap-cecair untuk nilai-nilai tetap kemeruapan nisbi komponen 1 kepada komponen 2 bagi sistem perduaan, $\alpha_{1,2}$.*



Rajah S.2.[a]: Lengkung-lengkung keseimbangan fasa wap-cecair untuk nilai-nilai tetap kemeruapan nisbi.

[i] *takrifkan kemeruapan nisbi* [2 markah]

Komen pada pemisahan jika:

[ii] $\alpha_{1,2} = 1$ [1 markah]

[iii] $\alpha_{1,2} < 1$ [1 markah]

[iv] *Lebih kecil $\alpha_{1,2}$ lebih baik pemisahan, betul atau salah?* [1 markah]

[b] A fractionation column is used to separate 200 kmol/h of a solution containing 40 mole% acetone and 60 mole% ethanol into an overhead product containing 85 mole% acetone and a bottom product containing 5 mole% acetone. A reflux ratio (L/D) of 3.25 is to be used and the feed is a two phase mixture that is 80% molar of liquid. Equilibrium data for acetone and ethanol at 1 atm are given in Table Q.2.[b].

Table : Q.2.[b]

x_A	0	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.70	0.80	0.90	1.00
y_A	0	0.26	0.35	0.42	0.48	0.52	0.57	0.61	0.67	0.74	0.80	0.87	0.93	1.00

Use the McCabe-Thiele method to compute the following, assuming a uniform pressure of 1 atm throughout the column.

[i] Amount of overhead and bottom products

[4 marks]

[ii] The minimum number of stages at total reflux

[2 marks]

[iii] The optimum feed location and the total number of equilibrium stages

[8 marks]

[iv] Actual number of trays if the tray efficiency is 0.75

[2 marks]

[v] The ratio R/R_{min}

[4 marks]

3. Triethylamine is used as an absorbent liquid in a packed tower to adsorb CO_2 using 1-in plastic pall rings as given in Table Q.3. The feed gas with a CO_2 concentration of 1.26 mole% is set to leave from the tower at a concentration of 0.04 mole%. If the exit liquid is in equilibrium with the entering gas, it would contain 0.8 mole% CO_2. The gas flow rate is 2.3 gmol/s, the liquid flow rate is 4.8 gmol/s, the tower diameter is 40 cm, and the overall gas phase mass transfer coefficient multiplies the interfacial area is 5×10^{-5} gmol/cm^3·s.

[a] Calculate the height of the packed tower needed to obtain the desired level of separation. Clearly state your assumptions.

[12 marks]

[b] Based on the dimension of the tower, determine whether flooding will occur or not?

[10 marks]

[b] *Satu turus pemeringkatan digunakan untuk memisahkan 200 kmol/j larutan yang mengandungi 40 %mol aseton dan 60 %mol etanol kepada produk atas mengandungi 85 %mol aseton dan produk bawah mengandungi 5 %mol aseton. Pecahan refluks (L/D) sebanyak 3.25 akan digunakan dan suapannya adalah campuran dua fasa dengan 80% molar cecair. Keseimbangan data bagi aseton dan etanol pada 1 atm ditunjukkan pada Rajah S.2.[b].*

Jadual : S.2.[b]

x_A	0	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.70	0.80	0.90	1.00
y_A	0	0.26	0.35	0.42	0.48	0.52	0.57	0.61	0.67	0.74	0.80	0.87	0.93	1.00

Gunakan kaedah McCabe-Thiele untuk menghitung yang berikut, dengan mengandaikan tekanan seragam 1 atm pada keseluruhan turus.

[i] *Kuantiti bagi produk-produk atas dan bawah*

[4 markah]

[ii] *Bilangan minimum dulang teori pada refluks jumlah*

[2 markah]

[iii] *Lokasi optimum suapan dan jumlah bilangan peringkat keseimbangan*

[8 markah]

[iv] *Bilangan dulang sebenar jika kecekapan dulang ialah 0.75*

[2 markah]

[v] *Nisbah bagi R/R_{min}*

[4 markah]

3. *Trietilamina digunakan sebagai cecair penyerap di menara terpadat dengan 1-inci cincin pengusung plastik untuk menyerap karbon dioksida. Gas suapan dengan kepekatan CO_2 1.26 %mol yang meninggalkan menara ditetapkan pada kepekatan 0.04 %mol. Jika cecair keluaran adalah berseimbangan dengan gas yang masuk , ia akan mengandungi 0.8 %mol CO_2. Kadar aliran gas 2.3 gmol/s, kadar aliran cecair adalah 4.8 gmol/s, diameter menara adalah 40 sm dan pekali keseluruhan pemindahan jisim fasa gas darab dengan kawasan antara muka adalah 5×10^{-5} gmol/sm^3·s.*

[a] *Kirakan ketinggian menara terpadat yang diperlukan untuk mendapatkan tahap pemisahan yang dikehendaki. Nyatakan andaian anda dengan jelas.*

[12 markah]

[b] *Berdasarkan dimensi menara tersebut, tentukan sama ada banjir akan berlaku atau tidak?*

[10 markah]

[c] Suggest the ways to increase the removal efficiency based on your decision made in part [b].

[3 marks]

Given:

The average density of the gas phase is 1.23 kg/m^3 and the liquid phase is 726 kg/m^3. The average kinematic viscosity of the gas is 1.0 cSt. Molecular weight: CO_2 (44); trimethylamine (101.19); air (28.97).

Table Q.3: Characteristics of dumped tower packings

Type	Material	Nominal size, in	Bulk density, lb/ft^3	Total area, ft^2/ft^3	Porosity (ε)	Packing factors	
						F_p	f_p
Raschig rings	Ceramic	½	55	112	0.64	580	1.52
		1	42	58	0.74	155	1.36
Pall rings	Plastic	1	5.5	63	0.90	55	1.36
		1½	4.8	39	0.91	40	1.18

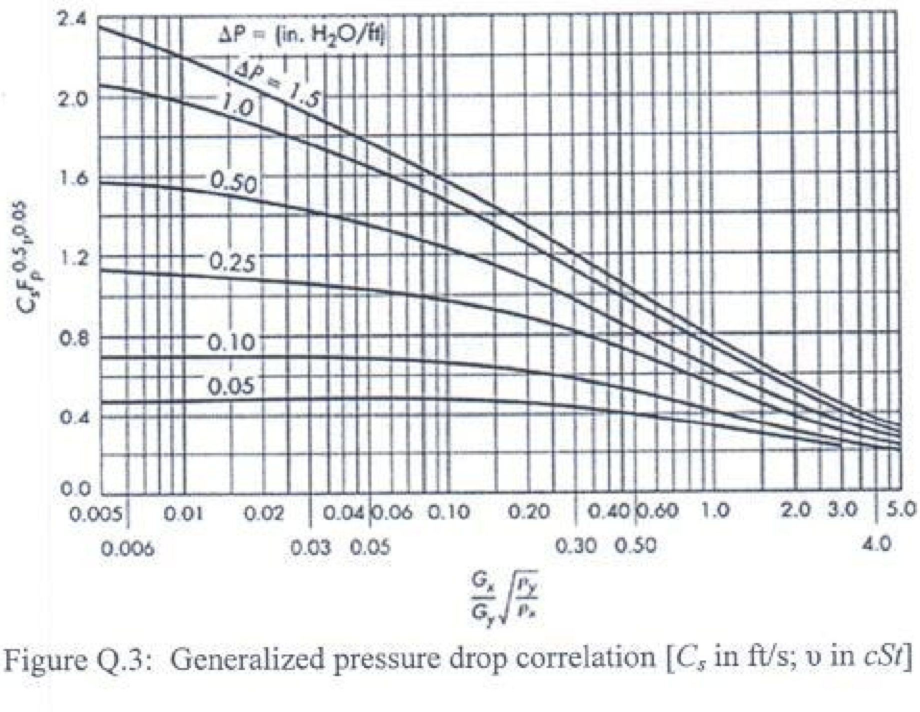


Figure Q.3: Generalized pressure drop correlation [C_s in ft/s; υ in cSt]

[c] *Cadangkan cara-cara untuk meningkatkan kecekapan penyingkiran berasaskan keputusan yang dibuat pada bahagian [b].*

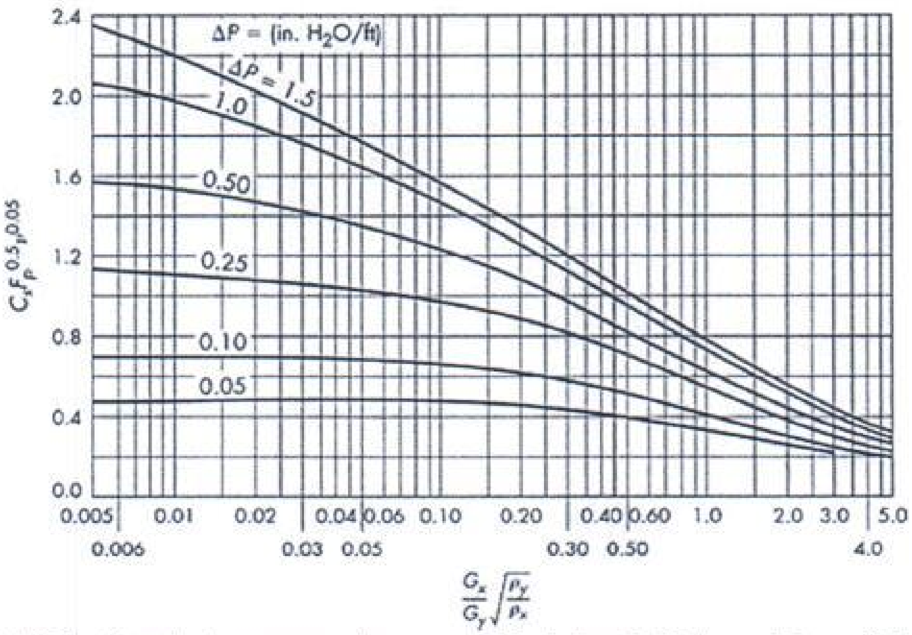
[3 markah]

Diberi:

Ketumpatan purata fasa gas adalah 1.23 kg/m^3 dan fasa cecair adalah 726 kg/m^3. Purata kelikatan kinematik gas adalah 1.0 cSt. Berat molekul : CO_2 (44); trimetilamina (101.19); udara (28.97).

Jadual S.3 : Ciri-ciri padatan menara terlonggok

Jenis	Bahan	Saiz Nomina, in	Ketumpatan pukal, paun/kaki^3	Jumlah keluasan, kaki^2/kaki^3	Keliangan (ε)	Faktor Padatan	
						F_p	f_p
Cincin Raschig	Seramik	½	55	112	0.64	580	1.52
		1	42	58	0.74	155	1.36
Cincin Pall	Plastik	1	5.5	63	0.90	55	1.36
		1½	4.8	39	0.91	40	1.18



Rajah S.3 : Korelasi susutan tekanan am [C_s dalam kaki / s; υ dalam cSt]

4. Acetone is miscible with water and serves as an important solvent typically for cleaning purposes in the laboratory. Recovery of acetone can be done via liquid-liquid extraction. In one of the process, mixture containing 40 wt% acetone in aqueous solution is extracted with an equal amount of trichloroethane (100 kg/h) in a single stage countercurrent flow operation. Trichloroethane and water are partially immiscible and their equilibrium and phase diagram are given in Appendix.

[a] What fraction of acetone can be extracted?

[10 marks]

[b] How many stages of countercurrent extraction are required if the final acetone concentration in raffinate is not more than 10 wt%?

[5 marks]

[c] If the system is changed to 2-stages crossflow extraction with the same amount of solvent in each stage, what will be the final purity of the raffinate?

[6 marks]

[d] Discuss the economic importance of designing solvent flow rate.

[4 marks]

4. *Aseton adalah boleh larut campur dengan air dan berfungsi sebagai pelarut penting untuk tujuan pembersihan di makmal. Pemulihan aseton boleh dilakukan melalui penyaringan cecair-cecair. Dalam salah satu proses, campuran yang mengandungi 40 %berat aseton dalam larutan akuas disaring dengan trikloroetana (100 kg/j) dengan amaun triklorometana yang sama dalam operasi satu peringkat aliran berlawanan. Trikloroetana dan air bercampur secara separa dan rajah keseimbangan dan fasa diberi dalam Lampiran.*

[a] *Berapakah bahagian aseton boleh disaring?*

[10 markah]

[b] *Berapakah peringkat penyaringan berlawanan aliran diperlukan jika kepekatan aseton akhir dalam rafinat tidak lebih daripada 10 %berat?*

[5 markah]

[c] *Jika sistem itu ditukar kepada penyaringan aliran silang 2 peringkat dengan jumlah pelarut yang sama dalam setiap peringkat, apakah ketulenan akhir rafinat itu?*

[6 markah]

[d] *Bincangkan kepentingan ekonomi dalam merekabentuk kadar aliran pelarut.*

[4 markah]

-oooOooo-

Appendix

Formulae and General Data

Gas constant: R = 8314.34 J/kmol.K= 8314.34 m^3.Pa/kmol.K = 82.06 cm^3.atm/mol.K
=82.06 x 10^{-3} m^3.atm/kmol.K = 62.36 L.mmHg/mol.K

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:

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

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

$$N_A = \frac{D_{AB}P}{RT(z_2 - z_1)p_{BM}}(p_{A1} - p_{A2})\,; \quad p_{BM} = \frac{p_{B2} - p_{B1}}{\ln(p_{B2}/p_{B1})}$$

$$N_A = \frac{D_{AB}\rho_M}{(z_2 - z_1)y_{BM}}(y_{A1} - y_{A2})\,; \quad y_{BM} = \frac{y_{B2} - y_{B1}}{\ln(y_{B2}/y_{B1})}$$

Molecular diffusion of solute in liquids:

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

$$N_A = \frac{D_{AB}c_{av}}{(z_2 - z_1)x_{BM}}(x_{A1} - x_{A2})\,; \quad x_{BM} = \frac{x_{B2} - x_{B1}}{\ln(x_{B2}/x_{B1})} \qquad c_{av} = \left(\frac{\rho}{M}\right)_{av} = \frac{\left(\frac{\rho_1}{M_1} + \frac{\rho_2}{M_2}\right)}{2}$$

TABLE 7.2-1. *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) $\frac{\text{kg mol}}{\text{s} \cdot \text{m}^2 \cdot \text{atm}}$	$\frac{\text{g mol}}{\text{s} \cdot \text{cm}^2 \cdot \text{atm}}$	$\frac{\text{lb mol}}{\text{h} \cdot \text{ft}^2 \cdot \text{atm}}$

Common Engineering Conversion Factors

Length	**Volume**
1 ft = 12 in = 0.3048 m, 1 yard = 3 ft 1 mi = 5280 ft = 1609.344 m 1 nautical mile (nmi) = 6076 ft	1 ft^3 = 0.028317 m^3 = 7.481 gal , 1 bbl = 42 U.S. gal 1 U.S. gal = 231 in^3 = 3.7853 L = 4qt = 0.833 Imp.gal. 1 L = 0.001 m^3 = 0.035315 ft^3 = 0.2642 U.S. gal
Mass	**Density**
1 slug = 32.174 lb_m = 14.594 kg 1 lb_m = 0.4536 kg = 7000 grains	1 slug/ft^3 = 515.38 kg/m^3 , 1 g/cm^3 = 1000 kg/m^3 1 lb_m/ft^3 = 16.0185 kg/m^3 , 1 lb_m/in^3 = 27.68 g/cm^3
Acceleration & Area	**Velocity**
1 ft/s^2 = 0.3048 m/s^2 1 ft^2 = 0.092903 m^2	1 ft/s = 0.3048 m/s , 1 knot = 1 min/h = 1.6878 ft/s 1 min/h = 1.4666666 ft/s (fps) = 0.44704 m/s
Mass Flow & Mass Flux	**Volume Flow**
1 slug/s = 14.594 kg/s. 1 lb_m/s = 0.4536 kg/s 1 kg/m^2s = 0.2046 lb_m/ft^2s = 0.00636 slug/ft^2s	1 gal/min = 0.00228 ft^3/s = 0.06309 L/s 1 million gal/day = 1.5472 ft^3/s = 0.04381 m^3/s
Pressure	**Force and Surface Tension**
1 lb_f/ft^3 = 47.88 Pa, 1 torr = 1 mm Hg 1 psi = 144 psf, 1 bar = 10^5 Pa 1 atm = 2116.2 psf = 14.696 psia = 101,325 Pa = 29.9 in Hg = 33.9 ft H_2O	1 lb_f = 4.448222 N = 16 oz, 1 dyne = 1 g cm/s^2 = 10^{-5}N 1 kg_f = 2.2046 lb_f = 9.80665 N 1 U.S. (short) ton = 2000 lb_f , 1 N = 0.2248 lb_f 1 N/m = 0.0685 lb_f/ft
Power	**Energy and Specific Energy**
1 hp = 550 (ft.lb_f)/s = 745.7 W 1 (ft.lb_f)/s = 1.3558 W 1 Watt = 3.4123 Btu/h = 0.00134 hp	1 ft lb_f = 1.35582 J, 1 hp·h = 2544.5 Btu 1 Btu = 252 cal = 1055.056 J = 778.17 ft lb_f 1 cal = 4.1855 J, 1 ft.lb_f/lb_m = 2.9890 J/kg
Specific Weight	**Heat Flux**
1 lb_f/ft^3 = 157.09 N/m^3	1 W/m^2 = 0.3171 Btu/(h ft^2)
Viscosity	**Kinematic Viscosity**
1 slug/(ft.s) = 47.88 kg/(m.s) = 478.8 poise (p) 1 p=1 g/(cm.s) 0.1 kg/(m.s) = 0.002088 slug/(ft s)	1 ft^2/h = 2.506 .10^{-5} m^2/s, 1 ft^2/s = 0.092903 m^2/s 1 stoke (st) = 1 cm^2/s = 0.0001 m^2/s = 0.001076 ft^2/s
Temperature Scale Readings	
°F = (9/5)°C + 32 °C = (5/9) (°F – 32)	°R = °F + 459.69 °K = °C + 273.16
Thermal Conductivity*	**Gas Constant***
1 cal/(s.cm.°C) = 242 Btu/(h.ft.°R) 1 Btu/(h.ft.°R) = 1.7307 W/(m.K)	R = 82.057 atm.cm^3/(gmol.K) = 62.361 mm Hg.L/(gmol.K) = 1.134 atm.ft^3/(lbmol.K) = 0.083144 bar.L/(gmol.K) = 10.73 psi. ft^3/(lbmol. °R) = 555.0 mm Hg.ft^3/(lbmol. °R)

- Note that the intervals in absolute (Kelvin) and °C are equal. Also, 1 °R = 1 °F.

Latent heat: 1 J/kg = 4.2995 × 10^{-4} Btu/lb_m = 10.76 lb_f.ft/slug = 0.3345 lb_f.ft/lb_m , 1 Btu/lb_m = 2325.9 J/kg

Heat transfer coefficient: 1 Btu/(h.ft^2.°F) = 5.6782 W/(m^2.°C).

Heat generation rate: 1 W/m^3 = 0.09665 Btu/(h ft^3)

Heat transfer per unit length: 1 W/m = 1.0403 Btu/(h ft)

Mass transfer coefficient: 1 m/s = 11.811 ft/h, 1 lb_{mol}/(h.ft^2) = 0.013562 kgmol/(s.m^2)

Unit conversion:
1 m = 3.280840 ft;

Absorption

$$\Delta P_{flood} = 0.115 F_p^{0.7}$$

$$C_s = u_o \sqrt{\frac{\rho_y}{\rho_x - \rho_y}}$$

$$z = \left[\frac{1}{k'_y a \big/ (1-y)_{iM}} \frac{1}{S} \frac{V}{(1-y)} \right]_{av} \int \frac{dy}{y - y_i}$$

$$Z_T = \frac{V/S}{K_y a} \int_a^b \frac{dy}{y - y^*}$$

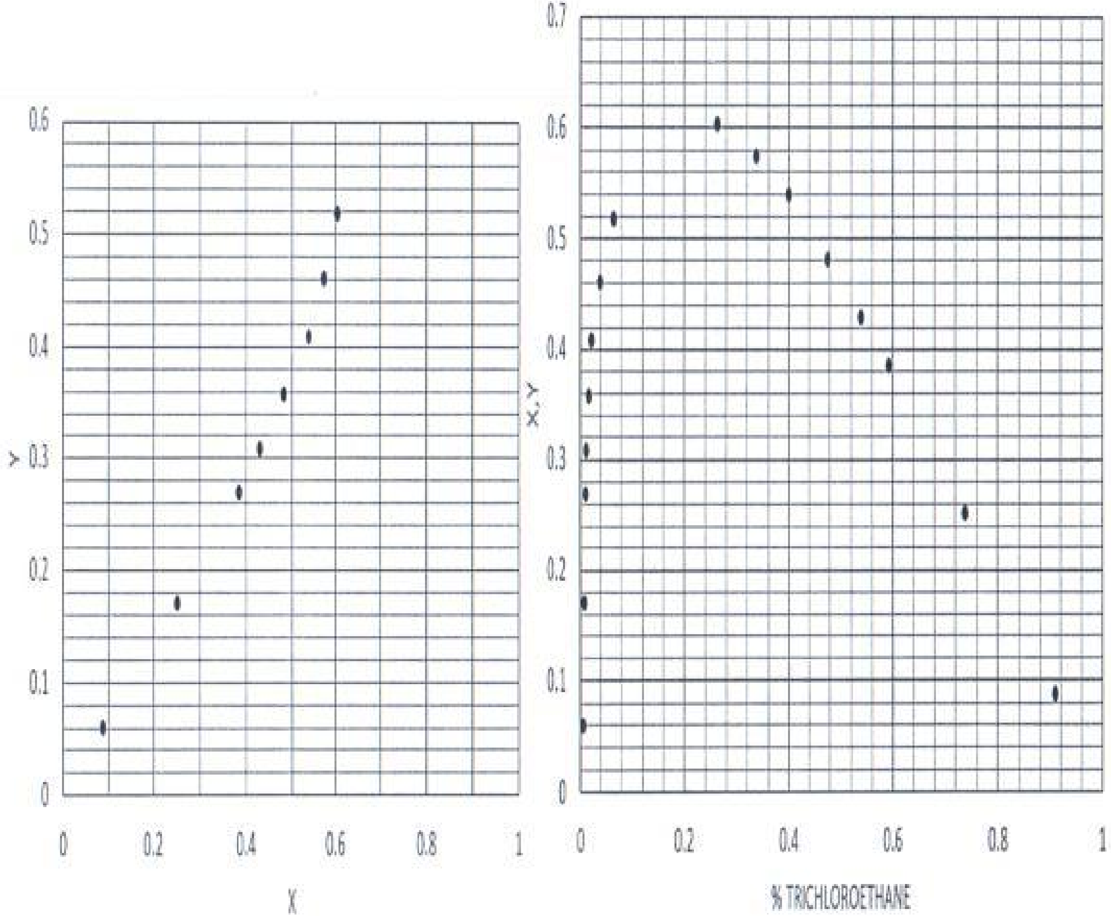
$$Z_T = H_{Oy} N_{Oy}$$

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

$$N_{Oy} = \frac{y_b - y_a}{\Delta y_{lm}}$$

$$\Delta y_{lm} = \frac{(y_b - y_b^*) - (y_a - y_a^*)}{\ln \frac{y_b - y_b^*}{y_a - y_a^*}}$$

Phase Diagram 1: <u>Phase diagram of acetone-water-trichloroethane system and their equilibrium line</u> **(For Single stage)**- *Please sketch on this graph and return with your answer booklets*



Phase Diagram 2: Phase diagram of acetone-water-trichloroethane system and their equilibrium line (**For multistage**). *Please sketch on this graph and return with your answer booklets*