

**Chemical Reactor Design Paper – III**

P. Pages : 3

Time : Three Hours



**TKN/KS/16/7838**

Max. Marks : 80

- Notes :
1. All questions carry equal marks.
  2. Answer **any five** questions.
  3. Due credit will be given to neatness and adequate dimensions.
  4. Assume suitable data wherever necessary.
  5. Diagrams and Chemical equations should be given wherever necessary.
  6. Illustrate your answers wherever necessary with the help of neat sketches.
  7. Use of slide rule, Logarithmic tables, Steam tables, Mollier's chart, Drawing instruments, Thermodynamic tables for moist air, Psychrometric charts and Refrigeration charts is permitted.

1. For fluid particle reaction  $A(\text{fluid}) + B(\text{Solid}) \rightarrow \text{Product}$ , assuming shrinking core model is followed and ash layer diffusion controls, derive an expression for calculating time required for conversion of solid B as a function of changing radius. **16**
2. a) An impurity A in a gas phase is to be reduced from 1% to 2 ppm by countercurrent contact with liquid containing reactant of concentration  $C_B = 3.2 \text{ mol/m}^3$   
 $K_{Ag} a = 32000 \text{ mol/hr.m}^3 \cdot \text{atm}$   $K_{Ar} a = K_{Bl} a = 0.5/\text{hr}$ ,  $L = 7 \times 10^5 \text{ mol/hr m}^2$   
 $G = 1 \times 10^5 \text{ mol/hr. m}^2$ ,  $H_A = 1.125 \times 10^{-3} \text{ atm. m}^3/\text{mol}$   $G = 56,000 \text{ mol/m}^3$   
The reaction  $A + B \rightarrow \text{product}$  is rapid : **12**
  - i) Find the height of the tower needed.
  - ii) What recommendations do you have (about the concentration of liquid phase reactant) that may help improve the process?
  - iii) What incoming concentration of B would give the minimum height of tower? What is this height?
- b) The reduction of iron ore of density  $P_B = 4.6 \text{ gm/cm}^3$  and size  $R = 5 \text{ mm}$  by hydrogen can be approximated by unreacted core model. With no water vapour present the stoichiometry of the reaction is  $4\text{H}_2 + \text{Fe}_3\text{O}_4 \rightarrow 4\text{H}_2\text{O} + 3\text{Fe}$  with rate approximately proportional to the concentration of hydrogen in the gas stream. The first order rate constant  $k_s = 1.93 \times 10^5 e^{-24000/RT}$ ,  $\text{cm/s}$  **4**
  - i) Taking  $D_e = 0.03 \text{ cm}^2/\text{sec}$  as the average value of the diffusion coefficient for hydrogen penetration of the product layer calculate the time necessary for complete conversion of a particle from oxide to metal at  $600^\circ\text{C}$ .
  - ii) Does any particular resistance control? If not, what is the relative importance of the various resistance steps?

3. a) With the help of neat sketches, explain the interface behaviour for liquid – phase reaction,  $A \text{ (from gas)} + bB \text{ (liquid)} \rightarrow \text{Product (liquid)}$  for complete range of rates of the reaction and the mass transfer. **6**
- b) A solid feed consisting of 20wt % of 1mm particles and smaller, 30wt % of 2mm particles, 50 wt% of 4mm particles is to be passed through a rotating tubular reactor, somewhat like a cement kiln, where it reacts with gas of uniform composition to give a hard non friable solid product. Experiments show that the progress of conversions can reasonably be represented by reaction control for the unreacted core model, and that the time for complete conversion of 4mm particles in 4hrs. Find the residence time needed in the tubular reactor for **10**
- i) 75% conversion of solids.
- ii) 95% conversion of solids
- iii) 100% conversion of solids
4. a) We plan to use an NaOH solution to hasten the removal of  $\text{CO}_2$  from air at  $25^\circ\text{C}$ . **6**
- i) What form of rate equation should be when  $P_{\text{CO}_2} = 0.01 \text{ atm}$  and the solution is 2N in NaOH.
- ii) How much can absorption be speeded compared to physical absorption with pure water? Assume the reaction is instantaneous and is represented by
- $$\text{CO}_2 + 2\text{OH}^- = \text{H}_2\text{O} + \text{CO}_3^{--}$$
- Data:  $k_g a = 80 \text{ mol/hr.liter.atm}$ ,  $k_l a = 25/\text{hr}$   $H = 30 \text{ atm.lit/mol}$ .
- b) For a single cylindrical pore of length  $L$ , with reactant  $A$  diffusing into the pore, and reacting on the surface by a first order reaction derive the equation for effectiveness factor. **10**
5. a) Discuss in brief the industrial applications of different types of reactors used for gas-liquid reaction on solid catalyst. **6**
- b) The following kinetic data on the reaction  $A \rightarrow R$  are obtained in an experimental packed bed reactor using various amounts of catalyst and a fixed feed rate  $F_{A0} = 10 \text{ kmol/hr}$  **10**
- |           |      |      |      |      |      |      |      |
|-----------|------|------|------|------|------|------|------|
| W. kg cat | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
| $X_A$     | 0.12 | 0.20 | 0.27 | 0.33 | 0.37 | 0.41 | 0.44 |
- i) Find the reaction rate at 40% conversion.
- ii) In designing a large packed bed reactor with  $F_{A0} = 400 \text{ kmol/hr}$  how much catalyst would be needed for 40% conversion.
- iii) How much catalyst would be needed in part (ii) if the reactor employed a very large recycle of product stream.

6. a) Write the performance equations for reactors used for gas-liquid reactions on solid catalyst for the following cases. 4
- i) For reactant liquid B used in excess for mixed flow of gas A and any flow of liquid B and
- ii) For reactant gas A used in excess for mixed flow of liquid B and any flow of gas A.
- b) The elementary irreversible organic liquid-phase reaction  $A + B \rightarrow C$  is carried out adiabatically in a flow reactor. An equal molar feed in A and B enters at  $27^\circ\text{C}$ , and the volumetric flow rate is  $2\text{ dm}^3/\text{s}$  12
- i) Calculate PFR and CSTR volumes necessary to achieve 85% conversion.
- ii) What is the maximum inlet temperature one could have so that the boiling point of liquid (550K) would not be exceeded even for complete conversion.
- iii) Plot the conversion and temperature as a function of PFR volume (i.e. distance down the reactor)
7. a) Discuss the mechanism of step growth polymerization in brief and hence derive the expression for  $P_j$ . 10
- b) Discuss the concept of multiple steady states in nonisothermal reactor design using heat generation term and heat removal term. 6
8. Write short notes on **any four**. 16
- i) Pseudo steady state hypothesis used in polymerization kinetics.
- ii) Thiele modulus in solid catalyzed reactions.
- iii) Moments of the distribution in polymers.
- iv) Modelling of batch polymerization reaction.
- v) Combination of Resistances in fluid-particle reactions.

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