A Review on Microbial Fuel Cell Performance for Energy Generation

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ABSTRACT

Much work in a microbial fuel cell (MFC) is necessary in today's context to meet an environment-friendly and sustainable technology for alternative energy. A huge depletion in fossil fuel is going on rapidly. There may be high chance of a fuel crisis and global warming shortly. MFC is a promising technology in the field of energy production. MFC is a promising technology in the field of energy production. MFC operates with the degradation of different types of wastes by generating various by-products. Proper design and operation of MFC help to get optimum output. The performance of MFC depends on appropriate electrode materials, substrates, pH and type of microbes grown. In MFC, microbial oxidation of natural wastes occurs at ambient temperature. The generated reaction produces energy.

Keywords: Microbial fuel cell, Microbial oxidation of waste, Wastewater treatment, Electricity generation.

1. INTRODUCTION

The necessity to search for eco-friendly energy sources is mainly because of limitations in fossil fuels and the creation of global warming due to rapid urbanization. Combustion of fossil fuels emits huge amounts of CO_2, which causes global warming. The natural environment is adversely affected by emitted CO_2 (Venkata Mohan *et al.* 2011). Huge consumption of fossil fuels-based sources increases pollution around the environment making human life threatenable. Other energy sources must be searched (Kadier *et al.* 2015). Microbial Fuel Cell (MFC) is an alternative route of the energy generation process with negligible CO_2 emission (Venkata Mohan *et al.* 2013).

MFCs act as bio-reactor which uses micro organisms to transform accessible biodegradable chemical substrates into electrical energy. Biodegradation of matters in MFC is possible due to the action of exoelectrogenic microbes grown under anaerobic conditions through sequences of metabolic activities (Du *et al.* 2007; He *et al.* 2017). The concept of MFC is useful, and manywork has to be done to enhance its feasibility. The MFC performance concept was mentioned early in the 19th century (Potter 1911), and can be used for biological waste degradation and production (He *et al.* 2017).

2. MATERIALS AND METHODS

2.1 Metabolic Reactions in Microbial Fuel Cell

A microbial fuel cell is a reactor that converts the organic matter in substrates into electricity by a bio- electrochemical process. A typical microbial fuel cell consists of anodic and cathodic chambers separated by a semipermeable membrane. An anodic chamber is enriched with the microbial community where oxidation of organic matter takes place, liberating protons and electrons (Rabaey & Verstraete 2005). The liberated electrons are transported to the anode by exoelectrogenic microbes or mediators. Electrons flow from anode to cathode through an external circuit generating current. Protons migrate from an anodic chamber to a cathodic chamber through semipermeable proton exchange membrane. Electron acceptors accept electrons and protons forming water or other products (Mercer 2014; Min & Logan 2004).

In MFC in which glucose is used as a substrate, the electromotive force or driving force that causes the flow of electrons can be expressed through a redox reaction (Grzebyk & Pozniak 2005).

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24e^-$$

$$6O_2 + 24H^+ + 24e^- \longrightarrow 12H_2O$$

In MFC, the energy contained in the substrate is directly converted into electricity with high conversion efficiency (Liu *et al.* 2004). It can operate at ambient and even high temperatures where thermophilic microbes can be used (Li 2013). For the degradation of organic load in MFC, extra oxygen is not needed as an anodic chamber acts as an oxidizing chamber, whereas aerated oxygen enhances the reduction potential of the cathodic chamber (Liu *et al.* 2004).

The growth and activities of microorganisms are concerned with energy generation (Chandrasekhar & Venkata Mohan 2012). Minor energy held by microorganisms is used for their growth and metabolism and the rest of the energy is used for electricity generation. The system's total energy is compensated for liveliness of microbes and the generation of electrochemical energy. Therefore, to generate bioelectricity from MFC, it is essential that microbes should compensate for the sum of energy for its liveliness and that being transformed into electrochemical energy (Chandrasekhar & Venkata Mohan 2014)

2.2 Enhancement of MFC Performance Using Mediators

Most microorganism can less efficiently transfer electrons to electrodes (Allen 1972). The mediator helps for efficient electron transfer from microbes to the electrode. Mediators transport electrons by forming a reversible redox process (Fultz & Durst 1982). Neutral red and thionine are some of the common mediators used in MFC. The neutral red as an electron mediator is better than thionine with low sludge reduction, while electricity is produced efficiently (Park & Zeikus 2000). Mediators should be non-decomposable during the redox process and soluble in media. Mediators pass through or are absorbed by cell membranes (Park *et al.* 1999; Park & Zeikus 1999). According to You *et al.* (2006), permanganate and hexacyanoferrate can be used as an electron acceptors in place of oxygen in the cathodic chamber. At the cathode, using permanganate as an electron acceptor had a higher power density than hexacyanoferrate and O_2. A two -chambered MFC using permanganate as the cathodic electron acceptor (oxidant) was found to generate a maximum power density of 115.6 mW/m^2, which was 4.5 and 11.3 times greater than that produced by using hexacyanoferrate (25.6 mWm^2) and oxygen (10.2 mW/m2, respectively) with very high open circuit potential (OCP). These results show that the cathodic reaction is a serious limiting factor in an MFC.

2.3 Mediator-less MFC

Most of the mediators used in MFC are strong oxidizing agents. So the use of mediators in MFC may have several challenges. Oxidizing agents as mediator is highly risky due to the possibility of secondary reactions producing toxic metabolites. The metabolites may release into the environment, causing ecological side effects (You *et al.* 2006).

A lot of research work is going on in mediator-less MFC operation. Such MFC can be operated using exoelectrogenic bacteria (eg. *Pseudomonas sp., Geobacteria sp; Shewanella sp;* etc.). These bacteria can transfer electrons without mediators (Rabaey *et al.* 2004b; Pandit *et al.* 2015). These microbes transfer electrons either by conductive appendages (Reguera *et al.* 2005), cell-bound proteins (Chaudhuri & Lovel 2003) or indigenously produced soluble mediators (Roller *et al.* 1984).

2.4 Factors Affecting the Performance of MFC

Electricity generation in MFC is concerned with the nature of the substrate, microbial community, and metabolism. The microbial metabolism is determined by the the Hence, anode's potential determines When MFC is operated at low external resistance, generates low current during biomass build-up, and hence has a high anode potential (low MFC cell potential). During the mode of operation, the metabolic turnover rate and hence the current, will increase. When a high resistance is used, the potential of the anode will be low (Liu & Logan 2004). Besides, different factors affect the performance of MFC.

2.4.1 Effect of Substrate

The substrate in the anode compartment is the main factor affecting MFC. The dominancy in the growth of microbial population depends on the composition of the substrate. The substrate used in MFC has various carbon sources like simple to complex carbon and wastewater rich in nitrogen and phosphorus. In MFC, electricity generation is directly proportional to substrate concentration. The substrate concentration is measured in terms of COD which influences the fuel cell operation both in batch and continuous mode determining optimum substrate concentration is very important to achieve maximum power generation. However, a high concentration of substrate may cause feedback inhibition. (Chandrasekhar & Venkata Mohan 2012).

2.4.2 Effect of Type of Microbes

Microbes which acts as biocatalyst has significant role in generating power in MFC. It can be operated with pure culture and mixed culture of microorganisms. Pure and mixed cultured exoelectrogenic microbes directly transport electrons outside the cell membrane or mediators help as a shuttle for electron transport. Pure culture such as *Shewanella sp., Geobacter sp., Pseudomonas sp.* or *Rhodoferax sp*. has been used in single and double- chambered MFC reactor. *Pseudomonas sp.* is mostly dominant in MFC, in which the O2 and nitrate act as terminal electron acceptors. (Rabaey *et al.* 2004b; Pandit *et al.* 2015). The growth of microorganisms will be on the electrode surface by forming bio-film or it can transfer electrons through shuttle vectors (Rabaey *et al.* 2004a).

2.4.3. Effect of pH

Abiotic factor like pH has a vital role in MFC performance affecting the growth of microbes. The low and high pH can adversely affect in microbes population (He *et al.* 2017). Most bacteria are active at pH values between 6 to 8 in the anodic chamber and neutral or slightly basic in the cathodic chamber (Gil *et al.* 2003). However, according to Timur *et al.* (2007), the reduction in current density was found to occur at a pH of 6 to 9.

2.4.4 Effect of Electrode Materials

Materials with good conductivity, high surface area, non-corrosive, and non-fouling can act as good anodic electrode materials. (Logan 2008). Various types of graphite materials are potential for electrodes. Different graphite rods used by Chaudhuri & Lovely (2003) and Bond *et al.* (2002) HB pencil graphite used by Parkash (2005), and graphite rods from batteries used by Deval and Dikshit (2013) were found to be good as an anodic electrode. A carbon paper loaded with a platinum catalyst on one side was used as a cathode by Logan (2008).

Dumas *et al.* (2007) studied stainless steel embedded in marine sediments as an electrode. However, the maximum power density of 4 mW m-2 was produced lower than the graphite electrode. Stainless steel could be alternative electrode material due to its outstanding corrosion resistance, electrical conductivity, and mechanical properties. According to Pocaznoi *et al.* (2012), plain stainless steel is more efficient bioanode than a flat graphite electrode.

MFC with Platinum metal electrodes through good materialadds high cost to large-scale development based electrode as cathode needs a higher dissolved oxygen level of at least 2.2 mg/L in the cathodolyte, which is 10 times higher than that needed for aerobic bacteria (Milner *et al.* 2016).

2.4.4 Effect of Ion Exchange Membrane / Proton Exchange Membrane (PEM)

Membranes with low-resistant, efficient transport of protons from the anode to the cathode, which do not allow to penetrate substrate and oxygen, are preferred. Nafion and Ultrex are widely used. Nafion is the most effective PEM recommended by Jana *et al.* (2010). A salt bridge can replace the PEM at the starting stage of research. It is a combination of agar and salts solidified in a tube. It has high internal resistance and a small surface area with very low power density production (Logan *et al.* 2006). Deval and Dikshit (2013) and Anupama *et al.* (2011) studied distillery wastewater with two-chamber MFC using a salt bridge instead of PEM to reduce the cost of MFC.

3. RESULTS AND DISCUSSION

3.1 Application of MFC

3.1.1 MFC as a Waste Water Treatment System

Much work is performed to operate MFC in wastewater treatment. MFC is recently popular for wastewater treatment and power generation (Chandrasekhar & Venkata Mohan 2012). Liu *et al.* (2004) performed single chamber MFC to treat the domestic wastewater and observed 50% to 70% COD removal. Anupama *et al.* (2011) studied the distillery wastewater treatment using double chamber MFC, the maximum COD removal of 64 % was achieved at the feed concentration of 6100 mg COD/L. The fuel cell produced a maximum current of 0.36 mA and a power density of 18.35 mW m^{-2}.

3.1.2 MFC as Bio-hydrogen Generation

MFC is also used for bio-hydrogen production. Escherichia coli uses formate and glucose as substrates, producing hydrogen at 100% and 60% respectively (Nandi & Sengupta 1998). Similarly Glucose/cellulose in microbial fermentation produces acetic acid followed by electro-hydro genesis to produce hydrogen (Cheng & Logan 2007).

3.1.3 MFC as Electricity Generation

MFC is alternatively used for bioelectricity generation. According to Parkash (2015), mediator-less MFC with graphite electrodes dipped in glucose produced the maximum voltage of 1.9 mV and 1.4 mV by *Hansenula anomala* and *Saccharomyces cerevisiae*. MFC contains plain graphite as an electrode showing a power density of up to 3.6 Wm-2 using different feed rates of glucose solution (Rabaey *et al.* 2003).

4. CONCLUSION

The heavy consumption of fossil fuel and gases in different activities creates global warming and pollution around the environment. A recent demand for alternative energy and petroleum products / gases / fossil fuels in the world has to be established by modifying microbial fuel cells with suitable and cost-effective electrode materials, separators and design. MFC uses a wide range of natural wastes / waste materials harmful to the environment and living beings for electricity generation. During the operation of MFC, toxic materials are converted into less toxic material making it sustainable for bio-electricity generation. Besides electricity, it can be used for different purposes like waste treatment and generation of by-products like bio-hydrogen etc. So multidisciplinary research is needed in search of advanced development of MCF using various waste materials for energy production.

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