04-CHEM-A3, MASS TRANSFER OPERATIONS

MAY 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. Any non-communication calculator is permitted.

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

5) 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

1) The diffusivity of the vapor of a volatile liquid in air can be conveniently determined with the volatile liquid contained in a narrow diameter vertical tube maintained at a constant pressure and an air stream is passed over the top of the tube sufficiently rapidly to ensure the partial pressure of the vapor there remains approximately zero. The following experimental data for carbon tetrachloride vapor and air 321 K and 1 atmosphere pressure was obtained:

Time, in sec	**Liquid Level Drop**, in cm
0	0.00
1600	0.25
11,000	1.29
27,400	2.32
80,200	4.39
117,500	5.47
168,600	6.70
199,700	7.38
289,300	9.03
383,100	10.48

Assuming the vapor is ideal and it is transferred from the liquid surface to the air stream by molecular diffusion, calculate the diffusivity mixture of carbon tetrachloride vapor in air.

DATA: Vapor pressure of carbon tetrachloride at 321 K = 37.6 kN/m^2
Density of liquid = 1540 kg/m^3

2) A 4 cm^3 mixture formed by adding 2 cm^3 of acetone to 2 cm^3 dibutyl phthalate is contained in a 6 mm diameter vertical glass tube, which is immersed in a thermostat maintained at 315 K. A stream of air at 315 K and 1 atmosphere pressure is passed over the open top of the tube to maintain a zero partial pressure of acetone vapor at that point. The liquid level is initially 11.5 mm below the top of the tube and the acetone vapor is transferred to the air stream by molecular diffusion alone. The dibutyl phthalate can be regarded as completely non-volatile and the partial pressure of acetone vapor may be calculated from Raoult's law on the assumption that the density of dibutyl phthalate is sufficiently greater than that of acetone for the liquid to be completely mixed.

Assuming the vapor is ideal and neglecting the effects of bulk flow in the vapor, calculate the time taken for the liquid level to fall to 5 cm below the top of the tube.

<u>DATA</u>: Vapor pressure of acetone at 315 K = 60.5 kN/m^2
Diffusivity of acetone vapor in air at 315 K = 0.123 cm^2/s
Density of liquid acetone = 764 kg/m^3
Density of liquid dibutyl phthalate = 1048 kg/m^3
Molecular weight of acetone = 58 g/mol
Molecular weight of dibutyl phthalate = 279 g/mol

PART B

3) At a particular location in a distillation column, where the temperature is 350 K and the pressure 500 m Hg, the mole fraction of the more volatile component in the vapor is 0.7 at the interface with the liquid and 0.5 in the bulk of the vapor. The molar latent heat of the more volatile component is 1.5 times that of the less volatile component. The resistance to mass transfer in the vapor may be considered to lie in a stagnant film of thickness 0.5 mm at the interface. The diffusivity in the vapor mixture is 2×10^{-5} m^2/s.

(a) Calculate the mass transfer rates (in kmol per m^2 per second) of the two components.

(b) Assuming ideal gas behavior, calculate the mole fractions and concentration gradients of the two components at the mid-point of the film.

4) Water evaporates from an open bowl at 349 K at the rate of 4.11×10^3 kg per m^2 per second. Assume ideal gas and neglect the partial pressure of vapor in the surrounding atmosphere.

(a) What is the effective gas-film thickness?

(b) The water is replaced by ethanol at 343 K. What will be its rate of evaporation in kg per m^2 per second if the film thickness is unchanged?

(c) At the surface of the ethanol, what proportion of the total mass transfer will then be attributable to bulk flow?

DATA:
Vapor pressure of water at 349 K = 34 mm Hg
Vapor pressure of ethanol at 343 K = 544 mm Hg
Diffusivity of water vapor in air = 2.6×10^{-5} m^2/s
Diffusivity of ethanol in air = 1.2×10^{-5} m^2/s
Density of mercury = 13.6 g/cm^3

PART C

5) A mixture of benzene and toluene containing 40% mole of benzene is separated in a distillation column at 101.3 kPa and reflux ratio of 4 to give a product of 95% mole benzene and a waste of 5% mole toluene. The equilibrium mole fraction data for benzene at 101.3 kPa is as follows:

Vapor Mole Fraction	Liquid Mole Fraction
0.21	0.1
0.37	0.2
0.51	0.3
0.64	0.4
0.72	0.5
0.79	0.6
0.86	0.7
0.91	0.8
0.96	0.9
0.98	0.95

(a) Calculate the mole fraction on the second plate of the distillation column from the top.

(b) Determine the number of plates required and the position of the feed if supplied to the column as liquid at its boiling point of 368 K.

(c) Find the minimum reflux ratio possible.

(d) Find the minimum number of plates required.

(e) If the feed is fed to the distillation column at 288 K, find the number of plates required if the reflux ratio remains unchanged.

6) A paraffin hydrocarbon of molecular mass 114 g/mol at 373 K, is to be separated from a mixture with a non-volatile organic compound of molecular mass of 135 g/mol by stripping with steam. The liquor contains 8% of the paraffin by mass and this is to be reduced to 0.08% using an upward flow of steam saturated at 373 K. The vapor pressure of the paraffin at 373 K is 53 kN/m^2 and the process takes place at one atmosphere pressure.

Assuming the system obeys Raoult's law, calculate the number of theoretical stages required if three times the minimum amount of steam is used.

7) A mixture of air and acetone vapor occupies a volume of 1 m^3 at 303 K and a total pressure of 100 kN/m^2. The vapor pressure of acetone at 303 K is 37.9 kN/m^2, and the adsorption equilibrium data for acetone on carbon at 303 K is given below:

Partial Pressure of Acetone, in N/m^2	**Weight Fraction**, in kg Acetone/kg Carbon
0	0
5	0.14
10	0.19
30	0.27
50	0.31
90	0.35

(a) If the relative saturation of the air by acetone is 40%, what mass of activated carbon must be added to the space so that, at equilibrium, the value is reduced to 5% at 303 K?

(b) If 1.6 kg of carbon is added, what is the relative saturation of the equilibrium mixture assuming the temperature is unchanged?