

ELECTRICITY PRODUCTION WITH VARIOUS TYPES OF ORGANIC WASTES THROUGH MFC TECHNOLOGY IN BANGLADESH PERSPECTIVE

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ABSTRACT

This study investigated the production of electricity in a microbial fuel cell (MFC). Here different compositions of kitchen waste are used. Alternative energy sources are now required due to global energy demands. The depletion of fossil fuel reserves and their adverse effects on the environment render reliance on them unsustainable. The emphasis is now on carbon-neutral, renewable, and alternative energy sources. They are essential to both economic and environmental sustainability. Microbial Fuel Cells (MFCs) are bioreactors. It uses the catalytic reactions of microorganisms to transform chemical energy from organic or inorganic compound substrates into electrical energy. A dual-chambered MFC was created using easily obtained and reasonably priced materials. A carbon electrode was used in MFC, and its thickness is 2 mm. The MFCs using kitchen wastage has verified to be a good method to green electricity generation.

INTRODUCTION

The need for energy is growing daily. The dramatic drop in fossil and conventional fuels like coal and natural gas in recent decades has made alternative energy sources more important. There are alternative ways to get energy without adding to the accumulation of greenhouse gases (GHG) in the atmosphere. Solar, nuclear, water, wind, geothermal, tidal, wave, and ocean currents are renewable energy sources.¹ Microbial fuel cells (MFCs) are one of the new technologies which are interesting in this context.²

Kitchen trash has high energy potential, biodegradability, and limitless supply. That's why it has attracted a lot of attention from the perspective of bio-energy recovery. Anaerobic digestion is a popular method that provides several advantages. It includes waste stabilization, volume reduction, and biogas recovery. There are several types of kitchen waste, such as food waste, vegetable waste, waste from fish and meat and more.³

A microbial fuel cell (MFC) or biological fuel cell is a bio-electrochemical device that generates electricity through natural bacterial interactions. MFC is an environmentally friendly method of producing electricity. A cation exchange membrane is sometimes referred to as a proton exchange membrane or cation exchange membrane. It is frequently used to divide an MFC reactor's anode and cathode compartments. Figure 1. Na⁺, K⁺, and NH₄⁺ are examples of cationic species that are more concentrated in the anode compartment than protons (H⁺). The membrane facilitates electrochemical migration by accelerating the movement of these cationic species to the cathode. Under MFC circumstances, the membrane accelerates the movement of these cationic species to the cathode to attain electro-neutrality. PEM is used by MFCs, including Ultrex, Nafion, and Salt Bridge.

A major influence of proton membrane exchange (PEM) is seen in MFC power output. It forms two electrolyte chambers, acts as an insulator to preserve the redox potential, and only permits specific ions to exchange.

The current work intends to investigate the feasibility of bioelectricity generation in dual-chambered MFCs. Ultrex as the proton exchange membrane (PEM), graphite rod as the electrode, and food waste leachate as the substrate is used here. The performance of MFC was evaluated at different organic loading rates (OLRs) and HRTs using commercially available PEM. The resistance was kept constant at 100 ohms. Keeping this, the maximum current and voltage capacity of this MFC were investigated.

The presence of proteins, oil, and size variation in food-based waste, together with its composite character, all have a substantial impact on treatment efficiency. The substrate loading rate was the basis for the study of MFC performance.

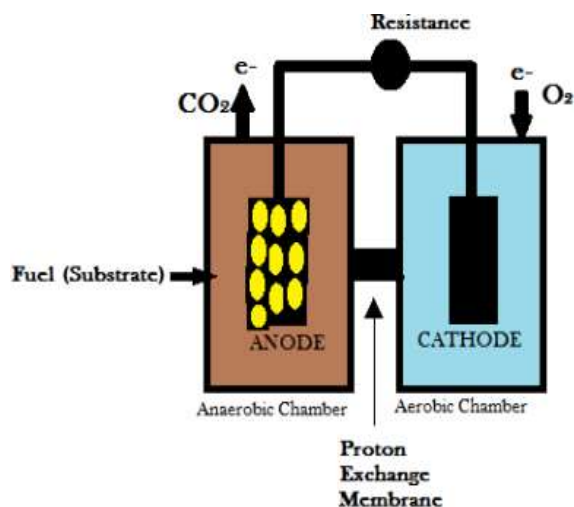


Figure 1. Schematic of a dual chamber microbial fuel cell

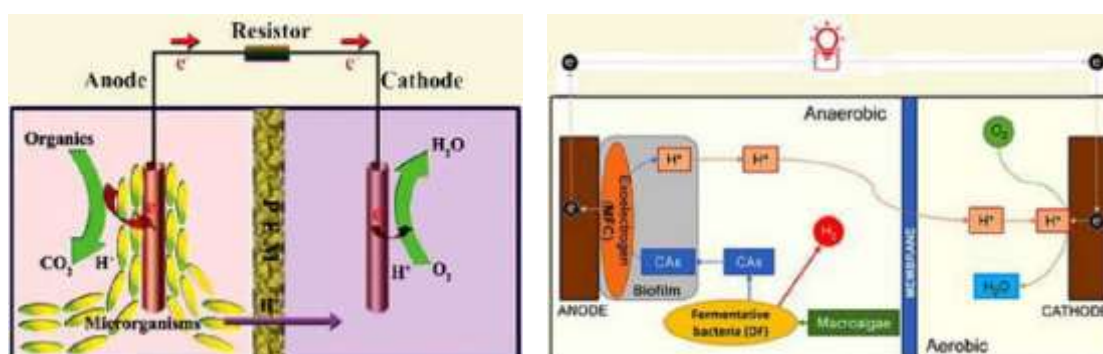


Figure 2. Schematic of electricity production process in MFC

MATERIALS AND METHODS

Organic raw material

Food wastage including fruit, and vegetable wastage:

One type of biomass produced is grated coconut kernel trash. It is made up of minerals, carbohydrates, dietary fibres, and different trace minerals. Because of its high concentration of sucrose, sorbitol, fructose, and glucose, this substance is a great source of MFC. In the MFC process, these nutrients help to generate more power and current. According to the Journal of Food Science, coconut-grated waste also contains species like yeast, moulds, Acinetobacter, Enterobacteriaceae, Flavobacterium, Microbacterium, and Micrococcus. These species might hasten the breakdown of the waste's organic and nutritious components.⁴

The results from screening fruit wastes as a substrate for MFC showed that fruit waste from oranges produced the highest voltage output 357 mV, followed by banana and mango fruit waste.⁵ It was observed that the MFCs with pineapple substrate generated higher values of the electrical parameters, resulting in voltage and current values of 0.3484 ± 0.003 V and 27.88 ± 0.23 mA, respectively.

Currently, there is an increasing interest in utilizing energy from organic matter (OM) as a potential energy source; for instance, wastewater is rich in OM with chemical components that act as electron carriers (Kim et al., 2010). Moreover, after processing, pineapple waste is frequently sent to landfills with no further application (Buliah et al., 2019). Pineapple production, which ranks 12th in the world, yields over 18 million tons, with by-products such as the peel containing 16.7% crude fibre (Ayeni et al., 2019; Adrizal et al., 2017). Various organic matter residues still possess monosaccharides obtained from sugars, polyalcohols, amino acids, organic acids, alcohols, and nitrogen-containing compounds, which can aid in electricity generation (Khandelwal et al., 2018). Therefore, food waste presents a feasible source of organic material that can be utilized for generating electrical energy (Girotto et al., 2015). Nonetheless, most research related to producing electrical energy from organic materials through microbial fuel cells (MFCs) has primarily concentrated on sewage waste, with limited studies investigating food waste, particularly from fruits (Yoshimura et al., 2018).

Tomatoes are abundant in carotenoids and flavonoids, which are compounds that can engage in redox reactions. The natural lycopene found in tomatoes boosts electricity generation. Additionally, they demonstrate considerable electrical conductivity. Banana biomass, which includes both the fruit and its peels, has been utilized as a source for generating methane gas. Research conducted by Elviliana and the team investigated the transformation of banana peel waste into electricity via microbial fuel cells (MFCs). Both banana and pineapple peel waste have been effectively used to produce electricity in double-chamber system MFCs.⁶

The limited understanding of utilizing red dragon fruit waste as a fuel source and the lack of awareness regarding its electrochemical capabilities drive us to explore its potential in electricity generation for the first time.

Malik et al. (2021) found that employing a carbon-dense source as fuel in MFCs leads to increased electric current values. In their study, they achieved peak outputs of 6.47 mA and 0.647 V by using food waste sourced from hotels, homes, and restaurants as the substrate.⁷

The 12kg substrate produced a maximum voltage of 139.5 mV for watermelon and 222.9 mV for pawpaw. The microbial fuel cells were observed over 1 week (7 days) for each quantity of waste watermelon and waste pawpaw used (1kg, 2kg, 4kg, 6kg, 8kg, 10kg, and 12kg), during which the generated voltage was measured daily with a digital multimeter (Model: DT9205A). Daily voltage readings were taken using the digital multimeter and recorded in millivolts (mV) over 24 hours. Additionally, power and power density values were computed.⁸

Vegetable wastage:

Vegetable market compostable solid waste is recognized for its capability to produce energy because of its significant organic composition and readily biodegradable characteristics. Large volumes of these wastes, which are abundant globally, are high in carbohydrate content and can be effectively utilized for energy recovery through fermentation.⁹

Fish:

Researchers indicated that the specific surface areas of devil fish fins and backbone were 13.7 and 0.61 m²/g, respectively, suggesting that both materials exhibit low porosity. Following the carbonization procedure, the specific surface areas of both bone chars increased to 107 and 109 m²/g, respectively. In this study, the devil fish fins, and backbone were not analyzed separately; instead, the specific area of the bone char was calculated, which turned out to be 1.27 times greater than the values reported by these researchers. The specific area of devil fish bone char was found to be superior to that of cattle bone char, felt carbon, and felt foil, even though felt carbon and felt foil underwent thermal treatment. The structure of any carbon material used as an electrode significantly influences the formation of an electroactive biofilm. It has been suggested that both a large specific area and a macroporous structure of an anode are essential for optimal MFC performance, indicating that the high specific area of devil fish bone char is likely to enhance microbial accessibility.¹⁰

The scales of the Rohu fish are utilized to create electricity by developing triboelectric nanogenerators that rely solely on human movement instead of a battery for power generation.

The electrical output generated by this fish scale-based device is capable of illuminating 90 commercial green LEDs, equivalent to 180 V. A current of 1.7 μ A has been recorded across a 1 M Ω resistor. ¹¹

Animal:

The efficiency of blue-green algae-based microbial fuel cells (PMFC) can be assessed by the concurrent treatment of actual slaughterhouse wastewater (SWW), ammonium elimination, and bioenergy generation. ¹²

Meat & fish waste

Substrate Composition: The organic composition of animal and fish bones is abundant in proteins, fats, carbohydrates, and minerals, creating an ideal environment for microbial proliferation. By crushing these bones, they can be utilized effectively. Specific bacteria can decompose them, akin to the processing of other organic materials in microbial fuel cells (MFCs).

Microbial Metabolism: When fish bones are placed in the anode chamber of an MFC, bacteria break down the organic materials, resulting in the release of electrons and protons.

Electricity Generation: The electrons generated from this degradation are transferred to the anode, producing an electrical current. Meanwhile, the protons move through the membrane to the cathode, where they react with electrons and an electron acceptor (typically oxygen) to create water.

Construction of Mediatorless Double Chamber Microbial Fuel Cell

A double-chamber microbial fuel cell is employed to extract electrons from bacteria while generating electricity. Two 745 ml containers served as the anodic and cathodic chambers. The anodic chamber was filled with organic waste. The chambers of the microbial fuel cell were connected using a salt bridge. Sodium chloride (NaCl) was dissolved in water and heated for about three minutes to ensure complete solubility. This experiment made use of two sets of electrodes. Graphite was utilized as both the anode and the cathode. This construction featured mediatorless double-chamber microbial fuel cells. In the anode chamber, a garbage sample consisting of decomposed organic materials was immersed in stagnant water and a growth medium. The cathode chamber contained distilled water and a 0.1M phosphate buffer in the same proportions as the anode chamber. Electricity production (measured in volts and milliamps) was recorded using a multimeter. A mediatorless multi-chamber MFC was created by connecting ten single-chamber MFCs in series to enhance electricity generation. In this design, each chamber contained both anode and cathode electrodes, with the anode of one chamber linked to the cathode of the next one in the series. The cathode of the first chamber was connected to the anode of the last chamber to measure the total electricity generation.

Potential electrogenic bacteria determination

Possible electrogenic bacteria were discovered using synthetic wastewater. To evaluate the energy generation potential of each isolate, a single-chamber microbial fuel cell (MFC) was employed for testing. Among the 44 isolates examined, 22 (or 50%) are electrogenic bacteria capable of producing electricity, while the remaining 50% are not. Figure 4 illustrates the power output for each bacterium based on the experimental results, and many of the potential microorganisms were also identified.

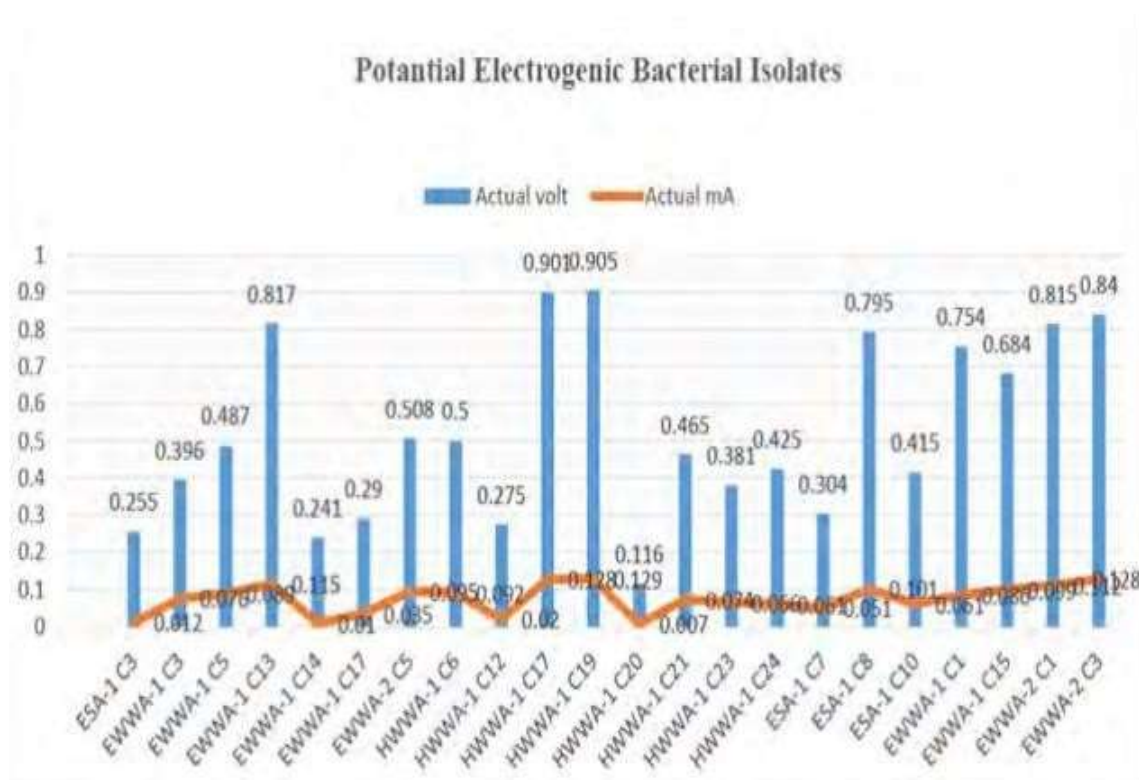


Figure 3: Electricity production by individual electrogenic bacterial isolate. Bar graph representing electricity production in voltage and line graph representing electricity production in milliamperes.

RESULT

The power density (PD) values that depend on the current density (DC) values are displayed in Fig. 4. The MCC with pineapple substrate had a maximum average DP of 782 ± 12.9 mW/cm² in a DC of 6.02 A/cm² with a peak voltage of 363.94 ± 7.2 mV. The PD values of the pineapple substrate in a state of decomposition were higher than the data obtained in other works where different substrates were used. Zhang et al. (2016) used residual sludge as substrate and carbon felt as anode, and they were able to obtain DP_{max} and DC values of 20.4 mW/cm² and 25.86 mA/cm², respectively. This could be because they adjusted the substrate to pH > 8. Yoshimura et al. (2018) also used pond muck and rice bran as a carbon anode and substrate in the MFCs, achieving a peak voltage of 400 mV, which is less than the values that the fruit in a breakdown condition obtained in our experiment. It has also been reported that using cattle manure as a substrate can provide 16.3 mW/m² of DP and a V_{max} of roughly 0.7 V on the first day, which is significantly less than our results (Inoue et al., 2013). Additionally, research indicates that pH levels might affect PD values; for instance, Jiang et al. (2016) demonstrated that the DP rose by 80%, or from 0.36 W/m² at a pH of 6 to 0.66 W/m² for a pH 9.5.¹³

Figure 5 displays the initial and final FTIR transmittance spectra of the used substrate. The O-H bonds are responsible for the most intense peak at 3331 cm⁻¹, while the alkane (C-H) bonds are responsible for the peaks at 2969 and 2805 cm⁻¹. Similarly, the presence of alkene compounds (C=C) is indicated by the 1686 cm⁻¹ peak, and the presence of NO₂ and C-H bonds is indicated by the 1496 and 968 cm⁻¹ peaks. Furthermore, the chemicals are consumed in the metabolism of the waste-associated microbes during the fermentation, degradation, and bioelectricity generation processes, resulting in a decrease in the observed transmittance peaks.¹⁴

The relationship between voltage and power density for watermelon was represented by a linear regression equation; $y = mx + C$. The r^2 value for watermelon (0.976) from the graph above [Figure 1] indicates that the connection between voltage and power density is significant. Similarly, the correlation for paw-paw also fitted a linear regression equation; $y = mx + C$. The r^2 value for paw-paw (0.957) from the graph above [Figure 2] demonstrates that the association between voltage and power density is significant.¹⁵

Every MFC unit in a series configuration operates independently, resulting in an overall increase in both current and voltage. The current and voltage readings can be observed in Fig. 4, although the external resistance connected to the system was not recorded.¹⁶

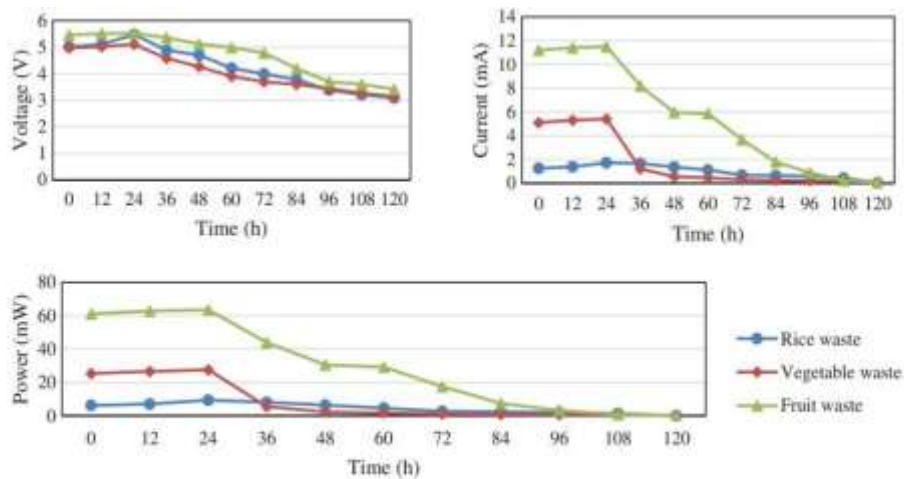


Figure 4: Voltage, current, and power values of rice, vegetable, and fruit wastes vs. time

We have made an experiment with potato shells, banana peel, orange peel, vegetable waste, meat waste and fish waste using MFC. Here is the table of obtained voltage from the experiment:



Fig. 5: Electricity Production Experiment by Kitchen Waste using MFC

Table 1: List of obtained voltage from different kinds of waste

Potato Shell	0.6	High starch content provides a good energy source for microbes.
Banana Peel	0.7	Rich in organic matter but may take longer to decompose fully for microbial digestion.
Orange Peel	0.3	Contains organic acids that can reduce microbial activity, resulting in lower voltage.
Vegetable Waste	0.5	Depending on the type of vegetable; fibrous waste may take longer to break down.
Meat Waste	0.1	Animal bones which are rich in organic material
Fish Waste	0.245	Fish scales, fin, fish bone are rich in organic matter including proteins, fats, and carbohydrates, and minerals.

CONCLUSION

According to the study's findings, microbial fuel cells (MFCs) present a viable way to convert biodegradable materials into a sustainable energy source by producing power from kitchen trash. The efficiency of various substrates, including pineapple and banana trash, varied, some produced larger power outputs than others. MFCs solve waste management issues in addition to offering an environmentally beneficial substitute for traditional energy production. The work shows the possibility of improving MFC performance by using inexpensive materials like carbon electrodes and proton exchange membranes. Notwithstanding its existing drawbacks, MFC technology offers a wealth of chances for innovation and scalability, supporting environmentally friendly practices and renewable energy sources.

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