National Exams December 2014

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.

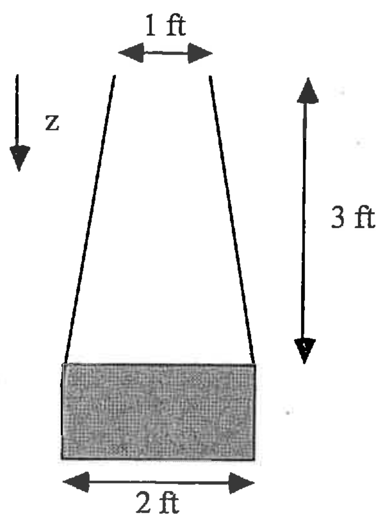
5) The examination is in three parts – Part A (Questions 1 and 2), Part B (Questions 3 and 4), and Part C (Questions 5, 6, and 7). Answer **ONE** question from Part A, **ONE** question from Part B, and **TWO** questions from Part C. **FOUR** questions constitute a complete paper.

6) Each question is of equal value.

PART A: ANSWER ONE OF QUESTIONS 1-2

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

1) A tank containing water has its top open to air. The tank is cylindrical with a diameter of 2 ft. The liquid level is maintained at a level of 3 ft. below the top of the tank as shown in the sketch. The surrounding air is at 310 K, 1 bar, and 40 percent relative humidity.



a) What is the molar concentration of water at the top of the tank, i.e. $z = 0$?
b) What is the molar concentration of water in the vapour phase at the air-water interface, i.e. $z = L$?

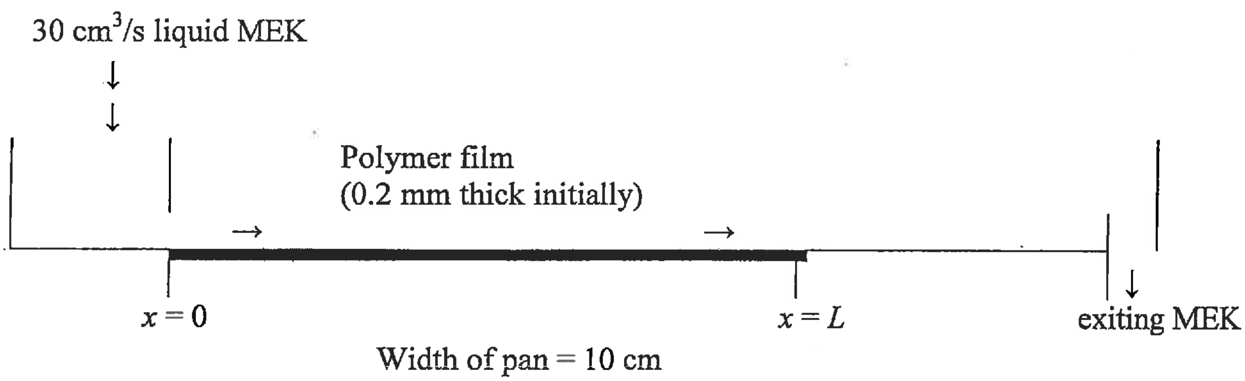
Note: Molecular weight of air = 28.9
Molecular weight of water = 18.0, density of water at 310 K = 997 kg/m^3
Vapour pressure of water at 310 K = 0.06221 bar, 1 bar = 10^5 Pa.

2) Pulverized coal pellets, which may be approximated as carbon spheres of radius r_0 = 1 mm, are burned in air at 1500 K and 1.0 atm. Oxygen is transferred to the particle surface by diffusion, where it is consumed in the reaction $C + O_2 \rightarrow CO_2$. The diffusivity D_{AB} for oxygen in air is 1.8 x 10^{-4} m^2/s. Assuming the surface reaction rate to be infinite and neglecting the change in the radius of the pellet, determine the steady-state molar consumption rate of oxygen in kmol/s.

PART B: ANSWER ONE OF QUESTIONS 3-4

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

3) In a manufacturing process, an organic solvent (methyl ethyl ketone, MEK) is used to dissolve a thin coating of polymer film away from a nonporous flat surface that is 20 cm. long and 10 cm. wide, as shown is the sketch. The thickness of the polymer film is initially uniform at 0.20 mm. In the present process, the polymer film is coated on a flat surface that is set in a pan that is 30 cm long and 10 cm wide. Liquid MEK flows across the polymer film from one end of the pan to the other at a rate of 30 cm^3/s. The depth of the liquid MEK in the pan is maintained at 2.0 cm. It may be assumed that the concentration of dissolved polymer in the bulk solvent is essentially zero ($C_{A,\infty} \approx 0$), although in reality the concentration of dissolved polymer increases very slightly from the entrance of the pan to its exit. It may also be assumed that the change in the thickness of the polymer film during the dissolution process does not affect the mass transfer process.



a) What are the Schmidt number and the average Sherwood number for this mass transfer process?
b) What is the average flux of dissolved polymer away from the surface (g of polymer/$cm^2 \cdot s$)?

Data:

$D_{AB} = 3.0 \times 10^{-6}$ cm^2/s = mass diffusivity of dissolved polymer (A) in MEK (B)
$\rho_{A,solid} = 1.05$ g/cm^3 = mass density of solid polymer (A)
$c_{A,s} = 0.04$ g/cm^3 = maximum solubility of of polymer (A) in MEK (B)
$\upsilon_B = 6.0 \times 10^{-3}$ cm^2/s = kinematic viscosity of liquid MEK
$\rho_B = 0.80$ g/cm^3 = mass density of liquid MEK

4) Boundary-layer analysis for fluid flow over a flat plate predicts the following relationships between the local Sherwood number (Sh_x), the Reynolds number (Re_x), and the Schmidt number (Sc):

$$\text{for laminar flow, } Sh_x = \frac{k_c x}{D_{AB}} = 0.332 Re_x^{1/2} Sc^{1/3}$$

$$\text{for turbulent flow, } Sh_x = \frac{k_c x}{D_{AB}} = 0.0292 Re_x^{4/5} Sc^{1/3}$$

The transition of the flow takes place at $Re_x = 2.0 \times 10^5$. Determine what percentage of the mass transfer occurs within the laminar zone of the flow over the flat plate if the Reynolds number at the end of the plate is $Re_L = 3.0 \times 10^6$.

PART C: ANSWER TWO OF QUESTIONS 5-7

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

5) An existing packed tower with a packing height of 12.0 m was used to test a gas absorption process that removes solute A from a gas stream. In this test, the mole fraction of solute A in the gas phase was reduced from 2.0 mol% to 0.5 mol%. The gas stream was fed to the bottom of the tower at a superficial molar velocity of 0.0136 kmol/m^2·s, and the pure solvent containing no solute A was fed to the top of the tower at a superficial molar velocity of 0.0272 kmol/m^2·s. The total system pressure of the process was maintained at 1.2 atm. At the temperature and total pressure of the process, the equilibrium distribution of the solute between the solvent and the carrier gas is described by the following form of Henry's Law:

$$y_A^* = 1.5x_A$$

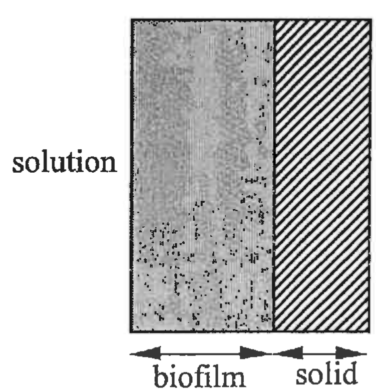
Estimate the overall mass transfer coefficient based on the driving force in the gas phase ($K_G a$).

6) The concentration of A within the biofilm shown in the sketch is given by

$$C_A = C_{A0}\left[\frac{cosh[m(L-z)]}{cosh[mL]}\right]$$

where $m = \sqrt{\frac{k_1}{D_{AB}}}$

$k_1 = 1.5 \times 10^{-4}\ s^{-1}$ = first order reaction rate constant
$D_{AB} = 1.26 \times 10^{-5}\ cm^2/s$ = mass diffusivity of A in the biofilm
$L = 0.2$ cm = biofilm thickness
z = distance from the outer (solution) surface of the biofilm
$C_{A0} = 0.4$ mol/L



Determine $C_{A\infty}$ if the mass transfer resistance in the solution is negligible and the concentration of A in the biofilm is related to the concentration of A in the solution ($C_{A\infty}$) by the equilibrium relation $C_A = 0.4C_{A\infty}$.

7) In an experimental study of the absorption of ammonia by water in a wetted-wall column, the value of K_G was found to be 2.75×10^{-6} kmol/m^2·s·kPa. At one point in the column, the composition of the gas and liquid phases were 8.0 mol% NH_3 and 0.115 mol% NH_3, respectively. The temperature was 300 K and the total pressure was 1 atm. Eighty percent of the total resistance to mass transfer was found to be in the gas phase. At 300 K and 1 atm, dilute ammonia-water solutions such as this follow Henry's law of the form

$$y_A^* = 1.64x_A$$

a) Determine k_y.
b) Determine the ammonia absorption rate in kmol/m^2·s.