Electricity Generation from a Microbial Fuel Cell Using Abattoir Wastewater

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ABSTRACT

Two dual chamber microbial fuel cells (MFCs) labelled MFC-A and MFC-B were fabricated with agar-agar salt bridge as the proton exchange membrane. Each of the MFCs contained wastewater gotten from an abattoir as the catholyte. The anolyte for MFC-A was potassium ferricyanide with double copper-copper electrodes while the anolyte for MFC-B was potassium permanganate with a single copper–copper electrode. Readings of voltage and current was taken for 10 to 12 hours daily for 14 days, a total of 495 hours. Also, the MFC performance was calculated in terms of various parameters such as Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), pH, conductivity and temperature. MFC-A showed a maximum voltage output of 1.812V while MFC-B showed a maximum of 1.718V. The BOD removal efficiency of MFCs A and B was calculated as 78.33% and 72.67%, respectively. MFC-A showed an average value of 1.643V on the last day of observation while MFC-B showed an average value of 1.531V on the 14th day. An MFC generates electricity from wastewater. The voltage generated in an MFC is independent of the number of electrodes used, potassium ferricyanide gives a better result than potassium permanganate. BOD removal efficiency increases with the number of electrodes used.

Keywords: Microbial fuel cell; Biological Oxygen Demand (BOD) removal; Abattoir

1.0 INTRODUCTION

Microbial fuel cells (MFCs) are devices that use bacteria to generate electricity from organic matter. Microbial fuel cell (MFC) technology has been used to convert the energy stored in chemical bonds in organic compounds to electricity which is achieved through the catalytic reactions by microorganisms. This has generated considerable interest among academic researchers in recent years [2] [4] [12]. Microbial fuel cells are not new – the idea of using microorganisms to catalyze fuel cells was explored from the 1970s [4] and microbial fuel cells treating domestic wastewater were presented in 1991 [6]. However, it is only recently that MFCs with an improved output power [7] was developed making practical applications more realistic. MFCs convert the energy available in a bio – degradable substrate directly into electricity. This is achieved through bacterial action on them causing them to break down and release electrons in the process which are transferred to an insoluble acceptor, such as the MFC anode. This transfer can occur either via membrane associated components or soluble electron shuttles. The electrons then flow through a conductor under resistance to a cathode, at which the electron acceptor is reduced. In contrast to anaerobic digestion, an MFC generates electrical current and an off-gas containing mainly carbon dioxide. MFCs are a promising technology for alternative electricity production from a variety of materials. The release of stored carbon in fossil fuels is increasing the concentration of carbon dioxide in the atmosphere, with increases from 316ppm in 1959 to 377 ppm in 2004 [3]. By 2100 it is estimated that CO_2 concentration will reach anywhere from 560 ppm to 970 ppm [2]. Today the greatest environmental challenge is to simultaneously solve energy production and CO_2 release. The use of fossil fuels, especially oil and gas, in recent years has accelerated and this triggers a global energy crisis. One of the ways to reduce the current global warming crisis is renewable energy resources. Developing alternative electricity production methods are given prime importance. New electricity production from renewable resources without a net carbon dioxide emission is much desired [3] [10]. The MFC provides an alternative source of energy because uses solid waste from the environment to produce a minimal voltage as the output which can be improved to serve a domestic purpose. The purpose of this work is therefore, to: (1) construct and test a prototype microbial fuel

cell that would be portable and environmentally friendly; (2) Determine the effects of voltage output and wastewater treatment efficiency in comparison to varying cell components; (3) Improve on current microbial fuel cells whose voltages are low.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

The wastewater was collected from a mini dam cited at an abattoir at the relief market located along Egbu road, Owerri, Imo state, Nigeria. The waste was screened properly for the removal of large objects with the use of a rake. It was collected on the day of the analysis in order to prevent the degradation of the organic content of the sample by microorganisms. Before analysis, the waste water sample was stirred thoroughly in order to produce a defined sample. The organic content is to be broken down by the microbes to produce electrons desired by the MFC set up.

2.2 Preparation of the salt bridge

The salt bridge was prepared using 2% Lab 1M, 20g Agar-agar and 1M, 58.44g of analytical NaCl. A 10cm salt bridge was made using a 1.0-inch diameter PVC pipe. Firstly, 20g of agar-agar and 58.44g of sodium chloride was added to 1000ml of water in a conical flask. It was then dissolved by whirling the conical flask. The mixture prepared was autoclaved at a temperature of 120^{o}C under high pressure and left for 15 minutes. One end of a PVC tube is sealed with aluminum foil in an easily detachable way and held standing vertically using soft support. The autoclaved mixture first allowed to cool to about 50-55^{o}C before it is emptied into the PVC tube in the soft support. This was then allowed to cool and solidify thereby forming the salt bridge which is used for the MFC set up.

2.3 Preparing the Chambers

A 1-litre poly acrylic container was purchased to serve as the cathode and anode chambers. A hole, equal in diameter to the 1-inch adopter used for plumbing work was made 5.6 cm from the base of the container. The 1-inch adopter serves as a point of attachment for the salt bridge which is supposed to interconnect the two chambers. After the hole is made, the 1-inch adopters were glued using an Abro sealant (available in plumbing stores). The sealant was used to seal the edges of the point of contact between the 1-inch adopter with the chamber to avoid leakages after which it was left for 20-25 minutes for the set-up to dry and solidify. After which a hole each was drilled into the top cover of both chambers to allow the passage of wires.

2.4 Coupling the microbial fuel cell

The microbial fuel cells used for this study are two dual chamber microbial fuel cells labeled A and B. The wastewater was placed into the anode as the anolyte and the top cover of the chamber was used to passively aerate the cathode. The cathode chamber contains potassium ferricyanide with double copper-copper electrodes in MFC-A while potassium permanganate is used in MFC-B with a single copper-copper electrode. The multimeter was connected to the cathode and the anode with the aid of the low resistance copper wire before they are inserted into the chamber. Next, the multimeter was placed at 2000 m for measuring DC voltage in millivolts and 2000 m for measuring DC currents in milliamperes. The initial reading was taken at 0.00h and allowed to acclimatize for 1h before subsequent readings were taken. All raw data were converted to conventional units using calibration factors.

3. RESULTS AND DISCUSSION

3.1 Voltage Production

At the start of the experiment, there was observation of the voltage production of different ranges. These voltages produced were taken as the initial voltages which are because of the acclimatization period of the microbial community in the wastewater. Readings of voltage and current output were taken every hour for 10 to 12 hours daily for 14 days. Over the 14 days period, the maximum voltage obtained from both cells was 1.812V. A better performance was recorded by MFC-A with potassium ferricyanide as catholyte and a double copper-copper electrode having 1.812V on the 14th day. The maximum voltage from MFC-B with potassium permanganate as catholyte with a single copper-copper electrode was 1.718V recorded on the 14th day. The maximum voltage compares favorably with other studies (0.81V for single dual chamber MFC with copper-copper electrode and potassium permanganate as catholyte [1], 1.56V for graphite electrode and bleaching powder dissolved in water as catholyte [11], 1.532V using permanganate solution [14]). The readings of voltage and current output for the first, second and fourteenth day of observation are shown in tables 1 and 2 for MFCs A and B respectively. The average voltage on the first day was calculated as 0.379V and 0.489V for MFCs A and B respectively while that for the fourteenth day was calculated as 1.643V and 1.531V for MFCs A and B, respectively. Figures 1, 2 and 3 represent graphs of the voltage against time as recorded on the first, second and fourteenth day of the study respectively for both MFCs. The highest points indicate the highest voltage. From Figure 1, the voltage showed fluctuations. From Figure 2, the readings from both MFCs were more stable compared to the first day of the study. The fourteenth day of the study shows a progressive increase in voltage for both MFCs up to the highest value of voltage, then there was a progressive decrease in value of voltage as shown in Figure 3. This progressive decrease in the voltage output could be due to the depletion of the microbial community. On the first day, a sharp increase in voltage of 0.524V and 0.636V was observed for MFCs A and B respectively for the first hour of observation (peaks of Figure 1). These voltages dropped steadily with time amid more fluctuations. This could be due to the fact that in an MFC it takes time for the bacteria to colonize the electrodes and manufacture enzymes or structures needed to transfer electrons outside the cell [9]. Tables 1 and 2 give the readings of voltage and current from MFCs A and B respectively for the period of study.

Table 1. Readings for MFC-A as recorded on the first, second and fourteenth day.

Day 1		
Time (h)	**#OCV (V)**	**##OCI (mA)**
0	0.524	0.238
1	0.447	0.214
2	0.259	0.140
3	0.320	0.221
4	0.340	0.240
5	0.345	0.260
6	0.366	0.272
7	0.364	0.282
8	0.388	0.285
9	0.391	0.293
10	0.395	0.308
11	0.391	0.306
12	0.401	0.330
Day 2		
Time (h)	**OCV (V)**	**OCI (mA)**

20	0.408	0.336
21	0.409	0.318
22	0.407	0.343
23	0.402	0.335
24	0.397	0.330
25	0.431	0.340
26	0.438	0.215
27	0.409	0.355
28	0.417	0.340
29	0.440	0.339
30	0.404	0.334
Day 14		
Time (h)	**OCV (V)**	**OCI (mA)**
484	1.454	0.964
485	1.508	1.070
486	1.554	1.720
487	1.572	1. 870
488	1.658	2.100
489	1.686	2.160
490	1.702	2.280
491	1.741	2.340
492	1.787	2.480
493	1. 812	2.740
494	1.598	2.550
495	1.588	2.440

#Open circuit voltage

Open circuit current

Table 2. Readings for MFC-B as recorded on the first, second and fourteenth day.

Day1		
Time (h)	**OCV (V)**	**OCI (mA)**
0	0.635	0.313

1	0.636	0.318
2	0.528	0.338
3	0.481	0.267
4	0.480	0.171
5	0.454	0.142
6	0.449	0.234
7	0.409	0.227
8	0.414	0.234
9	0.451	0.240
10	0.487	0.244
11	0.482	0.261
12	0.446	0.281
Day2		
Time (h)	**OCV (V)**	**OCI (mA)**
20	0.444	0.348
21	0.412	0.357
22	0.451	0.365
23	0.482	0.385
24	0.579	0.416
25	0.585	0.426
26	0.584	0.416
27	0.606	0.428
28	0.616	0.440
29	0.622	0.443
30	0.573	0.442
Day 14		
Time (h)	**OCV (V)**	**OCI (mA)**
484	1.366	1.440
485	1.392	1.520
486	1.400	1.680
487	1.448	1.740
488	1.485	1. 870
489	1.528	2.010
490	1.566	2.180

491	1.598	2.250
492	1.646	2.440
493	1.689	2.560
494	1.718	2.680
495	1.667	2.540

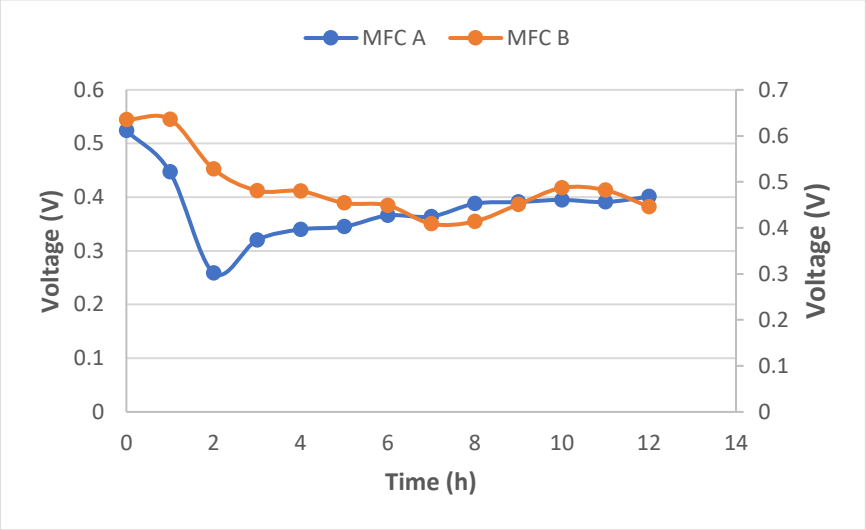

Fig. 1 Graph of voltage against time for Day 1 for MFCs A and B

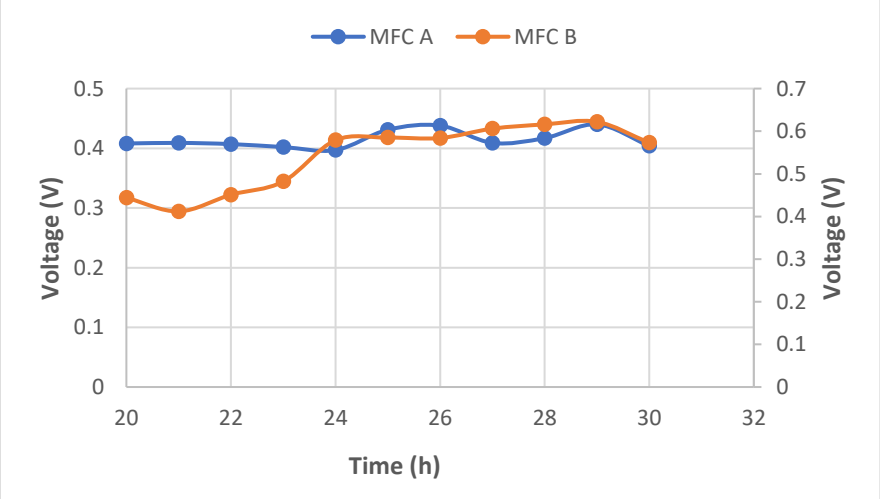

Fig. 2. Graph of voltage against time for Day 2 for MFCs A and B

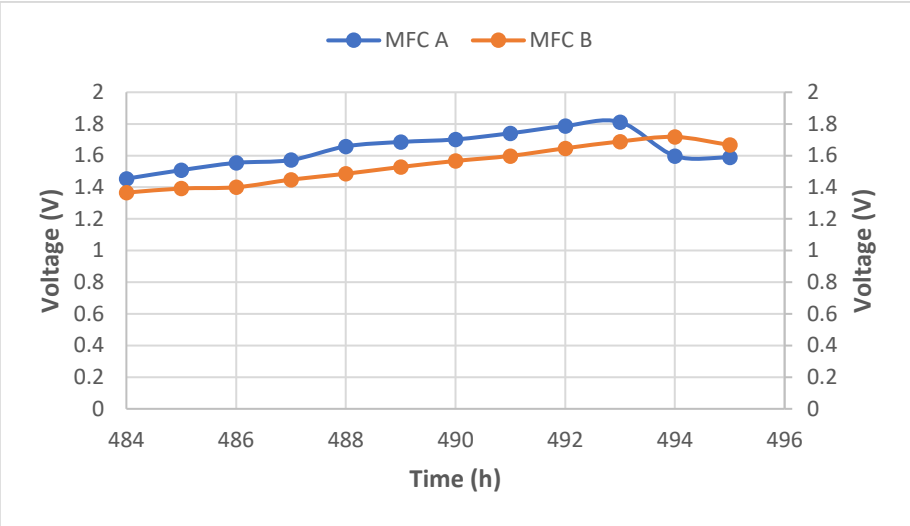

Fig. 3. Graph of voltage against time for Day 14 for MFCs A and B

3.2 Wastewater Treatment Ability

The ability of the MFC to treat wastewater was examined. This was obtained in efficiencies and calculated from the equation [1]:

$$\textbf{efficiency} = \frac{\textbf{initial parameter value} - \textbf{final parameter value}}{\textbf{initial parameter value}} \times \mathbf{100} \qquad \textbf{[1]}$$

Parameters examined in this study include Biological oxygen demand (BOD) removal efficiency, Total dissolved solids (TDS) removal efficiency, pH, Temperature, and conductivity. The BOD reflects what can be biologically removed [9]. The highest BOD removal efficiency of 78.33% was shown by MFC-A as compared to a BOD removal efficiency of 72.67% shown by MFC-B. This explains a good treatment ability by the MFCs because BOD removal is important especially where sewage effluent flows to a leaching field in tight soils" [5]. The higher BOD removal efficiency recorded in MFC-A could be inferenced to be due to the use of two copper electrodes per chamber as opposed to one copper electrode per chamber used in MFC-B. Also, not to be forgotten was the change in colour and odour of the wastewater after treatment. A change in colour from dark to pale colour and a non-pungent smell was observed thus, supporting the claim that MFC can also treat wastewater. Table 3 shows the wastewater treatment ability of the MFCs labeled A and B. These are graphically represented in figure 4.

Table 3. MFCs performance

MFC	#BOD	pH	Conductivity	Temperature	##TDS
A	78.33	3. 82	37.5	4.25	74.46
B	72.67	2.94	33.93	5.32	75

 # Biological Oxygen Demand

Total Dissolved Solids

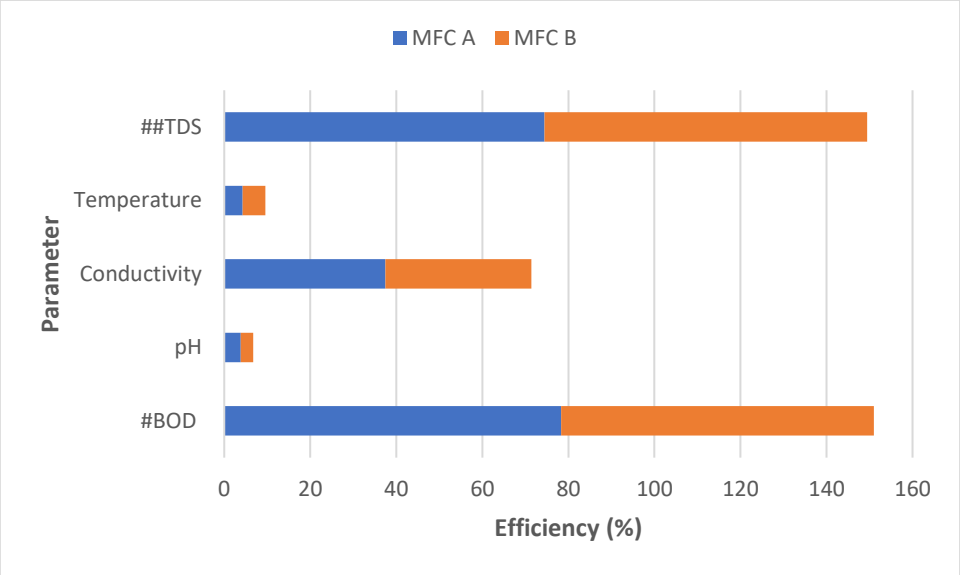

Fig. 4. Bar graph showing wastewater treatment efficiencies of MFCs A and B

 # Biological Oxygen Demand

Total Dissolved Solids

4. CONCLUSION

A microbial fuel cell can treat wastewater while also generating electricity. It was observed that the voltage output for both MFCs was not affected by the number of electrodes used, although, the wastewater treatment efficiency in terms of BOD increases with the number of electrodes as shown by MFC-A. Ferricyanide as an electron acceptor gives a better performance when compared to potassium permanganate. The highest voltage recorded is higher than the previous study conducted at the Federal University of Technology, Owerri [1]. If power generation can be increased, MFCs will revolutionize the energy sector by providing cheap a source of electric power and also cut the cost of wastewater treatment in developing and developed countries, thereby, making it affordable. More research needs to be conducted on improving the functionality of MFCs as regards to electricity generation as well as wastewater treatment. This will save millions of lives lost from the use of contaminated water and also save millions of tax payers money presently being spent on wastewater treatment.

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