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

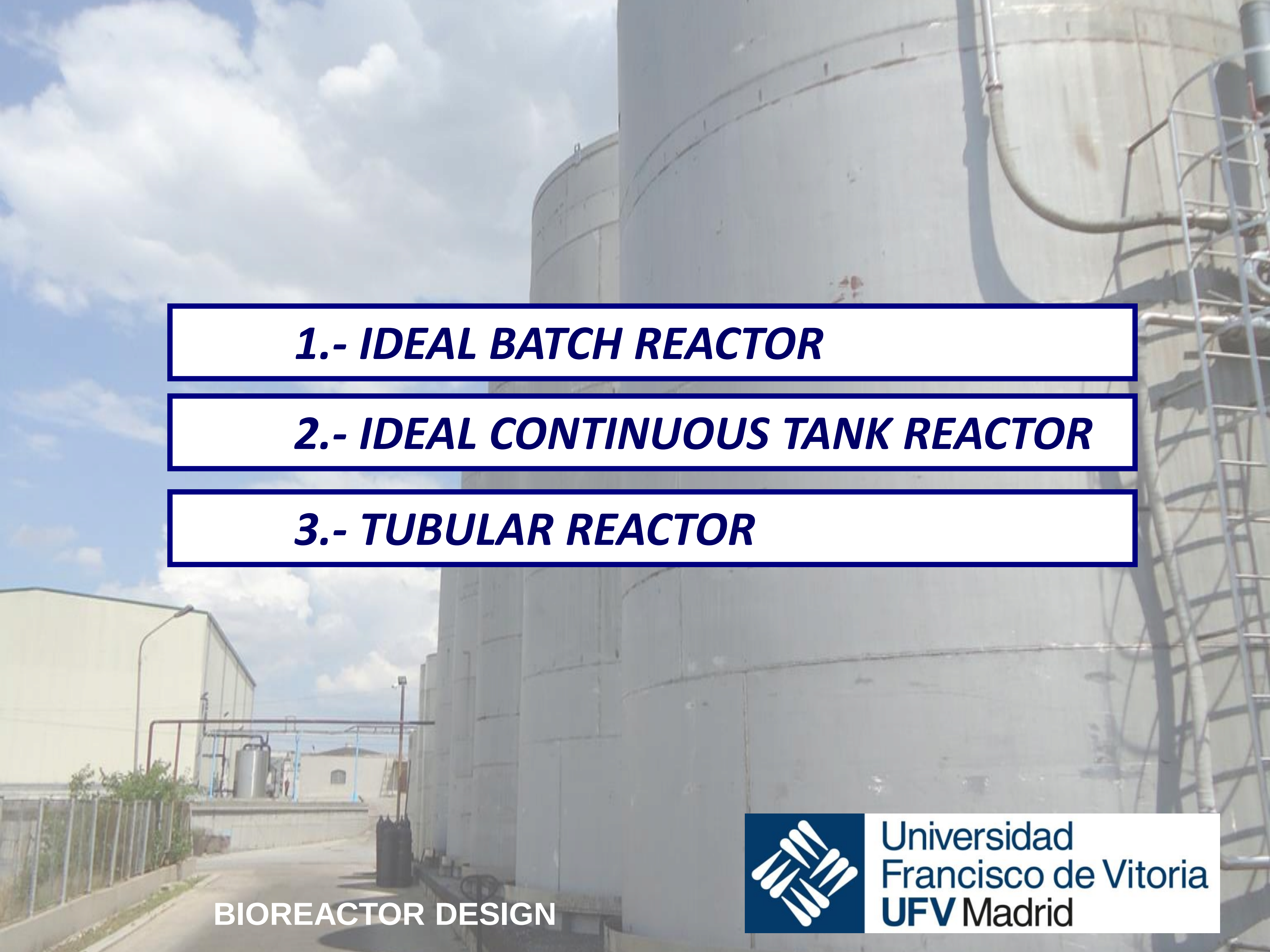
10.3 Tank vs Tubular reactor: Comparing efficiency

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).



1.- IDEAL BATCH REACTOR

2.- IDEAL CONTINUOUS TANK REACTOR

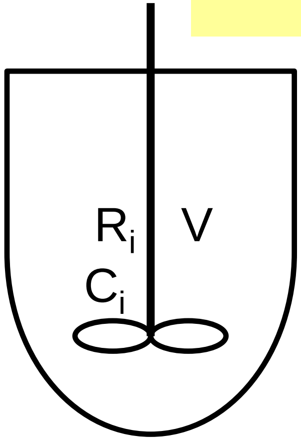
3.- TUBULAR REACTOR

Universidad Francisco de Vitoria UFV Madrid

1.- IDEAL BATCH REACTOR

1. IDEAL BATCH REACTOR

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



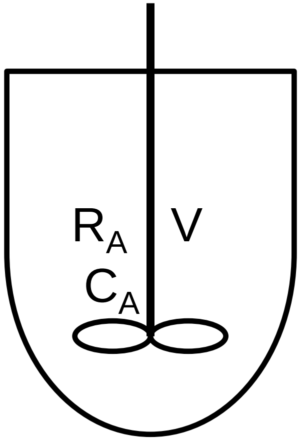
Inputs - Outputs + Generation = Accumulation

0 - 0 + Generation = Accumulation

Generation = Accumulation

1. IDEAL BATCH REACTOR

For "A" reagent:



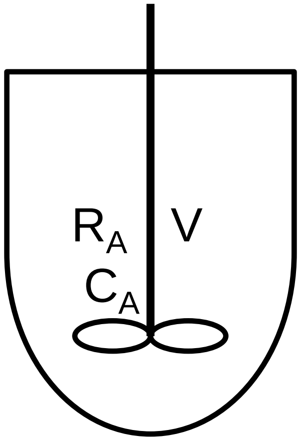
Generation = Accumulation

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

Moles of "A" disappearing in a certain time = Accumulated amount of "A"

1. IDEAL BATCH REACTOR

For “A” reagent:

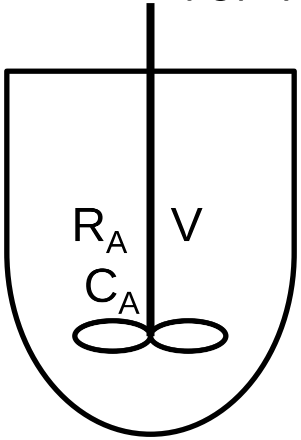


$$(R_A)\cdot V = \frac{dN_A}{dt}$$

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

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

1. IDEAL BATCH REACTOR



For "A" reagent

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

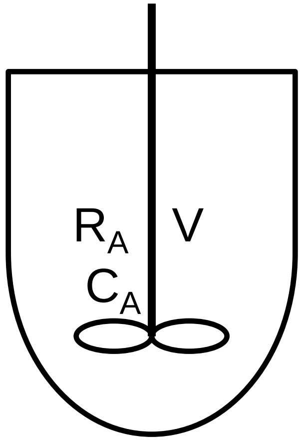
$$X_A = \frac{N_{A0} - N_A}{N_{A0}} \Rightarrow N_A = N_{A0}(1 - X_A)$$

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

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

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

1. IDEAL BATCH REACTOR



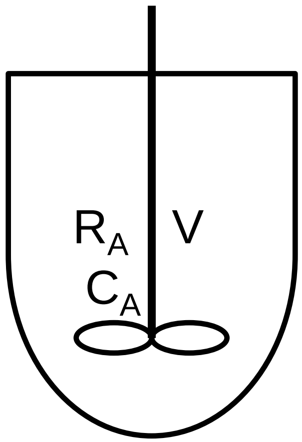
DESIGN EQUATION

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

$$A \Rightarrow \mathrm{Pr}\,oducts$$

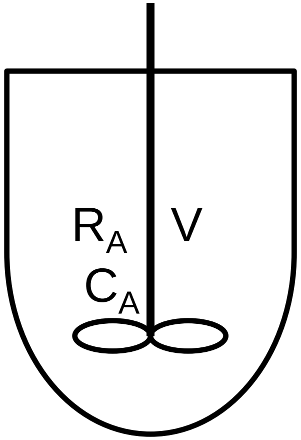
$$r = k \cdot [A]$$

$$R_A = -r$$

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

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

1. IDEAL BATCH REACTOR



DESIGN EQUATION – EASIEST CASE

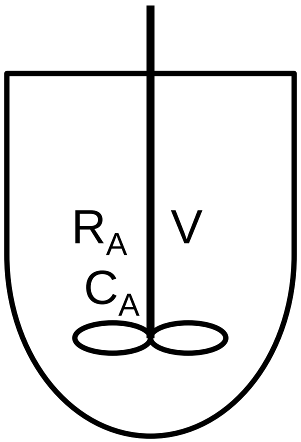
FIRST ORDER reaction

$$R_A = -k \cdot C_A$$

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

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

1. IDEAL BATCH REACTOR



DESIGN EQUATION – EASIEST CASE

FIRST ORDER reaction

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

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

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

1.- IDEAL BATCH REACTOR

2.- IDEAL CONTINUOUS TANK REACTOR

3.- TUBULAR REACTOR

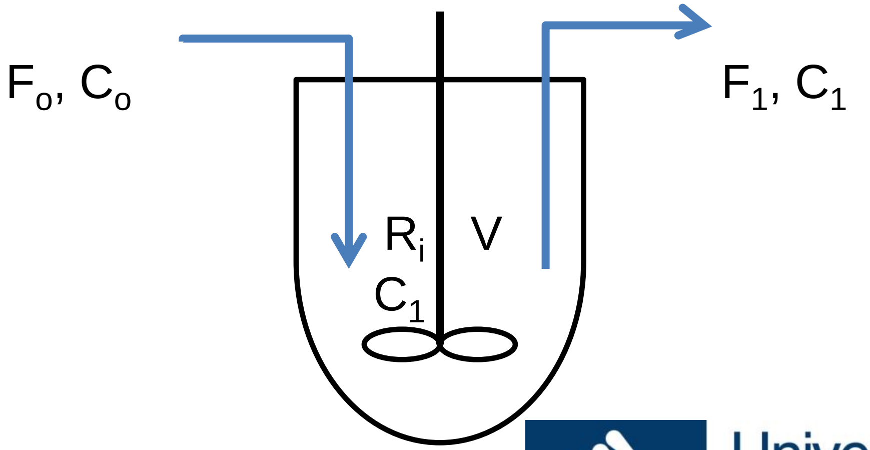
2.- IDEAL CONTINUOUS TANK REACTOR

Universidad Francisco de Vitoria UFV Madrid

2. IDEAL CONTINUOUS REACTOR

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

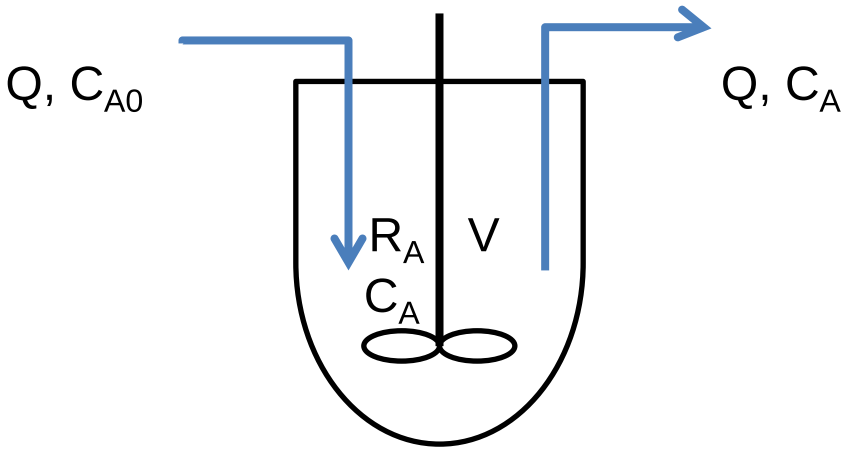
Inputs - Outputs + Generation = Accumulation



Universidad Francisco de Vitoria UFV Madrid

2. IDEAL CONTINUOUS REACTOR

For “A” reagent

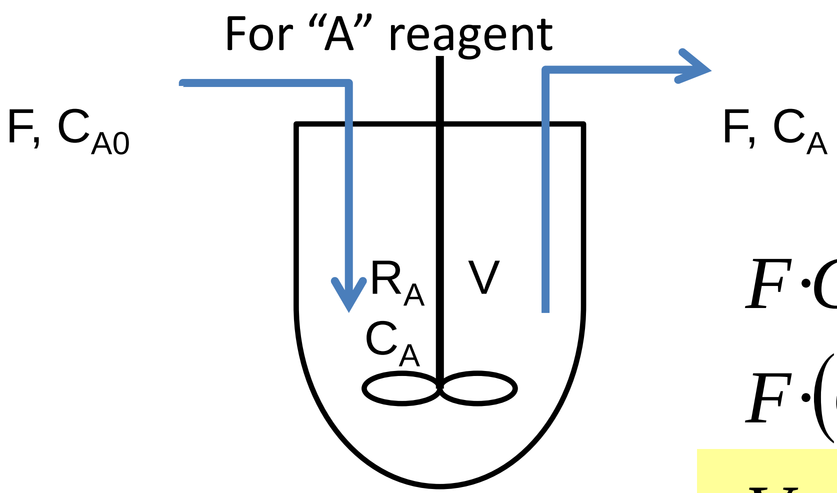


$$Accumulation = 0$$

Inputs - Outputs + Generation = 0

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

2. IDEAL CONTINUOUS REACTOR



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

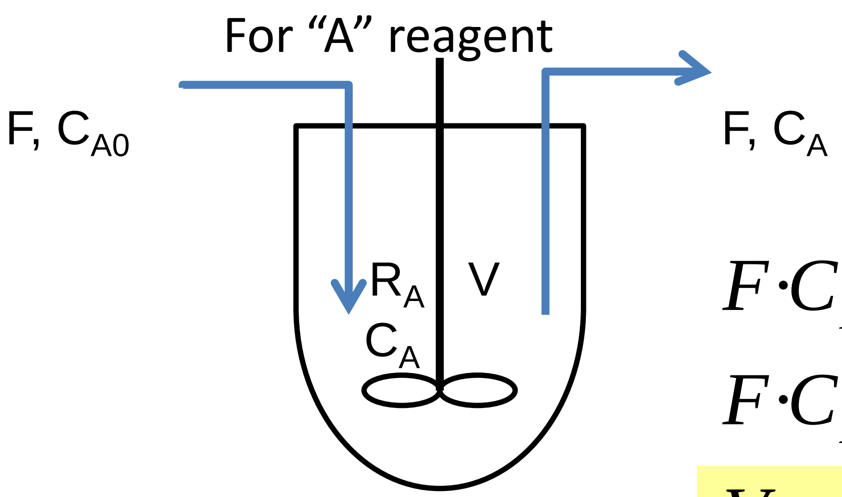
$$F \cdot (C_{A0} - C_A) = -(R_A) \cdot V$$

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

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

1.- IDEAL BATCH REACTOR

2.- IDEAL CONTINUOUS TANK REACTOR

3.- TUBULAR REACTOR

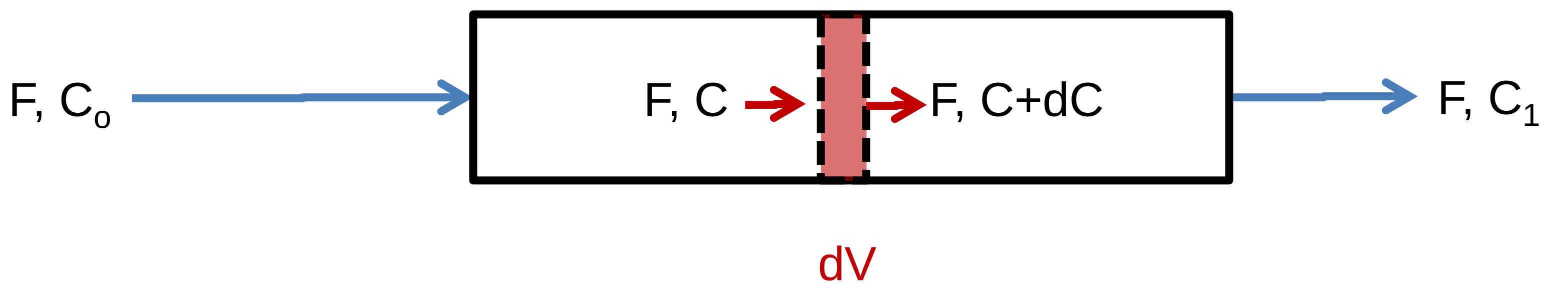
3.- TUBULAR REACTOR

Universidad Francisco de Vitoria
UFV Madrid

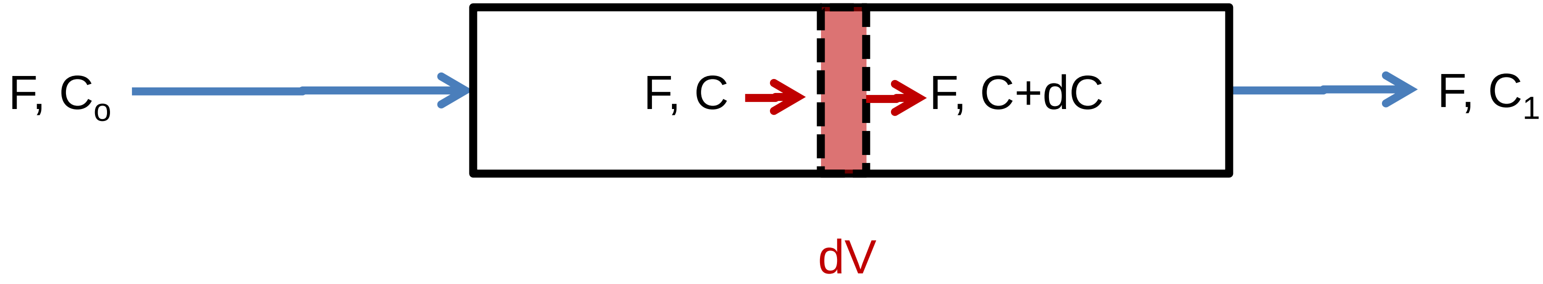
3. TUBULAR REACTOR

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

Inputs - Outputs + Generation = Accumulation



3. TUBULAR REACTOR



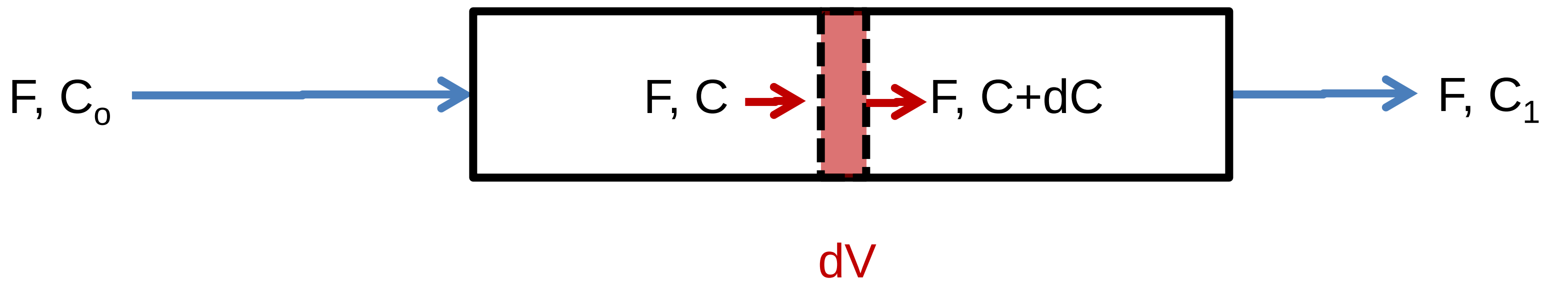
Inputs - Outputs + Generation = 0

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

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

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

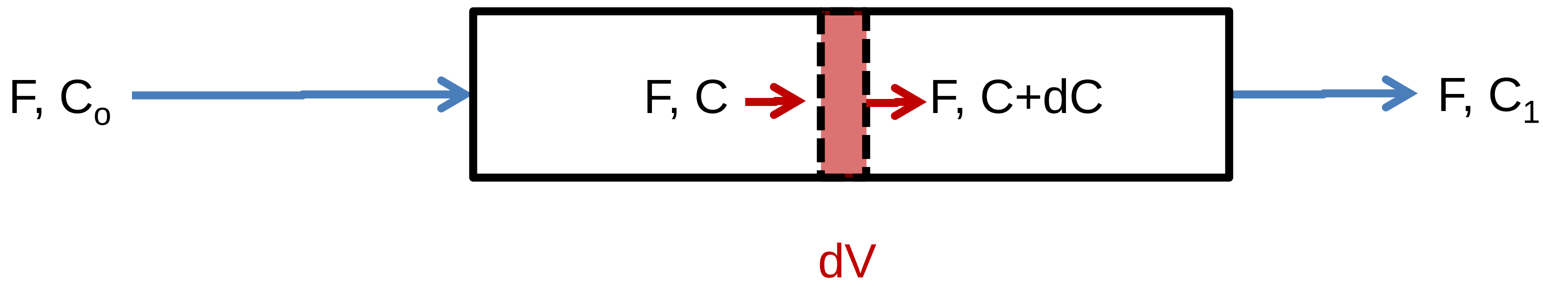
3. TUBULAR REACTOR



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

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

3. TUBULAR REACTOR



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

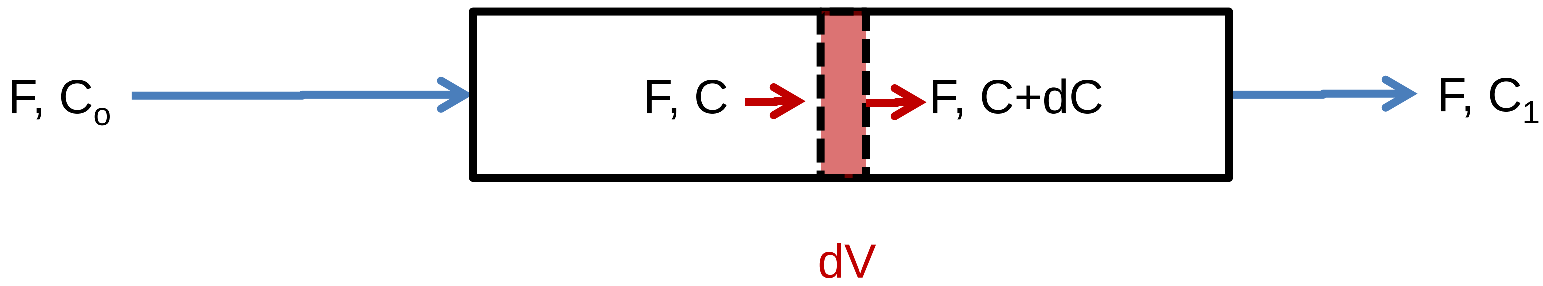
$$-F\cdot d\left(C_{A0}\cdot(1 - X_A)\right) + (R_A)\cdot dV = 0$$

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

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

Universidad Francisco de Vitoria UFV Madrid

3. TUBULAR REACTOR



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

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

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

ANY QUESTION?

Universidad Francisco de Vitoria UFV Madrid

SECTION II: KINETICS AND BIOREACTOR DESIGN:

LESSON 10.1. - Bioreactor design – Design Equations

JAVIER CALZADA FUNES

Biotechnology Department, Biosciences School

UNIVERSIDAD FRANCISCO DE VITORIA