BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI, PILANI CAMPUS
CHEMICAL ENGINEERING DEPARTMENT
Course Title: Separation Process I (CHE F244)
(Closed-Book)

Test: 1   Marks: 90   Date: 10/03/15   Time: 90 minutes

Note: Answers all parts of Question No. 1 together and make suitable assumptions if necessary.

1. **(4+6+6+4 = 20 Marks)**
   Give precise answers of the following questions.
   (a) What is the difference between N type flux and J type flux?
   (b) Derive an expression of overall gas phase mass transfer coefficient (K_y) based on mole fraction in case of large driving forces for the gas-liquid mass transfer. (Write all steps clearly)
   (c) What problems would you have if a tray tower is operated at low gas flow rate? Which type of tray would you prefer for such operations? Justify your answer with proper explanation.
   (d) When stepping off stages on an Y–X plot for an absorber or a stripper, does the process start and stop with the operating line or the equilibrium curve? Justify your answer.

2. **(20 Marks)**
   An open circular tank 8 meter in diameter contains n-propanol at 25^oC exposed to the atmosphere in such a manner that the liquid is covered with a stagnant air film estimated to be 5 mm thick. The concentration of propanol beyond the stagnant film is negligible. The vapor pressure of propanol at 25^oC is 20 mm Hg. If propanol is worth $1.20 per liter, what is the value of the loss of propanol from this tank in dollars per day? The specific gravity of propanol is 0.8. The diffusivity of n-propanol at 25^oC and molecular weight are 0.0306 m^2/h and 60.09 respectively.

3. **(25 Marks)**
   Acetone is to be recovered from a 5% acetone-air mixture by scrubbing with fresh water in a packed tower using counter-current flow. The liquid rate is 0.85 kg/m^2.s and the gas rate is 0.5 kg/m^2.s. The overall absorption coefficient K_{Ga} may be taken as 1.5×10^{-2} kmol per sec per m^3 and the gas film resistance controls the process. What should be the height of the tower and minimum water flow rate to remove 98% of the acetone? The equilibrium data for the mixture are:

Mole fraction of acetone in water	0.0099	0.0196	0.0360	0.0400
Mole fraction of acetone in air	0.0076	0.0156	0.0306	0.0333

   Molecular weights of acetone, water and air are 58, 18 and 29 respectively.

4. **(25 Marks)**
   In an experimental study of absorption of ammonia by water in a wetted wall column, the overall gas phase mass transfer coefficient was estimated to be 2.72×10^{-4} $kmol/m^2$.s.atm. At one point in the column, the gas contained 10 mol% ammonia and the liquid phase concentration was 6.42×10^{-2} kmol NH_3/m^3 of the solution. The temperature was 293 K and the total pressure was 1 atm. 80% of the total resistance to mass transfer was found to be in the gas phase. If Henry's law constant at 293 K is 9.35×10^{-3} atm m^3/kmol, calculate the individual gas phase film coefficient, interphase composition of ammonia in gas & liquid phase and molar flux.

ALL THE BEST

TEST – 1 (Solutions) CHE F244

(a) N-type flux: Mass transfer of one or more species result in a total net rate of bulk flow or flux in a direction relative to a fixed plane or stationary coordinate system.

J-type flux: The molar flux of A by ordinary molecular diffusion relative to the molar average velocity of the mixture in positive direction

(b) For vapor–liquid mass transfer uses mole-fraction driving forces, which define a set of mass-transfer coefficients k_y and k_x:

$$N_A = k_y (y_{Ab} - y_{Ai}) = K_y (y_{Ab} - y_A^*)$$

$$\frac{1}{K_y} = \frac{(y_{Ab} - y_A^*)}{k_y (y_{Ab} - y_{Ai})}$$

$$\frac{1}{K_y} = \frac{(y_{Ab} - y_{Ai}) + (y_{Ai} - y_A^*)}{k_y (y_{Ab} - y_{Ai})} = \frac{1}{k_y} + \frac{1}{k_y}\left(\frac{y_{Ai} - y_A^*}{y_{Ab} - y_{Ai}}\right)$$

$$\frac{k_x}{k_y} = \frac{(y_{Ab} - y_{Ai})}{(x_{Ai} - x_{Ab})}$$

Denoting two slopes of the equilibrium curve by

$$m_x = \left(\frac{y_{Ai} - y_A^*}{x_{Ai} - x_{Ab}}\right) \text{ and } m_y = \left(\frac{y_{Ab} - y_{Ai}}{x_A^* - x_{Ai}}\right)$$

By substitution:

$$\frac{1}{K_y} = \frac{1}{k_y} + \frac{m_x}{k_y}$$

(c) At low gas rates, the chances of weeping and dumping phenomena would increase. In these cases, the liquid will start coming from the perforations or no liquid will reach to downspouts. To reduce these phenomena in tray towers, we would prefer the valve or bubble cap trays. In these trays, the opening is covered by movable caps and only small opening will be possible at low gas rates which reduces the tendency of weeping.

(d) When stepping off stages on an Y–X plot for an absorber or a stripper, it starts from the operating line and stops at operating line. In case of absorber, it starts from the top condition of the absorber and terminate at the bottom condition of the absorber which is represented by operating line.

2. Mass transfer of component A through stagnant component B:

$$N_A = \frac{c D_{AB}}{z_2 - z_1} \ln\left(\frac{1 - x_{A2}}{1 - x_{A1}}\right) \qquad \boxed{2}$$

Given data:

$$z_2 - z_1 = 0.005 \text{ m}; \ A = \frac{\pi \times 8^2}{4} = 50.265 \text{ m}^2; \ D_{AB} = 0.0306 \text{ m}^2/\text{h} \qquad \boxed{1}$$

$$c = \frac{n}{V} = \frac{P}{RT} = \frac{1}{0.08205 \times 298} = 0.0409 \text{ kgmol/m}^3 \qquad \boxed{5}$$

$$x_{A1} = \frac{20}{760} = 0.0263; \ x_{A2} = 0 \qquad \boxed{3}$$

$$N_A = \frac{0.0409 \times 0.0306}{0.005} \ln\left(\frac{1 - 0}{1 - 0.0263}\right) = 0.00791 \text{ kgmol/h} \cdot \text{m}^2 \qquad \boxed{5}$$

Total No. of moles of propanol lost in one day = 0.00791×24×50.265=9.5423 kgmole

Amount of propanol in kg lost in one day = 9.5423×60.09 = 573.396 kg
Volume of propanol lost in day = 573.396/0.8 = 716.746 liters
Cost of propanol lost = 716.746 liter×$1.2/liter = $860.09

3.
Given data:
$y_1 = 0.05$

Average Molecular Weight of gas = 0.05×58+0.95×29 = 30.45
Gas flow rate = 0.5/30.45 = 0.0164 kmol/m².s; Liquid flow rate = 0.85/18 = 0.0472 kmol/m².s

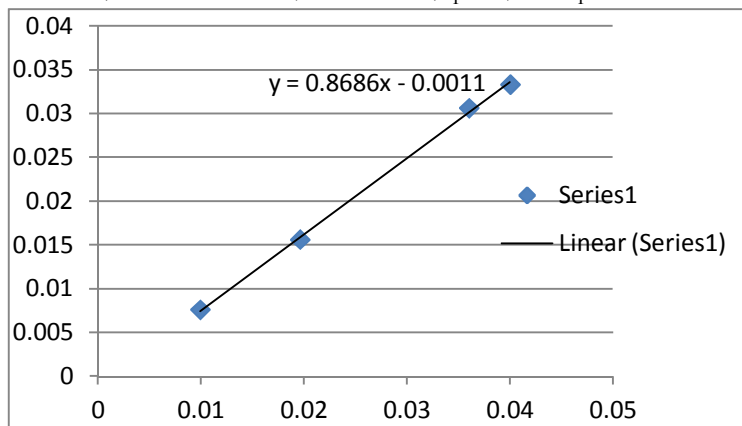$$y_2 = \frac{(0.05 \times 0.0164) \times 0.02}{0.95 \times 0.0164 + (0.05 \times 0.0164) \times 0.02} = 0.00105$$

$x_2 = 0$ (fresh solvent)
Outlet solvent composition can be calculated from material balance:
$0.0164(0.05 - 0.00105) = 0.0472(x_1 - 0) \Rightarrow x_1 = 0.017$

The equilibrium curve is linear so we can use the linear interpolation between two points.
For $x_1 = 0.017$; $y_1^* = 0.8686 \times 0.017 - 0.0011 = 0.01366$

$$H_{OG} = \frac{V}{K_G a S} = \frac{0.0164}{1.5 \times 10^{-2}} = 1.093 \, \text{m}$$

$$N_{OG} = \frac{y_1 - y_2}{\dfrac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln \dfrac{(y_1 - y_1^*)}{(y_2 - y_2^*)}}} = \frac{0.05 - 0.00105}{\dfrac{(0.05 - 0.01366) - (0.00105 - 0)}{\ln \dfrac{(0.05 - 0.01366)}{(0.00105 - 0)}}} = 4.916$$

$L = H_{OG} \times N_{OG} = 1.093 \times 4.916 = 5.373 \, \text{m}$
Minimum solvent flow rate:
$0.0164(0.05 - 0.00105) = L_{min}(0.0588 - 0) \Rightarrow L_{min} = 0.01365 \, \text{kmol/m}^2.\text{s}$

4.
It is given that at one point in the wetted wall column, the liquid phase concentration of ammonia is 6.42×10^{-2} kmol NH_3/m³ of solution and gas phase contains 10 mol% ammonia. It means, $p_{NH3} = 0.1$ atm.
Henry's law: $p_{NH_3} = 9.35 \times 10^{-3} c$, where p_{NH3} is partial pressure of ammonia in atm and c is concentration of ammonia in liquid phase in kmol/m³.

$$\frac{\text{Resistance in gas phase}}{\text{Total resistance in both phases}} = \frac{1/k_p}{1/K_P} = \frac{K_P}{k_p} = 0.8 = \frac{2.72 \times 10^{-4}}{k_p} = 0.8 \Rightarrow k_p = 3.4 \times 10^{-4} \text{ kmol/m}^2\text{.s.atm} \quad \boxed{5}$$

$$N_A = K_P(p_{NH_3} - p_{NH_3}^*)$$

$$p_{NH_3}^* = 9.35 \times 10^{-3} \times 6.42 \times 10^{-2} \Rightarrow p_{NH_3}^* = 0.00060027 \text{ atm} \quad \boxed{5}$$

$$N_A = 2.72 \times 10^{-4}(0.1 - 0.00060027) = 0.27036 \times 10^{-4} \text{ kmol/m}^2\text{.s} \quad \boxed{4}$$

$$N_A = k_p(p_{NH_3} - p_{NH_3,i}) = 3.4 \times 10^{-4}(0.1 - p_{NH_3,i}) = 0.27036 \times 10^{-4} \Rightarrow p_{NH_3,i} = 0.02048 \text{ atm} \quad \boxed{5}$$

$$c_{NH3,i} = \frac{0.02048}{9.35 \times 10^{-3}} = 2.19 \text{ kmol/m}^3 \quad \boxed{6}$$

Mole percent of ammonia at interface is 2.048%