Bioprocesses → Bioreactors

The job to be done: **Design and operate Bioprocesses towards best efficiency and productivity, at minimal cost!**

For achieve best efficiency or productivity [$kgP.m^{-3}.d^{-1}$]:

- Optimal Biomass (active one)
- Optimal Operation allowing highest kinetics for growth (production)
- Designing optimal feeding profile
- Optimize required transports of substrates/products (transport processes)
- Scaling up optimization for biggest reactors avoiding transport processes limitation…

Such bioprocesses are operated in bioreactors, which are reactors where microbial growth and product formation occur.

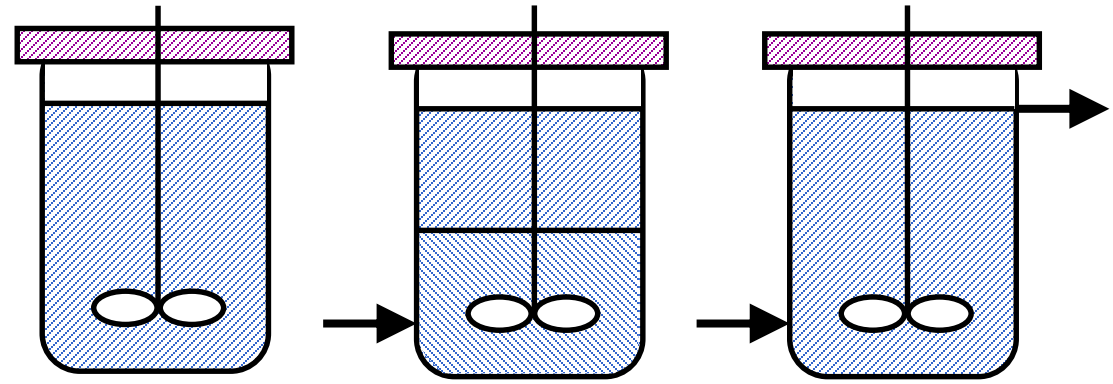
→What about bioreactors…

Bioprocesses → Bioreactors

From previous kinetic theory of specific rates $\mathbf{q_i}$: $_{\mu}$

- q_S (or) μ completely determines the **microbial behavior**
- q_S (or) μ must be controlled at an **optimal value μ_{opt}**

Generic type of process bioreactors:



Batch
2-12 days
Industry

Fed batch
1 – 3 days
Industry

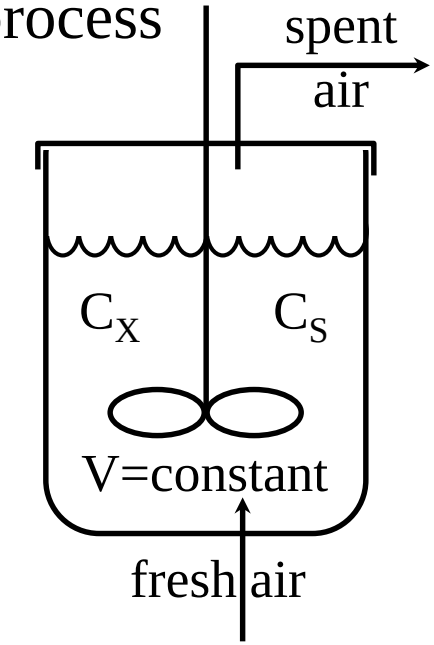
Continuous
(**Chemostat**)
10 - 100 days
Laboratory

1. **Batch** $\mu = \mu^{max}$ and $q_S = q_S^{max}$ → μ is **not** controlled
2. Chemostat **μ can be controlled** as $\mu = D$ (Dilution rate) at μ^{opt}
3. Fed batch r_S is controlled by (C_S and inflow)

Batch process (1)

DEFINITION: Parameters - State variables of Batch bioprocess

Parameters			state Variables
reactor	operator	micro-organism	
V	C_{S0} C_{X0}	q_S^{max} μ^{max} Y_{SX}^{max} m_S, K_S	C_S C_X



OPERATION:

1. Add growth medium solution (sterilized?): Substrate with initial concentration C_{S0}, N- and P-source, K^+, Mg^{2+}, salts, nutrients, vitamins, trace elements and chosen T, pH
2. Add electron acceptor (O_2, NO_3^-, etc).
3. Add (inoculum) micro-organism, C_{X0}

→ t = 0 ; Biomass= C_{X0} and Substrate = C_{S0}

Batch process (2)

DYNAMIC of the state variables.
How will C_S and C_X change with time?
Using of mass balances…

For Biomass C_X:

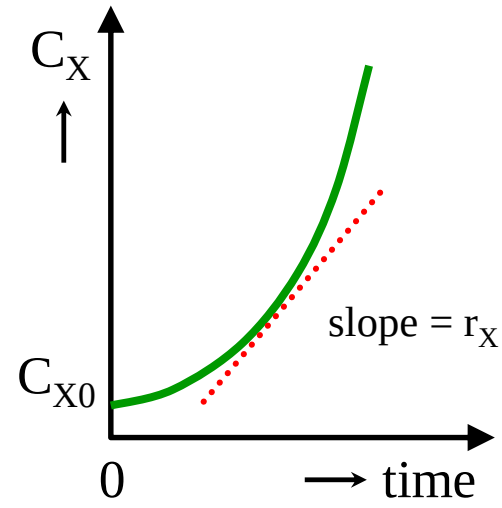
$$\frac{d(C_X V)}{dt} = \cancel{\text{transport of biomass}} + r_X V$$

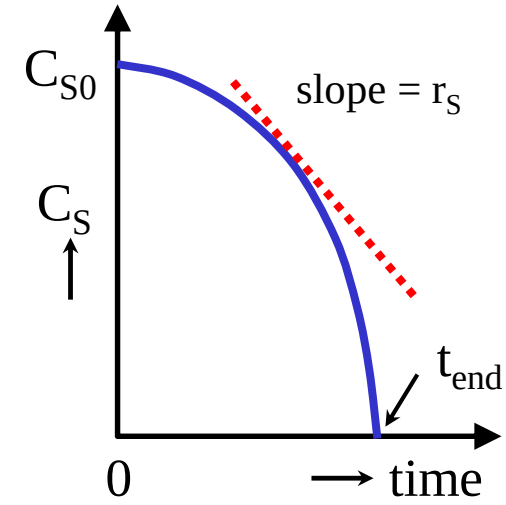
$$V = cst \rightarrow r_X = \frac{dC_X}{dt} = slope$$

For Substrate C_S:

$$\frac{d(C_S V)}{dt} = \cancel{\text{transport of biomass}} + r_S V$$

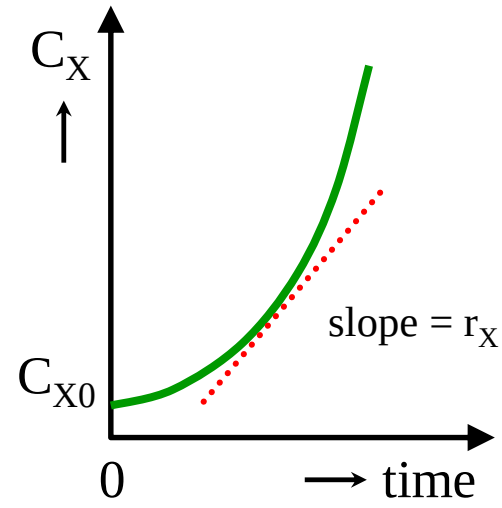
$$V = cst \rightarrow r_S = \frac{dC_S}{dt} = slope$$





Batch process (State variables)

DYNAMIC of the state variables from mass balances
As $\mu \approx \mu^{max} = cst$, and $q_S \approx q_S^{max} = cst$, as C_S is high.
At t = 0, biomass = C_{X0}, substrate = C_{S0}.



For Biomass C_X: $r_X = \mu C_X \rightarrow \frac{dC_X}{dt} = \mu^{max} . C_X$

→ **Exponential Growth**

$$C_x = C_{x0} \exp(\mu^{max} t)$$

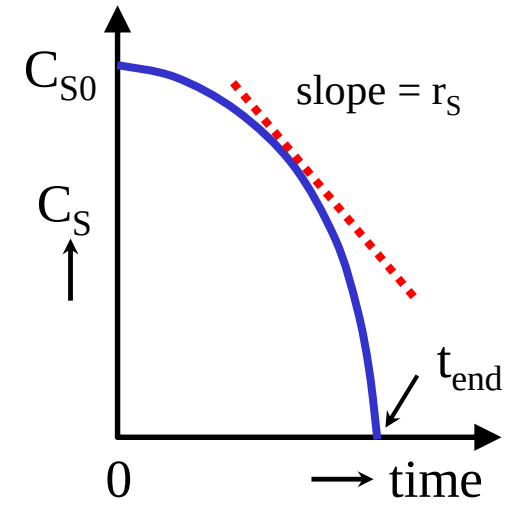
$P\left(\frac{1}{X}\right) = [\ln(x)]_{x0}^{x}$

For Substrate C_S: $r_s = q_s C_x \rightarrow \frac{dC_s}{dt} = -q_s^{max} C_X$

$$\frac{dC_s}{dt} = -q_s^{max} C_{x0} \exp(\mu^{max} t)$$

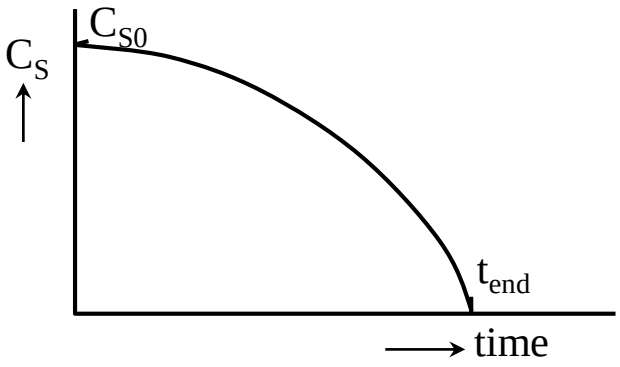
$$C_{S0} - C_S = \frac{q_S^{max}}{\mu^{max}} C_{X0} \left[\exp\left(\mu^{max} t\right) - 1 \right]$$

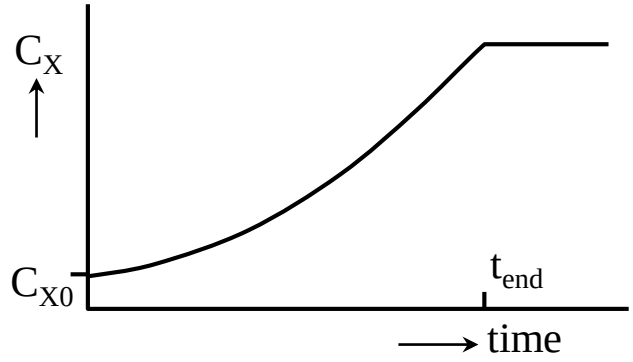
$P\left(\frac{1}{a} e^{(a*x)}\right) = \left[e^{(a*x)}\right]_{x0}^{x}$

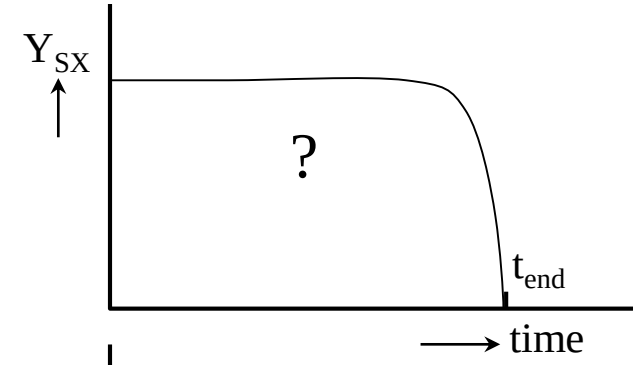


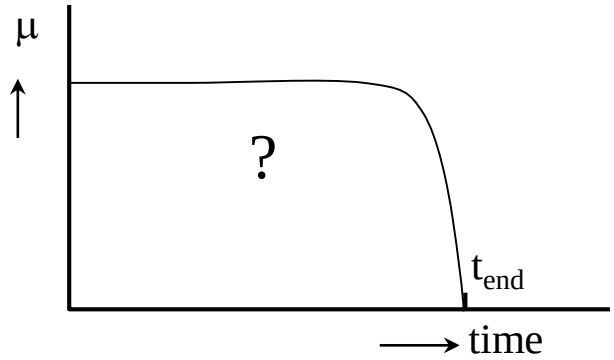
→ t_{end} can be determined with $C_S = 0$!

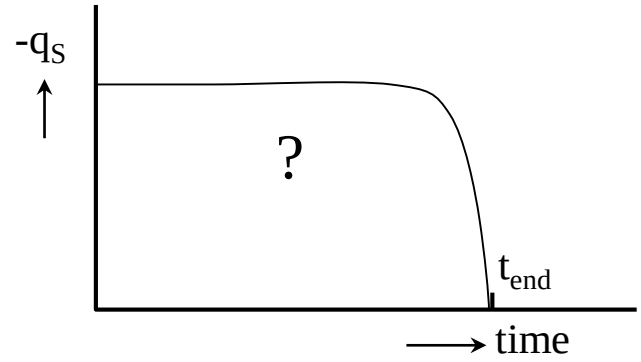
Batch process (Results)

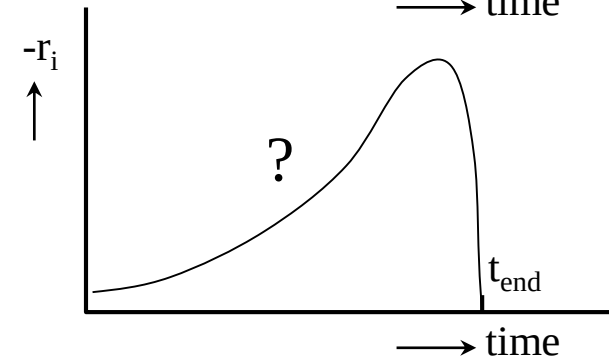


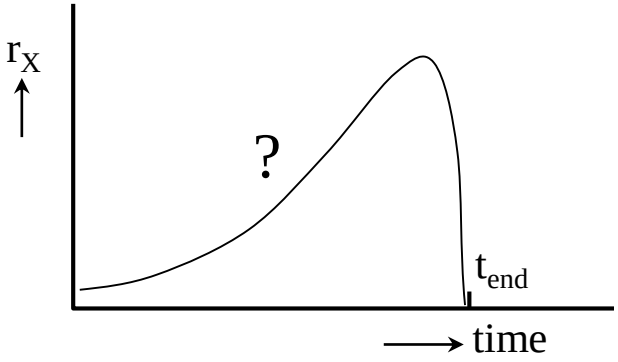


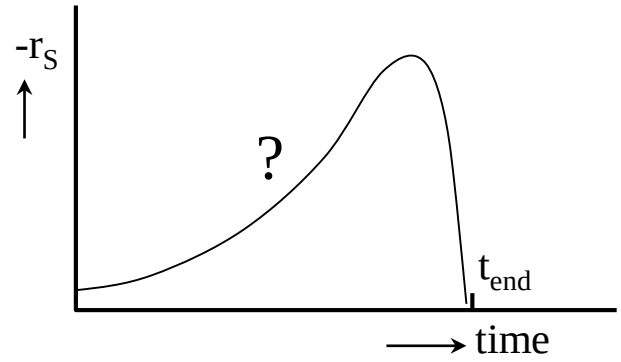












Batch process (Comments)

Batch bioprocess, under non limiting conditions (substrate), μ, Y_{SX} and q_S are constant → μ^{max}, Y_{SX}^{max}, q_S^{max}. This occur during Exponential Growth phase (and only during this phase!!!)

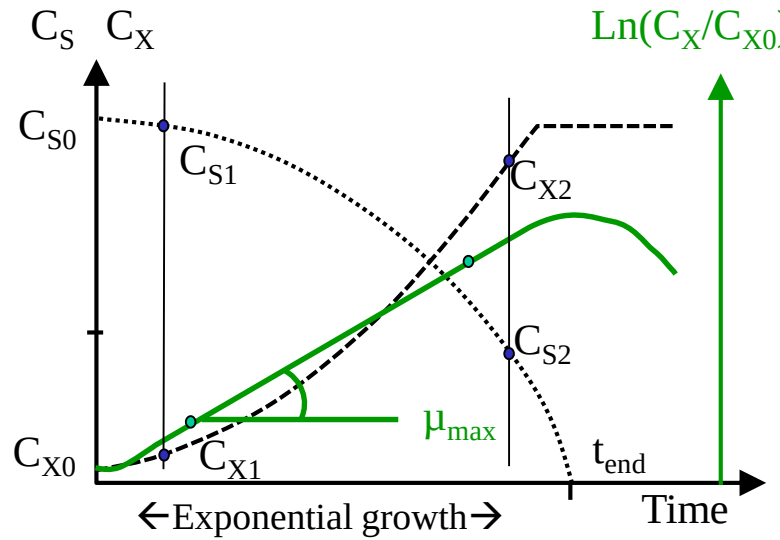
Microbiological biokinetic model parameters are easily determined by combining the exponential equation with C_S and C_X data versus time

$$C_x = C_{x0} \exp(\mu^{max} t)$$

During Exponential Growth phase (only!)

$$\mu^{max} = \text{slope } \ln\left(C_x / C_{x0}\right)$$

$$Y_{sx} \approx Y_{sx}^{max} = \frac{C_{X2} - C_{X1}}{C_{S1} - C_{S2}}$$



→ But μ, the most important rate (Herbert-Pirt Eq.) can not be controlled in batch bioprocess!

Bio-sample stability ?

Sampling of a bioprocess to access C_S and C_X. Once sampled, what behavior? - C_X does not significantly change within minutes
- But **C_S may strongly drop within minutes according q_S**

C_{SR} is the Residual Substrate of the bioprocess to be measured. The sample tube can be considered as a batch bioreactor (V = cst, No transport). From substrate mass balance:

With t = 0 ; $C_S = C_{SR}$; q_S^{max} = cst ; C_X = cst

$$\frac{dC_S}{dt} = q_S.C_X = -q_S^{max} \cdot \frac{C_S}{K_S + C_S} \cdot C_X$$

$$\frac{K_S + C_S}{C_S}.dC_S = -q_S^{max}.C_X.dt$$

$$K_S \ln\left(\frac{C_S}{C_{SR}}\right) + C_{S_R}\left(\frac{C_S}{C_{SR}} - 1\right) = -\left(q_S^{max} C_X\right)t$$

$$P\left(\frac{ax+b}{cx+d}\right) = \frac{ax+b}{c} - \frac{ad-bc}{c^2}.\ln|cx+d|$$

Assuming

			t(s)	C_S/C_{SR}
K_S	= 20 10-3	[gS.L^{-1}]	1	0.91
q_S^{max}	= 1∗10^{-3}	[gS.gX^{-1}.s^{-1}]	5	0.61
C_X	= 3.5	[gX.L^{-1}]	10	0.33
C_{SR}	= 20.10-3	[gS.L^{-1}]	**25**	**0.03**

→ How to prevent this ?