16-CHEM-A2, UNIT OPERATIONS and SEPARATION PROCESSES

National Exams MAY 2019

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** calculator.
4. All problems are worth 25 points. **Two problems** from **each** of parts **A** and **B** must be attempted.
5. **Only the first two** questions from each section as they appear in the answer book will be marked.
6. State all assumptions clearly.

PART A: UNIT OPERATIONS

A1. A batch centrifugal filter having a diameter of 750 mm and a height of 450 mm is used to filter a suspension (solids in water) at 25 °C having the following properties:

Concentration of solids in the feed = 60 g/L

Density of dry solid in the cake = 2000 kg/m^3

Porosity of cake = 0.435

Final thickness of cake = 15 cm

Specific cake resistance = 9.5 x 10^{10} ft/lb

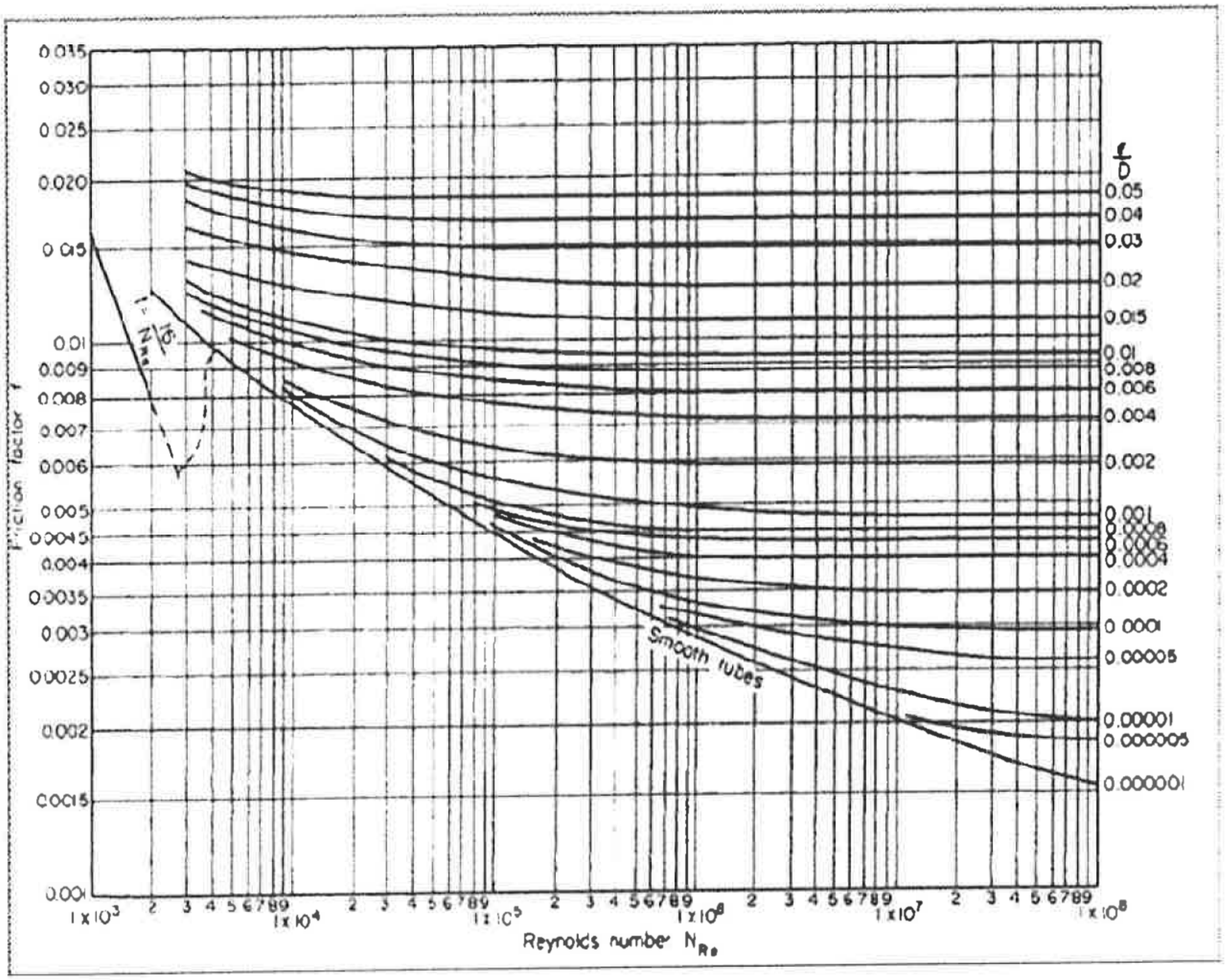
Filter medium resistance = 2.6 x 10^{10} ft^{-1}

Speed of centrifuge filter = 2000 rpm

The cake is washed with water under such conditions that the radius of the inner surface of the liquid is 200 mm. Assuming that the rate of flow of wash water equals the final flow rate of filtrate, calculate the rate of washing in cubic meters per hour.

DATA: Viscosity of water = 0.9cP = 9 x 10^{-4} Pa.s
Density of water = 998 kg/m^3

A2. A liquid (specific gravity = 2.6, viscosity = 2 x 10^{-3} Pa.s) flows through a hydraulically smooth long pipe of unknown diameter, resulting in a pressure drop of 0.183 lb_f/in^2 over a distance of 2.784 kilometers. Calculate the diameter of the pipe in inches if the mass flow rate of the liquid is 3,175 kg/hr.



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

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

A3. The pressure drop of water flowing through a bed of 20-mesh to 50-mesh resin (assume spherical particles) is said to be proportional to the flow rate and has a published value of 0.8 lb_f per square inch per foot at a flow rate of 10 gallons per minute per square foot.

(a) **[7.5 points]** Predict the pressure drop using an arithmetic average particle size and a bed void fraction of 0.35.

(b) **[10 points]** What average particle size would be needed for agreement with the published value of pressure drop?

(c) **[7.5 points]** What void fraction would be needed for agreement with the published value of pressure drop?

<u>DATA:</u> Viscosity of water = 1 cP = 1 x 10^{-3} Pa.s
Density of water = 1000 kg/m^3

PART B: SEPARATION PROCESSES

B1. 100 moles of a saturated liquid feed containing 40 mol% acetone and 60 mol% ethanol is to be separated in a packed tower into an overhead product containing 85% acetone and a bottom product containing 5% acetone. The distillation is to be carried out at 1 atm using the following acetone-ethanol vapor-liquid equilibrium data:

Temperature (K)	Liquid Mole Fraction of Acetone	Vapor Mole Fraction of Acetone
351.45	0.000	0.000
349.55	0.033	0.111
347.15	0.078	0.216
343.95	0.149	0.345
342.25	0.195	0.410
338.75	0.316	0.534
336.55	0.414	0.614
334.45	0.532	0.697
332.15	0.691	0.796
330.45	0.852	0.896
329.25	1.000	1.000

The local mass transfer coefficients for this process are

$$k'_y a = 0.2\ kmol/m^3.s\ (mole\ fraction)$$

$$k'_x a = 1.6\ kmol/m^3.s\ (mole\ fraction)$$

Assuming equal molar overflow, using a total condenser and reflux ratio of L/D = 2.5, determine the number of transfer units to perform the separation.

B2. Solute A is to be recovered from an inert carrier gas B by absorption into a non-volatile solvent. The gas mixture enters the absorber at a rate of 500 kmol/hr containing 30% by mole of A, and leaves the absorber with 1% by mole of A. Solvent enters the absorber at a rate of 1500 kmol/hr containing 0.1% by mole of A. The equilibrium relationship is the vapor phase mole fraction of A is 2.8 times the liquid phase mole fraction of A. The carrier gas is insoluble in the solvent. Compute and then construct x-y plot of equilibrium line and operating line on one graph using solute-free coordinates.

B3. The adsorption of sulfur dioxide (SO_2) on mordenite zeolite was studied at 0 °C and the following data was obtained:

Pressure of SO_2, in mm Hg	**SO_2 Uptake,** in mmol/g
5	1.75
10	2.20
15	2.40
20	2.62
30	2.75
40	2.85
50	3.00
60	3.05
70	3.12

(a) **[20 points]** Determine which isotherm fits the data and then evaluate the isotherm constants.

(b) **[5 points]** Calculate the total surface area of the solid.

DATA: Avagadro's number = 6.023 x 10^{23} molecules/mole

Density of liquid SO_2 at 0 °C in the adsorbed phase = 1430 kg/m^3

APPENDIX D

PARTICLE SIZE–U.S. SIEVE SIZE AND TYLER SCREEN MESH EQUIVALENTS

In the multiphase combustion area, we often encounter unburned and partially burned particles of different sizes. In the United States, these sizes are often expressed in a standard measured quantity in terms of either U.S. Sieve Size or Tyler Screen Mesh. Sieving or screening is a method of separating a mixture of particles (or grains) into two or more size fractions (see Tables E.1 and E.2). The over size particles are trapped above the screen while undersize particles can pass through the screen. Sieves can be used in stacks, to divide samples up into various size fractions and hence determine particle size distributions. Sieves and screen usually are used for larger particle sizes, $d_p \geq 37$ μm (0.037mm).

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TABLE D.1. Standard U.S. Sieve Sizes and Tyler Mesh Sizes

U.S. Sieve Size	Tyler Mesh Size	Opening (mm)	Opening (in)
—	2 1/2 mesh	8.00	0.312
—	3 mesh	6.73	0.265
No. 3 1/2	3 1/2 mesh	5.66	0.233
No. 4	4 mesh	4.76	0.187
No. 5	5 mesh	4.00	0.157
No. 6	6 mesh	3.36	0.132
No. 7	7 mesh	2.83	0.111
No. 8	8 mesh	2.38	0.0937
No. 10	9 mesh	2.00	0.0787
No. 12	10 mesh	1.68	0.0661
No. 14	12 mesh	1.41	0.0555
No. 16	14 mesh	1.19	0.0469
No. 18	16 mesh	1.00	0.0394
No. 20	20 mesh	0.841	0.0331
No. 25	24 mesh	0.707	0.0278
No. 30	28 mesh	0.595	0.0234
No. 35	32 mesh	0.500	0.0197
No. 40	35 mesh	0.420	0.0165
No. 45	42 mesh	0.354	0.0139
No. 50	48 mesh	0.297	0.0117
No. 60	60 mesh	0.250	0.0098
No. 70	65 mesh	0.210	0.0083
No. 80	80 mesh	0.177	0.0070
No. 100	100 mesh	0.149	0.0059
No. 120	115 mesh	0.125	0.0049
No. 140	150 mesh	0.105	0.0041
No. 170	170 mesh	0.088	0.0035
No. 200	200 mesh	0.074	0.0029
No. 230	250 mesh	0.063	0.0025
No. 270	270 mesh	0.053	0.0021
No. 325	325 mesh	0.044	0.0017
No. 400	400 mesh	0.037	0.0015

The Periodic Table of the Elements

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

Key: Element name → Mercury; Atomic # → 80; Symbol → Hg; Avg. Mass → 200.59

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

*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
**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)