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EXPERIMENTAL STUDY OF BIOELECTRICITY-MICROBIAL FUEL CELL FOR ELECTRICITY GENERATION: PERFORMANCE CHARACTERIZATION AND CAPACITY IMPROVEMENT

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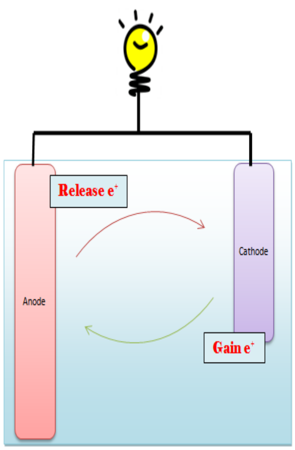
Graphical abstract



Abstract

Energy trending lately shown the need of new possible renewable energy. This paper studies about the capability and capacity generating of electricity by using Bio-electricity-Microbial Fuel Cell (Bio-MFC). Bio-MFC is the device that converts chemical energy to electrical energy by using microbes that exist in the sewage water. The energy contained in organic matter can be converted into useful electrical power. MFC can be operated by microbes that transfer electrons from anode to cathode for generating electricity. There are two major goals in this study. The first goal is to determine the performance characteristics of MFCs in this application. Specifically we investigate the relationship between the percentages of organic matter in a sample results in higher electricity production of MFCs power by that sample. As a result, the sewage (wastewater) chosen in the second series experiment because the sewage (wastewater) also produced the highest percentage of organic matter which is around 10%. Due to these, the higher percentage of organic matter corresponds to higher electricity production. The second goal is to determine the condition under which MFC work most efficiently to generating electricity. After get the best result of the combination for the electrode, which is combination of zinc and copper (900mV),the third series of experiments was coducted, that show the independent variable was in the ambient temperature. The reasons of these observations will be explained throughout the paper. The study proved that the electricity production of MFC can be increased by selecting the right condition of sample type, temperature and type of electrode.

Keywords: Microbes, Sustainable Energy Source, Renewable Electricity Production, Fuel Cell, Wastewater

1.0 INTRODUCTION

In the global scenario of increasing global energy demand, every industry demanding a reliable energy supply and renewable with low operational cost. The possibility of turning waste into useful energy are being the objective of most energy related research scientist. Energy recovery system is the suitable method to utilize this type of energy. The existing of billion of microbes in Sewage Treatment Plant (STP), has the highest possibility for energy generation.

Bioelectricity-Microbial (Bio-MFC) Fuel Cell is a device that harvests the power of respiring microbes in wastewaterconverted into organic substrates openly into electrical energy. Bio-MFC is a fuel cell, which convert chemical energy into electrical energy using oxidation reduction reaction (redox).

In a Bio-MFC, organic matter is oxidized by microbes and electrons are produced. The electrons are then transferred to a electron acceptor (EA) which is reduced by the electrons. EA's such as oxygen, nitrate, and sulphate can diffuse into the cell and accept electrons to form new products that leave the cell. However, some bacteria can transfer their electrons outside the cell (exogenously) to the awaiting EA [4]. It is these bacteria that can produce power within an MFC system.

Electrons and protons are produced through the oxidation of organic matter. The electrons are transferred to the anode electrode, and travel through wire to the cathode electrode. A catalyst at the cathode must be used to facilitate this reaction. These reactions produce carbon dioxide, from the decomposition of the organic matter and small amounts of wastewater at the cathode. Using glucose as an example of an organic substrate, 24 electrons and 24 protons are released in the anode chamber. These protons and electrons both travel to the cathode chamber where 6 molecules of oxygen are needed to create 12 water molecules. Six carbon dioxide molecules are created at the anode. Below are the chemical reaction that happen at both electrodes.

Anode reaction: $CH_3COO^- + 2H_2O \rightarrow 2CO_2 + 7H^+ + 8e^-$

Cathode reaction: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$

In addition, MFC is a free energy form a bacteria. Nowdays, a renewable energy are most important. So, a condition of a waste water treatment plant are ideal for the types of bacteria that can be used in an MFC. MFC will continuosly to be operate as it generates electricity from the bacteria cointained in the human lives in this world will produce wastage in daily life. The bacteria will only go extinct when human never produce wastage anymore. Besides, every resident must have their own sewage treatment plant, so the sewage plant gets continues sewage to produce everyday. Then, its easy to supply the electricity.

2.0 METHODOLOGY

The MFC is powered up by using bacteria inside the sample of type to generate electricity. Thus, it is expected that electricity production is affect by a number of factor that influence the metabolic process of bacteria and are particularly relevant in the experiment:

- The type of sample in this experiment
- The temperature at which the metabolic process takes place.
- The type of electrode that be used to transfer electron from anode to cathode

Next, the further elaborations on how these factors are investigated in this experiment.

For the sensor application, six different type of sample was choose to study, which is benthic mud, natural mineral, top soil, sewage, tap water and river. All the samples exist in the environment where sensors are commonly placed to monitor environment ecosystems. However, this initial belief was solely based upon qualitative data.It was possible that a higher percentage of organic matter existed in the benthic mud and sewage sample. It is believed that a sample with higher percentage of organic matter, presumably contains more bacteria and bacterial food source per a unit of sample, that allow for the production of more electrons and thus electricity, a hypothesis will be examine in this experiment. In addition, the type of bacteria found in the benthic and sewage sample may be more effective in producing electricity. Hence, before the completion of this experiment, it was unclear which bacteria sample would produce the greatest amount of electricity.

Bacteria grow and the metabolic process takes place within equal efficiency at all temperature between the freezing point of water (0°C) and the temperature at which protein or protoplasm coagulates (40°C)[1]. The metabolic process of bacteria slows down and the growth of the organism ceases when bacteria are place in an environment below the freezing temperature of water, but the bacteria present are not killed. However, when bacteria are in an environment above the protein or protoplasm coagulation temperature, most of them are killed. The MFC is able to produce a decent amount of electricity, thereby potentially being able to power sensors below the freezing point of water.

MFC consists of electrode that transfers the electrons from anode to cathode. This is because the use of reactivity series to produce a best result. In reactivity series, the most reactive element is placed at the top and the least reactive element at the bottom. More reactive metals have a greater tendency to lose electrons and form positive ions. In general, the greater the difference in reactivity between two metals in a displacement reaction, the greater the amount of energy released. The microbial fuel cell is transforms the chemical energy to electrical energy by using oxidation and reduction reaction. Oxidation is the loss of electrons from a substance whereas it is also the gain of oxygen by a substance. Reduction is the gain of electrons by a substance which then it is also the loss of oxygen from a substance. Usually, oxidation and reduction take place at the same time in a reaction. This type is call redox reaction. The oxidising agent is the chemical that causes oxidation then the reducing agent causes the other chemical to be reduced.

2.1 Full Hardware Setup

Figure 1 shows the basic diagram of the MFC experimental system used in this study, which was built from the acrylic.

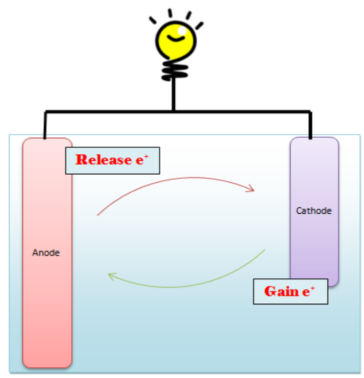


Figure 1 Diagram of MFC

The systems have two electrodes inside a container. In the container, there have a type of sample such as benthic mud, natural mineral, sewage, river and top soil. The electron will transfer from anode to cathode for generate electricity. Thisprocess is call oxidation and reduction.

3.0 RESULTS AND DISCUSSION

3.1 Objective Highlighting

Before the experiment, hypothesized that at the room temperature, sewage sample and aluminum and copper would generate the most electricity, which the thermal limits would be 16°C and 33°C, will produce a higher percentage of organic matter would lead to higher electricity production.

In the first of experiment, the independent variable being studied was the type of sample. The created MFC placed in room temperature (23°C) and measuring 4cm × 4cm × 2.5cm for each type of sample. Thus, 40 cm^3 of each type of sample was used in one trial. Three trials for each type of sample were conducted at once for accuracy. In each trial and for each sample, the electricity production was measured with a digital multimeter less than one minute after the construction of the MFC.

Table 1 provides the measured data from the first series of experiments and shows that the MFC powered by the top soil sample, has the lowest electricity production while the MFC powered by the benthic mud sample has the highest electricity production. The results was contradict with the initial hypothesis. In addition, a test was completed to measure the percentage of organic matter in each sample. The results are provided in Table 2. Figure 2 combines Tables 1 and 2, with the plots of electricity production versus percentage of organic matter. The benthic mud sample had the highest percentage of organic matter and electricity production. Due to these, the higher percentage of organic matter corresponds to higher electricity production.

Table 1 Electricity Production versus Sample Type

TYPE OF SAMPLE	ELECTRICITY PRODUCTION		
	First Trial	Secon d Trial	Third Trial
NATURAL MINERAL	944	935	913
TAP WATER	924	915	903
RIVER	1044	1040	1031
TOP SOIL	770	763	913
SEWAGE	942	917	810
BENTHIC MUD	867	878	883

Table 2 Percentage of Organic Matter versus Sample Type

TYPE OF SAMPLE	PERCENTAGE OF ORGANIC MATTER		
	First Trial	Secon d Trial	Third Trial
NATURAL MINERAL	2.0%	2.1%	1.9%
TAP WATER	2.3%	2.2%	2.4%
RIVER	4.9%	5.0%	5.1%
TOP SOIL	8.0%	8.5%	8.2%
SEWAGE (WASTEWATER)	9.8%	10.1%	10.0%
BENTHIC MUD	21.1%	19.8%	20.0%

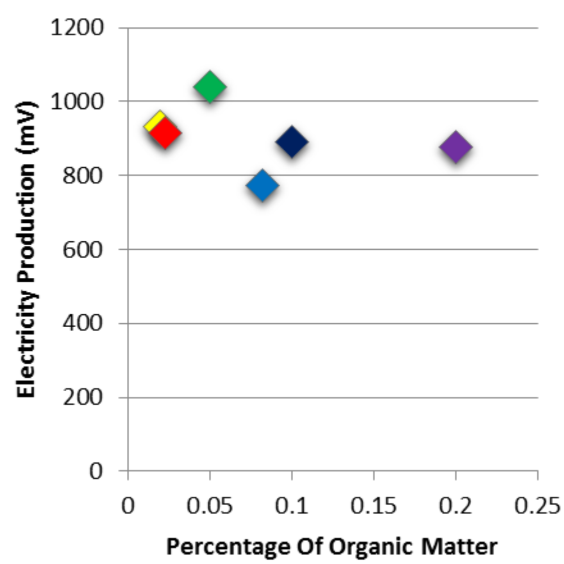


Figure 2 Electricity Production versus Percentage of Organic Matter

In the second series of experiment, the independent variable was the type of electrode that be used. The dependent variable was the electricity production of the MFC. For comparison, the room temperature (23°C) would also have been used. The sewage (wastewater) chosen in the second series experiment because the sewage (wastewater) also produced the highest percentage of organic matter. The sizing of the electrode that hasbeen used is 1.5 cm × 2.5 cm. Three trials were completed at each temperature at once for accuracy. In each trial and for each sample, the electricity production measured using a digital multimeter less than one minute after the construction of the MFC.Table 3 below show the experiment between metal of electrode to produce electricity.

Table 3 Metal of Electrode versus Electricity Production

Metal	Electricity production		
	First trial (mV)	Second trial (mV)	Third trial (mV)
Aluminum And Carbon	622	621	619
Aluminum And Zinc	219	222	223
Aluminum And Copper	830	841	834
Carbon And Zinc	891	899	900
Carbon And Copper	10	30	29
Zinc And Copper	856	859	855
Zinc And Zinc	19	20	20
Copper And Copper	9	9	10
Aluminum And Aluminum	300	302	305
Carbon And Carbon	79	78	79

After get the best result of the combination for the electrode, which is combination of zinc and copper,the third series of experiments was coducted, that show the independent variable was in the ambient temperature. The dependent variable was the electricity production of the MFC. For comparison, the room temperature (23°C) have been used. MFCs was created using sewage and measuring 4 cm × 4 cm × 2.5 cm for each temperature. Three trials were completed at each temperature at once for accuracy. In each trial and for each sample, the electricity production was measured with a digital multimeter less than one minute after the construction of the MFC.

Table 4 provides the measured data from the third series of experiments, and shows that electricity production was greatest at ambient temperature, which contradicts the hypothesis that the greatest electricity production would occur at the room temperature.

Table 4 Electricity Production versus Ambiet Temperature

Temperature (◦C)	Electricity Production		
	First Trial (mV)	Second trial (mV)	Third trial (mV)
33	820	841	843
24	910	921	921
16	1025	1024	1025

The measured data from the third series experiment, which are plotted in Figure 3. Figure 3 shows that the electricity production recorded at the beginning of the study is 0.86V. According to the pattern of the graph shown, the electricity production was starting to stabilize 10 hours after the MFC is operated, which mean that the formation of microbes on the surface of electrode took place in 10 hours for MFC operation. After the formation of microbes on the surface of electrode, the rate of electricity production was decreases because the competition occurs between the microbes to obtain their food from organic matter and nutrients in the waste water treatment. This phenomenon affect the rate of voltage produced becomes lower compared with the beginning of the MFC operation. The graph pattern shown by the operation of the MFC is consistent due to the efficiency of the reaction at the cathode. Another effect that consistency the voltage is the efficient rate of proton transfer to cathode, which helps in completing the electrical circuit.

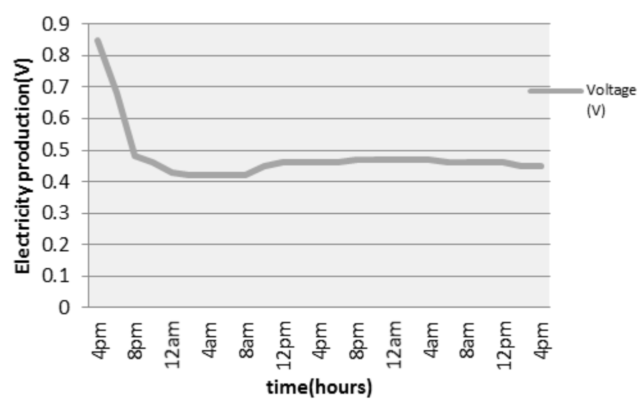


Figure 3 Electricity Production Versus Time Elapsed

4.0 CONCLUSION

By extracting bioenergy from wasterwater, the Bio-MFC technology exhibits a promising potential of power sources in remote area where it is difficult to find an alternative source. This experimental study investigates the performance of this type of cell and provides ways of increasing the efficiency for any application.

Based on the basic of the experimental result, the conclusion can be made that a Bio-MFC power by sewage (wastewater), measuring 4 cm × 4 cm × 2.5 cm, at 16°C produces the greatest amount of electricity. The electricity production for all MFC studies in this project decreases gradually over a period. Based on the analysis done by this project, microbes need energy to survive. In the same way, humans need food to live. It is know that microbes will grow as long as there is an abundant supply of nutrients. The rate of microbes' metabolism at the anode increase compatible when the electrical potential of the anode increases. Accordingly, to get the high voltage of waste water it must keep on replenishing the waste water at regular intervals.

In other words, the phenomenon of voltage drop of MFC should not is regarded as a mere natural electrical phenomenon. It should be appreciated from the perspective that voltage drop is taking place owing to the metabolism of microbes inside wastewater of MFC. More nutrients the microbes get, the more current generation would take place.

There are a few areas that could be further improved in this study. If possible, an apparatus would have to use that could maintain steadily increase or decrease temperature in an enclosed environment in order to definitively determine the thermal limits for an MFC. Nevertheless, the determination could have whether or not the thermal limits differed for MFCs powered by different samples and of different sizes. A test should have to see how the efficiency varies with sample size for MFCs placed at a variety of possible temperatures and sample types.

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