

Analysis of the Characteristic of a Dual Chamber Microbial Fuel Cell Based on Copper Wire Mesh

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ABSTRACT

Growing global energy demands and the environmental impacts of fossil fuels highlight the need for sustainable alternatives. Microbial Fuel Cells (MFCs) offer a promising technology by converting organic matter into electricity through microbial activity. This study investigates how electrode spacing influences the performance of a dual-chamber MFC using rice-washing wastewater as a renewable substrate. Copper plate and copper wire mesh electrodes, separated by a gel membrane, were assembled to evaluate system behavior at electrode distances of 1 cm, 3 cm, and 5 cm. Voltage, current, power, and power density were measured under various external loads to determine performance trends. The results show that an electrode spacing of 3 cm produced the highest output, with a maximum power of 207.5 mW, maximum voltage of 0.467 V, and an optimal power density of 0.001395 mW/mg. Although the 1 cm spacing enabled faster voltage stabilization, the overall efficiency was lower, while the 5 cm spacing resulted in reduced electrical output due to increased internal resistance. Peak power production occurred at an external resistance of 3 k Ω . These findings demonstrate that appropriate electrode spacing enhances ion and electron transport, improving MFC energy conversion efficiency. Overall, a 3 cm electrode distance provides the best balance of performance and stability, supporting its potential for small-scale, environmentally friendly energy generation using household organic waste.

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1. INTRODUCTION

The development of alternative energy technologies with minimal environmental impact has increased in response to the growing global demand for clean, sustainable energy. Microbial Fuel Cells (MFCs) convert chemical energy in organic matter directly into electricity through the metabolic activity of electrogenic microorganisms [1]-[7]. Organic wastes, such as rice-washing wastewater, are promising substrates because of their high starch and carbohydrate content, which promotes the growth of electroactive bacteria and enhances electron generation [8]-[13]. This approach provides a sustainable method for energy generation while valorizing household organic waste. Additionally, MFC's performance is strongly influenced by system configuration, with key factors including electrode spacing, which affects internal resistance, ion diffusion, and microbial interactions [14]-[16]. Recent studies have explored several factors that affect MFC performance, including membrane types [17], electrode materials, biofilm formation [18][19], and external resistance [20]. However, only a few studies have specifically addressed the optimal spacing of copper electrodes in dual-chamber MFCs using biodegradable substrates such as domestic rice washing water. Furthermore, despite the potential advantages in surface area and electron-collecting efficiency, the combination of flat copper plates with copper wire mesh remains poorly studied [21]-[23].

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MFCs are commonly constructed in either single-chamber or dual-chamber configurations. In single-chamber MFCs, both the anode and cathode are placed in the same compartment, often with air-exposed cathodes [24]-[27]. Although simple and economical, this design has limitations, including oxygen crossover to the anode, which disrupts microbial activity. In contrast, dual-chamber MFCs, as used in this study, feature separate anaerobic (anode) and aerobic (cathode) compartments separated by a membrane, enabling better environmental control and improved electrochemical efficiency [28]-[32]. This separation reduces oxygen diffusion to the anode, stabilizes microbial metabolism, and enables clearer analysis of design parameters, such as electrode spacing and membrane type.

In recent years, various biodegradable organic wastes have been explored as potential substrates for MFCs, including agricultural residues, food processing wastewater, and domestic greywater [33]-[37]. Among these, rice-washing wastewater stands out for its high starch and carbohydrate content, which provide an ideal nutrient source for electroactive bacteria [38][39]. This substrate is especially abundant in households across Asia and promotes robust microbial growth and electron production [40]. Utilizing such readily available waste not only improves the cost-effectiveness of MFCs but also contributes to environmental conservation through simultaneous waste treatment.

Several design and operational parameters influence MFC performance, including electrode material, membrane type, and, notably, electrode spacing [41]-[45]. Closer electrode spacing can reduce internal resistance and improve ion transport, but must be optimized to avoid limiting microbial activity or causing electrical short circuits. While carbon-based electrodes are common, copper electrodes offer high electrical conductivity and affordability. The combination of flat copper plates and copper wire mesh increases surface area and supports efficient biofilm development, although studies on their application remain limited [46]. Moreover, a recent study using aquaculture effluent demonstrated that electrode spacing significantly affects both voltage and current output, with 4 cm providing the optimal performance, reinforcing the critical role of spatial configuration in MFC design [47].

Despite the growing number of studies on MFCs, there is a lack of research on the impact of electrode spacing in dual-chamber MFCs using copper electrodes and biodegradable substrates, such as rice washing wastewater. Most existing studies emphasize carbon-based electrodes and single-chamber setups [14]. Furthermore, the integration of gel membranes as eco-friendly, low-cost separators has not been extensively studied. Therefore, this research aims to fill that gap by investigating the effect of different electrode spacings (1 cm, 3 cm, and 5 cm) using a copper electrode configuration (copper plate and wire mesh), rice washing wastewater as the substrate, and a gel membrane as the separator. The novelty of this study lies in its combined use of low-cost materials, a non-conventional copper electrode design, and an optimized spatial configuration, which provide insights into improving the energy efficiency and feasibility of MFCs for practical applications.

2. METHOD

This research adopts a quantitative experimental approach to evaluate the performance of a dual-chamber Microbial Fuel Cell (MFC) with electrode spacings of 1 cm, 3 cm, and 5 cm. The independent variable is electrode spacing dependent variables are voltage, current, power output, and volumetric power density. Controlled variables include temperature 28 °C, substrate volume, electrode materials, and chamber dimensions. The workflow is illustrated in Figure 1. The experimental workflow is illustrated in Figure 1.

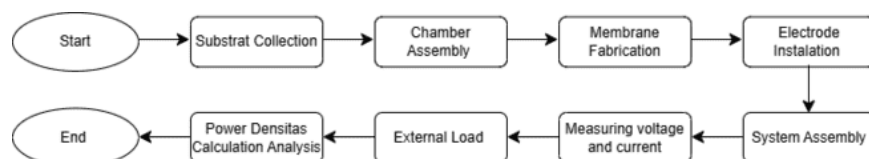
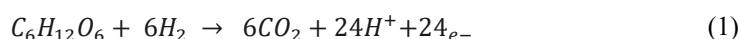


Figure 1. Research flowchart of the dual chamber MFCs experimental process

Electrochemical reactions in the MFC are represented as follows:

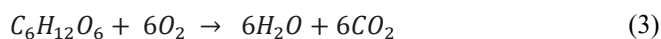
Anode,



Cathode,



Overall Reaction,



2.1 MFC Construction and Material

The experimental setup of the Microbial Fuel Cells (MFCs) used in this study is shown in [Figure 2](#). Electrical performance measurements, including voltage, current, and power, were conducted by varying the external resistance using a potentiometer, as illustrated in [Figure 3](#).

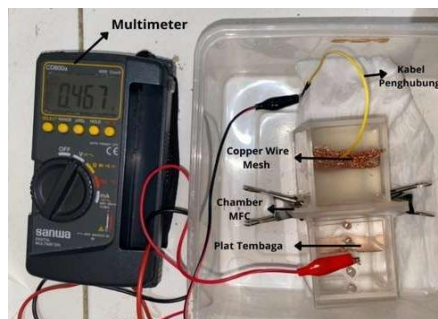


Figure 2. Set Up MFCs



Figure 3. Set up MFCs to measure Power, Voltage, and Current Using Potentiometer on MFCs

The MFC comprises two 125 cm³ acrylic chambers separated by an agar–NaCl gel membrane fabricated from 5 g agar and 1 g NaCl in 50 mL water [48][49]. The anode is copper wire mesh, and the cathode is a flat copper plate. This design aligns with previous studies demonstrating improved surface area and conductivity [50]-[52].

The general mechanism of a Microbial Fuel Cell (MFC) involves the oxidation of organic substrates by electroactive bacteria at the anode, releasing electrons and protons [53]-[60]. The electrons flow through an external circuit toward the cathode, while the protons migrate through a membrane separator. At the cathode, these electrons and protons react with oxygen to form water, thereby generating an electric current [61]. To measure the electrical output, instruments such as multimeters are used to monitor voltage and current, while a potentiometer acts as a variable external resistance to analyze power output under different loads. In addition, an oscilloscope is employed to visualize the waveform of the generated voltage. Although MFCs primarily produce a direct current (DC), slight fluctuations or noise may occur due to microbial activity and ion transport, which the oscilloscope can display in real time, providing insight into the stability and dynamic behavior of the system's electrical performance [62][63].

2.2 Substrate Preparation

Wastewater from domestic kitchens collected during rice washing was initially passed through a filter to remove suspended solids and impurities [40]. The filtrate pH was subsequently reduced to approximately 6.0 by adding dilute acid or an alkaline solution to ensure optimal microbial growth conditions [64]. The substrate was then maintained in an over-covered container at a consistent ambient temperature of about 28 °C

throughout the experiment. Due to its naturally high carbohydrate and organic matter content, rice-washing wastewater is a suitable fuel source that supports the development of electrogenic bacteria and the generation of electrons in the anode chamber [65][66].

2.3 Electroda and Membrane Installation

The electrode installation process used two types of copper-based materials as the anode and cathode [67]. A copper wire mesh was used as the anode, while a flat copper plate served as the cathode. To examine the effect of electrode spacing on the electrical performance of the MFC, the distance between the anode and cathode was carefully varied at 1 cm, 3 cm, and 5 cm across three different experimental setups.

A proton-conductive gel membrane, composed of agar and salt, was placed between the anode and cathode chambers [68]. This membrane acted as a semipermeable barrier, facilitating proton exchange while preventing substrate mixing between chambers [69]. The membrane was firmly secured in place within the channel connecting the two chambers, forming a sealed yet permeable interface. The design was based on membrane configurations used in prior dual-chamber MFC systems, ensuring compatibility with the electrochemical environment and supporting proton migration from the anode to the cathode compartment during microbial metabolism [70].

This installation strategy enabled an accurate assessment of how varying electrode distances affect internal resistance, ion transfer efficiency, and microbial interactions, all of which contribute to the system's overall power generation capabilities.

2.4 Experiment Design

Independent variable: variation of copper plate electrode distance with 1 cm, 3 cm, 5 cm

The dependent variable:

Mains voltage output

$$\text{Power} : P = V \times I \quad (4)$$

$$\text{Power Density} : \text{PowerDensity (mW/cm}^3\text{)} = \frac{\text{Power (W)}}{\text{Reaktor Volume(cm}^3\text{)}} \quad (5)$$

Volume

3. RESULTS AND DISCUSSION

The results indicate that a 3 cm electrode spacing provides the maximum power output in the dual-chamber MFC. This can be explained by the underlying electrochemical mechanisms: at the anode, microbes metabolize the organic matter in rice-washing wastewater, generating electrons and protons. Electrons flow through the external circuit to the cathode, while protons migrate through the gel membrane to the cathode, where oxygen reduction occurs. Electrode spacing affects internal resistance and ion transport efficiency a 1 cm spacing allows faster electron flow but may cause uneven substrate distribution, reducing overall power. Conversely, a 5 cm spacing increases internal resistance and slows proton transport, lowering electrical output. At 3 cm spacing, an optimal balance is achieved between ionic conductivity, electron flow, and substrate availability, resulting in maximum performance.

These observations are consistent with previous literature demonstrating that electrode spacing is a critical factor in optimizing mass transfer and energy conversion efficiency in MFCs [71] [72]. Understanding these electrochemical mechanisms supports the design of more efficient MFC systems for small-scale energy generation using household organic waste.

3.1 Electrical Testing & Data Acquisition

In the initial electrochemical evaluation, the dual-chamber MFC system was tested under open-circuit conditions to examine the spontaneous voltage and current generation in the absence of an external load. Using a precision digital multimeter, both voltage (V) and current (I) were recorded at one-minute intervals for a total duration of 15 minutes across three electrode spacing configurations: 1 cm, 3 cm, and 5 cm.

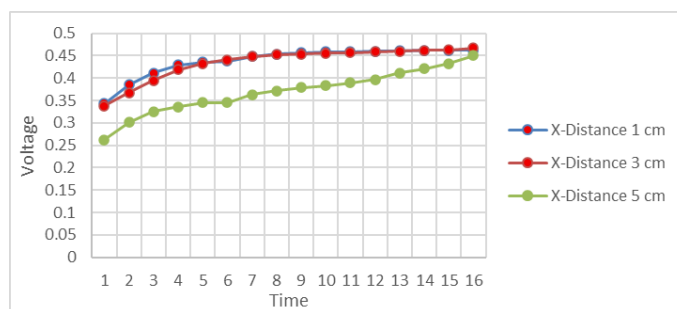


Figure 4. Voltage and Current Measurement

As summarized in Figure 4, the experimental results demonstrate that electrode spacing significantly influences voltage generation and the time required to achieve stability in dual-chamber microbial fuel cells (MFCs). A consistent trend was observed: decreasing the inter-electrode distance led to a more rapid and higher-voltage response. At a spacing of 5 cm, the voltage increased slowly, reaching only around 0.450 V by the 15th minute. This suggests that ion transfer between the electrodes is hindered due to the relatively greater distance, resulting in higher internal resistance and lower system efficiency. In contrast, at a 3 cm spacing, the voltage increased more rapidly and stabilized at approximately 0.467 V by the end of the observation period, indicating a more effective charge transfer and a better balance between internal resistance and microbial activity.

Interestingly, the 1 cm configuration yielded the highest and fastest voltage response, achieving stability as early as the 9th minute with a relatively stable voltage of 0.462 V. This behavior underscores the positive impact of reducing the electrode distance on minimizing ohmic losses and enhancing charge transfer within the MFC. The closer proximity between electrodes not only accelerates electrochemical reactions but also improves overall system performance. These findings are consistent with previous studies reporting that reducing the inter-electrode distance increases ionic conductivity, reduces voltage drop, and facilitates more efficient electron flow [52].

Moreover, the intermediate performance observed at 3 cm suggests a potential advantage, as moderate spacing may improve biofilm growth stability and provide an optimal balance for proton diffusion. Therefore, while closer electrode spacing generally enhances voltage generation and system responsiveness, selecting an appropriate distance, such as 3 cm, could also support long-term microbial activity and operational stability in MFC applications.

3.2 Power and Current Response under External Load

Once the highest-voltage point was determined, measurements continued using a potentiometer to vary the external load. The purpose of this test is to identify the optimal external resistance value that maximizes power output. The potentiometer does not act as a factor causing the change in current; rather, it is only a tool to simulate various load conditions.

The resistance value was gradually varied from 10 k Ω to 100 Ω . At each resistance value, voltage and current were recorded to calculate the power generated. The observed changes in current and voltage are the MFC system's response to load variations, not due to the direct influence of the potentiometer.

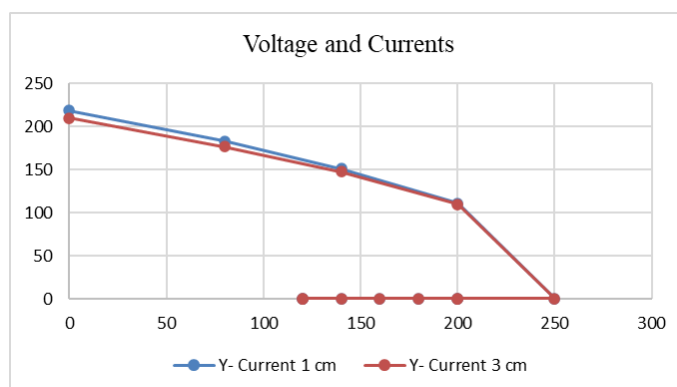


Figure 5. Voltage and Current Measurement

Figure 5 presents the relationship between resistance, voltage, current, and power output in the MFC system. At higher resistance levels (10 k Ω to 6 k Ω), both current and power output remain low and relatively

stable. As resistance decreases, current gradually increases, and a notable peak in power output of 207.5 mW is observed at 3 kΩ. Beyond this point, although the current continues to rise, the power declines due to voltage reduction. At the lowest resistance (100 Ω), the voltage drops to zero, resulting in no power generation. These results suggest that a balance between voltage and current is necessary to achieve optimal energy output in the system.

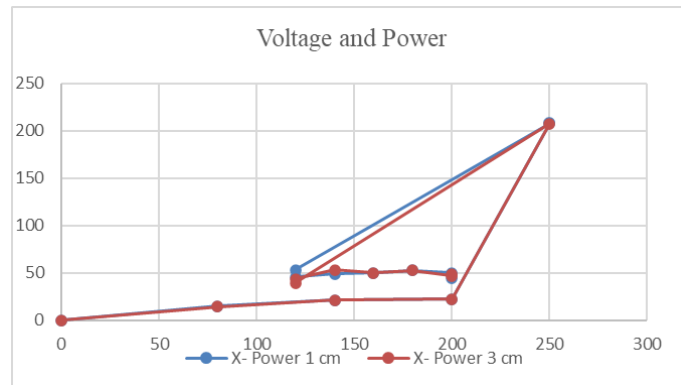


Figure 6. Voltage and Power Measurement

Based on the two sets of measurement data analyzed as shown in Figure 6, a clearer picture of how variations in resistance affect the voltage, current, and power generated by the system is obtained. Overall, changes in resistance directly affect the measured electrical output characteristics, although the relationship is nonlinear.

When the resistance is high, between 10 kΩ and 6 kΩ, the voltage tends to be high and fairly stable, while the current remains in the low microampere (μA) range. Even so, the power generated remains significant, ranging from 43 to 52 mW. This shows that the system is still capable of efficiently generating electrical energy, even at low current, provided the voltage is sufficient.

At distances of 1 and 3 cm, reducing the resistance to an intermediate value of about 3 kΩ simultaneously increased current and voltage. In this state, the maximum power is achieved at 207.5 mW, indicating that the resistance is the optimal operating point in this system. The combination of high voltage and increasing current creates ideal conditions for achieving maximum power. Thus, it can be concluded that in this system there is an optimal resistance value that produces the highest electrical power.

3.3 Power Density Measurement Analysis Results

Figure 7 shows the results of testing and calculating the power density of the Microbial Fuel Cell (MFC) with a reactor volume of 125 cm³ and using acrylic material which has a density of 1.18 g/cm³, so that the total mass of the reactor is 147.5 grams, several important findings related to the performance of microbial fuel cells were obtained [73].

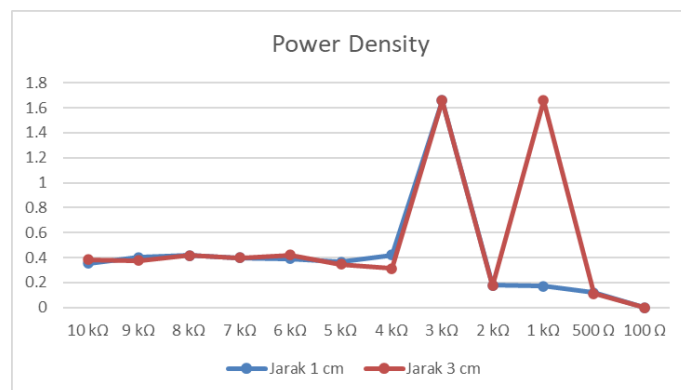


Figure 7. Power Density Calculation

Power density is calculated using two methods: per unit volume (mW/cm³) and per total reactor mass (mW/mg). The calculation results show the highest power density at an external resistance of 3 kΩ, with a

power of 0.2075 W, resulting in a power density of 0.16912 mW/cm³ and 0.001395 mW/mg. This value is the optimum point of the tested MFC system.

In general, an increase in electric current occurs as the external resistance decreases, but at a resistance below 3 k Ω , a decrease in resistance actually reduces power due to a significant decrease in voltage. This shows that there is an optimum resistance value that produces the highest power efficiency.

Thus, it can be concluded that external resistance greatly affects the performance of MFCs. Optimizing the resistance value is essential for achieving optimal performance. In addition, the power density calculation approach based on volume and mass provides a more comprehensive picture of efficiency, especially for small-scale designs and applications.

4. CONCLUSION AND LIMITATION

Electrode spacing strongly affects the performance of dual-chamber MFCs. A 3 cm spacing gave the highest voltage (0.467 V), maximum power (207.5 mW), and optimal power density. Shorter spacing (1 cm) stabilized voltage faster but with lower efficiency, while larger spacing (5 cm) reduced output. Therefore, 3 cm spacing with copper electrodes and a gel membrane is recommended for efficient small-scale energy generation from rice-washing wastewater.

The maximum power output of 207.5 mW (1.66 mW/cm³) was observed under optimal conditions, while other ranges (44–52 mW or 0.3456–0.4224 mW/cm³) remained stable. Although current increased in some cases, power decreased, indicating that energy efficiency depends not only on current magnitude but also on maintaining adequate voltage.

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