MICROBIAL FUEL CELLS: SUSTAINABLE TECHNOLOGY FOR ENERGY PRODUCTION AND WASTEWATER TREATMENT

OMEROGLU S.[1] **and SANIN F.D.**[1]

[1] Department of Environmental Engineering, Middle East Technical University, Ankara, Turkey,
E-mail: omeroglu@metu.edu.tr

ABSTRACT

Industrialization and growing population, creates an extreme pressure on the existing oil and coal reserves and causing a bottleneck called as "global energy crisis". Natural energy resources such as oil, coal and natural gas are finite and soon will be consumed together with the rising energy needs and this insecurity will also affect the global economy. Beside the technological and economical risks associated with the current energy practices, significant amounts of greenhouse gases (GHGs) are being released to the atmosphere by fossil fuels and contribute to global warming. For this reason, especially within the last decade, countries have devoted significant efforts to investigate and develop alternative technologies of renewable and sustainable energy resources to overcome the energy crisis and environmental pollution challenges. Microbial fuel cells (MFCs) are one of the renewable energy technologies that convert the chemical energy in the bonds of organic matter into electrical energy via the biocatalytic activity of microorganisms. In a MFC, substrate is first degraded in the anode chamber producing electrons and protons. The electrons are carried to the cathode via an external circuit, whereas the protons pass through the proton exchange membrane (PEM) to react with the terminal electron acceptor (O_2). MFC performance depends on many factors such as PEM, substrate type, reactor configuration, electrode materials, catalyst, etc.. Type of substrate is a basic parameter since the organic content of the feed may enhance or inhibit energy production. Wastewater is one of the substrates that could be used in a MFC. Today, existing wastewater treatment plants (WWTPs) are energy intensive and costly. Considering this, MFCs take the first place among sustainable energy practices by achieving wastewater treatment and sludge stabilization while supplying the energy required. However, although MFCs are perfect candidates for wastewater treatment, their large scale applications are limited due to economic and technical challenges. Therefore, the aim of this study is to investigate the parameters affecting the performance of a MFC.

Keywords: Electricity production, microbial fuel cell, bioenergy, wastewater treatment

1. Introduction

Today, with the increasing population and energy demand, the natural energy resources are being exploited. The insecure energy resources directly affect the production, posing a serious threat to global economy. Besides, current energy practices emit large amounts of greenhouse gases to the atmosphere (Langan *et al*, 2011). Considering these, bioenergy technologies such as microbial fuel cells (MFCs) are now being discussed.

MFCs are bioreactors converting the chemical energy in organic wastes into electrical energy via the catalytic reactions of microorganisms (Du *et al*, 2007). There exist several reactor configurations for MFCs but the working principle is the same. The organic waste is first degraded by anaerobic microorganisms in the anode chamber producing electrons (e^-) and protons (H^+) (Pant *et al*, 2010). Mediators transfer e^- to anode surface and from here, e^- are transmitted to cathode plate via an external circuit to generate electricity and protons move across the proton exchange membrane (PEM) to react with the terminal electron (O_2) (Du *et al*, 2007; Kılıç *et al*, 2011).

Different types of wastewaters can be used to feed a MFC. For instance, in the study of Huang *et al* (2011), MFCs were combined with anaerobic fluidized bed to treat distillery wastewater (80-90% COD removal) while generating electricity. Wastewaters with inhibitory contents can be also treated with MFCs as in the study carried out by Sun *et al* (2009), who achieved decolorization of active brilliant red X-3B dye using MFC. However, voltage output was affected by the initial dye concentration which was mostly due to the competitive inhibition of azo-dye.

In addition to wastewater, sludge samples can be also used to feed a MFC. Jiang *et al* (2009), showed that pretreatment (ultrasonication) enhances the MFC performance by solubilizing the COD. Lobato *et al* (2012), compared aerobic and anaerobic sludges and showed that the acclimation period is much shorter and the amount of electricity generated is much higher for anaerobic sludges compared to aerobically treated sludges.

PEM is an important component of MFC although using membranes to separate the chambers is a great challenge during operation (Du *et al*, 2007). It is increases the cost and internal resistance. However, it is much easier to control MFC by using a PEM. Today, Nafion membranes are most commonly used but cation exchange membranes (CEM) should be also tested to see the performance with far less costs (Nafion: ~\$1400/m^2, CMI 7000:~\$80/m^2) (Logan, 2008).

The coating material used for anode and cathode is very important and must be durable if MFCs are going to be used for continuous treatment. The requirements of anode and cathode are: high conductivity and specific surface area, non-corrosivity, non-fouling and inexpensive (Logan, 2008).

As stated before, there are different reactor configurations used for MFCs. The most commonly used type is dual chamber systems which consist of a anode and cathode chamber separated by a selective membrane or salt bridge (Min *et al*, 2005). Single chamber air cathode systems contain only anode chamber and protons are transferred from anode compartment to porous air cathode (Du *et al*, 2007). Although, single chamber air cathode and dual chamber systems may seem to be the most popular types of MFCs depending on the intended use MFCs can take various shapes such as miniature, upflow and stacked as shown in Figure 1.

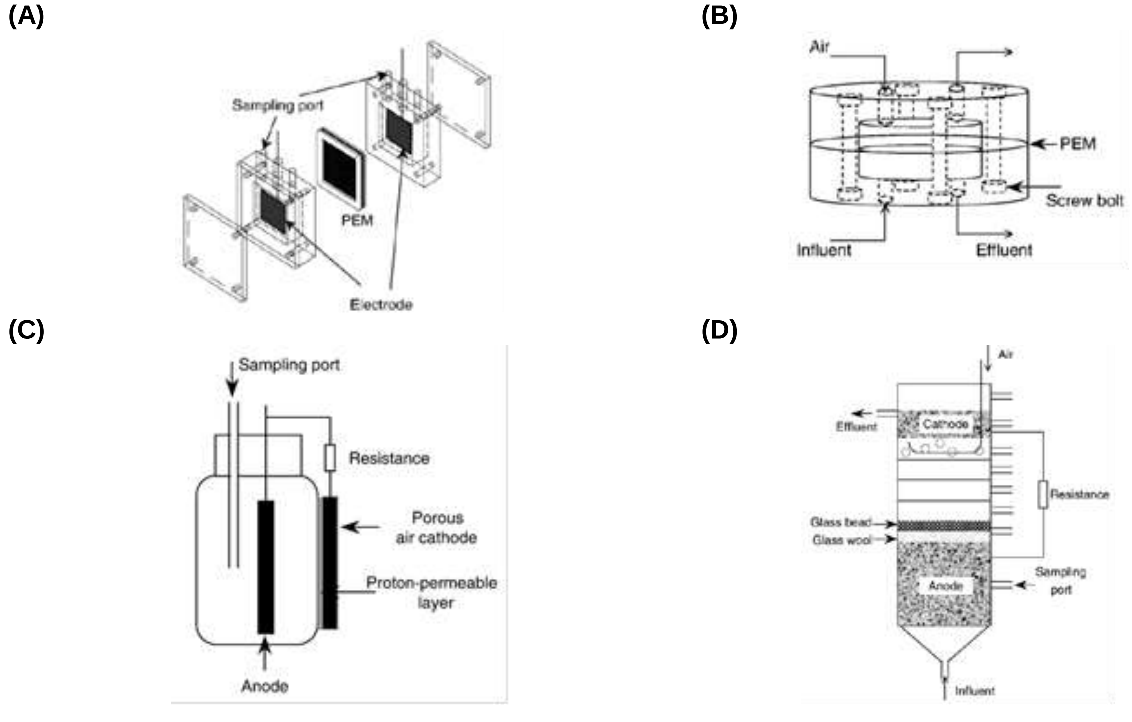

Figure 1: Schematic representation of different MFC configurations (A) cube type dual chamber MFC (B) miniature MFC (C) single chamber air cathode MFC and (D) upflow MFC (Du *et.al*, 2007)

MFCs are promising systems, in terms of wastewater/sludge treatment and energy production, but the high investment cost and operational expenses limit their applications. Unfortunately, studies to overcome the challenges of MFC operation are limited.

2. Aim of the study

Today billions are being spent for wastewater treatment and sludge stabilization. Therefore, producing significant energy during wastewater treatment makes MFCs a good option for wastewater treatment. Unfortunately, MFCs have some disadvantages, mostly associated with cost, such as the use of mediators, Pt catalyst, and fouling of PEM, limiting their full scale applications. To overcome this, circumstances to minimize cost while maximizing power output must be determined by understanding the energy metabolism, type of microorganisms and operational parameters. The variables that affect the energy metabolism and eventually voltage production are: electrode coating material, cell configuration, catalyst addition, mediator and PEM type. The limited information in this field is a gap in the literature and optimization of MFC design to improve power output could clear the way for large scale MFC operation. For this reason, this study aims to analyze the parameters (PEM, electrode material, need for catalyst and mediator) affecting the performance of a MFC and optimize the operational conditions.

3. Materials and methods

In this study dual chamber MFC is used. Anode and cathode plates are placed in parallel and connected through an external circuit. The anode chamber is sealed to achieve anaerobic conditions and purged with N_2 gas. The voltage produced is recorded using an online digital multimeter connected to a computer to gain stable voltages even if external resistance deviates (Figure 2).

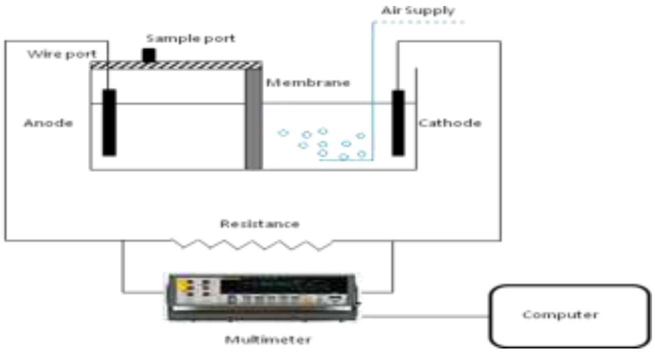

Figure 2: Schematic representation of MFC set-up

The reactors are fed with synthetic wastewater prepared. Based on COD reduction and voltage production, the reaction of the system to changing parameters are measured and compared. As voltage is measured, power density and coulombic efficiency are also calculated to plot polarization curves (cell voltage vs. power/current density). Polarization curves yield valuable information on the behavior of a MFC by marking the regions of: (i) activation loss, (ii) ohmic loss and (iii) mass transfer loss. These losses result from the electron transfer and internal resistances which depend on the PEM type and electrode material mostly. Therefore, analysis of these curves will be helpful in the comparison of materials and optimization of the system. Power density and coulombic efficiency are calculated using the following formula:

- Power density (P) = Current (I) x Voltage (V)/ Cross section area of anode (A)
- Coulombic efficiency (EC) (%) = C_P / C_{Ti} x 100
  Where, C_P is the total coulombs calculated by integrating the current over time and C_{Ti} is the theoretical amount of coulombs added on substrates.

The first stage of MFC optimization is the selection of two important materials: electrode and PEM. Most of the time, carbon fibers are used to coat the anode and cathodes, sometimes brush anodes or titanium wires and graphite fibers can also be used. In this project, the materials used for cathodes and anodes are optimized based on electron transfer efficiency, durability and cost. If the material selected for surface coating is optimized for electron transfer, then the need for platinum catalyst can be minimized. PEM affects both the proton transfer and anaerobic conditions in the anode chamber. Therefore, it should be selectively permeable and also acts a seal against oxygen transfer (or any other type of electron acceptor). Nafion, cation exchange or even anion exchange membranes can be used (Logan, 2008). However, the optimum one (in terms of cost and operation) have not been yet selected. That's why in this study, PEM has been selected as one of the parameters to be optimized for reactor operation.Supplying oxygen continuously, especially considering large scale systems, is a major problem and cost item. Oxygen is non-toxic and has a high oxidation potential but alternative electron acceptors must be also investigated such as algae based systems.

4. Conclusion

MFCs are one of the renewable energy alternatives that can produce significant quantities of electricity. The main idea of MFCs is to generate electricity through the breakdown of organics in wastewater to produce electrons. Although, production of energy from biomass has been known for many years, bioenergy and MFCs did not draw much attention until the global energy crisis, along with other renewable energy alternatives.

Although the investment cost of MFCs may seem significant, they bring many economic benefits. For instance, the electricity generated by MFCs can be further used for many applications. Especially for high organic content industrial effluents such as beverage or food industry, the amount of power generated will be considerably high and can be used during the production process. But beyond their economic gains, MFCs offer a significant environmental benefit and produce electricity with almost no net carbon emissions reducing the impact of energy sector on climate change and water resources.

Unfortunately, since today, the performance parameters and technical limitations have not been fully understood and MFCs do not have large scale applications. In addition to design challenges, MFCs require the use of expensive equipment for anode/cathode surfaces, PEM and catalyst initially. All these materials and their impact on MFC performance are interrelated and optimization of one affects the need of another. Therefore, in this study, different types of PEM, electrode, catalyst and electron acceptors will be tested to maximize MFC performance while minimizing the associated costs.

REFERENCES

1. Du Z., Li H., Gu T. (2007), A state of art review on microbial fuel cells: A promising technology for wastewater treatment and bioenergy, Biotechnology Advances, **25**, 464-482.
2. Huang J., Yang P., Guo Y., Zhang K. (2011), Electricity generation during wastewater treatment: An approach using an AFB-MFC for alcohol distillery wastewater, Desalination, **276**, 373-378.
3. Jiang J., Zhao Q., Zhang J., Zhang G., Lee D.J. (2009), Electricity generation from bio-treatment of sewage sludge with microbial fuel cell, Bioresource Technology, **100**, 5808-5812.
4. Kılıç A., Uysal Y., Çınar Ö. (2011), Laboratuvar ölçekli bir mikrobiyal yakıt hücresinde sentetik atıksudan elektrik üretimi, Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, **17**, 43-49.
5. Langan P., Gnanakaran S., Rector K.D., Pawley N., Fox D.T., Chof D.W. (2011), Exploring new strategies for cellulosic biofuels production, Energy and Environmental Science, **4**, 3820-3833.
6. Lobato J., Canizares P., Fernandez F.J., Rodrigo M.A. (2012), An evaluation of aerobic and anaerobic sludges as start-up material for microbial fuel cell systems, New Biotechnology, **29**, 415-420.
7. Logan B.E. (2008), Microbial Fuel Cells, John Wiley& Sons, New York.
8. Min B., Cheng S., Logan B.E. (2005), Electricity generation using membrane and salt bridge microbial fuel cells, Water Research, **39**, 1675-1686.
9. Pant D., Van Bogaert G., Diels L., Vanbroekhoven K. (2010), A review of the substrates used in microbial fuel cells (MFCs) for sustainable energy production, Bioresource Technology, **101**, 1533-1543.
10. Sun J., Hu Y-Y., Bi Z., Cao Y.Q. (2009), Simultaneous decolorization of azo dye and bioelectricity generation using a microfiltration membrane air-cathode single chamber microbial fuel cell, Bioresource Technology, **100**, 3185-3192.