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

---

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°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 $1.47 \times 10^{-3}\ mol/m^2{\cdot}s$. 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 $1.8 \times 10^{-5}\ kg/m{\cdot}s$ 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.