

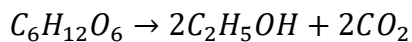
## Lab N04: Bioproduction: Ethanol Production by Fermentation

### Objective

To simulate bioethanol production in a batch bioreactor and analyze the evolution of biomass  $X$ , substrate  $S$ , and ethanol  $P$ , as well as the effect of key parameters on the fermentation process.

### Background

Fermentation is a biochemical process in which organic substrates rich in sugar are converted into simpler products through the action of microorganisms. In ethanol fermentation, *yeast, usually Saccharomyces cerevisiae*, convert sugars such as glucose  $C_6H_{12}O_6$  (derived from sources like sugarcane, sugar beet, molasses, and fruits like grapes, apples) into ethanol  $C_2H_5OH$  and carbon dioxide ( $CO_2$ ) under **anaerobic** or oxygen-limited conditions.



This process is widely used in food industries, biotechnology, and biofuel production.

In a laboratory, ethanol fermentation is performed by:

#### 1. Substrate preparation

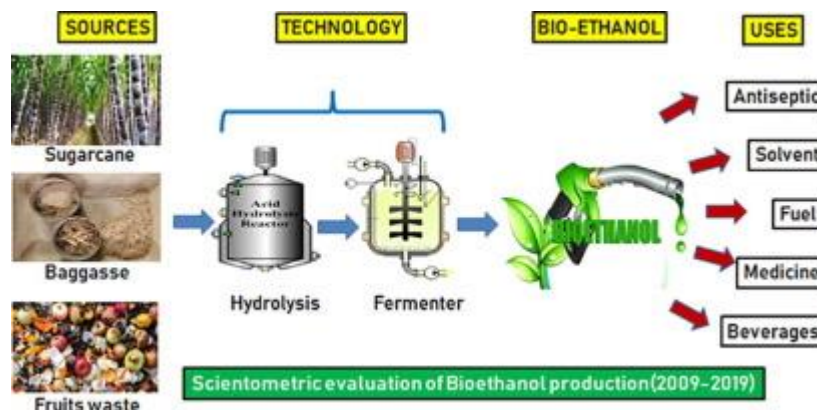
Sugars are obtained from raw materials (molasses, corn, apples...).

#### 2. Fermentation

After adding *Saccharomyces cerevisiae*, Glucose is converted into ethanol under anaerobic conditions (30–35°C, pH 4–5).

#### 3. Separation & purification

Ethanol is recovered by distillation and purified (dehydration if needed).



Industrial bioethanol fermentation is mainly carried out in **batch or fed-batch reactors**, while continuous reactors are less commonly used due to their complexity and sensitivity to contamination.

## Kinetic model of fermentation

- State variables: substrate  $S$ , biomass  $X$ , and ethanol  $P$ .
- Basic mass balance: Accumulation = Input – Output + Generation  
For batch-reactor: Accumulation = Generation

<b>biomass</b> $X$ [g/L]	<b>(yeast)</b>	$\frac{dX}{dt} = r_X$	$r_X = \mu X$ $\mu$ specific growth rate [ $h^{-1}$ ]
<b>Substrate</b> $S$ [g/L]	<b>(sugar)</b>	$\frac{dS}{dt} = r_S$	$r_S = -\frac{1}{Y_{X/S}} r_X = -\frac{1}{Y_{X/S}} \mu X$ $Y_{X/S}$ biomass yield coefficient on substrate [g biomass/g substrate]
<b>product</b> $P$ [g/L]	<b>(ethanol)</b>	$\frac{dP}{dt} = r_P$	$r_P = Y_{P/X} r_X = Y_{P/X} \mu X$ $Y_{P/X}$ : [g ethanol/g biomass]

We get:

**X:**

$$\frac{dX}{dt} = \mu X$$

**S:**

$$\frac{dS}{dt} = -\frac{1}{Y_{X/S}} \mu X$$

**P:**

$$\frac{dP}{dt} = Y_{P/X} \mu X$$

$S$  (feeds yeast)  $\rightarrow X$  (grows)  $\rightarrow P$  (produced)

Specific growth rate for ideal case is given by :  $\mu(S) = \mu_{\max} \frac{S}{K_S + S}$

$\mu$ : specific growth rate [ $h^{-1}$ ]

$S$ : substrate concentration [g/L]

$\mu_{\max}$ : maximum specific growth rate [ $h^{-1}$ ]

$K_S$ : saturation constant [g/L]

### Tasks:

- 1- Write the dynamic model equations for Biomass, Substrate and Ethanol.
- 2- Open MATLAB.
- 3- Write the code and run the script
- 4- Plot  $X(t)$ ,  $S(t)$ ,  $P(t)$
- 5- Explain the behavior of the curves.
- 6- Change the values  $S_0$ ,  $Y_{X/S}$ ,  $Y_{P/X}$  and see their effects on the process

### Questions:

- 1- How does the initial substrate  $S_0$  the effect  $X$ ,  $S$ , and  $P$ ?
- 2- What are the factors that affect fermentation?
- 3- What happens to the growth rate  $\mu$  when  $S$  becomes very small?
- 4- Why does the process stop at the end?
- 5- What does a high  $Y_{X/S}$  and  $Y_{P/X}$  mean physically?
- 6- What is the effect of increasing  $Y_{X/S}$ ?
- 7- Is this model realistic?