
UNIVERSITI SAINS MALAYSIA

First Semester Examination
2014/2015 Academic Session

December 2014 / January 2015

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 FIVE page of Appendix before you begin the examination.

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

1. [a] Use the Wilke-Chang equation to predict the diffusivity of ethanol (C_2H_6O) in a dilute solution in water at 288 K. The viscosity of water at 288 K is 1.153×10^{-3} Pa·s. Compare with the experimental value, 1.0×10^{-5} cm^2/s and determine the error. [4 marks]
- [b] A pure nitrogen as carrier gas flows parallel to the $0.6 m^2$ surface of a liquid acetone in an open tank. The acetone temperature is maintained at 290 K. The vapour pressure of acetone can be determined from the Antoine equation as shown below:-

$$\log_{10} p^* = A - \frac{B}{T + C} \quad p^* \text{ in mm Hg, } T \text{ in } ^\circ C$$

Table Q.1.[b].

Compound	Formula	Range ($^\circ C$)	A	B	C
Acetone	C_3H_6O	-12.9 to 55.3	7.11714	1210.595	229.664

If the average mass transfer coefficient, k_c , for the mass transfer of acetone into the nitrogen stream is 0.0324 m/s, determine the total rate in kg·mol/s of acetone transfer to the nitrogen phase. [5 marks]

- [c] In the absorption of ammonia into water from an air-ammonia mixture at 300 K and 1 atm, the individual film coefficients were estimated to be $k_L = 6.3$ cm/h and $k_G = 1.17$ kmol/ $m^2 \cdot h \cdot atm$. The equilibrium relationship for very dilute solution of ammonia in water at 300 K and 1 atm is

$$y_{A,i} = 1.64 x_{A,i}$$

Determine the:

- [i] gas mass transfer coefficient, k_y [4 marks]
- [ii] liquid mass transfer coefficient, k_x [4 marks]
- [iii] overall mass transfer coefficient, K_y [4 marks]
- [iv] fraction of the $\frac{\text{Resistance in gas phase}}{\text{Total resistance, both phases}}$ [4 marks]

Jawab SEMUA soalan.

1. [a] Gunakan persamaan Wilke-Chang untuk meramalkan kemesapan ethanol (C_2H_6O) dalam larutan cair di dalam air pada 288 K. Kelikatan air pada 288 K ialah $1.153 \times 10^{-3} \text{ Pa}\cdot\text{s}$. Bandingkan dengan nilai eksperimen, $1.0 \times 10^{-5} \text{ cm}^2/\text{s}$ dan tentukan ralatnya.

[4 markah]

- [b] Nitrogen tulen sebagai gas pembawa mengalir secara selari ke 0.6 m^2 permukaan cecair aseton di dalam sebuah tangki terbuka. Suhu aseton dikekalkan pada 290 K. Tekanan wap aseton boleh dihitung daripada persamaan Antoine seperti yang ditunjukkan di bawah:

$$\log_{10} p^* = A - \frac{B}{T + C} \quad p^* \text{ dalam mm Hg, } T \text{ dalam } ^\circ\text{C}$$

Jadual S.1. [b].

Sebatian	Formula	Julat ($^\circ\text{C}$)	A	B	C
Acetone	C_3H_6O	-12.9 to 55.3	7.11714	1210.595	229.664

Jika purata pekali pemindahan jisim, k_c bagi pemindahan jisim aseton ke dalam aliran nitrogen adalah 0.0324 m/s , hitungkan jumlah kadar pemindahan aseton ke fasa nitrogen dalam unit $\text{kg}\cdot\text{mol/s}$.

[5 markah]

- [c] Dalam penyerapan ammonia ke dalam air daripada campuran udara-ammonia pada 300 K dan 1 atm, pekali-pekali filem individu dianggarkan sebagai $k_L = 6.3 \text{ cm/j}$ dan $k_G = 1.17 \text{ kmol/m}^2\cdot\text{j}\cdot\text{atm}$. Hubungan keseimbangan bagi larutan ammonia yang sangat cair di dalam air pada 300 K dan 1 atm ialah

$$y_{A,i} = 1.64 x_{A,i}$$

Tentukan:

- [i] pekali pemindahan jisim gas, k_y [4 markah]
- [ii] pekali pemindahan jisim cecair, k_x [4 markah]
- [iii] pekali pemindahan jisim keseluruhan, K_y [4 markah]
- [iv] nisbah bagi $\frac{\text{Rintangan dalam fasa gas}}{\text{Jumlah rintangan, kedua - dua fasa}}$ [4 markah]

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2. [a] The various types of feed and slope of the q -line for a typical distillation process are shown in Figure Q.2.[a].

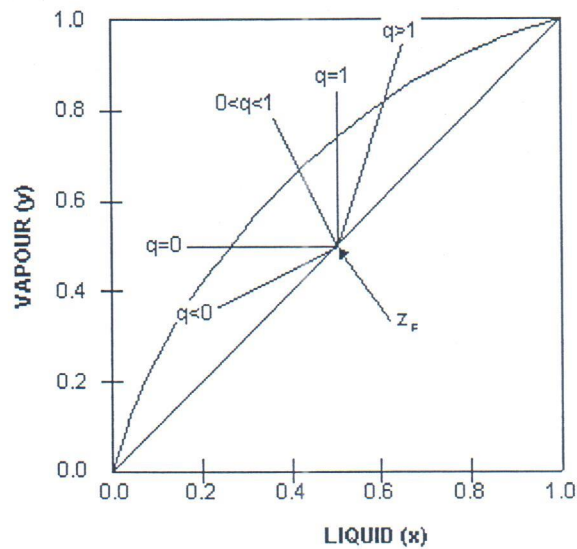


Figure Q.2.[a] Effect of thermal condition of feed on slope of q -line

State the types of the feed condition if:

- [i] $q > 1$
- [ii] $q = 1$
- [iii] $0 < q < 1$
- [iv] $q = 0$
- [v] $q < 0$

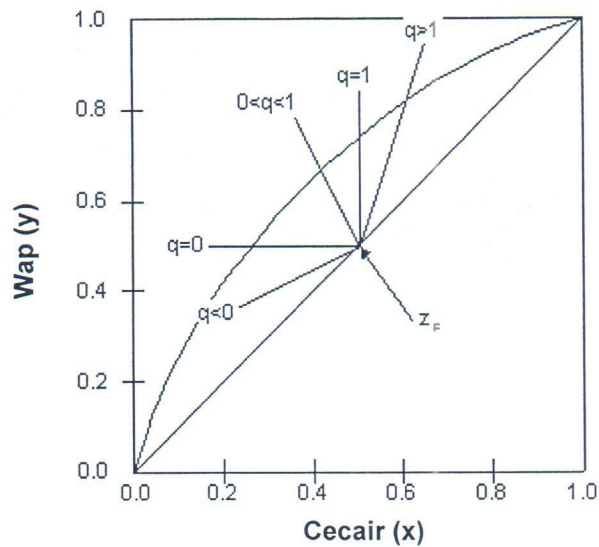
[5 marks]

- [b] A tray distillation column operating at 1 atm is used to continuously distillate 200 kmol/h of a binary mixture of 60 mol% benzene, 40 mol% toluene. A distillate and a bottom product containing 95 mol% and 5 mol% of benzene are to be produced. Before entering the column, the feed originally at 298 K is flash-vaporized at 1 atm to produce an equimolal vapour/liquid mixture ($V_F/F = L_F/F = 0.5$). A reflux ratio 30% above the minimum is specified. The equilibrium data for benzene and toluene is given in Table Q.2.[b]. Calculate:

- [i] quantity of the distillate and bottom products [4 marks]
- [ii] minimum number of theoretical stages, N_{\min} [3 marks]
- [iii] minimum reflux ratio [4 marks]
- [iv] number of equilibrium stages and the optimal location of the feed stage for the reflux ratio specified [9 marks]

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2. [a] Pelbagai jenis suapan dan kecerunan bagi garisan-q untuk proses penyulingan biasa ditunjukkan seperti dalam Rajah S.2.[a].



Rajah S.2.[a] Kesan keadaan terma terhadap suapan pada kecerunan garisan-q

Nyatakan jenis keadaan suapan jika:

- [i] $q > 1$
- [ii] $q = 1$
- [iii] $0 < q < 1$
- [iv] $q = 0$
- [v] $q < 0$

[5 markah]

- [b] Sebuah turus penyulingan dulang beroperasi pada 1 atm digunakan untuk menyuling secara berterusan 200 kmol/j campuran perduaan 60 %mol benzena, 40 %mol toluena. Hasil sulingan dan produk bawah mengandungi 95 %mol dan 5 %mol benzena akan dihasilkan. Sebelum memasuki turus, suapan pada asalnya 298 K diwapkan secara kilat pada 1 atm untuk menghasilkan sama molal campuran wap/cecair ($V_F/F = L_F/F = 0.5$). Nisbah refluks 30% di atas minimum telah ditentukan. Data keseimbangan bagi benzena/toluena adalah seperti yang ditunjukkan pada Jadual S.2.[b]. Hitungkan:

- [i] kuantiti bagi produk-produk sulingan dan bawah [4 markah]
- [ii] bilangan minimum peringkat teori, N_{min} [3 markah]
- [iii] nisbah refluks minimum [4 markah]
- [iv] bilangan peringkat keseimbangan dan lokasi optimum suapan untuk nisbah refluks yang ditentukan. [9 markah]

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Table Q.2.[b].

x	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
y	0.21	0.37	0.51	0.64	0.72	0.79	0.86	0.91	0.96

3. The equilibrium partial pressure of carbon dioxide (CO₂) over aqueous solutions of monoethanolamine (30 wt%) at atmospheric pressure (760 mmHg) are shown in Table Q.3.

Table Q.3.

mol CO ₂ mol solution	Partial pressure CO ₂ , mmHg		
	25°C	50°C	75°C
0.050	-	-	65
0.052	-	7.5	93.5
0.054	-	13.6	142.6
0.056	-	25.0	245
0.058	5.6	47.1	600
0.060	12.8	96.0	-
0.062	29.0	259	-
0.064	56.0	-	-
0.066	98.7	-	-
0.068	155	-	-
0.070	232	-	-

A manufacturing plant of dry ice will burn coke in air to produce a flue gas which contain 15 vol% CO₂, 6 vol% O₂, 79 vol% N₂ after cleaned and cooled. The gas will be blown into a scrubber with sieve-tray at 1 std atm, 25°C. The flue gas will be scrubbed with 30 wt% monoethanolamine solution entering at 25°C. The scrubbing liquid, which contain 0.058 mol CO₂ / mol solution is recycled from a stripper. The gas leaving the scrubber should contain 2 mol% CO₂. Assume isothermal operation. Determine:

- [a] the minimum liquid to gas ratio, (L/G)_{min} mol/mol. [9 marks]
- [b] the amount of solution (in kg) to enter the absorber per cubic meter of entering gas, for an L/G ratio of 1.2 times the minimum ($R = 8.3145 \text{ m}^3 \cdot \text{Pa} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$, MW CO₂ = 44, O₂ = 16, N₂ = 28, monoethanolamine (30 wt%) = 61, 1 atm = 101,325 Pa). [5 marks]
- [c] the number of theoretical trays for the conditions in part [b]. [5 marks]

Jadual S.2. [b].

x	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
y	0.21	0.37	0.51	0.64	0.72	0.79	0.86	0.91	0.96

3. Tekanan separa keseimbangan karbon dioksida (CO₂) ke atas larutan monoethanolamina (30 %berat) pada tekanan atmosfera (760 mmHg) adalah ditunjukkan dalam Jadual S.3.

Jadual S.3.

<i>mol CO₂</i> <i>mol larutan</i>	Tekanan separa CO ₂ , mmHg		
	25°C	50°C	75°C
0.050	-	-	65
0.052	-	7.5	93.5
0.054	-	13.6	142.6
0.056	-	25.0	245
0.058	5.6	47.1	600
0.060	12.8	96.0	-
0.062	29.0	259	-
0.064	56.0	-	-
0.066	98.7	-	-
0.068	155	-	-
0.070	232	-	-

Suatu loji yang mengilang ais kering akan membakar kok dalam udara untuk menghasilkan gas serombong dengan komposisi 15 % isipadu CO₂, 6 % isipadu O₂ dan 79% isipadu N₂ selepas dibersihkan dan disejukkan. Gas itu akan disuapkan ke dalam penggahar yang mengandungi dulang ayak pada 1 atm dan 25°C. Gas serombong itu akan digahar dengan larutan (30 %berat) monoethanolamina yang disuapkan pada suhu 25°C. Cecair penggahar yang mengandungi 0.058 mol CO₂/mol larutan adalah diedarkan semula daripada pelucut. Gas yang keluar daripada penggahar mengandungi 2 %mol CO₂. Operasi adalah dianggap isoterma. Tentukan:

[a] nisbah cecair kepada gas minimum, (L/G)_{min} mol/mol.

[9 markah]

[b] amaun larutan (dalam kilogram) yang akan disuapkan ke dalam penggahar bagi setiap 1 m³ gas yang masuk bagi nisbah L/G 1.2 kali nilai bagi minimum (R = 8.3145 m³.Pa.mol⁻¹K⁻¹, MW CO₂ = 44, O₂ = 16, N₂ = 28, monoethanolamina (30 %berat) = 61, 1 atm = 101,325 Pa).

[5 markah]

[c] bilangan dulang teoritikal bagi situasi di bahagian [b].

[5 markah]

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- [d] After one year operating the plant, the owner decided to further reduce the amount of CO₂ in the gas leaving the scrubber to 0.5 mol%. Briefly give 3 suggestions how can this separation be achieved by still using the same scrubber (maintaining the same scrubbing capacity) and with the same number of stages calculated in part [c].

[6 marks]

4. [a] Barium sulfate (BaSO₄) is converted into water soluble form, barium sulfide (BaS) by heating with coal. The resulting reaction mixture, barium black ash containing 65 wt% soluble BaS, is leach with pure water. The black ash is fed to a continuous countercurrent extraction system at 100 ton/day. The strong solution existing the extraction system is to contain 20 wt% BaS. Experiments show that for every 1 kg of insoluble solid, 1.5 kg of strong solution will be retained. The solution in the out-going overflow and that in the sludge leaving any thickener may be assumed to have the same BaS concentration. It is desired to keep the BaS lost with the final sludge to at most 1 kg/day. Calculate the number of thickeners required. The following equation may be used:

$$N = \frac{\ln [(y_b - x_b) / (y_a - x_a)]}{\ln [(y_b - y_a) / (x_b - x_a)]}$$

[12 marks]

- [b] Seeds containing 30 wt% of oil are extracted in a counter current plant and 95% of the oil is recovered in a solution containing 50 wt% of oil. If the seeds are extracted with fresh solvent and 1 kg of solution is removed in the underflow in association with every 2 kg of insoluble matter, how many ideal stages are required. Solve using the right triangular diagram.

[13 marks]

[d] Selepas menjalankan operasi loji selama satu tahun, pemilik loji membuat keputusan untuk mengurangkan amaun CO_2 di dalam gas yang akan meninggalkan penggahar kepada 0.5 %mol. Secara ringkas, cadangkan 3 cara bagaimana pemisahan tersebut boleh dicapai dengan masih menggunakan penggahar yang sama (mengekalkan kapasiti penggahar yang sama) dan bilangan dulang teoritikal yang dikira di bahagian [c].

[6 markah]

4. [a] Barium sulfat ($BaSO_4$) ditukarkan kepada kompaun boleh larut, barium sulfida (BaS) melalui proses pemanasan dengan arang batu. Campuran tindak balas yang terhasil, abu hitam barium yang mengandungi 65 %berat BaS boleh larut, dikuraskan dengan air tulen. Abu hitam itu disuapkan ke dalam sistem penyarian berlawanan arus berterusan pada kadar 100 tan/hari. Larutan pekat yang keluar daripada sistem penyarian tersebut mengandungi 20 %berat BaS . Data eksperimen menunjukkan bahawa bagi setiap 1 kg pepejal yang tidak larut, 1.5 kg larutan pekat akan tertahan. Larutan yang keluar pada aliran atas dan keluar di aliran enapcemar bagi setiap pemekat boleh dianggap mempunyai kepekatan BaS yang sama. BaS yang hilang bersama-sama dengan aliran enapcemar terakhir haruslah tidak melebihi 1 kg/hari. Kirakan bilangan pemekat yang diperlukan,. Persamaan berikut mungkin boleh digunakan.

$$N = \frac{\ln[(y_b - x_b)/(y_a - x_a)]}{\ln[(y_b - y_a)/(x_b - x_a)]}$$

[12 marks]

[b] Bijian yang mengandungi 30 %berat minyak akan disarikan dengan menggunakan loji berlawanan arus dan 95% minyak perlu diperolehi di dalam larutan yang mengandungi 50 %berat minyak. Sekiranya bijian disarikan dengan menggunakan pelarut baru dan 1 kg larutan dikeluarkan di aliran bawah bersama-sama setiap 2 kg bahan tak larut, berapakah peringkat unggul yang diperlukan. Selesaikan dengan menggunakan gambarajah segitiga tepat.

[13 markah]

Appendix

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 ² s = 0.2046 lb _m /ft ² s = 0.00636 slug/ft ² s	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 ² = 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 ₂ O	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)
<p>• Note that the intervals in absolute (Kelvin) and °C are equal. Also, 1 °R = 1 °F.</p> <p>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</p> <p>Heat transfer coefficient: 1 Btu/(h.ft².°F) = 5.6782 W/(m².°C).</p> <p>Heat generation rate: 1 W/m³ = 0.09665 Btu/(h ft³)</p> <p>Heat transfer per unit length: 1 W/m = 1.0403 Btu/(h ft)</p> <p>Mass transfer coefficient: 1 m/s = 11.811 ft/h, 1 lb_{mol}/(h.ft²) = 0.013562 kgmol/(s.m²)</p>	

The Wilke-Chang equation is given as

$$D_{AB} = 1.173 \times 10^{-16} \frac{(\phi M_B)^{0.5} T}{\mu_B V_A^{0.6}}$$

Recommended value for ϕ

Type of solvents	ϕ
Water	2.6
Methanol	1.9
Ethanol	1.5
Benzene, ether, heptane and other unassociated solvents	1.0

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 = 82.06 cm³.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/s²

Properties of water (unless otherwise stated): $\rho = 1000 \text{ kg/m}^3$, $\mu = 1.00 \text{ mPa.s}$

Diffusion:

Fick's Law:

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

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):

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

; δ = film thickness

$$(1-x_A)_{LM} = (x_B)_{LM} = \frac{x_{Ai} - x_{Ab}}{\ln[(1-x_{Ai})/(1-x_{Ab})]}$$

Mass transfer coefficients:

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

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

Overall mass transfer:

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

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

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

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

Turbulent mass transfer:

<i>Equimolar Counter Diffusion</i>		<i>Diffusion through Stagnant Film</i>	
<i>Flux</i>	<i>Mass Transfer Coefficient</i>	<i>Flux</i>	<i>Mass Transfer Coefficient</i>
Gases:		Gases:	
$N_A = k'_c(C_{A1} - C_{A\delta})$	$k'_c = \frac{D_{AB}}{\delta}$	$N_A = k_c(C_{A1} - C_{A\delta})$	$k_c = \frac{PD_{AB}}{\delta(\bar{P}_B)_M}$
$N_A = k'_G(\bar{P}_{A1} - \bar{P}_{A\delta})$	$k'_G = \frac{D_{AB}}{\delta RT}$	$N_A = k_G(\bar{P}_{A1} - \bar{P}_{A\delta})$	$k_G = \frac{PD_{AB}}{\delta RT(\bar{P}_B)_M}$
$N_A = k'_y(y_{A1} - y_{A\delta})$	$k'_y = \frac{PD_{AB}}{\delta RT}$	$N_A = k_y(y_{A1} - y_{A\delta})$	$k_y = \frac{P^2 D_{AB}}{\delta RT(\bar{P}_B)_M}$
Liquids:		Liquids:	
$N_A = k'_L(C_{A1} - C_{A\delta})$	$k'_L = \frac{D_{AB}}{\delta}$	$N_A = k_L(C_{A1} - C_{A\delta})$	$k_L = \frac{D_{AB}}{\delta(x_B)_M}$
$N_A = k'_x(x_{A1} - x_{A\delta})$	$k'_x = \frac{CD_{AB}}{\delta}$	$N_A = k_x(x_{A1} - x_{A\delta})$	$k_x = \frac{CD_{AB}}{\delta(x_B)_M}$

Conversions between mass-transfer coefficients

Gases:

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

Liquids:

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

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

TABLE *Atomic and Molar Volumes at the Normal Boiling Point*

<i>Material</i>	<i>Atomic Volume (m³/kg mol) 10³</i>	<i>Material</i>	<i>Atomic Volume (m³/kg mol) 10³</i>
C	14.8	Ring, 3-membered	-6
H	3.7	as in ethylene oxide	
O (except as below)	7.4	4-membered	-8.5
Doubly bound as carbonyl	7.4	5-membered	-11.5
Coupled to two other elements		6-membered	-15
In aldehydes, ketones	7.4	Naphthalene ring	-30
In methyl esters	9.1	Anthracene ring	-47.5
In methyl ethers	9.9		
In ethyl esters	9.9		
In ethyl ethers	9.9		
In higher esters	11.0		
In higher ethers	11.0	Air	29.9
In acids (-OH)	12.0	O ₂	25.6
Joined to S, P, N	8.3	N ₂	31.2
N		Br ₂	53.2
Doubly bonded	15.6	Cl ₂	48.4
In primary amines	10.5	CO	30.7
In secondary amines	12.0	CO ₂	34.0
Br 27.0		H ₂	14.3
Cl in RCHClR'	24.6	H ₂ O	18.8
Cl in RCl (terminal)	21.6	H ₂ S	32.9
F 8.7		NH ₃	25.8
I 37.0		NO	23.6
S 25.6		N ₂ O	36.4
P 27.0		SO ₂	44.8

*Molecular Volume
(m³/kg mol) 10³*

Source: G. Le Bas, *The Molecular Volumes of Liquid Chemical Compounds*. New York: David McKay Co., Inc., 1915.