National Exams December 2011

04-Chem-A3 Mass Transfer Operations

Three Hour 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 two parts – Part A (Questions 1 and 2), Part B (Questions 3, 4, 5 and 6). Answer **ONE** question from Part A, and **THREE** questions from Part B. **FOUR** questions constitute a complete paper.

6) Either question in Part A will count for 15%. Each question in Part B is of equal value, i.e. the remaining 85% of the marks are split equally into three.

PART A: ANSWER ONE OF QUESTIONS 1-2

Note: Four questions constitute a complete paper (with one from Part A, and three from Part B)

1) You are doing an experiment which involves the evaporation of liquid diethyl ether ($C_4H_{10}O$) in a glass cylinder 0.5 m tall and 100 mm in diameter. This happens under a fume hood at 30°C and 1.0 atm absolute pressure. The diffusion coefficient of $C_4H_{10}O$ in air at 30°C and atmospheric pressure is 0.0910 cm^2/s. Furthermore, the vapour pressure of $C_4H_{10}O$ can be calculated from

$$P_v(mm\,Hg) = exp\left[18.0 - \frac{3488}{T(K)}\right]$$

a) Calculate the rate of evaporation of diethyl ether (g/h) if the concentration at the top of the tube is 0.70 mole fraction.
b) Someone points out that the value of 0.70 mole fraction is too high for safe operation. Therefore, you plan to reduce the diethyl ether concentration by lowering the temperature of the entire experiment to 20°C and increasing the air flow in the fume hood. Calculate the resulting mole fraction, assuming that the rate of evaporation remains unchanged from Part (a).

2) Air at atmospheric pressure and 27°C flows at 2 m/s over an irregularly shaped piece of dry ice. The dry ice sublimes at a rate of 2.29 x 10^{-4} mol/s from an exposed surface area of 10 cm^2. The vapour pressure of dry ice under these conditions is 4.74 kPa.

a) Calculate the mass transfer coefficient, k_c (m/s).
b) Given that the mass diffusivity of CO_2 in air under these conditions is 1.55 x 10^{-5} m^2/s, calculate the heat transfer coefficient, $\bar{h}$ (W/m^2·K)

Table 1: Properties of Air at Atmospheric Pressure

T[K]	C_p [J/kg·K]	k [W/m·K]	$\alpha \times 10^5$ [m^2/s]	$\upsilon \times 10^5$ [m^2/s]
300	1005	0.0261	2.21	1.57

PART B: ANSWER THREE OF QUESTIONS 3-6

Note: Four questions constitute a complete paper (with one from Part A, three from Part B)

3) As part of an experimental study of the absorption of trichloroethylene (TCE) by water in a wetted-wall column, the following equilibrium values at 20°C were measured:

Table 2: Solubility of TCE in Water

Partial pressure of TCE [atm]	0.000	0.050	0.150	0.200
Solubility [mol/m^3]	0.000	5.000	15.000	20.000

The Relative Molecular Mass of TCE (C_2HCl_3) is 131.5 kg/kgmol and the density of water at 20°C is 998.15 kg/m^3.

a) Determine the Henry's Law constant (Pa/(kgmol/m^3)).
b) For absorption of TCE by water in a wetted-wall column, the overall mass transfer coefficient, K_y', was found to be 2.74 x 10^{-9} kgmol/m^3·s·Pa. At one point in the column, the gas phase contained 8 mol% TCE and the liquid-phase concentration was 0.064 kgmol/m^3 of solution. The tower operates at 20°C and atmospheric pressure. If 85% of the total resistance to mass transfer is encountered in the gas phase, determine the individual film mass transfer coefficients (k_y' and k_x').
c) Determine the gas-phase interfacial concentration (in terms of partial pressure of TCE in Pa) and the liquid-phase interfacial concentration (kgmol TCE/m^3 of solution) corresponding to this point in the column.

4) A 4.0 m high packed tower is being used to remove H_2S from a gas stream at 30°C and atmospheric pressure. The inlet gas volumetric flow per unit area of the column cross-section is 1200 m^3/m^2·h and contains 5% H_2S by volume. You need to remove 98% of the H_2S from the gas and absorb it in water which goes on to be treated further. It has been determined that the maximum concentration that can be tolerated by the treatment system is 500 ppm by weight. The equilibrium relationship is given by

$$y^* = 81.4x^*$$

The Relative Molecular Mass of H_2S is 34 kg/kgmol.

a) Calculate the flux of water required L' [kg/m^2·h].
b) Calculate the values of the overall mass transfer coefficients on the gas and liquid sides, $K_y a$ and $K_x a$.

5) Calculate the maximum possible rate of oxygen uptake at 37°C by microorganisms having a diameter of 0.667 μm suspended in an agitated aqueous solution. It is assumed that the surrounding liquid is saturated with oxygen at 1.0 atm, absolute pressure. You may assume that the microorganisms can use the oxygen much faster than the oxygen can diffuse to them. The microorganisms have a density very close to that of water. The diffusivity of oxygen in water at 37°C is 3.25×10^{-9} m^2/s and the solubility of oxygen from air into water is 2.26×10^{-7} mol O_2/cm^3 of liquid.

6) You are to design a hyperbolic natural-draught cooling tower handling 4180 kg/s of water. The water enters the tower at 28°C and is cooled to 21°C. Air enters the tower with a dry-bulb temperature of 14°C and a wet-bulb temperature of 11°C.

a) What are the absolute humidity, relative humidity, and enthalpy of the incoming air?
b) What is the absolute humidity of the saturated air leaving the tower? What is the evaporation rate of the water expressed as a percentage of the water flow rate?
c) Based on a height to diameter ratio of 3:2, calculate the diameter and height of the tower. Assume the performance coefficient of $C_t = 5.2$.

Use the psychometric chart provided and shows your work on the chart. **Do not forget to hand in your chart with the exam booklet, and write your name on the chart.**

 Humidity chart