V, lit/hr	C_A, mg/lit	Cell concentration, mg/lit
0.2	4	15.6
0.4	10	15
0.8	40	12
1.0	100	6

Find a rate equation to represent this growth.

6 + 6 = 12

7. (a) E.coli lives and grows on mannitol with the following kinetics: $r_C = 1.2\, C_A C_C / (C_A + 2)$ gm cell formed /hr. m^3 with $Y_{C/A} = 0.1$ gm cell/gm mannitol. It is desired to produce 1 Kg cell/day in a batch fermenter. We start with 1000 gm mannitol/m^3 and 0.1 gm/m^3 cells and continue the fermentation until the substrate drops to 10 gm/m^3. The plant operates day and night and the times for filling cleaning and emptying the reactor are 0.23 hours, find the volume of the fermenter needed. C_A and C_C are the concentrations of substrate and cells in gm/m^3 respectively.

(b) Show that the optimum residence time (τ_m) in chemostat with $C_{C_0} = 0$ is given by $k\tau_m = \frac{N}{N-1}$, where, $N^2 = \frac{K_S + C_{A_0}}{K_S}$. The system follows the Monods equation.

6 + 6 = 12

Group - E

8. (a) Enumerate the four different methods of Protein precipitation. Explain the principles of any one such method.

(b) The solubility of a protein is 15 g/dm^3 at ammonium sulphate concentration of 2.2 M and 0.25 g/dm^3 at 3.0 M. Calculate the solubility of the protein at 3.8 M of the salt using a suitable empirical relationship.

(2 + 4) + 6 = 12

9. An ultrafiltration plant is required to treat 50 m^3/day of a protein containing waste stream. The waste contains 0.05% of protein, which has to be concentrated to 2%, to recycle it to the main process stream. The tubular membrane to be used are available as 30 m^2/module. Pilot plant studies show that the flux rate, $J = 0.02 \ln(30/C_f)$ m/h where, C_f = concentration of protein in kg/m^3. However, due to fouling, the flux never exceeds 0.04 m/hr. Estimate the minimum number of membrane modules required, for operation of this process as two feed and bleed stages in series. Assume operation for 20 hours each day.

12

BIOPROCESS ENGINEERING
(CHEN 3233)

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) For an enzyme catalyzed reaction A → R, at low C_A
(a) the rate is proportional to C_A (b) the rate is proportional to C_{E0}
(c) the rate is independent of C_A (d) none of the above.

(ii) For an enzymatic reaction when substrate concentration equals the Michaelis Menten constant
(a) most of the enzyme is tied up as complex
(b) half of the enzyme is in free state, the other half is combined
(c) most of the enzyme is in free form
(d) none of the above.

(iii) The X-axis intercept of a plot of $\frac{C_{AO} - C_A}{In\frac{C_{AO}}{C_A}}$ versus $\frac{C_{EO}t}{In\frac{C_{AO}}{C_A}}$ of an enzymatic reaction in a batch reactor is
(a) $-K_m$ (b) k_3/K_m (c) K_m/k_3 (d) none of the above.

(iv) A plot of $-r_A$ versus $-r_A/C_A$ is called
(a) the Eadie Hofstee plot (b) the Hanse Woolf plot
(c) the Lineweaver and Burk plot (d) none of the above.

(v) The best combination of reactors to achieve the substrate concentration at the maximum cell growth rate is
(a) MFR followed by PFR (b) PFR followed by MFR
(c) Two MFRs in series (d) Two PFRs in series.

(vi) Relation between rate of substrate depletion and cell formation is given by
(a) $-r_A = Y_{C/A}(r_c)$ (b) $-r_A = Y_{A/C}(r_c)$
(c) $-r_A = -Y_{C/A}(r_c)$ (d) none of the above.

(vii) For low C_A, the Monod equation becomes
(a) Monod equation cannot be used (b) simply autocatalytic
(c) Monod equation becomes first order (d) none of the above.

(viii) HPLC stands for
(a) High Performance Liquid Chromatography
(b) High Propensity Liquid Chromatography
(c) High Purity Liquid Chromatography
(d) High Prospect Liquid Chromatography.

(ix) The method for separation of charged molecules from a solution by application of direct electric current is called
(a) Dialysis (b) Electro dialysis (c) Ion exchange (d) Ultrafiltration.

(x) Size-exclusion chromatography is synonymous with
(a) Electrophoresis (b) Paper Chromatography
(c) Molecular Sieve Chromatography (d) None of the above.

Group - B

2. (a) Prove that the initial slope of Michaelis Menten equation is $k_1k_3C_{E0}/(k_2 + k_3)$.

(b) The rate of urea conversion as a function of urea concentration in presence of enzyme urease is given below. Find the rate equation using Hanse – woolf method.

Concentration of urea (C_{urea}), kmol/m^3	0.2	0.02	0.01	0.005	0.002
Rate of urea conversion ($-r_{urea}$), kmol/m^3-s	1.08	0.55	0.38	0.20	0.09

5 + 7 = 12

3. (a) Substrate A decomposes in the presence of enzyme E (A→R). It is desired to design a batch fermenter for producing 1500 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 20% excess of the theoretically calculated volume. The reactor is cylindrical in shape. The system follows the following rate equation.

$$-r_A = 480\ hr^{-1}C_A/(336 + C_A),\ mol/m^3.hr.$$

(b) Deduce the performance equation of a chemostat for carrying out an enzymatic reaction following Michaelis Menten equation.

7 + 5 = 12

Group - C

4. In an enzymatic reaction, substrate C_A is converted irreversibly to product B. It is suspected that the product inhibits the reaction and consequently rate of the reaction is determined at four values of C_A at a particular product concentration. Comment on nature of inhibition with mechanism and find the rate equation.
Data: Enzymatic rate data (r, gm substrate/(liter) (hr) at four levels of C_A and product concentration.

C_A, g/l	Product concentration 27 g/l	Product concentration 0 g/l
-	rate	rate
0.1	0.036	0.088
0.4	0.064	0.156
1.6	0.079	0.195
6.4	0.084	0.207

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5. (a) Distinguish between Segregated model and non segregated model. Discuss briefly the differences between structured model and unstructured model.

(b) Assume that experimental measurements for a certain organism have shown that cells can convert two-third (wt/wt) of the substrate carbon to biomass. Calculate the stoichiometric coefficients for the following biological reaction:

$$C_{16}H_{34} + a\,O_2 + b\,NH_3 \rightarrow c(C_{4.4}H_{7.3}N_{0.86}O_{1.2}) + d\,H_2O + e\,CO_2.$$

6 + 6 = 12

Group - D

6. (a) The cell growth dynamics of a specific probiotic on glucose is given by $r_C = 1.2\,C_A\,C_C/(C_A + 2)$ gm cell formed /hr. m^3 with $Y_{C/A}$ = 0.1 gm cell/gm glucose. It is desired to produce 5 kg cell/day in a batch bioreactor. Starting with 1000 gm glucose/m^3 and 0.1 gm/m^3 cells the fermentation is continued until the substrate drops to 10 gm/m^3. The plant operates day and night and the times for filling cleaning and emptying the reactor are 0.23 hours, find the volume of the bioreactor needed. C_A and C_C are the concentrations of substrate and cells in gm/m^3 respectively.

(b) A culture of *E coli* was grown on lactose in a mixed flow reactor (V = 1 lit) using various flow rates of a C_{A0} = 160 mglactose/lit. The following results were obtained.