Research Journal of Engineering and Environmental Sciences 1(1) 2016 pp. 129-135

Research Journal of Engineering and Environmental Sciences

Journal homepage: www.rjees.com

RJEES

Original Research Article

EXPERIMENTAL UTILIZATION OF URINE TO RECHARGE SOIL MICROBIAL FUEL CELL FOR CONSTANT POWER GENERATION

[1]*Simeon, M.I. and [2]Raji, A.O.

[1]Department of Agricultural and Bioresources Engineering, Federal University of Technology, PMB 65, Minna, Nigeria
[2]Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria
*simeon.imologie@futminna.edu.ng; abdulganiy.raji@ui.edu.ng

ARTICLE INFORMATION

Article history:
Received 02 December 2016
Revised 23 January 2017
Accepted 24 January 2017
Available online 20 February 2017

Keywords:
Substrate
Urine
Soil
Fuel cell
Microorganisms
Power

ABSTRACT

The simplicity of the soil-based microbial fuel cells (MFCs) makes them very attractive, as perhaps, the only natural components they need to run are nutrient-rich soil combined with water to form mud. However, the MFC will cease to produce electricity when the soil runs out of its nutrient-rich characteristics and bacteria. It is against this background that this study was designed to study the possible utilization of urine to recharge soil MFCs that have run out of their nutrient rich characteristics. The mud-watt MFC was utilized for this study. It was run continuously for forty days until the power output was nearly zero. Fresh urine was then introduced into the soil and the power output was determined. The initial (24 hours after set-up) open circuit voltage (OCV) was 219 mV. A maximum OCV of 731 mV was obtained on day 14 of the study. The OCV of the MFC was 7.31 mV on day 40 prior to ejection of urine into the soil. Twenty four hours after the ejection of urine, the OCV was 360 mV and rose to 407 mV forty eight hours later. The OCV remained constant at this value for fifteen days after which urine was re-injected. The voltage drop across seven external loads also showed a similar trend. This study has demonstrated that fresh urine can be successfully utilized to recharge a soil-based MFC that has run out of its nutrient rich characteristics.

1. INTRODUCTION

The two recent global challenges are obviously environmental protection and energy crisis (Singh et al., 2010). The long-term availability of energy from sources that are affordable, accessible, eco-friendly and renewable is crucial to our economic growth and sustainability (Oyedepo, 2012). There have been persistent efforts in research and technology towards the development of renewable energy sources as perhaps, the most viable solution to the problem of environmental degradation posed by the continuous dependence on fossil-based fuel as the sole sources of energy (Ieropoulos et al., 2012). In addition to the well-known renewable energy sources such as solar energy, wind energy and hydropower, research attention has recently been drawn to MFCs as a potential part of this field of natural energy (Singh et al., 2010). MFCs are devices that use bacteria as the catalyst to oxidize organic and inorganic materials and generate electric current in the process (Logan and Regan, 2006).

MFCs are often classified based on configuration, electrode materials, membranes, number of chambers, source of substrates, microbes used and mechanism of electron transfer to the anode (Shikhi and Rani, 2012). MFCs without exogenous mediators are classified as "mediator-less" or "membrane-less". They do not require a mediator but use electrochemically active bacteria such as *Shewanella putrefaciens, Geobacter and Aeromonas hydrophila* to transfer electrons from the bacterial respiratory enzyme to the electrodes (Kim et al., 2003).

Soils have been identified with diverse species of microorganisms, including those that produce electricity by their natural metabolism. Moreover, the aerobic (oxygen consuming) microbes present in the soil act as an oxygen filter, much like the proton exchange membrane (PEM) materials used in double chamber MFC systems. Thus, soil or sediment microbial fuel cells (SMFCs) have been found to be very efficient as long as conditions remain favorable for electric current production by the anode-associated microbes (Ashley and Kelly, 2010). One requirement for a favorable condition of the soil MFC is the availability of the right substrate to replenish the soil organic contents used up over time by microbes during metabolism for enhanced electrogenesis (Rosenberg et al., 1996). When the organic content available in the soil for microbial metabolism is used up, there will be a continuous decline in voltage until the voltage output of the MFC becomes zero (Simeon et al., 2016a). Therefore, there is the need to recharge SMFCs over time in order to have continuous power production.

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 such as nitrogen, phosphorous and sulphate (Ieropoulos et al., 2012; Santoro et al., 2013). However, its utilization to recharge SMFC that has run out of its nutrient rich characteristics has, hitherto, not been reported. Therefore, this study is carried out to experimentally determine the re-chargeability of SMFCs with urine in much a similar way as a secondary cell is recharged after its power has been consumed.

2. MATERIALS AND METHODS

2.1. Soil Sampling and MFC Setup

Topsoil was collected from the vegetable garden at Appleton Junction adjacent U&I restaurant of the University of Ibadan (7°23′47″N 3°55′0″E), Ibadan, Oyo State, Nigeria. The soil sample was collected at a depth of 0-20 cm. This location was chosen because it is a rich farmland where crops have been cultivated over the years. The preparation of mud from soil sample and MFC setup were carried out according to the methods described by Simeon et al.

M.I. Simeon and A.O. Raji / Research Journal of Engineering and Environmental Sciences 1(1) 2016
pp. 129-135

(2016b). Figure 1 shows MFC components while Figure 2 is a setup showing the cathode (orange coloured electrode on the left) and the anode (green coloured electrode on the right) in position. The schematic diagram of the complete setup is given in Figure 3.

2.2. MFC Operation and Recharging

The soil MFC was operated for 40 days without the addition of any substrate. When the power output was approximately zero (indicating that the soil nutrients and carbon contents had been used up due to microbial metabolism), 3 ml of fresh urine was fed into the cell. This volume of urine, which was just sufficient to saturate the soil with water, was added on day 41 and day 57 (16 days interval when a drop in voltage was observed after the first treatment). The daily open circuit voltages (OCVs) and the voltage drop (V) across each of seven external loads (R) (47 Ω, 100 Ω, 220 Ω, 470 Ω, 1000 Ω, 2200 Ω and 4700 Ω) was measured with a digital Multi-meter (Kelvin 50LE). The power delivered to each external load was computed from Equation (1), according to Ohm's law.

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

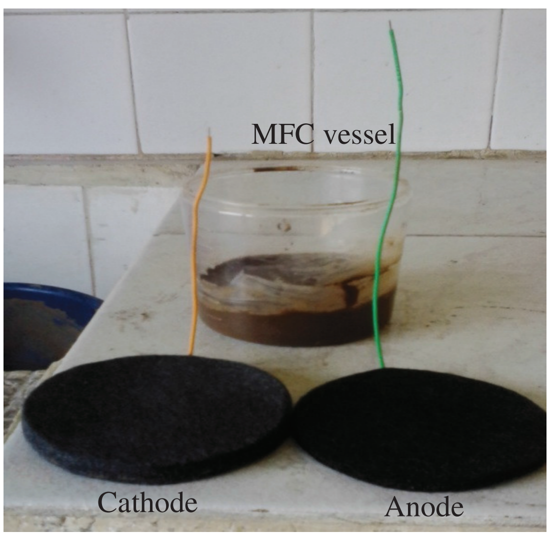

Figure 1: SMFC components


Figure 2: Anode and Cathode in MFC Vessel

M.I. Simeon and A.O. Raji / Research Journal of Engineering and Environmental Sciences 1(1) 2016
pp. 129-135

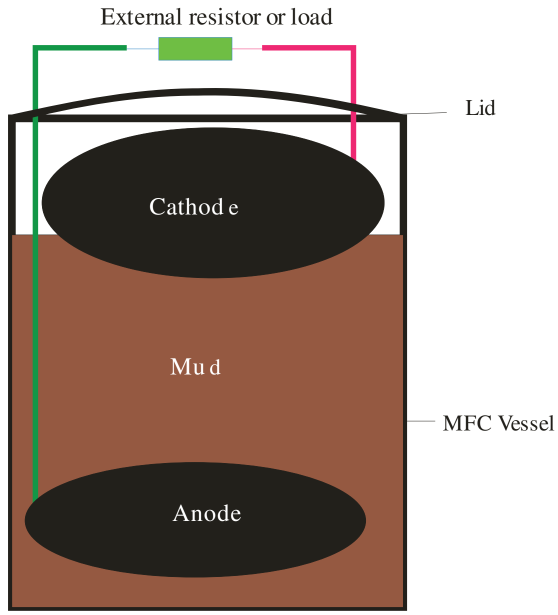

Figure 3: Complete MFC Setup.

3. RESULTS AND DISCUSSION

Figure 4 presents the OCV throughout the period of experiment, while Figure 5 presents the voltage drops across seven external resistances. Figures 4 showed that there was a steady increase in OCV from 219 mV (day 1) to 343 mV (day 3), after which the OCV increased exponentially from 414 mV (day 4) to a maximum of 731 mV (day 14). A steady decrease in voltage was observed between days 15 and 18, and then an exponential decrease up to day 40. The trend of Figure 4 within the first 40 days of MFC operation seemed to follow the phases that are typical in bacterial growth, as described by Jenna (2010). These results suggests that microorganisms present in the soil were actually responsible for the electricity generated (Simeon et al., 2016b). The exponential growth, as observed between Days 4 and 15 is very significant in this study. It is an indication that the soil MFC needs no initial charging but charges itself spontaneously to a maximum voltage after which it discharges exponentially if no new substrate is introduced. This is observed between days 15 and 26 as indicated in Figures 4 and 5.

M.I. Simeon and A.O. Raji / Research Journal of Engineering and Environmental Sciences 1(1) 2016
pp. 129-135

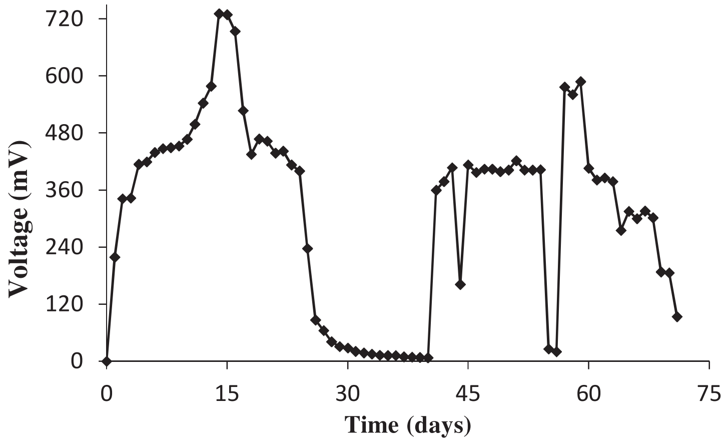

Figure 4: Open circuit voltage of the MFC

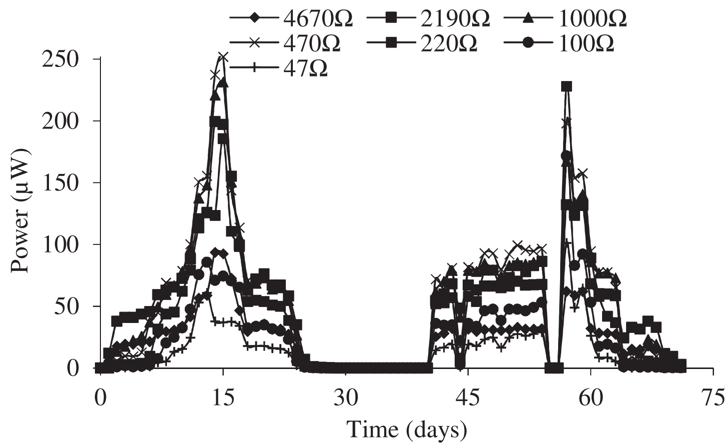

Figure 5: Power versus time plot

After a long period of operation (40 days) without replenishing the soil organic compounds and the nutrients, the power output of the MFC became too low ($5.5 \times 10^{-3} \pm 3.4 \times 10^{-3}$ µW) for any practical application as can be seen in Figures 5 between days 26 and 40 (14 days). This might be due to a loss of activation energy needed for electrons generation and transfer from or to the compound reacting at the electrode surface and thus a reduced redox reaction at the cathode (Logan and Regan, 2006). The long period of MFC's operation without addition of any substrate or moisture affected microbial metabolism which resulted in the MFC discharge as observed within these 14 days (Simeon et al., 2016b).

Introduction of urine on day 40 might have reactivated the microorganisms and thus increased their metabolism which resulted in increase of OCV from 7.31 mV (day 40) to 360 mV (day 41). The OCV further increased by 13.1 % after 48 hours before it dropped to 162 mV on day 44 of operation. This sudden drop in OCV and the voltage drop across the external loads may be attributed to decay due to urine hydrolysis, or lack of sufficient oxygen for cathodic reaction (Ieropoulos et al., 2012; Santoro et al., 2013). This was only transient as it was overcome when the MFC's lid was lifted to aerate the cathode. Constant powers were obtained across the external loads between day 45 and 53 as shown in the Figure 5. This is an indication that SMFCs can be fueled with urine to produce constant power. As clearly indicated in Figure 4, there was a sharp drop in OCV from 403 mV on day 54 to 26 mV and 20 mV on days 55 and 56 respectively. This was observed when the research location was changed and the fuel cell was moved from Ibadan (western Nigeria) to Minna (North-Central Nigeria), a distance of about 383 kilometers (238 miles). Thus, this drop in voltage may be due to 'microbial inactivity' due to their disturbance in transit or their reaction to the new environment (Verena, 2012). Their inactivity obviously resulted in loss of metabolism which affected the voltage output (Figure 5). The microorganisms were probably reactivated following the introduction of 3 ml of urine on day 56 as observed by the voltage overshoot from 20 mV (day 56) to 577 mV (day 57). This is an indication that fresh urine environment is well suited for microbial metabolism and proliferation. The voltage drops across the external resistances (Figure 5) are of importance as they describe the ability of the soil MFCs to deliver power to various external loads. Again, the trend of the power versus time plot between days 40 and 55 is an indication that soil MFCs can deliver stable power when fueled with urine; and this is one of the performance considerations for a good power source.

4. CONCLUSION

This study has shown that soil-based MFCs that have run out of their nutrient rich characteristics can be recharged easily with fresh urine. They will be very useful in powering sensors for remote control of farm machineries; especially in remote farms where electricity is not easily accessible. With this demonstration that production of constant power is feasible within the soil-based MFCs' systems fueled with urine, the development of a soil-based bio-battery for practical applications, which can be recharged easily with human urine now draws closer. Consequently, SMFCs can be produced, which will mimic a rechargeable or storage battery that can be charged, discharged into a load, and recharged many times. However, further studies are required to determine the best combination of different factors and optimum conditions for constant power generation of the soil MFC fueled with urine.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Ashley, E.F. and Kelly P.N. (2010). Microbial Fuel Cells: A Current Review. *Energies,* 3, pp. 899-919.

Ieropoulos, I., Greenman, J. and Melhuish, C. (2012). Urine Utilization by Microbial Fuel Cells: Energy Fuel for the Future. *Physical Chemistry Chemical Physics,* 14(1), pp. 94-98.

Jenna, R.J. (2010). *Microbial Fuel Cells in Landfill Applications*. A Final Report Prepared for the Environmental Research and Education Foundation Alexandria.

Kim, B.H., Chang, I.S., Gil, G.C., Park, H.S. and Kim, H.J. (2003). Novel BOD (biological oxygen demand) Sensor using Mediator-less Microbial Fuel Cell. *Biotechnology Letters,* 25 (7), pp. 541–545.

Logan B.E. and Regan J.M. (2006) Electricity-producing bacterial communities in microbial fuel cells. *TRENDS in Microbiology*, 14(12), pp. 512-518.

Rosenberg, E., Legman, R., Kushmaro, A., Adler, E., Abir, H. and Ron E.Z. (1996). Oil Bioremediation Using Insoluble Nitrogen Source. *Journal of Biotechnology,* 1, pp. 273-278.

Santoro, C., Ieropoulos, I., Greenman, J., Cristiani, P., Vadas, T., Mackay, A. and Li, B. (2013). Current generation in Membraneless Single Chamber Microbial Fuel Cells Treating Urine. *Journal of Power Sources,* 238, pp. 190-196

Shikhi, S. and Rani, A. (2012) Optimization of Growth Medium in Microbial Fuel Cell for Electricity Production by *Paenibacillus*. *International Journal of Science and Research*, 1(3), pp. 74-77.

Singh, D., Pratap, D., Baranwal, Y., Kumar, B. and Chaudhary, R.K. (2010). Microbial Fuel Cells: A Green Technology for Power Generation. *Annals of Biological Research,* 1(3), pp. 128-138.

Simeon M.I, Raji O.A., Musa J.J. and Kuti A. (2016a). Determination of the Suitability of Urine as Substrate in a Power Generating Soil Microbial Fuel Cell. In: *Proceedings of the Annual Conference of the School of Engineering & Engineering Technology*: 16-18 August 2016, Federal University of Technology Akure, Nigeria.

Simeon M.I., Raji O.A., Agidi G. and Adeoye P. A. (2016b). Performance of a Single Chamber Soil Microbial Fuel Cell across Varied External Loads for Power Generation. In: *Proceedings of the 37th Conference and Annual General meeting of the Nigerian Institution of Agricultural Engineers*: 4th - 7th October 2016, Minna, Nigeria.

Oyedepo, S.O. (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society,* 2(1), p. 15.

Verena, W. (2012). Effects of disturbances on microbial community composition and activity of biofilms from the Great Barrier Reef. *A Dissertation submitted to the Faculty of Biology and Chemistry*, University of Bremen, in fulfillment of the requirements for the degree of Doctor of Natural Science. Retrieved on January 19, 2017 from elib.suub.uni-bremen.de/edocs/00102631-1.pdf.