16-CHEM-A2, UNIT OPERATIONS and SEPARATION PROCESSES

MAY 2017

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.

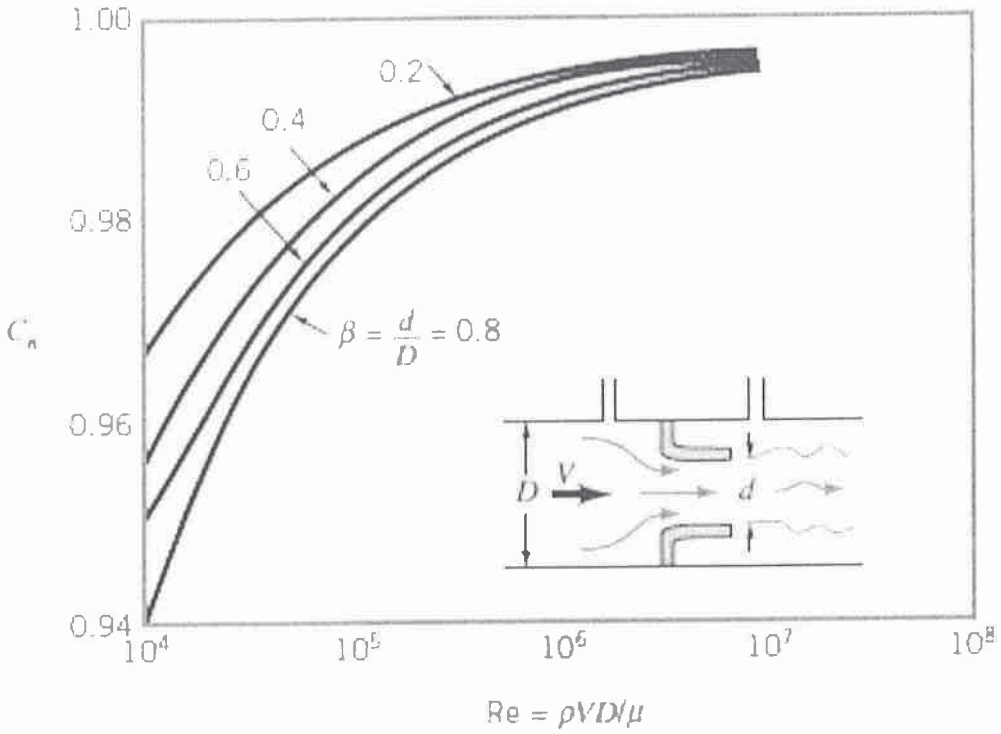
3. Candidates may use any **non-communicating** scientific calculator.

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.

PART A: UNIT OPERATIONS

A1. Ethanol flows through a 60-mm diameter pipe in a refinery. The pressure drop across the nozzle meter used to measure the flowrate is to be 4 kPa when the flowrate is 3 x 10^{-3} m^3/s. Determine the diameter of the nozzle.



Coefficient of Discharge (C_n) vs. Reynolds number (Re) for Nozzle Meters

"Measurement of Fluid Flow by Means of Orifice Plates, Nozzles, and Venturi Tubes Inserted in Circular Cross Section Conduits Running Full," Int. Organ. Stand. Rep. DIS-5167, Geneva, 1976.

DATA: Density of ethanol = 789 kg/m^3
Viscosity of ethanol = 1.19 x 10^{-3} $N.s/m^2$

A2. A Swenson-Walker crystallizer is to be used to produce 1 ton/hr of copperas ($FeSO_4.7H_2O$) crystals by cooling a saturated solution that enters the crystallizer at 120°F. The slurry leaving the crystallizer will be at 80°F. Cooling water enters the crystallizer jacket at 60°F and leaves at 70°F. At 120°F, the saturated solution contains 140 parts of copperas per 100 parts of excess water, and the saturated solution at 80°F contains 74 parts of copperas per 100 parts of excess water. It may be assumed that the overall heat transfer coefficient for the crystallizer is 35 BTU/hr.ft^2.°F. There are 3.5 ft^2 of cooling surface area per foot of crystallizer in length.

(a) **[15 points]** Estimate the cooling water required in gallons per minute.

(b) **[10 points]** Determine the number of crystallizer sections to be used.

DATA: Average specific heat capacity of initial solution = 0.70 BTU/lb °F
Heat of solution of $FeSO_4.7H_2O$ at 80°F = 28.5 BTU/lb

A3. A 6-inch plate-and-frame filter press using two frames, each 2 inches thick and having a total active filter area of 1 ft^2, is used to filter a slurry of calcium carbonate ($CaCO_3$) in water, and the following experimental data was obtained for constant-pressure filtration at a pressure difference of 30 lb_f/in^2 across the press:

Time of Filtration, in seconds	Weight of Filtrate, in pounds
0	0
26	5
98	10
211	15
361	20
555	25
788	30
1083	35

Determine the following based on the data obtained:

(a) **[15 points]** The values of volume of filtrate and time required to form the cake.
(b) **[4 points]** The value of the mean specific cake resistance.
(c) **[3 points]** The value of the mean porosity of the cake.
(d) **[3 points]** The value of the filter-medium resistance.

DATA:
Weight ratio of wet cake to dry cake = 1.473
Density of dry cake = 73.8 lb_m/ft^3
Weight fraction of $CaCO_3$ in slurry = 0.139
Viscosity of filtrate = 2.07 $lb_m/ft.hr$
Density of filtrate = 62.2 lb_m/ft^3
Density of filtrate = 164 lb_m/ft^3

PART B: SEPARATION PROCESSES

B1. In a batch reactor, 2.5 m^3 of wastewater solution containing 0.25 kg of phenol/m^3 is mixed with 3 kg of granular activated carbon until equilibrium is reached. The following experimental values were determined in a laboratory:

C_A, in g/cm^3	$C_{A,S}$, in grams solute per gram of activated carbon
0.004	0.026
0.0087	0.053
0.019	0.075
0.027	0.082
0.094	0.123
0.195	0.129

(a) **[5 points]** Plot an adsorption isotherm.

(b) **[10 points]** Determine the type of isotherm and calculate the isotherm parameters/constants.

(c) **[8 points]** Calculate the steady-state values of C_A and $C_{A,S}$ in the batch reactor.

(d) **[2 points]** Calculate the percentage of phenol that is recovered by the activated carbon adsorbent.

B2. A batch of sand was tray-dried with superheated steam and the following experimental data were obtained:

Drying Time, in hr	**Total Moisture**, in lb
0.00	4.57
0.25	4.29
0.50	4.05
0.75	3.84
1.00	3.60
1.25	3.37
1.50	3.12
1.75	2.91
2.00	2.68
2.25	2.47
2.50	2.24
2.75	2.02
3.00	1.79
3.25	1.56
3.50	1.39
3.75	1.18
4.00	0.95
4.25	0.78
4.50	0.60
4.75	0.48
5.00	0.36
5.50	0.26
6.00	0.14
6.50	0.07
7.00	0.02
7.50	0.00

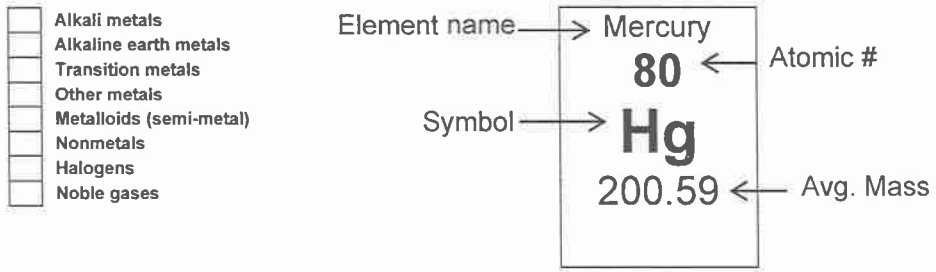
Obtain the drying-rate curve based on the experimental data.

B3. An air stream with an absolute humidity of 0.011 kg of water per kg of dry air is dried to a humidity of 0.002 kg of water per kg of dry air in an absorption tower packed with 2-inch Raschig rings. A 50% by weight sodium hydroxide (NaOH) solution is used. The equilibrium data for this system are presented in the following table:

X (mole of H_2O/mole of NaOH)	**Y** (mole of H_2O/mole of dry air)
0	0
1	4
2	11
3	28
4	67
5	100
6	126
7	142
8	157
9	170
10	177
12	190
16	202

If the flow of the absorbent solution is 25% larger than the minimum and the height of one transfer unit is 60 cm, calculate the height of the tower in order to carry out this operation.

The Periodic Table of the Elements



1																	18
Hydrogen 1 H 1.01	2											13	14	15	16	17	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	3	4	5	6	7	8	9	10	11	12	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)