



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

INTRODUCTION TO MICROBIAL FUEL CELLS

DR. PRASENJIT MONDAL
CHEMICAL ENGINEERING DEPARTMENT



Contents

- Energy related cells and fuel cell theory
- MFC and its working principle
- Mechanism of electron and hydrogen transfer in MFC
- Design of MFC
- Microorganisms for MFC
- Parameters affecting the performance of MFC
- Current and voltage calculation
- Types of MFC and some efforts for improvement



Different types of cells related to energy

Galvanic cell : It converts chemical energy to electrical energy.

Electrolytic cell : It converts electrical energy into **chemical free energy**.

Batteries : Devices that carry out these conversions. Conventionally these supply electrical energy from the chemical reactants stored within them.

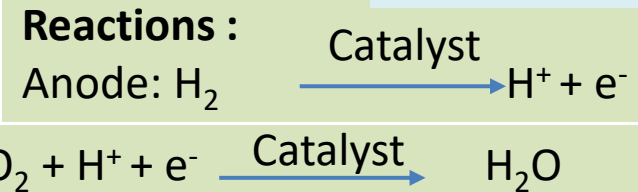
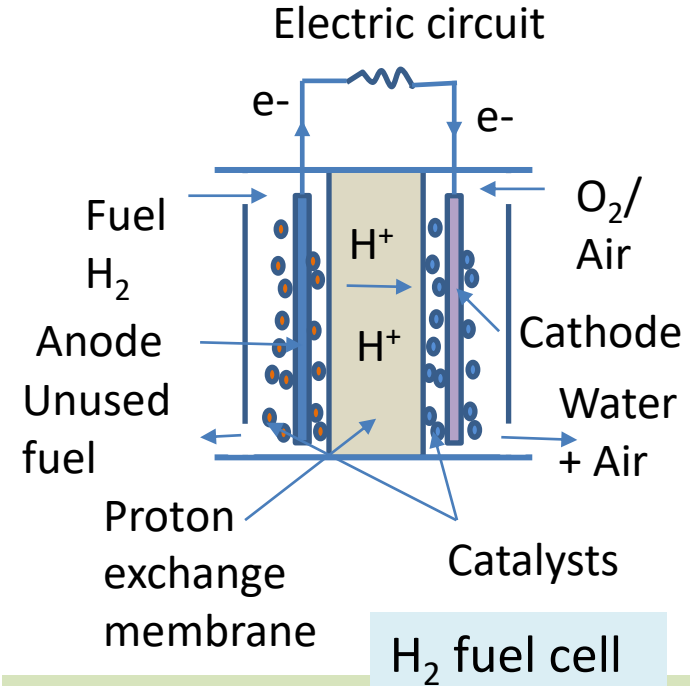
Fuel Cell: An electrochemical device in which the free energy of a chemical reaction is converted to electrical energy. The reactants are supplied from an external source as they are consumed. No combustion and no NO_x emissions.

Microbial fuel cells: A fuel cell in which chemical reaction is replaced by microbial reaction and the organic load of waste water is used as fuel.

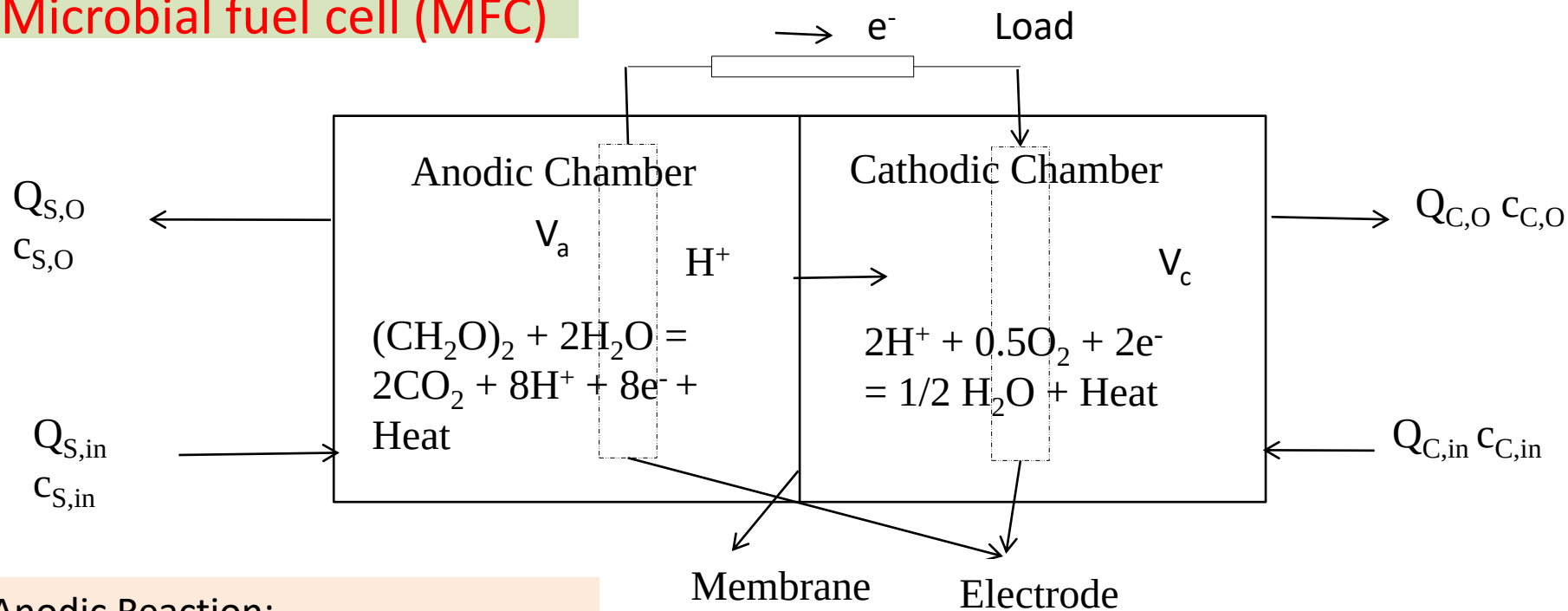


Fuel cell theory

- A fuel cell consists anodic and cathodic chamber. Separated by Electrolyte which allow the flow of proton and restrict the flow of electron.
- Hydrogen and Oxygen are fed into the cell.
- Catalyst at anode causes hydrogen atoms to give up electrons leaving positively charged protons.
- Oxygen ions at cathode side attract the protons.
- Protons pass through electrolyte membrane.
- Electrons are redirected to cathode through external circuit, which makes current.



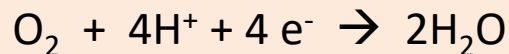
Microbial fuel cell (MFC)



Anodic Reaction:

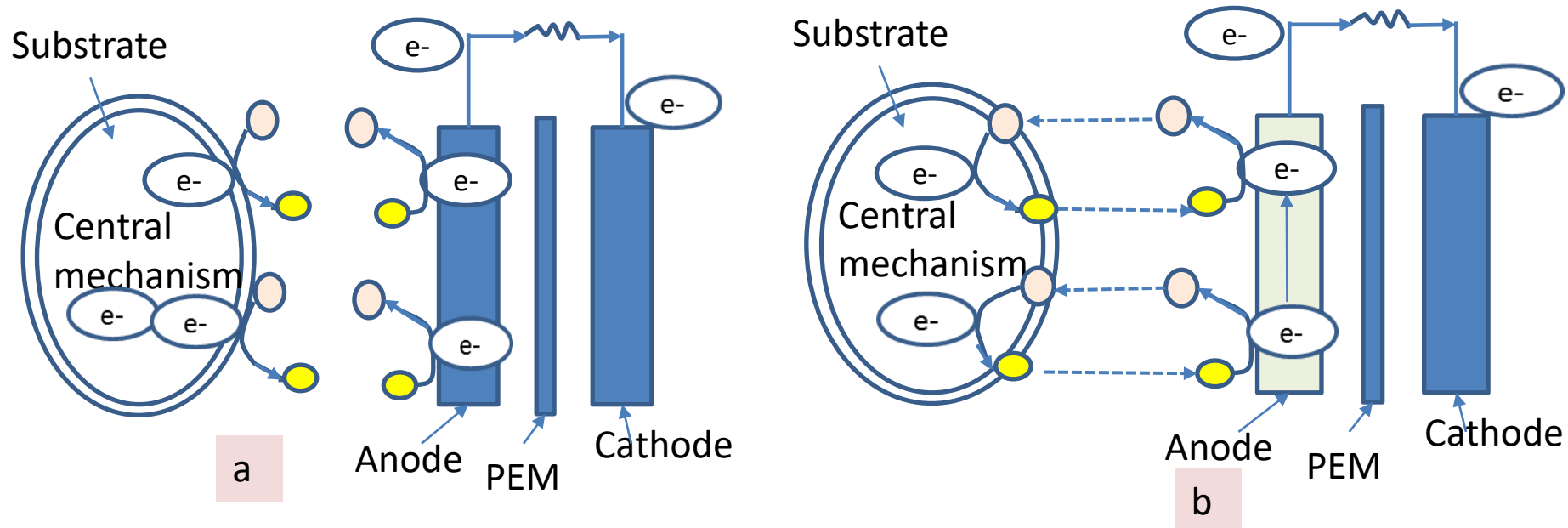


Cathodic Reaction:



Schematic diagram of a double chamber MFC

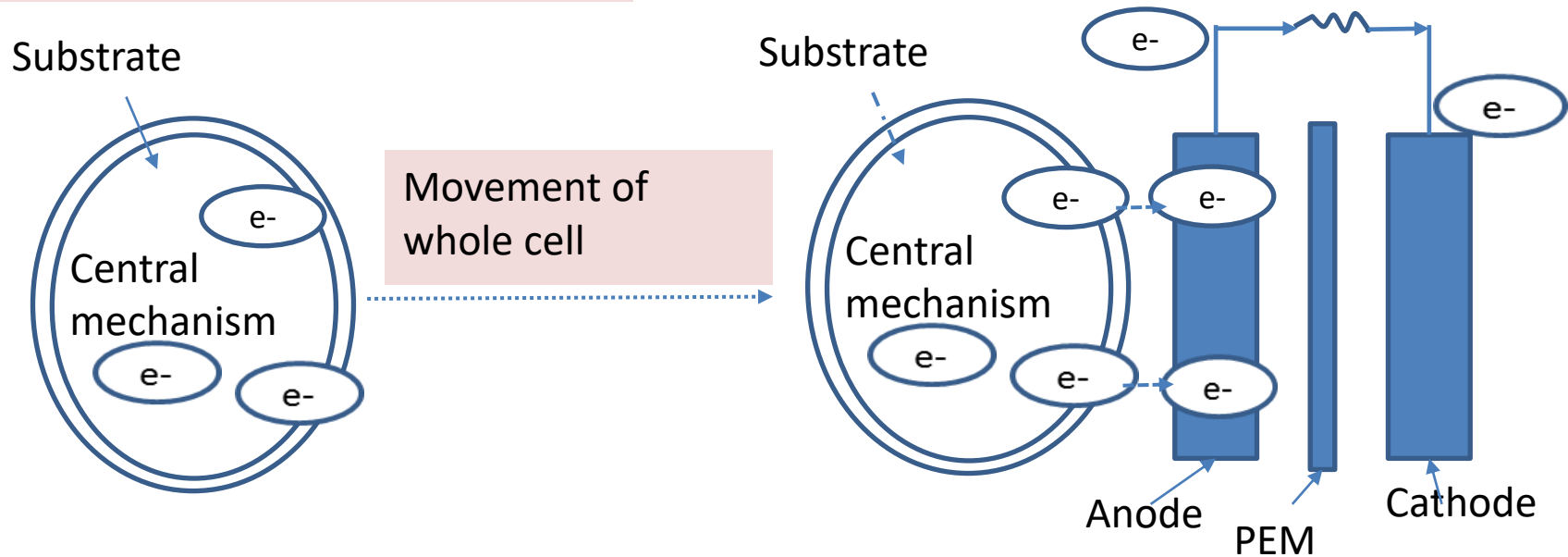
Electro transfer mechanism



[thionine](#), [methyl viologen](#), [methyl blue](#), [humic acid](#), [neutral red](#)

Indirect transfer; (a) through externally added (exogenous) mediator, (b) through self excreted(endogenous) mediator

Electro transfer mechanism

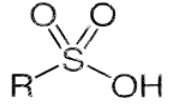


Electrochemically active [redox proteins](#) such as [cytochromes](#) are present on their outer membrane that can transfer electrons directly to the anode

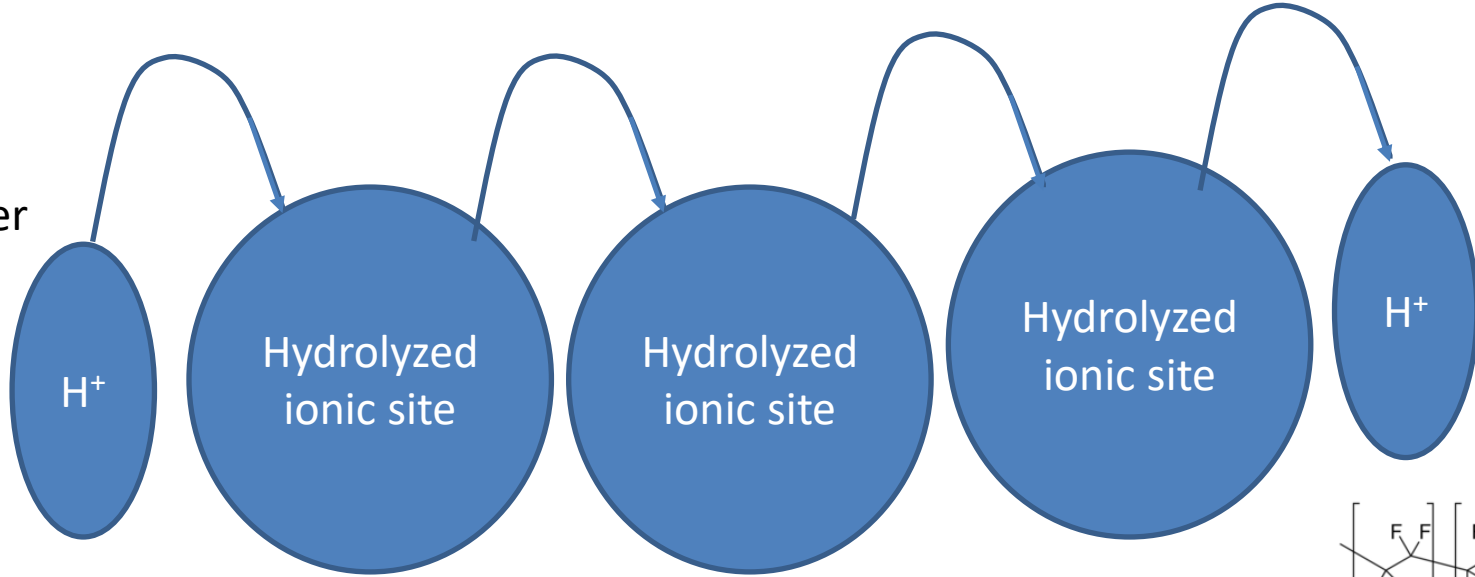
Direct electron transfer

Proton transfer mechanism

Hydrolyzed ionic sites: $\sim\text{SO}_3^- + \text{H}_3\text{O}^+$
(sulphonic acid)



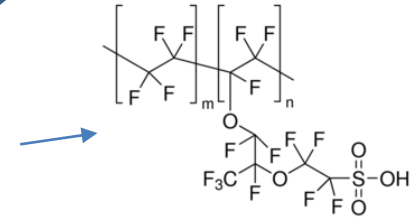
Anodic
chamber



Cathodic
chamber

Proton hopping mechanism

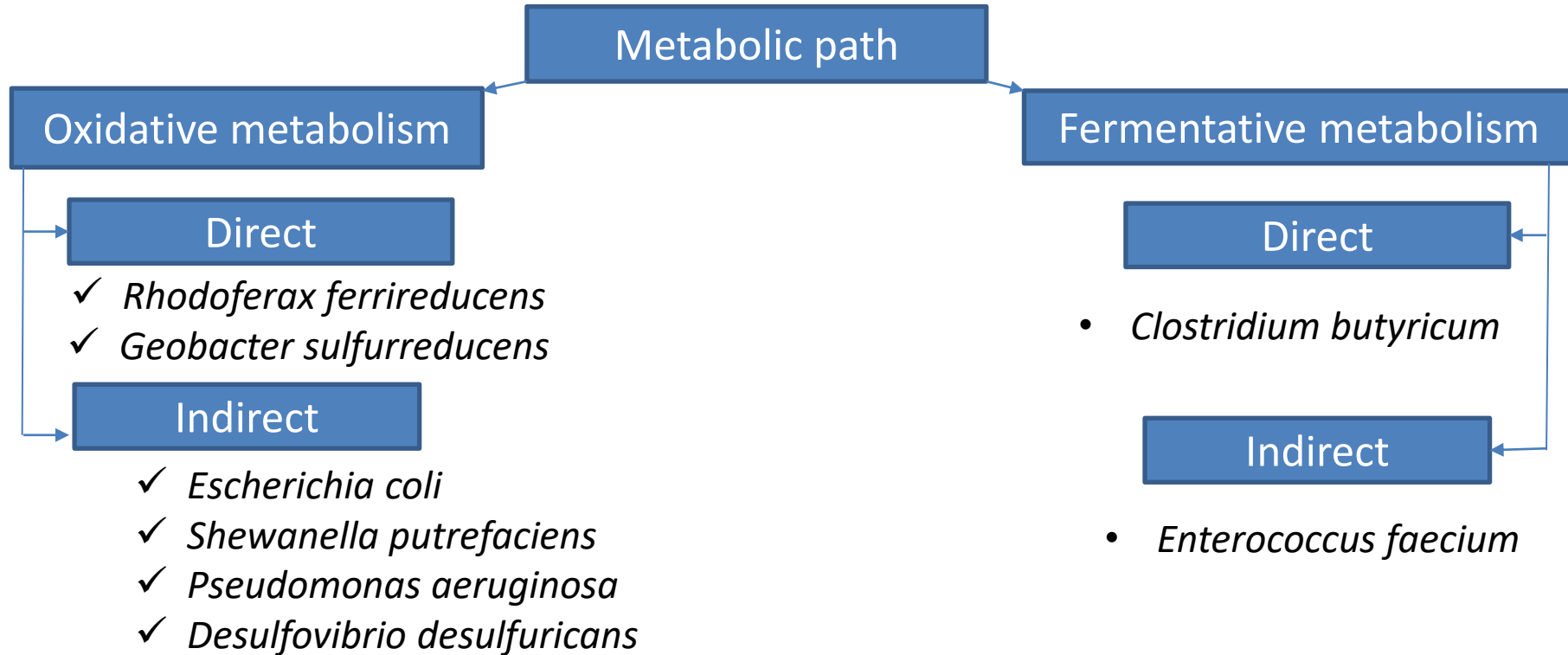
Nafion



Design of microbial fuel cells

Items	Materials
Anode	Graphite, graphite felt, carbon paper, carbon-cloth, Pt, Pt black, reticulated vitreous carbon (RVC)
Cathode	Graphite, graphite felt, carbon paper, carbon-cloth, Pt, Pt black, RVC
Proton exchange system	Salt bridge, porcelain septum, or solely electrolyte Proton exchange membrane: Nafion, Ultrex, polyethylene, poly (styrene-co-divinylbenzene), sulfonated polystyrene
Electrode catalyst	Polyaniline, electron mediator immobilized on anode, Pt, Pt black, MnO_2 , Fe^{3+} ,

Microorganisms with different metabolic paths and electron transport systems



Some Microbes used in MFC

Micro-organism	Substrate	Anode	Current (mA)	Power (mW/m ²)	Reference
<i>Shewanella putrefaciens</i>	lactate	woven graphite	0.031	0.19	Kim et al. 2012
<i>Geobacter sulfurreducens</i>	acetate	graphite	0.40	13	Bond and Lovley 2010
<i>Rhodoferax ferrireducens</i>	glucose	graphite	0.2	8	Chaudhuri and Lovley 2011
	glucose	woven graphite	0.57	17.4	Chaudhuri and Lovley 2011
	glucose	porous graphite	74	33	Chaudhuri and Lovley 2011

Some Microbes used in MFC

Micro-organism	Substrate	Anode	Current (mA)	Power (mW/m ²)	Reference
Mixed seawater culture	acetate	graphite	0.23	10	Bond et al. 2012
	sulphide /acetate	graphite	60	32	Tender et al. 2012
Mixed active sludge culture	acetate	graphite	5	-	Lee et al. 2013
	glucose	graphite	30	3600	Rabaey et al. 2013

Comparison of the performance of MFC in pure and mixed culture

Pure bacterial culture:

- Although these bacteria generally show high electron transfer efficiency, they have a slow growth rate, a high substrate specificity (mostly acetate or lactate) and relatively low energy transfer efficiency compared to mixed cultures. Furthermore, the use of a pure culture implies a continuous risk of contamination of the MFCs with undesired bacteria.

Mixed bacterial cultures:

- higher resistance against process disturbances,
- higher substrate consumption rates,
- smaller substrate specificity and
- higher power output



Parameters which affect the MFC operation

- ❖ Electrode material
- ❖ pH buffer and electrolyte
- ❖ Proton exchange system
- ❖ Operating conditions in the anodic chamber
- ❖ Operating conditions in the cathodic chamber
- ❖ Type and composition of substrate
- ❖ Type of oxidant used in cathodic chamber
- ❖ Presence and absence of catalyst

Voltage and Current Calculation

Current and Charge

The current I collected at an electrode is obtained by integration of all possible local current densities i_j over the electrode surface

$$I = \int_{A_F} \sum_j i_j dA$$

The charge (Coulombs) produced is calculated from the integration of cell current over time

$$Q = \int_0^t I dt$$



Voltage and Current Calculation

Voltage and over potential

Open circuit and closed circuit voltage

Ohm's law $V_{\text{cell}} = IR_{\text{ext}}$

The Cell power (P) = $V_{\text{cell}} I$

By summation of all polarization losses, the cell voltage is written as

$$V_{\text{cell}} = E_C - E_A - (\eta_{\text{act}} + \eta_{\text{Ohm}} + \eta_{\text{conc}} + \eta_{\text{pH diff}})$$

Where, η = Over potential or polarization potential,

i = Current density,

I = Total current through the MFC

V = Voltage (for the MFC) or potential,

R = Electrical resistance,

P = Microbial fuel cell power

E_C = electrode potential for the cathode

E_A = electrode potential for the anode

act = activation

conc= concentration

Alternatively

$$E_{\text{cell}} = E_{\text{emf}} - \eta_a - \eta_b - E_{\Delta pH} - E_{\text{ionic}} - E_T - E_m$$

where, E_{emf} is the open circuit voltage,

η_a is the anodic over potential

η_b is the cathodic over potential

$E_{\Delta pH}$ is the losses due to pH difference between cathodic and anodic solution

E_T is the transportation loss

E_m is the membrane loss

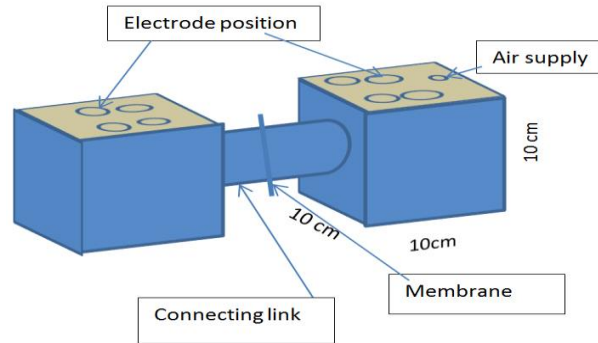
E_{ionic} is the ionic loss

Losses in MFC

- ❖ Ohmic losses
- ❖ Activation losses (because of accumulation of gasses (or other non-reagent products) at the interface between electrode and electrolyte)
- ❖ Bacterial metabolic losses
- ❖ Concentration losses (because of uneven depletion of reagents in the electrolyte, which causes concentration gradients in boundary layers)
- ❖ Mass transfer through the membrane
- ❖ Voltage loss due to pH difference between cathodic and anodic chamber

Types of MFC and improvement efforts

- Single chamber
- Double chamber
- Flat plate
- Membrane less MFC
- Up-flow MFC



Some efforts going on to improve the voltage and power generation in MFC are:

- Adding suitable metal ions and using metal reducing microorganisms
- Doping of catalysts on the electrode
- Increasing anode area and decreasing inter electrode distance
- Using more efficient microorganisms
- Using more suitable oxidant in cathode

Thanks...

