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DETERMINATION OF THE SUITABILITY OF URINE AS SUBSTRATE IN A POWER GENERATING SOIL MICROBIAL FUEL CELL

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ABSTRACT

Urine has been identified as a suitable substrate in Microbial Fuel Cells (MFC). However, its possible utilization in a soil-based Membrane-less Single Chamber Microbial Fuel Cell (MSCMFC) has, hitherto, not been reported. This study used the mud-watt MFC vessel inoculated with mud prepared from topsoil, and was operated across seven external loads for 19 days (456 hours) without adding any substrate to the soil. Urine was fed into the cell in four duration time, after the MFC output stabilized. For comparison, a fresh set up (control MFC) was made and operated under the same condition of temperature (27±3°C), but without the addition of urine. The performances of the MFCs were examined over seven external loads of resistances 4670Ω, 2190Ω, 1000Ω, 470Ω, 220Ω, 100Ω, and 47Ω. The Urine treated MFC and the control MFC both produced initial peak power output of 5.62µW. Both MFCs produced close values of power outputs up to the point of adding urine. At the final stage, the peak power output of the MFC treated with urine was 246.77µW; whereas the corresponding values for the control MFC were 0.007µW. This study showed that fresh (untreated) human urine can be successfully utilized as fuel in a soil-based MFC for the production of electrical energy for varied external loads.

Keywords: Microorganisms, metabolism, substrate, soil, urine, electricity

1.0 INTRODUCTION

Microbial Fuel Cell (MFC) technology is a new form of renewable energy technology that can generate electricity from what would otherwise be considered as waste. It is a bio-electrochemical system that harnesses the natural metabolisms of microbes to produce electrical power. Within the MFC, microbes consume or degrade the nutrients in their surrounding environment and release a portion of the energy contained in the food in the form of electrons (Li, 2013). The electrons are then transferred to a terminal electron acceptor (TEA) which is reduced by the electrons. TEAs such as oxygen, nitrate and sulphate can diffuse into the cell and accept electrons to form new products that can then leave the cell. However, some bacteria can transfer their electrons outside the cell (exogenously) to the

awaiting TEA. It is these bacteria that can produce power within an MFC system (Logan, 2008; Jenna, 2010).

A typical microbial fuel cell consists of anode and cathode compartments. In the anode compartment, fuel is oxidized by microorganisms thereby generating electrons and protons. Electrons are transferred to the cathode compartment through an external electric circuit, and the protons are transferred to the cathode compartment through a separator. Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water (Pranab and Deka, 2010).

The reasons for this recent interest in using bacteria to generate electricity are a combination of the growing needs for new sources of energy (Logan and Regan, 2006), and concerns about environmental pollution associated with the fossil fuel based methods of electricity generation. Apart from being environmentally friendly, MFC technology allows direct conversion of substrate energy to electricity, and thus ensures wastes to energy conversion. In addition, microbes are found virtually in all soils, sediments, and streams on the planet. This makes MFCs very attractive for applications that only require low power but where replacing batteries may be time consuming and expensive. MFCs can possibly be used to power sensors particularly in the river and deep water environments where it is difficult to replace batteries. Powered by MFCs, the sensors can be left alone in remote areas for many years without maintenance (Li, 2013). As long as conditions remain favorable for current production by the anode-associated microbes, an MFC has the potential to produce electricity indefinitely (Ashley and Kenny, 2010).

Soil MFCs are becoming popular in the field of research owing to the discovery that soils are naturally teeming with a diverse consortium of microbes, including the electrogenic microoganism needed for MFCs, and are full of complex sugars and other nutrients that have accumulated over millions of years of plant and animal material decay. The major problem associated with the soil MFCs is loss of power as a result of exhaustion of metabolizable substrate in the soil after a long period of operation. Substrates, in the form of organic materials which the microbes are able to degrade, must be sufficiently available in order to sustain power production in a soil MFC. The most commonly used substrates which have been reported as successfully utilized for basic MFC operations and electricity generation are acetate and glucose (Surajit *et al*., 2010). Brewery wastewater has been successfully used as substrate as it is supplemented with growth promoting organic matter and devoid of inhibitory substances (Feng *et al*., 2010). Recently, urine which has hitherto been regarded as waste has been identified as a suitable fuel for MFCs since it contains high amounts of organic compounds, nitrogen, phosphorous and sulphate (Ieropoulos *et al*., 2012). However, its suitability in a soil MFC has, hitherto, not been determined.

Therefore, this study is carried out to determine the possible utilization of urine as a suitable substrate in a soil MFC for power generation across varied external loads.

2.0 MATERIALS AND METHODS

2.1 Collection of Materials.

Topsoil was collected from the vegetable garden at Appleton Junction adjacent U&I restaurant of the University of Ibadan. This location was chosen because it is a rich soil where crops have been cultivated over the years. Different locations were randomly selected and the soil samples were thoroughly mixed to obtain a sample volume of one liter.

A Membrane-less Single Chamber Microbial Fuel Cell (MSCMFC) kit, assembled in the USA, was purchased from science buddies stored online. The components of the kits are;

- 1 SCMFC vessel
- A digital clock
- 7 external loads (resistors) of resistances 4.67kΩ, 2.19kΩ, 1kΩ, 470Ω, 220Ω, 100Ω and 47Ω.
- 1 Digital multi-meter
- A pair of Nitrile gloves
- A pair of crocodile clips
- Hacker board with 3 capacitors and a Light Emitting Diode (LED).
- Electrodes (Anode and cathode fibers with their corresponding wires made of graphite)

Four liters of distilled water was purchased from the Pharmaceutical Chemistry Laboratory, University of Ibadan, Ibadan, Nigeria.

2.2 Preparation of Mud and MFC Set-up

The mud was prepared by straining 500ml of soil sample thoroughly, using a plastic strainer, to remove any small hard particles (such as pebbles, rocks, twigs). Distilled water was added to the fine soil obtained after straining and mixed thoroughly until it was well prepared into mud. The MFC (Plate 1) was set up according to the method described by Science Buddies Staff (2014).

Plate 1: Soil MFC Complete Set-up

2.3 Urine Collection, Preparation and Utilization

Neat (unprocessed) urine samples were taken from a single healthy volunteer according to the method described by Ieropoulos *et al*., (2012). After 19 days (456 hours) of continuous operation of the cell, when a fairly stable voltage output had been obtained for three consecutive days, the anode and the cathode wires were unplugged from the hacker board. With the nitrile gloves put on, the cathode was gently lifted with proper precaution so as not to get any mud on top of the cathode. A clean 3ml medicine dropper was used to suck up fresh urine from the container. The urine was added in drops to the top of the mud, spread out evenly across the mud's surface (as shown in Plate 2). The cell was kept undisturbed for 5 minutes to allow the urine soak into the mud. Then, the fuel cell was re-assembled and left for 24 hours, after which the voltage drops across the seven resistors were measured and the power output computed. Addition of the same volume of urine was repeated on days 24, 32 and 36 (after 576, 768 and 864 hours of operation respectively); each time a stable power output was obtained for at least two days. This was done in order to investigate the response of the power output to the same substrate feeding at different time.

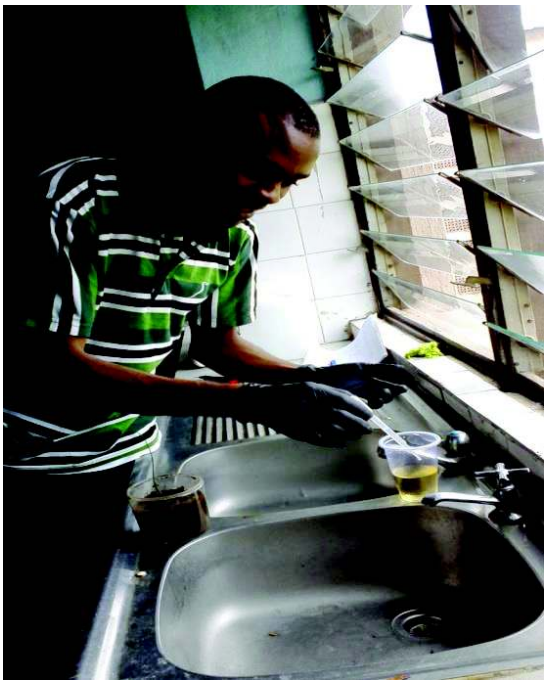

Plate 2: Urine Utilization in the soil MFC

2.4 MFC Operation

Initially the MFC was operated for 19 days (456 hours), when the power output reached a stable maximum, without adding any substrate to the soil. After the voltage measurement of day 19, 3mL of freshly collected human urine was fed into the cell at four duration times. This volume of urine, which was just sufficient to saturate the soil with water, was added each time a decline in voltage was observed after a fairly stable voltage output had been obtained for at least 2 days. The MFC was operated for 40 days (960 hours), for enough duration for experimentation and data acquisition. For comparison, a fresh set up (control MFC) was made and operated for 40 days also, under the same conditions as the first one; but without the addition of urine. Both MFCs were operated at ambient temperature range of 27$\pm$3°C

3. RESULTS

The first set of voltages measured across the external loads 4670 Ω, 2190 Ω, 1000 Ω, 470 Ω, 220 Ω, 100 Ω and 47 Ω were 162, 105, 64, 25, 12, 5 and 2 mV respectively. The daily peak voltage increased from 162mV on day 1 to a maximum of 686 mV on day 18 (Figure 2), prior to the addition of urine. The maximum power across 4670Ω, 2190Ω, 470 Ω, 220 Ω and 100 Ω reach their peak powers of 100.77, 195.90, 342.23, 320.30, 290.95, 246.49 µW respectively. The peak power across the 47Ω resistor was 221.36 µW and it was recorded on day 16 (384 hours) of MFC operation. Thus, the maximum power point (MPP) of the MFC prior to urine addition was 342.23 µW at the 1000Ω resistor.

The mean voltage drops across the external loads before and after the treatment with urine are presented in Table 1, while Table 2 presents the corresponding voltage drop for the control experiment.

Table 1: Mean voltage across external loads (Urine treated MFC)

External loads (Ω)	voltage before urine addition (mV)	voltage after urine addition (mV)
4670	458.74 ± 165.85	561.67 ± 90.56
2190	410.32 ± 178.50	526.43 ± 84.92
1000	332.89 ± 168.63	444.29 ± 66.09
470	227.47 ± 123.96	348.48 ± 39.66
220	142.21 ± 89.55	246.81 ± 9.77
100	78.16 ± 57.83	157.19 ± 7.67
47	40.57 ± 34.57	87.62 ± 5.88

Table 2: Mean voltage across external loads (control MFC)

External loads (Ω)	Voltage (mV)
4670	248.99 ± 209.61
2190	211.53 ± 185.59
1000	160.75 ± 148.25
470	107.18 ± 105.76
220	60.51 ± 62.54
100	30.26 ± 32.42
47	15.09 ± 16.82

The power trends of the MFCs treated with urine and the control MFC over 960hours of operation are presented in Figure 1 and Figure 2 respectively.

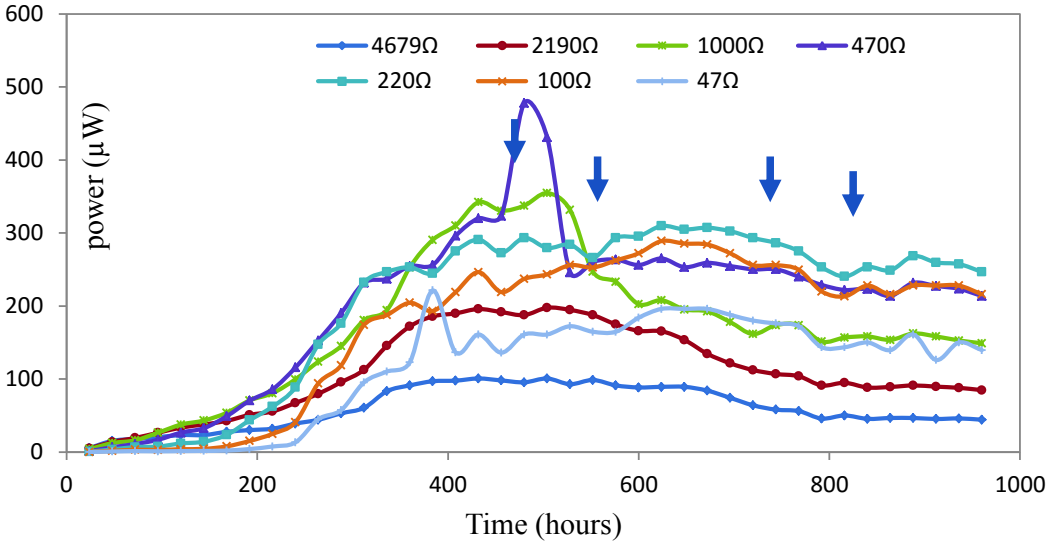

Figure 1: Power versus time plot of the MSCMFC across seven external loads. Indicates the points of addition of urine.

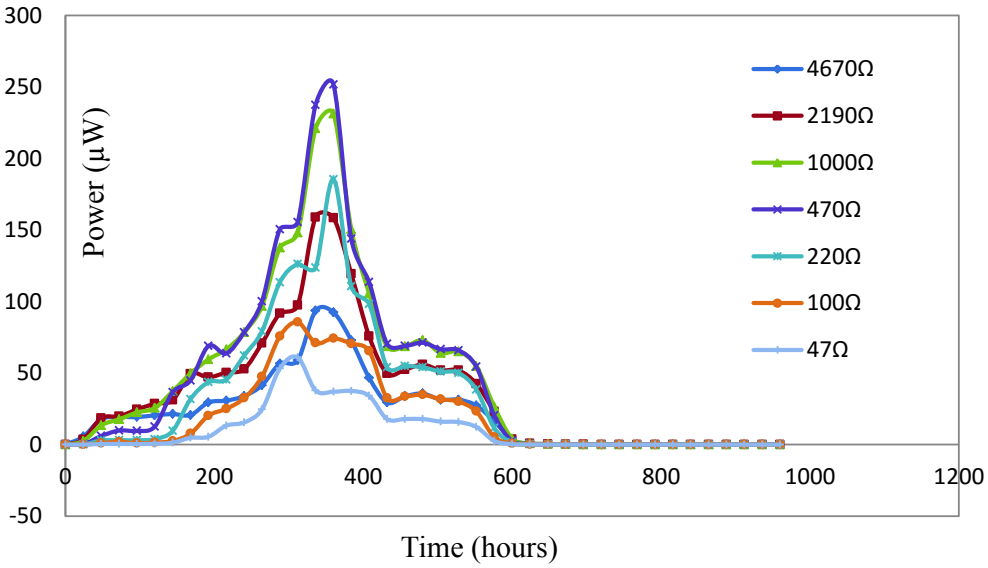

Figure 2: Power versus time plot of the MSCMFC (control) across seven external loads

4. DISCUSSION

The voltage drops across the external loads were fairly stable for three consecutive days for all the resistors (as shown in Figure 1). A slight drop below the stable values was observed on day 19 indicating a drop in substrate concentration of the soil. Hence, urine was fed into the MFC on day 19 after the day's measurement. The peak powers of the soil MFC across the resistors (except 47 Ω) were recorded on day 18 (432hours) of MFC operation.

The steady increase in voltages across the external loads, from Day 1 up to day 18 as presented in Figures 1 and 2 before the addition of urine is an indication of the growth of the soil microorganisms. These results suggested that a microbial community conducive to extracellular electron transfer was becoming established within the MFC over time. According to Jenna (2010), Exo-electrogens have a competitive advantage in microbial fuel cells due to their ability to use the anode material as a terminal electron acceptor. This population can increase over time and therefore increase the amount of electron transfer in the system. The result from this present study showed that the soil based MFCs are capable of producing electricity for more than 40 days (960hours) continuously without any additional substrate apart from the water used to prepare the soil into mud. This is evident from the 40 days data obtained from the control MFC of this study as presented in Figure 2.

Each of the power versus time plots (Figures 1 and 2) mimic the phases that are typical in bacterial growth. The growth process begins with a lag phase as bacteria become accustomed to the environmental conditions and little growth is observed. This phase is followed by exponential growth of the microbial population and then the stationary phase where little growth is seen, but living cells are maintained. Lastly, a negative growth phase occurs if no new nutrients and carbon source are supplied to the bacteria (Jenna, 2010). The lag phase is represented in Figure 1 between 0-200 hours while the trend between 200-480 hours indicates the exponential growth. No obvious negative growth phase was established for the urine treated MFC. The initial drop in power experienced between 480 to 528hours across some loads is attributed to activation loss due to microorganism's reaction to the initial addition of urine. The absence of a negative growth phase in the urine treated MFC is obviously due to ejection of urine to the cell which served as substrate for the microbes to metabolize and remain active. Thus, the stationary phase was maintained between 528hours up to the 960hours of operation. These four phases are clearly established in the power versus time plot of the control MFC (Figure 2). These results proved that microorganisms present in the soil were actually responsible for the electricity generated.

As can be inferred from Tables 1 and 2 and Figure 1, the urine treated MFC showed a better performance compared to the control MFC which tended towards zero value at the end of the experiment. Table 1 also shows that the average performance of the MFC after treatment with urine is higher than its performance before the treatment across all external loads. This better performance is attributed to the enhanced availability of utilizable substrate in urine for sustained microbial metabolism. The optimum performances of both MFCs were achieved with the 470 Ω external load which is an indication that the soil MFCs are best suited to power external loads with resistance of about 470 Ω. This could also mean that the internal resistances of the MFCs in this study are close to 470 Ω; since for optimum operation of an MFC, the external resistance should be equal to the internal resistance, especially for MFCs with symmetrical power density curves (Logan *et al*., 2006).

5. CONCLUSIONS

The present study describes a way of directly producing electricity from the soil fuelled with urine. The results of this research are promising for future developments in MFCs for electricity generation using soil and urine which are cheaply available. This is not another MFC study that simply demonstrates the utilization of wastewater, but it is a clear demonstration that human urine can be an abundant fuel for electricity generation within soil-based MFCs' systems. The impact from this could be enormous, not only for the waste management industry, but also for people as a paradigm shift in the way they think of urine as mere wastewater. With an annual global production rate of trillions of litres of urine, this is a technology that could help change the world.

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