National Exams May 2015

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) In the production of decaffeinated coffee, whole coffee beans are treated with a non-carcinogenic organic solvent that leaches out the caffeine. The amount of solvent used is very large in comparison with the amount of coffee beans.

- Treat the coffee beans as spheres with a 6-mm diameter.
- The diffusivity of caffeine in the solvent is $D_{AB} = 1.8 \times 10^{-6}$ cm^2/s
- The equilibrium solubility coefficient α for caffeine is given by

$$\alpha = \frac{concentration\ in\ solvent}{concentration\ in\ wet\ bean} = 0.1$$

a) Calculate the time required to reduce the caffeine concentration in the beans to 3% of its initial value if the solvent is stagnant.

b) <u>Estimate</u> the order of magnitude of the time required to reduce the caffeine content to 3% of its initial value if the solvent is well stirred such that the system has a very high mass transfer coefficient.

c) How could you reduce the time required for the processes described in parts (a) and (b)?

2) Pure water flows through a pipe at a rate of 0.5 L/s, and the flow is turbulent. The wall of the pipe is coated with salt, which dissolves into the water. The solubility of the salt in the water is 0.21 mol/L. The concentration of the salt in the water at the outlet of the pipe is measured at 0.01 mol/L. If the flow rate were to be tripled to 1.5 L/s what would you expect the concentration of salt at the outlet of the pipe to become?

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) A long cylindrical rod of naphthalene (molecular weight = 128, density = 1.15 g/cm^3) that is 3 mm in diameter is subjected to a cross-flow of air with a velocity of 91.44 cm/s and a temperature of 34°C. Naphthalene sublimes into vapour at this temperature and at atmospheric pressure. How much time is required for 10% of the mass of the rod to be lost to the air?

Data:

Diffusivity of naphthalene in air = D_{AB} =	8×10^{-6} cm^2/s
Vapour pressure of naphthalene at 34°C =	26 Pa
Kinematic viscosity of air =	0.16 cm^2/s

4) A common procedure for increasing the moisture content of air is to bubble it through a column of water. Assume the air bubbles to be spheres of radius 1.2 mm that are in thermal equilibrium with the water at 300K. How long should the bubbles remain in the water in order for the vapour concentration at r = 0.2 mm to reach 99% of the maximum possible concentration. The air is at 10% relative humidity when it enters the water. Diffusivity of water in air at this temperature is 0.26 cm^2/s.

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 organic amine is used to absorb carbon dioxide from a gas stream in a packed tower. The entering gas, which contains 1.26 mol% CO_2, must leave the column with only 0.04 mol% CO_2. The amine enters pure, without CO_2. The gas flow rate is 2.3 mol/s and the liquid flow rate is 4.8 mol/s. The tower's diameter is 40 cm, and the overall mass transfer coefficient times the area per volume K_ya is 5 x 10^{-5} mol/cm^3·s. The equilibrium line is given by $y = 1.58x^*$. How tall should this tower be?

6) Carburization is a heat-treatment process in which iron or steel absorbs carbon liberated when the metal is heated in the presence of a carbon-bearing material. In this case, a cylindrical steel roller that is 10 mm in diameter is to be carburized at 900°C in a concentrated carbon gas. This roller is made of steel that already contains 0.2% carbon, and the aim of the process is to increase that percentage to 0.5% carbon at a depth of 0.4 mm into the surface. Estimate the time required to accomplish this. Use the following data:

Density of the steel =	7850 kg/m^3
Density of the carbon gas =	100 kg/m^3
Diffusivity of carbon in steel =	2.0 x 10^{-11} m^2/s

7) A rotary drier is fed with sand at a rate of 1.0 kg/s. The feed is 50% water and the sand is discharged with 3% moisture. The air enters at 380 K with an absolute humidity of 0.007 kg/kg. The wet sand enters at 294 K and leaves at 309 K. The air leaves at 310 K.

Calculate the mass flow rate of the air passing through the dryer and the humidity of the air leaving the dryer. The heat loss from the dryer due to radiation is 25 kJ/kg of dry air.

Heat of vaporization of water at 294 K =	2450 kJ/kg
Heat capacity of sand =	0.88 kJ/kg·K
Heat capacity of dry air =	0.99 kJ/kg·K
Heat capacity of vapour =	2.01 kJ/kg·K

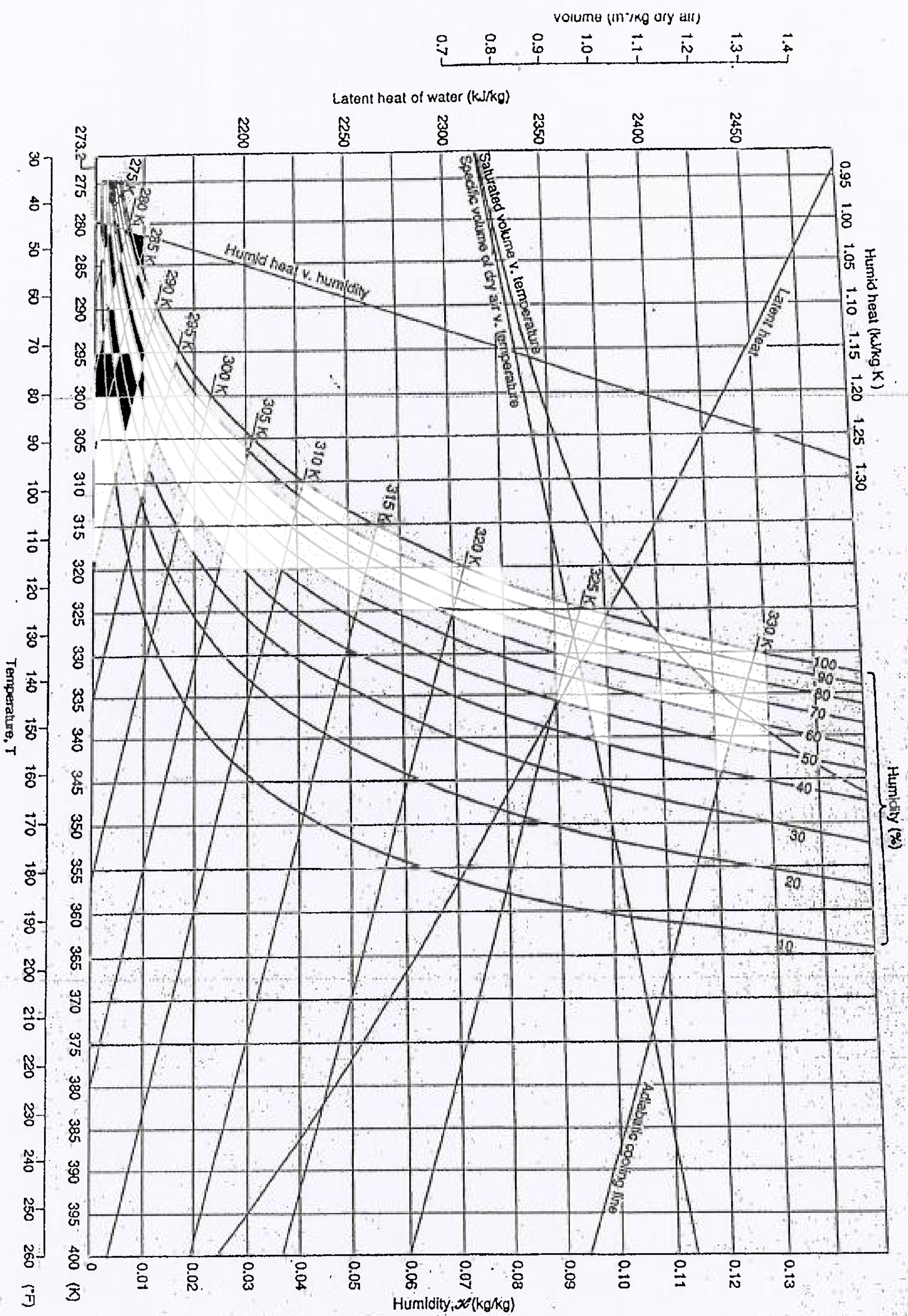

Fig. 7.7: Humidity-temperature chart for air-water system at 101.325 kPa