

Preliminary investigation of single chamber single electrode microbial fuel cell using sewage sludge as a substrate

M Sai Chaithanya, Somil Thakur, Kumar Sonu and Bhaskar Das

Department of Environmental and Water Resources Engineering, School of Civil and Chemical Engineering, VIT University, Vellore, Tamil Nadu 632014, India

Email: bhaskardas@vit.ac.in

Abstract. A microbial fuel cell (MFC) consists of a cathode and anode; micro-organisms transfer electrons acquired from the degradation of organic matter in the substrate to anode; and thereby to cathode; by using an external circuit to generate electricity. In the present study, a single chamber single electrode microbial fuel cell has been fabricated to generate electricity from the sludge of the sewage treatment plant at two different ambient temperature range of $25 \pm 4^\circ\text{C}$ and $32 \pm 4^\circ\text{C}$ under aerobic condition. No work has been done yet by using the single electrode in any MFC system; it is hypothesized that single electrode submerged partially in substrate and rest to atmosphere can function as both cathode and anode. The maximum voltage obtained was about 2890 mV after 80 (hrs) at temperature range of $25 \pm 4^\circ\text{C}$, with surface power density of 1108.29 mW/m^2 . When the ambient temperature was $32 \pm 4^\circ\text{C}$, maximum voltage obtained was 1652 mV after 40 (hrs.) surface power density reduced to 865.57 mW/m^2 . When amount of substrate was decreased for certain area of electrode at $25 \pm 4^\circ\text{C}$ range, electricity generation decreased and it also shortened the time to reach peak voltage. On the other hand, when the ambient temperature was increased to $32 \pm 4^\circ\text{C}$, the maximum potential energy generated was less than that of previous experiment at $25 \pm 4^\circ\text{C}$ for the same substrate. Also the time to reach peak voltage decreased to 40 hrs. When comparing with other single chamber single electrode MFC, the present model is generating more electricity than any MFC using sewage sludge as substrate except platinum electrode, which is much costlier than electrode used in the present study.

1. Introduction

Depletion of conventional energy sources at a rapid rate is becoming a major factor to find some alternate fuel sources [16]. Many researchers over the years have been working on different technologies. Some of them are better than others in terms of hygienic environment. One of those technologies is microbial fuel cells. MFC technology is self-sustained, environment friendly and pollution less. The microbial fuel cell is a device which generates electricity by the metabolic activities of the microbes. Microorganisms transfer the electrons obtained from the metabolism of organic matters in the anode and thereby to the cathode through an external circuit, hence generate electricity [1,2]. Though a century old technique, which was initially recognized for treatment of wastewater, MFC is gaining its interest for the generation of electricity, bio-hydrogen and also used as biosensor [3,4]. Any biodegradable organic matter ranging from pure compounds such as glycerol, acetate, starch, glucose, cysteine, and ethanol [3, 5] to complex mixtures of organic matter such as wastewater [6], cow dung [2], kitchen waste [6] can act as ideal substrates for generation of sustainable energy from MFC. The performance of microbial fuel cell depends upon the types of electrode materials, microbe & substrate and its concentration, pH, temperature



and ionic strength.

The various types of electrode that can be used in the construction of the microbial fuel cell are graphite; Granular activated carbon, Platinum (Pt.), Pt. black, stainless-steel, carbon paper, reticulated vitreous carbon (RVS). The design of MFC may be (1)- Two compartment MFC systems consisting of an anodic chamber and cathodic chamber separated by proton exchange membrane (PEM) or sometime salt bridge to allowing the proton to move across the blocking the diffusion of oxygen into the anode [3]. (2)- Single compartment MFC systems consisting of single anodic chamber without the any aerated cathodic chamber. (3)- The anode chamber is coupled to a porous air-cathode exposing directly to the air.

The Single-compartment MFC systems is cheaper than that of two compartment MFC. The traditional dual chamber which is bulky due to two separate anode and cathode chambers, single chamber containing single anode chamber omitting the cathode chamber where cathode is placed as membrane and exposed to air is much more efficient and cost effective than dual chamber MFC.

Table1 shows the performance of single chamber microbial fuel cell for different substrate on the basis of maximum power density. The maximum surface power density of 6000 mW/m^2 using platinum electrode modified polyanilineco and sewage sludge was found from the literature available [7]. When the sewage sludge used with graphite electrode, 152 mW/m^2 of maximum surface power density could be achieved [7].

Table 1: Performance of single chamber MFC under different types of industrial wastes

| Sl. No. | Industry/Substrate | System configuration | Maximum surface power density | Refs. |
|---------|------------------------------|--|-------------------------------|-------|
| 1 | Sewage sludge | Electrode: Single chamber (graphite electrode | 152 mW/m^2 | [7] |
| | | Single chamber (Platinum and polyanilineco-modified) | 6000 mW/m^2 | [7] |
| 2 | Glycerol -waste water | Single-chamber Temperature ($^{\circ}\text{C}$): 30°C pH: 7 | 600 mW/m^2 | [8] |
| 3 | Meat packing wastewater | One-chamber, Carbon paper loaded with 0.35 mg platinum/ cm^2 Temperature ($^{\circ}\text{C}$): NA pH: NA | $80 \pm 1 \text{ mW/m}^2$ | [9] |
| 4 | Starch processing wastewater | One-chamber air-cathode MFC with carbon paper anode (25 cm^2) Temperature ($^{\circ}\text{C}$): $30 \pm 1^{\circ}\text{C}$ pH: 7.1 ± 0.1 | 239.4 mW/m^2 | [10] |
| 5 | Swine wastewater | Single-chambered air cathode Temperature ($^{\circ}\text{C}$): 30°C pH: NA. | 261 mW/m^2 | [11] |
| 6 | Brewery wastewater | One-chamber air-cathode MFC with non-wet proofed carbon cloth as anode (7 cm^2) and wet proofed carbon cloth containing Pt as cathode Temperature ($^{\circ}\text{C}$): 30°C pH: 6.5 ± 0.2 | 205 mW/m^2 | [12] |
| 7 | Paper recycling wastewater | One-chamber MFC with graphite fiber-brush anode ($5418 \text{ m}^2/\text{m}^3$ brush volume), Temperature ($^{\circ}\text{C}$): $22-26^{\circ}\text{C}$ (Room temperature) pH: 7 | $501 \pm 20 \text{ mW/m}^2$ | [13] |

In conventional single chamber MFC the anode and cathode are separated by a membrane or sometimes cathode is directly exposed to air. In both the cases, anode and cathode are completely

made of different materials in design and composition. In our present study for the first time we are using single chamber single electrode MFC where the same electrode has been used as anode as well as the cathode. The substrate used here is domestic sewage sludge.

2. Materials and Methods

2.1 Collection and preservation of sample

The sewage sludge is collected from the waste water treatment plant at VIT University, Vellore campus. The sludge was preserved at 4 °C after collection and before using in MFC [12]. The physiochemical characteristics of the sludge used in MFC are shown in the **Table 2**. The COD analysis was performed by closed reflux method of APHA standard [14]

Table 2. Physico-chemical properties of sewage sludge used in MFC.

| Sl.No | Parameters | Values |
|-------|---------------------|------------|
| 1 | COD | 80000 mg/l |
| 2 | % of Total Solid | 17.2 |
| 3 | % of Volatile Solid | 11.6 |
| 5 | Colour | Grey |
| 6 | pH | 5.3 |

2.2 Design

Six numbers of single chamber MFCs having graphite electrode as dual anode and cathode connected externally in series with copper wire have been used in this present study. Each electrode is submerged into the sludge and partially exposed to atmosphere acting as anode and cathode respectively. About 70% of the total lengths of the electrodes were in the sludge and the rest 30% of the length was exposed to the air. **Figure 1** shows the experimental setup in detail.

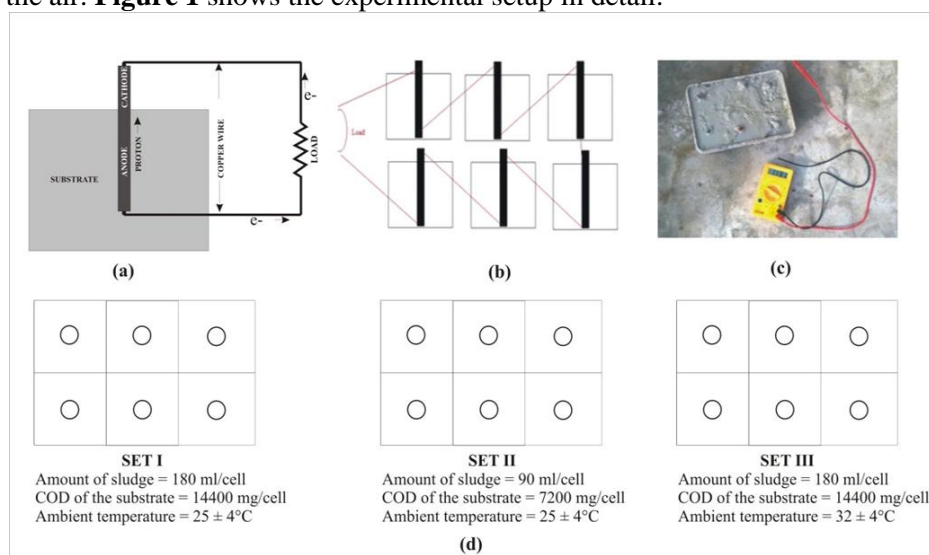


Figure 1. Single chamber single electrode MFC. (a) Circuit diagram of single cell of single chamber single electrode MFC. (b) Schematic representation of the circuit diagram of single chamber single electrodes MFC in series. (c) Photograph of the experimental setup of the combination of single chamber single electrode. (d) Schematic representation of the three different setups of MFC studied.

2.3 Components in microbial fuel cell.

Graphite electrodes were taken from the used dry cell to absorb electrons from the substrate. Before using, the electrodes were cleaned with 0.1 M HCl and stored in deionized water for 12 hr. The dimensions of the electrode were 10 mm diameter and 57 mm, respectively having 40 mm (70% length) as anode and 17 mm as cathode. Hence the surface area of an anode is 1256 mm². The electrodes were connected in series by using copper wires of 0.7 ohms resistance. The voltage of the system was monitored by using a multimeter (Model No.MAS83OL). pH meter was used to measure the pH of the substrate. The collected sewage sludge was mixed uniformly, added to the container. The micro-organisms present in the sludge starts utilizing the organic matter and start the metabolic activities in aerobic condition.

2.4 Performance evaluation criteria

For all the three sets the voltage output were recorded by the multimeter across the resistor of 1000 ohm at the regular interval of 8 hrs and continuously operated until the energy generation is diminished to zero (least count of the multimeter is 0.01 mV). The first two sets were operated at ambient temperature of $25 \pm 4^\circ\text{C}$ while the third set is operated at ambient temperature of $32 \pm 4^\circ\text{C}$, which was within 10 days.

The surface power density P (mW/m²) is calculated as $P = V^2 / (R \times A \times 1000)$, where V (mV) is the measured fuel cell voltage, R (ohm) external resistant and A (m²) projected surface area of the anode 1000 is needed for maintaining the units.

3. Result and Discussion

The maximum voltage obtained from the study was about 2890 mV after 80 (hrs.) for the SET I at ambient temperature of $25 \pm 4^\circ\text{C}$ (**Figure 2**). At the same average ambient temperature in SET II, we could able to achieve 2554 mV after 40 (hrs.) where the quantity (hence the amount of available COD) of the sewage sludge is half that of SET I. In SET III though the quality of sewage sludge is same as that of SET I but we could able to achieve only 1652 mV after 40 (hrs.) at an average ambient temperature of $32 \pm 4^\circ\text{C}$. The results were according to the fact that at high temperatures the reduction in voltage generated is more. [14]

Another important thing to be noted is, when the system is connected to a capacitor to discharge the electrons completely, it is observed that, when the current is reaching to a minimum value, it is surprisingly increasing again to certain extent, which indicates that fuel cell system is not letting the capacitor to discharge the system completely. Hence it is hypothesized that it may happen due to the rapid transfer of electrons from micro-organisms to the electrode to maintain equilibrium.

Table 3. Change of pH and COD in three different sets of Microbial Fuel Cell

| | SET I | | SET II | | SET III | |
|----------------------------|---------|------------------|---------|----------------|---------|----------------|
| | Initial | Final | Initial | Final | Initial | Final |
| pH | 5.3 | 4.5 | 5.3 | 4.6 | 5.3 | 6.1 |
| COD (mg/L) [% decrease] | 80000 | 58000 [27.5%] | 80000 | 72000 [10%] | 80000 | 56000 [30%] |

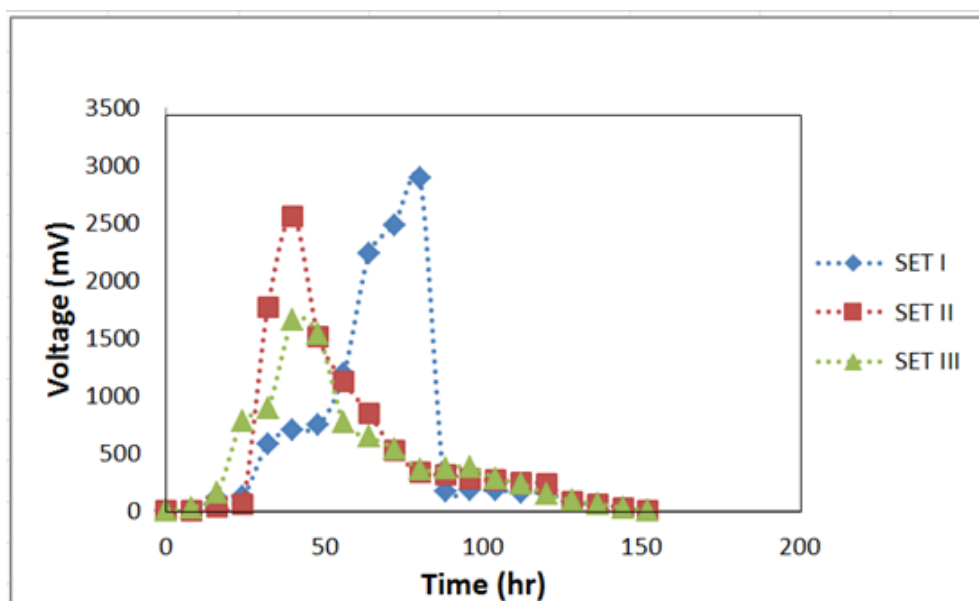


Figure 2. Voltage (mV) vs. Time (hrs.) for all the 3 SETs.

The pH of the sewage sludge found to decrease from 5.3 to 4.5 in SET I (**Table 3**). For SET II, the pH reduced from 5.3 to 4.6 but in SET III the pH increased from 5.3 to 6.1. At the end of the 152 (hrs.), the COD of the sewage sludge for the SET I was 58000 mg/l (reduction of 27.5%), In case of SET II the COD was 72000 mg/l (reduction of 10%), finally for the SET III it is 56000 mg/l (reduction of 30%). The COD reduction is less when compared to other studies, which may be due to the higher initial COD values of sludge.

Results obtained from the SET III clearly indicate that at elevated temperature the metabolic activities of the microbes reduce and even the pH of the sewage sludge is increased, thereby reducing the surface power density. But at same time there is slight improvement in the COD reduction.

4. Conclusion

The present study is a novel and economical single chamber single electrode microbial fuel cell for the generation of electricity. Result found is very encouraging when compared to other single chamber MFC. The highest surface power density found to be 1108.29 mW/m² which is more than any other single chamber MFC excluding platinum electrode (**Table 1**). It is hypothesized that; the part of electrode submerged in the substrate is behaving as anode; as it is comparatively anaerobic and part exposed to atmosphere is acting as a cathode; as it is in aerobic zone; hence the layer of substrate separating cathode region and anode region is the reason behind the working of same electrode as both cathode and anode. It has been observed that this system is not effective for COD removal. Further study is required with different range of COD (low and medium) to know the actual reason behind this behavior. As per the very preliminary study conducted on the presented single chamber single electrode MFC it can be undoubtedly said that the current model is capable of generation of electricity from the domestic sewage sludge economically and effectively; but needs further modification in optimisation and design for making it commercially viable.

Acknowledgement

Dr. Bhaskar Das and other authors acknowledge the help of VIT University, Vellore 632014 for the financial support and laboratory facilities to carry out this research works.

References

- [1] Potter M C(1911), Electrical effects accompanying the decomposition of organic compounds, *Proc R Soc London Ser B*, **84**,260-76.
- [2] Guang Zhao, Fang Ma, Li Wei, Hong Chua, Chein-Chi Chang & Xiao-Jun Zhang(2012), Electricity generation from cattle dung using microbial fuel cell technology during anaerobic acidogenesis and the development of microbial populations, *Waste Management*,**32**,1651–58.
- [3] Logan BE, Hamelers B, Rozendal R, Schroder U, Keller J, Freguia S, Aelterman P, Verstraete W & Rabaey K(2006). Microbial Fuel Cells: Methodology and Technology. *Environ Sci Technol*, **40**,5181-92
- [4] Wang H, Park JD & Ren ZJ(2015), Practical Energy Harvesting for Microbial Fuel Cells: A Review. *Environ Sci Technol*, **49** 3267-77.
- [5] Kim JR, Jung SH, Regan JM & Logan BE(2007) ,Electricity generation and microbial community analysis of alcohol powered microbial fuel cells, *Biores Technol*, **98**,2568–77.
- [6] Das S & Mangwani N(2010). Recent development in microbial fuel cell: a review. *Journal of Scientific and Industrial Research*. 69,727-31.
- [7] Mostafa Rahimnejad , Arash Adhami , Soheil Darvari , Alireza Zirepour & Sang Eun Oh(2015), Microbial fuel cell as new technology for bioelectricity generation: A review, *Alexandria Engineering Journal*, **54**,745–56.
- [8] Vanita Roshan Nimji, Chien Jin chen, chien Cheng Chen, Min-Jen Tsing, Jin Shuh Jean & Hau Ren Chen(2010), Glycerol degradation in single-chamber microbial fuel cells, *Bioresource Technol*, **102**,2629-34.
- [9] Heilmann J & Logan BE(2006), Production of electricity from proteins using a microbial fuel cell, *Water Environ Res*, **78**,531–37.
- [10] Liu H, Cheng S A & Logan B E(2005),Production of electricity from acetate or butyrate using a single-chamber microbial fuel cell, *Environ Sci Technol*, **39**,658-62.
- [11] Min B, Kim JR, Oh S, Regan JM & Logan BE(2005), Electricity generation from swine wastewater using microbial fuel cells, *Water Res*, **39**.4961–68.
- [12] Feng Y, Wang X, Logan BE & Lee H(2008), Brewery wastewater treatment using air-cathode microbial fuel cells, *Appl Microbiol Biotechnol*, **78**,873–80.
- [13] Huang, LP & Logan BE ,Electricity generation and treatment of paper recycling wastewater using a microbial fuel cell, *Appl Microbiol Biotechnol*, **80** (2008)349–55
- [14] APHA-AWWA-WPCF,(1998). Standard Methods for the Examination of Water andWastewater, *20th ed. American Public Health Association/American WaterWorks Association/Water Environment Federation*, Washington DC, USA.
- [15] Olga Tkach, Lihong Liu and Aijie Wang(2016), Electricity generation by Enterobacter sp. Of single chamber microbial fuel cells at different temperatires, *Journal of clean energy technology*,**4**.
- [16] Satish V. Khedkar(2016),Studies in energy generation from cow dung in microbial fuel cell, *International Journal Of Pure And Applied Research in Engineering and Technology*,**4(8)** 343-51