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HYDROGEN GENERATION THROUGH MICROBIAL FUEL CELL (MFC): A REVIEW

Chala Dida[1], Pinaki P. Nayak[2], Gaurav Saini[3*]

[1,2,3]*Department of Civil Engineering, School of Engineering & Technology, Sharda University,*

Abstract - A microbial fuel cell (MFC) is a bio-electrochemical device that harnesses the power of respiring microbes to convert organic substrates directly into electrical energy. At its core, the MFC is a fuel cell, which transforms chemical energy into electricity using oxidation reduction reactions. The microbial fuel cells rely on living biocatalysts to facilitate the movement of electrons throughout their systems instead of the traditional chemically catalyzed oxidation of a fuel at the anode and reduction at the cathode. Microbial fuel cells (MFC) have gained importance in the last few decades due to their ability to produce energy. MFC typically consists of several components primarily divided into two chambers, that is, a chamber containing the anode and cathode, respectively. These chambers are separated by a proton exchange membrane (PEM). The microbes present in the anodic chamber are provided with a favourable substrate which is an aerobically degraded to release electrons which are transported from the anode to the cathode via external circuit and the protons generated are selectively passed through the exchange membrane. Both these products produced due to the action of the microbes in the anodic compartment travel to the cathode and react with oxygen to produce water. MFCs are devices that can convert chemical energy into electrical energy by the process of oxidation of various carbon sources or even organic wastes carried out by electrochemically active bacteria (EAB). The current work presents a state-of-the-art review on this important topic.

Keywords - Microbial fuel cells, Wastewater treatment, Bioelectricity generation,

I. INTRODUCTION

Microbial fuel cell (MFC) technology is an advanced approach for electricity generation with the subsequent treatment of wastewater. A great effort has been made to research MFCs due to their potential for generating cleaner energy with a reduction in the net-carbon foot- print on nature. The first observation of bacteria generating electrical potential was reported as early as 1911, but the real breakthrough occurred in 1999 with the finding of mediatorless fuel cells. In a typical dual-chambered MFC (consisting of anode and cathode chambers), microorganisms degrade organic matter in the anode to release protons and electrons. Electrons travel through an external circuit and are received by a terminal electron acceptor (TEA) in the cathode. Many compounds, including nitrate, sulfate, and others, can function as a TEA, with the most common being oxygen. The protons released during oxidation traverse the proton exchange membrane (PEM) that is present between the two chambers to reach the cathode where the TEA is reduced. The proton-permeable membrane additionally keeps the anode anoxic, as the presence of oxygen can affect electricity generation by alternative substrate utilization. MFCs are unique alternative energy sources because they utilize a self-sustainable process involving self-replicating biocatalysts or microbes. Although the prospect of implementing MFCs for practical purposes seems challenging, the main limit upon the economic viability of such systems is a very low power output. The amount of power generated from microbial fuel cells is difficult to compare with other commonly used systems, although introduction of air cathodes has significantly changed the scenario. MFCs for practical purposes seems challenging, the main limit upon the economic viability of such systems is a very low power output. The amount of power generated from microbial fuel cells is difficult to compare with other commonly used systems, although introduction of air cathodes has significantly changed the scenario [1]. Microbial fuel cell (MFC) research is a rapidly evolving field that lacks established terminology and methods for the analysis of system performance. This makes it difficult for researchers to compare devices on an equivalent basis. The construction and analysis of MFCs requires knowledge of different scientific and engineering fields, ranging from microbiology and electrochemistry to materials and environmental engineering. Describing MFC systems therefore involves an understanding of these different scientific and engineering principles [2]. Microbial fuel cell (MFC) systems employ the catalytic activity of microbes to produce electricity from the oxidation of organic, and in some cases inorganic, substrates.

MFC systems have been primarily explored for their use in bioremediation and bioenergy applications; however, these systems also offer a unique strategy for the cultivation of synergistic microbial communities. It has been hypothesized that the mechanism(s) of microbial electron transfer that enable electricity production in MFCs may be a cooperative strategy within mixed microbial consortia that is associated with, or is an alternative to, interspecies hydrogen (H_2) transfer. Microbial fermentation processes and methanogenesis in ruminant animals are highly dependent on the consumption and production of H_2 in the rumen [3].

1. Microbial fuel cell

Microbial fuel cells (MFCs) are devices that use bacteria as the catalysts to oxidize organic and inorganic matter and generate current. Electrons produced by the bacteria from these substrates are transferred to the anode (negative terminal) and flow to the cathode (positive terminal) linked by a conductive material containing a resistor, or operated under a load (i.e., producing electricity that runs a device [2]. We know that, electricity can be generated from bacteria. In earlier period the bacteria have to be grown in laboratory for the production of electricity. As we have more amount of wastewater we can use that for generation of electricity. The bacteria already present in wastewater reduce the organic matter into electricity. Coliforms like *E. coli*, *Enterobacter*, *micrococci*, *lacto bacilli*, *pseudomonads*, facultative *clostridia* and *streptococci* are predominant in wastewater. These bacteria help in generation of power. The amount of energy that can be acquired by MFCs is relatively low if compared to other fuel cell technologies, but they have a unique feature in the field of fuel cells: they can harvest chemical energy from numerous classes of wastes, with the potential to effectively and directly convert into electrical energy numerous non-purified organic substrates, naturally present in different environments. Moreover, operating at room temperature and pH close to neutrality. [5]

The current paper discusses the theory and applications of this technology and presents a state-of-the-art review of microbial fuel cells.

2. Hydrogen production

A MFC can also harness energy in the form of hydrogen. The MFC can be modified to produce hydrogen instead of electricity [6]. MFCs can also be modified to produce hydrogen gas (H_2) by removing oxygen at the cathode and adding in a small voltage via the bioelectrochemically assisted microbial reactor (BEAMR) process or the biocatalyzed electrolysis process. This may be an economically viable process for producing H_2, because a recent U.S. Department of Energy report estimates that 10–12 mol-H_2 would need to be made per mole of glucose to make this route of H_2 production. Biohydrogen production via the BEAMR process is not limited to glucose. Any biodegradable substrate that produces electricity in an MFC should work in a BEAMR system. Recent research has shown that the process works with domestic wastewater, but H_2 recoveries in current reactor designs are still too low to make H_2 production with BEAMR likely to be as viable as electricity production with MFCs. For the BEAMR process, high-strength wastewaters appear to have the most immediate promise for H_2 recovery [7].

3. Wastewater management

The MFCs have shown the potential to treat different industrial, urban or domestic wastewaters. Though, the highly toxic wastewaters cannot be completely treated in MFCs, however MFCs are able to reduce the COD of wastewaters much enough to meet discharge regulations before it is released into the environment. The MFCs have proved up to 98 % COD removal from the wastewater [8]. Waste water effluent from industrial, municipal and other source acts as a primary source for energy, harvesting and simultaneously proving to be a suitable substrate toward bioremediation. Microbial fuel technology proves to be an ideal, solution to the long-lasting question of wastewater management [9]. MFC technology that was considered to be used for wastewater treatment early in 1991 is favourable as a completely different method because of capturing energy in the form of electricity or hydrogen gas [10]. For an efficient treating system, high operational sustainability and low material costs are worthwhile characteristics. Scientists have reported that to remove nitrogen and organic matters from leachate [11], biological treatment is prevalently used as a credible and highly cost-effective method [7].

4. Efficiency

The power outputs of MFCs have improved rapidly over the last decade, which is essential in full scale wastewater treatment plants. However, the currently achievable MFC power production has been improved by several orders of magnitude (approximately 10^6) within a short period [1]. This improvement was obtained by altering their experimental designs such as optimization of the MFC configurations, their physical and chemical operating conditions, and their choice of microorganisms. For example, by using a larger CEM (30.6 cm^2), the power was increased by 184% compared with that obtained with a smaller CEM (3.5 cm^2). In addition, enhanced voltage and current generation can be achieved using a stacked MFC with a hexacyano ferrate cathode by connecting several MFCs either in series or in parallel.

The connection of the 6 MFC units produced an increase in voltages (2.02 V at 228 W/m^3) and current (255 mA at 248 W/m^3), while retaining high power output [7]. Operating MFC in a continuous-flow mode holds potential advantages over a batch mode by maintaining a more stable substrate supply, more controllable environmental conditions for bacteria, and better mass transfer conditions. A maximum power density of 1010 W m^{-3} (1800 mW m^{-2}) was generated at a current density of 0.9 mA cm^{-2}, which was over 60% higher than that operated in the fed-batch mode. The ohmic resistance of the electrolyte of double-CEA MFC was 3.9 as measured using EIS.(K) Several modifications of the anode and cathode have been made to improve MFCs' performance. Various physical and chemical alterations have been used to obtain high-performance anodes and cathodes [2]. The main objective of MFCs is to achieve a suitable current and power for the application in small electrical devices. Rahimnejad et al. turn on ten LED lamps and one digital clock with fabricated stacked MFC as power source and both devices were successfully operated for the duration of 2 days [9]. Improvement in power density (PD) over the years has been observed from <1mW/m^2 to several watts depending on the surface area of electrodes. Alteration of parameters such as electrode materials or introduction of low-cost or membraneless MFC systems was optimized, but practical implementation has not been achieved due to the loss of generated power. In addition to an internal loss of power, scaling up and optimization of the reactor [1].

5. Application

MFCs have wide potential applications in various directions which may be developed because of extensive research. MFCs do not require any additional energy and work with extremely sensitive biocatalysts capable of quickly reacting to environmental changes. MFCs can be ideal choices for remote area sensors because they capture the microbial metabolic response to an environment and express it as electrical response [1]. The main applications of MFCs developed in recent decades are classified in the following forms. MFC is a fantastic technology that can use a wide variety of substrates, materials, and system architectures with bacteria to achieve bioenergy production despite the fact that power levels in all these systems were relatively low. It is particularly preferred for sustainable long-term power applications, with potential health and safety issues. Clytonbetin (2006) demonstrated if an MFC could convey 25mW of power, it would be suitable for cardiac stimulation; however, the amount of surface area needed is quite large [9]. Our petroleum resources will be depleted in about 200 years and after that, vehicles will no longer be equipped with petrol tanks. Researchers in the world are working to find an alternative for this. One very good alternative which is less wasteful and cleaner, is producing bioelectricity for vehicles directly from different substrates such as carbohydrate sources using MFCs. Complete oxidation of a monosaccharide such as glucose or disaccharide like sucrose to water and carbon dioxide can generate 16×10^6 J/Kg energy. This amounts to about 5 kWh of generated electrical energy. The most important goal of MFCs is to reach a suitable power generation level for application in small electrical devices [12]. In general, MFC use to generate electricity, Hydrogen, for wastewater treatment and also help to develop sustainable waste water treatment system. Moreover, conventional sewage treatment requires high energy and capital cost so there is great interest for finding clean and sustainable energy with very low or zero emission and cost effective that is an alternative for treatment technology [13].

6. Advantages and disadvantages

MFC is the big source of energy due to its cost efficiency and eco–friendly. Generally, we harvest renewable energy from solar energy, geothermal energy, and wind or water energy. But using MFC we can extract electricity from waste water. We actually spend large amount of money in cleaning the waste water if we make use of MFC and waste water we can save money. The cost of construction and operation of bio-cathode MFCs are lower than abiotic MFCs. The most common types of catalysts of non-biological cathode are Pt including Pt-coated metals, transition metal elements and ferricyanide. Pt is such a kind of efficient metal that the catalytic reaction with the Pt-catalyzed electrodes can improve the electrical properties of a MFC nearly 4-fold. Advantage of MFC is, it is best technology under development which can be used as wastewater treatment system, and it uses discarded organic materials to run the system. A disadvantage of this system is, energy output is too low and using for large energy requirements is impossible at current level of the technology.

7. Limitations

Power generated by the cell may not be enough to run a sensor or a transmitter continuously. This is the principal problem with using microbial cells. It can be solved by increasing the surface area of the electrodes. Also the other solution is to use a suitable power management program: the data are transferred only when enough energy is stored and this occurs by using ultra capacitor, finally, the other limitation of MFCs is that they cannot operate at extremely low temperatures due to the fact that microbial reactions are slow at low temperatures [9, 13].

CONCLUSION

The ultimate achievement in MFCs will be when they can be used solely as a method of renewable energy production. Right now, the high costs of materials for MFCs and the relatively cheap price of fossil fuels makes it unlikely that electricity production can be competitive with existing energy production methods. However, MFCs are carbon neutral and power can be, generate with cellulosic materials. Thus, advancements in power densities, reductions in materials costs, and a global need to produce power without net CO_2 emissions may one day make MFCs practical just for electricity production. It will be a great success in the field of renewable energy production if we will integrate this small production of electricity in to powerful electricity. Ruminant production systems are faced with a variety of challenges. Chief among them are the need to: (1) improve the efficiency by which grains and forages are converted to food and fiber to meet increasing global demand; (2) complete the conversion of natural resources into consumable products in a sustainable manner with limited environmental impact; and (3) achieve these goals while supporting and improving animal health and well-being. Microbial communities play an integral role in all of these challenges such that the health, efficiency, and environmental impact of a ruminant cannot be distinguished from that of its inherent microbial community. In general, MFC has some limitation in current processing situations, but it will be solved and use as one of alternative sources of energy. Availability of fossil fuel and other energy option in the market has hampered the attention of research people focus on the developments of this energy option. Due to scarcity of energy facing the world this energy option will applicable in the world energy harvesting sooner.

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