Reg. No.

MANIPAL INSTITUTE OF TECHNOLOGY

MANIPAL

(A constituent unit of MAHE, Manipal)

V SEMESTER B.TECH (BIOTECHNOLOGY)

END SEMESTER EXAMINATIONS, DECEMBER 2023 (REGULAR)

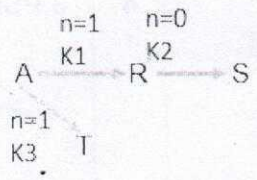
SUBJECT: BIOREACTION ENGINEERING (BIO 3104)

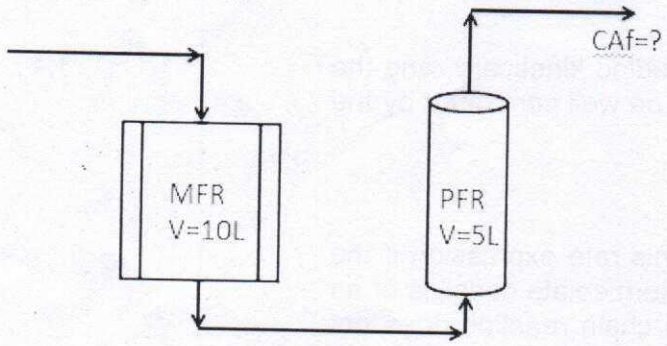
REVISED CREDIT SYSTEM

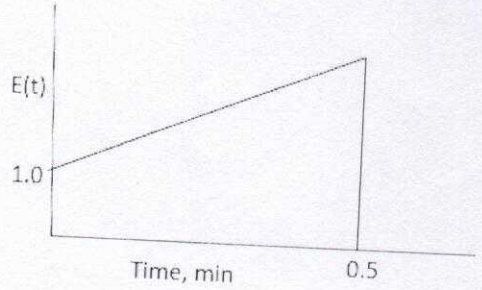
Time: 3 Hours (01/12/2023) MAX. MARKS: 50

Instructions to Candidates:

- Answer **ALL** the questions.
- Missing data may be suitable assumed.

SL No		Marks	CO	PO	BTL
1A.	Explain: Why Kinetic models are needed.	2	1	1,4	3
1B.	For the following First order followed by zero order series reaction that is taking place in a batch fermenter  Find the $C_{R,max}$ and t_{max}	4	1	1,4	3
1C.	reversible reaction 2A + B =A B has been studied kinetically, and the rate of reaction of product has been found to be well correlated by the following rate equation: $r_{A2B} = \frac{0.72CA^2CB}{1+2CA}$ What reaction mechanism is suggested by this rate expression if the chemistry of the reaction suggests that the intermediate consists of an association of reactant molecules and that a chain reaction does not occur?	4	1	1,4	3
2A.	The first order homogeneous gaseous decomposition A ->2.5 R is carried out in an isothermal batch reactor at 2 atm with 20 % inerts present, and the volume increases by 60% in 20 min. In a constant – volume reactor, find the time required for the pressure to reach 8 atm if the initial pressure is 5 atm, 2 atm of which consist of inert.	4	2	1,4	3
2B.	The following biochemical reaction is carried out in a batch fermenter	3	2	1,4	3

	with Bacillus species to produce certain product P. A + B → P. Researcher has taken 10 M of A and 10 M of B at the start to carry out the above fermentation reaction. Researcher has suspected that above reaction obeys 2nd order reaction kinetics. Substantiate the following batch reactor data to 2nd order kinetics. Time, h: 0, 4, 8, 12, 16, 20, 24 CA, M: 10, 6.67, 5.26, 3.57, 3.13, 2.38, 2.00						
2C	strate A decomposes in a batch fermenter as follows: A › Product. The position of A in the fermenter is measured at various times and shown e following table. Find the rate equation to represent the data using rential method of analysis. Time,h: 0, 20, 40, 60, 120, 180, 300 CA, M: 10, 8, 6, 5, 3, 2, 1	3	2	1,4	3
3A.	A homogeneous liquid phase reaction A → R, $-r_A = kC_A^2$ Takes place with 50% conversion in a mixed reactor i. What will be the conversion if this reactor is replaced by one 6 times as large-all else remaining unchanged? ii. What will be the conversion if the original reactor is replaced by a plug flow reactor of equal size-else remaining unchanged?	4	4	3, PS02	3
3B.	A particular biochemical product is produced using a bacillus species in a cascade reactor system of MFR + PFR as shown in the fig 1. The substrate concentration at 1 M, v_0=10 lit/min is pumped into the MFR of volume 10 liters. Then the reaction mixture is sent through the PFR of 5 liters capacity. Reaction system follows the 2nd order kinetics with K=1 liter/gmole.min. Find the conversion of the substrate at the exit of cascade reactor system. V0=10lit/min, CA0=1M 	3	4	3,PSO2	3
3C	Derive the dimensionless reaction rate group (DRRG) expression for the first order gas reaction that is taking place in PFR.	3	4	3,PS02	3
4A.	Write the design equations for recycle reactor and represent graphically. Write the condition for optimum recycle ratio (R_{opt}). Represent R_{opt} graphically the for the following autocatalytic reaction: A +R ›R + R	5	4	3,PS02	3
4B.	in the various accessories needed for the operation of batch fermenter ell cultures. Derive the expression for the batch reaction time for the	3	3	3,PS02	3

	rsion of substrate from S_0 to S_f during batch cultivation of bakers yeast.				
4C	lo you operate the chemostat at steady state? With the help of ting diagram explain the critical dilution rate and washout.	2	3	3,PS02	3
5A.	cro fluid reacts according to A → R as it flows through a non-ideal actor. Find the conversion of macro fluid A for the following flow pattern inetics. cs: C_{A0}=2 mol/liter, $-r_A=KC_A^2$, K=2 liter.mol^{-1} min^{-1}  	4	5	1,4,PSO2	3
5B.	RTD results for the non-ideal bioreactor are shown in the following table for pulse input. Find the conversion for macro fluid with kinetics (-rA)=k, k=0.5, CA0=10 M Time, min: 0, 5, 10, 15, 20, 25, 30, 35 E (t): 0, 0.03, 0.05, 0.05, 0.04, 0.02, 0.01, 0	4	5	1,4,PSO2	3
5C	Differentiate between macro and micro fluid.	2	5	1,4,PSO2	3

Scheme of Evaluation

Bioreaction Engineering

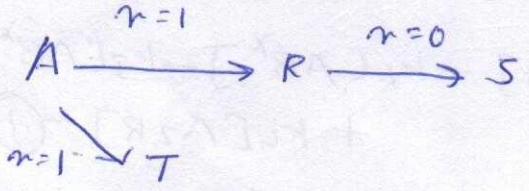
1A. Kinetic Models are needed: 2 × 1 = 02

① For Non-elementary Reactions

② To Establish the theoretical rate expression

③ For Modeling and Simulation

1B.



$$-r_A = -\frac{dC_A}{dt} = (K_1 + K_3)\, C_A \qquad \text{½}$$

$$C_A = C_{A0} \cdot e^{-(K_1+K_3)t} \qquad \text{½}$$

$$r_R = \frac{dC_R}{dt} = K_1 C_A - K_2$$

$$\frac{dC_R}{dt} + K_2 = K_1 \cdot C_{A0} \cdot e^{-(K_1+K_3)t} \qquad \text{½}$$

$$C_R = \frac{K_1 C_{A0} \cdot e^{-(K_1+K_3)t}}{-(K_1+K_3)} - K_2 t + C \qquad \text{½}$$

$$C = \frac{K_1 C_{A0}}{(K_1+K_3)} \quad \Big| \quad C_R = \frac{K_1 C_{A0}}{(K_1+K_3)} - K_2 t - \frac{K_1 C_{A0}}{(K_1+K_3)} e^{-(K_1+K_3)t}$$

$$C_R = \frac{K_1 C_{A0}}{(K_1+K_3)} \left[1 - e^{-(K_1+K_3)t}\right] - K_2 t \qquad \text{½}$$

$$\frac{dC_R}{dt} = 0 \Rightarrow K_1 C_{A0} e^{-(K_1+K_3)t_{max}} = K_2 \qquad \text{½}$$

$$\boxed{t_{max} = \frac{\ln\left(\frac{K_1 C_{A0}}{K_2}\right)}{(K_1+K_3)}} \qquad \text{½}$$

Substituted t_{max} in C_R, Get $C_{R,max}$: ½

04

(1C)

$2A + B = A_2B$.

$$A + B \rightleftharpoons AB^* \quad \Big\} (1)$$
$$AB^* + A \rightleftharpoons A_2B$$

$$A + B \xrightarrow{k_1} AB^* \quad -(2)$$
$$AB^* \xrightarrow{k_2} A + B \quad -(3)$$
$$AB^* + A \xrightarrow{k_3} A_2B \quad -(4)$$
$$A_2B \xrightarrow{k_4} AB^* + A \quad -(5)$$

½

$$r_{A_2B} = k_3[AB^*][A] - k_4[A_2B] \quad -(6)$$

½

$$r_{AB^*} = k_1[A][B] - k_2[AB^*] - k_3[AB^*] + k_4[A_2B] \quad -(7)$$

½

½

$$r_{AB^*} = 0$$

$$[AB^*] = \frac{k_1[A][B] + k_4[A_2B]}{k_2 + k_3[A]} \quad -(8)$$

½

$$r_{A_2B} = \frac{k_1k_3[A]^2[B] - k_2k_4[A_2B]}{k_2 + k_3[A]} \quad -(9)$$

½

If k_4 is small

$$r_{A_2B} = \frac{\frac{k_1k_3}{k_2}[A]^2[B]}{1 + \frac{k_3}{k_2}[A]} \quad -(10)$$

½

Matches with Experimental rate expression $r_{A_2B} = \frac{0.72\, C_A^2 C_B}{1 + 2 C_A}$.

½

04

(2A)

$A \longrightarrow 2.5R$.

Case (1) Variable Volume batch Reactor

$$-r_A = \frac{C_{A0}}{\varepsilon_A} \frac{C_{A0}}{(1+\varepsilon_A X_A)} \frac{dX_A}{dt} = \frac{kC_{A0}(1-X_A)}{(1+\varepsilon_A X_A)}$$

½

$$-\ln(1-X_A) = kt \Rightarrow C_A X_A = 0.6$$

½

Calculation of ϵ_A

Basis : 1 mole

$X_A = 0$

A : 0.8
I : 0.2
R : 0.0
1.0

$X_A = 1.0$

A = 0
R = 2.0
I = 0.2
2.2

$$\epsilon_A = \frac{2.2 - 1.0}{1.0} = 1.2$$

$$X_A = \frac{0.6}{1.2} = 0.5, \quad -\ln(1 - 0.5) = K \times 20$$

$$K = 0.035 \text{ min}^{-1}$$

Case (ii) Constant volume batch reaction

$$-\frac{dC_A}{dt} = KC_A \Rightarrow -\ln\frac{C_A}{C_{A0}} = Kt$$

$$-\ln\frac{p_A}{p_{A0}} = Kt$$

$p_{A0} = 5 - 2 = 3$ atm

$p_A = p_{A0} - \frac{a}{\Delta n}(\pi - \pi_0)$

$p_A = 3 - \frac{1}{1.5}(8 - 5)$

$p_A = 1$ atm

$$-\ln\frac{1}{3} = 0.035 \times t$$

$$\boxed{t = 31.4 \text{ min}}$$

(2B) $C_{A0} = C_{B0} = 10\text{M} \Rightarrow \frac{C_{B0}}{C_{A0}} = 1.0 \Rightarrow \boxed{C_A = C_B}$

$$-r_A = -\frac{dC_A}{dt} = KC_A \cdot C_B = KC_A^2$$

$$\boxed{\frac{1}{C_A} - \frac{1}{C_{A0}} = Kt}$$

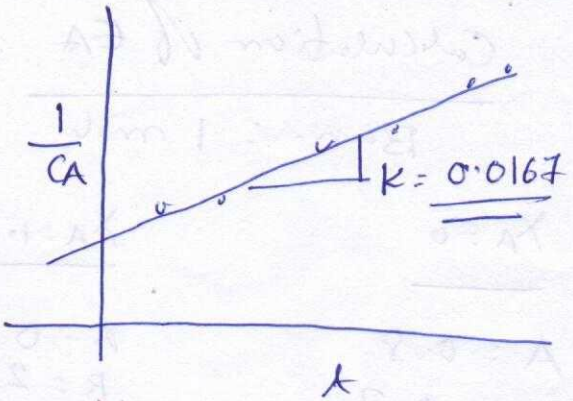
t	0	4	8	12	16	20	24
C_A	10	6.67	5.26	3.57	3.13	2.38	2.0
$\frac{1}{C_A}$	0.1	0.15	0.19	0.28	0.32	0.42	0.5

Data fit in a straight line with slope = 0.0167

Hence kinetics follows

Obeys 2nd order kinetics

$$\boxed{k = 0.0167}$$



03

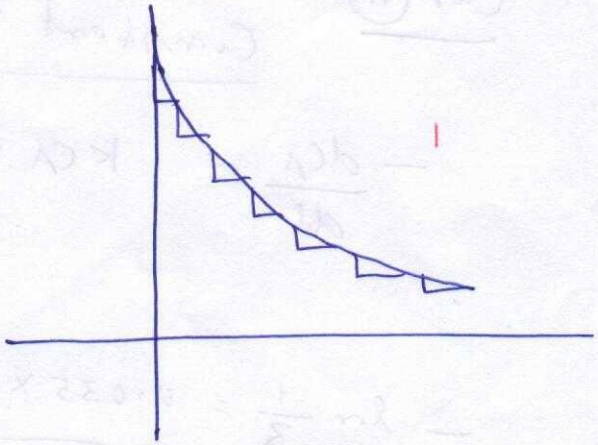
(2c)

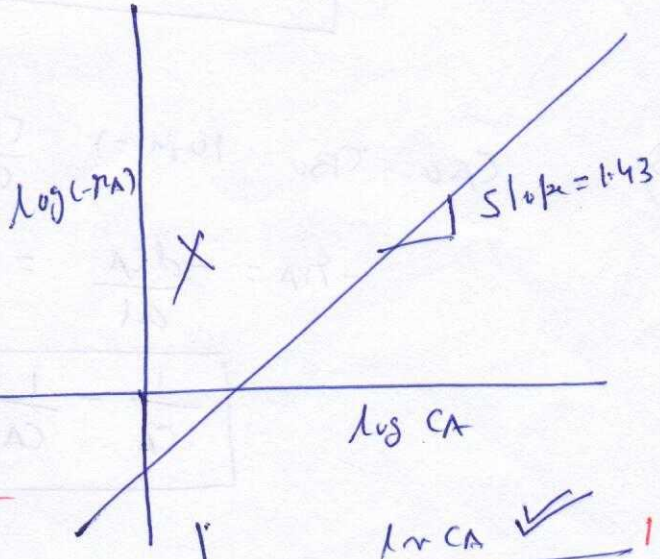
Assume nth order reaction

$$-r_A = -\frac{dC_A}{dt} = k C_A^n \quad -(1)$$

$$\ln(-r_A) = \ln k + n \ln C_A \quad -(2)$$

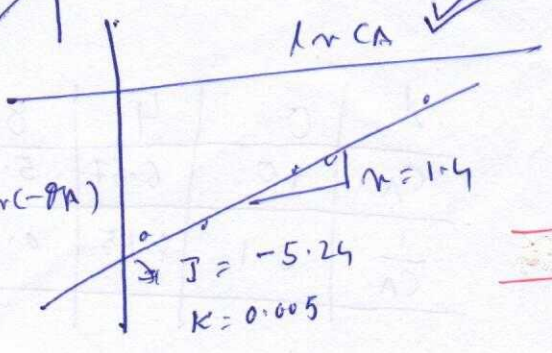
t	C_A	$-r_A = -\frac{dC_A}{dt}$
0	10	0.1333
20	8	0.1031
40	6	0.0658
60	5	0.0410
120	3	0.0238
180	2	0.0108
300	1	0.0065





Rate eqn

$$-r_A = -\frac{dC_A}{dt} = 0.005 C_A^{1.43}$$



03

(3A) $A \longrightarrow R$, $-r_A = k C_A^2$

- Take place in MFR.
- Liquid reaction

$$\tau = \frac{C_{A0} - C_A}{-r_A} \quad \text{½}$$

$$k\tau = \frac{C_{A0} X_A}{C_{A0}^2 (1-X_A)^2} \Rightarrow k\tau C_{A0} = \frac{X_A}{(1-X_A)^2} = 2 \quad 1$$

Now 4 times the original MFR.

$$\therefore \quad 4 k\tau C_{A0} = \frac{X_A}{(1-X_A)^2} \Rightarrow 4 \times 2 = 8 = \frac{X_A}{(1-X_A)^2} \quad 1$$

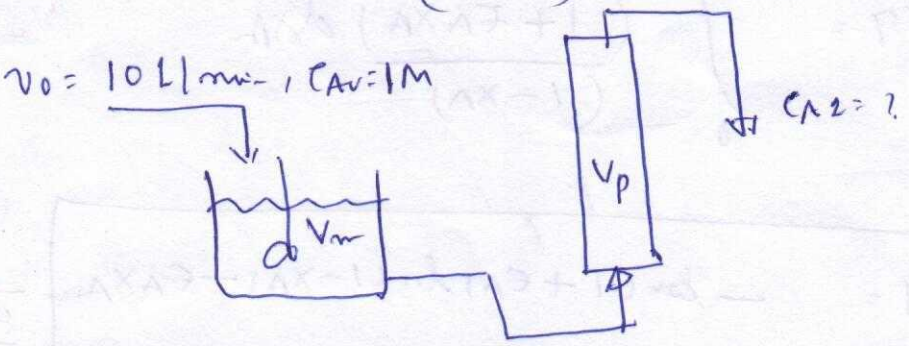
$$X_A^2 - 2.125 X_A + 1 = 0 \Rightarrow X_A = 0.7 \quad \text{½}$$

original reactor is replaced with PFR

$$k\tau C_{A0} = \int_0^{X_A} \frac{dX_A}{(1-X_A)^2} \quad \text{½}$$

$$2 = \frac{X_A}{(1-X_A)} \Rightarrow X_A = \frac{2}{3} = 0.667 \quad \text{½} \quad 04$$

(3B)



- Liquid reaction
- 2nd order kinetics
- MFR + PFR.

$$\tau = \frac{C_{A0} X_A}{k C_{A1}^2 (1-X_A)^2} \quad \text{½} \quad \text{½}$$

$$X_A^2 - 3X_A + 1 = 0$$

$$X_A = 0.381 \quad \text{½}$$

$$C_{A1} = 0.619$$

For PFR

$$\tau = -\int_{C_{A1}}^{C_{A2}} \frac{dC_A}{k C_A^2} \quad -\tfrac{1}{2}$$

$$k\tau = \frac{1}{C_{A2}} - \frac{1}{C_{A1}} \quad \tfrac{1}{2}$$

$$C_{A2} = 0.472 \quad \tfrac{1}{2}$$

$$\boxed{X_{A2} = 0.527} \quad \underline{0.3}$$

(3c)

$$k\tau = \int_0^{X_A} \frac{dX_A}{-r_A}$$

$$\tau = C_{A0} \int_0^{X_A} \frac{dX_A}{-r_A} \quad \tfrac{1}{2}$$

$$\tau = C_{A0} \int_0^{X_A} \frac{dX_A}{k C_{A0}(1-X_A)/(1+\varepsilon_A X_A)} \quad 1$$

$$k\tau = \int_0^{X_A} \frac{(1+\varepsilon_A X_A)\, dX_A}{(1-X_A)} \quad \tfrac{1}{2}$$

$$\boxed{k\tau = -[(1+\varepsilon_A)\ln(1-X_A) - \varepsilon_A X_A]} \quad \tfrac{1}{2}\ \underline{0.3}$$

(4A) Design eqn for Recycle Reactor

For Chemical Tank

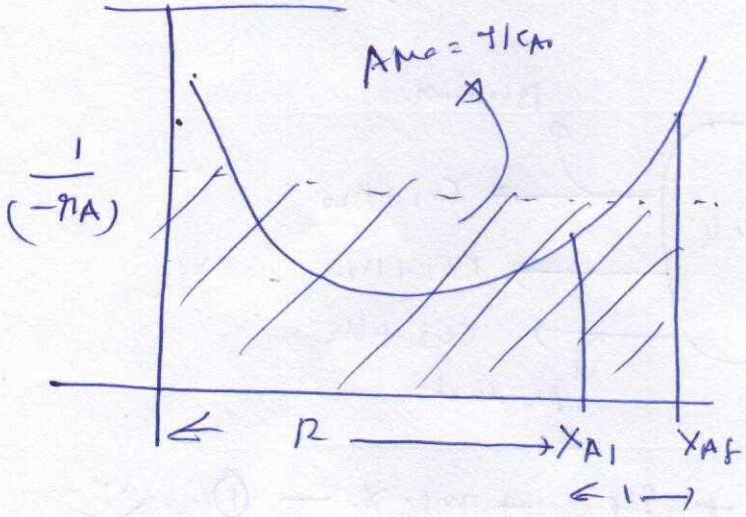
$$\frac{\tau}{C_{A0}} = (1+R)\cdot \int_{\frac{R}{R+1}X_{Af}}^{X_{Af}} \frac{dX_A}{(-r_A)} \quad \tfrac{1}{2}$$

For Constant Volume

$$\tau = -(1+R)\int_{\frac{C_{A0}+RC_{Af}}{1+R}}^{C_{Af}} \frac{dC_A}{(-r_A)}$$

½

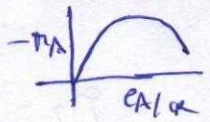
Graphical Method



For Autocatalytic Rxn:

$A + R \rightarrow R + R$

$-r_A = k C_A C_R$



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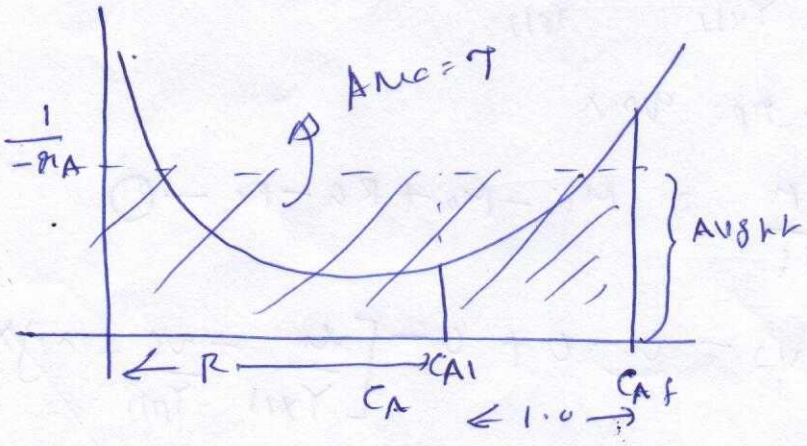
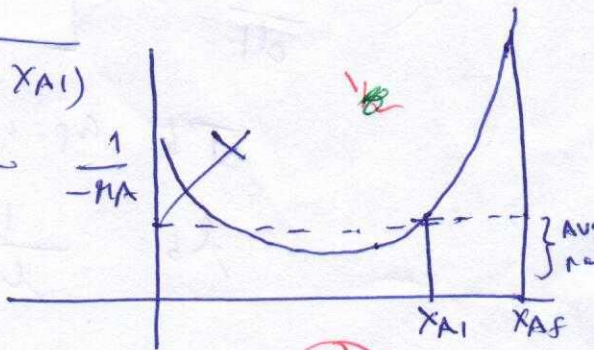


Condition for optimum Recycle Ratio

$$\frac{1}{(-r_A)}\bigg|_{X_{A1}} = \frac{\int_{X_{A1}}^{X_{Af}} \frac{dX_A}{(-r_A)}}{(X_{Af} - X_{A1})}$$

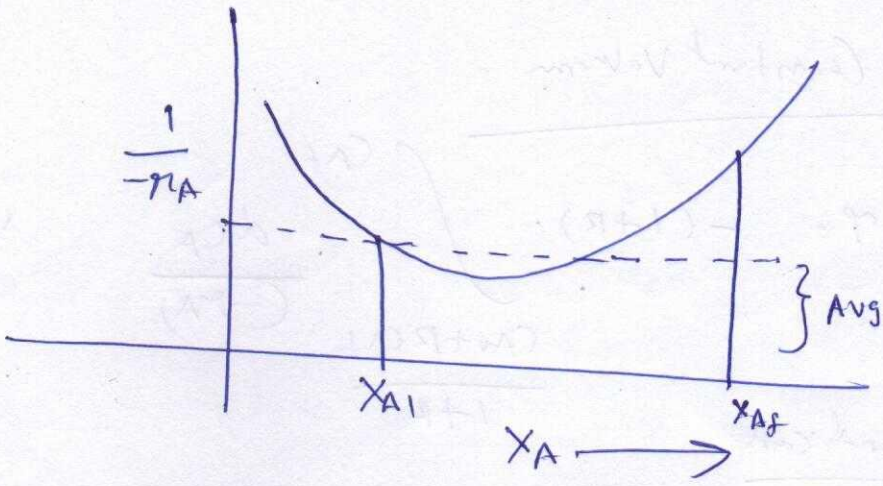
½

Initial rate = Avg. rate



½

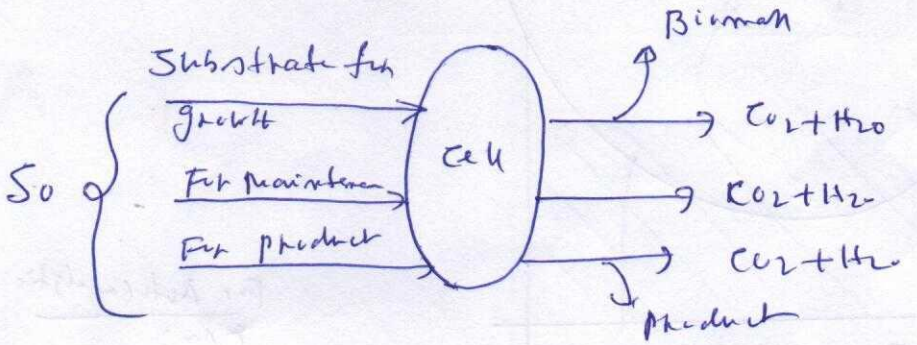
04



1

05

(4B)



½

$$-r_S = \frac{r_x}{Y_{XS}} + \frac{r_p}{Y_{PS}} + m_s \cdot X \quad \text{— ①}$$ ½

$r_x = \mu X$, $r_p = q_p \cdot X$

$$\frac{dM}{dt} = M_i - M_o + R_a - R_c \quad \text{— ②}$$

$$\frac{d}{dt}(S \cdot V) = 0 - 0 + 0 - \left[\frac{\mu}{Y_{XS}} + \frac{q_p}{Y_{PS}} + m_s\right] X V \quad \text{— ③}$$ ½

$$\frac{dS}{dt} = -\left[\frac{\mu_m}{Y_{XS}} + \frac{q_p}{Y_{PS}} + m_s\right] X \quad \text{— ④}$$ ½

$$\frac{dS}{dt} = -\left[\frac{\mu_m}{Y_{XS}} + \frac{q_p}{Y_{PS}} + m_s\right] X_0 e^{\mu_m \cdot t}$$ ½

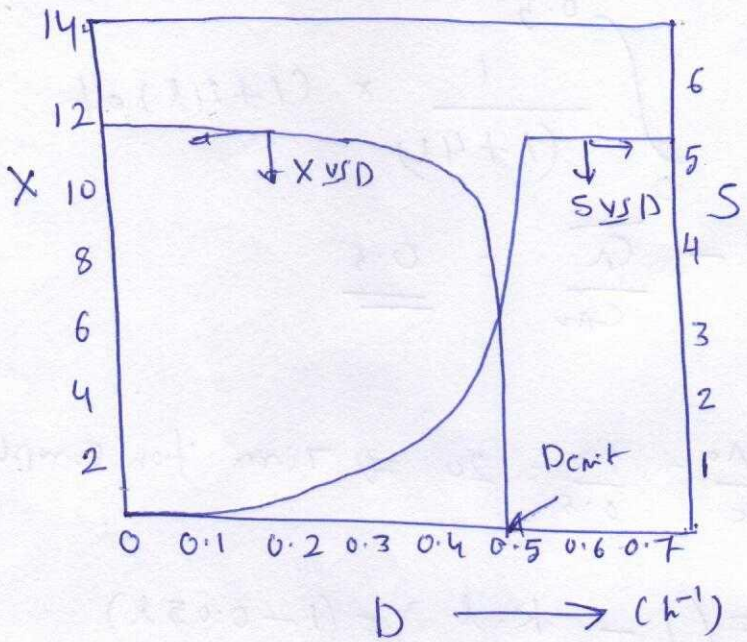
If $q_p = 0$, $m_s = 0$

$$t_b = \frac{1}{\mu_m} \ln\left[1 + \frac{Y_{XS}(S_0 - S_f)}{X_0}\right]$$ ½

03

(4C)

$\boxed{\mu = D}$ ⇒ Condition for steady state operation of A. Chemostat. ½



1

Dcrit : critical dilution rate when biomass Concentration becomes Zero in Chemostat

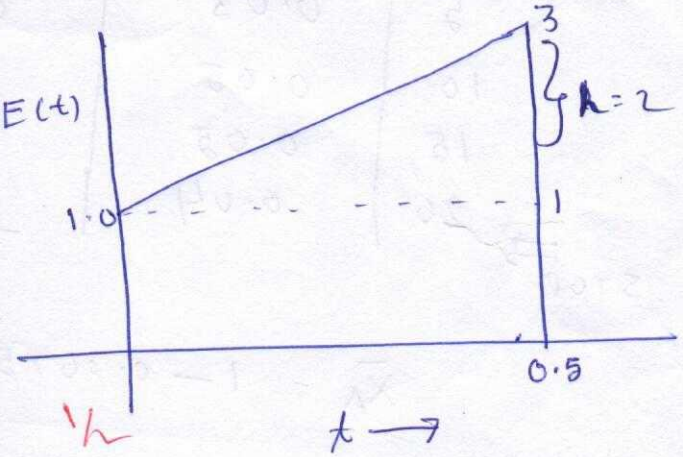
At $D = D_{crit}$
$X = 0$
$S = S_0$
} Insert out ½

02

(5A)

$C_{A0} = 2M, -r_A = kC_A^2$

$\int_0^{0.5} E(t)\,dt = 1.0$ ½



½

Area of Rectangle + Area of Triangle = 1.0

0.5 + Area of Triangle = 1.0 ⟹ A = 2 ½

½

$E(t) = 4t + 1.0$

$\frac{\overline{C_A}}{C_{A0}} = \int_0^{0.5} \left(\frac{C_A}{C_{A0}}\right)_{batch} \cdot E(t)\,dt$ ½

$-r_A = kC_A^2$

$$\left(\frac{C_A}{C_{A0}}\right)_{batch} = \frac{1}{1+kC_{A0}t} = \frac{1}{1+4t}$$ ½

$$\left(\overline{\frac{C_A}{C_{A0}}}\right) = \int_0^{0.5} \frac{1}{(1+4t)} \times (1+4t)\,dt$$ 1

$$\overline{X_A} = 1 - \overline{\frac{C_A}{C_{A0}}} = 0.5$$ ½ / 04

5B

$$t = \frac{C_{A0}}{k} = \frac{10}{0.5} = 20 \Rightarrow \text{Time for completion}$$ ½

$$\left(\frac{C_A}{C_{A0}}\right)_{\substack{batch \\ (n=0)}} = \left(1 - \frac{k.t}{C_{A0}}\right) = (1-0.05t)$$ ½

½

$$\overline{X_A} = 1 - \sum (1-0.05t)\,E(t)\,\Delta t$$

t	$E(t)$	$(1-0.05t)\,E(t)$
0	0	0
5	0.03	0.0225
10	0.05	0.025
15	0.05	0.0125
20	0.04	0
		0.06

STOP ⇒

2

1.12.2023 COE VP (Murthy)

$$\overline{X_A} = 1 - 0.06 \times 5 = 0.7$$ ½ / 04

5C

MICRO FLUID:- Well-mixed, No differentiation bet. younger and older molecule

(1)

MACRO FLUID:- ~~There~~ 10^{12}–10^{16} individual molecule grouped together to form aggregate, ~~The~~ Each aggregate act as a batch reaction, There is a differentiation bet. younger and older molecule. (1) / 02

Mech. fluid