UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2007/2008

April 2008

EKC 111 – Mass Balance
[Imbangan Jisim]

Duration : 3 hours
[Masa : 3 jam]

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

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

Instructions: Answer **SEVEN** (7) questions. Answer **ALL** (4) questions from Section A. Answer **THREE** (3) questions from Section B.

[Arahan: *Jawab **TUJUH** (7) soalan. Jawab **SEMUA** (4) soalan dari Bahagian A. Jawab **TIGA** (3) soalan dari Bahagian B.]*

You may answer your questions either in Bahasa Malaysia or in English.

[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

Section A : Answer ALL questions.
Bahagian A : Jawab SEMUA soalan.

1. A group of student is preparing 50% sulfuric acid (H_2SO_4) for the ChemE-car competition. They achieved this by mixing a dilute waste acid containing 28% H_2SO_4 with a purchased acid containing 96% H_2SO_4. Calculate how many kilograms of the purchased acid must be bought for each 100 kg of dilute waste acid.

Sekumpulan pelajar menyediakan asid sulfurik (H_2SO_4) 50% untuk pertandingan Chem-E-Car. Pelajar-pelajar tersebut berjaya melakukannya melalui percampuran asid sisa cair yang mengandungi 28% H_2SO_4 dengan asid yang dibeli mengandungi 96% H_2SO_4. Kirakan berapa kilogram asidkah yang harus dibeli bagi setiap 100 kg asid sisa cair.

[10 marks/markah]

2. [a] About 45 million tons of sulfuric acid (H_2SO_4) are manufactured every year in the world, topping the list of all chemicals in quantity produced. Calculate:

Dianggarkan 45 juta tan asid sulfurik (H_2SO_4) dihasilkan setiap tahun di dunia, mengatasi kesemua senarai kuantiti bahan kimia yang dihasilkan. Kirakan:

[i] The ton-moles of sulfuric acid produced per year
Asid sulfurik terhasil setiap tahun dalam tan-mol

[ii] The grams of sulfuric acid produced per year (1 ton = 2000 lb)
Asid sulfurik terhasil setiap tahun dalam gram (1 tan = 2000 lb)

[iii] The pounds of sulfuric acid per person in the world, assuming the world population is 6 billion
Asid sulfurik terhasil setiap tahun dalam 'pound' bagi setiap manusia di dunia, dianggarkan populasi dunia adalah seramai 6 bilion

[iv] What is the US dollar value of the worldwide market if sulfuric acid sells for about USD75/ton? Convert the US dollar amount into Ringgit Malaysia if 1 USD is equal to RM3.40.
Berapakah pasaran dunia dalam nilai matawang US sekiranya asid sulfurik dijual dengan harga USD75 setan? Tukarkan nilai matawang US tersebut kepada Ringgit sekiranya 1 USD bersamaan dengan RM3.40.

[4 marks/markah]

[b] Oxygen at 100°C and 75 psia flows through a pipe at 115 lb/min. Calculate the molar flow rate (lbmol/min) and the volumetric flow rate (m^3/min) at both the actual temperature and pressure and at STP.

Oksigen pada 100°C dan 75 psia mengalir melalui suatu paip pada kadar 115 lb/min. Kirakan kadar aliran molar (lbmol/min) dan kadar aliran isipadu (m^3/min) pada kedua-dua suhu dan tekanan sebenar serta pada STP.

[6 marks/markah]

3. The label has come off a cylinder of a gas in your laboratory. You know only that one species of gas is contained in the cylinder. But you do not know whether it is hydrogen, oxygen or nitrogen. You are required to identify the gas. You are given a 5 litre flask, temperature measurement, weighing scale and the gas cylinder were equipped with a pressure gauge. State the known and unknown variable about this particular situation. Visualise the situation through a sketch. Outline the steps to determine the gas.

Dalam makmal anda, sebuah silinder gas telah tertanggal labelnya. Anda mengetahui bahawa hanya sejenis gas yang ada dalam silinder tersebut. Namun begitu, anda tidak mengetahui sama ada gas tersebut adalah hidrogen, oksigen atau nitrogen. Anda perlu menentukan gas tersebut. Anda diberi kelalang 5 liter, pengukur suhu, penimbang dan silinder gas yang dilengkapi dengan tolok tekanan. Sila nyatakan pembolehubah yang diketahui dan tidak ketahui. Gambarkan keadaan tersebut melalui lakaran. Senaraikan langkah-langkah untuk menentukan gas tersebut.

[10 marks/markah]

4. A stream of hydrogen is flowing at temperature 50°C. This stream of hydrogen later merges with a stream of 1-butene. The process stream of hydrogen and 1-butene is then flowing at 35 kmol/h containing 15 mole % of hydrogen. The stream pressure is 10.0 atm absolute and the velocity is 150 m/min.

Satu aliran hidrogen mengalir pada suhu 50°C. Aliran tersebut bertemu dengan satu aliran 1-butena. Aliran kombinasi hidrogen dan 1-butena kemudiannya mengalir pada 35 kmol/j dengan komposisi 15% mol hidrogen. Tekanan aliran tersebut adalah pada 10.0 atm mutlak dan kelajuannya 150 m/min.

[a] If you are provided with a generalised compressibility chart, outline the procedure to calculate the volumetric flow rate of the hydrogen.

Jika anda dibekalkan dengan carta kebolehmampatan umum, senaraikan tatacara pengiraan kadar pengaliran isipadu hidrogen tersebut.

[3 marks/markah]

[b] If you are not given the chart, propose and state possible alternative methods.

Jika anda tidak dibekalkan carta itu, cadangkan dan nyatakan kaedah alternatif yang mungkin.

[2 marks/markah]

[c] Determine the diameter (inches) of the pipe transporting both gases.

Tentukan garispusat (inci) paip yang membawa kedua-dua gas tersebut.

[5 marks/markah]

Section B : Answer any THREE questions.
Bahagian B : Jawab mana-mana TIGA soalan.

5. [a] In order to make nitrocellulose membrane, a PhD student must prepare 1000 lb of an 8% nitrocellulose solution. She has in stock a 5.5% solution. How much dry nitrocellulose (100% nitrocellulose) must she dissolve in the solution to prepare the 1000 lb of 8% nitrocellulose solution?

Untuk membuat membran nitroselulosa, seorang pelajar PhD mesti menyediakan 1000 lb larutan nitroselulosa 8%. Pelajar tersebut mempunyai suatu larutan 5.5% dalam simpanan. Berapa banyakkah nitroselulosa kering (nitroselulosa 100%) yang harus pelajar tersebut larutkan dalam larutan untuk menyediakan 1000 lb larutan nitroselulosa 8%?

[6 marks/markah]

[b] Figure Q.5. [b] shows a gas containing 80 mol% CH_4 (methane) and 20 mol% He (helium) is sent through a quarts diffusion tube to recover the He. 20% by weight of the original gas is recovered and its composition is 50 mol% He. Calculate the composition of the waste gas if 100 kg moles of gas are processed per minute.

Rajah S.5. [b] menunjukkan penghantaran suatu gas yang mengandungi 80% mol CH_4 (metana) dan 20% mol He (helium) melalui tiub resapan kuarza untuk memulihkan He. 20% berat gas asal dapat dipulihkan dan komposisi gas terpulih ialah 50% mol He. Kirakan komposisi gas sisa jika 100 kg mol gas diproses per minit.

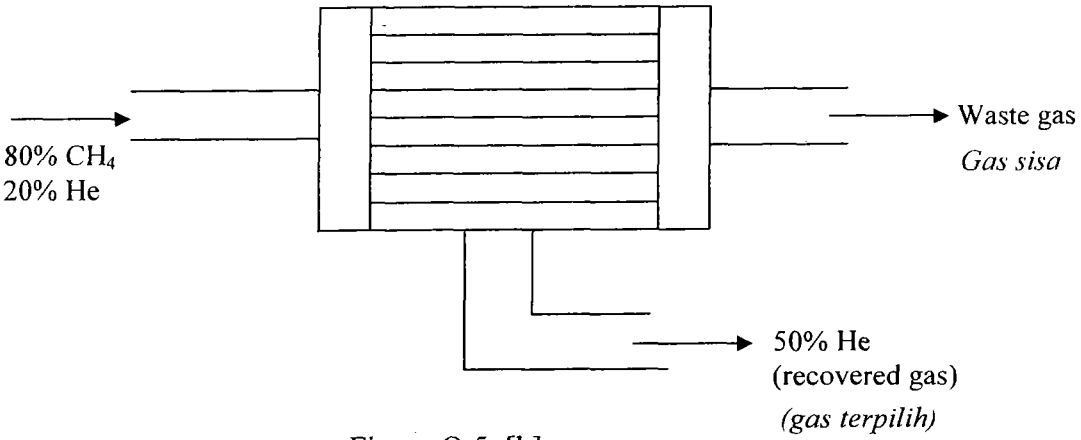


Figure Q.5. [b]
Rajah S.5. [b]

Given: MW for CH_4 = 16
MW for He = 4

Diberi: MW bagi CH_4 = 16
MW bagi He = 4

[14 marks/markah]

6. [a] Strawberries contain about 15 wt % solids and the rest is water. To make strawberry jam, the fresh fruit is crushed and then mixed with sugar in a 45:55 mass ration. The mixture is heated to evaporate the water until the jam mixture contains one-third of water by mass.

Buah strawberi mengandungi 15 berat % pepejal dan selebihnya adalah air. Untuk membuat jem strawberi, buah strawberi segar dihancurkan dan kemudian dicampurkan dengan gula pada kadar nisbah jisim 45:55. Campuran tersebut dipanaskan untuk menyejat kandungan air sehingga campuran jem tersebut mengandungi satu pertiga air dalam bentuk jisim.

[i] Draw and label flowchart of the process.

Lakarkan dan label carta aliran proses tersebut.

[ii] Calculate how many kilograms of strawberries are needed to make a kilogram of jam and how much water is evaporated?

Kirakan berapa banyak kilogram buah strawberi diperlukan untuk membuat 1 kilogram jem dan berapa banyakkah air yang tersejat?

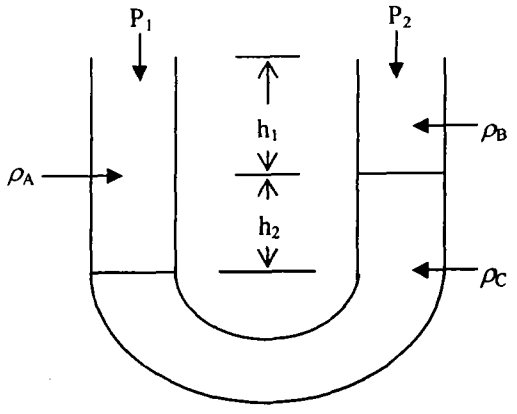
[iii] If you decided to make another batch of the jam, how much strawberries and sugar would you need to make 1 litre of jam. (density of the jam is 1.2 g/mL).

Sekiranya anda memutuskan untuk membuat satu lagi kelompok jem tersebut, berapa banyakkah buah strawberi yang anda perlukan untuk menghasilkan 1 liter jem tersebut. (ketumpatan jem diberi sebagai 1.2 g/mL).

[10 marks/markah]

[b] Three different liquids are used in the manometer shown here.

Tiga bendalir yang berlainan digunakan dalam manometer yang ditunjukkan di sini.



[i] Derive an expression for $P_1 - P_2$ in terms of ρ_A, ρ_B, ρ_C, h_1 and h_2.

Terbitkan satu persamaan bagi $P_1 - P_2$ dalam bentuk ρ_A, ρ_B, ρ_C, h_1 dan h_2.

[ii] Suppose fluid A is methanol, B is water and C is a manometer fluid with specific gravity of 1.37; pressure P_2 = 35.7 in Hg; h_1 = 300 mm and h_2 = 9.45 inch. Calculate P_1 in kPa.
(Given that $\rho_A = 0.792$ g/cm^3)

Sekiranya bendalir A ialah metanol, B ialah air dan C ialah bendalir manometer dengan graviti tentu 1.37; tekanan P_2 = 35.7 inci Hg; h_1 = 300 mm dan h_2 = 9.45 inci. Kirakan P_1 dalam unit kPa.
(Diberikan $\rho_A = 0.792$ g/sm^3)

[10 marks/markah]

7. Dehydration of natural gas is necessary to prevent the formation of gas hydrates, which can plug valves and other components of a gas pipeline, and also to reduce potential corrosion problems. Water removal can be accomplished as shown in the following schematic diagram.

Penghidratan gas asli bertujuan menghalang pembentukan hidratan gas di mana ia akan menyumbatkan injap, komponen-komponen paip gas dan mengurangkan potensi masalah penghakisan. Penyingkiran air boleh dijayakan seperti ditunjukkan dalam gambarajah skema berikutnya.

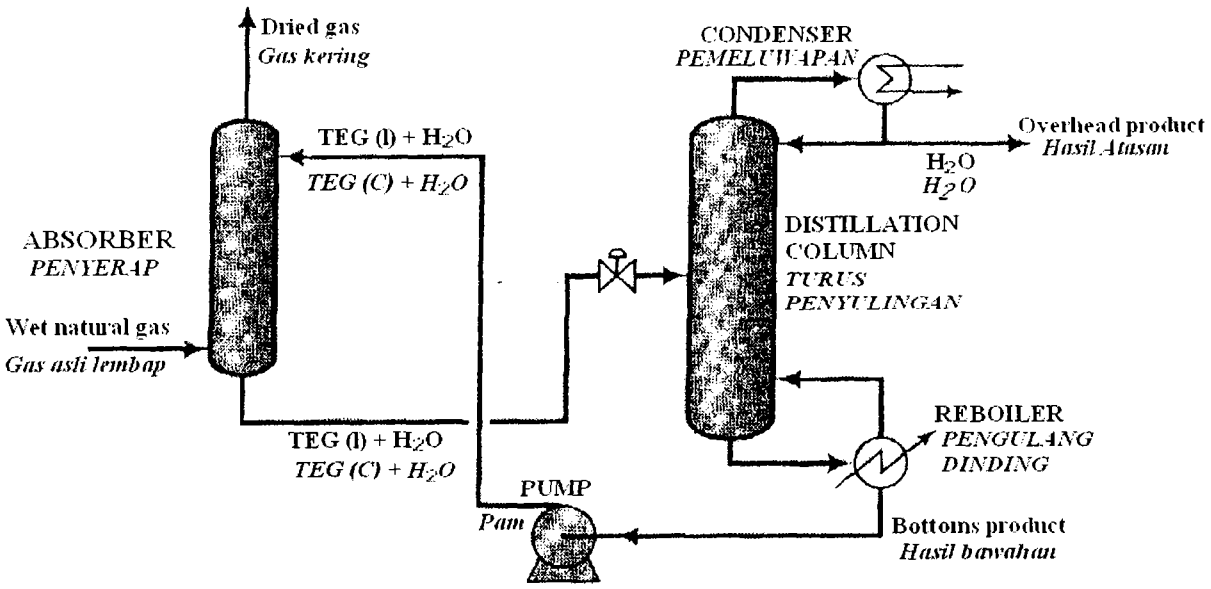


Figure Q.7.
Rajah S.7.

Natural gas containing 80 lbm $H_2O/10^6$ SCF gas [(SCF = ft^3 (STP)] enters the bottom of an absorber at a rate of 4.0×10^6 SCF/day. A liquid stream containing triethlyene glycol (TEG, molecular weight = 150.2) and a small amount of water is fed to the top of the absorber. The absorber operates at 500 psia and 90°F. The dried gas leaving the absorber contains 10 lbm $H_2O/10^6$ SCF gas. The solvent leaving the absorber, which contains all the TEG-water mixture fed to the column plus all the water absorbed from the natural gas, goes to a distillation column. The overhead product stream from the distillation column contains only liquid water. The bottom product stream, which contains TEG and water, is the stream recycled to the absorber.

...7/-

Gas asli mengandungi 80 lbm $H_2O/10^6$ SCF gas [(SCF = ft^3 (STP)] memasuki bahagian bawah penyerap pada kadar 4.0 x 10^6 SCF/hari. Satu aliran cecair mengandungi tri-etilena glikol (TEG, berat molekul = 150.2) dan sedikit air disuapkan di bahagian atas penyerap. Penyerap itu beroperasi pada 500 psia dan 90°F. Gas kering yang keluar mengandungi 10 lbm $H_2O/10^6$ SCF gas. Pelarut yang keluar dari penyerap mengandungi campuran air-TEG yang telah disuap ke turus dan juga semua air yang diserap dari gas asli kemudian dihantar ke turus penyulingan. Aliran hasil atas dari turus penyulingan hanya mengandungi air. Aliran hasil bawah yang mengandungi TEG dan air adalah aliran kitaran semula ke penyerap.

[a] Draw and completely label a flow chart of the process.

Lukis dan labelkan selengkapnya carta aliran proses tersebut.

[2 marks/markah]

[b] Calculate the mass flow rate (lbm/year) and volumetric flow rate (ft^3/day) of the overhead product from the distillation column.

Kirakan kadar aliran jisim (lbm/tahun) dan kadar aliran isipadu ($kaki^3$/hari) untuk hasil atas turus penyulingan tersebut.

[7 marks/markah]

[c] The maximum possible amount of dehydration is achieved if the gas leaving the absorption column is in equilibrium with the solvent entering the column. If the Henry's Law constant for water in TEG at 90°F is 0.398 psia/mol fraction, calculate the maximum allowable mole fraction of water in the solvent fed to the absorber? Defend the use of Henry's Law in this calculation.

Jumlah kemungkinan maksimum penyahhidratan yang akan dicapai jika gas yang keluar dari turus penyerap adalah pada keseimbangan dengan pelarut yang memasuki turus itu. Pemalar Hukum Henry bagi air dalam TEG adalah 0.398 psia/ pecahan mol pada 90°F, kirakan pecahan mol maksimum air yang dibenarkan dalam suapan pelarut ke penyerap. Beri justifikasi penggunaan Hukum Henry dalam pengiraan ini.

[3 marks/markah]

[d] A column of infinite height would be required to achieve equilibrium between the gas and liquid at the top of the absorber. For the desired separation to be achieved in practice, the mole fraction of water in the entering solvent must be less than the value calculated in part (b). Suppose it is 80% of that value and the flow rate of TEG in the circulating solvent is 37 lbm TEG/lbm water absorbed in the column. Calculate the flow rate (lbm/day) of the solvent stream entering the absorber and the mole fraction of water in the solvent stream leaving the absorber.

Turus ketinggian ketakhinggaan adalah perlu untuk mencapai keseimbangan antara gas dan cecair pada bahagian atas penyerap. Untuk pemisahan yang praktikal dicapai, pecahan mol air dalam aliran pelarut masuk perlu kurang dari nilai yang dikira pada bahagian (b). Andaikan 80% nilai dan kadar aliran TEG dalam pelarut aliran kitar semula adalah 37 lbm TEG/lbm air diserap dalam turus. Kirakan kadar aliran (lbm/hari) untuk aliran pelarut memasuki penyerap dan pecahan mol air dalam aliran pelarut keluar dari penyerap.

[6 marks/markah]

[e] What is the purpose of the distillation column and absorber in the process?
Apakah tujuan turus penyulingan dan penyerap dalam proses tersebut?

[2 marks/markah]

8. The gas-phase reaction between methanol and acetic acid to form methyl acetate and water

$$\underset{(A)}{CH_3OH} + \underset{(B)}{CH_3COOH} \rightleftharpoons \underset{(C)}{CH_3COOCH_3} + \underset{(D)}{H_2O}$$

takes place in a batch reactor and proceeds to equilibrium. When the reaction mixture comes to equilibrium, the mole fractions of the four reactive species satisfy the relation.

$$\frac{y_C\, y_D}{y_A\, y_B} = 4.87$$

Tindakbalas fasa gas antara metanol dan asid asetik membentuk metil asetat dan air

$$\underset{(A)}{CH_3OH} + \underset{(B)}{CH_3COOH} \rightleftharpoons \underset{(C)}{CH_3COOCH_3} + \underset{(D)}{H_2O}$$

berlaku dalam reaktor kelompok dan mencapai keseimbangan. Bila campuran tindakbalas mencapai keseimbangan, pecahan mol bagi keempat-empat spesis reaktif perlu memenuhi persamaan.

$$\frac{y_C\, y_D}{y_A\, y_B} = 4.87$$

[a] Suppose the feed to the reactor consists of n_{AO}, n_{BO}, n_{CO}, n_{DO} and n_{IO} gram moles of A, B, C, D and an inert gas, I, respectively. Let ξ (mol) be the extent of reaction. Write expressions for the gram moles of each reactive species in the final product, n_A (ξ), n_B (ξ), n_C (ξ) and n_D (ξ). Then use these expressions and the given equilibrium relation to derive an equation for ξ_e, the equilibrium extent of reaction in terms of n_{AO},....n_{IO}.

Andaikan suapan ke reaktor mengandungi masing-masing n_{AO}, n_{BO}, n_{CO}, n_{DO} dan n_{IO} mol gram bagi A, B, C, D dan gas lengai, I. Biarkan ξ (mol) sebagai tindakbalas had. Tulis ungkapan bagi mol gram setiap spesis reaktif dalam hasil akhir, n_A (ξ), n_B (ξ), n_C (ξ) dan n_D (ξ). Kemudian, gunakan ungkapan dan hubungan persamaan keseimbangan yang diberi untuk menerbitkan persamaan tindakbalas keseimbangan had ξ_e, dalam ungkapan n_{AO}, ...n_{IO}.

[7 marks/markah]

[b] If the feed to the reactor contains equimolar quantities of methanol and acetic acid and no other species, calculate the equilibrium fractional conversion.

Jika suapan reaktor mengandungi kuantiti sama molar metanol dan asid asetik dan tiada spesis lain, kirakan penukaran pecahan keseimbangan.

[2 marks/markah]

[c] It is desired to produce 70 mol of methyl ecetate starting with 80 mol of acetic acid. If the reaction proceeds to equilibrium, calculate the quantity of methanol must be fed? Compute the composition of the final product.

Proses itu memerlukan permulaan 80 mol asid asetik bagi mengeluarkan 70 mol metil asetat. Jika tindakbalas berterusan hingga keseimbangan, kirakan kuantiti metanol yang perlu disuap? Kirakan komposisi hasil akhir.

[6 marks/markah]

[d] If you as the consultant were asked to advice on the commercial aspects of the process, what would you need to advise for the process to be profitable besides the equilibrium composition.

Jika anda sebagai perunding diminta nasihat mengenai aspek komersial proses ini, apakah yang anda perlu cadangkan selain dari aspek keseimbangan agar proses ini menguntungkan.

[5 marks/markah]

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Appendix
Lampiran

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 = 14696 psi = 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	
Specific Heat or Gas Constant*	**Thermal Conductivity***
1 (ft lb_f)/(slug °R) = 0.16723 (N m) (kg K) 1 Btu/(lb °R) = 4186.8 J/(kg K)	1 cal/(s cm °C) = 242 Btu/(h ft °R) 1 Btu/(h ft °R) = 1.7307 W/(m K)

• 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_fft/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)

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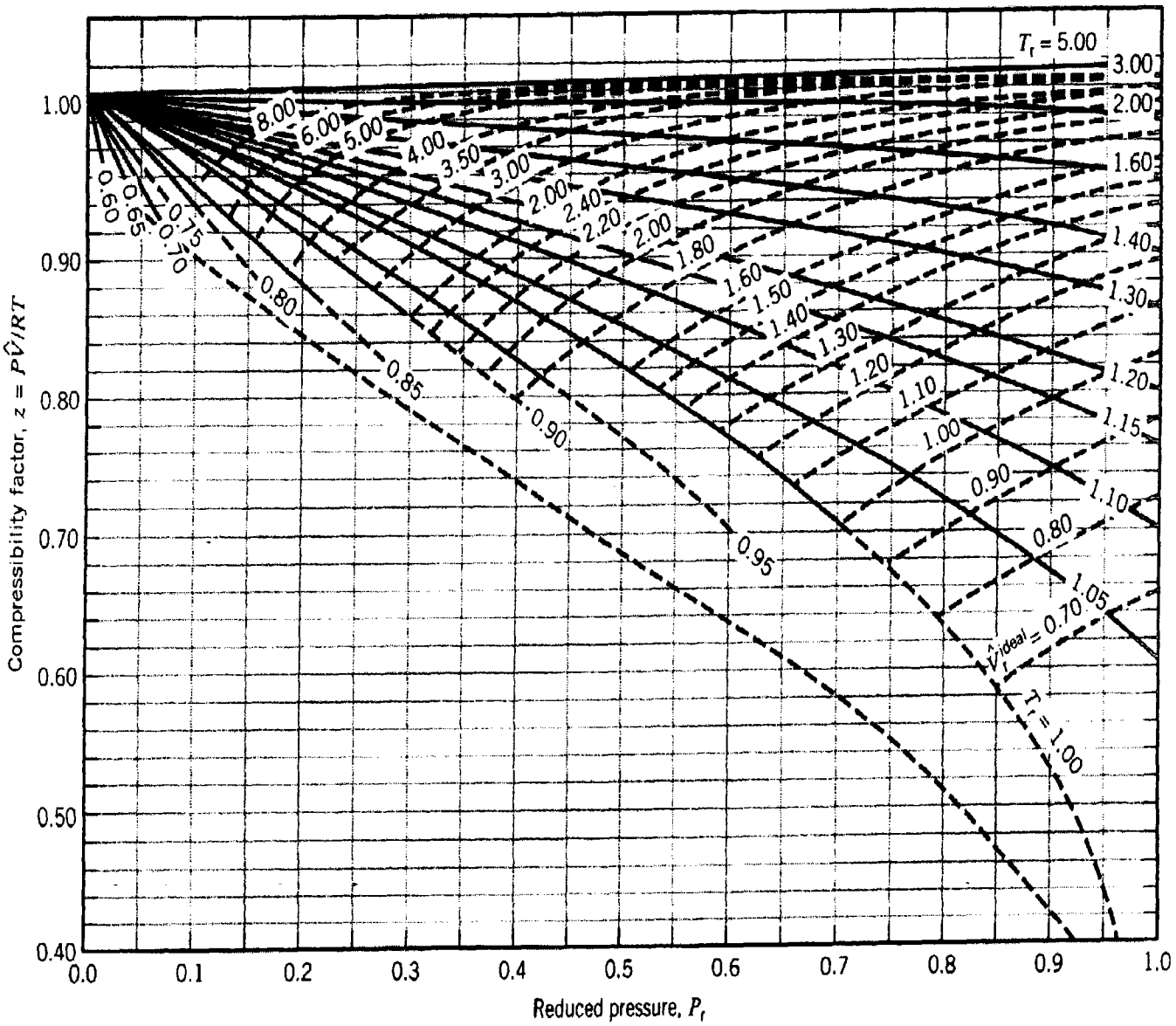

Generalized compressibility chart, low pressures. (From D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, copyright © 1974, p. 175. Reprinted by permission of Prentice Hall, Inc., Englewood Cliffs, NJ.)