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Fundamentals and Field Application of Microbial Fuel cells (MFCs)

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ABSTRACT

Introduction of Microbial fuel cells (MFCs) technology has shown metabolic degradation of wide range organic substrates in wastewater and sludge. Intensified studies are geared towards elucidation behavior of bacteria in the process. This review presents the fundamentals of MFC technology and its application as power source for subsea and biomedical devices as well as biotreatment of wastewater. A wide variety of industrial, agro/agro allied and domestic wastewater as sources of organic and inorganic substrate is effectively converted to electricity with about 40-90% COD and BOD reduction, while achieving applicable power generation and Columbic efficiency. A good knowledge of the MFC is required for sustainable improvement of the MFC application.

Keywords: microbial fuel cell; electricity generation; biotreatment; wastewater

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INTRODUCTION

The dwindling fate of the world's major energy source in terms of depletion and its environmental effect has put stockholders on the quest for a 'greener', more sustainable, environmentally friendly and cost effective energy source [1, 2]. The role fossil fuel plays in global warming and the impact of crude oil handling facility has heightened the desire for a more reliable energy source. Microbial Fuel Cell Technology (MFC), an energy recovery process, which converts biodegradable organic substrate into energy, has gain wide research interest. MFC produces energy from a variety of wastewater including industrial, domestic and synthetic wastewater [2-5]. This makes the MFC technology a veritable and complimentary source of energy over the fossil fuel providing the energy supply and waste treatment [5-9].

The potency of the MFC in energy generation has been widely studied. Energy is been harvested from various wastewater sources including industrial brewery wastewater [10, 11, 13] Paper wastewater [10, 11], Sugar processing [10, 12], Agro allied wastewater [2, 13, 14, 15, 16] and Domestic wastewater [17] and Synthetic water [2, 18]

While the MFC is studied vigorous in the past six to seven years, resulting in the development of several MFC configuration and higher electricity harvesting MFC setup, there are many limitations in the system leading to few field application. Scale-up, high production cost and low electricity generation has been sported as areas that needed to be improved upon in the MFC technology.

This paper review presents the fundamentals of a microbial fuel cell, and its application in the area of electricity generation and wastewater treatment. The limitation of the MFC technology is also highlighted.

Microbial Fuel Cell (MFC)

The MFC is a device that produces electricity from the metabolic activity of microbes which transform chemical energy by anaerobic chemical reaction in an anode chamber into electrical energy. The MFC as shown in figure 1, consist of the anode and the cathode separated by an ion exchange membrane known as Proton exchange membrane, PEM or Cation exchange Membrane CEM. The MFC component includes the PEM, two electrodes (Anode and cathode), anode and cathode chamber. The anode chamber contains the fuel also known as substrate usually made of organic and or inorganic matter which undergoes anaerobic metabolic degradation catalyzed by bacteria to produce proton and electron [18, 19]. The electron produced in the bulk anode electrolyte is shuttled to the anode electrode by anodophiles present in the substrate (Mediatorless-MFC), or supplied externally (Mediator-MFC) [13, 20]. The electron produced in the anode chamber flows through an external connection into the cathode chamber while the proton passes through the exchange membrane to the cathode.

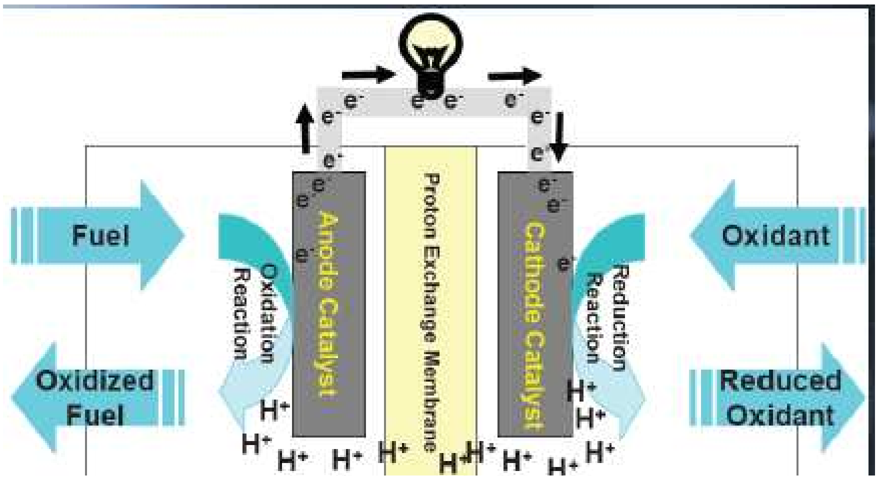

Figure 1: Typical Microbial Fuel Cell [1].

Classification of Microbial fuel cell

Single and Dual Chamber MFC

Different configurations and modes of MFC have been developed in a bid to optimize the efficiency of the MFC and reduce the limitations in the fuel cell units. The MFC types based on configuration includes the single and dual chamber. The single chamber has the anode and the cathode compartment house in the same compartment with the cathode exposed directly to air while their electrolyte is the same as shown in Figure 2. The dual chamber is made of two separate compartments, as shown in Figure 2B, connected together by a Proton exchange membrane [19, 21].

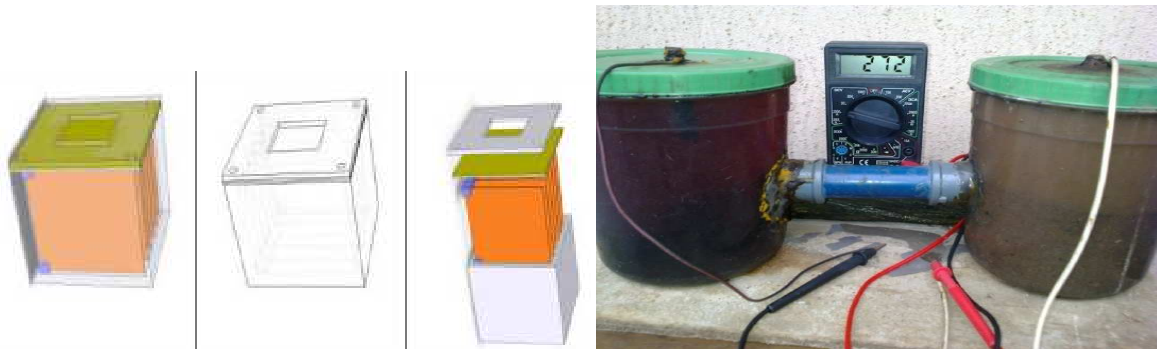

Figure 2 A) Single Chamber MFC [22] **B) Dual Chamber MFC [15]**

Mediator and Mediator-less MFC

The Mediator-less MFC (MLMFC) is a type of MFC does not use mediator to transfer electrons to the electrode. Mediator which were in use in the earlier development of the MFC have been found to be toxic to the endogenous anodophile microorganism there by reducing the efficiency of the MFC [23]. The additional advantage of the MLMFC is cost of the mediator which increase the overhead cost of the MFC. Cost is reduced by the adoption of the mediator-less MFC [23, 25].

Components of Microbial Fuel Cell

The need for wider application and increase power output of MFCs has resulted to the alteration of the essential physical components of MFCs which includes the anode, cathode and proton exchange membrane [19]. Optimization studies are mainly focused on overcoming the barriers to electron and proton generation and transport and to enhance the formation of biofilm [13].

The Anode and Cathode Chamber

In the Anode chamber, Electricigens which are active bacteria oxidize the substrate to generate electrons and protons, and transport the electrons to the anode electrode surface to form biofilm [19, 26]. These electrons travel to the cathode through the external circuit while the protons travel to the cathode by diffusing through the electrolyte and exchange membrane. The protons on passing to the cathode chamber forms water by combining with the electrons and oxygen, with the aid of catalyst [2, 27].

Proton exchange membrane (PEM)

The Proton exchange membrane permits the passage of protons to the cathode chamber. Nafion (DuPont, USA) a type of PEM developed for optimum transport of proton generated in the anode chamber to the cathode chamber due to its selectivity. Nafion is expensive resulting to increase in unit cost of MFC. Ultrex CMI-7000 (Membrane International Incorp., Glen Rock, NJ) is also applied as an alternative for the Nafion as it is comparatively cheaper and in some cases perform better than Nafion [19]. The design of a cheaper PEM has been reported to me a major factor to improve the unit cost of MFC [19, 28]. PEM in some cases is called CEM based on the fact that it allows for the transfer of other ions like Na+, K+, NH4 +, Ca2+, and Mg2+ apart from proton. These competitive transfers has been noted to inhibit proton transport through PEM including the Nafion and eventually reduce the performance of MFCs. [19, 29].

Electrode Materials and Catalysts

Research has shown that the selection of material such as substrate, anode and cathode electrode for MFC has a major effect on the efficiency of the MFC [28]. The material affect key parameters of coulombic efficiency (CE) (the ratio of total electrons recovered as current, to maximum possible electrons if all substrate removal produced current) and power density (PD). The basic properties of the MFC electrode include biocompatibility, conductivity, non-corrosive and surface area. Many materials that have found application as electrode in MFCs include carbon paper, cloth, foam, and felt; graphite rod, foil, brush and granules, activated carbon, reticulated vitreous carbon,; metals, aluminum, nickel and stainless steel Carbon felt, graphite with Mn^{4+} or Fe^{3+}, platinum, graphite-ceramic composite, cobalt, wood ash cement composite [19, 28, 30, 31, 32].

MFC Operational Factors

The operational factor that affected the performance of MFC includes the pH, DO concentration, material type and surface area of electrode, temperature, presence of catalyst and electrolyte strength [13,19]. Power losses occur in MFC due to overpotential, This is losses which can be minimized by MFC reactor configuration, electrode type, surface area and spacing, use of protons-selective PEM. Larger surface area electrode has shown result of threefold higher current [13]. This is the same with type of electrode. Also closer electrode spacing between the anode and cathode reduces the internal resistance of the MFC thereby improving, proton transport. The level of DO affects the performance of MFCs the presence of oxygen greatly improves on the proton sink as electron acceptor in the cathode but also plays an inhibitory role on anaerobic anodic bacteria [13].

Microorganisms in a Microbial Fuel Cell

Microorganisms in the MFC breakdown organic or and inorganic substrates in the anode chamber to produce and transfer electrons to an electrode surface, this biochemical reaction generates proton also which migrate to the cathode and combine with the electron and mainly oxygen as catholyte, which is reduced at the cathode surface. This produces electricity and metabolizes the wastewater which is mainly the MFC fuel, microbes acting as a catalyst on the anode surface. Consortiums of microorganisms are found in association with electrodes in MFC. These include [13, 33]; anodophilic biofilm that interact directly or indirectly with the anode.

- *Brevibacillus* sp. found in abundant member of a MFC community. Power production by *Brevibacillus* sp. is low unless it is cocultured with a *Pseudomonas* sp. or supernatant from a MFC run with the *Pseudomonas* sp. is added.
- *Firmicutes* and *Acidobacteria*,
- *Proteobacteria*
- *Saccharomyces cerevisiae*
- *Hansenula anomala*.
- *Shewanella oneidensis*
- *Geothrix fermentans*
- *Rhodoferax ferrireducens*.

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Applications of Microbial Fuel Cells

Waste water treatment

MFC has found application in the area of waste treatment as a variety of waste water can be oxidized ranging from acetate [2, 20], phenol [34, 35], pyridine [36], glucose [2], starch [2], cellulose [2], to complex substrates like domestic waste water [2], petroleum contaminates [3, 37, 38] including Industrial: brewery wastewater [3, 10, 13], Paper wastewater [10] Sugar processing [10, 12], Agro and agro allied wastewater [2, 13, 14, 15, 16]. The application of MFC for biotreatment of wastewater has recorded effective conversion of organic matter in wastewater into electricity with about 40-90% COD and BOD reduction.

Implanted Medical Devices

A major application of the MFC is in the powering of implanted medical devices using glucose in human body and oxygen from blood as anode and cathode respectively [22]. This application of MFC supplements power requirements for biomedical devices implanted in the human body reducing the need for routine surgery for the replacement of batteries [13, 22].

Biosensors

MFC has found application in monitoring and control of biological waste treatment unit. This is obtainable due to correlation of Coulombic yield of MFC and strength of organic matter in wastewater which serves as biosensor reading [24, 39].

CONCLUSION

This paper review reported the fundamentals of Microbial Fuel Cell (MFC) technology as an alternative energy source under development. The MFC technology which involves the biochemical conversion of organic and inorganic substrate into electrical energy is also report as a renewable energy which has found application in wastewater biotreatment and biosensor as well as in biomedical devices.

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