SECTION II: KINETICS AND BIOREACTOR DESIGN:

LESSON 11. - Special Bioreactors

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ISSUES IN THIS UNIT
SPECIAL BIOREACTORS
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AIMS FOR TODAY'S LESSON

TALKING ABOUT OTHER PARTICULAR KINDS OF BIOREACTORS:

Solid State Fermentation

Pulsating Bioreactors

Photobioreactors

Process intensification

Microbial Fuel Cells

…

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).

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1.- SPECIAL BIOREACTORS

2.- SOLID STATE FERMENTATIONS

3.- PULSATING BIOREACTORS

4.- PHOTOBIOREACTORS

5.- PROCESS INTENSIFICATION

6.- MICROBIAL FUEL CELLS

1.- SPECIAL BIOREACTORS

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CLASSIFICATION OF BIOREACTORS

According:

A. **To geometry of vessel.**

B. **To operational conditions**

C. **To involved phases.**

D. **To Biocatalyst status**

CLASSIFICATION OF BIOREACTORS

BIOCATALYST STATUS

- **Free Biocatalysts (in suspension)**
- **Immobilized Biocatalysts**
- **Special Biocatalysts**

CLASSIFICATION OF BIOREACTORS

BIOCATALYST STATUS

Special Biocatalysts

- Substrate = solid ➔ **Solid State Fermentation**

- Light energy is needed for transformation (photosynthesis)

➔ **Photobioreactors.**

- Simultaneous transformation and total or partial separation of products ➔ **intensification of processes**

CHALLENGES AND TRENDS IN FERMENTATION PROCESSES:

- **Microbial proteins**
- **Plant tissues**
- **Obtaining Enzymes**
- **Cultures of mammalian cells**
- **Microbial leaching**
- **...**

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2.- SOLID STATE FERMENTATIONS

SOLID STATE FERMENTATIONS

Process aimed at obtaining biomolecules based on microbial growth on a solid support.

- Alternative to fermentations in liquid medium.
- Pharmaceutical industries, food cosmetics, fuels, textile, enzyme production, ...
- Advances in control and instrumentation allow high productivities.

SOLID STATE FERMENTATIONS

PHENOMENOLOGY:

- GAS PHASE: depending on the culture:

  areobiosis / anaerobiosis.
- LIQUID PHASE: humidity.
- SOLID PHASE: microorganisms, substrate, support, products,…

REACTORS:

- TANK REACTORS
- ROTATING REACTORS

SOLID STATE FERMENTATIONS

SOLID STATE FERMENTATIONS

ADVANTAGES:

- High volumetric productivity.
- Greater simplicity and low energy requirements.
- Correct agitation and mixing allows aeration requirements.
- Natural habitat of many bacteria and fungi can be reproduced.
- Post-fermentative stages are simplified.

SOLID STATE FERMENTATIONS

DISADVANTAGES:

- Heterogeneous medium: bad mixture
- Difficult control
- Bigger volumes ➔ gradients (mycelia breakage, ...)

SOLID STATE FERMENTATIONS

VARIABLES:

- Humiduty
- % Inoculum
- Temperature
- pH
- Particle Size
- Aeration / agitation
- Food: pre-treatment
- Sterility: vapor, chemical agents

SOLID STATE FERMENTATIONS

EXAMPLE 1: soy sauce production

KOGI METHOD

1st PHASE: Aerobic ROTATING FERM.

molds (*Aspergillus, Rhizopus*)

cereal grains (rice, corn, ...)

2$_{nd}$ PHASE: Anaerobic (submerged)

yeasts (*Saccharomyces, Torulopsis*)

8-10 months

Programmed temperature

SOLID STATE FERMENTATIONS

EXAMPLE 2:

COMPOSTING

- Humidity (50-60%)
- Aerobic (5-15% vol), thermophilic (55 ° C)
- Profile pH
- Fungi, bacteria
- Organic waste

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3.- PULSATING BIOREACTORS

PULSATING BIOREACTORS

Fermenter causing mixing within the culture medium by means of external pulses, without introducing any mechanical part.

- **Different external devices:**

  Plates, pistons,…

- **Gas pulses**

  Aerobic processes

  High viscosity

- **Applications:**

  Production of Metabolites

  Waste treatment

PULSATING BIOREACTORS

Microorganism	Product	Características proceso
Cyathus striatus	Antibiotics	Aerobic, high viscosity
Aspergillus niger	Citric acid	Aerobic, high viscosity
Zymomonas mobilis	Ethanol	----
Acetobacter aceti	Acetic acid	Aerobic, immobilization
Levadura	SCP	Aerobic
Cultivo mixto	Waste Treatment	Aerobic, anaerobic

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4.- PHOTOBIOREACTORS

PHOTOBIOREACTORS

Fermenter using light energy in order to carry out a biotransformation ➔ photosynthesis

- Photosynthetic organisms:

  photosynthetic bacteria, microalgae, cyanobacteria, ...
- $CO_2 \rightarrow$ Metabolites (autotroph)
- Light energy (phothotoph)
- Donor of e^- (H_2O)

PHOTOBIOREACTORS

- Production of value-added metabolites
  - Pigments, antioxidants, pharmaceuticals
- Environment
  - Removal of toxic substances
  - (heavy metals, CO_2 fixation)
  - Contaminated soils
  - Regeneration of atmosphere within closed systems

PHOTOBIOREACTORS

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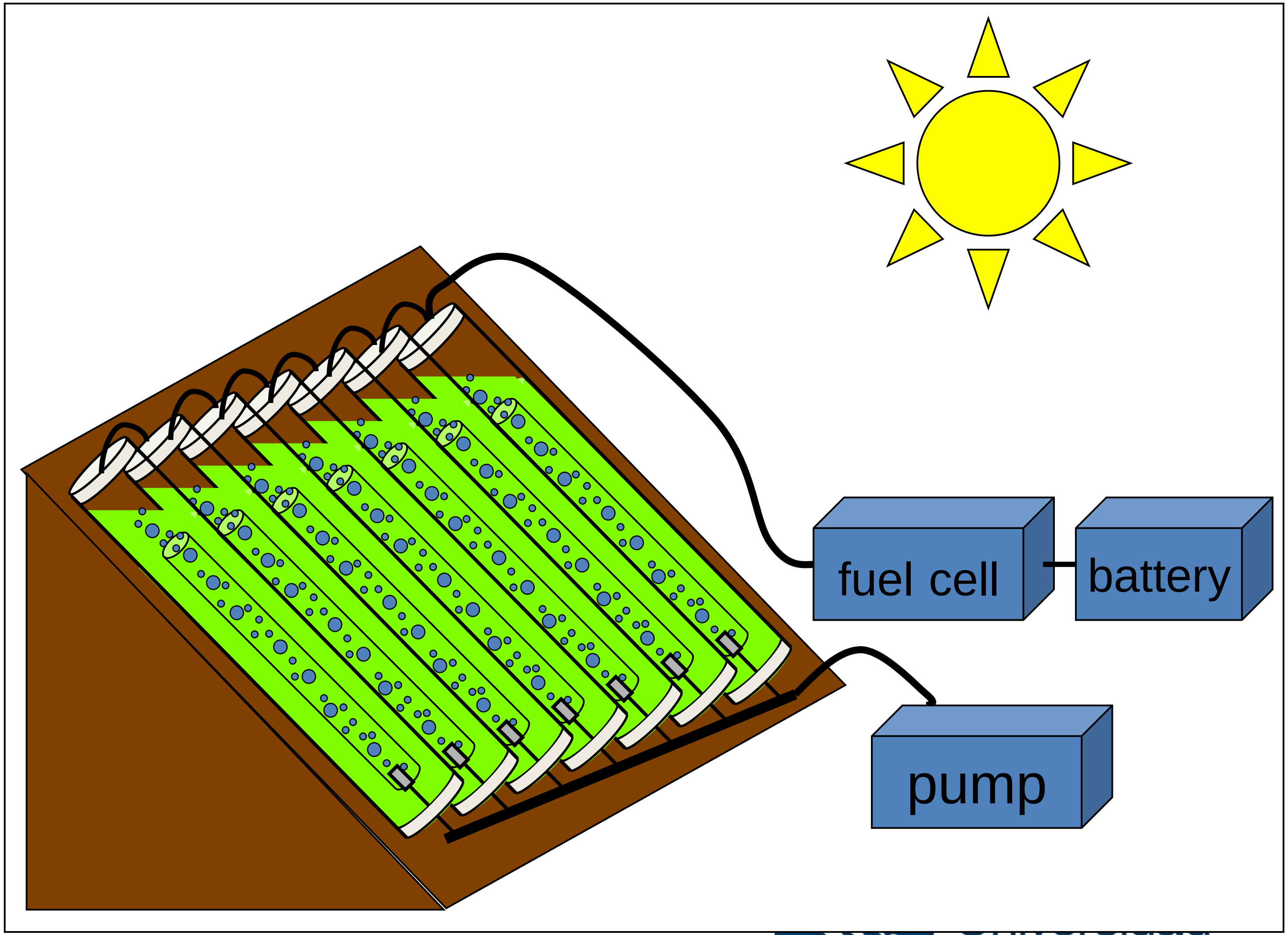
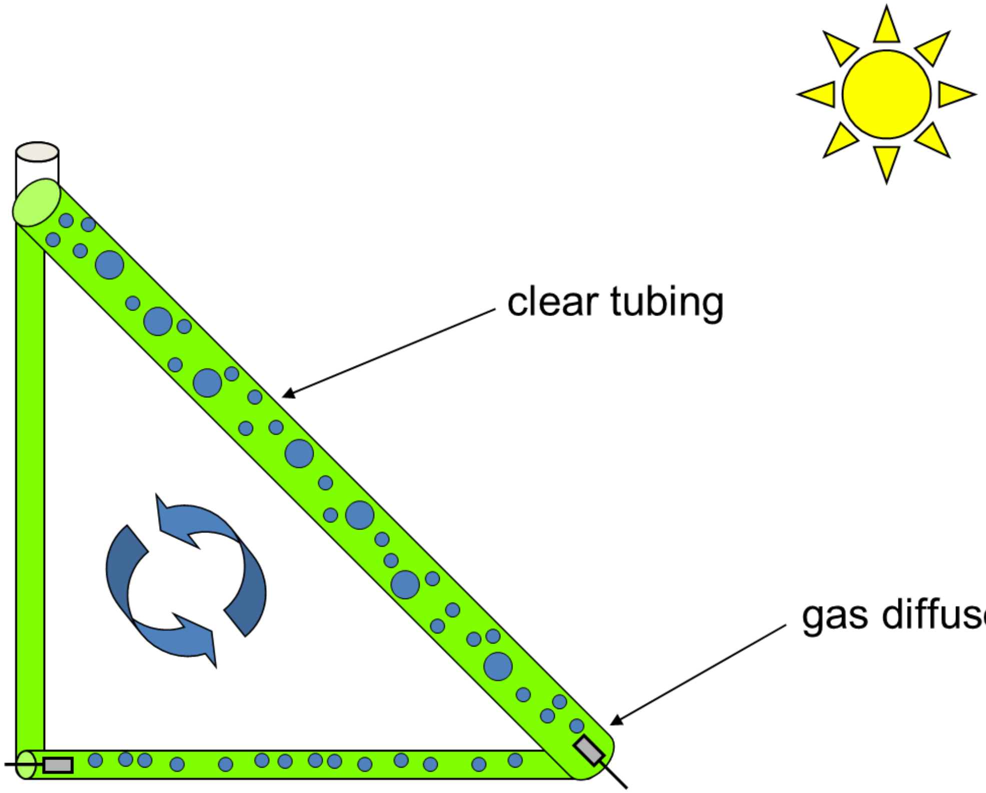
PHOTOBIOREACTORS



PHOTOBIOREACTORS



PHOTOBIOREACTORS

- **Artificial light**

- Continuous
- Good control conditions
- Constant product quality
- Allows sterilization
- High energy expense
- Difficult scaling up

PHOTOBIOREACTORS

- **Natural light**

- Low energy expense
- Difficult control
- Purity
- Light-dark phases
- Lower Productivity

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5.- PROCESS INTENSIFICATION

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PROCESS INTENSIFICATION

Situation in which, simultaneously with **transformation**, total or partial **separation of products** is carried out.

Reaction and **separation** are combined within a single unit.

Membrane selectively allows separation of reagents or products.

PROCESS INTENSIFICATION

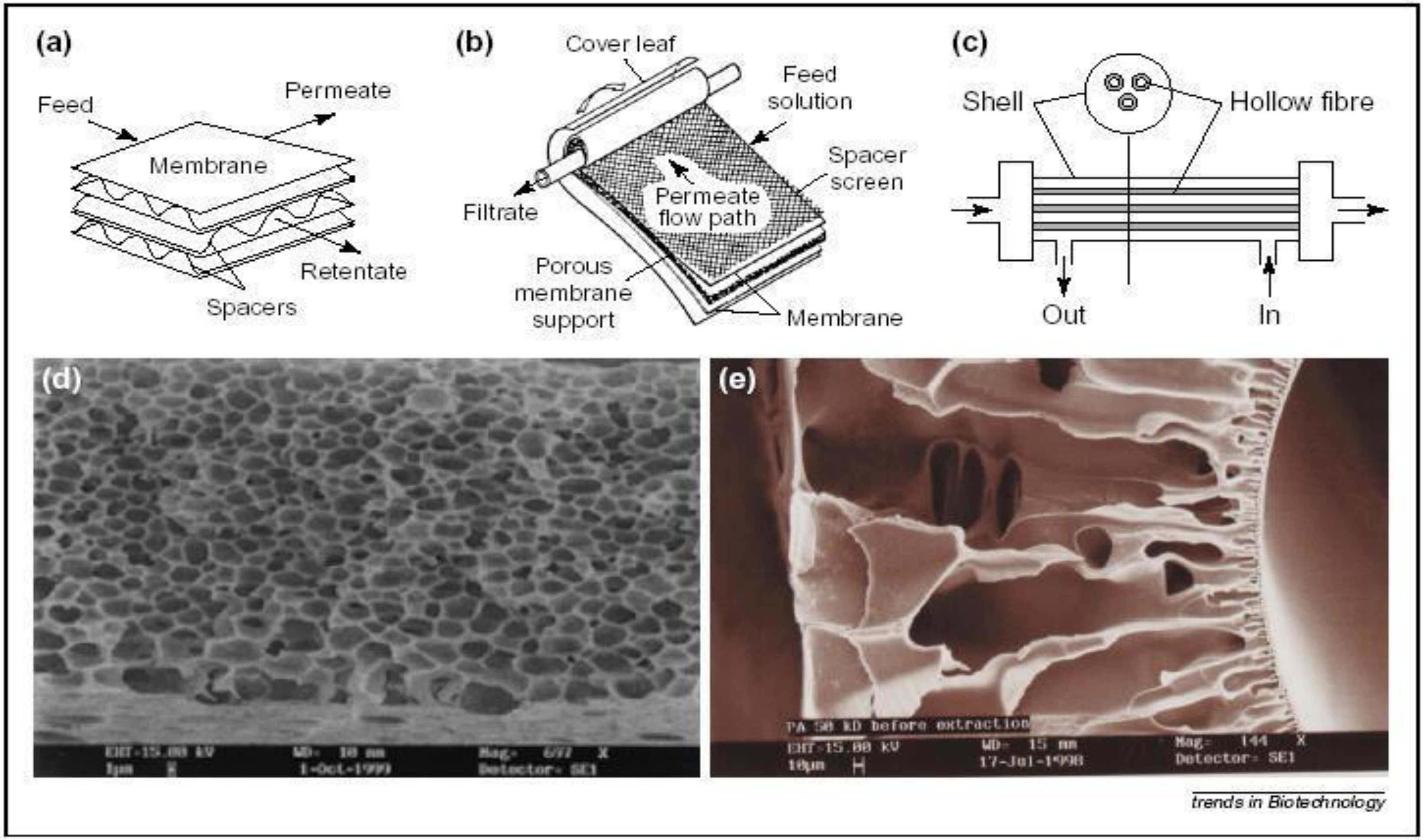
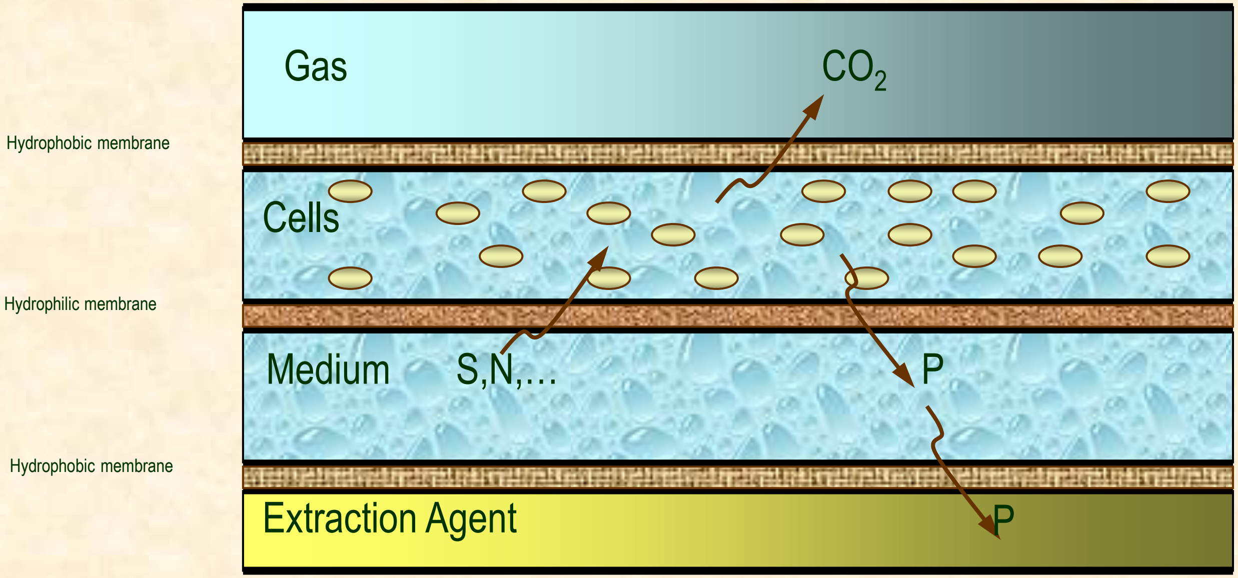


Figure 2
The different types of membrane and membrane modules: flat-sheet membranes assembled in (**a**) plate and frame, and (**b**) spiral wound modules; (**c**) a hollow fibre membrane assembled in a tube-and-shell module; (**d**) a symmetric membrane: a cross section of a flat membrane made of polyetheretherketone (PEEK-WC); and (**e**) an asymmetric membrane: a cross section of a capillary membrane made of polyamide.

PROCESS INTENSIFICATION

- Extraction



- Pervaporation
-- Volatile Comps
-- Permeation comps
-- ↓P permeate zone

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PROCESS INTENSIFICATION

FOOD AND AGRICULTURE INDUSTRY

Biocatalytic reactors combined with microfiltration, ultrafiltration, reverse osmosis or membrane extraction.

- Reduction of juice viscosity by hydrolysis of pectins.
- Reduction of lactose content in milk by conversion into digestible sugars.
- Removal of peroxides from products.

Table 2. Applications of biocatalytic membrane reactors in the agro-food industry

Reaction	Membrane bioreactor	Purpose
Hydrolysis of lactose to glucose and β-galactose (β-galactosidase)	Axial-annular flow reactor	Delactosization of milk or whey for human consumption
Hydrolysis of high-molecular-weight protein in milk (trypsin and chymotrypsin)	Asymmetric hollow fibre with gelified enzyme	Production of baby food
Hydrolysis of raffinose (α-galactosidase and invertase)	Hollow fibre reactor with segregated enzyme	Production of monomeric sugars
Hydrolysis of starch to maltose (α-amylase, β-amylase, pullulanase)	CSTR with UF membrane	Production of syrups
Fermentation of sugars (yeast)	CSTR with UF membrane	Brewing industry
Anaerobic fermentation (yeast)	CSTR with UF membrane	Production of alcohol
Hydrolysis of pectines (pectinase)	CSTR with UF membrane	Production of bitterness and clarification of fruit juice and wine
Fermentation of *Lactobacillus bulgaricus*	CSTR with UF membrane	Production of carboxylic acids
Removal of limonene and naringin (β-cyclodextrin)	CSTR with UF membrane	Production of bitterness and clarification of fruit juice
Hydrolysis of K-casein (endopeptidase)	CSTR with UF membrane	Milk coagulation for dairy products
Hydrolysis of collagen and muscle proteins (protease, papain)	CSTR with UF membrane	Meat tenderization
Conversion of glucose to gluconic acid (glucose oxidase and catalase)	Packed bed reactor	Prevention of discolouration and off-flavour of egg products during storage
Hydrolysis of triglycerides to fatty acids and glycerol (lipase)	UF capillary membrane reactor	Production of foods, cosmetics and emulsificants

Table 3. Applications of biocatalytic membrane reactors in pharmaceutical and biomedical treatments

Reaction	Membrane reactor	Purpose
Conversion of fumaric acid to L-aspartic acid (*Escherichia coli* with aspartase)	Entrapment in polyacrylamide gel	Pharmaceuticals and feed additives
Conversion of L-aspartic acid to L-alanine (*Pseudomonas dacunhae*)	Entrapment in polyacrylamide gel	Pharmaceuticals
Conversion of cortexolone to hydrocortisone and prednisolone (*Curvularia lunata/Candida simplex*)	Entrapment in polyacrylamide gel	Production of steroids
Conversion of acetyl-D,L-amino acid to L-amino acid (aminoacylase)	Ionic binding to DEAE-sephadex	Production of L-amino acids for pharmaceutical use
Synthesis of tyrosine from phenol, pyruvate and ammonia (tyrosinase)	Entrapment in cellulose triacetate membrane	Production of L-amino acids for pharmaceutical use
Hydrolysis of a cyano-ester to ibuprofen (lipase)	Entrapment in biphasic hollow fibre reactor	Production of anti-inflammatories
Production of ampicillin and amoxycillin (penicillin amidase)	Entrapment in cellulose triacetate fibers	Production of antibiotics
Hydrolysis of a diltiazem precursor (lipase)	Entrapment in biphasic hollow fibre reactor	Production of calcium-channel blocker
Hydrolysis of 5-*p*-HP-hydantoine to D-*p*-HP-glycine (hydantoinase and carbamylase)	Entrapment in UF polysulfone membrane	Intermediate for the production of cephalosporin
Dehydrogenation reactions (NAD(P)H-dependent enzyme systems)	Confination with UF-charged membrane	Production of enantiomeric amino acids
Hydrolysis of DNA to oligonucleotides (DNase)	Gelification on UF capillary membrane	Production of pharmaceutical substances
Hydrolysis of hydrogen peroxide (bovine liver catalase)	Entrapment in cellulose triacetate membrane	Treatment in liver failure
Hydrolysis of whey proteins (trypsin, chymotrypsin)	Polysulfone UF membrane	Production of peptides for medical use
Hydrolysis of arginine and asparagine (arginase and asparaginase)	Entrapment in polyuretane membrane	Care and prevention of leukaemia and cancer

Abbreviation: UF, ultrafiltration.

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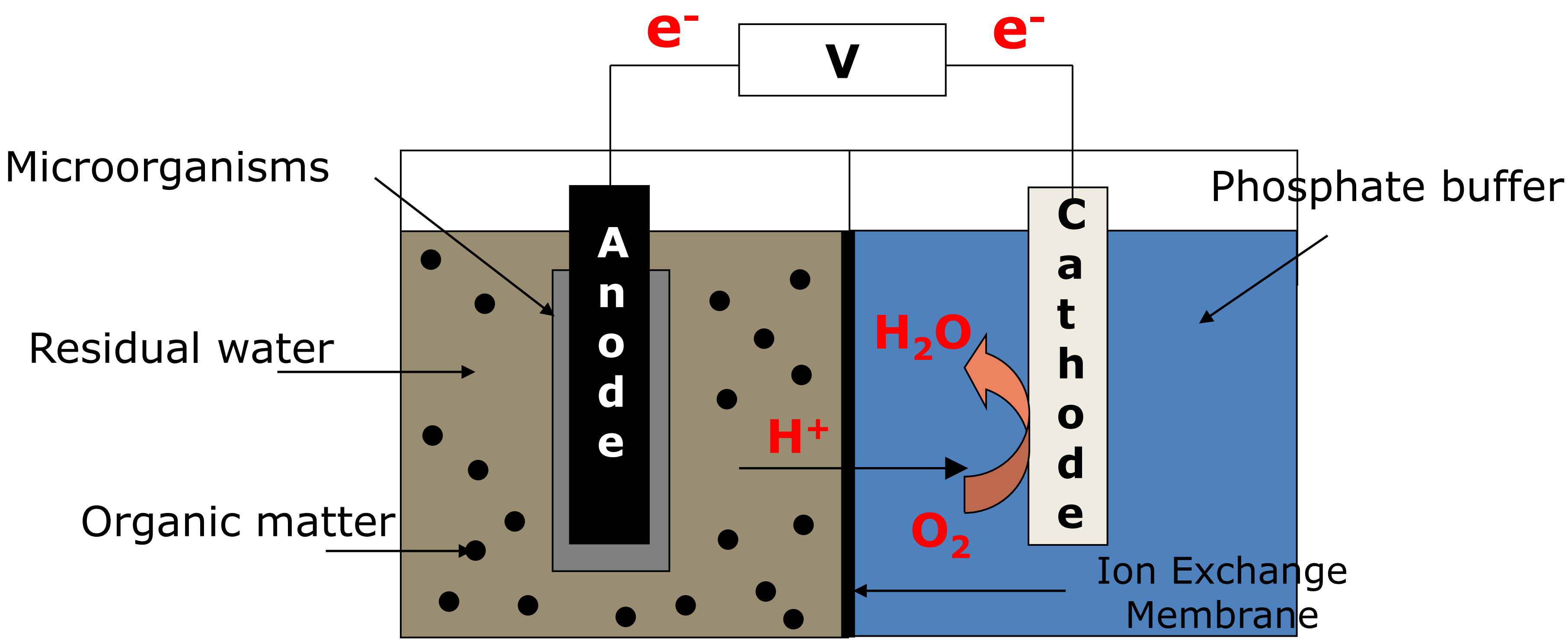
MICROBIAL FUEL CELLS

Bioelectrochemical systems capable of producing certain amounts of energy by **effectively purifying waste water**



$$C_xH_yO_z + pH_2O \xrightarrow{\text{Enzimas}} xCO_2 + qH^+ + qe^-$$

$$4H^+ + 4e^- + O_2 \rightarrow 2H_2O$$

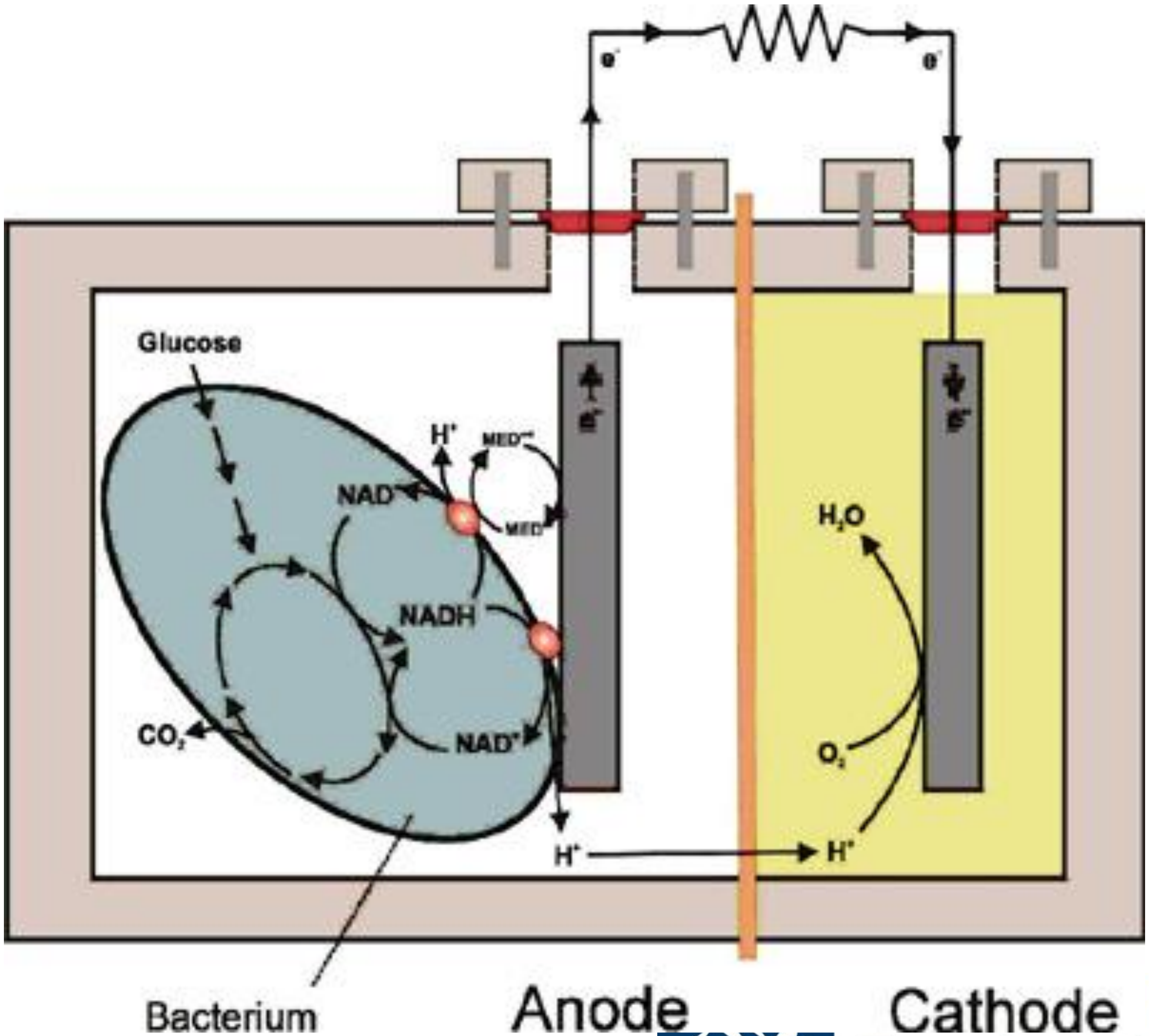
MICROBIAL FUEL CELLS

AIM: capturing electrons to produce electricity.

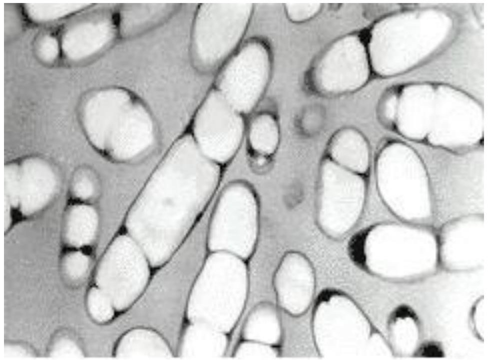
HOW:

- Through microbial oxidation of organic matter under anaerobic conditions.
- Diffusion of protons through a semipermeable membrane.
- Transfer of electrons transfer from the anode to the cathode.
- Reduction in cathode.

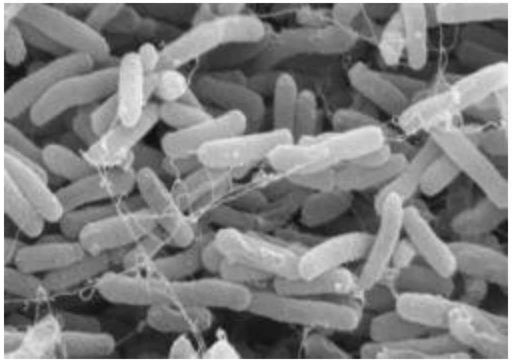
MICROBIAL FUEL CELLS



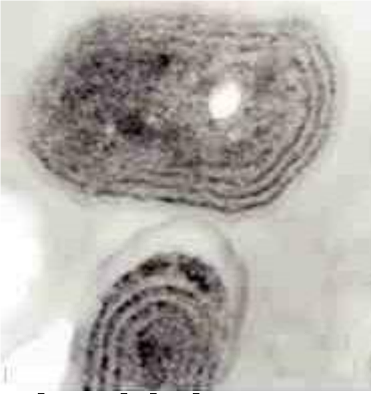
MICROBIAL FUEL CELLS



Alcaligenes eutrophus

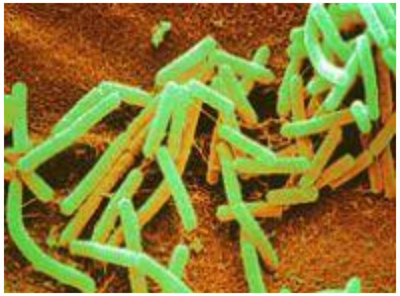


E. Coli



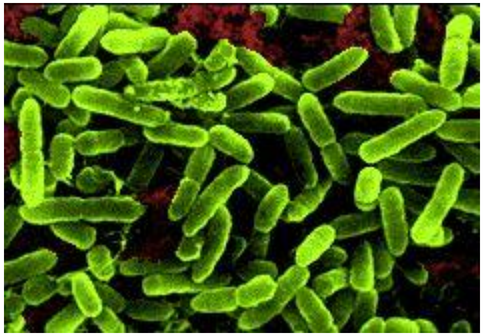
Anacystis nidulans

Proteus vulgaris



Bacillus subtilis

Pseudomonas putida

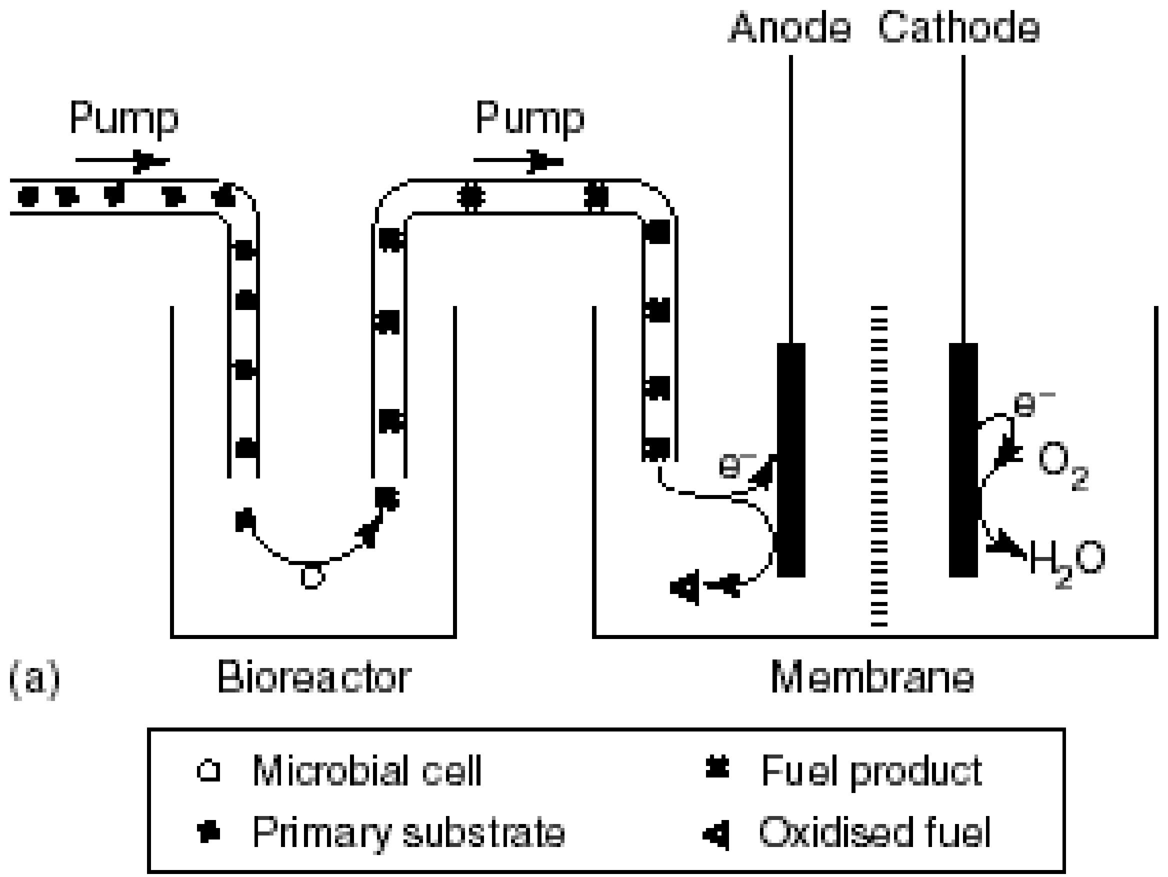


Pseudomonas aeruginosa

Streptococcus lactis

Approach I: **Fuel products (say hydrogen gas) are produced by fermentation of raw materials in the biocatalytic microbial reactor (*BIOREACTOR*) and transported to a biofuel cell.**

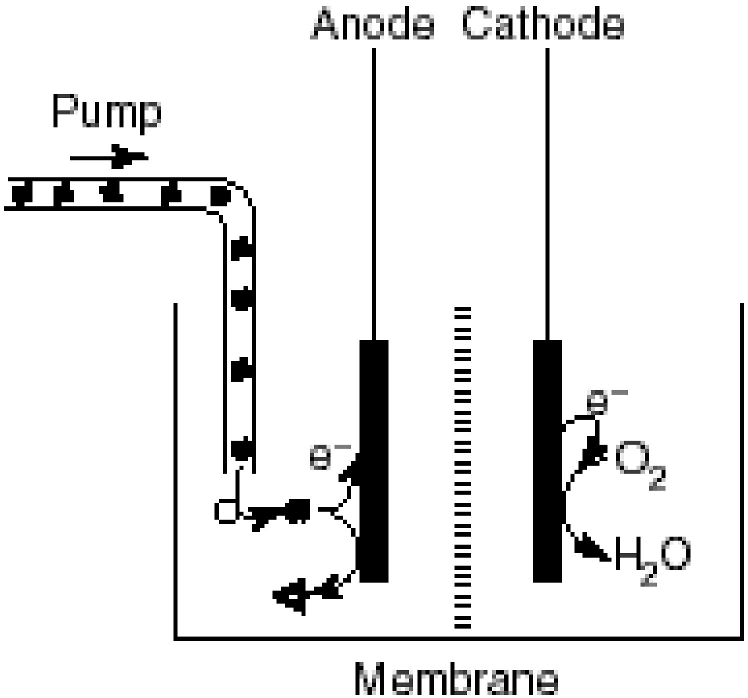
The bioreactor is not directly integrated with the electrochemical part, allowing H_2/O_2 fuel cells to be conjugated with it.



Approach II: **Microbiological fermentation can proceed in the anodic compartment itself.**

It is a true biofuel cell!

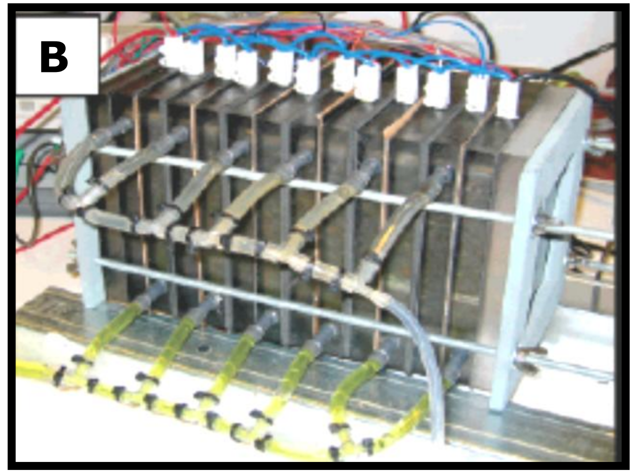
(not a combination of a bioreactor and a conventional fuel cell).



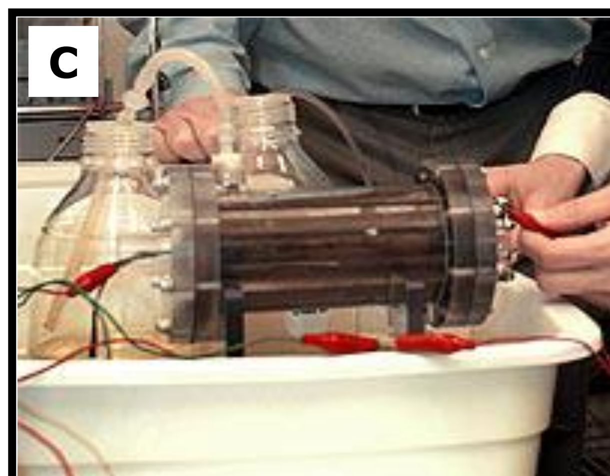
Hydrogen gas is produced biologically, but it is oxidized electrochemically in presence of biological components under milder conditions (than conventional Fuel cells) as dictated by the biological system

MICROBIAL FUEL CELLS

Double Chamber Batch Cellss

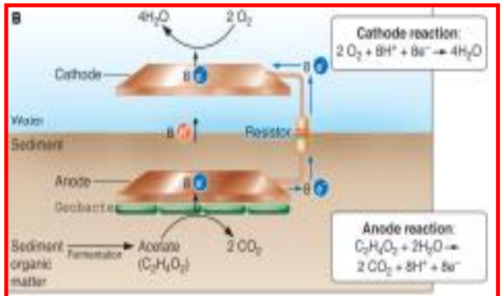


Continuous Cells



Tubular

MICROBIAL FUEL CELLS



V = 12 V
P= 0.5 kW
DQO = 5000 mg/L

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MICROBIAL FUEL CELLS

FIELDS OF APPLICATION:

- Food processing industry (canning)
- Urban wastewater treatment
- Fish farms and animal farms
- Oil platforms
- Oceanographic ships and submarine vessels
- Aerospace industry

ANY QUESTION?

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