

**16-CHEM-A2, UNIT OPERATIONS and SEPARATION PROCESSES**

December 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 slurry containing 5 kg of water/kg of solids is to be thickened to a sludge containing 1.5 kg of water/kg of solids in a continuous operation. Laboratory tests using five different concentrations of the slurry yielded the following data:

<b>Concentration</b> (kg of water/kg of solids)	<b>Rate of Sedimentation</b> (mm/s)
5.0	0.20
4.2	0.12
3.7	0.094
3.1	0.07
2.5	0.05

Calculate the minimum area of a thickener required to effect the separation for a flow of 4788 kg/hr of solids.

- A2.** A liquid flows through two pipes connected in series at a rate of 12,000 kg/hr. The two pipes consist of 100 meters of horizontal smooth-walled 50-mm straight pipe followed by a reducer to 38 mm with 60 meters of horizontal smooth-walled straight pipe. Frictional loss for the reducer amounts to 0.2 velocity heads. Determine the frictional pressure drop across the pipe system.

**DATA:**           Viscosity of liquid =  $3 \times 10^{-3}$  N.s/m<sup>2</sup>  
                           Density of liquid = 850 kg/m<sup>3</sup>

A3. There is a requirement for the power demand to be kept to a minimum when designing a fluidized bed. A 1-meter diameter fluidized bed is filled with 1800 kg of 2-mm diameter spherical particles to a depth of 1.6 meters. The density of spherical particles is  $2100 \text{ kg/m}^3$ . The fluidizing gas, flowing at a rate of  $830 \text{ m}^3/\text{hr}$ , has a density of  $1.21 \text{ kg/m}^3$  and a viscosity of  $1.42 \times 10^{-5} \text{ N}\cdot\text{s/m}^2$ . The Kozeny constant can be taken as 5.

- (a) [10 points] Determine the pressure drop over the fluidized bed.
- (b) [3 points] Determine the power requirement for flow of gas through the fluidized bed.

**PART B: SEPARATION PROCESSES**

- B1.** A feed solution containing 70 moles of benzene and 30 moles of toluene mixture is fed to a distillation column at a total pressure of 1 atm. One third of the feed is vaporized, and average volatility ratio of the system ( $\alpha$ ) is 2.5. Calculate the composition of distillate and bottoms using the following:
- (a) [13 points] Flash distillation.
- (b) [12 points] Differential distillation.
- B2.** 1400 kg of granular solid is to be dried under constant drying conditions from a moisture content of 0.2 kg/kg of dry solid to a final moisture content of 0.02 kg/kg of dry solid. The material has an effective area of  $6.15 \times 10^{-2} \text{ m}^2/\text{kg}$ . Calculate the time required for drying based on the following data obtained for the material:

Moisture Content (kg/kg of dry solid)	Rate of Drying (kg/hr.m <sup>2</sup> )
0.3	1.71
0.2	1.71
0.14	1.71
0.096	1.46
0.056	1.29
0.042	0.88
0.026	0.54
0.016	0.376

- B3. The adsorption of ethane ( $C_2H_6$ ) on Linde molecular sieve type 5A was studied at 35 °C and the following data was obtained:

Pressure, in mm Hg	Ethane Uptake, in $cm^3$ (STP)/g
0.17	0.059
0.95	0.318
5.57	1.638
12.09	3.613
111.32	24.236
220.87	34.278
300.05	38.340
401.25	41.779
500.18	44.037
602.74	45.693

- (a) [20 points] Determine if Langmuir isotherm or Freundlich isotherm can be used to model the data.
- (b) [5 points] Calculate the total surface area of the solid.

DATA: Avagadro's number =  $6.023 \times 10^{23}$  molecules/mole  
Density of liquified ethane =  $354.9 \text{ kg/m}^3$

# The Periodic Table of the Elements

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		Element name →										Atomic # ←	
		Symbol →										Avg. Mass ←	
		Mercury										80	
		Hg										200.59	
Hydrogen 1 <b>H</b> 1.01	Helium 2 <b>He</b> 4.00											Fluorine 9 <b>F</b> 19.00	Neon 10 <b>Ne</b> 20.18
Lithium 3 <b>Li</b> 6.94	Beryllium 4 <b>Be</b> 9.01	Boron 5 <b>B</b> 10.81	Carbon 6 <b>C</b> 12.01	Nitrogen 7 <b>N</b> 14.01	Oxygen 8 <b>O</b> 16.00	Fluorine 9 <b>F</b> 19.00	Neon 10 <b>Ne</b> 20.18	Aluminum 13 <b>Al</b> 26.98	Silicon 14 <b>Si</b> 28.09	Phosphorus 15 <b>P</b> 30.97	Sulfur 16 <b>S</b> 32.07	Chlorine 17 <b>Cl</b> 35.45	Argon 18 <b>Ar</b> 39.95
Sodium 11 <b>Na</b> 22.99	Magnesium 12 <b>Mg</b> 24.31											Bromine 35 <b>Br</b> 79.90	Krypton 36 <b>Kr</b> 83.80
Potassium 19 <b>K</b> 39.10	Calcium 20 <b>Ca</b> 40.08	Gallium 31 <b>Ga</b> 69.72	Germanium 32 <b>Ge</b> 72.61	Arsenic 33 <b>As</b> 74.92	Selenium 34 <b>Se</b> 78.96	Bromine 35 <b>Br</b> 79.90	Krypton 36 <b>Kr</b> 83.80	Zinc 30 <b>Zn</b> 65.39	Copper 29 <b>Cu</b> 63.55	Nickel 28 <b>Ni</b> 58.69	Cobalt 27 <b>Co</b> 58.93	Iron 26 <b>Fe</b> 55.85	Manganese 25 <b>Mn</b> 54.94
Rubidium 37 <b>Rb</b> 85.47	Strontium 38 <b>Sr</b> 87.62	Indium 49 <b>In</b> 114.82	Tin 50 <b>Sn</b> 118.71	Antimony 51 <b>Sb</b> 121.76	Tellurium 52 <b>Te</b> 127.60	Iodine 53 <b>I</b> 126.90	Xenon 54 <b>Xe</b> 131.29	Cadmium 48 <b>Cd</b> 112.41	Silver 47 <b>Ag</b> 107.87	Palladium 46 <b>Pd</b> 106.42	Rhodium 45 <b>Rh</b> 102.91	Ruthenium 44 <b>Ru</b> 101.07	Technetium 43 <b>Tc</b> (98)
Cesium 55 <b>Cs</b> 132.91	Barium 56 <b>Ba</b> 137.33	Thallium 81 <b>Tl</b> 204.38	Lead 82 <b>Pb</b> 207.20	Bismuth 83 <b>Bi</b> 208.98	Polonium 84 <b>Po</b> (209)	Astatine 85 <b>At</b> (210)	Radon 86 <b>Rn</b> (222)	Mercury 80 <b>Hg</b> 200.59	Gold 79 <b>Au</b> 196.97	Ptassium 78 <b>Pt</b> 195.08	Iridium 77 <b>Ir</b> 192.22	Osmium 76 <b>Os</b> 190.23	Rhenium 75 <b>Re</b> 186.21
Francium 87 <b>Fr</b> (223)	Radium 88 <b>Ra</b> (226)	Ununquadium 114 <b>Uuq</b> (289)	Ununpentium 115 <b>Uup</b> (288)	Ununhexium 116 <b>Uuh</b> (293)	Ununseptium 117 <b>Uus</b> (294?)	Ununoctium 118 <b>Uuo</b> (294)	Copernicium 112 <b>Cn</b> (285)	Roentgenium 111 <b>Rg</b> (280)	Darmstadtium 110 <b>Ds</b> (281)	Einsteinium 99 <b>Es</b> (252)	Fermium 100 <b>Fm</b> (257)	Mendelevium 101 <b>Md</b> (258)	Nobelium 102 <b>No</b> (259)

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

Lanthanum 57 <b>La</b> 138.91	Cerium 58 <b>Ce</b> 140.12	Praseodymium 59 <b>Pr</b> 140.91	Neodymium 60 <b>Nd</b> 144.24	Promethium 61 <b>Pm</b> (145)	Samarium 62 <b>Sm</b> 150.36	Eurprium 63 <b>Eu</b> 151.97	Gadolinium 64 <b>Gd</b> 157.25	Terbium 65 <b>Tb</b> 158.93	Dysprosium 66 <b>Dy</b> 162.50	Ytterbium 70 <b>Yb</b> 173.04
Actinium 89 <b>Ac</b> (227)	Thorium 90 <b>Th</b> 232.04	Protactinium 91 <b>Pa</b> 231.04	Uranium 92 <b>U</b> 238.03	Neptunium 93 <b>Np</b> (237)	Plutonium 94 <b>Pu</b> (244)	Americium 95 <b>Am</b> (243)	Curium 96 <b>Cm</b> (247)	Berkelium 97 <b>Bk</b> (247)	Californium 98 <b>Cf</b> (251)	Nobelium 102 <b>No</b> (259)

\*lanthanides

\*\*actinides

