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A review on microbial fuel cell

Munaza Kausar

Institute of Industrial Biotechnology Govt. College University, Lahore
Corresponding author: *Munaza Kausar, Institute of Industrial Biotechnology Govt. College University, Lahore.

Abstract
Microbial fuel cell is a kind of bioreactor in which different kinds of bacteria are used for the sake of electricity production. Bacteria can be used as single bacterial cultures and as mixtures of bacteria. Different materials can be used for the anodes and cathodes. Biofilm use substrate for the sake of electrons production. Electricity is produced due to the movement of electrons.

Keywords: Bioreactor, Biofilm

1. Microbial fuel cell

Due to the global shortage of electrical energy scientists are striving to find alternative energy sources. During experiments it was observed that some microbial strains can be used for electricity generation. In this way a microbial fuel cell was produced (Leropoulos *et al*., 2012). A microbial fuel cell (MFC) is a kind of bioreactor which converts the biochemical energy of organic compounds into electrical energy through different metabolic reactions.A historical study of microbial fuel cell tells that different scientists worked on different microorganisms and found that they are safe to be used as fuel cells (Rinaldi *et al*., 2008).

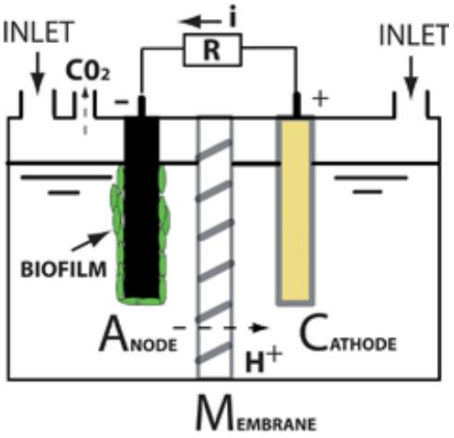

Figure 1: A typical microbial fuel cell

2. Working principle of microbial fuel cell

A typical microbial fuel cell consists of an anode and a cathode. The two electrodes are separated by a membrane which act as an ion exchanger such as Nafion, Ultrex or a salt bridge (Bond *et al*., 2002, Park *et al*., 1999, Rabaey *et al*., 2003, Freguia *et al*., 2007). They are linked together by an electric circuit. Microorganisms are used as biofilms in MFC.

The anode of MFC consists of a biofilm of anaerobic bacteria. In anodic compartment, a solution of some organic compound is added so that it can be used by biofilm's bacteria to produce free electrons and cations. In this compartment oxidation of organic compounds (fuel) occur so that the current can flow through the circuit. In cathodic compartment of MFC, aerobic bacteria are used. Cations pass through the salt bridge. Basically these cations reacts with oxygen in cathodic compartmentand reduction occurs. Free electrons pass through the external circuit to the cathode and takes part in reduction. Due to the flow of electronselectrical energy is produced which is accompanied by internal resistance. This resistance causes the cell voltage to drop. It can calculated by the formula given below;

$E_{cell} = [E_{cathode} - |\eta_{act,\,c} + \eta_{conc.c}|\,] - [E_{anode} - |\eta_{act,\,a} + \eta_{conc.a}|] - \eta_{ohm}$

In the above equation, $E_{cathode}$is the cathodic potential,$E_{anode}$is the anodic potential, η_{act} is the activation polarization, η_{conc} is the concentration polarization and η_{ohm} is the ohmic loss.

Activation polarization is basically the activation energy required by the organic compounds of anodic compartment to undergo oxidation. It depends on MFC temperature, current density flowing through the circuit and MFC mediators.

Concentration polarization depends on the energy loss during the process, accumulation of reaction products and depletion of reactant of MFC. **Ohmic losses** are due to the internal resistance of MFC and it can be determined by ohm's law.

3. Biochemistry of microbial fuel cell

Inside MFC organic compounds are used as fuel. They are catabolized by bacteria either through aerobic or anaerobic reactions. During respiration, aerobic catabolism of organic compounds (fuel) occurs. This process usually involves heterotrophic bacteria which requires different nutrients including nitrogen, potassium, phosphorous and some other ones. During fermentation, anaerobic catabolism of organic compounds (fuel) occurs. Different kinds of bacteria which can transfer free electrons from anode to the cathode, are involved including *Rhodoferax ferrireducens,Enterococcus gallinarum, Pseudomionas aeruginosa, Geobacter sulfurreducens,Geobacter metallireducens*and*Shewanella putrefaciens*(Richter *et al*., 2007).

In MFC microorganisms use two kinds of methods to transfer the electrons. One is direct electron transfer and other is mediator basedelectron transfer. First one involve the presence of cytochromes. If these cytochromes are directly attached to the anode then it becomes easy to transfer electrons and direct electron transfer occurs. If bacterial cell is at some distance from the anode then special structures of bacteria named pilli are used to transfer electrons. Pilli attach the bacteria to the anode and transfer of electrons occurs.

In mediator based electron transfer, redox mediators are used. They can be exogenous or endogenous (shuttle). A typical mediator should be active electrochemically, should physically contact with electrode and its electrode potential should be near to the redox potential of substrate. Exogenous mediator needs to be supplied continuously. They can be toxic to the MFC. Therefore endogenous mediators are preferred over exogenous one. Secondary metabolites produced during process can act as endogenous mediators (Hernandez *et al*., 2001).They can transfer electrons more effectively.

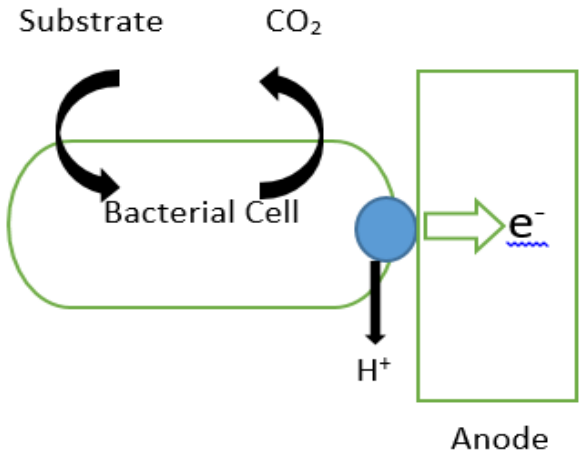

Figure 2: Direct electron transfer without pilli

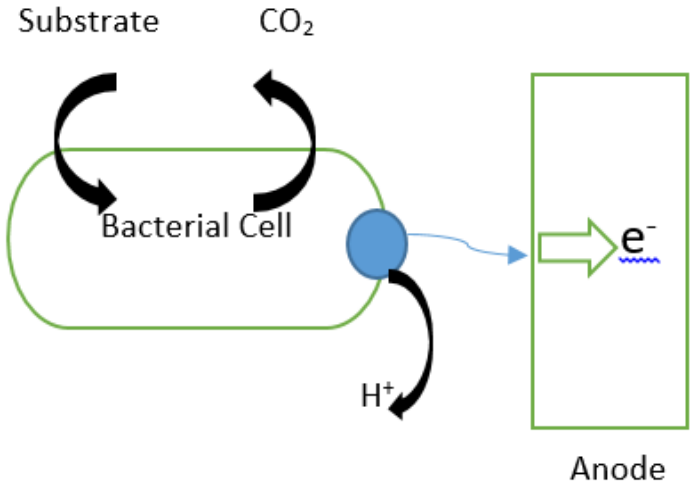

Figure 3: Electron transfer with pilli

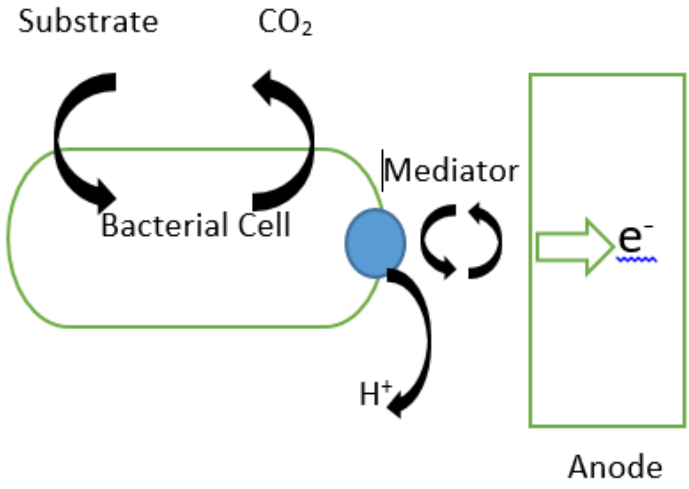

Figure 4: Electron transfer through mediators

Different kinds of mediators which can be used in MFC are given below in the table:

Table1: Redox potential of mediators

Mediators	**Redox Potential (V)**	**Rate of Reduction umol(g dry wt)$^{-1}$s^{-1}**
Resorufin	-0.051	0.61
New Methylene Blue	0.021	0.20
Phenothiazinone	1.43	0.130
Thionine	0.064	7.10

Mixed culture microbial fuel cells are also prepared (Jung *et al*., 2007, Shukla *et al*., 2004). In these MFC bacteria show good performance. Some bacterial products are used by other ones for better performance. Some bacteria work in conjunction with others. In this way the overall performance of MFC is increased. Energy production from organic compounds (fuel) is enhanced. The inter-relation of microorganisms is shown in the figure given below:

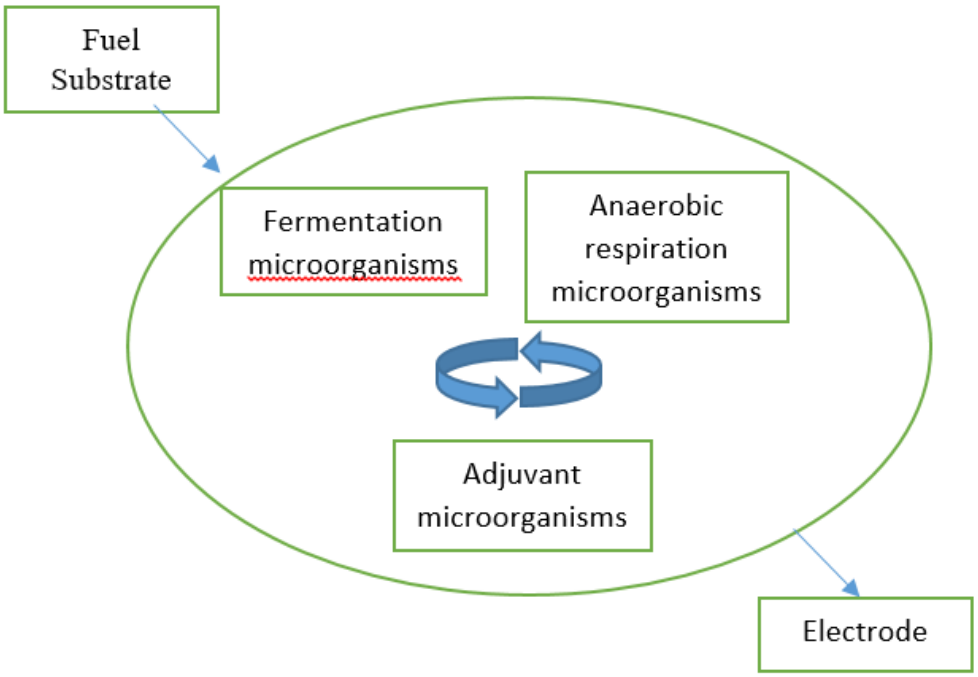

Figure 5: Interdependancy of microbial strains

This picture shows that fermentation microorganisms, anaerobic microorganisms and adjuvant microorganisms are linked with respect to their performance (Hai Pham*et al*., 2008, Aelterman *et al*., 2006)

Table 2: Basic components and materials for MFCs

Components	Materials
Anode	Stainless steel mesh, graphite plates, granules, carbon paper, carbon foam, reticulated vitreous carbon
Cathode	Graphite, Carbon felt, Carbon cloth, Glassy carbon, reticulated vitreous carbon
Ion Exchange membrane	Salt Bridge, Anion exchange membrane, Nafion, Ultrex
Electrode Catalyst	MnO_2, Polyaniline, electron mediator immobilized anode

4. Microbial fuel cell configuration and materials

A typical microbial fuel cell consists of anode, cathode and a separating membrane which are composed of certain materials. These materials can affect the power density and coulombic efficiency (total electrons involved in current production to the total electrons produced) of MFC. Some materials of MFC are listed in the table given below (Liu *et al*., 2004, Sell *et al*., 1989, Zhao *et al*., 2005)

Different kinds of MFC configurations have been developed. Mostly two chambered microbial fuel cells are used. Similarly different mode of actions are employed in microbial fuel cell including batch, fed batch and continuous mode (Kim *et al*., 2008).

Anode composition

Anode composition is very important for the proper functioning of microbial fuel cell. As biofilms are attached with anode, therefore, anode composition should be such that microorganisms can easily interact with them and oxidation process and electron transfer can occur effectively. Different materials are used for anode formation including different kinds of graphite, non-corrosive stainless steel, carbon paper, carbon cloth and carbon foam (Aelterman *et al*., 2006, Logan *et al*., 2006, Chaudhuri *et al*., 2003).

The output of microbial fuel cell can be enhanced by modifying the anode material. If Mn(IV) or Fe(III) in the substrate ofgraphite anode are linked to the neutral red then electron transfer can be enhanced (Park *et al*., 2002).Polyaniline(PANI)–Ptand Tungsten carbide have found to be very effective as anodic material because they can improve electrical conductivity and current generation (Schroder *et al*., 2003, Niessen *et al*., 2004, A. Lowy *et al*., 2006). Pt and Tungsten carbide are comparable to each other in performance (Park *et al*., 2007, Rosenbaum *et al*., 2006). Similarly some other modifications can be made in anode and current production can be increased.

Cathode composition

Different materials are used for the cathode formation. Fe^{+3} graphite cathode is found to very effective in electron capturing and passing it to the oxygen for the sake of reduction. If E.Coli is taken as biocatalyst in cathode chamber and anode is prepared of Mn^{+4} graphite then considerable amount of current can be produced (Park & Zeikus., 2002). On the other hand if cathode is made of lead dioxide and glucose is used as a substrate then good amount of current can be produced (Morris *et al*., 2007). On the other hand ferricyanide or permanganatecan be used as electrolytes in cathode compartment because they can act as good electron acceptor as compared to oxygen

(Aelterman *et al*., 2006, You *et al*., 2006, Oh *et al*., 2004).

Bacteria used in Microbial fuel cell

Bacteria which can play role in electricity generation are used in microbial fuel cell and they are named as electricigens or anodophilic bacteria (Lovely., 2006, Logan *et al*., 2006) . These bacteria can completely oxidize their substrates and resulting electrons are transfer to the cathode via internal shuttles (mediators) (Bond & Lovely., 2003). Commonly used bacteria for electricity generation includes *Geobacter metallireducens, Shewanella putrefaciens* and *Geobacteraceae sulfurreducens*(Schroder, 2007, Lovely., 2006*).*In some cases mixed cultures of bacteria can be used in microbial fuel cells. This mixture consists of electrochemically active bacteria which can live symbiotically. These mixture include *Shewanella* and*Geobacter* species, ß-*Proteobacteria,*□-*Proteobacteria,*ε-*Proteobacteria*(Kim *et al*., 2004, Reimers *et al*., 2007).

5. Conclusion

Microbial fuel cell is a great discovery of scientists. Its composition is simple, therefore, it can be used easily. Different bacterial species can be used in microbial fuel cell but they should be electricigens. It can be used for electricity generation, biohydrogen production, in biosensors, in waste water treatment and bioremediation.

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