INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Spring Semester Examination 2022-23

Date of Examination: ________________ **Session: (FN/AN)** ______ **Duration: 2 hrs. Full Marks: 30**

Subject No.: CH21202 and CH31001 **Subject: Mass Transfer 1**

Department/Center/School: Chemical Engineering

Specific charts, graph paper, log book etc., required : No

Special Instructions (if any): (1) Answer ALL Questions. (2)No queries will be entertained during the exam.
(3)Any missing data may be assumed suitably giving proper justification.
(4) Use relevant equations and diagrams, wherever necessary

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1. Decomposition of N_2O_4 to NO_2 is being carried out on catalyst surface according to the following reaction
$N_2O_4 \rightarrow 2NO_2$

At one place in the apparatus, pressure is 1 atm and temperature is 200^{0}C. The analysis of bulk gas is 33.33% N_2O_4 and rest is NO_2 by volume. The circumstances such that N_2O_4 diffuse on the catalyst surface and products after the reaction diffuses back though a 1mm thick gas film. Estimate the local rate of cracking (Moles of N_2O_4 / surface area of catalyst.s) which might be considered to occur if the reaction is diffusion-controlled (chemical reaction rate is very rapid) with the concentration of N_2O_4 at the catalyst surface equal to zero. **[6 marks]**

Diffusivity of gases can be estimated using Wilke-Lee equation:

$$D_{AM} = \frac{\left(1.084 - 0.249 * \sqrt{1/M_A + 1/M_B}\right) T^{1.5} \sqrt{1/M_A + 1/M_B}}{P(\gamma_{AB})^2 f\left(\frac{kT}{\varepsilon_{AB}}\right)}$$

Where M_A and M_B are molecular weights of A and B, respectively.

P – Pressure in Pa and T – Temperature in K

Gas	γ in nm	$\frac{\varepsilon_A}{k}$ (K)
N_2O_4	0.3798	71.4
NO_2	0.2827	59.7

2. Two large vessels are connected by a tapered tube of length L. The end radii of the tubes are r1 and r2. The vessels contain mixtures of gases A and B at the same total pressure and Temperature. Derive the rate of diffusion expression through the tube at steady state if the partial pressure of A in one vessel is higher than other vessel. Assume that the compositions of gases in two vessels are fairly constant in spite of the diffusional transport occurring through the connecting tube. **[3marks]**

3. (a) The molar flux from a 5 cm diameter naphthalene ball placed in stagnant air at 40°C and atmospheric pressure, is 1.47 × 10^{-3} $mol/m^2{\cdot}s$. Assume the vapor pressure of naphthalene to be 0.15 atm at 40 °C and negligible bulk concentration of naphthalene in air. Find the value of diffusivity and mass transfer coefficient based on concentration driving force. Derive the necessary relation between diffusivity and molar flux.
(b) If air starts blowing across the surface of naphthalene ball at 3 m/s by what factor will the mass transfer rate increase, all other conditions remaining the same? For mass transfer from a single sphere into gas streams: $Sh = 2 + 0.552\, Re^{0.5}\, Sc^{0.33}$ The viscosity and density of air are 1.8 × 10^{-5} $kg/m{\cdot}s$ and 1.123 kg/m^3, respectively. **[8 marks]**

4. Consider the interphase mass-transfer process for the chlorine dioxide, ClO_2-air-water system. ClO_2 gas (solute A) is sparingly soluble in water. The equilibrium relationship can be described by Henry's law ($P_A^* = H\, C_A^*$)

where Henry's law constant (H) for the dilute solution of ClO_2 in water is 7.7×10^{-4}atm/(mol/m3). At the current conditions of operation, the mole fraction of ClO_2 in the bulk gas phase is $y_A = 0.040$ and the mole fraction of ClO_2 in the bulk liquid phase is $x_A = 0.00040$. The mass density of the liquid phase is 992.3 kg/m^3 and is not dependent on the very small amount of ClO_2 dissolved in it. The total system pressure is 1.5 atm. **[8 marks]**

(a) Is the process gas absorption or liquid stripping?

(b) If the ClO_2 partial pressure in the bulk gas phase is maintained at 0.06 atm, what is the maximum possible dissolved ClO_2 concentration, mol/m3, in the liquid?

(c) If k_x = 1.0 mol/(m^2·s) and k_G= 0.010 mol/(m^2·s·atm), what is K_y, the overall mass-transfer coefficient based upon the overall gas phase driving force?

(d) Calculate overall mass transfer resistance based upon the overall gas phase driving force and contribution of the liquid phase and gas phase resistance to the overall mass transfer resistance.

(e) Based upon the bulk gas and liquid phase compositions, what is the mass transfer flux for ClO_2 in unit mol/(m ^{2}·s)?

5. Answer the following questions: **[5x1 mark]**

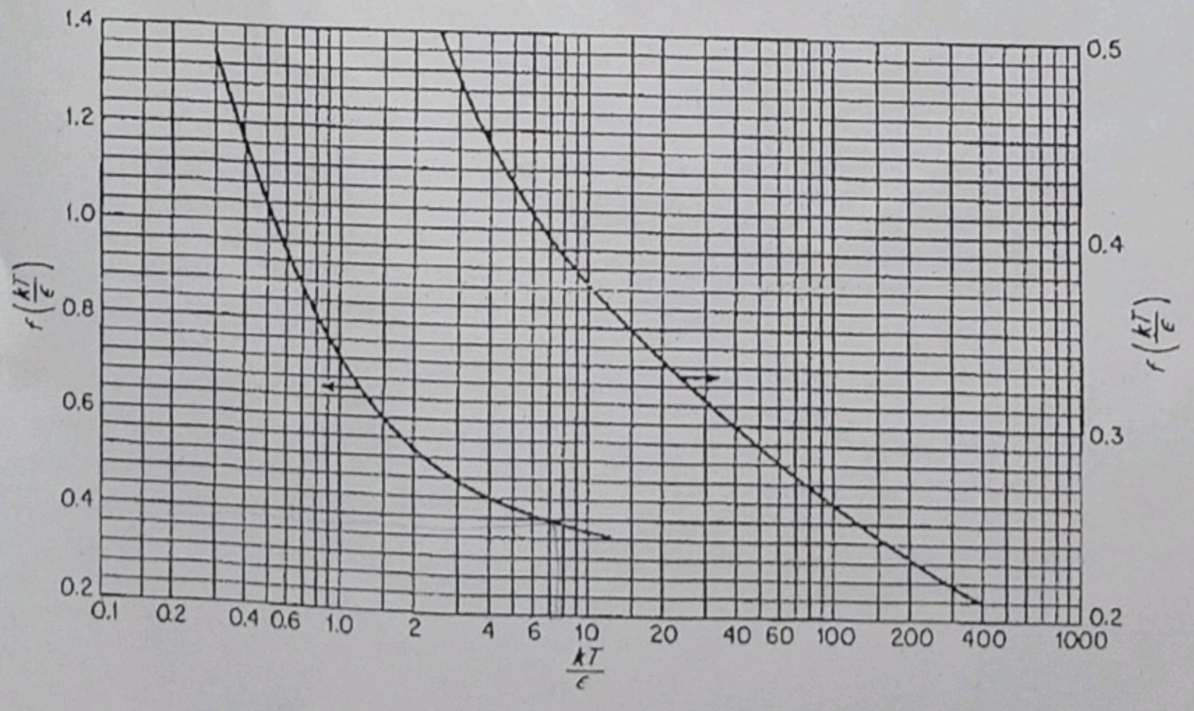
(i) If a Stefan tube experiment is carried out at few degrees lower than the boiling point temperature of the liquid, can the pseudo-steady state approximation is valid in this case? Why?

(ii) A 10 cm diameter bubble of pure gas A rises through a quiescent liquid at a steady velocity of 25 cm/s and the average mass transfer coefficient found to be 0.013 cm/s. What would be the mass transfer coefficient if bubble of 5cm diameter rises through the liquid at a velocity of 10 cm/s?

(iii) Under what conditions, Knudsen and surface diffusion is prevalent?

(iv) Write the analogous equations for heat, mass and momentum transport

(v) State the drawbacks of penetration theory.



INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

End-Spring Semester Examination, 2022-2023

***Subject* : Mass Transfer - I** ***Subject No.*: CH21202/CH31001**

***Date*: 21.04.2023 (AN)** ***Time*: 3 Hrs** ***Full Marks*: 50**

Specific charts, graph paper, log book etc., required: Normal graph paper ($\geq$ 3 nos. per candidate)

***Instructions* :** (1) Use relevant equations and diagrams, wherever necessary.
(2) Any missing data may be assumed suitably giving proper justification.
(3) Answer all parts of a question at one place only.

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1. **(a)** What are 'Dumping' and 'Priming' of a Sieve Tray Tower?
(b) When is split flow tray preferred over cross flow tray?
(c) A tray tower is to be designed to absorb CO_2 from a flue gas stream by scrubbing into an aqueous amine solution at 25°C. Approximately, 180 m^3/h (at 25°C and 1 atm) of gas is to be processed and the CO_2 content of the gas is to be reduced from 15 mol% to 2 mol%. The scrubbing liquid, which is recycled from a stripper, will contain 0.058 mol CO_2/mol solution. Determine (i) the minimum liquid rate, kmol/h and (ii) the number of real trays required for a liquid rate 1.2 times the minimum. Assume an overall tray efficiency of 53%.

Equilibrium Data:

Mole CO_2/mole amine solution	0.058	0.060	0.062	0.064	0.066	0.068
p_{CO2} (mm Hg)	5.6	12.8	29.0	56.0	98.7	155.0

[2+1+(4+3)]

2. **(a)** For dilute mixtures and cases where Henry's law applies, prove that the number of overall gas phase transfer units for co-current gas absorption in packed towers is given by

$$N_{tOG} = \frac{A}{A+1} \ln \left[\frac{y_1 - mx_1}{y_2 - mx_2}\right]$$

where the notations have their usual meanings.

(b) Ammonia is to be removed from an ammonia-air mixture by water scrubbing in a 0.30 m diameter tower packed with 25 mm Berl saddles. The gas mixture is available at the rate of 150 m^3/h (at 25°C and 1 atm) with 6% ammonia by volume. Calculate the depth of the packing required for a final ammonia content of 0.05% by volume. At 25°C, ammonia-water solutions follow Henry's law up to 6 mole% ammonia in liquid and m = 1.4. The water rate is 250 kg/h and $K_G a$ is given as 265 kmol/m^3 h atm.

OR

(a) What are the factors that influence N_{tOL} and H_{tOL} of a packed desorption tower?

(b) A relatively nonvolatile hydrocarbon oil containing 3.5 mol% benzene is being stripped at a rate of 160 kmol/h by direct superheated steam in a packed tower to reduce the benzene content to 0.1%. The gas-liquid equilibrium may be represented by $y^* = 22.5\,x$, where y^* is the mole fraction of benzene in the steam and x is the mole fraction of benzene in the oil. Steam can be considered as inert gas and will not condense. Determine the height of the packing if the diameter of the tower is 1.5 m. The steam rate is 270 kg/h and $K_x a$ is 150 kmol/m^3 h (Δx^*).

[4+6]

P.T.O.

3. (a) How is butadiene separated from C_4-stream of naphtha cracker?
(b) Why are the heat-sensitive high-boiling materials not degraded during purification by steam distillation?
(c) A liquid mixture containing 50 mol% ethanol (A) and 50 mol% n-propanol (B) is subjected to differential distillation at atmospheric pressure with 50 mol% of the liquid distilled. What will be the compositions of the composited distillate and the residue? The vapour pressures of A and B at 80°C are given as 787 mm Hg and 364 mm Hg, respectively.

OR

(c) A liquid mixture containing 50 mol% ethanol (A) and 50 mol% n-propanol (B), at 80°C, is to be continuously flash vaporized at atmospheric pressure to vaporize 50 mol % of the feed. What will be the composition of the vapour and liquid if the vaporizer is an ideal one? The vapour pressures of A and B at 80°C are 787 mm Hg and 364 mm Hg, respectively.

[3+2+5]

4. (a) How does the cost of a distillation column vary with reflux ratio?
(b) A mixture of diethylamine (DEA) and triethylamine (TEA) containing 50 mol% of DEA is to be continuously fractionated at a rate of 8700 kg/h and at a total pressure of 113.3 kPa. The top product should have 98% more volatile component and the bottom product 2%. The feed will be 50 mol% vaporized before it enters the tower. A total condenser will be used and the reflux will be returned at the bubble point. Determine (i) the product rates, kg/h; (ii) the minimum reflux ratio; (iii) the number of theoretical trays required at a reflux ratio 1.5 times the minimum and (iv) the location of the feed tray.
The equilibrium data for the system are given below:

x	0.02	0.104	0.227	0.34	0.428	0.52	0.65	0.79	0.90	0.95
y	0.052	0.231	0.45	0.6	0.694	0.765	0.845	0.915	0.963	0.982

[2+ (2+2+3+1)]

5. (a) Draw model operating line and equilibrium line diagrams on X-Y plane for (i) co-current absorption and (ii) counter-current stripping processes.
(b) Derive the relationship between the nucleation rate, growth rate and the population density function of vanishingly small size.
(c) The crystal growth rate in an MSMPR crystallizer under a given set of condition is 5×10^{-8} m/s. The holdup of the suspension is 10 m^3 and the suspension withdrawal rate is 4 m^3/h. The zero-size population density is 5×10^{10}/cm. liter. Calculate the total number of crystals, and mass of the crystal in the size range of 0.5 mm to 1 mm per unit volume of the product. Volume shape factor and the density of the crystals can be taken as 0.6 and 2700 kg/ m^3.

[2+2+6]

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