7. (a) A fermentation industry wishes to produce a valuable biochemical by maintaining maximum rate of cell growth condition as far as possible. Starting with 15.5 mg/dm³ of cells and 150 mg/dm³ of substrate, the fermentation was carried out. The yield of cell was found to be 0.65 mg cell/mg substrate.

The cell growth rate was reported to be $r_C = \frac{1.2C_AC_C}{C_A+2}\frac{mgcellsformed}{hr.dm^3}$. Find the maximum rate of cell growth that can be achieved at this condition

(b) A fermentation reaction having the following rate equation $R_c = \frac{1.2C_AC_C}{C_A+2}$, C_A = gm substrate/m³ and $Y_{C/A}$ = 0.1 gm cell/gm substrate is carried out in a mixed flow reactor of volume 0.75m³. Find the outlet concentration of cells produced for optimum operation when 1 m³/h of substrate solution (C_{A0} = 6 gm/m³) is fed to the reactor.

7 + 5 =12

Group – E

8. A batch reactor has a 230 kg charge of a solution of acetic anhydride at 15.5⁰C containing acetic anhydride at a concentration of 0.22 kmol/m³. The solution density is 1048 kg/m³ and its specific heat 0.9 kcal/(kg)(⁰C). The first order reaction has ΔH = -50,000 kcal/kmol of anhydride hydrolysed. Find the time for 80% conversion under adiabatic condition.

Data:

Temperature, ⁰C	4.44	10	15.5	21.11	26.7	32.2
Rate constant, k, min⁻¹	0.035	0.057	0.084	0.123	0.174	0.245

12

9. The elementary gas phase reaction A + B ⇌ 2C, is to be carried out in a plug flow reactor. The feed contains only A and B in stoichiometric proportions at 580.5 kPa and 77⁰C. The molar feed rate of A is 20 mol/s. The reaction is carried out adiabatically. Determine the volume of the reactor necessary to achieve 70% conversion.

Data:

k = 0.035 dm³/mol-min at 273K, E = 70,000 j/mol, standard heat of reaction = -20,000 j/mol, ΔC_P = 0, C_{PA}= 25 j/mol.k, C_{PB} = 15 j/mol.k and C_{PC}= 20 j/mol.k.

12

REACTOR DESIGN
(CHEN 4141)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) The volume expansion factor of A for the isothermal gas phase reaction, $A \rightarrow 3B$, in presence of 50% A and %0% inert is
(a) 0.5 (b) 1 (c) 2 (d) 3.

(ii) 1 liter / sec of gaseous reactant A is introduced into a mixed flow reactor having volume 4 liters. The stoichiometry is A → 3R. The conversion is 50%, and under these conditions the residence time is
(a) 1 sec (b) 2 sec
(c) ½ sec (d) none of the above.

(iii) For a reaction having order (n) greater than unity, the best combination of reactors will be
(a) PFR, small mixed, large mixed (b) Large mixed, small mixed, PFR
(c) Small mixed, large mixed, PFR (d) Small mixed, PFR, large mixed.

(iv) A consecutive reaction, $A \xrightarrow{C_1} B \xrightarrow{C_2} C$, is characterized by
(a) maxima in the concentration of A (b) maxima in the concentration of B
(c) maxima in the concentration of C (d) high exothermicity.

(v) Under strong pore diffusion regime a nth order reaction behaves like a
(a) (n + 1) order reaction (b) $\frac{(n+1)}{2}$ order reaction
(c) $\frac{(n-1)}{2}$ order reaction (d) zero order reaction.

(vi) The plot of rate versus substrate concentration of an enzymatic reaction gives a section of rectangular hyperbola. The system represents a
(a) shifting order reaction (b) first order reaction
(c) zero order reaction (d) none of the above.

(vii) The Michaelis Menten theory is based on the assumption that is used in
(a) homogeneous catalysis
(b) heterogeneous catalysis
(c) both homogeneous and heterogeneous catalysis
(d) none of the above.

(viii) The Damkohler number is given by
(a) rate of reaction of a reactant/rate of diffusion of reactant to catalyst surface
(b) rate of reaction of a reactant/rate of convective transport of a reactant at the reactor entrance
(c) rate of convective transport of a reactant / rate of reaction of a reactant
(d) rate of diffusion of a reactant/rate of convection.

(ix) In order to avoid wash out of cells from a chemostat, $k\tau_m$ should be
(a) equal to unity (b) greater than unity
(c) less than unity (d) none of the above.

(x) Dimension of dilution ratio (D) is
(a) time (b) $time^{-1}$
(c) mol/volume/time (d) none of the above.

Group – B

2. A commercial installation produces 40 kmol R/hr by hydrolysis in a MFR of a feed stream containing 1 $kmol/m^3$ of reactant A. Because of large excess of water used the reaction may be considered first order, or A → R even though it is bimolecular. The effluent stream from the reactor goes to a counter-current extraction column in which R is quantitatively extracted. Two percent of the incoming A passes through the system unreacted. Fixed and operating costs for this process are $20/hr, reactant cost is $1.00/kmol, and R can be sold at $1.32/kmol. It is suspected that the plant is not being operated at optimum condition. Therefore, you have been asked to study the operation with the aim of optimizing them.
(i) What are the percent profits on an hourly basis?
(ii) How should the installation be operated (feed rate of A, conversion of A and production rate of R) to maximize the profit? What are these profits on an hourly basis?
Note: All R produced may be sold. Separation equipment is flexible since it has been designed to adapt to large changes in capacity.

12

3. (a) The irreversible reaction A (g) → $\frac{1}{3}R$ (g, l)) is carried out isothermally and without pressure drop in a PFR at 298 K and 2 atm. As the concentration of R increases down the reactor and R begins to condense. The vapour pressure of R at 298 K is 0.5 atm. If an equal molar mixture of A and inert, I, is fed to the reactor at what conversion of A will R begin to condense?

(b) For a certain chemical reaction A → R, the following data were obtained:

Temperature, ^0C	100	110	120	130	140	150
Rate constant, s^{-1}	1.055×10^{-16}	1.070×10^{-15}	9.25×10^{-15}	6.94×10^{-14}	4.58×10^{-13}	3.19×10^{-12}

Find the activation energy and frequency factor for this reaction.

6 + 6 = 12

Group – C

4. A 20 liter MFR is to treat a reactant which decomposes as follows
$A \rightarrow R,\ r_R = 4hr^{-1}C_A$
$A \rightarrow S,\ r_S = 1hr^{-1}C_A$
Find the feed rate and conversion of reactant so as to maximize profits. What are these on an hourly basis?
Data: Feed material A costs $1/mol at C_{A0} = 1 mol/lit, product R sells for $5/mol and s has no value. The total operating cost of reactant and product separation equipment is $25/hr + $1.25/mol A feed to the reactor. Unconverted A is not recycled.

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5. (a) In a laboratory packed bed reactor (L_m = 10 cm and u_0 = 2 cm/s) conversion is 97% for the first order reaction A → R.
What would be the conversion in a larger fluidized bed pilot plant (L_m = 100 cm and u_0 = 20 cm/s) in which the estimated bubble size is 8 cm? Data: u_{mf} = 3.2 cm/s, $\varepsilon_{mf} = \varepsilon_m = 0.5$, $D = D_e$ = 0.204 cm^2/s, $\alpha = 0.34$
Subscript m refers to the fixed bed or settled bed condition.

(b) Deduce the performance equation of fluidized bed reactor using bubble bed model.

7 + 5 = 12

Group – D

6. Substrate A decomposes in the presence of enzyme E (A → R). It is desired to design a batch fermenter for producing 2000 kg R/day from a feed containing C_{A0} = 1000 mol/m^3. The conversion of A is 90 %. The plant should operate day and night and times for filling, cleaning and draining may be taken as 0.5 hrs. The molecular weight of A is 179 and the initial enzyme concentration is 10 mol/m^3. Find the length and diameter of the reactor if the aspect ratio is 2 and the actual reactor volume is 25% excess of the theoretically calculated volume. The reactor is cylindrical in shape. The system follows Michaelis-Menten equation having k_3 and K_m values 48 hr^{-1} and 336 mol/m^3 respectively.

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