



SECTION II: KINETICS AND BIOREACTOR DESIGN:

LESSON 10.1. - Bioreactor design – Design Equations



JAVIER CALZADA FUNES

Biotechnology Department, Biosciences School

UNIVERSIDAD FRANCISCO DE VITORIA

AIMS FOR TODAY'S LESSON

10.1 Design equations

10.2 Exercises

10.3 Tank vs Tubular reactor: Comparing efficiency

10.4 Recycle, By-pass and Purge

10.5 Bioreactor association

REFERENCES:

- Asenjo, J.A. y Merchuck, J.C. (1994), *Bioreactor System Design*. Marcel Dekker. 1-12.
- Atkinson, B. (2002), *Reactores Bioquímicos*, Reverté (Barcelona).
- Bailey, J.E., Ollis D.F. (1986), *Biochemical Engineering Fundamentals*, McGraw-Hill (Nueva York).
- Doran, P.M. (2013), *Bioprocess Engineering Principles*, Academic Press (Londres).

A photograph of an industrial facility featuring several large, cylindrical, light-colored storage tanks. A metal staircase is visible on the right side of the tanks. In the background, there are other industrial buildings and a clear blue sky with some clouds.

1.- IDEAL BATCH REACTOR

2.- IDEAL CONTINUOUS TANK REACTOR

3.- TUBULAR REACTOR

A photograph of an industrial facility featuring several large, vertical, cylindrical storage tanks. The tanks are light-colored with horizontal rivet lines. A metal staircase is visible on the right side of the tanks. In the background, there is a yellow industrial building and a blue sky with white clouds. A dark blue banner with white text is overlaid on the image.

1.- IDEAL BATCH REACTOR

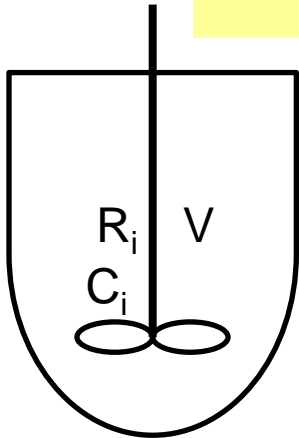
BIOREACTOR DESIGN



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1. IDEAL BATCH REACTOR

- No entrance nor exit.
- Complete Mix is supposed → constant composition everywhere within the reactor.



$$\text{Inputs} - \text{Outputs} + \text{Generation} = \text{Accumulation}$$



0



0



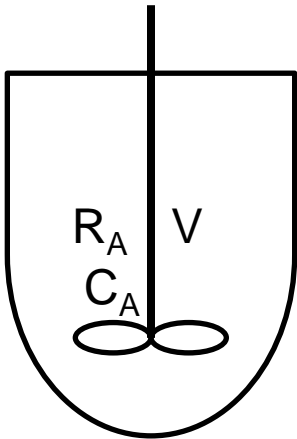
+ Generation = Accumulation



$$\text{Generation} = \text{Accumulation}$$

1. IDEAL BATCH REACTOR

For "A" reagent:



Generation = Accumulation

$$(R_A) \cdot V = \frac{dN_A}{dt}$$

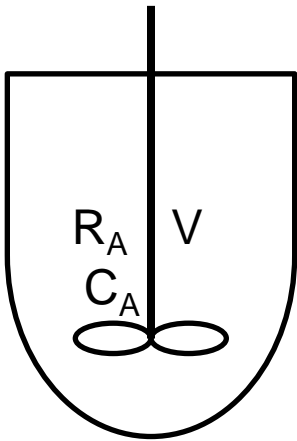
Moles of "A"
disappearing in
a certain time

=

Accumulated
amount of "A"

1. IDEAL BATCH REACTOR

For "A" reagent:



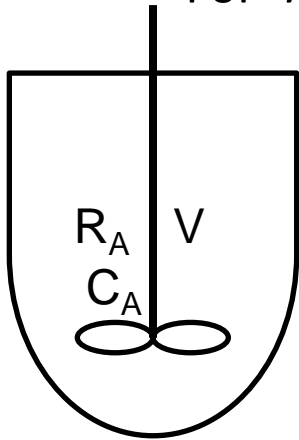
$$(R_A) \cdot V = \frac{dN_A}{dt}$$

$$dt = \frac{dN_A}{(R_A) \cdot V} \Rightarrow dt = \frac{dC_A}{(R_A)}$$

$$\int_0^t dt = \int_{C_{A0}}^{C_A} \frac{dC_A}{(R_A)} \Rightarrow t = \int_{C_{A0}}^{C_A} \frac{dC_A}{(R_A)}$$

1. IDEAL BATCH REACTOR

For "A" reagent



"A" conversion $X_A = \frac{N_{A0} - N_A}{N_{A0}}$

$$X_A = \frac{N_{A0} - N_A}{N_{A0}} \Rightarrow N_A = N_{A0}(1 - X_A)$$

$$\frac{dN_A}{dt} = -N_{A0} \frac{dX_A}{dt}; \quad (R_A) \cdot V = -N_{A0} \frac{dX_A}{dt}$$

$$dt = -N_{A0} \frac{dX_A}{(R_A) \cdot V} \Rightarrow dt = -C_{A0} \frac{dX_A}{(R_A)}$$

$$\int_0^t dt = \int_0^{X_A} -C_{A0} \frac{dX_A}{(R_A)} \Rightarrow t = -C_{A0} \int_0^{X_A} \frac{dX_A}{(R_A)}$$

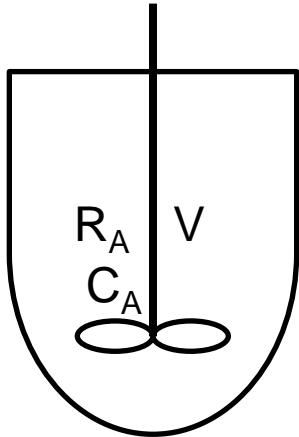


1. IDEAL BATCH REACTOR

DESIGN EQUATION

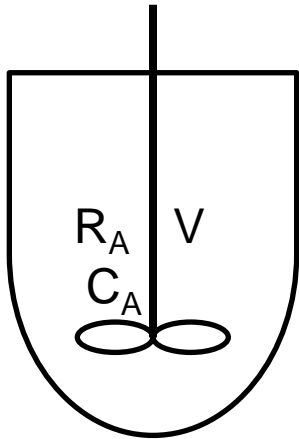
Generation = Accumulation

$$(R_A) \cdot V = \frac{dN_A}{dt}$$



$$t = -C_{A0} \int_0^{X_A} \frac{dX_A}{(R_A)} = \int_{C_{A0}}^{C_A} \frac{dC_A}{(R_A)}$$

1. IDEAL BATCH REACTOR



DESIGN EQUATION – **EASIEST CASE**

FIRST ORDER reaction



$$r = k \cdot [A]$$

$$R_A = -r$$

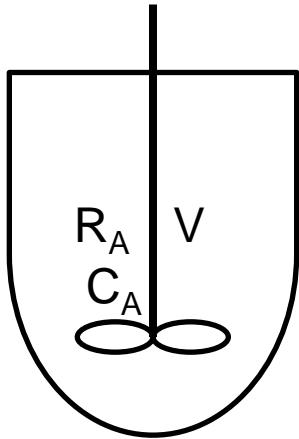
$$R_A = -k \cdot [A]$$

$$R_A = -k \cdot [A]_0 \cdot (1 - X_A)$$

1. IDEAL BATCH REACTOR

DESIGN EQUATION – **EASIEST CASE**

FIRST ORDER reaction



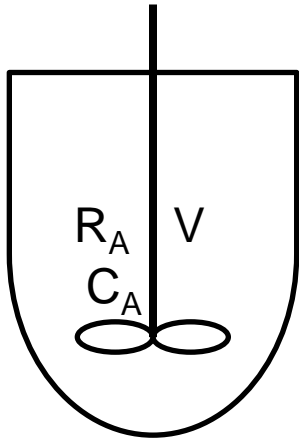
$$R_A = -k \cdot C_A$$

$$t = \int_{C_{A0}}^{C_A} \frac{dC_A}{(-k \cdot C_A)} = \frac{1}{k} \cdot \int_{C_{A0}}^{C_A} \frac{dC_A}{(-C_A)}$$

$$t = \frac{1}{k} \cdot \ln \left(\frac{C_{A0}}{C_A} \right)$$

1. IDEAL BATCH REACTOR

DESIGN EQUATION – **EASIEST CASE**



FIRST ORDER reaction

$$R_A = -k \cdot C_{A0} \cdot (1 - X_A)$$

$$t = -C_{A0} \int_0^{X_A} \frac{dX_A}{(-k \cdot C_{A0} \cdot (1 - X_A))} = \int_0^{X_A} \frac{dX_A}{(k \cdot (1 - X_A))}$$

$$t = \frac{1}{k} \cdot \int_0^{X_A} \frac{dX_A}{1 - X_A} = \frac{1}{k} \cdot \ln \left(\frac{1}{1 - X_A} \right)$$



A photograph of an industrial facility featuring several large, cylindrical metal storage tanks. The tanks are light-colored and show signs of wear. A metal staircase is visible on the right side of the tanks. In the background, there are other industrial buildings and a clear blue sky with some clouds.

1.- IDEAL BATCH REACTOR

2.- IDEAL CONTINUOUS TANK REACTOR

3.- TUBULAR REACTOR

A photograph of an industrial facility featuring several large, vertical, cylindrical storage tanks. The tanks are light-colored with visible horizontal weld lines. To the right of the tanks, there is a complex network of pipes and a metal ladder. In the background, a yellow industrial building and a blue sky with white clouds are visible.

2.- IDEAL CONTINUOUS TANK REACTOR

BIOREACTOR DESIGN

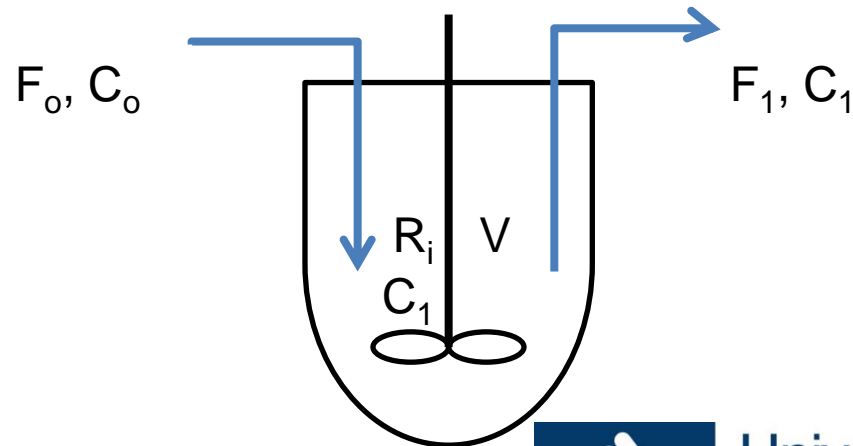


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2. IDEAL CONTINUOUS REACTOR

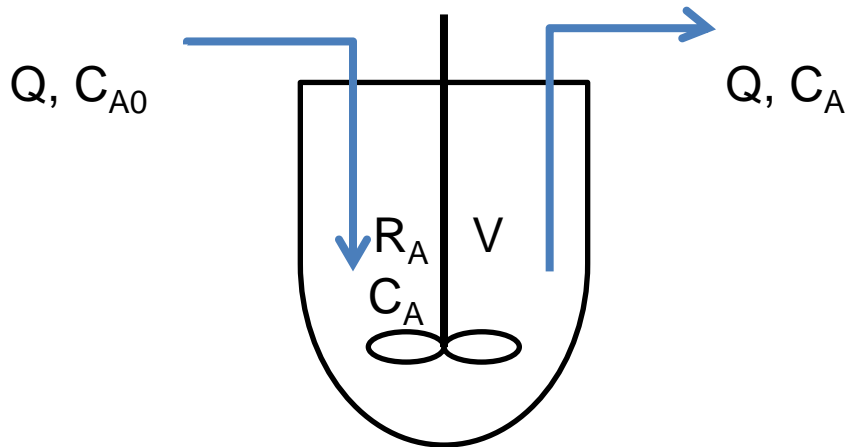
- Uniform entrance and exit $\rightarrow F_0 = F_1$
- Complete Mix is supposed \rightarrow constant composition everywhere within the reactor.
- Steady State, constant volume \rightarrow no accumulation

Inputs - Outputs + Generation = Accumulation



2. IDEAL CONTINUOUS REACTOR

For "A" reagent

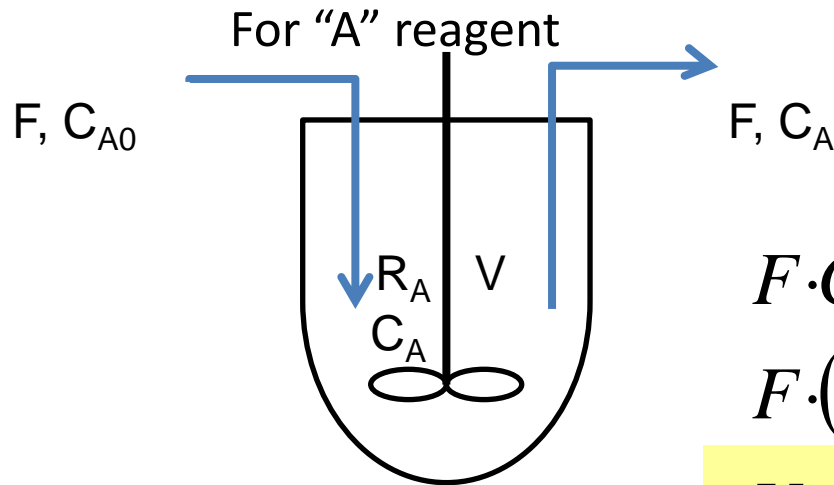


Accumulation = 0

Inputs - Outputs + Generation = 0

$$F \cdot C_{A0} - F \cdot C_A + (R_A) \cdot V = 0$$

2. IDEAL CONTINUOUS REACTOR



$$F \cdot C_{A0} - F \cdot C_A + (R_A) \cdot V = 0$$

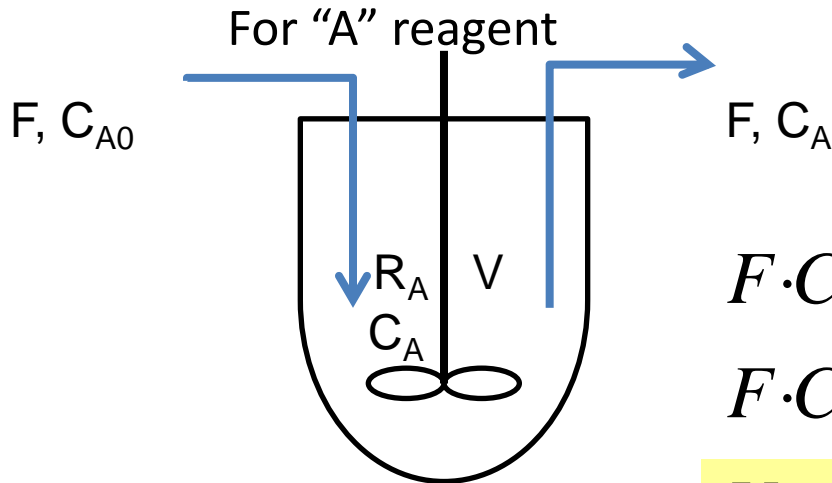
$$F \cdot (C_{A0} - C_A) = - (R_A) \cdot V$$

$$\frac{V}{F} = \frac{C_{A0} - C_A}{- (R_A)}$$

DESIGN EQUATION

Residence time = V/F

2. IDEAL CONTINUOUS REACTOR



$$F \cdot C_{A0} - F \cdot C_{A0} \cdot (1 - X_A) + (R_A) \cdot V = 0$$

$$F \cdot C_{A0} (X_A) = - (R_A) \cdot V$$

$$\frac{V}{F} = \frac{C_{A0} (X_A)}{- (R_A)}$$

DESIGN EQUATION

Residence time = V/F



A photograph of an industrial facility featuring several large, cylindrical, light-colored storage tanks. A metal staircase is visible on the right side of the tanks. In the background, there are other industrial buildings and a clear blue sky with some clouds.

1.- IDEAL BATCH REACTOR

2.- IDEAL CONTINUOUS TANK REACTOR

3.- TUBULAR REACTOR

A photograph of an industrial facility featuring several large, vertical, cylindrical tanks. The tanks are light-colored with horizontal rivet lines. A metal staircase is visible on the right side of the tanks. In the background, there are other industrial buildings and a clear blue sky with scattered white clouds.

3.- TUBULAR REACTOR

BIOREACTOR DESIGN

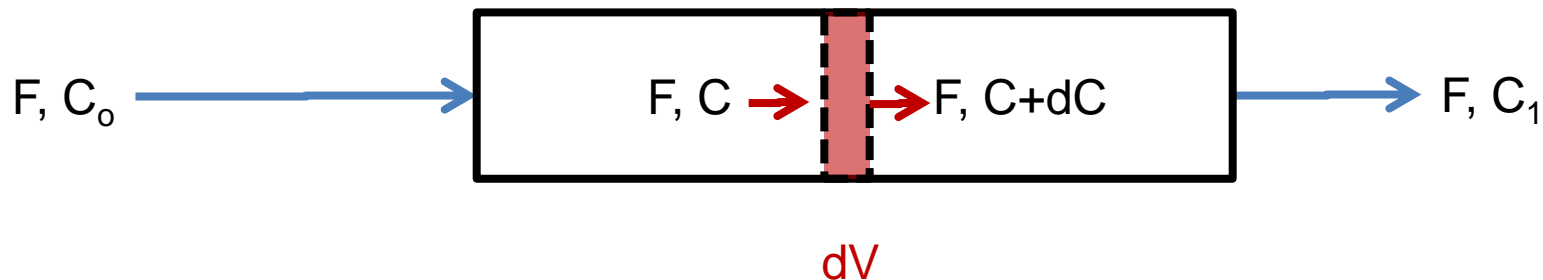


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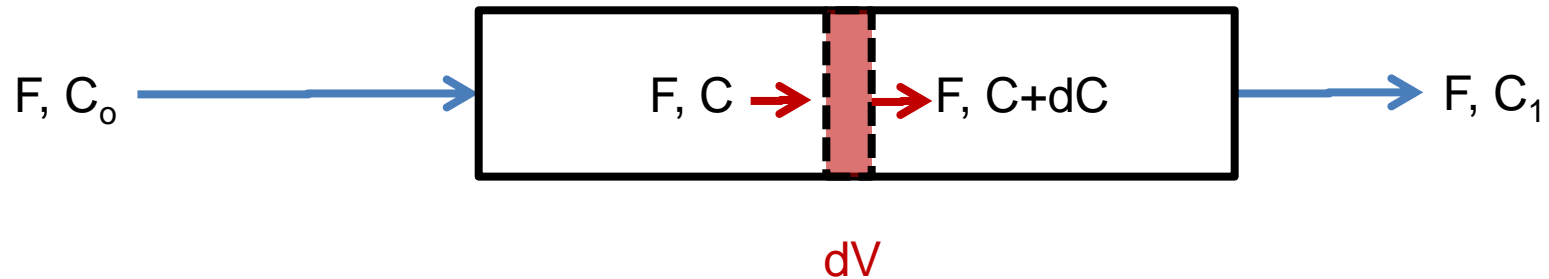
3. TUBULAR REACTOR

- Uniform entrance and exit $\rightarrow F_0 = F_1$
- Plug Flow is supposed \rightarrow no element of fluid is mixed with another one entering before or after it.
- Steady State, constant volume \rightarrow no accumulation

Inputs - Outputs + Generation = Accumulation



3. TUBULAR REACTOR



$$\text{Inputs} - \text{Outputs} + \text{Generation} = 0$$

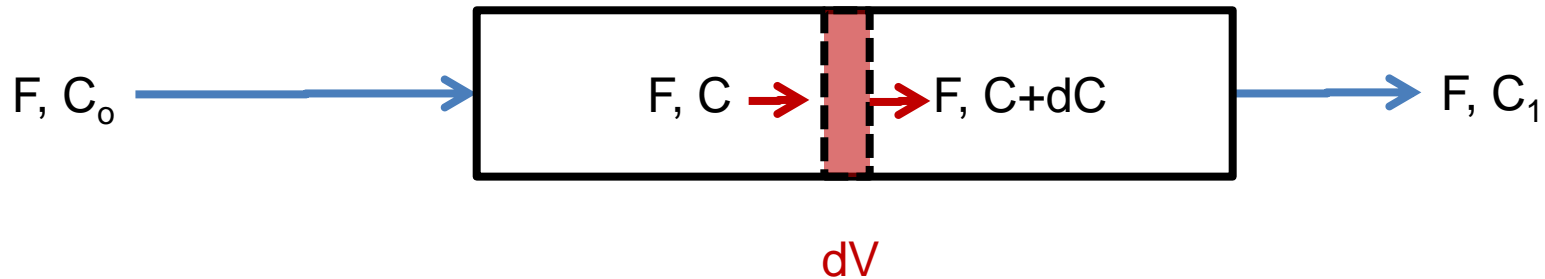
$$F \cdot C_A - F \cdot (C_A + dC_A) + (R_A) \cdot dV = 0$$

$$-F \cdot dC_A + (R_A) \cdot dV = 0$$

$$-F \cdot dC_A = -(R_A) \cdot dV$$



3. TUBULAR REACTOR

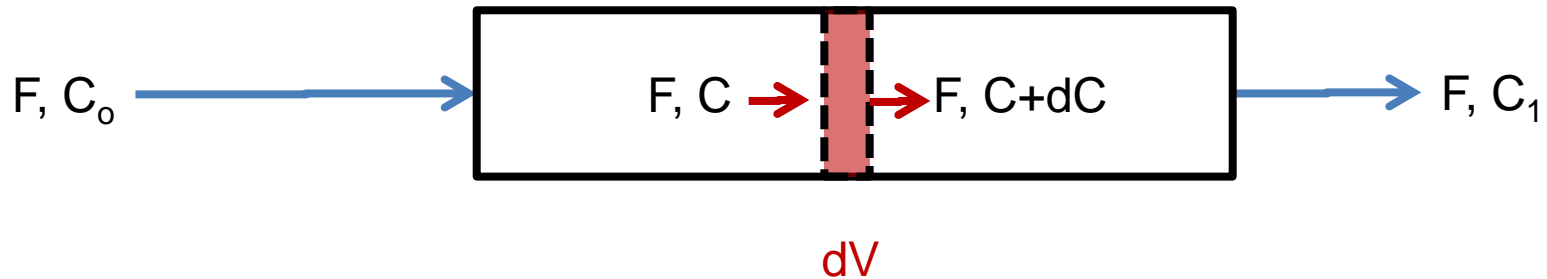


$$-F \cdot dC_A + (R_A) \cdot dV = 0 \Rightarrow \frac{dC_A}{(R_A)} = \frac{dV}{F}$$

$$\int_{C_{A0}}^{C_A} \frac{dC_A}{(R_A)} = \int_0^V \frac{dV}{F} \Rightarrow \int_{C_{A0}}^{C_A} \frac{dC_A}{(R_A)} = \frac{V}{F}$$



3. TUBULAR REACTOR



$$-F \cdot dC_A + (R_A) \cdot dV = 0$$

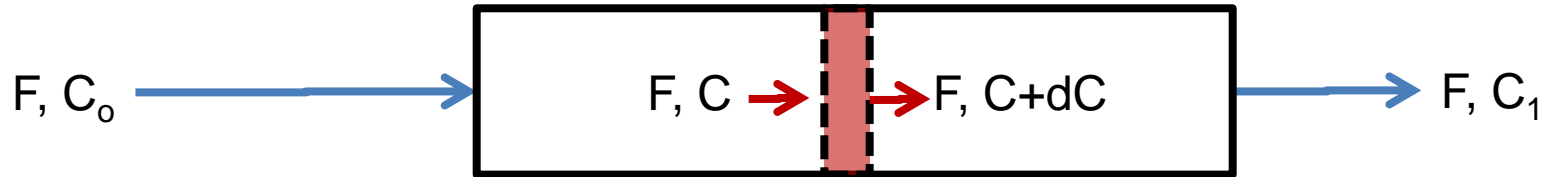
$$-F \cdot d(C_{A0} \cdot (1 - X_A)) + (R_A) \cdot dV = 0$$

$$C_{A0} \cdot F \cdot dX_A + (R_A) \cdot dV = 0$$

$$C_{A0} \cdot F \cdot dX_A = -(R_A) \cdot dV$$



3. TUBULAR REACTOR



$$C_{A0} \cdot F \cdot dX_A = -(R_A) \cdot dV$$

$$\frac{C_{A0} dX_A}{-(R_A)} = \frac{dV}{F} \Rightarrow \int_0^{X_A} \frac{C_{A0} dX_A}{-(R_A)} = \int_0^V \frac{dV}{F}$$

$$\int_0^{X_A} \frac{C_{A0} dX_A}{-(R_A)} = \frac{V}{F}$$



A photograph of an industrial facility featuring several large, cylindrical, light-colored storage tanks. The tanks are arranged in a row, with the closest one being the most prominent. A metal staircase and various pipes are visible on the side of the tanks. In the background, there is a yellow industrial building and a clear blue sky with scattered white clouds.

ANY QUESTION?

BIOREACTOR DESIGN



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SECTION II: KINETICS AND BIOREACTOR DESIGN:

LESSON 10.1. - Bioreactor design – Design Equations



JAVIER CALZADA FUNES

Biotechnology Department, Biosciences School

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