Design and Power Generation of a Vermiculture-Based Microbial Fuel Cell Assembly (VBMFC) with Eudrilus eugeniae

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Abstract: A Vermiculture-based Microbial Fuel Cell (VBMFC) is a novel concept combining vermiculture and Microbial Fuel Cells (MFCs) to propose a solution to both solid waste management and non-renewable energy problems. In theory, the earthworms would act as a biocatalyst, degrading the bulk of the waste to simpler substances that can then be more readily available to electrogenic bacteria as substrate. For the first time, a VBMFC was designed and constructed to process banana peels using *Eudrilus eugeniae*. The assembly was kept at ambient conditions and was maintained by light watering and feeding every day. The assembly was shown to generate increasing voltage, current, and power, until it plateaus and reaches an equilibrium value of about 800 mV and 65 µA. A maximum power density of 5.60 mW/m^2 electrode surface area was obtained. The effectivity of the VBMFC set-up was attributed to the differing degradation rates of *E. eugeniae* and the microflora, wherein the role of the former is to degrade the bulk waste to make it easier for microorganisms to degrade later. Overall, this preliminary study was able to demonstrate that a functional VBMFC is possible. Further optimization studies are therefore recommended to allow for the scale-up of this technology.

1 INTRODUCTION

Solid waste management and the prevailing use of non-renewable sources for electricity generation has been two of the most serious concerns haunting our society today. As our population grows, the demand for more energy and more space for waste disposal also grows. In the Philippines alone, about 40,000 tons of solid waste is generated everyday, and about 57% of that is residential. Of the residential waste fraction, 52% is biodegradable consisting of kitchen scraps, food wastes, and other readily degraded materials [1]. It is of interest if the biodegradable fraction of the municipal solid waste can be utilized, mainly as electricity, to lessen the burden on the problems both posed by solid wastes and non-renewable energy.

Vermiculture has long been known of its ability to transform solid biodegradable waste to nutrient-rich earthworm waste [2]. The earthworm species used is vital in the success of this technology. *Eudrilus eugeniae*, commonly known as the African nightcrawler, has long been used in vermicomposting in tropical temperatures [3]. The vermicast produced can then be used as a nutrient-rich soil additive as a fertilizer. The nutrient recycling process of earthworms in vermiculture also attracts a wide variety of microflora in the vermicast, and the vast diversity in microorganisms are proven to be beneficial to plants [4]. The presence of a diverse group of bacteria, possibly containing electrogens [5], makes the vermiculture process an attractive system to integrate a Microbial Fuel Cell (MFC). Thus, this study demonstrates the first known attempt to generate electricity through a Vermiculture-Based Microbial Fuel Cell (VBMFC).

In theory, the earthworms would act as a biocatalyst, as their purpose in vermiculture is to degrade the complex molecules of biodegradable wastes to simpler structures, which can be used by bacteria. If the bacteria present are electrogens, electricity harvesting can be possible through properly placed electrodes. This means that the VBMFC can continually produce electricity as long

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as the earthworms are fed, and proper conditions such as humidity and water content are maintained. In this study, the main ojective is to design a functional VBMFC and to measure its performance in terms of power generation, using *Eudrilus eugeniae*, and its organic matter degrading capacity. This technology has the potential to simultaneously solve both problems on electricity generation and solid waste management if designed and studies carefully.

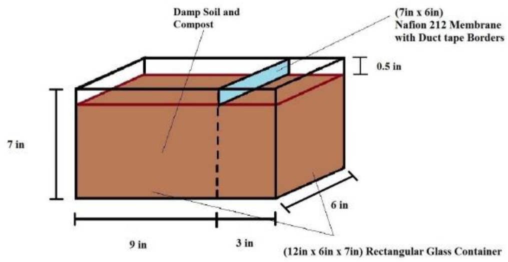

Figure 1: Vermicultue-based microbial fuel cell (VBMFC) assembly

2 METHODOLOGY

2.1. VBMFC Design

The VBMFC assembly is shown in Figure 1. The larger portion serves as the anodic compartment, and the smaller one is the cathodic compartment. The two parts of the cell were divided by a proton-exchange membrane (Nafion 212) attached flush to the sides and bottom of the container, mainly to conduct protons while preventing earthworms from crossing compartments. Graphite electrodes (4 in x 4 in plates) were placed on both compartments, on opposite sides, connected by copper wires. Moist garden soil was placed on the compartments. A plastic lid was used to loosely cover the top of the set-up to minimize moisture loss and to prevent the escape of earthworms.

2.2 Experimental set-up

E. eugeniae was obtained from a vermiculture farm in Bulacan, Philippines. 80 adult worms were placed in the anodic compartment at the start of the experiment. The set-up was maintained by minimal daily watering as to maintain moist soil but not damp, and the worms were fed with one fresh banana peel (67 g) every other day. The assembly was kept in a dimly-lit place at room temperature (25ºC – 30ºC) for majority of the experiment.

2.3 Data acquisition and analysis

The open circuit voltage and current of the VBMFC was manually monitored four times everyday, for thirty days, using a digital multimeter. From the gathered data, power can be determined ($P = I/V$) as well as power density ($P_D = P/A$). All parameters were plotted against time to analyse their evolution as the assembly matures.

3 RESULTS AND DISCUSSION

The measured voltage and current over the span of 30 days are shown in Figures 2 and 3.

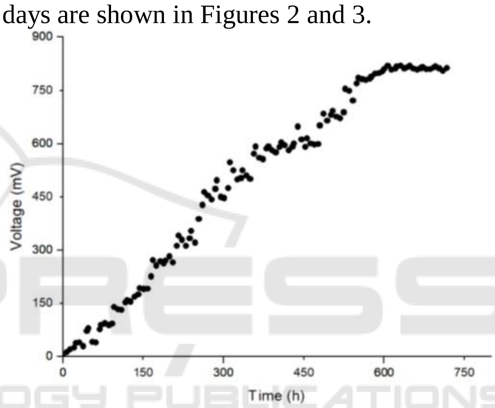

Figure 2: Voltage measured from VBMFC

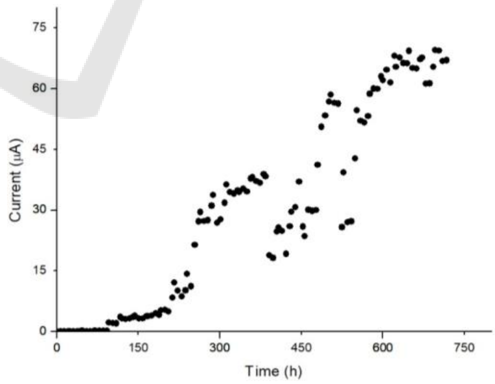

Figure 3: Current output of VBMFC

Both voltage and current steadily increased through time, reaching a plateau at day 26. At this point, the system is considered to be at equilibrium and it will stay that way unless conditions were to change. The equilibrium open circuit voltage of the cell was about 800 mV; this value is significantly higher compared to voltages generated by Plant-Microbial Fuel Cells (PMFCs) [6] mainly because PMFCs are reliant on the plant's rhizodeposits to produce electricity. The VBMFC is expected to continuously generate power as long as feed is continuously introduced to the system, and if the worms will reproduce to compensate for the losses along the way.

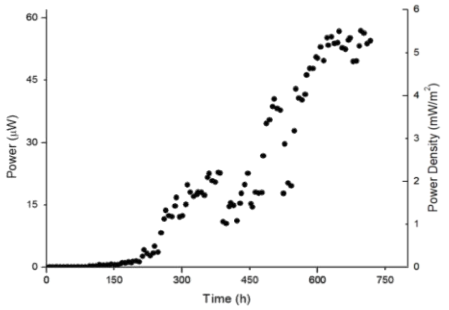

Figure 4: Power and power density of VBMFC

The obtained power and power density are illustrated in Figure 4. As with both voltage and current, power and power density were also observed to increase through time as equilibrium is being established. This increase in power generation can be attributed to the breaking down of the banana peels by the earthworms, giving bacteria an easier access to the nutrients of the food. In a previous study, it has been found that *E. eugeniae* working on market waste as the substrate was able to increase the organic carbon and nitrogen content of the soil by 55.8% and 56.9%, respectively [7]. The degrading action of the earthworm provided simpler organic compounds for the bacteria to consume, thus producing power. The maximum power density generated was 5.60 mW/m^2.

It has been observed that some of the worms opted to crossover to the cathodic site due to overcrowding in the anodic side. However, there is no food available in the cathode compartment so the worms inevitably went back to the anode compartment where there is always food.

The consistent readings on all parameters were attributed to the presence of a proton-exchange membrane (PEM) which facilitated the orderly transfer of protons from the anode to the cathode while preventing oxygen crossover. However, the PEM represents majority of the cost of the VBMFC assembly. Without looking at costs of construction, the PEM chosen is known to withstand degradation in proton-exchange membrane fuel cells (PEMFCs) and can be a valuable part of the VBMFC assembly [8]. However, soil degradation of Nafion-212 as well as its degradation under microbial influence should be further studied, for it might behave differently.

The biodegradation capability of the VBMFC was also seen in this study. The reactor was able to process 33.5 g/day of banana peels, according to what is fed. The value could be greater if more feed is given to the earthworms. This can be a good starting point for the design of larger and more efficient VBMFCs.

As it stands, a hypothetical 1-hectare VBMFC of the present design can process about 2632 tons of biodegradable waste per year, while simultaneously generating 490.56 kWh of electric energy. This can be an effective low-cost solid waste treatment option that can also yield useful by-products, mainly vermicompost and earthworm biomass which can be used as a high-protein feed for animals (such as fishes).

The VBMFC can be treated as a continuous reactor. Its input is solely biodegradable waste and the outputs are biomass (earthworms), vermiculite, and electricity. The solid waste acting as the feed is converted to useful products. In conventional vermiculture, only vermicompost and earthworm biomass are produced. In the VBMFC, electricity generation is added as another beneficial product. With more development, this technology can soon be used in larger scales for higher waste degradation capacities.

Daily periodicity in the power generation was observed (Figure 5). As measurements were taken in 7-hour intervals (7:00 am, 2:00 pm, 9:00 pm, and 12:00 mn), the obtained power was observed to be lower in the morning and afternoon, then would shoot up to higher values in the evening. This can be attributed to the nocturnal nature of *E. eugeniae*, wherein it mainly feeds at night. Its motion churning the soil and active waste production are the hypothesized reason for the observed daily periodicity of power output. Several t-tests at 95% confidence interval confirmed that there is no significant difference between normalized powers at 7:00 am and 2:00 pm, but they are lower than the normalized power at 9:00 pm and 12:00 mn.

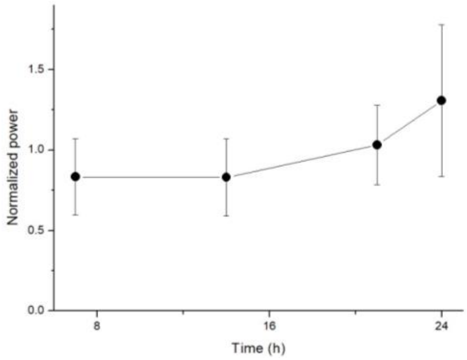

Figure 5: Daily averaged power output normalized against daily average power

4 CONCLUSIONS

The presented study was a preliminary investigation on the possibility of integrating electricity generation while treating biodegradable solid waste through the design of a VBMFC.

The observed values of voltage, current, power, and power density were all increasing through time, and indication that the substrate degraded by worms was transformed to a more readily consumed organic matter by electrogens. Power generation also followed a daily periodic trend with lower power during the day which then increases by night. Furthermore, the generated power rivals those of some plant-microbial fuel cells. With further optimization studies, this technology could have the potential for scale-up and industrialization.

In conclusion, it was demonstrated that a VBMFC is capable of simultaneous solid biodegradable waste treatment and electricity generation with *E. eugeniae* as a biocatalyst.

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