Paper ID: 143

Performance Analysis of Power Generation in Dual Chamber Microbial Fuel Cell Using Municipal Wastewater

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Abstract

Microbial Fuel Cells (MFCs) have recently become a focal point of research interest because of the growing need for energy crisis solutions and wastewater treatment. This study investigates the performance analysis of electricity generation in Dual Chamber Microbial Fuel Cells (DCMFCs) using municipal wastewater. The function of DCMFCs is converting the organic substrate into electricity based on the activities of electrogenic bacteria. In this research, a model of DCMFC was constructed and operated to measure the voltage, current, and power output on an hourly and daily basis. The research findings revealed that the maximum power output reached 3014 mW per hour and 1006 mW daily. The results show that power generation experiences sharp fluctuations, with rapid increases and decreases over short durations, while gradually declining over the long term. This research highlights the potential of DCMFC to solve sustainable energy needs while reducing environmental pollution.

Keywords: Microbial Fuel Cell, DCMFC, Sustainable Energy, Waste Water Treatment, Fuel Cell

1. Introduction

Fossil fuels are depleting at an alarming rate with the increased growth of energy demand. The world is very much concerned about the fact that the environmental pollution caused by burning these fuels increases the greenhouse effect and contributes to global warming, which causes ice melting from the north and south poles. Therefore, research efforts are diverting toward developing alternative sources of energy [1]. Microbial fuel cells (MFCs) are promising solutions for power generation and waste treatment. The metabolic actions of microorganisms drive the conversion of organic matters into electricity in microbial fuel cells. It provides a dual benefit of waste reduction and renewable energy generation. This system has the potential to generate electricity while treating wastewater, which offers an environmentally friendly alternative to traditional methods. An MFC consists of an anode electrode, a cathode electrode, and an electrolyte. A proton exchange membrane (PEM) separates the anode and cathode chambers. By forming a biofilm on the anode, planktonic microorganisms can be used to finish the oxidation of substrates. The final products of the oxidation process will include protons, electrons, and other metabolites. When the bacteria release their electrons, they migrate to the anode and are transferred through an external load to the cathode. However, the protons diffuse to the cathode or percolate through the PEM to complete the circuit to undergo electron reduction. A flow of electricity is created when electrons go through the external load. An environmentally benign process occurs when protons are reduced with the help of oxygen at the anode, producing water as a byproduct [2].

Anode Reaction: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$ (1)

Cathode Reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (2)

Overall Reaction: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (3)

In the anode compartment, reaction (1) occurs where bacteria or microbes oxidize glucose ($C_6H_{12}O_6$) and produce

carbon dioxide (CO_2), protons (H^+), and electrons (e^-) in an anaerobic environment (without oxygen). The electrons and protons are then released as part of the reaction. In the cathode compartment, reaction (2) takes place where oxygen (O_2) is reduced by accepting electrons from the external circuit and protons (H^+) from the anode, forming water (H_2O) in the presence of oxygen. The overall reaction (3) represents the complete oxidation of glucose to carbon dioxide and water. The MFC generates electrical energy from the flow of electrons in the circuit, while protons move through the membrane, and oxygen is reduced at the cathode.

In the last few years, research on microbial fuel cells has increased due to their numerous advantages in wastewater treatment and energy production. MFCs enable the direct conversion of organic waste into electrical energy in a single step, offering higher conversion efficiencies compared to conventional methods such as the activated sludge process (ASP) and anaerobic digestion. A key advantage of MFCs is their ability to operate without the requirement of gas treatment, a significant challenge in anaerobic digestion, which involves handling gases like methane (CH_4), hydrogen (H_2), CO_2, and trace amounts of hydrogen sulfide (H_2S). Furthermore, while ASP requires considerable energy input for the aeration process, MFCs are equipped with passively aerated cathodes, allowing them to function without the need for additional aeration energy. Another benefit is the reduced sludge production in MFCs compared to traditional systems, further improving their overall efficiency and sustainability. Additionally, MFCs can be configured in stacks to serve as decentralized energy sources, offering a flexible and scalable solution for renewable energy generation from waste streams. Microbial fuel cells draw great attention as they have dual benefits: generating electricity and treating wastewater. It can produce electricity from the day-to-day organic waste [3]. Fan et al. showed an excellent maximum power of 6.9 W/m² from a single chamber MFC, which consisted of two cathodes constructed with platinum catalysts [4]. New technologies, including the use of algae, have been utilized to increase the power output and performance of MFCs. Algae can be integrated into both the anode and cathode. In the anode, It acts as a substrate, while in the cathode, it contributes to more oxygen generation [5]. The theoretical maximum power output from microbial fuel cells can be determined using the Nernst-Michaelis equation. However, in practical work, the power output decreases due to the reduction of electron acceptor in the cathode [6]. Research shows that lighting has a significant effect on the power density of MFCs. It was observed that the longer the exposure to light, the greater the increase in power output [7]. The modern world utilizes different wastewater treatment techniques, such as ion exchange, thermal treatment, lime soda, etc. MFCs have the potential to perform well as a treatment plant for organic matter in wastewater strems. Experiments have shown that it has excellent COD removal efficiency [8]. MFCs are currently a focus of research as they can be used as an alternative treatment plant that also generates energy output [9]. With MFCs, different combinations can be made, such as single chamber MFC, dual chamber MFC, plant MFC, etc., which provide design flexibility and enhance the performance under various environmental conditions [10].

MFCs are effective in low-temperature environments, so they can be used in cold countries for simultaneous power production and wastewater treatment. They can be installed in industries where large amounts of waste are available [11]. The critical component of an MFC is the microorganisms that convert the organic waste into electricity. The research found that different microorganisms show different efficiencies with different organic waste materials. Selecting the suitable microorganism is an essential factor of research in this field [12]. In some bacteria, the lipopolysaccharide (LPS) layer is so dense that it resists the electron flow to the electrode surface and decreases the power output. Different reagents, such as chitosan (CS), PEI, and EDTA, are used to modify the LPS layer and improve the electron transfer ability. As a result, new channels are formed for electron transfer, increasing the surface area available for electron transfer [13]. Previous research has shown the performance of MFCs with plant integration, light duration, temperature, pH, bacterial cell modification, etc. This study focuses on the performance analysis of power generation in a dual-chamber MFC using municipal wastewater and observes the power output over both short and long periods. It also investigates the reasons behind the variation in power output of MFC on an hourly and daily basis.

2. Methodology

2.1 Raw Materials and Experimental Setup

Fig. 1 shows the model of the Dual Chamber Microbial Fuel Cell (DCMFC), which was constructed for this study. The size of each compartment was 8-inch length, 6-inch width, and 8-inch height. Each of them was made of 5 mm thick Nasir Glass. The compartments were connected by a PVC pipe attached with the M-seal. The length and diameter of the pipe were 4 inches and 2 inches, respectively. A 1 M NaCl solution mixed with agar-agar powder was used to create the salt bridge. A zinc (Zn) rod was used as the anode, and a copper (Cu) rod was used as the cathode. Two copper wires were attached to the Zn and Cu rods. A glass cover was used to seal the anode compartment. The wastewater and fresh tap water were used as electrolytes. The raw materials used for constructing the model are shown in Table 1.

Table 1. Raw materials for the experimental setup.

Name of Material	Dimension or Quantity
Nasir Glass	5 mm
PVC pipe	2-inch Dia.
NaCl	-
Zn rod	-
Cu rod	-
Cu wire	-
M-seal	-
Municipal Waste Water	5.12 L
Fresh Tap Water	5.12 L
Agar-agar Powder	-

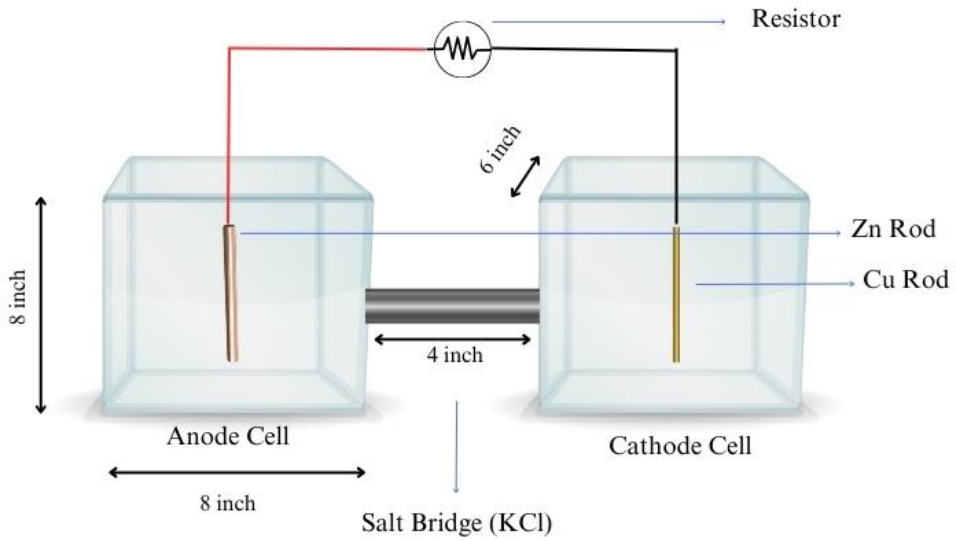


Fig. 1. Construction model of the dual chamber microbial fuel cell.

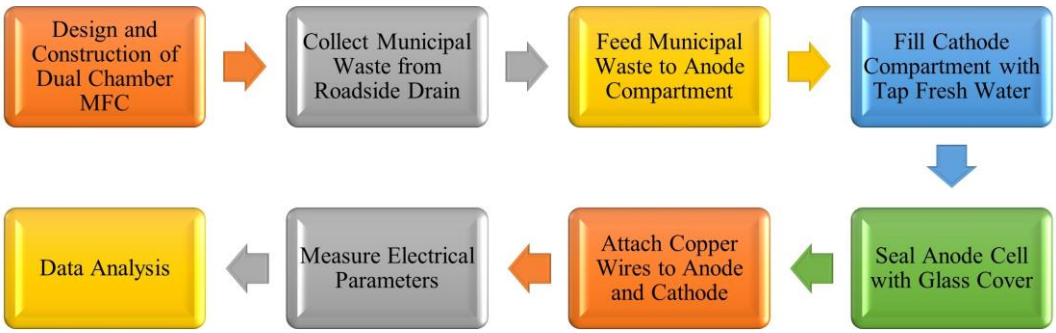


Fig. 2. Flow chart of the steps for conducting the experiment.

2.2 Experimental Procedure

The experiment was aimed to analyze power generation from a DCMFC using municipal waste. The experimental steps are shown in Fig. 2. The procedure was as follows: municipal waste was collected from a roadside drain and fed into the anode compartment, while tap water was used in the cathode compartment. The anode cell was sealed with a glass cover to maintain airtight conditions, whereas the cathode cell was remained open to the air for better oxygen entrainment. The salt bridge was prepared by heating a 1M NaCl solution with agar powder in a container. Surgical gauze was then soaked in the solution for 7-8 hours, after which the wet gauze was inserted into the pipe designed for the salt bridge in the middle of the setup. Copper wires were attached

to both the anode and cathode, and a digital multimeter (VICTOR VC830L) was used to measure electrical parameters like voltage and current. The power output was subsequently calculated using the appropriate formula (4):

$$P = V \times I \tag{4}$$

Fig. 3 shows the DCMFC experimental setup. The experiment was run for 12 days, and the data (voltage and current) was recorded every hour for the first 13 hours, and then every 24 hours hereafter. The power was calculated for each data set using (4), where V represents voltage, I represents current, and P represents the power output.

3. Results and Discussion

This section presents the performance of DCMFC through figures, emphasizing key parameters such as voltage output and current density.

3.1 Hourly Performance of Microbial Fuel Cell

Fig. 4 (a) shows the variation of voltage and current with time (hourly). The voltage starts at 600 mV and increases steadily. It peaks at 1370 mV between the 6th and 8th hours. After reaching the peak, the voltage declines slowly and falls to 870 mV by the 13th hour. The current follows a similar trend, starting at around 1.18 mA. It increases to a peak of 2.2 mA and then decreases in line with the voltage, falling to 1.25 mA by the 13th hour. On the other hand, Fig. 4 (b) illustrates the power variation of MFC in hours. In the first few hours (hours 1–7), there is a significant increase in power output, peaking at 3014 mW at hour 7, after which the power declines to 1087.5 mW. This variation can be attributed to various factors, including the availability of nutrients, microbial activity, and environmental conditions, such as temperature fluctuations throughout the day. At the start of the experiment, there were abundant nutrients in the organic waste. That is why the power builds up over time and eventually reaches its maximum. Even though the temperature was at room temperature, the effect was relatively small. As the power reached the peak, microbial activity continuously broke the nutrients down, leading to a gradual decrease in power. Continuous feeding of waste to the anode can increase power output and help reach the peak.

3.2 Daily Performance of Microbial Fuel Cell

Fig. 5 (a) shows how the voltage and current changed over 12 days. The voltage starts at 600 mV and gradually increases, peaking around the third day at 700 mV. After the peak, the voltage decreases, falling to 310 mV by day 12. The current follows a similar pattern, starting around 1.18 mA, increasing slightly, and peaking near the third day at 1.52 mA. Afterward, it declines rapidly, reaching below 0.5 mA by day 12.



Fig. 3. Experimental setup of DCMFC.

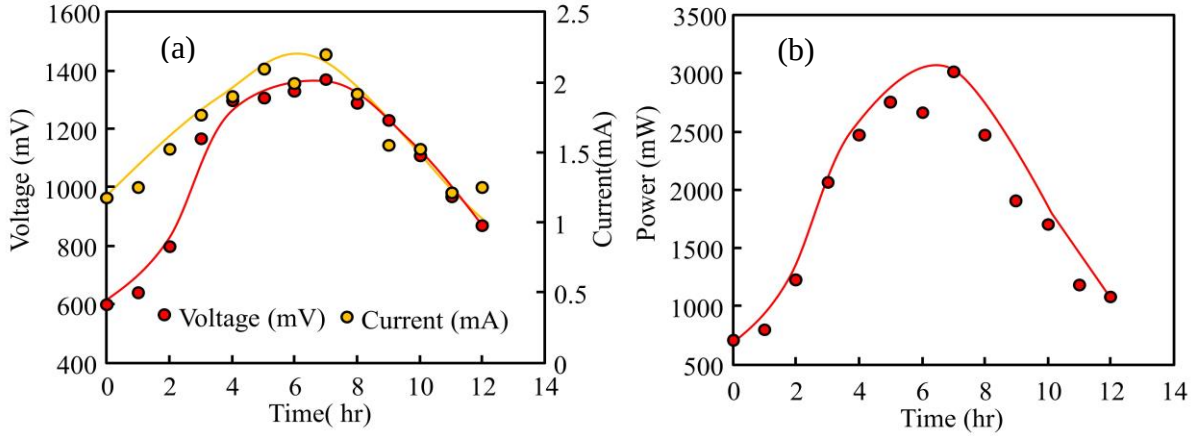


Fig. 4. Voltage, current, and power generation vs time (hour)

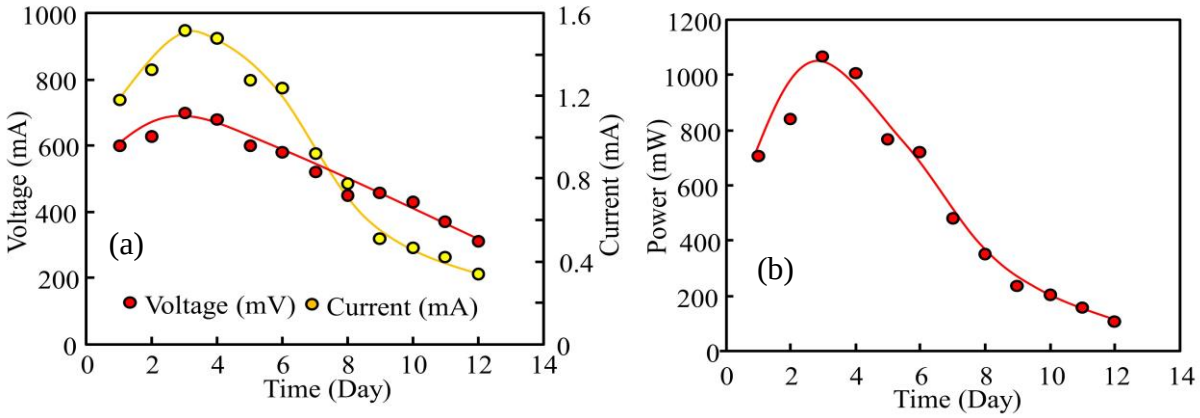


Fig. 5. Voltage, current, and power generation vs time (day)

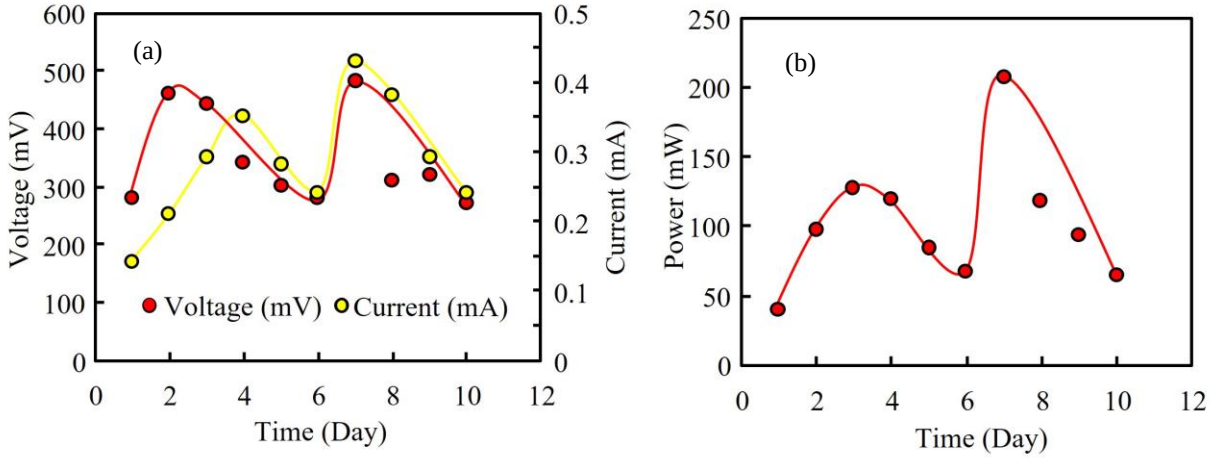


Fig. 6. Voltage, current, and power generation vs time (day) for glucose

From the power vs. time graph in Fig. 5 (b), it can be seen that in the first few days (Day 1 to Day 4), the power output increases, peaking on Day 4 with 1006.4 mW of power. After Day 4, the power output starts declining steadily, reaching below 200 mW by Day 12. The fuel cell undergoes a stabilization period in the first few days. Later, the performance degrades, likely due to the depletion of nutrients for the microorganisms or a decline in their activity. The power decreases over time (days) due to the depletion of nutrients in the MFC. This result indicates that the MFC can produce a significant amount of power for up to 6-7 days. The power output increased and peaked again due to increased microbial activity, as some of the organic waste broke down later compared to the initial peak. Using different waste substrates would vary both the power density and duration.

3.3 Daily Performance of Microbial Fuel Cell for Glucose Substrate

Fig. 6 (a) shows the variation of voltage and current with time (day) for 10 days in the MFC using glucose as substrate. In this case, artificial wastewater was utilized by adding 10 g/l of glucose to the water. The graph shows different trends compared to municipal wastewater. The voltage starts at 280 mV and the current at 0.14 mA on Day 1. The voltage increased fast and reached the first peak at 460 mV on Day 2. The first current peak is found on Day 4 at 0.35 mA. Both voltage and current decrease after reaching the first peak. After Day 6, the voltage and current increased again, reaching the second peak on Day 7. The voltage and current at the second peak were 480 mV and 0.43 mA, respectively. Later, both started to decrease again. Fig. 6 (b) shows the power curve for the MFC over 10 days. It touched the first peak on Day 3 at 127.6 mW and the second peak on Day 7 at 206.4 mW. Afterward, it began to decrease. The reason behind the increase in power is the improved microbial activity. Later, it drops due to the accumulation of metabolic byproducts and increased biofilm thickness. However, the power starts to rise again as the microbial community adapts to the new environment and breaks down the metabolic products of glucose.

4. Conclusion

Microbial fuel cells show promising results in generating electricity from wastewater. The experiment shows that the MFC produces high voltage, current, and power during initial stages, both on an daily and hourly basis. The maximum voltage output recorded was 1370 mV hourly and 700 mV daily. The overall peak power of 3014 mW was found on the first day at hour 7 due to the high concentration of nutrients in wastewater. Eventually, the power output reduced gradually as the nutrients available in the organic component were broken down by microbial bacteria. The research indicates that the MFC power output is heavily dependent on microbial activity and system conditions. The power output can be increased by replacing the wastewater with a new sample containing rich organic components, which would boost the microbial activity again so that higher voltage and power output can be achieved. Adding additives can also improve the power output. Microbial fuel cells have the potential to offer a new source of sustainable energy, especially in urban areas where large amounts of domestic and industrial waste are produced daily.

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