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12
9

NATIONAL INSTITUTE OF TECHNOLOGY HAMIRPUR
(An Institute of National Importance under Ministry of HRD)
Department of Chemical Engineering

CH-322 CHEMICAL REACTION ENGINEERING-II
END-SEMESTER EXAMINATION

Maximum Marks: 50 | Time: 3 hours

Instructions:

- **Make suitable assumptions if necessary and clearly state them.**
- Marks will be deducted for omitting steps.
- Draw the figure wherever needed.
- The question paper is of **three** pages and has **five** questions. **Attempt all questions.**

Q1. (10 Marks)

a) Elucidate the various steps involved in heterogeneous catalytic reactions.

b) A solid-catalyzed gaseous reaction has the form

$$A + B \rightarrow C$$

Sketch curves of the initial rate (rate at zero conversion) vs. the total pressure for the following cases:

i. The mechanism is the reaction between adsorbed A and adsorbed B molecules on the catalyst. The controlling step is the surface reaction.

ii. The mechanism is the same as (*i*), but adsorption of A is controlling.

iii. The mechanism is the same as (*ii*), but desorption of C is controlling. Assume that the overall equilibrium constant is large with respect to the adsorption equilibrium constants.

iv. The mechanism is a reaction between adsorbed A and B in the gas-phase. The controlling step is the surface reaction.

In each instance suppose that the reactants are present in an equimolal mixture.

Q2. (10 Marks)

As a scientist in a well-known R&D Laboratory, you have recently determined reactions rates for the oxidation of sulfur dioxide, using a packed bed of Pt-on-Alumina catalyst pellets. A differential reactor has been employed in this regard, and the partial pressures as measured from bulk-stream compositions have been corrected to fluid-phase values at the catalyst surface. The total pressure has been kept constant at 790 mm Hg. From previous findings and qualitative nature of the rate data, a suitable combination appeared to be a controlling surface

10

reaction between adsorbed atomic oxygen and adsorbed sulfur dioxide. In order to determine all the constants in the rate equation for this mechanism, it is necessary to vary each partial pressure independently in the experimental work. Thus measuring the rate of reaction at different total pressures but at constant composition is not sufficient to determine all the adsorption equilibrium constants. Similarly, if the data are obtained at constant composition of initial reactants but varying conversions, the partial pressures of the individual components do not vary independently. However, in these cases it is possible to verify the validity of the rate equation even though values of the separate adsorption equilibrium constants cannot be ascertained. You have studied the effect of the conversion alone and presented the data at 480°C in Table Q2.

Table Q2

Rate (r), g mol/(h)(g catalyst)	Partial pressure (atm) at catalyst surface		
	SO_3	SO_2	O_2
0.02	0.0428	0.0255	0.186
0.04	0.0331	0.0352	0.190
0.06	0.0272	0.0409	0.193
0.08	0.0236	0.0443	0.195
0.10	0.0214	0.0464	0.196
0.12	0.0201	0.0476	0.197

a) Derive the rate equation suggested from assumed mechanism.

b) Test how well the derived rate equation fits the experimental data.

Q3. (10 Marks)

a) Propose a mechanism to offset catalyst decay in a hydrotreater.

b) The catalytic decomposition of reactant ($A \rightarrow R$) is studied in a packed bed reactor filled with 2.0 mm pellets and using a very high recycle rate of product gases (assume mixed flow). The results of a long-time run and additional data are presented in Table Q3. Determine rate kinetics of reaction and deactivation, both in the diffusion-free and in the strong pore diffusion resistance regime.

Table Q3

t, hr	0	1	2	3	4
X_A	0.80	0.73	0.65	0.55	0.45

Additional data: $D_e = 4 \times 10^{-10}$ m^3/m cat.s, $\rho_c = 1500$ kg/m^3 cat, $\tau' = \frac{WC_{Ao}}{F_{Ao}} = 5000$ kg.s/m^3

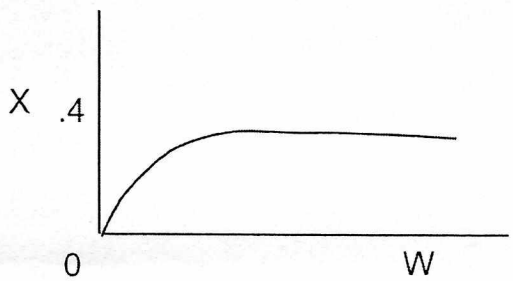
11

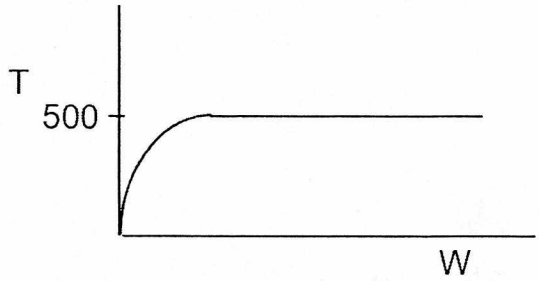
Q4. (10 Marks)

A mass transfer limited chemical reaction is carried out in two packed bed reactors of equal volume and catalyst packing, connected in series. Presently, 90% conversion is reported in this arrangement. You have decided to separate the reactors and divide the flow rate equally among each of the two reactors. These arrangements are warranted to decrease the pressure drop which eventually reduces pumping requirements. Do you think this is a good idea in terms of achieving a higher conversion? The effects of small changes in temperature and pressure on mass transfer can be neglected.

Q5. (10 Marks)

The species A and B react to form species C, D, and E in a packed bed reactor. The catalyst does not decay. The reaction is elementary. The following profiles were obtained:





Which of the following statements are true and false for this system? Justify your answer for each case.

a) The above profiles could represent an adiabatic system where the addition of inerts will increase the conversion.

b) The above profiles could represent a system where decreasing the flow rate will increase the conversion.

c) The above profiles could represent a system where if the feed temperature is increased, one cannot tell from the above profiles whether or not the conversion will increase or decrease.

d) There could be a heat exchanger on the reactor for which the heat flow is:

$$\frac{d\dot{Q}}{dW} = \frac{1000\ \text{kJ}}{\text{kg s K}}(T - 500)$$

**********ALL THE BEST **********