Standard Correction of the Exam of the 2nd Semester

Bioreactors and Non-Ideal Reactors

Activity 01

Part 1: Determination of C(t) and E(t): 4,5 pts

01/ Definition of a tracer: A tracer is a chemical or radioactive substance that should be added to a reactor in order to determine the residence time distribution and to evaluate the behavior of the fluid inside the reactor. ***0,5pt***

We use it in order to: determine the RTD and to check the behavior of fluid inside the reactor. ***0,5pt***

02/ Figures C(t) and E(t) — Determination of the values of E(t):

The exit-age distribution function is defined as:

$$E(t) = C\_pulse / A = C\_pulse / \int C(t)\,dt$$

Calculation of the area A = ∫C(t) dt:

$\int C(t)\,dt = \int_0^{10} C(t)\,dt + \int_{10}^{14} C(t)\,dt$

$\Rightarrow \int_0^{10} C(t)\,dt = (\Delta t/3) \times (x_0 + 4x_1 + 2x_2 + ...)$ [Simpson's rule]

$\int_0^{10} C(t)\,dt = 47.43$ g·min/m³ … ① ***0,5 pt***

$\Rightarrow \int_{10}^{14} C(t)\,dt = (\Delta t/3) \times [1(1.5) + 4(0.6) + 1(0)]$

$\int_{10}^{14} C(t)\,dt = 2.6$ g·min/m³ … ② ***0,5 pt***

① + ② = 47.43 + 2.6 = 50.03 g·min/m³ ***0,5 pt***

A = 50.03 g·min/m³

Table of E(t) values:

t (min)	0	1	2	3	4	5	6	7	8	9	10	12	14
E(t) (min^{-1})	0	0.02	0.1	0.16	0.2	0.16	0.12	0.08	0.06	0.04	0.03	0.012	0

Curve 1: C(t) ***01pt***

Curve 2: E(t) ***01pt***

Part 02: Adiabatic Reactor: 5,5pts

01/ Definition: An adiabatic reactor is a special case of non-isothermal reactor where no heat is transferred with the surroundings. ***0,5pt***

02/ Calculation of the feed of n-C_4H_{10} at the inlet of the reactor:

At the inlet: 90% of n-butane (A) and 10% of i-butane (B)

So: $F_{A0} = 163 \times 0.9$ ***0,5pt***

F_{A0} = 146.7 kmol/h ***0,5pt***

03/ The reactor temperature:

$$T = T_0 + (-\Delta H\_R) \times X / \Sigma\Theta_i C_{p\ i}$$

Calculation of heat capacity:

$\Sigma\Theta_i C_{p\,i} = 0.9 \times (141) + 0.1 \times (161)$ ***0,5pt***

$\Sigma\Theta_i C_{p\,i}$ **= 143 J/mol·K** **0,5pt**

Finally: T = 330 + (−(−6900)) × 0.70 / 143 ***0,5pt***

$T_{reactor}$ **= 364 K** ***0,5pt***

04/ Required volume of CSTR to achieve 70% conversion:

We know that: $V = F\_A_0 \times X / (-r\_A)$ … ①

And: $-r\_A = 31.1 \times (1 - X/X_e)$ … ②

And: $X_e = K\_c / (1 + K\_c)$

Temperature conversion: 0°C → 273 K ; 60°C → 333 K

So: $X_e = 3.03 / (1 + 3.03) = 0.75$ ***0,5pt***

So: Kc = 3.03 at 60°C = 3.03 at 333 K

$\Rightarrow -r_A = 31.1 \times (1 - 0.70/0.75) = 2.07$ kmol/m³·h ***0,5pt***

$V_{CSTR} = F\_A_0 \times X\_A / (-r_A) = 146.7 \times 0.70 / 2.07$

$V_{CSTR} \approx$ **49.6 m³** ***1pt***

Activity 02

Part 1: Bioreactors *5pt*

01/ Three types of bioreactors: ***0,5x3pt***

- Airlift Bioreactor
- Bubble Column Bioreactor
- Continuous Stirred Tank Bioreactor (CSTB)
- Fluidized Bed Bioreactor
- Packed Bed Bioreactor
- Photo Bioreactor

02/ General principle of working of bioreactors: ***1pt***

In bioreactors, the idea is simple: create the best environment for cells to grow. So, first we add nutrients (glucose, sucrose), then set the right conditions (pH, temperature), then add microorganisms (bacteria, yeast...), finally, make the reactor work (the agitator will mix everything).

03/ Enzyme fermentation can be divided into:

a) Fermentation in presence of Enzyme: ***0,5pt***

$$A \rightarrow (Enzyme\ E) \rightarrow R$$ ***0,5pt***

b) Fermentation in presence of microbes: ***0,5pt***

$$A \rightarrow(microbes)\rightarrow R + more\ microbes$$ ***0,5pt***

04/ Main difference between the 2 types of fermentation: ***0,5pt***

The enzyme acts as a catalytic agent and it does not reproduce itself, while in microbial fermentation, the microbe reproduces itself many times.

Part 2: Enzymatic Fermentation *1pt*

01/ Michaelis–Menten theory:

The theory proposed by Michaelis–Menten is that the reaction of fermentation comes up in 2 steps ⇒ creation of an intermediate substance (EA): ***0,5pt***

$$A + E \rightleftharpoons(1/2)\ X(EA)\ \rightarrow(3)\ R$$ ***0,5pt***

Part 3: Derivation of the Michaelis–Menten Theory *2pt*

In M–M theory, the rate of formation of EA is equal to the rate of disappearance of EA:

$$k_1 \cdot [E] \cdot [A] = k_2 \cdot [EA] + k_3 \cdot [EA] \quad ... ①$$ ***0,5pt***

$$C\_tot,E = C\_EA + C_0 \quad ... ②$$ ***0,5pt***

① becomes: $k_1 [E][A] = (k_2 + k_3)[EA]$

$$[EA] = k_1[E][A] / (k_2 + k_3) \quad ... ⑤$$

② becomes: $[E_T] = [EA] + [E] \Rightarrow [E] = [E_T] - [EA] \quad ... ⑥$

Replacing ⑤ in ⑥:

$$[EA] = k_1([E_0] - [EA])[A] / (k_2 + k_3)$$

After simplification:

$$[EA] = k_1[E_0][A] / (k_2 + k_3 + k_1[A])$$

0,5 pt

Rate equation: $r\_R = k_3 [EA] \Rightarrow [EA] = r\_R / k_3$

We define the Michaelis constant: $K_M = (k_2 + k_3) / k_1$

So: $k_2 + k_3 + k_1 [A] = k_1 (K_M + [A])$

Replacing in the rate equation:

$$r_R = [EA] \cdot k_3 = k_3 k_1 [E_0][A] / (k_1 (K_M + [A]))$$

$r_R = [EA] \cdot k_3 = k_3 [E_0][A] / (K_M + [A])$ ***0,5pt***

Part 4: Numeric Application *2pt*

01/ Calculate the rate of the reaction:

Given: $k_3 = 100\ s^{-1}$, $K_M = 0.05$ mol/L, $[E_0] = 0.001$ mol/L

$$r_R = (100 \times 0.001 \times [A]) / (0.05 + [A]) = 0.1[A] / (0.05 + [A])$$ ***0,5pt***

Table of r_R values:

[A] (mol/L)	0.001	0.005	0.01	0.02	0.05	0.10	0.20	0.50	1.00	2.00
r_R (mol/L·s)	0.00196	0.00909	0.01667	0.02857	0.050	0.0667	0.080	0.0909	0.095	0.0976

Curve : r_R([A]) ***1pt***

03/ Interpretation:

• **At low [A]** (e.g. [A] = 0.001 mol/L → r = 0.00196 mol/L·s): the rate of the reaction is very slow. ***0,25pt***

• **At high [A]** (e.g. [A] = 2.00 mol/L → r = 0.0976 mol/L·s): the rate of the reaction is very high (approaching Vmax). ***0,25pt***