16-CHEM-A2, UNIT OPERATIONS and SEPARATION PROCESSES

DECEMBER 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.
6. State all assumptions clearly.

PART A: UNIT OPERATIONS

A1. Bench tests were done on a new valve to determine the energy loss as a function of valve closure. This involves mounting the valve into a plumbing system and measuring the flow rate through the valve and supplying a flow of water with a constant head of 1.5 m from an overhead tank. The valve is fitted to a 1.5-meter long, 20-mm internal diameter horizontal smooth-walled pipe. The following test data was obtained:

Valve Closure, in %	**Water Flow Rate,** in m^3/min
0	8.4×10^{-2}
25	6.0×10^{-2}
40	3.6×10^{-2}

Calculate the loss factor (k_v) for each valve closure position using the following equation for head loss (h):

$$h = k_v \, (u^2/2g)$$

where u is the average velocity of flowing water and g is the acceleration due to gravity.

DATA: Density of water = 1000 kg/m^3
Viscosity of water = 1×10^{-3} N.s/m^2

A2. A centrifugal pump operating at 2500 rpm was used to provide experimental data of flow as well as delivery pressure and torque on the rotating shaft. The performance of the pump is as follows:

Volumetric Flow Rate (in m^3/s)	**Differential Pressure** (in kN/m^2)	**Force on Arm** (in N)
1.47×10^{-3}	18.8	4.6
1.31×10^{-3}	36.0	4.1
1.18×10^{-3}	44.8	4.0
1.00×10^{-3}	61.5	3.7
0.91×10^{-3}	63.6	3.3
0.71×10^{-3}	71.5	3.0
0.48×10^{-3}	79.7	2.4

The force on a torque arm linked to the pump has a length of 17.9 cm as measured from the axis of the rotating shaft. Determine the maximum efficiency of the pump and the corresponding flow rate.

A3. Continuous separation of spherical particles of waste ore in wash water is accomplished in a rectangular lagoon (10 m wide x 50 m long x 2 m deep). The ore particles are suspended in the flow of the wash water at a rate of 360 m^3/hr. Determine the size of the ore particle that can be retained by the lagoon if the maximum ore particle size obeys Stoke's law for a particle Reynolds number below a value of 0.4.

DATA:
Viscosity of wash water = 1 x 10^{-3} N.s/m^2
Density of ore = 2.8 g/cc
Density of wash water = 1.0 g/cc

PART B: SEPARATION PROCESSES

B1. 96% of acetone (C_3H_6O) is to be absorbed from a 2% by mole mixture of acetone in air in a continuous countercurrent absorption tower using 20% more than the minimum liquid rate of pure water as the solvent, which is introduced at the top of the tower. The gas mixture is blown into the bottom of the tower at a flow rate of 450 kg/hr. The absorption tower, which operates at atmospheric pressure and 300K, is packed with 2.54 cm Raschig rings. The equilibrium relation is $y = 2.5x$, where y and x are mole fractions of acetone in air and water, respectively. The following relationship is available for height of a transfer unit based on overall resistance in terms of gas/vapor phase (H_{oy}):

$$H_{oy} = H_y + \{(mG/L)\, H_x\}$$

where

$H_y \rightarrow$ height of a transfer unit based on resistance in terms of gas/vapor phase = 0.54 m

$H_x \rightarrow$ height of a transfer unit based on resistance in terms of liquid phase = 0.32 m

$m \rightarrow$ slope of equilibrium line

$G \rightarrow$ mass flow rate of gas/vapor phase

$L \rightarrow$ mass flow rate of liquid phase

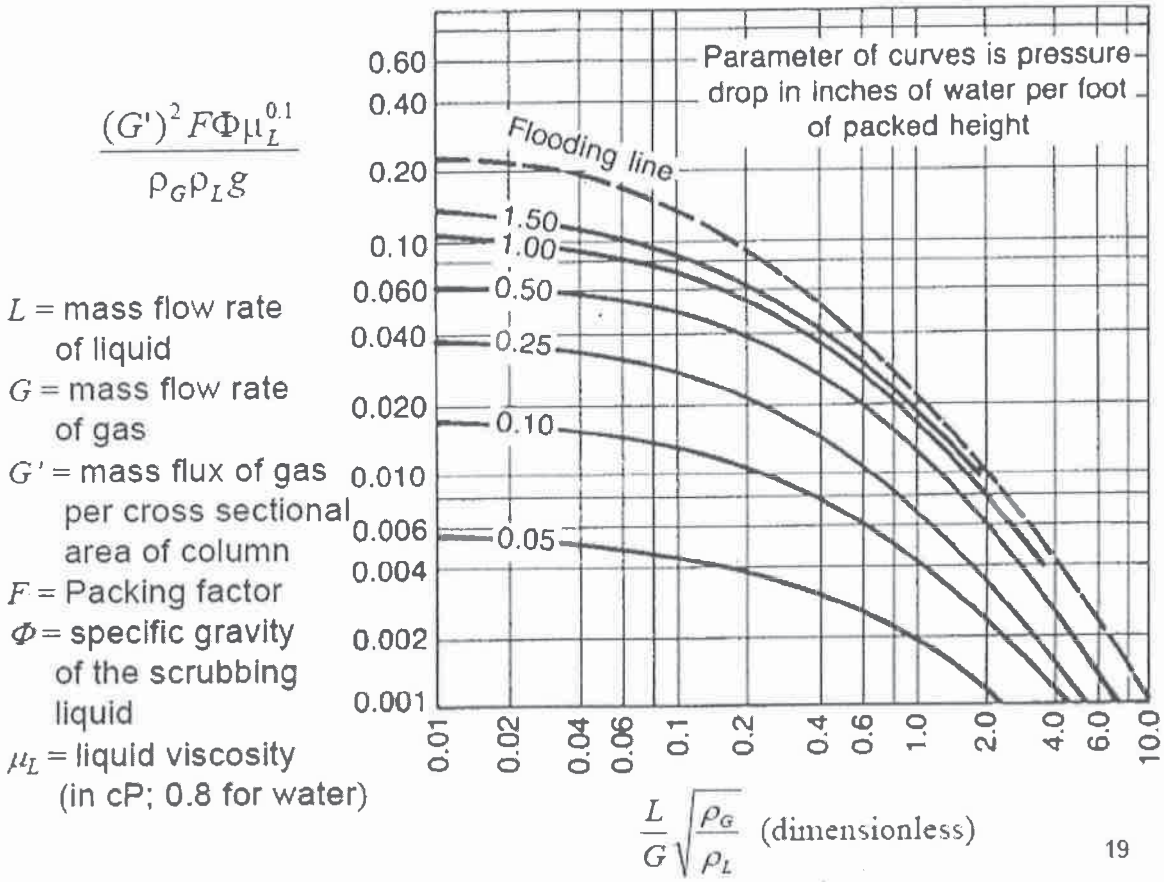
(a) **[15 points]** Find the height of absorption tower.

(b) **[10 points]** Find the diameter of the absorption tower operating at 50% of the flooding velocity.

DATA:

Viscosity of solution (μ_L) = 0.86 cP
Density of acetone-air mixture (ρ_G) = 1.181 kg/m^3
Density of pure water and acetone-water solution (ρ_L) = 998.4 kg/m^3
Characteristic packing factor (F) = 160

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. A wet slab of material (0.35 m^2 area and 7 mm thick) was batch dried, and the drying rate (N) in $kg/m^2.s$ was given by the following equation:

$$N = 0.95\ (X - 0.01)$$

where X → moisture content in kg moisture per kg of dry solid.

The slab is dried only from one side with the edges sealed. Density of the material is 1200 kg/m^3. What is the time needed to reduce the moisture content from 35% to 5% on a wet basis?

B3. Potassium chloride (KCl) crystals of 1.1 mm average size are to be produced at a rate of 800 kg per batch in an evaporative crystallizer under vacuum at 40 °C. At the start, the crystallizer is filled with a saturated solution of KCl and seeded with reasonably uniformed-sized 80 μm crystals. A maximum slurry density of 150 kg of crystals per m^3 of slurry is allowed, and the crystal growth rate can be assumed to remain constant at 3×10^{-8} m/s. Determine the following:

(a) [8 points] Volume of crystallizer assuming the vessel was 70% filled at the beginning.
(b) [8 points] Mass of seeds used.
(c) [3 points] Batch time.
(d) [6 points] Initial and final rate of evaporation.

DATA:
Solubility of KCl in water at 40 °C = 400 kg/m^3
Density of KCl solution = 1300 kg/m^3
Density of crystals = 1900 kg/m^3
Shape factor of crystals = 1

The Periodic Table of the Elements

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

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

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)