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Article · September 2018

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International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 9, September 2018, pp. 98–105, Article ID: IJMET_09_09_012
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=9
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

A STUDY ON MICROBIAL FUEL CELL (MFC) WITH GRAPHITE ELECTRODE TO POWER UNDERWATER MONITORING DEVICES

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ABSTRACT

In recent decades, the world's energy demand continues to increase while causing various types of environmental pollutions and global energy crisis. Microbial Fuel Cell (MFC) is a bio-electrochemical system that produces electricity by making use of chemical energy. Although Microbial fuel cells (MFCs) have the potential of generating electricity from a number of compounds, it is still far from achieving expected output due to irreversible reactions taking place in the anode and cathode compartments. Hence, the aim of this study was to generate power via MFC using graphite electrode. The MFC was fabricated by following a scientific procedure and several experiments were conducted to determine the voltages and power density produced with varied resistors. It was found that with the increase in oxygen supply, the voltage increases accordingly due to the increase in bacteria activity. However, as the catalyst decreases, the expected power output also decreases due to a decrease in bacteria activity. Conclusively, the following parameters are directly proportional to one another: voltage produced, bacteria activities and the existent/supply of catalyst.

Keywords: Microbial fuel cell; Graphite electrode; power; sustainable energy

Cite this Article: M. I. N. Ma'arof, Girma T. Chala, Saravanan a/l Ravichanthiran, and Abigail F. Diasip, A Study on Microbial Fuel Cell (Mfc) with Graphite Electrode to Power Underwater Monitoring Devices, International Journal of Mechanical Engineering and Technology, 9(9), 2018, pp. 98–105.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=9

1. INTRODUCTION

Reserves of fossil fuels are depleting due to the growth in energy demand [1, 2]. Malaysia is highly dependent on fuel oil, natural gas and coal to generate power [3, 4]. However, greenhouse gases (GHGs) are produced as a result of fossil fuels burning leading to climate changes as well as environmental deterioration [5-7]. Total dependency in these forms of energy is much as well a mere investment towards potential disaster. Hence, the country is highly recommended to practice a paradigm shift in viewing potential sources of energies. Therefore, it is more strategically and scientifically wiser to develop sustainable or alternative forms of energies. One example of a sustainable and renewable energy source is the Microbial Fuel Cells. Microbial Fuel Cells (MFC) is a fuel cell where oxidation reactions are carried out to produce electricity by making use of chemical energy [8, 9]. Although the idea of generating electricity from microbial fuel cells dates back to 100 years, it is only now that the Microbial Fuel Cell is being studied and understood. Currently, Microbial Fuel Cells are being used for remote sensing, hydrogen production, desalination, wastewater treatment, remote power source and as a remedy for pollution among others. MFC utilizes the power released from respiring microbes to produce electricity by converting the organic substances. In order to ease the electrons movement throughout the system, MFC makes relies on living biocatalysts [10]. Microbial fuel cells produce electricity when organic molecules are reduced due to bacterial oxidization. The redox reaction that causes electrons to move around is the respiration of bacteria.

A MFC is conventionally comprises of a cathode, an anode and a membrane [11]. The anode and cathode compartments are divided by membrane which is cation specific. At the anode, organic fuel generating protons are oxidized by microbes which then move across the membrane to reach the cathode. From the anode to the outer circuit, the electrons that go through it are also oxidized by microbes to generate current [12]. As for a MFC, the two chambers connected via a membrane are inked together by an outer wire. As soon as an organic substance reaches the anode compartment, the organic substance is oxidized and reduced by the bacteria in order to produce life sustaining ATP that stimulates bacteria cellular machinery. The electron acceptor that is the anode in the bacteria's electron transport chain produces protons, electrons, and carbon dioxide are produced as by-products [13]. The newly generated electrons use the wire as a conductive bridge to move from the anode to the cathode. Meanwhile, protons move without restriction via the PEM which links anode compartment to the cathode chamber. Thus, in completing the circuit, the oxidizing agent or oxygen present at the cathode recombines with hydrogen and the electrons from the cathode to produce pure water [14].

Presently, researchers are trying to find ways to optimize electron transfer, electrode materials and the various combinations and types of bacteria [15]. Research conducted in understanding Microbial fuel cell (MFC) is globally minimal. Although Microbial fuel cells (MFCs) have the potential of generating electricity from a number compounds, such as renewable biomass, organic water or even natural organic matter, it is still far from achieving levels of output due to irreversible reactions taking place in the anode and cathode compartments that have a negative impact on the MFC output. The objective of this study was therefore to generate power via MFC by using graphite electrode. The findings could be utilized either directly in term of developing a sustainable power source for underwater equipped; or indirectly, for instances, with respect to the newly found overall relationship between the electrical voltages produced, bacteria activities and the existent/supply of catalyst.

2. EXPERIMENTAL SETUP AND TECHNIQUES

2.1. Experimental setup

For this study, a double chamber microbial fuel cell was used where one chamber was aerobic, whilst, the other chamber was anaerobic. The design was selected based on the literature review since its enables for numerous distinctive configurations to be workable. The MFC included two graphite electrodes, anode and cathode, for transferring electrons. Electrode materials must be conductive, biocompatible, and chemically stable in the reactor solution. The MFC was fabricated using anode and cathode container, two plastic containers with sealable lids, acrylic, mud, air pump, sealing materials epoxy, digital multimeter, and resistors of 16,000 Ω, 5,000 Ω, 2500Ω, 1000 Ω and 100 Ω. Cylindrical shape was selected for the anodic chamber as it is the most efficient shape that helps enhance the performance. Moreover, it could be sealed tightly. Bar-shaped porous graphite was used for both electrodes as a non-corrosive metals and has a non-detrimental effect upon the microbes. The electrode with large surface area would affect the potential of the electrode. Hence, the Porous electrode has a large surface area compared to the other electrodes such as aluminum. The electrode which has more pore can be used for collection of electron and prevents clogging. The conventional MFC's ion exchange membrane is usually a two chamber MFC manufactured over an "H" shape, comprising of two plastic compartments connected with a PVP pipe which acts as a separator known as Cation Exchange Membrane (CEM). The PVP pipe was stuffed with agar-agar mixed with salt. Figure 1 shows the schematic diagram of the experimental setup.

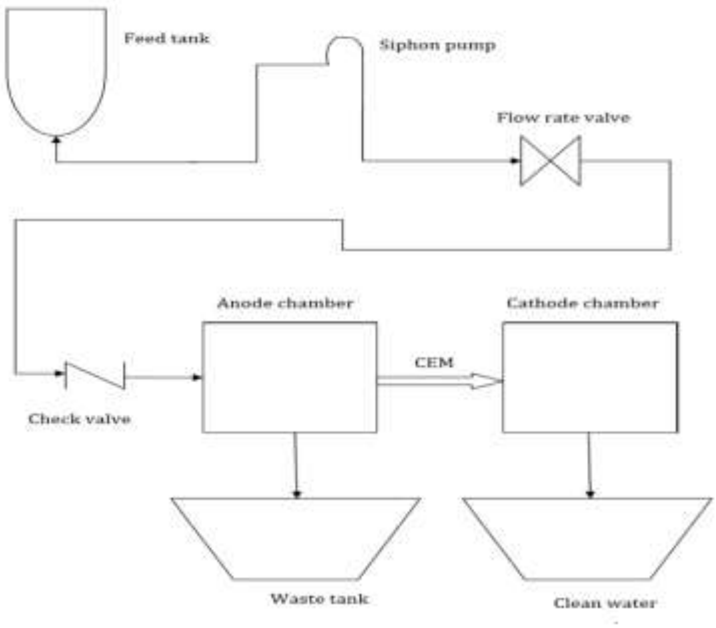

Figure 1 Experimental setup

2.2. Experimental techniques

The continuous feeding system was selected for this study. The chamber was sealed tightly in an oxygen free environment. The other chamber contains water exposed to the air. The feed tank was then placed above the anode compartments causing the siphoning activity to take place where it draws the food and nutrition from the feed tank into the same compartment. A Flow valve with a 6.25mm of tubes to control the feed rate of the water and food was integrated to the system. In addition, a check valve was connected to prevent the backflow of the solution from the water tank to the anode compartments, and this was also done to the anode compartment to the feed tank. As the anode camber was initially placed with the waste which contains microbe organisms, the chamber was sealed tightly in for a range of time where it allows a perfect biofilm to form. The perfect biofilm can be maintained in a feeding system once the healthy biofilm was established on the electrodes in the anode chamber. To make sure that there was a present of healthy bacteria, the feeding system had to deliver a satisfactory amount of food at any given time. In the anode chamber, diffusion must occur for feed to take place. In addition, there must be absents of oxygen and other contaminants at the anode.

The chemical reactions that occur in the cathode chamber are shown below:

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^- \text{ (at anode)}$$

$$48H^+ + 48e^- + 24O_2 \rightarrow 24H_2O \quad \text{(at cathode)}$$

2.3. Data collection and analysis

The power output of the MFC is determined as follows:

$$P = \frac{E^2 cell}{R} \quad (1)$$

In a MFC, the electromotive force (EMF) is interpreted as the voltage, V to calculate the current value, I, the EMF is divided by the external resistor. The "standard cell electromotive force" is often defined as E^0emf. The standard cell electromotive force is determined as follows:

$$E^0 emf = \frac{\Delta G^0}{nf} \quad (2)$$

Where: ΔG^0 is the "Gibbs free energy". This process is carried out under standard conditions of 298.15K and 1 bar pressure. n refers to the number of electrons per reaction mole of the substrate. F is Faraday's constant which is 9.64853 × 104 C/mol.

The power inputs were recorded at regular time intervals. The data was collected in daily basis via a Multipurpose-meter. Power, current density, and power density were calculated as follows.

The area of Anodic in the Anode chamber = Anodic area in mm^2

$$\text{Power, P = Voltage (V) x Current (I)} \quad (3)$$

$$\text{Current density} = \frac{\text{current(I)}}{\text{anodic area (mm}^2\text{)}} \quad (4)$$

$$\text{Power Density} = \frac{\text{power}}{\text{anodic area (mm}^2\text{)}} \quad (5)$$

Surface area of each electrode was calculated as follows:

$$A = 2\pi r^2 + \pi \text{DL} \quad (6)$$

Where r=6 mm and L=130 mm.

3. RESULTS AND DISCUSSION

These experimental readings were taken under open circuit voltage system to observe the voltage change of each day without any resistors. The experiment was then repeated by using 0.1kΩ, 1.0kΩ, 2.5kΩ, 5.0kΩ and 16.0kΩ for another 10 days to determine the effect of resistor on the power output of MFC. Table 1 shows the average reading of the voltage from three different readings.

Table 1 Data collection of an open circuit system for graphite electrode

Experiment days	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
V, (1^{st} Reading)	0.25	0.34	0.53	0.73	0.94	1.02	0.96	0.72	0.71	0.69
V, (2^{nd} Reading)	0.26	0.35	0.56	0.76	0.93	1.00	0.95	0.71	0.71	0.68
V, (3^{rd} Reading)	0.25	0.35	0.55	0.75	0.91	1.00	0.93	0.72	0.71	0.70
Average reading for	0.25	0.35	0.55	0.75	0.93	1.00	0.95	0.72	0.71	0.69

Figure 2 shows the reading of voltage against the current for different resistors for a period of 10 days. It can be seen that the trend of the graph is increasing steadily and reached its peak at 6th day. This was due to the number of bacteria present in the system where the bacteria required certain time of period to form the anodic biofilm. It then declined from 6th day onwards till the 10th day due to the decrease in the catalyst in the system. It was assumed that the decrease in substrate concentration which is the agar-agar causes the bacteria for not attaining sufficient amount of necessary food to get through the inoculation for its growth to produce potential energy.

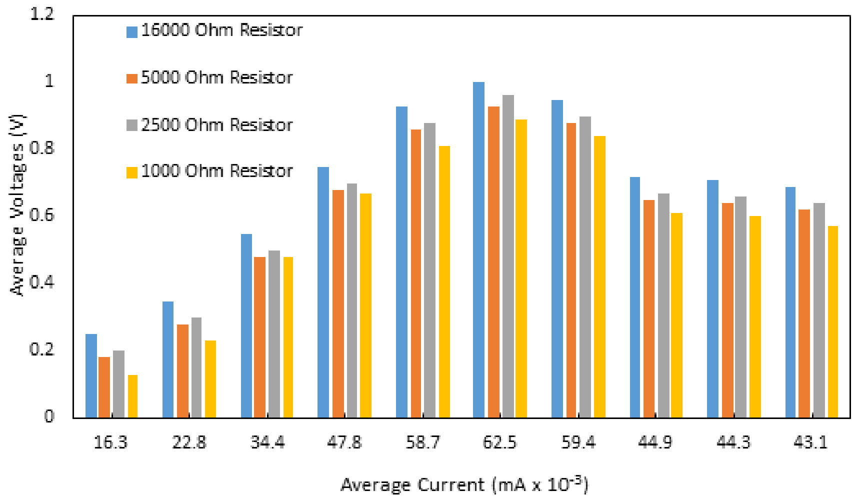

Figure 2 Voltage vs current with various resistor for 10 days period

The power against the period of 10 days in using Graphite electrode is depicted in Figure 3. The power produced for 160kΩ was the lowest among the other resistors. When a large number of resistant was attached as a load to the system, a large amount of voltage was produced from the system. However, the production of the current was relatively small. If a small number of resistant was attached as a load to the system, the voltage that produced across the compartment will be low compared to the current where it will be maximum of the fuel cell that can be produced. Therefore, the power obtained from the system would be high for certain period of time.

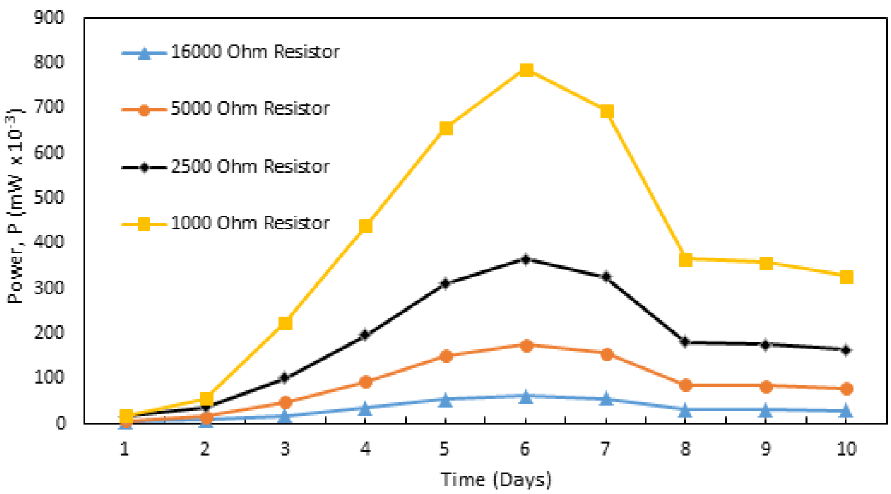

Figure 3 Power produced for 10 days period for graphite electrode

The power readings over 10 days period with its polynomial equation are depicted in Figure 4. The purpose of using polynomial equations was to discover the period for the electron movements completely stop transferring across both chamber in the system. If there was no flow of electrons from anode compartment towards the cathode compartment, there would be no electricity produced. Therefore, to find the period for the electron movement to completely disappear or stop transferring in the system, it was mathematically estimated for different resistors.

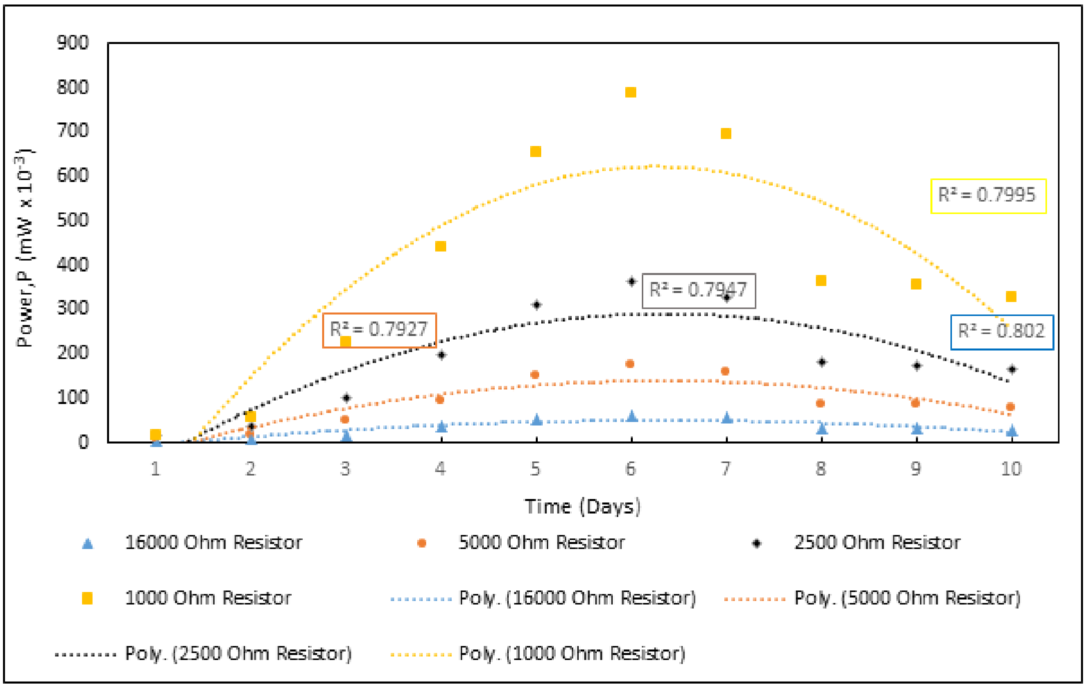

Figure 4 Power over 10 days period together with polynomial equations for Graphite electrode

Table 2 shows the polynomial equations for different resistors. It predicts the time at which the electrons stop in the system. It can be seen that electrons transferring time for different resistors were different as there might not enough catalyst for the bacteria to live in the system. For 16 kΩ, 5 kΩ, 2.5kΩ and 1kΩ resistors, the periods for electron to stop transferring were 11.43 days, 11.33 days, 11.35 days and 11.26 days, respectively. However, there were some amount of voltage present on the 20^{th} day and 24^{th} day which was 0.354 V and 0.223 V. Therefore, hypothesis can be made where the period for electron to stop transferring is independent on the resistors across both chambers. In short, the electron was not fully cleared from the system as there are certain potential for it to be gone from the system. If the bacteria still exists in the system with the catalyst, there is still a potential for the electron to transfer across the system for a long period of time.

Table 2 The period for electron to stop transferring for graphite electrode

Resistors used (kΩ)	Polynomial equations	Period for electron to stop transferring, (Days)
16	y = -1.9481x2 + 24.649x - 27.225	11.43
5	y = -5.5996x2 + 70.853x - 84.145	11.33
2.5	y = -11.536x2 + 146.02x - 170.96	11.35
1	y = -26.045x2 + 325.96x - 396.94	11.26

4. CONCLUSION

A study on Microbial Fuel Cell with graphite electrode to power underwater monitoring devices was conducted. The MFC was fabricated following a proper methodology and several experiments were then conducted to test the effects of different kinds of resistors. The amount of bio-waste required to generate electricity was quantified and validated. It was observed that the period for electron to stop transferring is independent on the resistors across both chambers. When the bacteria still exists in the system with catalyst, there is a potential for the electron to transfer across the system for a long period of time. It was found that the following parameters are directly proportional to one another: voltage produced, bacteria activities and the existent/supply of catalyst. For future studies, it is recommended to explore the use of agricultural and industrial wastes as sustainable energy sources. Malaysia has access to various renewable resources therefore has the potential to achieve sustainable energy.

ACKNOWLEDGEMENT

The authors would like to thank INTI International University for the support provided.

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