

16-CHEM-A2, UNIT OPERATIONS and SEPARATION PROCESSES

MAY 2018

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an **open book exam**. One textbook of your choice with notations listed on the margins etc., but no loose notes are permitted into the exam.
3. Candidates may use any **non-communicating** scientific calculator.
4. All problems are worth 25 points. At least **two problems** from **each** of parts **A** and **B** must be attempted.
5. **Only the first two** questions as they appear in the answer book from each section will be marked.
6. State all assumptions clearly.

PART A: UNIT OPERATIONS

- A1.** A filter cake (thickness of 5.1 cm) was washed at a rate of $8.1 \times 10^{-3} \text{ m}^3/\text{m}^2 \cdot \text{min}$ with pure water to remove soluble salts present in the voids. The composition of the cake is given below:

	Mass Fraction	Density, in kg/m^3
Inert Solids	0.4789	1420
Water	0.4641	1000
Soluble Salts	0.0570	1363

At the end of the washing period, the cake was analyzed and found to have mass fraction of 0.24% of salts on a moisture-free basis. Calculate the following:

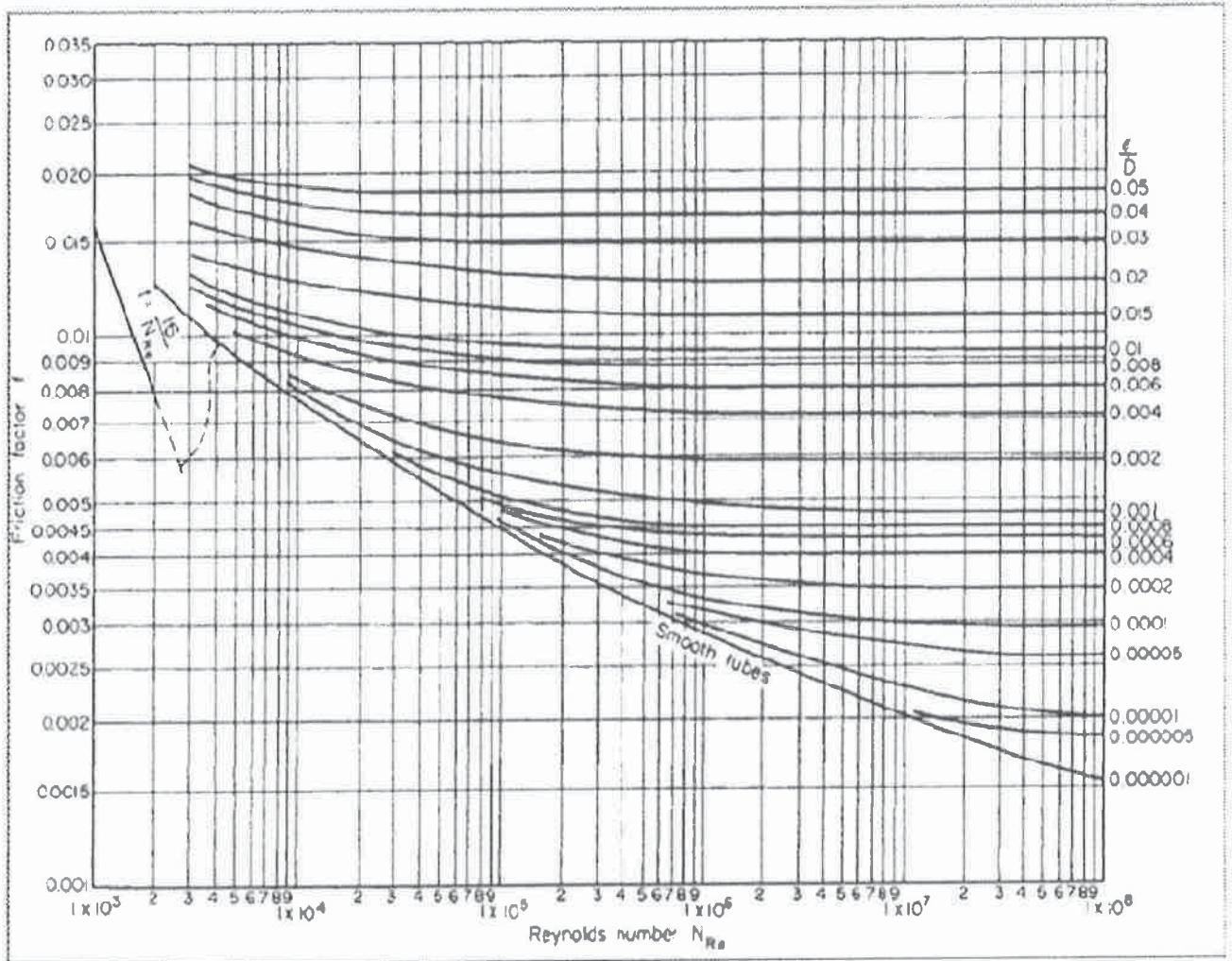
- (a) [5 points] Average porosity of the cake.
- (b) [3 points] Volume fraction of salts on a moisture-free basis at the end of washing period.
- (c) [4 points] Average cake density.
- (d) [4 points] Mass of dry inert solid per unit area of filtration.
- (e) [6 points] Initial and final mass of solute per unit area of filtration.
- (f) [3 points] Void volume per unit area of filtration.

- A2. Water at 60 °F is to be pumped from a reservoir to a storage tank on top of a building through an open pipe at a flow rate of 610 gal/min. The reservoir's water level is 10 ft above the pipe inlet and 200 ft below the water level in the tank. Both reservoir and tank are open to atmosphere. The piping system (525 ft long and a roughness parameter of 1.5×10^{-4} ft) has an inner diameter of 4 inches, and contains two gate valves and five 90° elbows. Calculate the pump power requirement (in HP or kW) if it is rated as 60% efficient.

DATA: Viscosity of water = 7.587×10^{-4} lb_m/ft.s
 Density of water = 62.37 lb_m/ft³

Fitting Loss Coefficient (K_f) Table

Fitting	K_f
Globe valve, wide open	10.0
Angle valve, wide open	5.0
Gate valve, wide open	0.2
Gate valve, half open	5.6
Return bend	2.2
Tee	1.8
Elbow, 90°	0.9
Elbow, 45°	0.4



Fanning friction factor (f) vs. Reynolds number (Re) for pipes

Transactions of the American Society of Mechanical Engineers, vol. 66, p.672 (1944)

- A3. A spherical particle having a diameter of 9.3×10^{-3} inches and a specific gravity of 1.85 is placed on a horizontal screen. Air is blown through the screen vertically at a temperature of 20 oC and a pressure of 1 atm. Calculate the following:
- (a) [10 points] Velocity required to just lift the particle.
 - (b) [3 points] Particle Reynolds number at the condition of part (a).
 - (c) [5 points] Drag force.
 - (d) [7 points] Drag coefficient C_D .

DATA: Viscosity of air = 1.23×10^{-5} lb_m/ft.s
 Density of air = 7.52×10^{-2} lb_m/ft³
 Gravitational constant (g_c) = 32.2 lb_m.ft/lb_f.s²

PART B: SEPARATION PROCESSES

B1. Air containing 5% by mole of ammonia (NH_3) is contacted with water in an absorption tower packed with 1-inch ceramic Raschig rings and operating at 1 atm (absolute) and 20 °C. The entering gas flow rate is 40 lbmol/hr and the entering water flow rate is 3200 lb_m/hr. 90% of the NH_3 is to be removed from air.

- (a) [15 points] Find the diameter of the packed absorption tower operating at 70% of the flooding.
- (b) [10 points] Determine the pressure drop per foot of packing.

DATA:

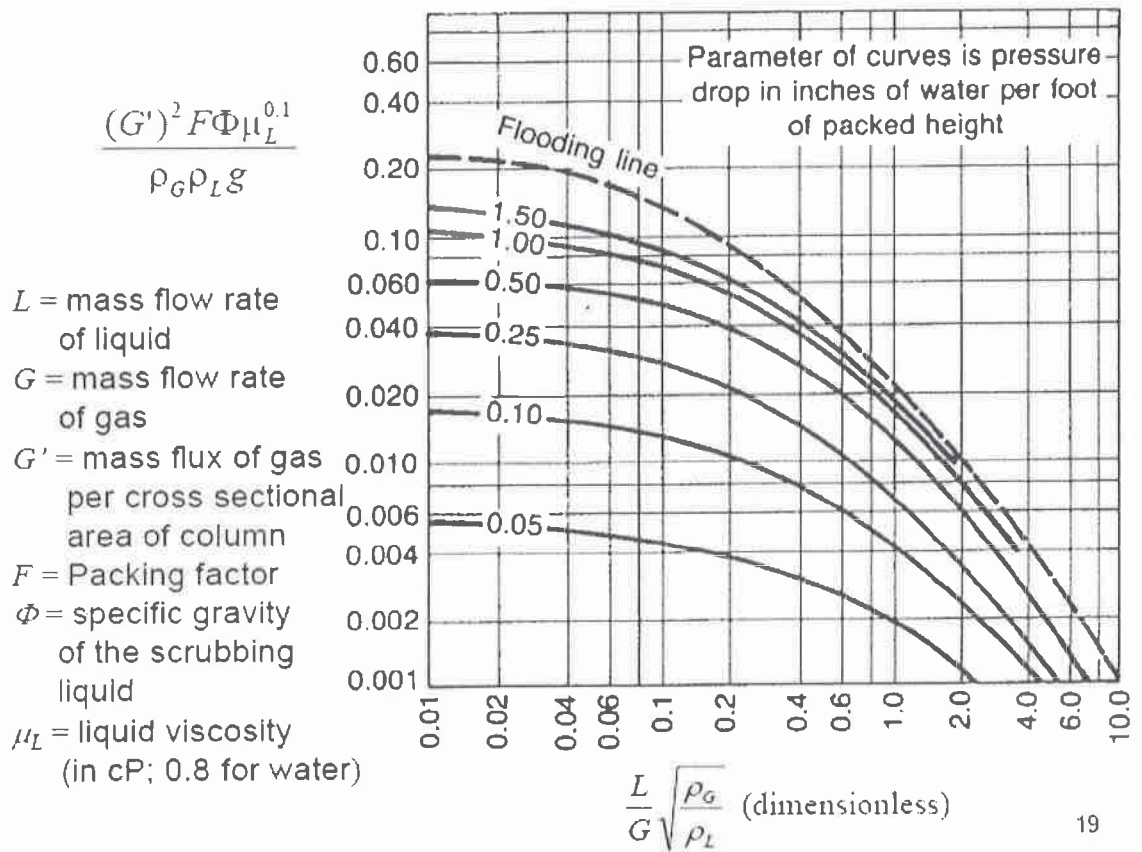
Viscosity of water and ammonia-water solution (μ_L) = 1.0 cP

Density of ammonia-air mixture at 0 °C (ρ_G) = 0.0791 lb_m/ft³

Density of pure water and ammonia-water solution (ρ_L) = 62.3 lb_m/ft³

Characteristic packing factor (F) = 155

Specific gravity of water = 1.0



Sherwood Flooding Correlation for Packed Towers

"Packed Tower Design and Applications" By Ralph E. Stigle, Jr., Gulf Publishing Company, Houston, Texas, 1996.

- B2.** Adsorption of papain (a cysteine protease enzyme present in papaya) from an aqueous solution on the solid matrix of activated charcoal was carried out in the laboratory and the following equilibrium data was obtained:

Concentration of Papain in Solution (in grams of papain/gram of solution)	Concentration of Papain in Adsorbent (in grams of papain/gram of charcoal)
9.295	0.3511
18.667	0.6109
28.754	0.6614
38.278	1.1953
48.355	1.2626

- (a) [13 points] Evaluate the constants for Langmuir Isotherm.
- (b) [10 points] Evaluate the constants for Freundlich Isotherm.
- (c) [2 points] Which isotherm gives a better fit for the equilibrium data?

- B3.** 250 kg of an aqueous solution of pyridine containing 50% pyridine by weight is extracted in two stages using 200 kg chlorobenzene in each stage. The mutual solubility of water-chlorobenzene and the equilibrium distribution of pyridine between them (all in weight percentage) are given below:

Pyridine	Chlorobenzene	Water
0	99.95	0.05
0	0.08	99.92
5.02	0.16	94.82
11.05	88.28	0.67
11.05	0.24	88.71
18.90	0.38	80.72
18.95	79.90	1.15
24.10	74.28	1.26
25.50	0.58	73.92
28.60	69.15	2.25
31.55	65.58	2.87
35.05	61.00	3.95
36.10	1.85	62.05
40.60	53.00	6.40
44.95	4.18	50.87
49.00	37.80	13.20
53.20	8.90	37.90

- (a) [20 points] What will be the concentration of pyridine in the raffinate?
 (b) [5 points] Estimate the percentage of pyridine extracted.

The Periodic Table of the Elements

1 Hydrogen 1 H 1.01																	18 Helium 2 He 4.00	
2 Lithium 3 Li 6.94		4 Beryllium 4 Be 9.01											13 Boron 5 B 10.81	14 Carbon 6 C 12.01	15 Nitrogen 7 N 14.01	16 Oxygen 8 O 16.00	17 Fluorine 9 F 19.00	18 Neon 10 Ne 20.18
11 Sodium 11 Na 22.99		12 Magnesium 12 Mg 24.31											13 Aluminum 13 Al 26.98	14 Silicon 14 Si 28.09	15 Phosphorus 15 P 30.97	16 Sulfur 16 S 32.07	17 Chlorine 17 Cl 35.45	18 Argon 18 Ar 39.95
19 Potassium 19 K 39.10		20 Calcium 20 Ca 40.08	21 Scandium 21 Sc 44.96	22 Titanium 22 Ti 47.88	23 Vanadium 23 V 50.94	24 Chromium 24 Cr 52.00	25 Manganese 25 Mn 54.94	26 Iron 26 Fe 55.85	27 Cobalt 27 Co 58.93	28 Nickel 28 Ni 58.69	29 Copper 29 Cu 63.55	30 Zinc 30 Zn 65.39	31 Gallium 31 Ga 69.72	32 Germanium 32 Ge 72.61	33 Arsenic 33 As 74.92	34 Selenium 34 Se 78.96	35 Bromine 35 Br 79.90	36 Krypton 36 Kr 83.80
37 Rubidium 37 Rb 85.47		38 Strontium 38 Sr 87.62	39 Yttrium 39 Y 88.91	40 Zirconium 40 Zr 91.22	41 Niobium 41 Nb 92.91	42 Molybdenum 42 Mo 95.94	43 Technetium 43 Tc (98)	44 Ruthenium 44 Ru 101.07	45 Rhodium 45 Rh 102.91	46 Palladium 46 Pd 106.42	47 Silver 47 Ag 107.87	48 Cadmium 48 Cd 112.41	49 Indium 49 In 114.82	50 Tin 50 Sn 118.71	51 Antimony 51 Sb 121.76	52 Tellurium 52 Te 127.60	53 Iodine 53 I 126.90	54 Xenon 54 Xe 131.29
55 Cesium 55 Cs 132.91		56 Barium 56 Ba 137.33	57-70 * Lutetium 71 Lu 174.97	72 Hafnium 72 Hf 178.49	73 Tantalum 73 Ta 180.95	74 Tungsten 74 W 183.84	75 Rhenium 75 Re 186.21	76 Osmium 76 Os 190.23	77 Iridium 77 Ir 192.22	78 Platinum 78 Pt 195.08	79 Gold 79 Au 196.97	80 Mercury 80 Hg 200.59	81 Thallium 81 Tl 204.38	82 Lead 82 Pb 207.20	83 Bismuth 83 Bi 208.98	84 Polonium 84 Po (209)	85 Astatine 85 At (210)	86 Radon 86 Rn (222)
87 Francium 87 Fr (223)		88 Radium 88 Ra (226)	89-102 ** Lawrencium 103 Lr (262)	104 Rutherfordium 104 Rf (267)	105 Dubnium 105 Db (268)	106 Seaborgium 106 Sg (271)	107 Bohrium 107 Bh (272)	108 Hassium 108 Hs (270)	109 Meitnerium 109 Mt (276)	110 Darmstadtium 110 Ds (281)	111 Roentgenium 111 Rg (280)	112 Copernicium 112 Cn (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294?)	118 Uuo (294)

- Alkali metals
- Alkaline earth metals
- Transition metals
- Other metals
- Metalloids (semi-metal)
- Nonmetals
- Halogens
- Noble gases

Element name → Mercury
Atomic # ← 80
Symbol → Hg
Avg. Mass ← 200.59

*lanthanides

Lanthanum 57 La 138.91	Cerium 58 Ce 140.12	Praseodymium 59 Pr 140.91	Neodymium 60 Nd 144.24	Promethium 61 Pm (145)	Samarium 62 Sm 150.36	Europium 63 Eu 151.97	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.93	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.93	Erbium 68 Er 167.26	Thulium 69 Tm 168.93	Ytterbium 70 Yb 173.04
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**actinides

Actinium 89 Ac (227)	Thorium 90 Th 232.04	Protactinium 91 Pa 231.04	Uranium 92 U 238.03	Neptunium 93 Np (237)	Plutonium 94 Pu (244)	Americium 95 Am (243)	Curium 96 Cm (247)	Berkelium 97 Bk (247)	Californium 98 Cf (251)	Einsteinium 99 Es (252)	Fermium 100 Fm (257)	Mendelevium 101 Md (258)	Nobelium 102 No (259)
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