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DESIGN OF A MODULAR MICROBIAL FUEL BATTERY FOR MICROPOWER UTILITIES USING FRUIT WASTES AS ELECTROLYTE

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Abstract

This paper is focused on the design of a microbial fuel battery for micro-power applications. Two membraneless Microbial Fuel Batteries (MFB) were built with cheap, readily available and locally sourced materials. Polyethylene plastics, aluminium (anode), graphite (cathode) and copper wires were the selected materials to build the two (2) microbial fuel batteries. Organic matter (fruit waste) was charged into each Microbial Fuel Cell (MFC) in both MFBs. The ratio of the surface area of aluminium electrodes to graphite electrode used in the MFB was 2:1. Each MFB consisted of 12 MFCs connected in series while the microbial fuel batteries were connected in parallel. The set up was used to power multiple LED bulbs which were used to light up a sign board. The result of the study showed that the voltage output curve pattern is almost linear with the MFC showing 0.8V voltage drop over a period of 15 days, while the MFB had a voltage drop of 0.8V over a period of 7 days. The current output was observed to be dependent on the pH value. The more acidic the pH of the organic matter in the MFC, the more current generated. The result from the study showed that the use of multiple MFB can generate more power for powering sign posts, traffic lights, safety sign posts etc. particularly at night times with little or no amount spent on electricity. This indicates that fruit waste other than some common substrates like cowdung, poultry droppings, food waste etc. can be treated/recycled through MFCs to produce electrolyte for power generation all year round.

***Keywords**:* Current, Voltage, Power, Organic waste, Fuel cell, Microorganisms

1. Introduction

Nigeria's epileptic power supply has over the past two decade limited economic growth and development. Daily power generation in Nigeria has never reached 7000MW for her population of over 180 million. The continually increasing population of Nigeria implies a continuous increase in the amount of waste generated, increasing the amount of unchecked waste indiscriminately disposed in the environment which continually dilapidates the environment and leads to public health risks and economic loss[1, 2]. Waste generated can be processed to add value to the economy rather than hamper its aesthetics. Organic waste for example can be processed to harness electrical energy during organic decomposition, and this can significantly augment the energy mix in Nigeria[3].

A number of methods can be employed for processing waste materials generated in Nigeria to energy. This includes thermal process (such as combustion, pyrolysis and gasification) which require moderate to high temperature input to disintegrate the waste materials and biological process (such as aerobic digestion and anaerobic digestion) which require the presence of microorganisms for effective breakdown of organic matter[4]. Apart from bio-digesters and engineered landfill systems, Microbial Fuel Cell (MFC) is one of the biological methods that can be employed in the conversion of organic waste to electricity. It consist of anode and cathode demarcated by cation specific membrane, in which microorganisms at the anode

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oxidize the organic substrate generating protons passing through the membrane to the cathode and electrons passing through the anodes to an electrical circuit for the generation of current[5, 6].

When organic substrate like sugar is broken down by microorganisms in aerobic condition, carbon dioxide and water are produced as the products of cellular respiration. However, if the process takes place under anaerobic condition, carbon dioxide, protons and electrons are produced as a result of cellular respiration. Therefore, anaerobic condition is more ideal for the anode chamber of MFCs, as the presence of oxygen inhibits the production of electricity [7, 8].

The anodic chamber of the MFC consists of the anode electrode and it is also the chamber where the organic waste is fed. A good anode material is required to have a large surface area for bacteria attachment and high electrical conductivity for charge transfer, as well as good current collection capability [9]. This is because during decomposition of organic feedstock, there is a biofilm formed around the surface of the anode, and it is the electrons receptor. However, the cathodic chamber of the MFC is made up of cathodic electrode subjected to catholyte flow which consists of an oxidizing agent (protons) in solution. The oxidizing agent is reduced as it receives electrons that flow to the cathode via a wire connected to the cathodic electrodes[10].

MFC technology has found profitability in domestic, industrial and environmental applications such as wastewater treatment and niche applications, Bioremediation, Renewable electricity production from biomass, Hydrogen production [11, 12]. In Nigeria, MFC technology can be utilised in the above listed. Its application can also be useful in powering indicator bulbs for safety signs as well as powering night lamps for illuminating pedestrian walkways.The need to harness the chemical energy stored in organic waste and convert it to electrical energy necessitated thedesign and fabrication of a microbial fuel battery to augment the energy mix for increased power generation that is optimum for micro-power applications.

2. Materials and Methods

The materials and components used in the design and fabrication of the MFC are discussed here. A single chambered MFC was designed and fabricated using locally, cheap and readily available materials. 50 Kg of fruit wastes (such as Pawpaw, Pineapple, Water melon, Apple, Banana, Oranges, Carrot, Cucumber) collected from Uselu Market in Benin City were blended and charged into the MFC chambers. The following materials and equipment were used in the fabrication of a single chambered MFC as shown in Table 1 while specifications of the Led Bulb are shown in Table 2.

Table 1: MFC working material/equipment and description

S/N	Materials	Description
1.	Polyethylene bottles	With little or no reaction with the organic matter, polyethylene plastics were selected for use and to function as the microbial fuel cell chamber.
2.	Electrodes	Two different materials (aluminium plate and graphite rods) with different voltage potential were selected for use and to create a potential difference in the organic matter.
3.	Organic matter	The organic matter selected was used as the source of energy in the microbial fuel cell.
4.	Pen-type pH meter(pH-2011)	This equipment was selected for use to collect the pH level of the organic matter.
5.	Electrical multimeter	This equipment was selected for use to obtain the electrical voltage and current readings of the MFC.
6.	LED bulbs	Used to test the functionality of the MFC.
7.	Flexible wire	This was selected as a result of their ability to transfer electrons with little resistance.

Table 2: Led Bulb Specifications

Power Rating	2mW
Wavelength	295-305nm
spectral width	15nm
Expected Lifetime	> 10,000hrs
Thermal Resistance	35ºC/W
Viewing Angle	7º

The method employed was first to select an indicator bulb which can be powered by a single microbial fuel cell and the volume of organic matter needed to generate the required power. This was carried out experimentally. Multiple microbial fuel cells were then built and their functionality tested with the selected indicator bulb, after which they were connected in series, increasing the voltage output and making it a microbial fuel battery. Two sets of the microbial fuel batteries were built using selected materials and connected in parallel. The built microbial fuel batteries were then connected through an electrical switch to power LED bulbs. Figure 1 represents pictorial (Isometric) view of the components used in the fabricated MFC. Figure 2 is a pictorial view of the fabricated switch box while Figure 3 shows the pictorial views of the microbial fuel battery CAD and its fabrication.

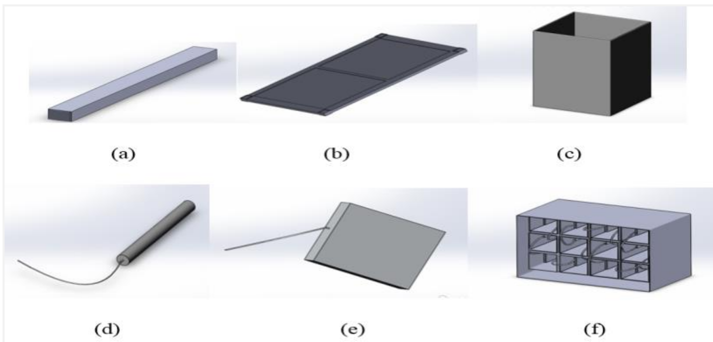

Figure 1: Pictorial (trimetric) view of the component used in the fabricated MFC. (a) Square metal pipe. (b) Sheet metal. (c) Plastic container. (d) Graphite electrode. (e) Aluminium electrode. (f) Stacked MFC.

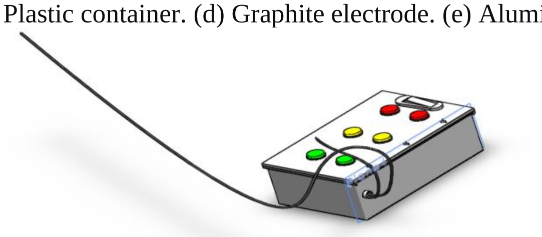

Figure 2: Pictorial view of the fabricated switch box

Figure 3: Pictorial view of the MFB (a) CAD Model of the MFC (b) Pictorial view of the fabricated for stacked MFC.(c). Pictorial view illuminated LED bulb from power obtained from stacked MFC

3. Design Calculations

Mathematical formulae were used to calculate the values for different parametersas expressed through Equation 3.1 to Equation 3.6

Area of aluminium electrodes (A_a) = 2 X length (l_a) X breadth (b_a)

$A_a = 2 \text{ X } l_a \text{ X } b_a$ (1)

Area of graphite electrode (A_g) = Area of cylinder (A_c)

Area of cylinder = Area of top and bottom circles + Area of side

Area of top and bottom circles $= 2 \text{ X } \pi r_g^2 = 2\pi r_g^2$ (2)

Area of side $= 2\pi r_g \text{ X } h_g = 2\pi r h_g$ (3)

Therefore, Area of graphite electrode (A_g) $= 2\pi r_g^2 + 2\pi r_g h_g$

$= 2\pi r_g(r_g + h_g)$ (4)

Power (P) = voltage (V) X current (I)

i.e. P = VI (5)

Volume of containers (V_{c1}) = length (l_{c1}) X breadth (b_{c1}) X height (h_{c1}) (6)

3.1 Volume of Organic Matter

Plastic containers used were hollow rectangular shapes having dimensions of 130mm X 65mm X 65mm (measured).
Volume of plastic container = length (l_{c1}) X breadth (b_{c1}) X height (h_{c1}) (7)

3.2 Electrode Specifications

The aluminium used was cut into the shape of a rectangle and measured. Both sides of the aluminium plate were fully immersed in the organic matter and hence both side of the aluminium plate were active in the course of the experiment. All dimensions of aluminium plates were measured.The graphite rods were totally immersed in the organic matter and hence the entire area of the graphite rod was active during the course of the experiment. All dimensions of graphite rods were measured.Figure 4 illustrates the series and parallel MFC connections.

Area of graphite electrode (A_g) = $2\pi r_g(r_g + h_g)$ (8)

Where. π = constant = 3.142, r_g = radius of graphite rod = 6mm, l_g = length of graphite rod

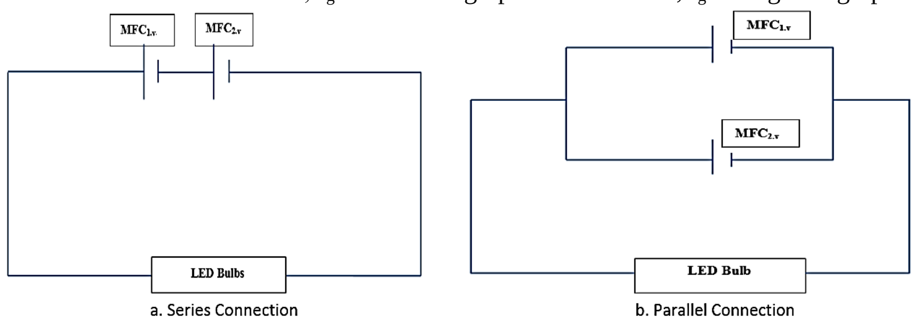

Figure 4: Series connection of the MFCs and Parallel Connection of MFC

3.3 Series Connection of the MFCs

Total MFC voltage output ($MFC_{T.volt}$) = $MFC_{1.v} + MFC_{2.v}$ (9)

Total MFC current output ($MFC_{t.current}$) = $\frac{1}{MFCt.current} = \frac{1}{MFCI1} + \frac{1}{MFCI2}$ (10)

$MFC_{t.current} = \frac{MFCI1 + MFCI2}{(MFCI1\ X\ MFCI2)}$ (11)

3.4 Parallel Connection of the MFCs

Total voltage output ($MFC_{t.volt}$)

$$\frac{1}{MFCt.volt} = \frac{1}{MFC1.v} + \frac{1}{MFC2.v} \quad (12)$$

$$MFC_{t.volt} = \frac{(MFC2.v)+MFC1.v}{(MFC1.v\ X\ MFC2.v)} \quad (13)$$

Total current output ($MFC_{T.current}$) = $MFC_{I1} + MFC_{I2}$ (14)

3.5 Microbial Fuel Battery Design Specification

Number of stacked MFC = 2

Number of single cells in each microbial fuel battery = 12

The plastic container used for each single cell in the MFB was of the same type and dimension. Plastic containers used were a hollow rectangular shape having dimensions of 65mm X 65mm X 130mm.

4. Results and Discussion

Data obtained was possible with the use of a multimeter, pH meter and mathematical relations expressed stated in equation 1-15. The result of the experiments conducted was to investigate the current, voltage, power and power density of a membraneless MFC. Table 3 shows the calculated results obtained for the MFC components while Figure 4-5 represents electrode specification in the fabricated MFBs 1 and 2.

Table 3:Calculated Results obtained for the MFC Components

1.	Volume of plastic container	549250mm^2
2.	Area of aluminium electrode	6000mm^2
3.	Area of graphite electrode (A_g)	3242.54mm^2
4.	Ratio of graphite electrode to aluminium electrode	3242.54mm^2 : 6000mm^2
5.	Volume of hollow rectangular box	549250mm^2
6.	Volume of single cell 1	507000mm^2
	Volume of single cell 2	507000mm^2
	Volume of single cell 3	507000mm^2
	Volume of single cell 4	507000mm^2
	Volume of single cell 5	507000mm^2
	Volume of single cell 6	507000mm^2
	Volume of single cell 7	507000mm^2
	Volume of single cell 8	507000mm^2
	Volume of single cell 9	507000mm^2
	Volume of single cell 10	507000mm^2
	Volume of single cell 11	507000mm^2
	Volume of single cell 12	507000mm^2
	Total volume of electrolyte in one stacked MFC	6084000mm^2

Table 4: Specification of electrodes in MFB Connected MFB 1

CELL 1		**CELL 2**		**CELL 3**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6600	Aluminium	6000	Aluminium	6240
Graphite	3242.54	Graphite	3050.02	Graphite	3204.84
CELL 4		**CELL 5**		**CELL 6**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6000	Aluminium	6300	Aluminium	6160
Graphite	3054.02	Graphite	3317.95	Graphite	3129.43
CELL 7		**CELL 8**		**CELL 9**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6240	Aluminium	6600	Aluminium	6000
Graphite	3242.54	Graphite	3242.54	Graphite	3129.43
CELL 10		**CELL 11**		**CELL 12**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	5500	Aluminium	6496	Aluminium	6360
Graphite	3242.54	Graphite	3167.14	Graphite	3127.43
Total area of aluminium electrode (mm^2)				74496	
Total area of graphite electrode (mm^2)				35152.42	
Ratio of graphite to aluminium electrode				1 : 2	

Table 5: Specification of electrodes in MFB Connected in MFB 2

CELL 1		**CELL 2**		**CELL 3**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6160	Aluminium	6600	Aluminium	5500
Graphite	3242.54	Graphite	3242.54	Graphite	3204.54
CELL 4		**CELL 5**		**CELL 6**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6240	Aluminium	6600	Aluminium	6000
Graphite	3129.43	Graphite	3129.43	Graphite	3129.43
CELL 7		**CELL 8**		**CELL 9**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6720	Aluminium	6000	Aluminium	6264
Graphite	3242.54	Graphite	3167.14	Graphite	3317.95
CELL 10		**CELL 11**		**CELL 12**	
Electrode	Area (mm^2)	Electrode	Area (mm^2)	Electrode	Area (mm^2)
Aluminium	6600	Aluminium	5500	Aluminium	6240
Graphite	3342.54	Graphite	3242.54	Graphite	3129.43
Total area of aluminium electrode (mm^2)				74424	
Total area of graphite electrode (mm^2)				35366.05	
Ratio of graphite to aluminium electrode				1 : 2	

Table 6 shows the readings obtained from the microbial fuel cell set up to investigate the behaviour of the selected parameters i.e. pH value, voltage output and current output. The organic matter charged into the microbial fuel cell is fruit waste. Table 6 shows result of experiment to investigate the current, voltage and power output from membraneless MFC.

Table 6: Readings from the experimental microbial fuel cell

Days	pH	Voltage (V)	Current (mA)	Power (mW)
1	4.37	0.31	12.46	3.86
2	4.83	0.31	11.94	3.70
3	5.27	0.3	9.55	2.87
4	5.30	0.29	7.41	2.15
5	5.34	0.29	6.29	1.82
6	5.39	0.28	6.45	1.81
7	5.72	0.28	5.97	1.67
8	6.11	0.28	5.17	1.45
9	6.42	0.28	6.38	1.78
10	6.83	0.27	6.07	1.64
11	9.14	0.27	8.59	2.32
12	8.51	0.27	7.25	1.96
13	8.28	0.26	7.54	1.96
14	8.17	0.23	6.32	1.45
15	8.09	0.23	6.81	1.57

The highest acidic pH value of the organic matter was 4.37, which also produced a maximum current value of 12.46mA and a maximum voltage value of 0.31V. The organic matter pH value was acidic for a period of 10 days after which it changed into being alkaline through the period under investigation. There was a significant increase in the current output. The average value of the voltage output was 0.28V and the average value of the current output was 7.61mA. The curve pattern exhibited by the pH, voltage and current are shown in Figure 5. It can been seen that when the organic matter had a pH value in the acidic range, the higher the acidic pH value, the higher the current output. The pH curve pattern as is seen in Figure 5 shows a gradual and steady increase until a sudden climb indicating a change in the organic decomposition process.

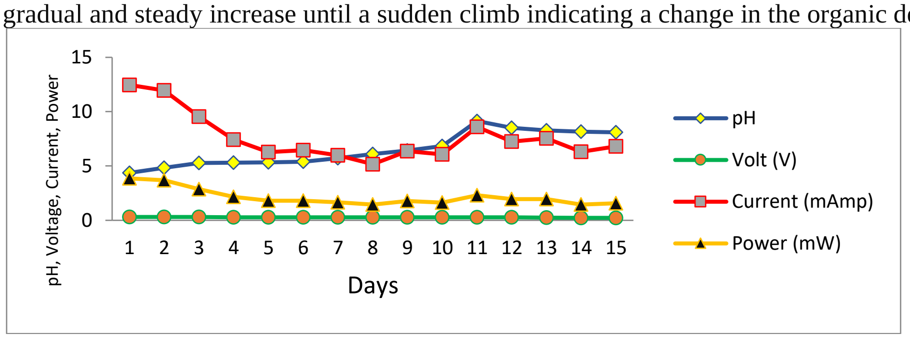

Figure 5: Graphical pattern exhibited by the pH, voltage, current output and power output.

The current curve pattern shows a steep decrease at the initial stage followed by a gradual decrease. The pattern becomes irregular at the final stages during the period under investigation. The voltage curve pattern exhibited was seen to almost linearize. It gradually declined from a value of 0.31V to a value of 0.23V. Table 7 shows the voltage and current output reading obtained from the fabricated MFB.

Table 7: Reading from the fabricated microbial fuel battery (MFB)

Days	Voltage (V)	Current (mA)	Power (mW)
1	3.17	14.78	46.85
2	3.17	14.54	46.09
3	3.16	11.09	35.04
4	3.14	9.85	30.93
5	3.13	7.41	23.19
6	3.13	6.49	20.31
7	3.09	5.22	16.13

The expected result is the increase in the voltage output which is evident in the reading from Table 7. This proves that the MFB obeyed the principles of electricity. The highest voltage obtained was 3.17V which corresponded to the highest current output of 14.78mA. The voltage drop over a period of 7 days was 0.08V. The curve pattern exhibited by the voltage and current output as well as the power output of the microbial fuel battery is shown in Figure 6. The voltage curve pattern is almost linear showing a slight fall as compared with the current curve pattern which showed an obvious decline. The maximum value of voltage obtained from the cell was 0.31V. The experimental MFB gave a maximum voltage output of 3.17V; thereby proving that it does obey the principles of electricity. This is in agreement with the findings of Olga et al. [13] onelectricity generation by *Enterobacter sp.* of single-chamber microbial fuel cells at different temperatures. The fabricated MFC was connected in series to increase the voltage of the organic battery, while both MFBs were connected in parallel to increase the current output as shown in Figure 6.

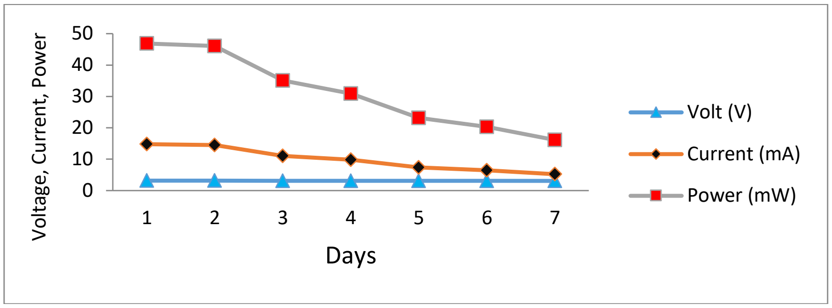

Figure 6: Graph of voltage output, current output and power generated from the fabricated MFB

The voltage output from the fabricated MFB was less than the expected voltage output. This could be as a result of the resistance of the materials as well as the internal resistance of in the system. The power supplied was enough to power the LED indicator bulbs which were used to light up a sign post which could be clearly seen from a distance of about 150 meters at night time. This result could find application in the use of safety indicators for open parks at night times. As a result of the stages off organic decomposition, the current output was unsteady, implying a high dependence of the current output on the activities of the microbes responsible for organic matter decomposition.

5. Conclusion

MFB (organic battery) having single chambered MFCs was designed and fabricated using readily available and locally sourced materials and it was used to power multiple LED indicator bulbs. There were fluctuations in values of voltage and current data obtained with voltage showing less fluctuations compared to the current data. This was as a result of the microbial activities taking place in the organic matter. The result of the study showed that the voltage output curve pattern is almost linear with the microbial fuel cell (MFC) showing 0.8V voltage drop over a period of 15 days, while the microbial fuel battery (MFB) had a voltage drop of 0.8V over a period of 7 days. The average voltage output and current output from the experimental MFC was 0.28V and 7.61mA respectively. From the results obtained, though weak, an acidic MFC produces more power but lasts only a few days when compared with an alkaline cell which produces less power but lasts longer. The MFC can be designed to either function as an alkaline or acidic cell. The result obtained from the MFB (organic battery) shows that it is a suitable alternative energy source for powering road traffic light, caution signs, reading lambs etc. which run on micro power.

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