UNIVERSITI SAINS MALAYSIA

First Semester Examination
2015/2016 Academic Session

December 2015 / January 2016

EKC 217 – Mass Transfer
[Pemindahan Jisim]

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH muka surat yang bercetak dan EMPAT 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] What is the best way to make a cup of tasty coffee from the coffee beans and sugar cubes. Justify your answer from the mass transfer point of view.

[3 marks]

[b] A thin polymeric membrane is used to separate helium from a gas stream. Under steady-state conditions the concentration of helium in the membrane is known to be 0.02 and 0.005 kmol/m^3 at the inlet and outlet surfaces, respectively. If the membrane is 1 mm thick and the binary diffusion coefficient of helium with respect to the polymeric membrane is 1×10^{-9} m^2/s, what is the diffusive flux (kg/s·m^2)? Given the molecular weight of helium is 4 kg/kmol.

[5 marks]

[c] At a particular location in a countercurrent stripper for removing solute A from a liquid stream, the mole fraction of species A in the bulk gas phase is 0.01, and the mole fraction of solute A in the bulk liquid phase is 0.035. The total system pressure is 2 atm, and the temperature is 300 K. Eighty percent (80%) of the resistance to mass transfer is in the liquid phase. The equilibrium concentrations are given in the x-y diagram as shown in Figure Q.1.[c].

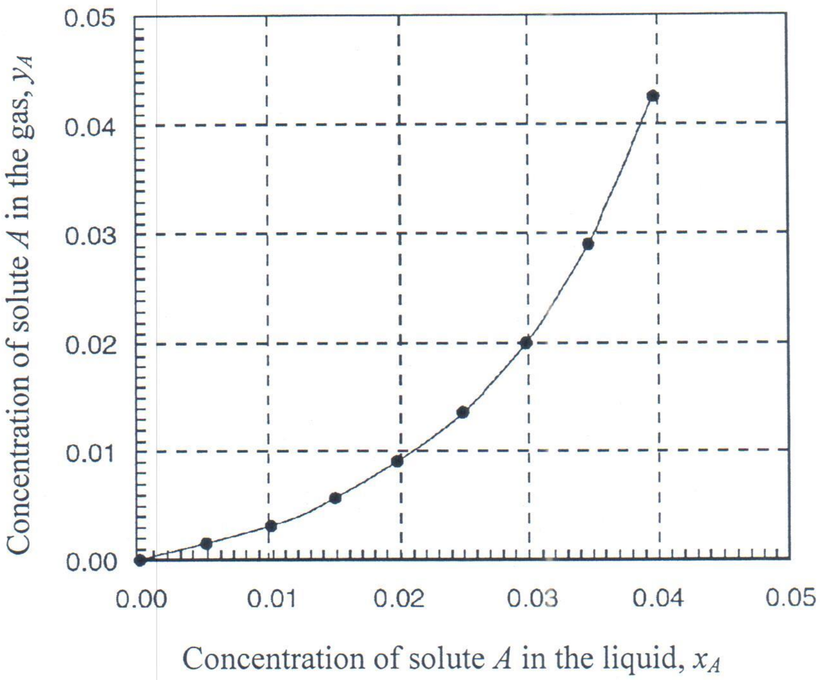


Figure Q.1.[c]: The equilibrium concentrations of solute A

[i] Determine the interfacial compositions, $x_{A,\,i}$ and $y_{A,\,i}$

[8 marks]

[ii] If k_y = 1.25 gmol/m^2·s·(mole fraction), calculate the overall coefficient, K_y, for the gas phase at the operating point of the process

[3 marks]

[iii] Calculate the overall gas phase coefficient K_G and K_c

[6 marks]

Jawab SEMUA soalan.

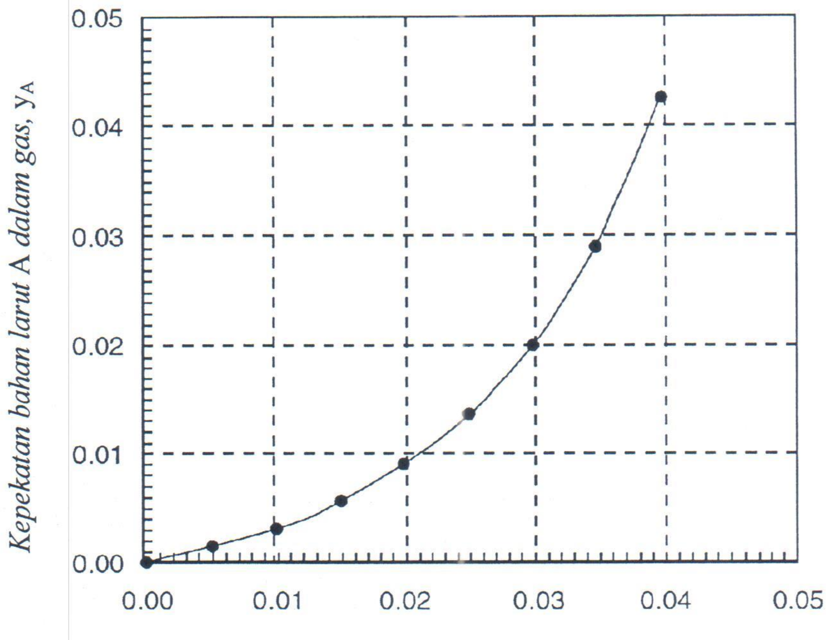
1. [a] *Apakah cara terbaik untuk membuat secawan kopi yang sedap dari biji kopi dan ketulan gula? Jelaskan jawapan anda dari segi pemindahan jisim.*

[3 markah]

[b] *Satu membran polimer nipis digunakan untuk memisahkan helium daripada aliran gas. Pada keadaan mantap, kepekatan helium pada permukaan membran di bahagian masuk dan keluar ialah masing-masing 0.02 dan 0.005 kmol/m^3. Jika ketebalan membran adalah 1 mm dan pekali resapan binari helium berdasarkan kepada membran polimer adalah 1×10^{-9} m^2/s, apakah fluks meresap (kg/s·m^2)? Berat molekul helium adalah 4 kg/kmol.*

[5 markah]

[c] *Pada lokasi yang tertentu dalam sebuah pelucut arus berlawanan untuk mengeluarkan bahan larut A dari aliran cecair, pecahan mol spesies A dalam fasa gas pukal adalah 0.01, dan pecahan mol bahan larut A dalam fasa cecair pukal adalah 0.035. Jumlah tekanan sistem adalah 2 atm dan suhu adalah 300K. Lapan puluh peratus (80%) daripada rintangan kepada pemindahan jisim berada dalam fasa cecair. Kepekatan keseimbangan diberikan dalam rajah x-y seperti yang ditunjukkan dalam Rajah S.1.[c].*



Rajah S.1.[c]: Kepekatan keseimbangan bahan larut A

[i] *Tentukan komposisi-komposisi antara muka, $x_{A,i}$ dan $y_{A,i}$*

[8 markah]

[ii] *Jika $k_y = 1.25$ gmol/m^2·s·(pecahan mol), hitungkan pekali keseluruhan, K_y, untuk fasa gas pada titik operasi proses*

[3 markah]

[iii] *Hitungkan pekali keseluruhan fasa gas K_G dan K_c*

[6 markah]

2. [a] What are the values of the conditions of the feed by the quantity q for the five possible feed conditions of a typical distillation process as shown in the Table Q.2.[a]?

[5 marks]

Table Q.2.[a]

No.	Feed Condition	q
(i)	Superheated vapour	
(ii)	Subcooled liquid	
(iii)	Partially vaporized	
(iv)	Boiling point liquid	
(v)	Saturated vapour	

[b] A bubble cap fractionating column consisting of 12 plates working at an average efficiency of 75% is being used to distill 1000 kg/h of aqueous methanol at its boiling point entering the tower. The feed, overhead product and bottom product are 50 mol%, 90 mol% and 10 mol% methanol, respectively. A total condenser is used with the reflux at its saturation temperature. If the reflux ratio is 1.7 times the minimum, check whether the column is feasible to perform the separation. The vapour liquid equilibrium (VLE) data are shown in the Table Q.2.[b].

Table Q.2.[b].

x	0	0.08	0.10	0.20	0.30	0.40	0.50	0.70	0.80	0.95	1.00
y	0	0.365	0.418	0.579	0.665	0.729	0.779	0.870	0.958	0.979	1.00

[20 marks]

3. MN Corporation has a 4-stage sieve tower that is designed to recover ethyl propanol from an inert gas stream using water. The tower is designed to treat 100 kmol/h of inlet gas stream that contains 2.2 mol% alcohol. Ignoring the amount of alcohol in the inlet liquid feed stream, the aim of the tower is to produce an exit gas stream that only contains 20% (mol) of the alcohol from the inlet gas stream. Based on the operating sheet of the tower, it was suggested to use recycle water containing 0.5 mol% alcohol as the solvent and the total amount of feed liquid stream should be set at 50 kmol/h. However, after running the absorption process for a few times, it was found that the exit gas composition obtained was not as desired. As a chemical engineer working in MN Corporation, your plant manager has instructed you to:

[a] Identify possible causes why the recovery of alcohol is not as the desired value. Support your argument with facts and data.

[10 marks]

2. [a] *Apakah nilai-nilai untuk keadaan suapan dalam kuantiti* q *bagi lima keadaan yang mungkin untuk satu proses penyulingan biasa seperti yang ditunjukkan dalam Jadual S.2.[a]?*

[5 markah]

Jadual S.2.[a]

No.	*Keadaan suapan*	q
(i)	*Wap panas lampau*	
(ii)	*Cecair tersubdingin*	
(iii)	*Pegewapan separa*	
(iv)	*Cecair takat didih*	
(v)	*Wap tepu*	

[b] *Satu turus pemeringkatan tukup gelembung yang terdiri daripada 12 plat beroperasi pada kecekapan purata 75% digunakan untuk menyuling 1000 kg/j cecair metanol pada takat didihnya memasuki turus. Suapan, produk atas dan produk bawah masing-masing mempunyai 50 %mol, 90 %mol dan 10 %mol methanol. Pemeluwap jumlahan digunakan dengan refluks pada suhu ketepuan. Jika nisbah refluks adalah 1.7 kali nilai minimum, semak sama ada turus tersebut mampu untuk melaksanakan pemisahan. Keseimbangan cecair wap (VLE) data adalah ditunjukkan seperti di Jadual S.2.[b]:*

Rajah S.2.[b]

x	0	0.08	0.10	0.20	0.30	0.40	0.50	0.70	0.80	0.95	1.00
y	0	0.365	0.418	0.579	0.665	0.729	0.779	0.870	0.958	0.979	1.00

[20 markah]

3. *Perbadanan MN mempunyai satu turus ayak 4-peringkat yang direkabentuk untuk memulihkan etil propanol daripada aliran gas lengai dengan menggunakan air. Turus tersebut direkabentuk untuk merawat 100 kmol/jam aliran gas lengai yang mengandungi 2.2 %mol alkohol. Dengan mengabaikan kuantiti alkohol dalam aliran cecair suapan, tujuan turus ini adalah untuk menghasilkan aliran gas keluaran yang hanya mengandungi 20% (mol) alkohol daripada aliran gas suapan. Berdasarkan maklumat operasi turus tersebut, adalah dicadangkan untuk menggunakan air kitar semula yang mengandungi 0.5 %mol alkohol sebagai pelarut dan jumlah kuantiti aliran cecair suapan harus ditetapkan pada 50 kmol/j. Walau bagaimanapun, selepas menjalankan proses penjerapan tersebut untuk beberapa kali, didapati bahawa komposisi aliran gas keluaran adalah tidak seperti yang dikehendaki. Sebagai seorang Jurutera Kimia yang bekerja di Perbadanan MN, pengurus loji telah mengarahkan anda untuk:*

[a] *Mengenalpasti sebab-sebab yang mungkin boleh menyebabkan nilai pemulihan alkohol adalah tidak seperti yang dikehendaki. Jawapan anda haruslah disokong dengan fakta dan data.*

[10 markah]

[b] Suggest multiple possible ways how you can overcome this problem if your company insisted to use the 4-stage tower and without changing the inlet gas stream. Your suggestions should be supported with facts and data. State clearly any assumptions made and discuss the limitations or advantages of each suggestions made.

[15 marks]

Given: The system is dilute and the equilibrium relationship can be taken as $y = 0.68x$.

4. [a] Describe a leaching process.

[2 marks]

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

[3 marks]

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

[2 marks]

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

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

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. The products from the reaction entering the first unit with no excess reactants but with 0.6 kg of H_2O per kg Na_2CO_3. The extract from the system contains 5 kg of NaOH per 100 kg of H_2O.

[i] How much pure wash water must be used per kg of Na_2CO_3?

[12 marks]

[ii] Calculate the number of stages required for the extraction.

[6 marks]

Additional information given:

- Process temperature: 30°C
- Process pressure: 1 atm
- Specific gravity of the $CaCO_3$ slurry: 1.12
- Molecular weight of $CaCO_3$: 100
- Molecular weight of Na_2CO_3: 106
- Molecular weight of NaOH: 40
- Molecular weight of H_2O: 18
- $CaCO_3$ is assumed completely insoluble
- Usefull equation:

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

[b] *Cadangkan beberapa cara bagaimana masalah ini boleh di atasi sekiranya syarikat anda masih ingin menggunakan turus 4-peringkat tersebut dan tanpa mengubah aliran gas suapan. Cadangan anda perlu disokong dengan fakta dan data. Nyatakan dengan jelas sebarang anggapan yang dibuat dan bincangkan kelebihan dan kekurangan setiap cadangan yang dibuat.*

[15 markah]

Diberi: Sistem adalah cair dan hubungan keseimbangan boleh diambil kira sebagai y = 0.68x.

4. [a] *Takrifkan proses pengurasan.*

[2 markah]

[b] *Nyatakan tiga faktor yang boleh mempengaruhi proses pengurasan.*

[3 markah]

[c] *Apakah yang anda faham apabila keseimbangan dicapai dalam proses pengurasan.*

[2 markah]

[d] *Satu sistem penyarian berlawanan-arus digunakan untuk menyari enapcemar daripada tindak balas berikut.*

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

$CaCO_3$ membawa bersama-samanya 1.5 kali berat larutan apabila mengalir daripada satu unit ke unit lain. Sistem penyarian tersebut perlu memulihkan 99% NaOH. Produk daripada tindak balas di atas yang memasuki unit pertama adalah tanpa bahan tindak balas berlebihan tetapi dengan 0.6 kg H_2O per kg Na_2CO_3. Hasil sarian daripada sistem tersebut mengandungi 5 kg NaOH per 100 kg H_2O.

[i] *Berapa banyak air tulen yang perlu digunakan per kg Na_2CO_3?*

[12 markah]

[ii] *Kirakan bilangan peringkat yang diperlukan bagi proses penyarian di atas.*

[6 markah]

Data tambahan diberi:

- *Suhu proses: 30°C*
- *Tekanan proses: 1 atm*
- *Graviti tentu mendakan $CaCO_3$:1.12*
- *Berat molekul $CaCO_3$: 100*
- *Berat molekul Na_2CO_3: 106*
- *Berat molekul NaOH: 40*
- *Berat molekul H_2O: 18*
- *$CaCO_3$ dianggap tidak boleh larut*
- *Persamaan yang berguna:*

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

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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:

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

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

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

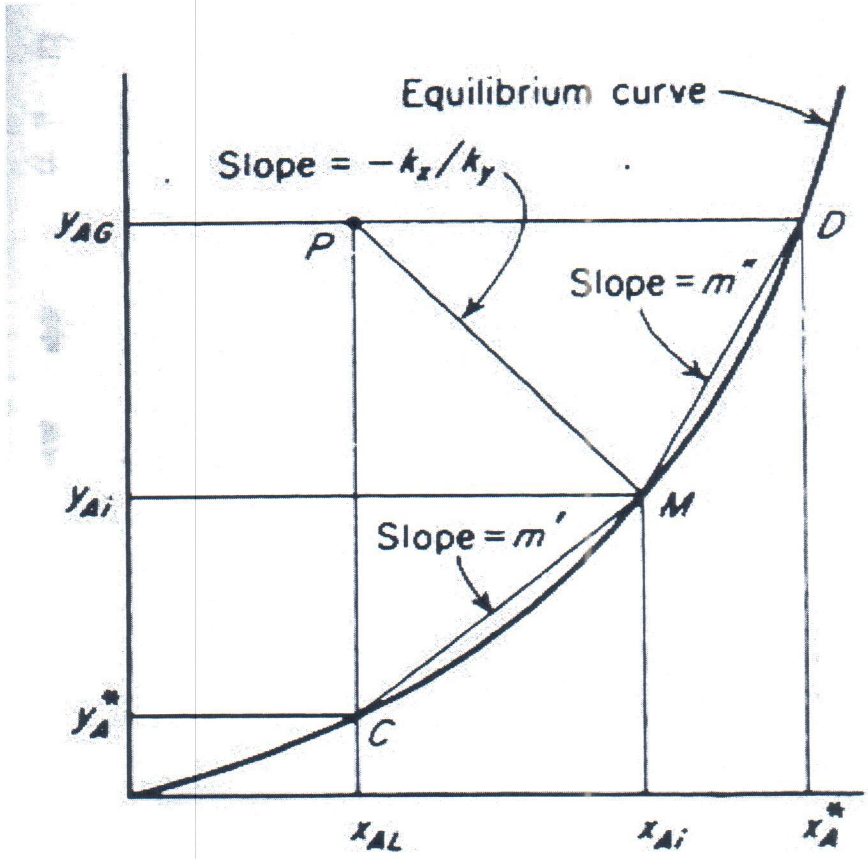
$$N_A = \frac{D_{AB}\rho_M}{(z_2 - z_1)y_{BM}}(y_{A1} - y_{A2})\,;\; y_{BM} = \frac{y_{B2} - y_{B1}}{\ln(y_{B2}/y_{B1})}$$

Molecular diffusion of solute in liquids:

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

$$N_A = \frac{D_{AB}}{(z_2 - z_1)x_{BM}}\left(\frac{\rho}{M}\right)_{av}(x_{A1} - x_{A2})\;;\; x_{BM} = \frac{x_{B2} - x_{B1}}{\ln(x_{B2}/x_{B1})}$$

Interphase Mass Transfer:



Overall concentration difference

$$N_A = k_y(y_{A,G} - y_{A,i}) = k_x(x_{A,i} - x_{A,L})$$

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

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

$$\frac{\text{Resistance in gas phase}}{\text{Total resistance, both phases}} = \frac{1/k_y}{1/K_y}$$

$$\frac{\text{Resistance in liquid phase}}{\text{Total resistance, both phases}} = \frac{1/k_x}{1/K_x}$$

...3/-

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 lmp.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			
$^oF = (9/5)^oC + 32$	$^oC = (5/9)(^oF - 32)$	$^oR = {}^oF + 459.69$	$^oK = {}^oC + 273.16$

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)