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Generation of Electricity by Using Microbial Fuel Cell Prototype Fed by Sewage: Case Study at the University of Dar es Salaam

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Abstract

The access to electricity is still not reliable in Tanzania. Whilst, there are several locations within the country that have wastewater cites that are not economically used to produce electricity. At the University of Dar es Salaam (UDSM), there are main grid power, and few scattered solar panels. This study was intended to bridge the divide between the current increasing power demands of the UDSM by exploiting not so much used sources, such as electric energy from wastewater. This study was undertaken to develop a Microbial Fuel Cell (MFC) prototype fed by sewage in Dar es Salaam, for electricity generation using cost effective materials for the cathode compartment. The collection of samples took place using sewage substrates from the UDSM oxidation ponds. The untreated sewage was collected from oxidation ponds. Preliminary experiments were carried out to identify the cathode and substrate that produced better results in terms of volts and current output. Aluminium produced the most desirable results compared to copper, stainless steel and mild steel in all the substrates. On the other hand, untreated sewage with aluminium/carbon electrodes produced higher voltage and current compared to treated sewage with the same electrodes. Thereafter, a prototype of the MFC was developed by connecting three single chambered cells in series of 628 cm^3 volume of untreated sewage with aluminium and carbon electrodes. The prototype generated a stable voltage of 1.73 V and a current of 0.07 mA recorded for a period of one hour. The power generated was enough to light a 6.25 mW LED bulb of 25 mA across a 100 Ω resister. Therefore, untreated sewage produced more power in MFCs with aluminium/carbon electrodes compared to the other tested materials.

Keywords: Aluminium electrodes, charcoal electrode, alternative energy source, wastewater.

Introduction

High oil prices, growing concerns over energy security and threats arising from climate change have stimulated investment in the development of alternative energy resources (Awan et al. 2022, Marcel et al. 2021). The issue of inadequate electricity supply is rampant in the developing nations, where more than 850 million people are neither connected to the grid nor to off-grid systems (IEA et al. 2021). Suggested solutions of generating electricity, include use of human body waste (Emetere et al. 2021, Pandit et al. 2022) municipal solid wastes (Josue and Mushi 2022, Omari et al. 2014) and waste waters. The Microbial Fuel

Cell (MFC) is one of the technologies that aim to produce electricity from wastewaters. It uses microorganisms such as bacteria to oxidize biodegradable substrates as fuels through biological processes to produce electrons (Köroğlu et al. 2014, Obileke et al. 2021). These electrons are then shuttled to an external electron acceptor (anode), and transferred to a cathode via copper wire, thus producing electricity (Li et al. 2013, Obileke et al. 2021, Botti et al. 2023), as shown in Figure 1. The MFC finds applications in pharmaceutical process in cleaning waste water that circulates back to the world's ever-increasing population (Thapa et al. 2022). This technology can easily be learned by the population and equip them with skills ready to be deployed in the matter of using alternative energies.

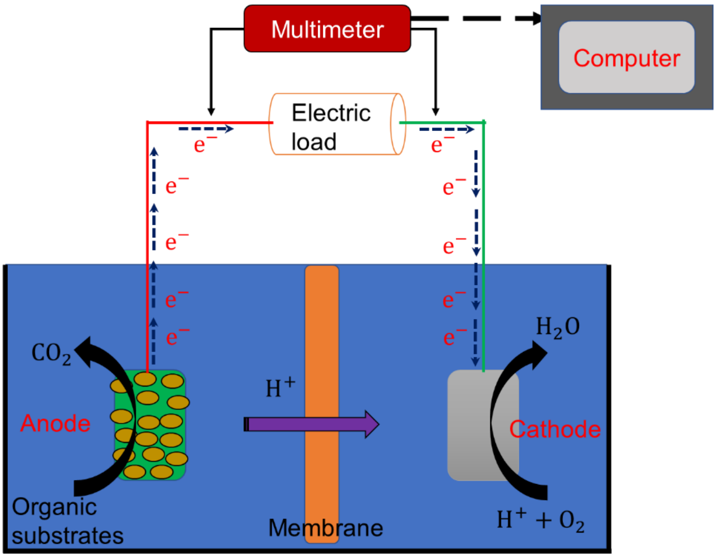

Figure 1: A schematic diagram of a dual-function MFC (Kim et al. 2011, Ghazi and Saleh 2018).

The earliest MFC concept was demonstrated by Potter in 1910 (Potter 1910, Potter 1911). However, the power output was small whenever someone explored this concept. This did not generate much interest until in the 1980s when it was discovered that current density and the power output could be greatly enhanced by the addition of electron mediators (Du et al. 2007).

Park and Zeikus (2003) developed an MFC which produced a current of 14 mA with power density of 787 mW/m^2 using sewage as the substrate. Another work was done by Schröder et al. (2003) who reported a current density of 15 A/m^2 with a dual chambered MFC using a platinum coated anode. Oh et al. (2004) validated that power production got increased when the cathode surface area was increased from 22.5 cm^2 to 67.5 cm^2, and fourteen years later, an improvement was proposed by Prasad and Tripathi (2022), and this improvement was on power management. On the other hand, Fan et al. (2007) demonstrated that replacing phosphate buffer with bicarbonate buffer at 9.9 pH increases output power. Aelterman et al. (2006) generated current along with a considerable voltage output via series parallel combination of the MFC cells. Waste water treatment method (Munoz-Cupa et al. 2021, Verma et al. 2021) is a promising tool for environmental conservation and nutrients circulation within nature whilst producing electricity. Moreover, Mohan et al. (2007), Franks and Nevin (2010) and Gupte et al. (2022) observed that overall voltage generation, power yield and substrate degradation were all dependent on organic substrates loading rate to the cell. Hidayat et al. (2022), Huang et al. (2011) and Banik et al. (2012) used bio-cathodes on MFCs which showed that electron transport is best in continuous operational mode.

The objective of the present research is to develop indigenous (to the UDSM) models of MFCs built with simple materials, which can produce maximum power under various process conditions. There were some successes as reported by Tharali et al. (2016), for which the MFC was regarded as a sustainable energy production process which could maintain constant power density. Currently, the limiting factor in the production of electricity with MFC technology on a large scale is the design and material used for the cathode. Platinum is frequently used in the cathode compartment but is expensive and subject to sulfide poisoning from waste water and therefore prohibitive for large scale applications. Overcoming obstacles like these has led researchers to attempt to seek efficient cathode materials and designs (Perlow 2012).

Materials and Methods

Site description

The University of Dar es Salaam is located in Dar es Salaam, Tanzania at the following coordinates - Latitude: -6°46' 53.76" S; and Longitude: 39°12' 20.41" E. The waste water oxidation ponds are found at north-east side of the university. They cover about 20,434.21 m^2; thus, they could be used as an affordable source of manufacturing MFCs substrates.

Substrate samples

Samples of the sewage substrates were obtained from the University of Dar-es-Salaam waste stabilization ponds and were categorized as untreated and treated sewage. The treatment of sewage was done by filtering the collected sewage by using 5 µm filter, thereby reducing the suspended solids.

Electrodes

Charcoal rod of diameter 2.2 cm and height of 15 cm was used for the anode, due to their easy availability and also its ability to behave as a cathode (Chai et al. 2009, Harini et al. 2021). Carbon electrodes from 1.5 V dry cells were used for the prototype. This is because the carbon rods have proved good results from previous studies and contain more carbon content compared to charcoal (Ahn et al. 2014, Wei et al. 2011, Dange et al. 2022). For the cathode, four types of materials were tested inclusive of copper, aluminium, stainless steel and mild steel. Their characterization is based on their capability to behave as a cathode (Ozansoy and Heard 2011).

Casing material

Preliminary experiments boxes were done on a plastic cylindrical container of diameter 10 cm, and height of 15 cm. This represented a single chamber MFC with the cathode and anode in the same compartment. The MFC prototype was made using transparent plastic cylindrical containers. Each container acted as a single chamber cell. These chambers were connected in series such that they could contain 628 cm^3 volume of waste water.

Electrode materials in sewage substrates

Copper, aluminium, stainless steel and mild steel of length 10 cm, width 5 cm and thickness 0.02 cm as shown in Figure 2 (a) were tested as cathodes in a single chamber MFC of diameter 10 cm and height of 8 cm. Charcoal of diameter 2.2 cm and height 16 cm was used as the anode in all tests. The sewage substrates were characterized as untreated and treated. Each cathode material was put in the cylindrical container of sewage volume of 628 cm^3 and charcoal as the anode in all tests. The materials were tested separately one after the other, successively. Thereafter measurements of voltage and current were taken for each cathode material. Voltage and current measurements were obtained using two types of digital multimetres; Fluke 179, true RMS Multimetre and Multi Display Multimetre as shown in Figure 2.

(a) (b)

Figure 2: Photos of (a) electrode materials: CU-copper, AL-aluminium, SS-stainless steel, and MS-mild steel; and (b) digital multimetres.

One–hour experiment on aluminium/charcoal electrodes in sewage substrates

The experiment was performed to characterize the performance of sample substrates in terms of voltage and current. In this case, two types of substrates were used, i.e., treated and untreated sewage. Both were put in separate containers with same volume of 628 cm^3. Aluminium was used as cathode while charcoal was used as anode in both cases. This is because aluminium produced better results from the preliminary tests compared to copper, mild steel and stainless steel. The behaviour of voltage and current was observed for a period of one hour at intervals of 5 min and data recorded for both tests.

Four-hour experiment on aluminium/charcoal electrodes in untreated sewage

Similar experiments to those of one-hour tests for untreated sewage were conducted for a period of four hours so as to deduce the operating behaviour of the MFC in terms of voltage and current output with respect to time. Untreated sewage was selected because it produced more voltage and current with respect to time compared to the treated sewage. From this, the aim was to identify a suitable substrate in terms of performance characteristics.

Experiment on MFC prototype

This experiment was done to formulate a laboratory experimental set-up for Microbial Fuel Cell fed with sewage for electricity generation using the selected cathode and substrate material that produced better results from the preliminary experiments, to characterize the laboratory experimental set-up for MFC in terms of voltage, current and power output and finally to develop a MFC prototype that can be used to power small electrical appliances such as Light Emitting Diodes (LEDs). Sewage of volume 628 cm^3 in each container was used as the substrate. Carbon electrodes from 1.5 V dry cells were used as the anodes, while aluminium plates of length 10 cm, width 5 cm and thickness 0.02 cm were used as cathodes. Measurements of voltage and current for both individual cells and a combination of the cells were taken using a digital multimetre model GDM: 8135. A 6.25 mW LED bulb with a resistor of 100 Ω was connected across the combination of cells and the performance characteristic with respect to voltage and current was recorded for a period of one hour at intervals of five minutes.

Results and Discussion

Performance characteristics of electrode materials in sewage substrates

The results indicating the performance characteristics of electrode materials in sewage substrates are shown in Figure 3. It can be deduced that the electrode performance in terms of power output, for all the substrates, copper produced the least power output, followed by stainless, then mild steel, while aluminium produced the highest. In terms of substrates, untreated sewage produced more power output compared to treated sewage, for all the electrodes except mild steel. This shows that aluminium has the best ability to behave as a cathode material compared to the others, while untreated sewage gives better power output with aluminium than the rest of the electrodes. Hence it is a better substrate compared to treated sewage.

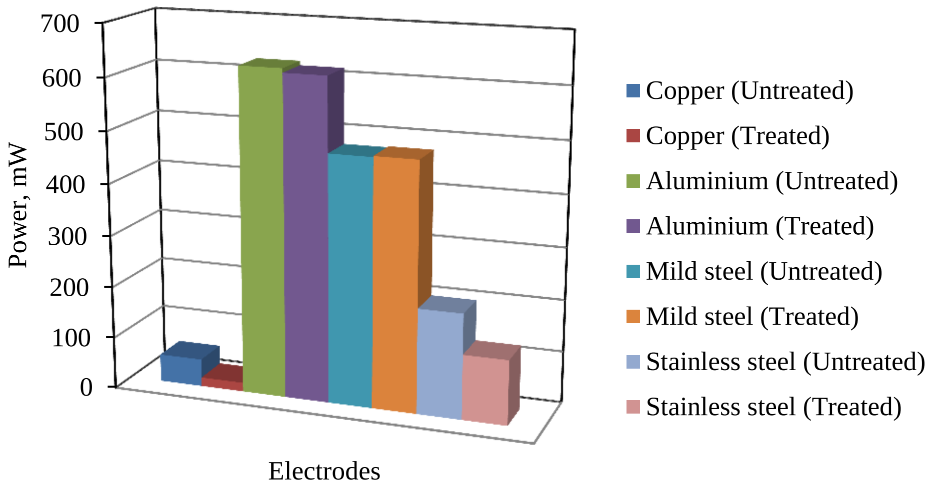

Figure 3: Characteristics for electrode materials.

The fact that aluminium has the highest capability to behave as a cathode material compared to the other materials can be explained from the electrochemical series of metals. When two different metals are connected together in a cell, the metal with the higher force pushes its electrons on to the other metal. The further apart the metals are in the electrochemical series, the higher the voltage. Electrons flow along the wire from the metal higher in the electrochemical series to the metal lower down. Aluminium is among the top metals, while copper is at the bottom, hence has the least capability to behave as a cathode.

Performance of MFC with sewage for one hour period

From the experiment set-up of electrode materials in treated and untreated sewage for a period of one hour. The electrode materials remaining constant while changing the substrate, we can deduce from Figure 4 and Figure 5 that the power output decreases with time for treated sewage, while for untreated sewage it increases with time, for a period of one hour. For the treated sewage, the voltage-current curve has a negative slope. This is because it contains fewer bacteria, its concentration is low and the rate of multiplication of the bacteria is also lower compared to untreated sewage. On the other hand, the untreated sewage gave a positive slope as compared to literature (Watson and Logan 2011) because the factors favouring MFC performance such as concentration, type of bacteria and rate of bacteria multiplication are more compared to treated sewage.

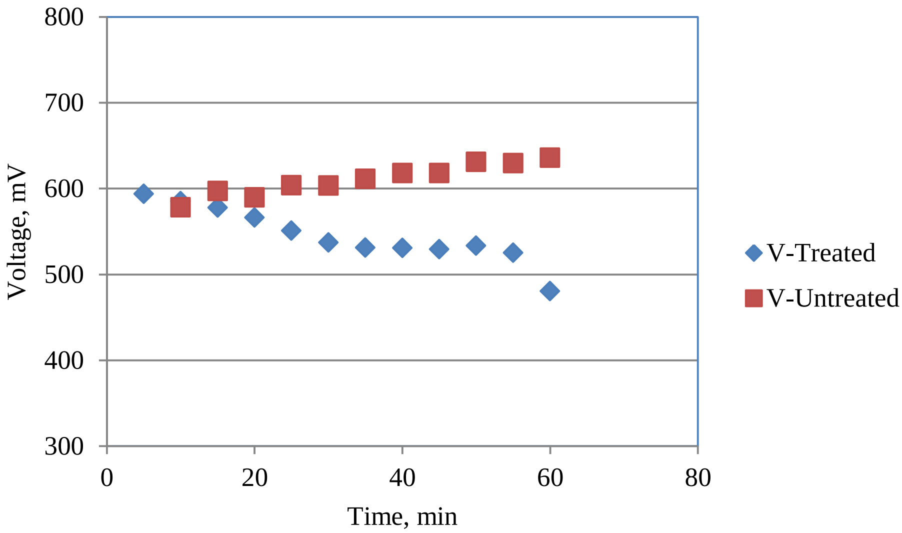

Figure 4: Voltage produced of sewage for one hour period.

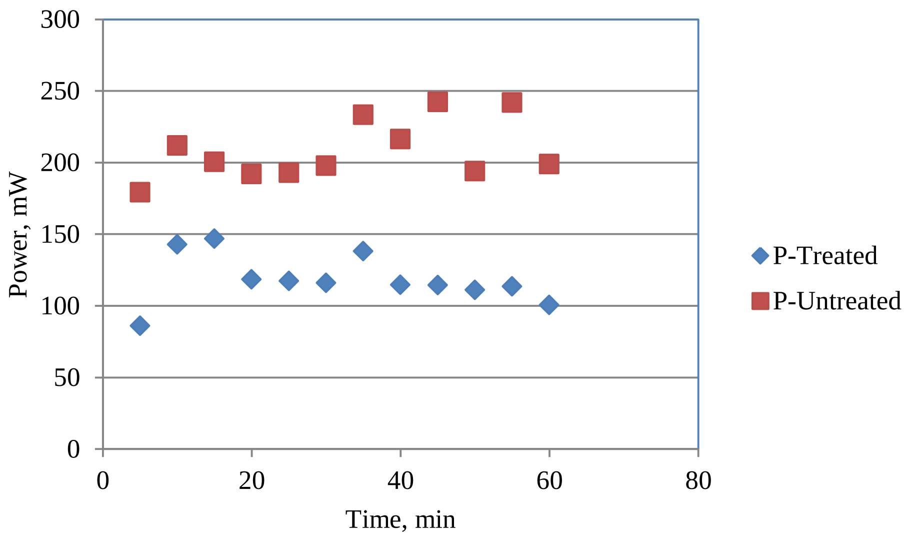

Figure 5: Power produced by sewage for one hour period.

Performance of MFC with untreated sewage for four hours

From the experiment set-up of untreated sewage for a period of four hours, it can be deduced that the performance of the MFC within the period of four hours, is low at the beginning, then it increases until it reaches its maximum value after which it reduces back to the lowest value. This is clearly indicated in Figure 6. This means there is a challenge of maintaining the power output at the Maximum Power Point (MPP). This can be achieved by trickle charging which ensures that the MFC operates with fresh untreated sewage all the time to maintain the number of bacteria and substrate concentration which is capable of producing the maximum power output. The experimental results obtained agreed to those obtained from the research works by Obasi et al. (2012), Rahimnejad et al. (2014), which showed the feasibility of power generation in a mediator-less dual chambered microbial fuel cell, utilizing cassava starch as the Proton Exchange Membrane (PEM). The study employed swine house effluent as the substrate, graphite electrodes and a phosphate buffer solution, as shown in Figure 7.

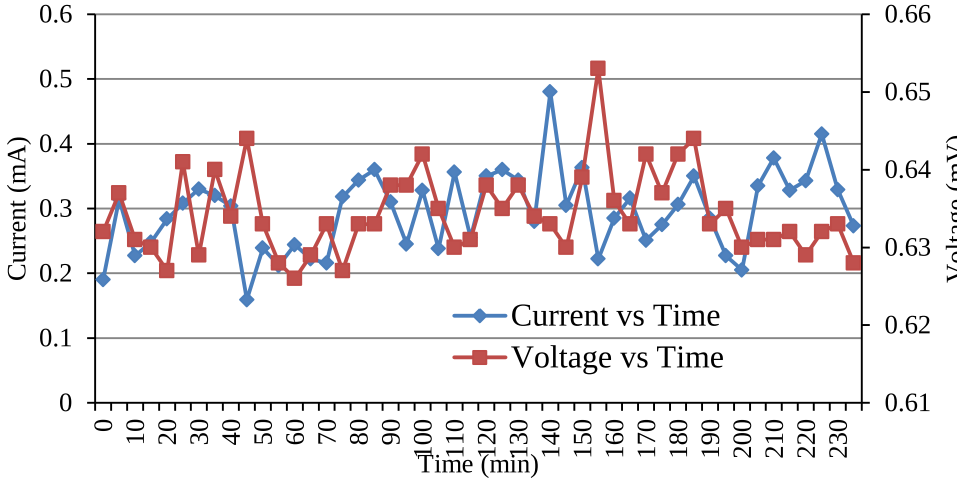

Figure 6: Characteristic of untreated sewage.

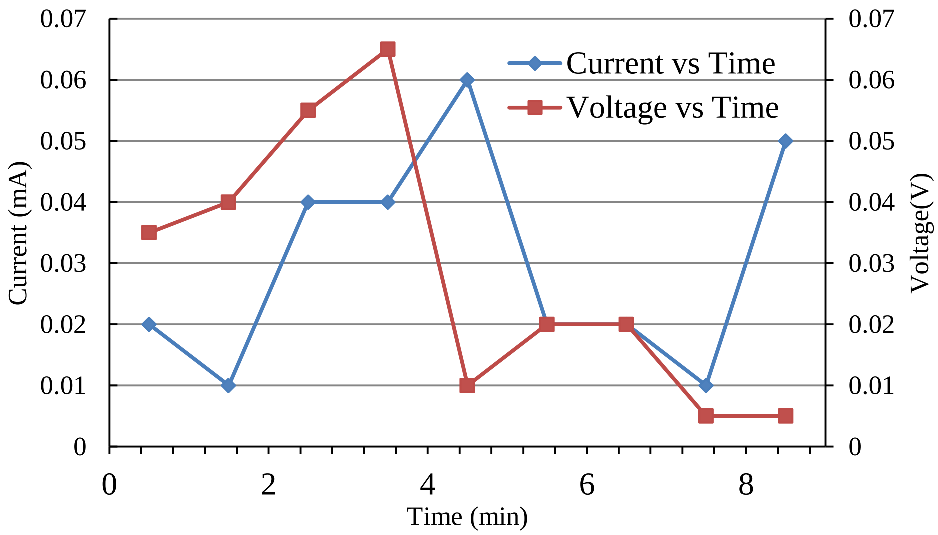

Figure 7: Comparison with literature (Source: Obasi et al. 2012).

Performance characteristics of MFC prototype

From the experiment where untreated sewage with aluminium and carbon electrodes was used in three similar containers of volume 628 cm^3, it can be deduced that a voltage of 1.7 V and current of 0.07 mA for a period of one hour can power a 6.25 mW LED bulb of 25 mA across a 100 Ω load, without a change in brightness. These materials have been used due to the fact that they produce better results as seen from the preliminary experiments. The performance of the MFC in terms of voltage, current and power output is indicated in Figure 8.

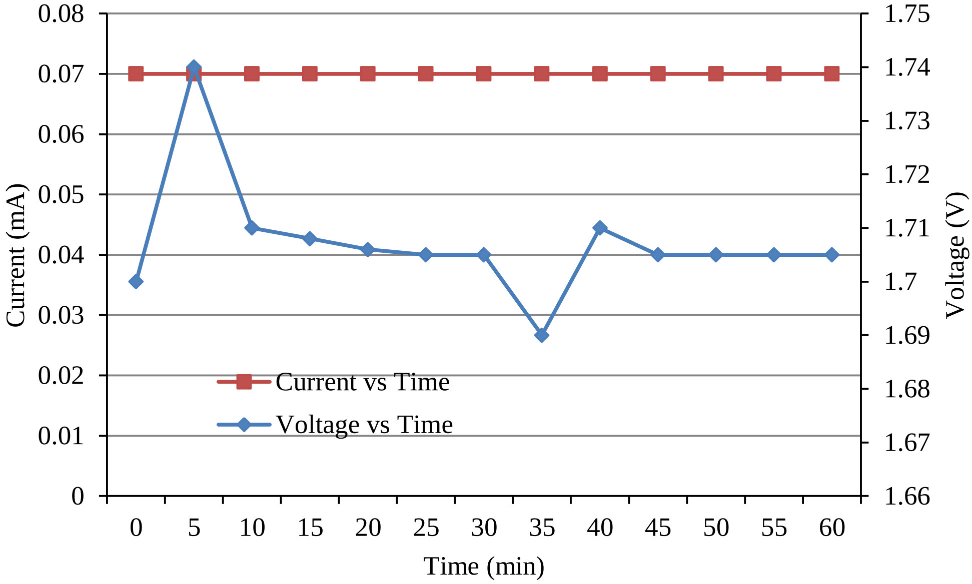

Figure 8: Characteristics of MFC prototype.

Conclusions and Recommendations

Aluminium produced better results as a cathode material compared to stainless steel, mild steel and copper in sewage as observed in the preliminary experiments. The experimental results showed that the performance characteristics of the MFC increases in untreated sewage with respect to time because it contains more bacteria compared to the fewer bacteria in treated sewage after it has undergone the oxidation process. A prototype of MFC can be formulated in the laboratory. The cells can be connected to yield more voltage, current and power output. Untreated sewage as the substrate and aluminium and carbon electrodes can produce good results in MFCs. A voltage of up to 1.7 V and current of 0.7 mA has been achieved with this setting and it is able to power small appliances like LEDs.

This study has revealed some challenges that would require in future work to investigate the performance when the microbial fuel cell is to be set at the sewage disposal site. This is because from the performance characteristic trend, the voltage versus current increases up to a maximum and then decreases with time as the substrate concentration reduces in the electrolysis process. Hence trickle charging should be ensured to maintain constant voltage and current output.

Further research should be carried out to find ways of increasing the voltage and current output, so that more appliances can be powered by MFCs. The use of Airtight Casings from Perspex glass for the MFC cells should be investigated. This is for the purpose of using anaerobic bacteria to produce more electrons.

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