



## Analysis and Performance Evaluation of Microbial Fuel Cells for Electricity Generation

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**ABSTRACT:** This research work is focused on the analysis and performance evaluation of microbial fuel cells (MFCs) consisting of multiple one chamber connected in series and parallels for investigation of electricity generation. Using six units (i.e., unit A, unit B, unit C, unit D, unit E, unit F, unit G and unit H) stacked MFCs, the fuel cells were analyzed and evaluated for performance. The results obtained with a single unit microbial fuel cells show that, unit (A) produced an average power of 0.224mW, unit (B) an average power of 0.179mW, unit (C) an average power of 0.138mW, unit (D) an average power of 0.092mW, unit (E) an average power of 0.058mW, unit (F) an average power of 0.036mW, unit (G) an average power of 0.018mW, and unit (H) an average power of 0.005mW. It was observed that decrease in number of microbial fuel cells lead to a corresponding decrease in voltage and current generated, thus drop in power. Conversely, when the unit microbial fuel cells were connected together in series and parallel, improvement in power generation was recorded. An average power of 2.681mW and 2.572mW were obtained from series and parallel connection respectively.

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As a result of unavailability and rapidly increase in costs of energy supply couple with waste disposal and increasing public concerns with eco-friendly environmental, conversion of biodegradable waste to energy is becoming a more economically viable practice (Orhorhoro *et al.*, 2017a), (Orhorhoro *et al.*, 2017b). Generally, energy sources can be classified into renewable energy source and non-renewable energy source (Akdeniz *et al.*, 2002). Non-renewable energy sources are group into two major classifications: nuclear and fossil energy (Rahimnejad *et al.*, 2009). Fossil fuel has negative effect on our eco-system owing to the emission of carbon dioxide (Orhorhoro *et al.*, 2016a), (Orhorhoro *et al.*, 2016b). Consumption of fossil fuels has severely imperiled human life through its drastic aftermaths, such as global warming and atmospheric pollution (Tardast *et al.*, 2012). Due to the hazard recorded from non-renewable energy source, the world attention is now on renewable energy sources such as biofuel, solar, wind, hydro, etc. that are environmental friendly (Zhou *et al.*, 2013).

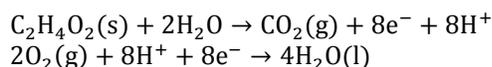
However, one of the recently proposed alternative energy sources is the microbial fuel cells (MFCs).

MFCs have gained much recognition because of its power generation potential from biodegradable organic waste (Lewis, 1996). MFCs are of numerous advantages over other kinds of energy generators. For example; there is no emission of environmental polluting gases such as oxide from sulphur, carbon, nitrogen (i.e., SO<sub>x</sub>, NO<sub>x</sub>, CO<sub>2</sub> and CO) (Lewis, 1996). MFCs are fuel cells that make use of active microorganism as a biocatalyst in an anaerobic anode compartment for production of bioelectricity (Rahimnejad *et al.*, 2011), (Zhou *et al.*, 2012). MFCs generate electricity directly from various biodegradable organic wastes through microbial release of electrons to an electrode. MFCs can also be used to recover energy from wastewater, while in the process eliminating the need for wastewater aeration and reducing sludge production (Hassan *et al.*, 2014).

Typical microbial fuel cells (Fig. 1) consist of anode and cathode compartments physically separated by a proton exchange membrane (PEM) (Rahimnejad *et al.*, 2012). Active biocatalyst in the anode oxidizes the biodegradable organic substrates and produces electrons and protons (Jana *et al.*, 2013). The protons are conducted to the cathode chamber through the

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proton exchange membrane, and the electrons are conveyed through the external circuit (Ghasemi *et al.*, 2015). The active biocatalyst in the anode compartment oxidizes the carbon substrates, and generates electrons and protons. Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water (Jana *et al.*, 2013). However, oxygen in the anode chamber inhibits the production of bio-electricity. For this reason, a pragmatic system must be design to keep the bacteria separated from oxygen (anaerobic chamber for anodic reaction) (Kim *et al.*, 2008). Equation 1 and equation 2 show anodic reaction of acetic acid.



The performance of MFCs is affected by several factors such as (Rabaey *et al.*, 2006); Supply and consumption of oxygen in cathode chamber; Oxidation of substrates in anode chamber; Electron shuttle from anode compartment to anode surface; and Permeability of proton exchange membrane

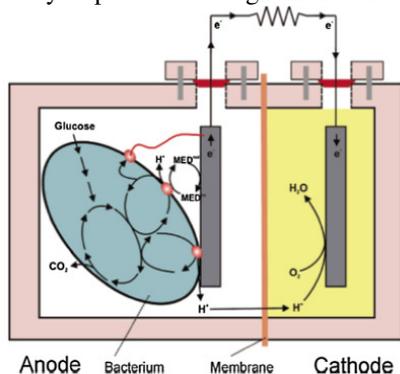


Fig. 1: MFCs system with anode and cathode compartments (Rahimnejad *et al.*, 2012).

MFCs have various practical applications ranging from breweries, domestic wastewater treatment (black water, water from abattoir etc.), desalination plants, hydrogen production, remote sensing, and pollution remediation, etc. (Lewis, 1996), (Zhou *et al.*, 2013). Widespread use of MFCs in these areas can help in converting biodegradable organic waste into useful energy thereby making our environment healthy (Mehmood *et al.*, 2009), (Sharma, and Li, 2010). Nigeria is a very conducive place for bio-degradable activities because it has a dry and humid climate with average room temperature of 23°C and maximum temperature range of 37°C-40°C (NESP, 2015). Nigeria has a large population that make bio-waste readily available with a very good number of this population suffering poor electricity supply, therefore, we envisage a time where every household harness the electrical energy potentials of a microbial fuel cell. In

this research work, analysis and performance evaluation of microbial fuel cells for electricity generation was investigated.

## MATERIALS AND METHOD

MFCs consisting of one multiple chambers connected in series and parallels were used in this research work. The key to this choice is mainly to increase voltage and reduce spaces occupied by the MFCs. The MFCs were incorporated with graphite electrode for the anode and zinc electrode for the cathode, for transferring electrons. The anode is the positive terminal where the electrons were deposited and transferred by bacteria as electrons got generated. The cathode is the negative terminal where electrons are transferred from the anode. The buildup of electrons in anode caused the potential difference between the two electrodes, so that the electrons could flow from anode to cathode thereby generating electricity. Also, the electrodes were connected in parallel in order to increase its surface area thereby increasing current. Six units (i.e., unit A, unit B, unit C, unit D, unit E, Unit F, and Unit G) stacked microbial fuel cells were used for the analysis and performance evaluation. Unit A contained 16 microbial fuel cells of 60cl each, connected in series, unit B contained 14 microbial fuel cells of 60cl each connected in series, unit C contained 10 microbial fuel cells of 60cl each connected in series, unit D contained 8 microbial fuel cells of 60cl each connected in series, unit E contained 6 microbial fuel cells of 60cl each connected in series, unit F contained 4 microbial fuel cells of 60cl each connected in series, unit G contained 3 microbial fuel cells, and unit H contained 2 microbial fuel cells of 60cl each connected in series. Distilled water was poured into the cells and initial readings taken. The water was emptied and the cells were filled with bio-waste and wastewater. Variations in pH, voltage, currents were monitored and recorded. The same substrates composition was used throughout this research work.

## RESULTS AND DISCUSSION

The results obtained after twelve (12) days on unit A-unit G single are shown in Table 1-Table 6. Table 5 present the combined results of all the units connected together in series and parallels. Unit A contained 16 microbial fuel cells of 60cl each, connected in series. It was observed that as the pH gradually moves towards neutrality, drop in voltage, current and power readings were recorded. Improve currents and voltage were recorded when the pH readings were at the acidic and alkaline medium. Average voltage reading of 0.51V, and an average current reading of 0.44mA were obtained. These values were used to determine the power which was obtained as 0.224mW.

**Table 1:** Unit (A) Single Chamber Fuel Cell

Day	pH	Voltage (V)	Current (mA)	Power (10 <sup>-3</sup> W)
1	5.8	0.69	0.64	0.442
2	5.9	0.66	0.60	0.396
3	5.9	0.65	0.59	0.384
4	6.0	0.63	0.54	0.340
5	6.1	0.60	0.50	0.300
6	6.3	0.56	0.49	0.274
7	6.4	0.53	0.44	0.233
8	6.6	0.52	0.41	0.213
9	9.4	0.54	0.49	0.265
10	8.3	0.44	0.42	0.185
11	7.8	0.18	0.10	0.018
12	7.6	0.13	0.09	0.012
Σ	82.1	6.13	5.31	2.688
A	6.84	0.51	0.44	0.224

**Table 2:** Unit (B) Single Chamber Fuel Cell

Day	pH	Voltage (V)	Current (mA)	Power (10 <sup>-3</sup> W)
1	5.8	0.65	0.56	0.364
2	5.9	0.62	0.52	0.322
3	5.9	0.61	0.50	0.305
4	6.0	0.59	0.48	0.283
5	6.1	0.56	0.43	0.241
6	6.3	0.52	0.42	0.218
7	6.4	0.49	0.38	0.186
8	6.6	0.48	0.35	0.168
9	9.4	0.50	0.41	0.205
10	8.3	0.40	0.35	0.140
11	7.8	0.14	0.09	0.013
12	7.6	0.10	0.07	0.007
Σ	82.1	5.66	4.56	2.148
A	6.84	0.47	0.38	0.179

**Table 3:** Unit C Single Chamber Fuel Cell

Day	pH	Voltage (V)	Current (mA)	Power (10 <sup>-3</sup> W)
1	5.8	0.60	0.52	0.312
2	5.9	0.56	0.46	0.258
3	5.9	0.54	0.45	0.243
4	6.0	0.53	0.43	0.228
5	6.1	0.50	0.39	0.195
6	6.3	0.46	0.37	0.170
7	6.4	0.44	0.35	0.154
8	6.6	0.42	0.33	0.139
9	9.4	0.40	0.31	0.124
10	8.3	0.38	0.28	0.106
11	7.8	0.10	0.05	0.005
12	7.6	0.07	0.03	0.002
Σ	82.1	5.00	3.97	1.656
A	6.84	0.417	0.331	0.138

The gradual drops in voltage and current were due to increase in bacteria activity at the anode. The bacteria form a bio-film at the anode and as the bacteria food decreases, some of the bacteria die leading to the decrease in the voltage produced (Rahimnejad *et al.*, 2009). The pH concentration of the substrate was lowest on the first day and highest on the 9<sup>th</sup> day (Table1), and this was due to fermentation of the substrate which involves breaking down of long chain

fatty acid to acetic acid (Orhorhoro *et al.*, 2017a). The current produced is directly proportional to the voltage, and power. The pH, voltage, current, and power generated from unit B microbial fuel cell is shown in Table 2.

Unit B contained 14 microbial fuel cells of 60cl each connected in series. As reported with unit A, the power, currents and voltages produced in the duration of twelve days depend on the rate of hydrolysis and fermentation taking place in the system. Low values and high values of pH readings favored voltage, and current generation, thus improved power. However, unlike in unit A, the power, current, and voltage generated were low and this was as a result of reduced number of microbial fuel cell. The trends follow the same pattern for unit C, unit D, unit E, unit F, unit G, and unit H.

It was observed that the higher the number of microbial fuel cells, the higher the voltages, currents and power generated. For unit B microbial fuel cell, an average voltage, current and power of 0.47volts, 0.38mA, and 0.179mw were obtained. Table 3 shows the results obtained with unit C microbial fuel cell. Unit C contained 10 microbial fuel cells of 60cl plastic bottle each connected in series. The results obtained showed a linear relationship between voltages, current and power. An average voltage of 0.417volts, current of 0.331mA, and power of 0.138mw were obtained. There was gradual drop in voltage, current and power readings as the process progresses.

This changes in current, voltage, and power go in line with unit (A) and unit B microbial fuel cells. However, the average values of voltage, current and power obtained were lower than unit A and unit B. This process was repeated for unit D that comprises of 8 microbial fuel cells; unit E that comprises of 6 microbial fuel cells; unit F that comprises of 4 microbial fuel cells; unit G that comprises of 3 microbial fuel cells; and unit H that comprises of 2 microbial fuel cells. The summary of results obtained is shown in Table 4.

There was a continuous decrease in average voltage, average current and average power as the number of microbial fuel cells connected in series decrease from 16MFCs to 2MFCs. However, to generate optimum power, all the units (i.e., unit A-unit H) were connected both in parallel and series. The parallel connection of all the unit cells improves the currents while the series connection improves the voltage (Table 5).

**Table 4:** Summary of Results obtained with Unit (A)-Unit (H) Single Chamber Fuel Cell

Cell connections	Average pH	Average Voltage (V)	Average Current (mA)	Average Power (mw)
Series connection of 16 MFCs (Unit A)	6.84	0.510	0.440	0.224
Series connection of 14 MFCs (Unit B)	6.84	0.470	0.380	0.179
Series connection of 10 MFCs (Unit C)	6.84	0.417	0.331	0.138
Series connection of 8 MFCs (Unit D)	6.84	0.366	0.251	0.092
Series connection of 6 MFCs (Unit E)	6.84	0.318	0.183	0.058
Series connection of 4 MFCs (Unit F)	6.84	0.266	0.134	0.036
Series connection of 3 MFCs (Unit G)	6.84	0.215	0.084	0.018
Series connection of 2 MFCs (Unit H)	6.84	0.167	0.035	0.005

**Table 5:** Summary of Results obtained with Unit (A)-Unit (H) Stacked Microbial Fuel Cell

Cell connections	Average Voltage (V)	Current (mA)	Average Power (mw)
Series connection of all units (A-H)	2.654	1.010	2.681
Parallel connection of all units (A-H)	1.425	1.805	2.572

**Conclusion:** This research work is focused on the analysis and performance evaluation of microbial fuel cells. The results obtained with a single unit microbial fuel cells show that, unit (A) produced an average power of 0.224mW, unit (B) an average power of 0.179mW, unit (C) an average power of 0.138mW, unit (D) an average power of 0.092mW, unit (E) an average power of 0.058mW, unit (F) an average power of 0.036mW, unit (G) an average power of 0.018mW, and unit (H) an average power of 0.005mW. It was observed that a decrease in number of microbial fuel cells lead to a corresponding decrease in voltage and current generated, thus drop in power. Conversely, when the unit microbial fuel cells were connected in series and parallel, improvement in power generated was recorded. An average power of 2.681mW and 2.572mW were obtained from series and parallel connection respectively. Therefore, for optimum power generation, currents and voltages can be increased by connecting several microbial fuel cells in parallel and in series respectively.

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