04-CHEM-A3, MASS TRANSFER OPERATIONS

DECEMBER 2016

Three Hours Duration

NOTES:

1) If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.

2) Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.

3) This is an open-book exam.

4) Any non-communicating calculator is permitted.

5) The examination is in three parts – Part A (Questions 1 and 2)
Part B (Questions 3 and 4)
Part C (Questions 5 to 7)

6) Answer **ONE** question from Part A, **ONE** question from Part B, and **TWO** questions from Part C. **FOUR** questions constitute a complete paper.

7) Each question is of equal value.

PART A

1) A chamber of 1 m^3 volume contains air at 293 K, 101.3 kPa and a partial pressure of water vapor of 0.8 kPa. A bowl of liquid with a free surface of 0.01 m^2 and maintained at 303 K is introduced into the chamber. The mass transfer resistance is equivalent to that of a stagnant gas film of 0.25 mm thickness, and the effects of bulk flow can be neglected.

How long will it take for the air to become 90% saturated at 293 K? How much water must be evaporated?

DATA:
Saturation vapor pressure of water at 293 K = 2.3 kPa
Saturation vapor pressure of water at 303 K = 4.3 kPa
Diffusivity of water vapor in air = 0.24 cm^2/s

2) Water evaporates at 350 K from an open bowl (30 cm diameter) into the atmosphere. The air currents are sufficiently strong to remove the water vapor as it is formed and the resistance to its mass transfer in air is equivalent to that of a 1 mm layer for conditions of molecular diffusion. The water can be considered as well mixed and the water equivalent of the system is equal to 10 kg.

What is the rate of cooling due to evaporation?

DATA:
Vapor pressure of water at 350 K = 41.8 kN/m^2
Diffusivity of water vapor in air = 0.2 cm^2/s
Specific volume of water vapor at NTP = 22.4 m^3/kg
Latent heat of vaporization of water at 350 K = 2318 kJ/kg
Specific heat capacity of water at 350 K = 4.187 kJ/kg K

PART B

3) Ethanol at 289 K flows in a thin film down the outside surface of an inclined plane 2 meters wide and 4 meters long. Ethanol-free air at 303 K and 1 atm flows across the width of the plate parallel to the surface. At the average temperature of the gas film, the diffusivity of ethanol vapor in air is 1.32×10^{-5} m^2/s. The vapor pressure of ethanol at 289 K is 6.45×10^{-2} atm. The kinematic viscosity of ethanol vapor is 1.533×10^{-6} m^2/s.

If the air velocity is 3 m/s, determine the rate at which liquid ethanol should be supplied to the top of the plate so that evaporation will prevent it from reaching the very bottom of the plate.

4) The absorption of carbon dioxide from carbon dioxide-air mixture in a solution containing 100 kg/m^3 of sodium hydroxide were made in a 250 mm diameter tower packed to a height of 3 meters using 19 mm Raschig rings. The following results were obtained at atmospheric pressure;

Gas rate = 0.34 kg/m^2s Liquid rate = 3.94 kg/m^2s

The carbon dioxide in the inlet gas was 315 parts per million and the carbon dioxide in the exit gas was 31 parts per million. Assume negligible vapor pressure of carbon dioxide over the solution.

What is the value of the overall gas mass transfer coefficient K_Ga in $kmol/s.m^2.(kPa)$

PART C

5) A mixture of ethanol and water containing 16% mole of ethanol is continuously distilled in a plate-fractionating column to give a product containing 77% mole ethanol and a waste of 2% mole ethanol. It is proposed to withdraw 25% of ethanol in the entering stream as a side stream containing 50% mole of ethanol. The equilibrium mole fraction data for ethanol is given below:

Liquid Mole Fraction	Vapor Mole Fraction
0.00350	0.02050
0.00450	0.02750
0.01750	0.13150
0.05850	0.30500
0.06800	0.36150
0.09350	0.41100
0.16500	0.52000
0.21250	0.54550
0.24100	0.56750
0.36150	0.60600
0.47400	0.65050
0.49850	0.65550
0.58150	0.69700
0.64600	0.72900
0.72300	0.77600
0.79000	0.82000
0.83700	0.85200
0.87310	0.88170
0.88800	0.89300
0.89730	0.90120

Determine the number of theoretical plates required and the plate from which side the stream should be withdrawn if the feed is liquid at its boiling point and a reflux ratio of 2 is used.

6) Spherical particles (diameter = 15 nm, density = 2290 kg/m^3) are pressed together to form a pellet. The following equilibrium data were obtained for the adsorption of nitrogen at 77 K:

P/P^0	cm^3 liquid N_2/kg solid
0.1	66.7
0.2	75.2
0.3	83.9
0.4	93.4
0.5	108.4
0.6	130.0
0.7	150.2
0.8	202.0
0.9	348.0

Here P is the pressure of the adsorbate and P^0 is the vapor pressure of the adsorbate at 77K. The density of liquid nitrogen at 77 K is 808 kg/m^3.

Obtain an estimate of the total surface area of the pellet from the adsorption isotherm.

7) 10 m^3 of a process fluid containing 20 kg/m^3 of an enzyme is to be concentrated to 200 kg/m^3 by means of ultrafiltration using membranes. Tests have shown that the enzyme is completely retained by a high-molecular weight, surface modified polysulfone membrane with a filtration flux (J, in m/hr) given by the following equation;

$$J = 0.04 \ln (250/C_f)$$

where C_f is the enzyme concentration in kg/m^3. Four hours is available for carrying out the process.

(a) Calculate the area of membrane needed to carry out the concentration as a simple batch process.

(b) The average filtration flux (J_{av}, in m/hr) during the simple batch process using the following approximation equation:

$$J_{av} = J_f + 0.27\,(J_i - J_f)$$

where J_i is the initial filtration flux and J_f is the final filtration flux.

Is this approximation suitable for designing the membrane filtration process?

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
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)