# Evaluation of Separator Performance in a Vermiculture Based Microbial Fuel Cell Assembly (VBMFC) with Eudrilus Eugeniae

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Abstract: Vermiculture-based Microbial Fuel Cells (VBMFC) generate electricity by using earthworms as catalysts that speed up the degradation of bulk organic substrates, leaving simpler compounds for exoelectrogenic bacteria to feast on. In this type of set-up, renewable electricity is generated while simultaneously reducing the volume of solid waste. Eudrilus eugeniae, commonly known as African nightcrawler, was used as the model earthworm for this study. The worms were fed with a total of 1.854 kg of watermelon peels. These peels act as the substrate for the bacteria to metabolize and generate electricity. The main objective of the study is to determine what type of separator would yield a higher power output. Results show that the control system (no separator) produced the highest maximum voltage of 40.5 mV. On the other hand, VBMFCs with clay membranes had the highest average voltage of 9.68 mV. Polarization curves were used to measure the optimal current, maximum power density, and internal resistance of the three systems. The control system had the largest optimum current density of 1.23 mA/m2 and the highest maximum power density of 0.056 mW/m2. On the other hand, vessel that had cotton cloth as separator had a better current density and maximum power density than the vessel with clay membrane, which offered the most resistance. Overall, the absence of a separator seems to benefit power generation, as well as helping to offset the cost of construction as the membrane separator often is the most expensive part of the set-up.

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## 1. INTRODUCTION

The energy demand in the world right now continues to increase and it prompts an increased usage of fossil fuels, consequently trigerring environmental pollution. The dependence on fossil fuels, such as oil and gas, is not sustainable in view of the fact that it is limited, its supply is decreasing, and it poses negative effects on the environment. As a result of this, many researches are focused on alternative, renewable, and also carbon neutral energy sources which are necessary for the sustainability of the environment and economy [1].

The global community recognized that solid waste management is an issue that requires serious attention. The aggressive pursuit for economic growth, by developing countries like the Philippines, has resulted in the manufacture, distribution and use of products and generation of wastes that contributes to enhanced environmental degradation [2]. In the past years, the Microbial Fuel Cell (MFC) technology has gained the attention of the scientific community due to its attractive quality of being able to cleam wastewater while generating electricity [3]. MFC are devices in which bacteria generate electrical power by oxidizing simple compounds such as dissolved organic matter in wastewater. This technology depicts a new and promising approach for power generation. MFCs not only clean wastewater, but they also transform organics in the wastewater into energy that can be useful. With the world's finite supply of fossil fuels and the impact of fossil fuels on climate change, the ability of MFC technology to generate renewable and also carbon neutral energy has cause huge interest globally. MFCs have been broadly seen as a standout amongst the most promising alternative sources of renewable energy [4].

The success of MFCs do not come without limitations. For one, it mainly relies on wastewater for its source of energy. To solve solid waste management issues, the MFC needs to be modified to accommodate soil-based decomposition. With that, the concept of a Vermiculture-based Microbial

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Fuel Cell (VBMFC) was born. In this set-up, solid biodegradable waste is fed to earthworms, much like in vermiculture. The worm castings then become a prime nutrient source for bacteria to consume and generate electricity with carefully-placed electrodes. Desirable qualities for a VBMFC would be high power generation, low internal resistance, and low cost, much like in MFCs. Earthworm selection is also to be considered. Commonly, Red wigglers (Eisenia fetida) are thought to be the most adaptable of all the vermicomposting worms, but comparing it with other worms in terms of selected parameters (e.g. size, time of maturity, incubation time, ideal working temperature, etc.), the African nightcrawler seems more capable. In laboratory tests, E. eugeniae outperformed E. fetida at 25 ℃ (77°F) in tests utilizing cattle manure as the feedstock. Also, some assert that E. eugeniae also slightly sensitive to handling and disturbance. It appears that it is not usual for E. eugeniae to start roving after disturbance or even clear reasons at all. That being said, E. eugeniae appear to be the most popular choice among vermicomposters due to its quick growth and bigger size compared to E. fetida [5].

There are still some ongoing studies on ways to collect electricity from different variants of MFC like Plant-Microbial Fuel Cells (PMFCs) [6] and Constructed-Wetland Microbial Fuel Cells (CWMFCs). However, there are no studies that explore VBMFCs for their power generation and waste management capabilities. In terms of its operation, it is similar to an MFC but differs on the substrate. Conventionally, MFCs include a membrane separator to segregate charges in the anode and cathode compartments. However, commercially available membranes are costly, and it is generally attractive for MFC technology to be low-cost. Thus, alternative materials are to be sought. The objective of this study is to determine the performance of cotton cloth and clay as membrane separators in VBMFC using *E. euginae* as decomposer. In addition, polarization curves will be used to measure the optimal current, maximum power, and internal resistance of the VBMFCs.

# 2 METHODOLOGY

## 2.1 VBMFC Design

The VBMFC assembly is shown in Figure 1. Polycarbonate plastic was cut and assembled into a rectangular vessel measuring 12 inches by 6 inches with a height of 8 inches. The edges were then sealed with hot glue and duct tape. Two carbon fiber sheets measuring 6 inches by 8 inches each were attached to the inner opposite sides of the vessel to act as electrodes. Alligator clips were latched into the top part of the carbon fiber to attach them to copper wires. The other ends of the connecting wire were connected to an external 2000 ohms resistor to continuously polarize the set-up. The experimental separators were attached as seen in Fig. 1. Two types of separators were tested against a control: clay and cotton cloth. Both types of separators were cut to the size of the set-up cross-section and attached to the containers. Moist loam soil was used to fill the container. Triplicates were prepared for every experimental set-up.

## 2.2 Experimental Set-up

*E. euginae* was obtained from a vermiculture farm in Manila, Philippines. 50 adult worms were placed in the anodic compartment for set-ups with separators, and were scattered in the control set-ups (without separator). Since the worms are sensitive to light, all set-ups were covered with dark-colored cloth to maintain a dark environment without suffocating the worms. Good moisture was maintained by daily spraying of distilled water, taking care not to flood the set-ups.

The worms were fed starting on their second day on the containers with fresh watermelon peels. They were fed *ad libitum*, although care was exercised to not let the watermelon peels decompose before they were consumed. 5-g portions of peels were added in every container until it is consumed.

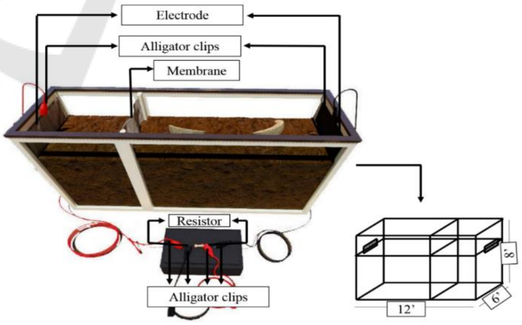

Figure 1. Vermicultue-based microbial fuel cell (VBMFC) assembly

## 2.3 Data Acquisition and Analysis

The voltage of the VBMFC set-ups were manually measured everyday against a 2000-ohm resistance, for 25 days, using a digital multimeter (RS Pro RS14). From the gathered data, power can be

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determined ($P = V/R$) as well as power density ($P_D = P/A$). All parameters were plotted against time to analyse their evolution as the assembly matures. Polarization curves were generated at the end of the experimental period.

# 3. RESULTS AND DISCUSSION

## 3.1 Voltage of VBMFCs

As seen on Fig. 2, the maximum average voltage for the control was obtained on day 23 with a value of 0.405 V and the lowest average voltage on day 8 with a value of 0.001 V. For the cotton separator, the maximum average voltage was obtained on day 17 with a value of 0.025 V and the lowest average voltage on days 2 and 5 with a value of 0.001 V. Lastly, for the clay separator set-up, the maximum average voltage was obtained on day 18 with a value of 0.0255 V and the lowest average voltage on days 2, 5 and 12 with a value of 0.001 V. These are summarized in Table 1.

The maximum voltage of the control system is significantly higher than the experimental cotton and clay separators ($\alpha = 0.05$). In terms of the average voltage, there is no significant difference between the values from the control and the clay separator, although both are significantly larger than that of the cotton separator. For voltage readings, it can be seen that using a clay separator or no separation at all is more advantageous than using cotton.

There are some factors that may hinder the VBMFC from generating its maximum potential voltage, one of which is resistances, both inherent and induced. In the operation of the VBMFCs, the junctions between the electrodes and the connecting wires are often sources of resistance from rusting. Another factor to consider is the adaptation of bacteria to the working environment and the formation and destruction of exoelectrogenic biofilm in the electrodes due to the constant movement of earthworms.

## 3.2 Polarization

The constructed polarization curves are shown in Fig. 3.

The control system had the highest optimum current density of 1.227 mA/m$^2$ amongst the other systems. Control system is a Single Chamber MFC (SC-MFC) which does not incorporate the use of membranes. In Ohms law, current is inversely proportional to resistance. Therefore, higher current occurs at lower internal resistances [7] .

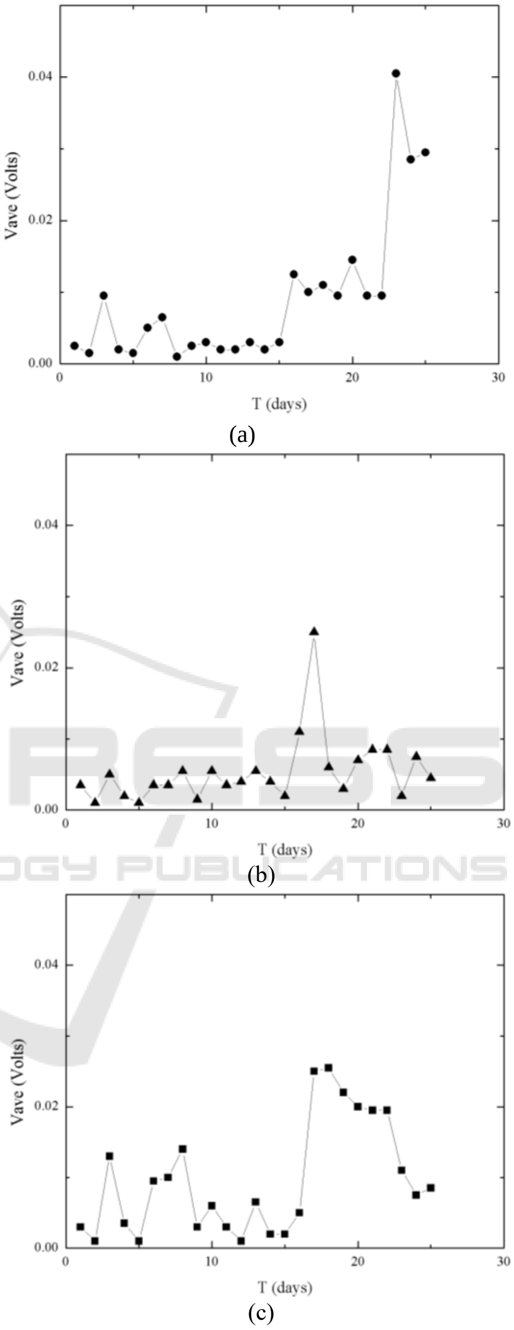

Figure 2: Average voltage measured from the constructed VBMFCs: control (a), cotton separator; (b), and clay separator (c)

In another context, the control system had the highest Maximum Power Point (MPP) obtained at 0.0560 mW/m$^2$. The maximum output power of the fuel cell is proportional to the square of the open-circuit voltage and is inversely proportional to its

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internal resistance. When the load resistance is equal to the internal resistance, the output power of the fuel cell is at the maximum. Thus, monitoring the internal resistance of the microbial fuel cell effectively is not only the necessary condition for realizing the maximum power output, but also a key action to ensure the health and performance of the microbial fuel cell.

Table 1. Maximum and average voltage of VBMFC

| System | $V_{max}$ (mV) | $V_{ave}$ (mV) |
|---|---|---|
| Control | 40.5 | 8.89 |
| Cotton cloth membrane | 25 | 5.36 |
| Clay membrane | 25.5 | 9.68 |

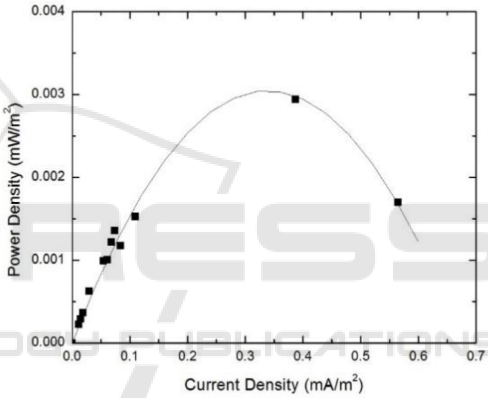
Table 2. Maximum Power and Optimum Current Density of VBMFC

| **System** | Internal Resistance (Ω) | Optimum current density (mA/m2) | **Maximum power density ($mW/m^2$)** |
|---|---|---|---|
| Control | 1240 | 1.227 | 0.0560 |
| Cotton cloth | 2874 | 0.338 | 0.0030 |
| Clay | 5493 | 0.247 | 0.0009 |

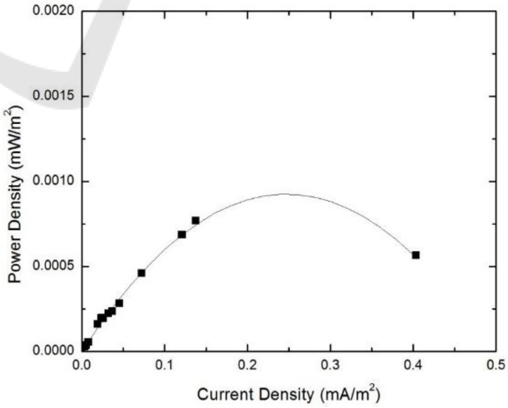
On the other hand, the vessel with cotton cloth as membrane had a better current density and maximum power than the vessel with clay membrane. These dual chamber MFC corporates membranes that allows internal ionic fluxes but prevents mixing of anodic reducing solution and cathodic oxidant. This membrane, however, is one of the principal cost factors in an MFC plant and increases the cell’s internal resistance [8]. Other factors that contributes to lesser conductivity and power are ohmic losses, activation losses and microbial losses. Ohmic losses can be reduced by minimizing the electrode spacing, using a membrane with a low resistivity and checking thoroughly all contacts. Low activation losses can be achieved by increasing the electrode surface area, improving electrode catalysis, increasing the operating temperature, and through the establishment of an enriched biofilm on the electrode.

## 4. CONCLUSIONS

This study has shown that electricity generation is possible in a VBMFC, albeit its magnitude is still small compared to other sources of energy. The set-ups with no membrane separators exhibited the highest voltage, current density, and power density, along with the lowest internal resistance. With regard to the two experimental separators, cotton cloth exhibited less internal resistance and thus would lead to higher power density compared to the clay separator. All of these were confirmed by polarization studies. The elimination of the membrane separator would cut down significantly on the building cost of VBMFCs.



(a)



(b)

Figure 3: Polarization curves of VBMFCs with cotton separator (a), and clay separator (b)

It is therefore recommended for future studies to further develop the VBMFC technology through optimizations for electrode materials, substrate, type of earthworm, and configurations.

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