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Design, construction, and testing of generation of electric energy using microbial fuel cell

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Abstract
This paper aimed to design, build, and test microbial fuel cells that source their fuel from organic waste, using microbial fuel cells to power LED lights. The research concluded that microbial fuel is a prospective energy source for future electricity that can be produced and used by all consumers. Single Chamber Microbial fuel cells were set up using material readily available around, i.e. the slurry and, in the market, i.e. the other microbial fuel cell. Microbial fuel cells are a type of bio-electrochemical system that converts chemical energy from organic compounds/renewable energy sources to electrical energy/bio-electrical energy through microbial catalysis at the anode under anaerobic conditions. The process is becoming an attractive and alternative methodology for generating electricity. Based on the tests, the single chamber MFC has a minimum two-and-a-half-month lifespan and can produce a maximum voltage of over 500 mV. Of the thirty MFCs that were manufactured, eighteen of them—producing a steady and increasing voltage—were linked in series within the frame. Five red LED lights were successfully powered by the entire arrangement. This demonstrates that a larger number of MFCs installed may generate more electricity to run a control system.

Keywords: Microbial fuel cells; Microorganisms; Electrical circuits; Renewable energy; Sustainable technology; Energy independence

1. Introduction
Microbiological Fuel Cells Global energy demands are only expected to rise, and to promote energy independence, research projects are concentrating on alternative, renewable, and carbon-neutral energy sources. Microbial fuel cells (MFCs) are a sustainable and renewable technology that produces electricity through the use of microorganisms. It is regarded as a neutral energy source (Lovley, 2006). Using bacteria as a biocatalyst to oxidize the biodegradable substrates, MFCs are fuel cells that can transform chemical energy found in organic substrates into electrical energy. MFCs are bioelectrical devices that produce electrical current by using microorganisms as biocatalysts to transform organic into chemical energy (Aelterman et al. 2006; Bermek et al. 2014; Kumar et al 2016). Microbial fuel cell (MFC) technology is now one of the most enticing methods for producing sustainable energy and simultaneously treating wastewater.

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An anaerobic bio-electrochemical system known as a microbial fuel cell (MFC) uses microbial catalysis at the anode to transform chemical energy found in organic molecules and renewable energy sources into electrical energy or bio-electrical energy. The approach is starting to gain popularity as a viable substitute for traditional methods of producing power.

1.1. History of Microbial Fuel Cell

It was first proposed in the early 1900s to use bacteria to generate power. Potter invented the microbial fuel cell in the 20th century. Even though he was able to produce electricity from Escherichia coli, there was little media attention to his effort. Nevertheless, Barnet Cohen managed to develop microbial half-fuel cells that could generate over 35 volts when linked in series, albeit at a very low current of 2 milliamperes. The subject was discovered in research by Delduca et al. that employed hydrogen generated by Clostridium butyricum's fermentation of glucose as the reactant at the anode of a hydrogen and air fuel cell. Even while the cell worked, its dependability was compromised by the microorganisms' unsteady hydrogen generation. Suzuki et al. addressed this problem in 1976, leading to the successful MFC design that year. Little was known about the operation of microbial fuel cells in the late 1970s. H. Peter Bennetto of King's College London and Robin M. Allen both conducted more research on the concept. The fuel cell was perceived as a potential means of producing power for underdeveloped nations. His research, which began in the early 1980s, contributed to our understanding of fuel cell operation, and he was widely regarded as the leading expert on the subject. In collaboration with Foster's Brewing, the University of Queensland, Australia, completed the construction of a prototype MFC in May 2007. The 10L design of the prototype produced power, carbon dioxide, and clean water from brewery effluent. It was first proposed in the early 1900s to use bacteria to generate power. Potter invented the microbial fuel cell in the 20th century. Even though he was able to produce electricity from Escherichia coli, there was little media attention to his effort. Nevertheless, Barnet Cohen managed to develop microbial half-fuel cells that could generate over 35 volts when linked in series, albeit at a very low current of 2 milliamperes. The subject was discovered in research by Delduca et al. that employed hydrogen generated by Clostridium butyricum's fermentation of glucose as the reactant at the anode of a hydrogen and air fuel cell. Even while the cell worked, its dependability was compromised by the microorganisms' unsteady hydrogen generation. Suzuki et al. addressed this problem in 1976, leading to the successful MFC design that year. Little was known about the operation of microbial fuel cells in the late 1970s. H. Peter Bennetto of King's College London and Robin M. Allen both conducted more research on the concept. The fuel cell was perceived as a potential means of producing power for underdeveloped nations. His research, which began in the early 1980s, contributed to our understanding of fuel cell operation, and he was widely regarded as the leading expert on the subject. In collaboration with Foster's Brewing, the University of Queensland, Australia, completed the construction of a prototype MFC in May 2007. The 10L design of the prototype produced power, carbon dioxide, and clean water from brewery effluent.

1.2. Design Types of Microbial Fuel Cells

Despite their many variations, all reactors operate according to the same principles. Various materials are being utilized in the construction of MFC designs. They are used in a variety of settings to increase efficiency, increase power output, and reduce overall expenses.

1.2.1. Two-chamber MFC

This design, which has two chambers with an ion exchange membrane separating the anode and cathode compartments, is the most often used one. The literature indicates that the power output from these systems is often poor because of their complicated design, high internal resistance, and electrode-based losses. This design is typically utilized in fundamental research (Du et al., 2007).

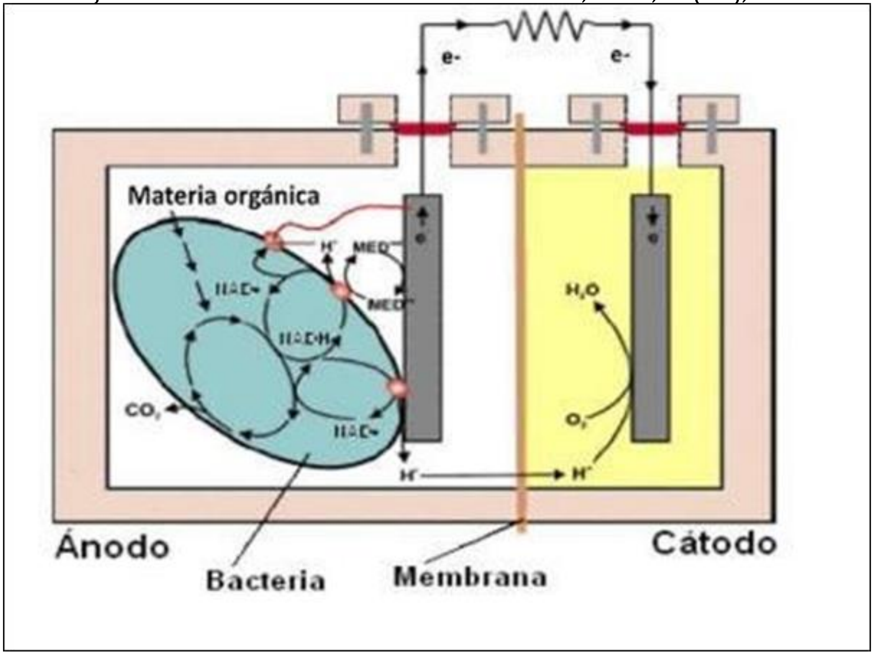

Figure 1 Double Chamber Microbial fuel cell

1.2.2. Single chamber MFC

compartment in this configuration. The cathode and anode are kept apart by PEM and situated nearby or far apart. According to Liang et al. (2007), if the anode is closer to the cathode, the power density improves and internal ohmic resistance is reduced because fewer catholytes are needed to combine the two chambers. It provides a more economical, straightforward design and generates electricity more effectively than the double chamber MFC (Du et al., 2007). On the other hand, the main disadvantages of the membrane-less configuration are microbial contamination and back diffusion of oxygen from cathode to anode without PEM (Kim 2008).

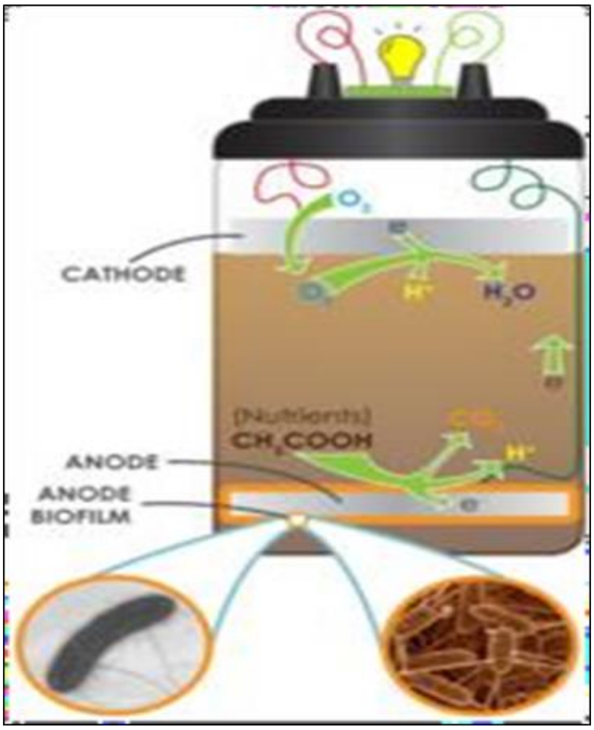

Figure 2 Single Chamber Microbial Fuel

1.2.3. Single chamber MFC Up-flow MFC

The anode (bottom) and cathode (top) of the cylinder-shaped MFC are divided by layers of glass wool and glass beads. The anode's bottom provides the feed, which rises above the cathode and exits at the top. A gradient is provided by the diffusion barrier between the electrodes to enable the MFCs to function properly (Du et al., 2007; Kim 2008; Schwartz, 2007). Since there is no physical barrier in this design, difficulties related to proton transfer are avoided, making it a desirable option for wastewater treatment (Kim 2008).

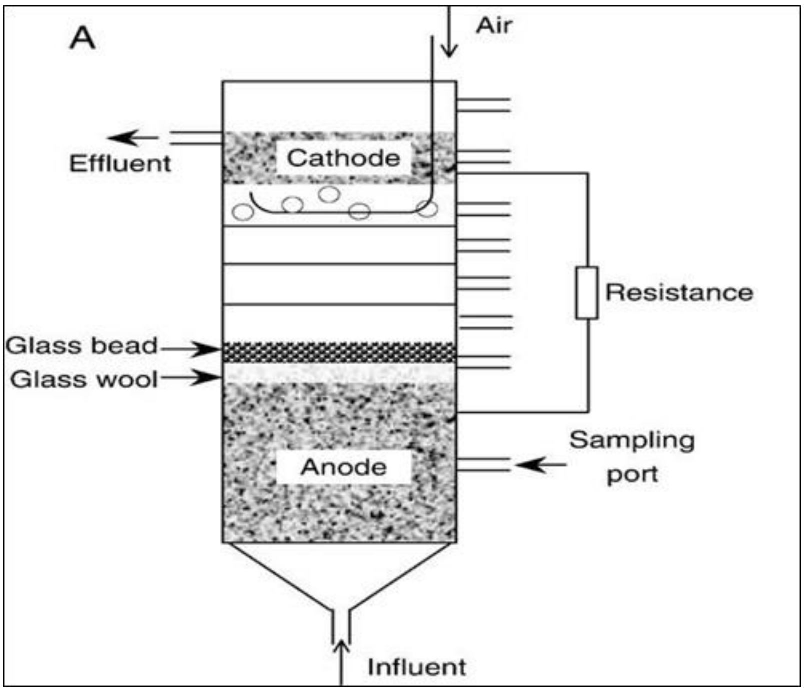

Figure 3 MFC showing the upward flow

1.2.4. Stacked MFC

To obtain high current output, multiple single-cell MFCs are coupled in parallel or series in this design (Du et al., 2007). When operated at the same volumetric flow, a parallel connection can provide more energy than a series connection due to a greater electrochemical reaction rate, but it is more likely to short circuit than a series connection (Aelterman et al., 2006; Schwartz, 2007).

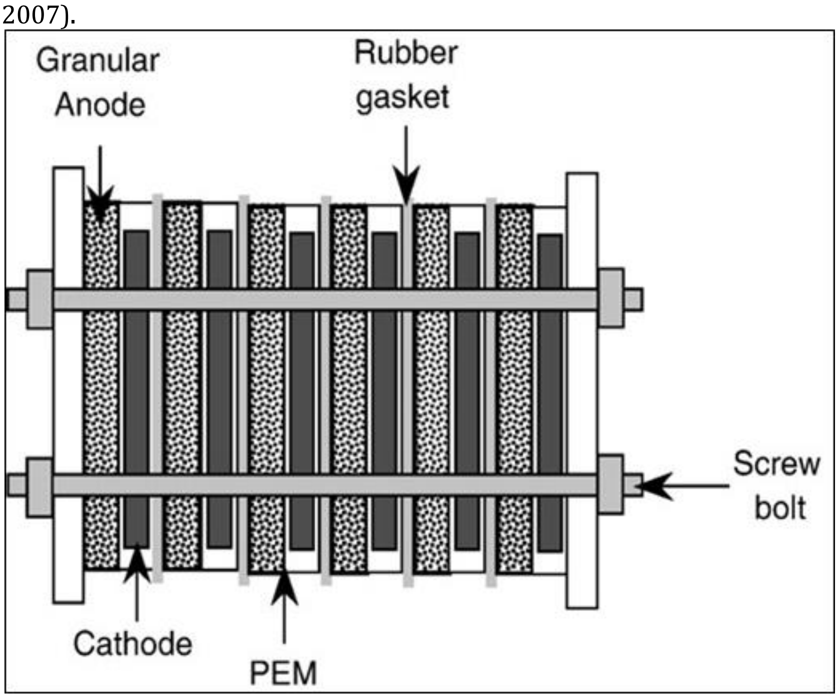

Figure 4 Stacked MFC

1.3. Categories of microbial fuel cell

There are two types of microbial fuel cells, regardless of how they are designed. This is reliant on the microorganisms in the MFC. They consist of

- microbial fuel cells with mediators
- microbial fuel cells with no mediators

1.3.1. microbial fuel cell with a mediator

Early in the 20th century, MFCs made their initial demonstrations using a mediator. Electrons from the bacteria are chemically transferred to the anode electrode in this process. The method was challenging to market since mediators such as methyl blue, methyl viologen, humid acid, thionine, and neutral red were costly and frequently hazardous.

1.3.2. microbial fuel cell with less mediator

By using electrochemically active bacteria to transmit electrons from the bacterial respiratory enzymes to the electrode, these mediator-free microbial fuel cells avoid the need for a mediator. Shewanella putrefaciens (Fe(III) reducer), Aeromonashydrophila, and other bacteria are examples of electrochemically active microorganisms. Under some circumstances, the anode could act as an electron acceptor for the bacteria, allowing it to breathe straight into the electrode as part of its regular cycle.

1.4. Electrode materials

The performance of MFCs is impacted by the choice of electrode material. A range of materials have been studied for use as electrodes to improve the MFCs' efficiency and power production. Because of their stability, high electric conductivity, and huge surface area, carbon cloth, felt, graphite felt, carbon mesh, and graphite fiber brush are commonly used for anodes (Logan, 2010; Logan and Regan, 2006). According to Chen et al. (2008) and Du et al. (2007), cathodes consist of platinum (Pt), platinum black, activated carbon (AC), graphite-based cathodes, and biocathodes. Despite having a greater catalytic activity with oxygen than other electrodes, platinum-coated electrodes produce power more efficiently and superiorly, but they are not economical (Logan, 2010; Oh et al., 2004). Manganese oxides, iron, cobalt-based compounds, and ferric iron are some of the substitute catalysts for platinum. Because of its excellent performance and low overpotential3, ferricyanide (K3(Fe (CN)6) is often utilized as an electron acceptor in MFCs (Logan and Regan, 2006).

According to Huang et al. (2011), the biocathodes boost power by lowering the overpotential. Alternatively, oxygen can be included in the cathode, which is favored as it makes cell operation simpler and is the most often utilized electron acceptor in MFC.

1.5. Microbial electrolysis

Microbial electrolysis cell (MEC) is a form of mediator-less MFC. While MFCs use the breakdown of organic molecules in water by bacteria to produce electric current, MECs partially reverse this process by providing bacteria with a voltage to make hydrogen or methane. This enhances the voltage produced by organic matter's microbial breakdown, which results in the electrolysis of water or the creation of methane. Microbial electrosynthesis, in which bacteria use an external electric current to decrease carbon dioxide and produce multi-carbon organic molecules, is a full reverse of the MFC concept.

1.6. Electrical Generation Process

In aerobic environments, bacteria create carbon dioxide and water when they eat a material like sugar. On the other hand, in the absence of oxygen, they generate protons, electrons, and carbon dioxide, as follows:

$$C_{12}H_{22}O_{11} + 13H_2O \longrightarrow 12CO_2 + 48H^+ + 48e^-$$

Microbial fuel cells channel generated electrons by connecting to the cell's electron transport chain through inorganic mediators. The mediator starts to release electrons from the electron transport chain that are often picked up by oxygen or other intermediates after it passes through the outer lipid membranes of cells and the outer membrane of bacteria. After being reduced, the mediator leaves the cell carrying electrons, which it transfers to an electrode to form the anode. The mediator is recycled back to its initial oxidized condition upon the release of the electrons, allowing the process to be repeated. Only in anaerobic environments is this possible; in the presence of oxygen, which has a higher electronegativity, oxygen will gather the electrons. Bacteria in the anodic chamber identify the anode as the terminal electron acceptor in MFC functioning. Consequently, the redox potential of the anode has a significant impact on the microbial activity. Exo-electrogens are organisms that can generate an electric current. The exo-electrogens need to be accommodated in a fuel cell to convert this current into useful power. A substrate like glucose is added to a solution containing the mediator and a microorganism like yeast. To prevent oxygen from entering and force the microorganism to engage in anaerobic respiration, this combination is placed in a sealed chamber. To serve as the anode, an electrode is inserted into the mixture. The positively charged cathode and another solution are located in the MFC's second chamber. It is comparable to the oxygen sink located outside of the biological cell after the electron transport chain. An oxidizing substance included in the solution absorbs electrons from the cathode. Similar to the electron chain in the yeast cell, this might be any number of molecules, including oxygen; however, a solid oxidizing agent is a more practical alternative because it uses less volume. There is a wire (or other electrically conductive channel) between the two electrodes. An ion exchange membrane, also known as a salt bridge, completes the circuit and links the two chambers. It permits the protons generated to move from the anode chamber to the cathode chamber. The reduced mediator transfers electrons from the cell to the electrode, where it is oxidized during the deposit of electrons. The electrons then flow across the wire to the second electrode, which functions as an electron sink, and finally arrive at an oxidizing material.

1.7. A Soil-Based Microbial Fuel Cell

The fundamental concepts of MFC are followed by soil-based microbial fuel cells, in which soil serves as the proton exchange membrane (PEM), the inoculum, and the nutrient-rich anodic medium. The cathode is exposed to air and rests on top of the earth, while the anode is buried at a certain depth in the ground. Soils are naturally rich in complex sugars and other nutrients that have accumulated from the decomposition of plant and animal matter. They are also teeming with a varied range of microorganisms, including the electrogenic bacteria required for MFCs. Furthermore, the redox potential of the soil decreases with depth because the aerobic (oxygen-consuming) microorganisms in the soil function as an oxygen filter, much like the pricy PEM materials used in laboratory MFC systems.

1.8. Applications

There are several applications for their microbial fuel cells, such as the following:

1.8.1. Power generation

MFCs are appealing for low-power power generating applications, including wireless sensor networks, where changing batteries would not be feasible (Chua et al, 2013). Fuel cells may be fed with almost any organic substance; this includes connecting fuel cells to wastewater treatment facilities. MFCs are an effective and clean way to produce electricity and single-chamber mediatorless MFCs (uncoated graphite electrodes). Higher power production was observed with a biofilm-covered graphite anode. Fuel cell emissions are well under regulatory limits (Choi et al, 2000). MFCs use energy more efficiently than standard internal combustion engines, which are limited by the Carnot Cycle. In dual and single-chamber mediator-less MFCs (uncoated graphite electrodes), bioelectricity has been produced from synthetic and chemical process effluent. An anode coated in biofilm produced more power than the other. The emissions from fuel cells are far within the legal limitations (Choi et al, 2000).

1.8.2. Biosensor

The energy content of wastewater utilized as fuel directly correlates with the current produced by a microbial fuel cell (Kim et al., 2003). Using MFCs as a biosensor, wastewater's solute content may be determined. Wastewater is frequently evaluated based on the levels of biochemical oxygen demand, or BOD. Real-time BOD levels may be obtained with an MFC-type BOD sensor. Because oxygen and nitrate are preferable electron acceptors over the electrode, an MFC produces less current. The presence of these electron acceptors causes MFC BOD sensors to underestimate BOD levels. By employing terminal oxidizer inhibitors like cyanide and azide to stop aerobic and nitrate respiration in the MFC, this may be presented. (Et al., Chang, 2005).

1.8.3. Wastewater Treatment

MFCs employ anaerobic digestion to harvest energy in the water treatment process. Pathogens may be lessened by the procedure. But turning biogas into power demands temperatures above 300C and an additional step. Because a higher surface area presents power output issues, scaling MFCs is difficult (Zhang et al, 2013).

2. Material selection

Electricity for the LED display panel is provided by the microbial fuel cells. The components needed to build the entire structure, including the microbial fuel cell, were purchased locally at many Lagos marketplaces.

2.1. Component of the System

The parts that will comprise the device's structure are as follows:

2.1.1. The Frame Assembly

It serves as the project's framework. It is a container for the microbiological fuel cells that are linked in parallel and series, as well as a lighting source. Iron will be used for the frame, with PVC covering it.

2.1.2. The LED display

These are red LEDs that are interconnected in parallel on a Ferro board to take in power from the source.

2.1.3. Microbial Fuel Cell (MFC)

The lighting system gets its electricity from this source. It is a bio-electrochemical system that uses microbial catalysis at the anode under anaerobic circumstances to transfer chemical energy from organic molecules and renewable energy sources into electrical energy or bio-electrical energy. The following are the main parts of the microbial fuel cell:

Microbial Fuel Cell vessels

This is a clear plastic container that is cylindrical. This is where the entire microbial fuel cell component is contained. It is made up of a container with a snug cover.

Electrode

This is activated carbon covered with stainless steel discs, which will serve as electrodes (i.e. anode and cathode)

Jumper wire

The wire functions as a conductor, carrying the bio-electrons produced by the slurry on the electrode (anode).

Capacitors

It is a tiny part used for energy storage. As power from the MFC is received, it can accumulate energy and then release it quickly in order to cause the LED to blink.

Slurry

They are also known as substrates since they are made up of a mixture of soil, cow dung, and wastewater sludge. The material was chosen because it is easily accessible and mostly consists of electrogenic bacteria, such as ***Shewanella and Geobacter species***, which can aid in the production of electricity. At Lagos State Polytechnic, Ikorodu, the cow yard is where all the ingredients for the mixture would be obtained.

2.2. METHODOLOGY

2.2.1. Preparation of the slurry

The waste combination that included the bacteria was made up of fine topsoil, cow dung, and sludge. The trash was combined with distilled water in a plastic paint until the combination resembled cookie dough. If the mixture feels too moist, more waste mixture will be added, or if the mud is too crumbly, more water will be added.

2.2.2. Preparation of the electrode

The inside circle of the container was fitted with a circular incision made from stainless steel mesh. Every edge of the stainless steel was attached with a wire. For the carbon to stay on the mesh, the stainless steel was smeared with an adhesive that had been covered with activated carbon and crushed using a hydraulic jack. These act as the cathode and anode electrodes.

2.2.3. Assembling the Microbial Fuel Cell

- The first microbial fuel cell was used, and rubber gloves were placed on.
- The first MFC vessel was filled with the prepared slurry up to the line adjacent to the plastic vessel's "1" (which indicates one centimeter [cm]). The anode was placed on top of the full mud in the vessel and the mud was patted to a flat surface. There was an exposed wire coming from the anode. The wire ought not to be embedded in the mud. After gently pressing the anode flat into the mud to ensure that there were no air bubbles behind the anode, the vessel was filled with slurry to the line adjacent to the "5" mark, or 5 cm. After the mud has been filled, smooth down its surface once again with a pat. Next, thread the wire along the edge of the jar and gently press the cathode into the mud. To make sure that no liquid or slurry coated the cathode's top, the cathode's wire protruded from the top side. For a few minutes, the mud was let to rest within the container. Any extra liquid was then gently drained off.

- Any muck on the rim of the vessel was cleaned with a fresh paper towel or rag. After the cables through the side were positioned out, the blue plastic lid was removed to cover the vessel.

2.3. Test of MFC Design

Every MFC was tested at 300°C in the identical conditions. The solution was poured into the MFCs. Each Kiwi-Mesh cathode had one alligator clip attached to it, and caps were secured to every MFC. Each MFC had a resistor attached so that the power could be measured. Each MFC was attached to a multimeter, and readings of the starting voltage were obtained.

2.4. Experimental Setup

The frame assembly was built like a set of layered cabinets. The microbial fuel cells were connected in series and parallel from the bottom to the top, and they were stacked or organized between the layers. The control panel, which will store the electricity and scale it up to a higher voltage for the LED display screen, will be linked to the end cathode and anode wires of the MFCs in series. The cabinet will be trodden on by the LED display panel.

3. Results

After a month of bacterial growth, data was taken from batches of MFCs once a week for seven weeks. The voltage of observation, expressed in millivolts (mV), is shown below:

Table 1 Voltage readings for the first batch of MFCs

S/N	VOLTAGE (mV)						
	WK1	**WK2**	**WK3**	**WK4**	**WK5**	**WK6**	**WK71**
1	359	438	469	486	543	523	501
2	88	102	134	98	56	34	006
3	312	325	345	313	256	189	98
4	344	248	236	268	238	254	24
5	92	105	132	100	86	46	23
6	330	336	299	342	359	381	412
7	96	89	99	63	34	16	003
8	76	56	51	35	12	007	000
9	156	298	288	293	301	296	223
10	31	33	31	24	15	003	000
11	196	176	126	98	53	21	004

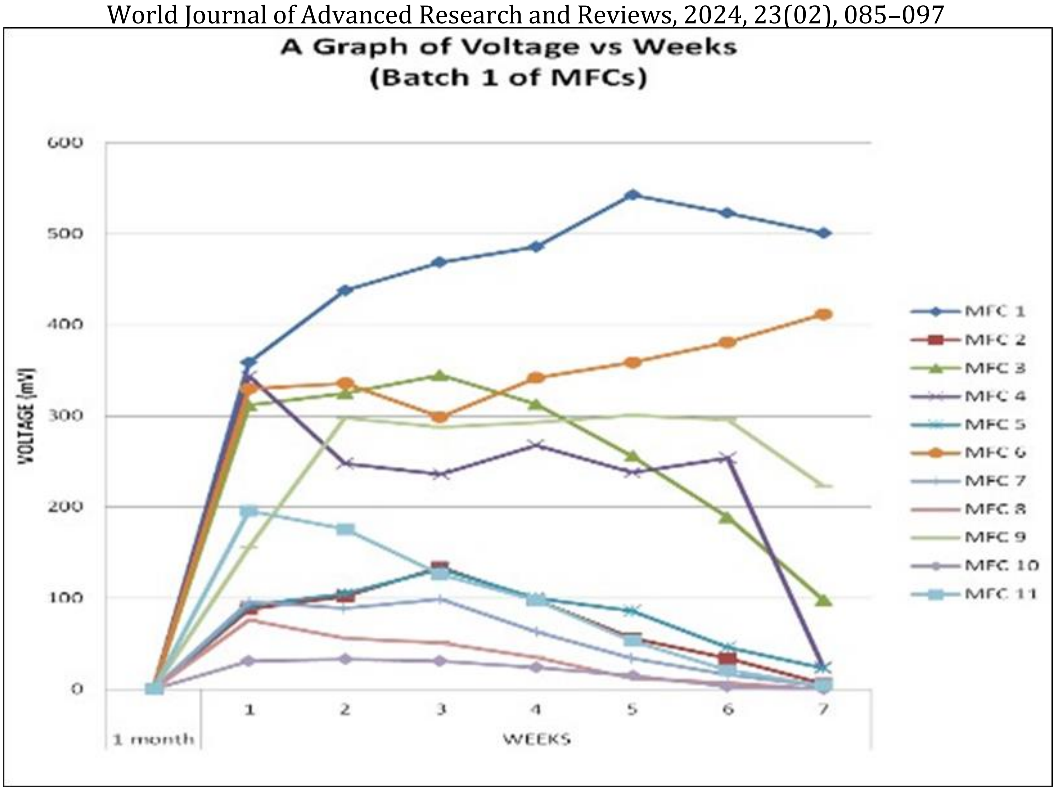

Figure 5 A Graph of Voltage vs Weeks

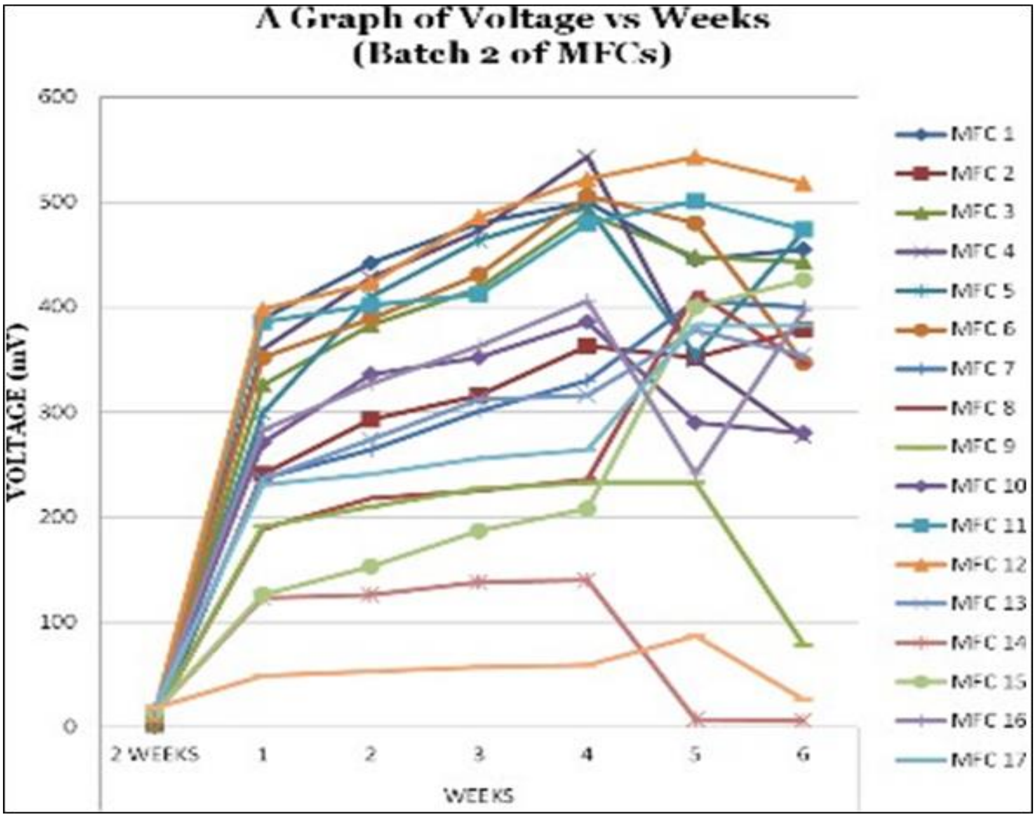

Figure 6 A Graph of Voltage Vs Weeks

4. Discussion

From Table 1, the result shows the microbial fuel cell's lifespan. The MFs were assembled using identical materials and configurations, but their functions and perhaps the microbe population vary, resulting in a range of voltages. MFC1.

Produce the highest voltage of 359mV, this shows there are effective activities of the microbes. MFC10produced the lowest voltage of 31mV which was not encouraging. Every week the voltage produced was taken and recorded. MFC1 produced a peak voltage of 534Mv in the 5th week and dropped to a voltage of 501mV but MFC 6 shows a progressive growth from 330mV to 412mV. Most of the MFC reached its peak at the 5th week of the test and then dropped. Several MFCs (2, 4, 7, 8, 10, and 11) produce voltage below 10mV. By the preceding week, the majority of theMFCs would have completed their life spans (i.e. the microbe would have exhausted all the nutrients and also stopped reproducing). The majority of the MFCs' life span lasted for two months and three weeks, these were because the microbial activities (feeding, growth, and reproduction) in the slurry had begun two weeks before it was set up into MFC because it was prepared and stored.

Table 2 shows the voltage produced by each MFC from the second batch setup. The voltage was taken after two weeks the MFCs were set up in the vessels. From the first observation taking, six MFCs generate voltages above 300mv. MFC 1 produced the highest voltage of 389mV, but MFC 18 provided the lowest voltage of 49mV in the first readings taken. The majority of microorganisms attain their maximal operation from the voltage generated in the fourth week of the test, as demonstrated by the MFCs' development. 543 mV was the highest/peak voltage that was generated.

At the end of each test for the MFC's life span, it was observed that the MFCs have a minimum life span of two months and can generate a voltage up to a maximum of 530mV. With sixteen MFCs linked in series and a maximum voltage of 2.43V, the device was configured to provide high and stable voltage. Five red LEDs linked in parallel, each with a voltage and current requirement of 2.3 V and 20 mA, were powered by it. From the LEDs were able to determine the maximum current produced by the MFCs. The current draw produced was 100mA (i.e. 5× 20mA).

Figure 7 Prepared Slurry for the MFCs

Figure 8 Preparation of Electrodes using Stainless steel mesh and Activated Carbon

Figure 9 A prepared microbial fuel cell

Figure 10 MFCs stacked and connected to power

5. Conclusion

The study concluded that microbial fuel is a potential energy source for future power generation that everyone may manufacture and utilize. Single-microbial fuel cells were assembled utilizing materials that were easily accessible, such as slurry, and materials that could be purchased in bulk from the market. According to the experiments, the single chamber MFC has a minimum two-and-a-half-month lifespan and can produce a maximum voltage of more than 500mV. Of the thirty MFCs that were manufactured, eighteen of them—producing a steady and increasing voltage—were linked in series within the frame. Five red LED lights were successfully powered by the entire arrangement. This demonstrates that a larger number of MFCs installed may generate more electricity, enough to run a control system.

Recommendation

In case of further research and improvement on the MFCs to power a device, the following are recommended:

- The use of a hacker board (blinker board) as a device used to store power produced by the MFCs and release a short boost of higher voltage as output.
- Chemicals or organic matter that have the potential to improve microbial activities thereby increasing the energy produced should be employed.
- Other electrode materials (such as graphite felt cloth or platinum electrodes) that have a better efficiency of receiving electric current effectively from the microbes to the external circuit should be considered.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no form of competing interest.

Data Availability Statement

All datasets for this research are available upon request from the corresponding author.

Author Contributions

All authors contributed equally to the writing of this paper, and have read and approved the final draft.

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