International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Electricity Generation from Dairy Farm Wastes In a Dual-Chamber Microbial Fuel Cell Using Aluminium Electrodes

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Abstract*: Microbial fuel cells play a key role in generating wealth out of waste as they serve the binary purpose of electricity production along with waste treatment. A variety of organic substances can be used as substrates in microbial fuel cells. In this work, three substrates naturally obtained as dairy farm waste, viz. cattle manure, yogurt waste, and cow urine along with their various combinations were tested for power generation in a microbial fuel cell. All three substrates are a promising source of electrogenic bacteria. The potential use of aluminium as electrode material for electricity generation in microbial fuel cell was also investigated. The output circuit voltage was recorded at regular time intervals over a period of around 15-25 days. Maximum output voltage of 1.170 V was recorded for cattle manure as substrate on graphite electrode with a stabilization period of 16 days. The combination of cattle manure and yogurt waste on aluminium electrode gave peak output voltage of 1.122 V with a stabilization period of 10 days. The addition of cow urine did not show any significant increase in the output.

***Keywords*: Aluminium electrodes, Cattle manure, Microbial fuel cell, Yogurt waste**

I. INTRODUCTION

Microbial fuel cells (MFCs) are a promising source of electricity generation through microbial activity on organic substrates. They directly convert chemical energy to electrical energy through biochemical interactions, in a single step, thus increasing the conversion efficiency [1]. MFCs do not require high temperatures and pressures to operate [2] and hence find wide potential applications in remote locations lacking proper electrical infrastructure [3]. They can be used as biosensors, for wastewater treatment as well as for bio-hydrogen production [4]. In the recent years, MFCs have grabbed the attention of numerous researchers, noticeable by the rise in number of publications in this field [5], [6]. The performance characteristics of MFCs can be evaluated by different parameters such as output circuit voltage (OCV), current density, power density, loading rate, energy efficiency etc. [7]. Although a variety of substances can be used as substrates [8], the primary focus has been on treatment of wastes [9]–[11]. Dual benefits of energy generation and waste disposal can be achieved in these types of MFCs. Studies on MFCs employing dairy farm wastes such as animal manure [12]–[21], cow urine [22] and yogurt waste [23]–[25] have been reported in literature. Cattle manure has a strong potential as renewable feedstock for bio-electricity production [14]. Even yogurt bacteria possess the capacity to generate power [26]. However, the literature on yogurt waste as a substrate in MFC is scarce.

Apart from substrates, electrode material also plays a significant role in the output of MFCs [27]. Selection of anode material could be a limiting factor for determining the performance of an MFC. Carbon based electrodes have gained popularity as compared to other materials due to their better performance characteristics such as biocompatibility, chemical stability and low costs [28]. For example, in a study by Scott and Murano [12], the output voltage for carbon anode was found to be higher than Pt/C anode. However, its low conductivity might be a hindrance to its large scale applications. Metals such as copper and aluminium can be potential electrode materials on account of their high conductivity. Das [1] has reported that copper, brass, and aluminium inhibit microbial growth and hence are not suitable anode materials. Ouitrakul et al. [29] have analyzed the impedance for MFC electrodes made of different materials. They have shown that aluminium and stainless steel electrodes generate higher OCV than carbon fiber cloth in an MFC. Srikanth et al. [30] have studied the microbial growth on different electrode materials and presented that aluminium and copper anodes showed negative aspects in terms of electron discharge, energy conversion and bacterial growth. Contrary to earlier works, Baudler et al. [28] have shown that copper is a promising anode material. Apart from its good biochemical activity, they have mentioned that copper needs minimum electrode thickness, owing to its high conductivity, and is cheaper than graphite. This also holds true for aluminium. Hence, in this study, the efficacy of aluminium electrode on the output voltages of MFCs utilizing different combinations of dairy farm waste, viz. cattle manure, yogurt waste, and cow urine has been investigated.

Manuscript received on February 10, 2020.
Revised Manuscript received on February 20, 2020.
Manuscript published on March 30, 2020.
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II. THEORY

MFCs are bio-electrochemical devices in which substrates (carbohydrates) are broken down to smaller molecules by electrogenic anaerobic microbes, thereby releasing carbon dioxide, electrons, and protons.

The electrons reach the anode and then travel through an external circuit to the cathode, thereby generating electricity [5]–[6]. Dual-chamber MFCs consist of aerobic (cathodic) and anaerobic (anodic) chambers. The microbial decomposition of substrates occurs in the anaerobic chamber. The protons travel from the anodic to cathodic chamber through a proton exchange membrane. At the cathode, the electrons and protons combine with oxygen to form water. The reactions take place at the anode and cathode according to (1) and (2), respectively:

$$C_nH_{2m}O_m + (2n-m)\,H_2O \longrightarrow n\,CO_2 + 4n\,H^+ + 4n\,e^- \quad (1)$$

$$n\,O_2 + 4n\,H^+ + 4n\,e^- \longrightarrow 2n\,H_2O \quad (2)$$

Overall, the process involves conversion of organic substrate to carbon dioxide and water with generation of electricity as a by-product [4]. A schematic diagram of a dual-chamber MFC is shown in Fig. 1.

III. EXPERIMENTAL SECTION

The microbial fuel cell setup consisted of two high density poly-ethylene (HDPE) containers of volume 10^{-3} m^3 each. The containers were connected near the bottom by a poly vinyl chloride (PVC) pipe having an internal diameter of 0.032 m. The pipe was filled with agar-agar gel which acted as a salt bridgefor transfer of protons. The anode and cathode for each set of experiment consisted of the same material. Flat plate electrodes of two different materials, viz. aluminium and graphite were purchased. The dimensions of the electrodes were 0.051 m × 0.042 m with negligible thickness. Thin copper wires were connected to the electrodes. The substrates, viz. cattle manure, yogurt waste, and cow urine were obtained from a local dairy farm. In each experiment, the anaerobic chamber was filled with a combination of different substrates as shown in Table-I. In sets I, II, III, IV, VI & VII, 15 g of solid substrate (cattle manure/yogurt waste) was used; while in sets V & VIII, 7.5 g of each solid substrate was utilized. In sets I-V, the substrates were suspended in 10^{-3} m^3 of distilled water. In sets VI-VIII, the solid substrates were suspended in 10^{-3} m^3 of liquid substrate (i.e. cow urine). The aerobic chamber was

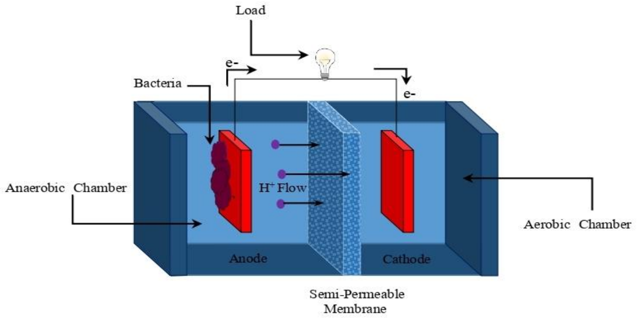

Fig. 1. Schematic representation of a microbial fuel cell

Table-I. List of substrates and electrode materials used in this work

Set	Substrate 1	Substrate 2	Substrate 3	Electrode material
I	Cattle Manure	–	–	Graphite
II	Cattle Manure	–	–	Aluminium
III	–	Yogurt waste	–	Graphite
IV	–	Yogurt waste	–	Aluminium
V	Cattle Manure	Yogurt waste	–	Aluminium
VI	–	Yogurt waste	Cow urine	Aluminium
VII	Cattle Manure	–	Cow urine	Aluminium
VIII	Cattle Manure	Yogurt waste	Cow urine	Aluminium

filled with water and 5 × 10^{-3} kg of potassium permanganate was added to it as an oxidizing agent. the open circuit voltage generated by the microbial fuel cell was measured for around 15-25 days at regular time intervals. a digital multi-meter (htc dm-88) having dc voltage range of 10 mv to 1000 v was used for the purpose.

IV. RESULTS AND DISCUSSION

Firstly, the effect of electrode material on the open circuit voltage was tested for two different substrates, viz. cattle manure and yogurt waste. For cattle manure as substrate (sets I & II), it was found that graphite electrode gave a higher OCV than aluminium electrode. The maximum OCV obtained was 1.170 V, which is comparable to the voltage of 1.180 V published in literature [15]. While the aluminium electrode gave almost stable output throughout, the output on graphite electrode stabilized after 16 days (see Fig. 2). For yogurt waste as substrate (sets III & IV), aluminium electrode gave better results as compared to graphite. The maximum OCV was 0.770 V for aluminium, while that for graphite was only 0.173 V. This could be due to poor and non-uniform bacterial colonization on graphite anode [23]. However, the output was unstable in both the cases as shown in Fig. 3. When a mixture of cattle manure and yogurt waste was used as a substrate on aluminium anode (set V), the resulting output voltages were higher than those obtained individually in sets II & IV (see Fig. 4). The peak OCV was 1.122 V and the output almost stabilized after 10 days. Fig. 5 shows the comparison between output voltages obtained from using cattle manure as sole substrate on graphite anode (set I) and using cattle manure with yogurt waste on aluminium anode (set V). Both the systems gave stable and almost comparable outputs. The addition of cow urine to yogurt waste on aluminium electrode (set VI) showed a slight increase in the output voltage than yogurt waste alone (set IV). However, the output was highly unstable. The

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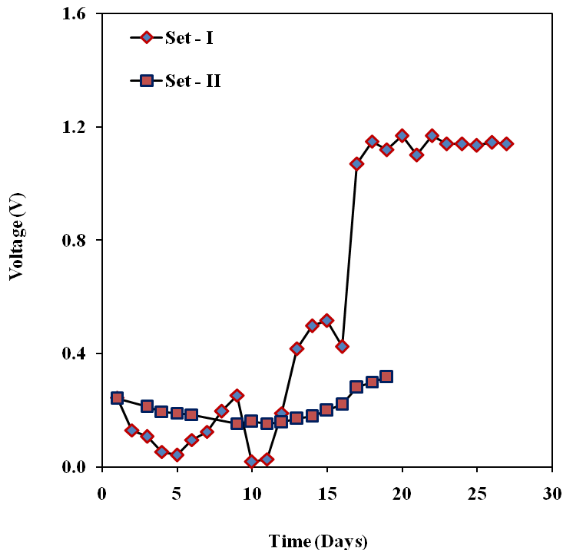

Fig. 2. Comparison of OCV for cattle manure as substrate on aluminium and graphite electrodes

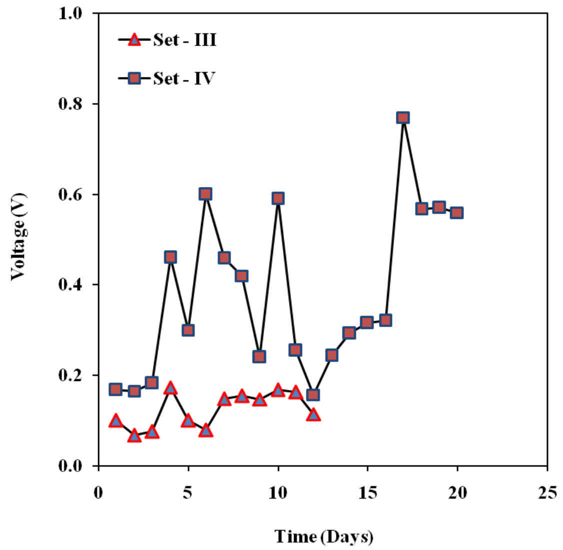

Fig. 3. Comparison of OCV for yogurt waste as substrate on aluminium and graphite electrodes

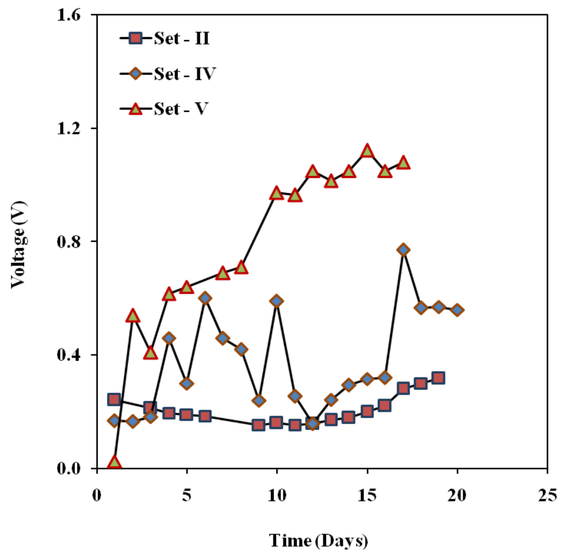

Fig. 4. Enhancement in OCV for cattle manure and yogurt waste as co-substrates on aluminium anode

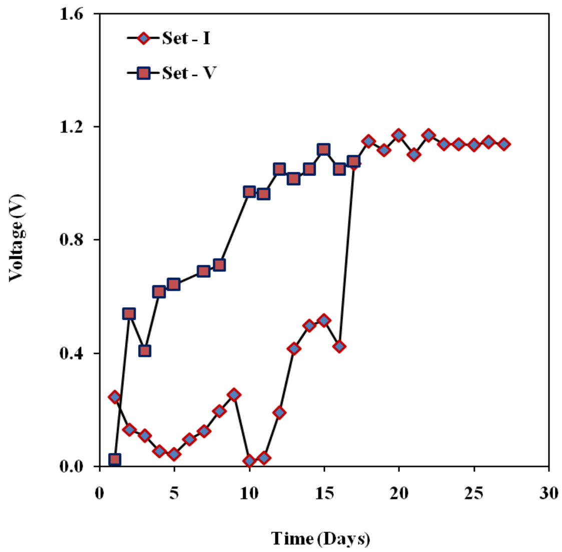

Fig. 5. Comparison of OCV for cattle manure as substrate on graphite electrode vs. cattle manure and yogurt waste as co-substrates on aluminium electrode

combination of cattle manure and cow urine on aluminium electrode (set VII) gave lesser output than cattle manure alone (set II). It was seen that the output of the ternary mixture comprising cattle manure, yogurt waste, and cow urine (set VIII) was nearly the same as that of cattle manure and cow urine mixture (set VII). The best results from this study are compared with those reported in literature as summarized in Table-II.

Table-II. Comparison of open circuit voltage values from literature to this study

Substrate	Anode	OCV (V)	Reference
Farm manure	Carbon	0.700	[12]
Cattle manure	Graphite fiber	0.590	[13]
Cattle manure	Carbon fiber	–	[14]
Cattle dung	Carbon brush	1.180	[15]
Cattle manure	Carbon felt	0.700	[16]
Dairy manure	Graphite fiber	1.000	[17]
Dairy manure	Graphite fiber	0.850	[18]
Swine manure	Graphite rod	–	[19]
Pig manure	Carbon felt	0.500	[20]
Dairy manure	Graphite rod	1.100	[21]

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DOI: 10.35940/ijrte.D8086.038620
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Table-II. Comparison of open circuit voltage values from literature to this study (continued)

Substrate	Anode	OCV (V)	Reference
Cow urine	Carbon felt	0.947	[22]
Yogurt wastewater	Graphite felt	0.500	[23]
Yogurt wastewater	SS fiber felt	0.750	[25]
Yogurt	Carbon paper	0.160	[26]
Cattle manure	Graphite plate	1.170	This study
Cattle manure + Yogurt waste	Aluminium	1.122	This study

V. CONCLUSIONS

This work evaluated the performance of dairy farm wastes as potential substrates for microbial fuel cells and aluminium as electrode material. Cattle manure gave the highest output of 1.170 V with graphite anode. Yogurt waste showed better results on aluminium than graphite. The mixture of cattle manure and yogurt waste produced a peak output of 1.122 V on aluminium anode. Cow urine as a co-substrate to yogurt waste showed an insignificant increase in the MFC performance. Based on these results, it can be inferred that aluminium has the ability to be used as electrode material in microbial fuel cells. Yogurt waste, alone or in combination with cattle manure, has great potential of being used as a substrate in microbial fuel cells with aluminium anode.

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