**Birla Institute of Technology and Science, Pilani – Pilani Campus**
**Semester-II, 2021-22**
**Comprehensive Examination (Regular)**
**CHE G641: Reaction Engineering**

**Date: 6/5/2022** | **Marks: 100 (Weightage: 40%)**
**Day: Friday** | **Duration: 3 Hrs**

*Instructions:* Take suitable assumptions wherever necessary and state them clearly.

## PART-A: CLOSED BOOK (Max. Marks: 40)

**Q.1** **A.** Discuss the following:

i.) Significance of Ranz-Marshall Correlation **4**

ii.) Limitations of the Shrinking Core Model **4**

iii.) Factors that influence the heterogeneous reactor design **4**

**B.** Convert the following Shrinking Core Model equation into its dimensionless form and identify the important dimensionless numbers formed and write their significance: **8**

$$\left(\frac{C_{Ag}b}{\rho_B}\right)t = \frac{R}{3k_g}X_B + \frac{R^2}{6D_e}\left[1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)\right] + \frac{R}{k_s}\left[1 - (1 - X_B)^{1/3}\right]$$

**Q.2** Consider the reversible product-formation reaction in an enzyme-catalyzed bio-reaction: **10**

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} (ES) \underset{k_{-2}}{\overset{k_2}{\rightleftharpoons}} E + P$$

Develop a rate expression (in the form as given below) for product-formation using the quasi-steady-state approximation, and determine the unknowns A, B, C and D:

$$v = \frac{d[P]}{dt} = \frac{A[S] + B[P]}{1 + C[S] + D[P]}$$

**Q.3** Derive an expression to show that the total amount of cell in the culture increases linearly with time in a fed-batch culture **10**

## PART-B: OPEN BOOK (Max. Marks: 60)

**Q.4** Enzyme E catalyzes the decomposition of substrate A. To see whether substance B acts as inhibitor we make two kinetic runs in a batch reactor, one with B present, the other without B. From the data recorded below: **12**

a) Find a rate equation to represent the decomposition of A.
b) What is the role of B in this decomposition?
c) Suggest a mechanism for the reaction.

Run1: $C_{A0}$=600 mol/m$^3$, $C_{E0}$= 8 gm/m$^3$, no B present

| $C_A$ | 350 | 160 | 40 | 10 |
|---|---|---|---|---|
| t, hr | 1 | 2 | 3 | 4 |

Run 2: $C_{A0}$=800 mol/m$^3$, $C_{E0}$ = 8 gm/m$^3$, $C_B$=$C_{B0}$=100 mol/m$^3$

| $C_A$ | 560 | 340 | 180 | 80 | 30 |
|---|---|---|---|---|---|
| t, hr | 1 | 2 | 3 | 4 | 5 |

**Q.5** The enzyme, urease, is immobilized in Ca-alginate beads 2 mm in diameter. When the urea concentration in the bulk liquid is 0.5 mM the rate of urea hydrolysis is v=10 mmoles-l-h. Diffusivity of urea in Ca-alginate beads is $D_e = 1.5 \times 10^{-5}$ cm$^2$/sec, and the Michaelis constant for the enzyme is $K_m' = 0.2$ mM. By neglecting the liquid film resistance on the beads (i.e., $[S_o]=[S_s]$) determine the following: **12**

a) Maximum rate of hydrolysis $V_m$, Thiele modulus ($\phi$), and effectiveness factor ($\eta$).

b) What would be the $V_m$, $\phi$, and $\eta$ values for a particle size of $D_p$=4 mm?

Hint: Assume $\eta=3/\phi$ for large values of $\phi$ ($\phi > 2$).

**Q.6** Escherichia coli were cultured in a 10 L CSTR at 30ºC. Its kinetics equation follows the Monod equation, where $\mu_{max}=1.0$ h$^{-1}$ and $K_s=0.2$ g/L. Glucose's feed concentration is 10 g/L, the feed volumetric flow rate is 5 L/h, and $Y_{x/s}=0.5$. Determine the following: **12**

a) Cell concentration in the reactor
b) Cell productivity
c) Substrate concentration when the dilution rate is one-half of the maximum
d) Optimal feed rate
e) Optimal cell concentration in the reactor

**Q.7** A continuous stirred tank fermenter is operated at a series of dilution rates though at constant, sterile, feed concentration, pH, aeration rate and temperature. The following data were obtained when the limiting substrate concentration was 1.2 g/l and the working volume of the fermenter was 10 liters: **12**

| **Feed flowrate (l/h)** | 0.79 | 1.03 | 1.31 | 1.78 | 2.39 | 2.68 |
|---|---|---|---|---|---|---|
| **Exit substrate conc. (mg/l)** | 36.9 | 49.1 | 64.4 | 93.4 | 138.8 | 164.2 |
| **Dry weight cell density (mg/l)** | 487 | 490 | 489 | 482 | 466 | 465 |

Determine the following:

i) The kinetic constants $K_s$, $\mu_m$ and $k_d$ as used in the modified Monod equation:

$$\mu = \frac{\mu_m S}{K_s + S} - k_d$$

ii) The growth yield coefficient, $Y_{X/S}$

**Q.8** Consider a small industrial fermenter running in a continuous mode with a fresh feed flowrate of 62 l/h, the effluent from the fermenter contains 10 mg/l of the original substrate. The same fermenter is then connected to a settler–thickener which has the ability to concentrate the biomass in the effluent from the tank by a factor of 3, and from this, a recycle stream of concentrated biomass is set up. The flowrate of this stream is 38 l/h and the fresh feed flowrate is at the same time increased to 100 l/h. Assume that the microbial system follows Monod kinetics. Data: $\mu_m$=0.15 h$^{-1}$ and $K_s$ = 95 mg/l. **12**

Determine the following:

a) Dilution rate when there is no recycle
b) Volume of the fermenter when there is no recycle
c) Net specific growth rate with recycle of biomass
d) Substrate concentration in the recycle stream

*****Best Wishes*****