Microbial Fuel Cells: A Promising Tool for Power Generation

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Abstract: ***The non-renewable resources of energy are exhausting in an alarming rate globally. Hence, the search for alternate renewable energy sources are the need of the hour to cope up with the merging power needs. Microbial Fuel Cells are one of the most promising tools not only to generate power but also to curb waste menace. Moreover, MFC has applications in waste treatment, power generation, robotics, defense, implanted medical devices etc. The future of MFCs are promising as it engenders green technology without CO_2 emission.***

Keywords: Microbial Fuel Cells, Electrical Energy, Power Generation

1. Introduction

Microbial Fuel Cells (MFCs) converts chemical energy into electrical energy *via* substrate oxidation with the aid of microorganisms which act as biocatalysts. Microbial fuel cell comprises a novel method for treatment of waste and biological power genesis at the same time. In short, Microbial fuel cells (MFCs) are devices which uses bacterial metabolism for the generation of electricity from a wide spectrum of organic substrates. Electrons which are developed by the bacteria through oxidation of substrates are transposed to the anode and further it flows to the cathode which are connected by a conductive material containing a resistor, or operated under a load (Figure 1).

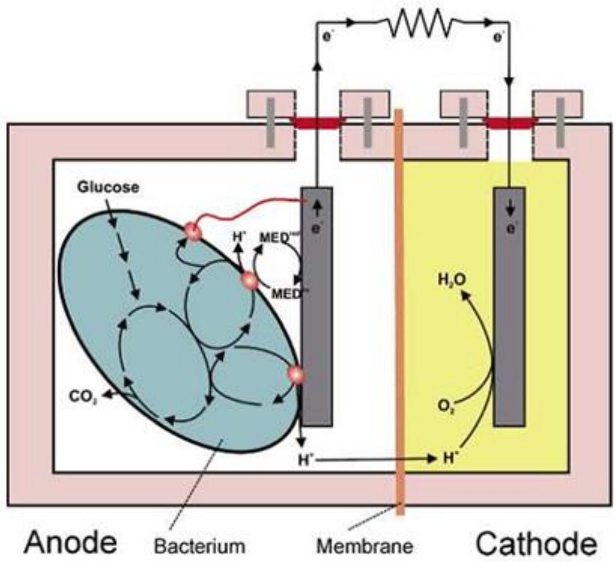

Figure 1: Basic principles of an MFC

2. Principle

M.C Potter in 1911 started the study of MFC to generate electricity from the bacteria - *Escherichia coli* (Potter, 1912). Currently it is well established that electricity can be produced directly from the degradation of organic matter in MFC. During consumption of sugar the microorganisms under aerobic condition produce carbon dioxide and water, but when oxygen is absent, the end product is carbon dioxide, protons and electrons which is given below.

$$C_{12}H_{22}O_{11} + 13H_2O \longrightarrow 12CO_2 + 48H^+ + 48e^-$$

The cells thenceforth are made to use inorganic mediators to incorporate into the electron transport chain of cells and to admit the electrons that are produced. When the mediator crosses the outer cell lipid membranes and plasma wall, it begins to liberate electrons from the electron transport chain which in normal cases are taken up by oxygen and other intermediates. The reduced mediator leaves the cell with electrons that it carries to an electrode where it wedges them which makes the electrode electrogeneric anode. After the release of electrons the mediator returns to its oxidized state and repeats the process. It should be noted that this can happen under anaerobic conditions only. On the other hand, if oxygen is present, it will collect all the electrons as it has more electronegativity than the mediator. Mediators like natural red, methylene blue, thionine or resorfuin are used by various researchers in MFCs in diverse studies (Bennetto *et al.*, 1983 and Junqiu *et al.*, 2009).

This is the principle behind generation and flow of electrons from micro-organisms in MFCs. The whole process shall be conciliated in a fuel cell to turn the process into a usable supply of electric energy. For creating a complete circuit, the mediator and the microorganism are mixed together in a solution to which is added to suitable substrate like glucose. The whole set up is in anaerobic chamber forcing the microorganism to use anaerobic respiration. The electrode fitted in the solution will act as the anode. In the second chamber, another solution with an electrode which is positively charged will serve as cathode and is equivalent of the oxygen sink at the end of the electron transport chain. However, it is external to the biological cell.

During the use of glucose as an organic substrate, 24 electrons and 24 protons are released in the anode chamber. These protons and electrons both travel to the cathode chamber where 6 molecules of oxygen are needed to create 12 water molecules. Six carbon dioxide molecules are created at the anode.

$$\text{Anode: } C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24H^+ + 24e^-$$
$$\text{Cathode: } 24H^+ + 24e^- + 6O_2 \longrightarrow 12H_2O$$

The whole MFC reactions can be concluded as, an anode respiring bacterium digests the organic waste to carbon dioxide and transfers the electrons released to the anode. Then the electrons are transferred from the microorganism to the anode, which involve direct electron transfer *via* outer membrane cytochromes, mediators or nanowires. Then, the electrons travel from the anode through an external circuit to generate electrical energy. In the end, the electrons complete the circuit by travelling to the cathode, where they are taken up by oxygen and hydrogen ions to form water.

Microorganisms in MFC

The microorganisms using in MFC are those who can directly transfer electrons to anode using anode as terminal electron acceptors, those who can't directly but use mediators to transfer electrons to anode and those who can accepts electron from cathode. The major sources of these microorganisms are marine sediments, waste water, fresh water sediments and mining. Almost all microorganisms used in MFC are metal reducers in nature.

Table 1: Commonly used bacteria in MFCs

Sl. No.	Bacteria	Mode of action
1.	*Actinobacillus succinogenes*	Needs exogenous mediators
2.	*Aeromonas hydrophila*	Mediator less MFC
3.	*Erwinia dissolven*	Mediator based MFC
4.	*Geobacter sp.*	Mediator less MFC
5.	*Klebsiella pneumonia*	Mediator based MFC
6.	*Proteus mirabilis*	Mediator based MFC
7.	*Pseudomonas aeruginosa*	Exogenous mediators
8.	*Rhodoferax ferrireducens*	Mediator less MFC
9.	*Shewanella oneidensis*	Exogenous mediators
10.	*S. putrefacien*	Mediator less MFC, Exogenous mediators improve electricity production
11.	*Streptococcus lactis*	Mediator based MFC

(Rabaey *et al*., 2004; Das and Neelam, 2010)

Conventional Fuel Cell (CFC) and Microbial Fuel Cell (MFC)

The intention of a fuel cell is to produce electrical energy from a fuel with the help of electrochemical conversions. The Conventional Fuel Cells (CFC) employs either hydrogen (H_2) or other high grade hydrocarbons like methanol as fuels, and normally uses oxygen as oxidizing agent. In CFC, the hydrogen-hydrogen (H-H) bond and oxygen-oxygen (O-O) bonds are broken, and new hydrogen-oxygen (H-O-H) bonds are created. The energy of the H-O-H bond configuration is lower than the bond for the reactants (O-O and H-H), and therefore energy is being released. In order to attain high voltage and current, fuel cells are connected and packed together in close bunks. The CFC technology is incessantly mending, and has already started to take up the fight on the electronics market, where instead of becoming gradually depleted like a battery, a fuel cell produces electricity as long as it has a supply of fuel and oxidizer. And since hydrocarbons are far more compact than lithium batteries, electronic gadgets could run for many days on a small tank.

CFC uses expensive materials such as platinum to act as a catalyst, while MFC uses bacteria to promote and increase the reaction rate in the anode reaction. Moreover, instead of using hydrogen (H_2) or other high grade hydrocarbons as fuel, MFC uses biological materials as its nutrient and energy source.

Table 2: CFC and MFC comparison

Description	CFC	MFC
Fuel	Hydrogen (H_2)	Lactate or other biological mass
Waste/ Exhaust	H_2O	H_2O and partially decomposed nutrition / fuel
Anode Catalyst	Typically platinum Expensive material	Microorganisms
Reaction Mechanisms	Combustion kinetics	Live biological system
Current density	~1 A/cm^2	~1 A/cm^2

Applications of MFC

Electricity generation is the prime application of MFCs. MFCs is found application in low power wireless systems too. Reports are available using the MFC to utilize the body glucose to power implanted medical devices (Ieropoulos *et al*., 2003). MFC has application in robotics like self sustainable autonomous robots. Waste water treatment and subsequent electricity generation was well established with production of lesser solid waste. MFCs directly convert substrate energy into electricity which is advantageous in every aspect. In short, the emergence of MFC technology has plethora of applications in the daily lives as it is ecofriendly and green technology.

MFC Future

There are many challenges remaining for full exploitation of MFCs, to find ways to make it cost effective, and to create MFC bioreactors for wastewater treatment. Discovery of new organisms that can directly transfer electrons to or from an electrode is essential to mitigate polluted water or soil with generation of power. There is a wide scope for development of MFCs as the power density is too low for deployment in automobiles and other industrial applications. Moreover, the microorganism can be genetically modified to form high reducing recombinant strains with MFC applications. Studies are needed to lower the internal resistance and corrosion in MFC. The use to power up medical implants and hand held appliances are still in infancy. MFCs can also have utilization in defence to power up remote surveillance and communication gears for use in unmanned places.

3. Conclusion

MFC convert biochemical metabolic energy into electrical energy *via* the utilization of organic waste products such as domestic waste water, lignocellulosic biomass, industrial waste water and landfill leachate. MFC can be also used for bioremediation and production of secondary fuel. However, the MFC technology is still in infancy and needs special attention in future research endeavours.

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