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INVESTIGATION OF PERFORMANCE OF A DUAL-CHAMBER MICROBIAL FUEL CELL AT VARYING pH

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Abstract

One of the recent talked-about issues is zero-carbon emission for ensuring sustainable development. Microbial fuel cell (MFC), a bioelectrochemical process, has attracted much attention due to its potential to be an alternative renewable energy source that can reduce carbon dioxide and methane emission as well. An additional benefit of MFC is that it is aptly capable of treating wastewater. Moreover, this technology is considered to be cheaper and poses no negative impact on environment. In this research a dual-chamber microbial fuel cell was constructed using low-cost and locally available materials. The designed dimension of each chamber was 30.5 cm × 20 cm × 20 cm where working volume was set as 5 L due to ease of handling. The MFC was operated using cow dung substrates, which were collected from the nearby village of Jashore University of Science and Technology campus. The wastewater used in this research was collected from the drain of the same campus (23.23424°N, 89.12609°E). Each set of experiment was conducted for two weeks (14 days) at a stretch. Considering bioelectricity production by the MFC, cow dung was found to be effective. Maximum power (0.8 mW) was produced in a single day during the experiment at a substrate concentration of 25 g/L. The cow dung along with the collected wastewater was investigated to find the effect of factors such as pH. Experiments were performed at varying pH (7, 8 and 10) at room temperature for 14 days. The maximum extent of current density (270 mA/m^2), power density (167 mW/m^2), and voltage (881 mV) were found at pH 8 by using drainage wastewater as a feedstock in combination with cow dung from the microbial fuel cell. The treatment of wastewater using the MFC demonstrated varied efficacy, achieving COD removal rates of 88.3% at pH 7, 90.2% at pH 8, and 84.4% at pH 10. The results highlight the MFC's potential as a dual-purpose technology for effective pollutant removal and bioelectricity generation, particularly at an optimal pH of 8. These findings underscore the MFC's potential for dual-use in pollutant removal and energy generation, contributing to energy security.

Keywords: Bioelectricity, Cow dung, Microbial fuel cell, Wastewater, Substrate

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1. Introduction

Valorization of wastewater as well as waste materials for bioelectricity generation through treatment has attracted attention of the scientific community in recent years. Microbial fuel cell (MFC), one of the widely studied technologies, has been recognized as a promising and challenging technology for producing electrical energy and at the same time for the treatment of wastewater (Delord et al., 2017; He et al., 2017). MFC uses living microbes (e.g., bacteria) as a bio-electrocatalyst and involved in redox reaction of natural substrates. It has the potential to cut down the energy consumption of wastewater treatment process and to recover the bioenergy contained in various types of wastewaters (Trapero et al., 2017). In microbial fuel cell operations, substrate is considered as one of the important biological factors that affect bioenergy production. Unlike the conventional biological processes for wastewater treatment, microbial fuel cell has a complex design because of two different redox reactions (e.g., anodic oxidation and cathodic reduction) at distinct locations (Mohanakrishna et al., 2012). Performances of MFC depends on several factors which include but not limited to the ingredients of anode and cathode, space between electrodes, interactions between the bacteria and the electrode material, external resistance, pH of the substrate, substrate concentration, environmental temperature (Oyiwona et al., 2018). Although, in recent years, research on wastewater treatment using microbial fuel cell is gradually increasing, but these research works are still in the laboratory research stage and there is much scope to improve the whole MFC system.

Microbial fuel cell is considered to be a new green energy technology integrating sewage processing and bioelectricity generation (Logan, 2009). The MFC degrades organic matters with microorganisms (e.g.,

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bacteria) and transforms chemical energy into electricity (Lovley, 2006). A typical microbial fuel cell principally consists of two separate chambers (anode chamber and cathode chamber) connected through a permeable ion exchange membrane. Electrode, electrolyte, and the membrane are the three most vital key components of microbial fuel cell. As a substrate, wastewaters can be treated in the anodic chamber and at the same time bioelectricity will be generated (Aghababaie et al., 2015). Different types of organic wastewaters are generally used as electrolytes (Halim et al., 2021). MFC can be inoculated by pure or mixed culture of bacteria. Diverse sources of bacteria (wastewater, sediments, activated sludge etc.) have been reported to be applied in the literature (Aghababaie et al., 2015).

Although the microbial fuel cell has been proven to be an emerging research field, there are still gaps and scopes for its development, which include but not limited to modification of design, ease of construction, minimization of cost, and optimization of operational pH. To the best of the authors' knowledge, no study has been performed on MFC operation using drain water of the campus of Jashore University of Science and Technology. In this study, drain water from the campus of Jashore University of Science and Technology was used as substrate along with cow dung. Even though there are numerous drain water sources available, the drain water of the university campus was selected for this study to simulate real-world scenarios typical of urban wastewater, which aligns with the aim of developing low-cost, scalable microbial fuel cell (MFC) techniques. The intent was to highlight the campus wastewater streams, which is often underutilized in energy recovery efforts. Therefore, this work focuses on construction of a dual-chamber microbial fuel cell with low cost and its operation at different substrate pH levels. The influence of substrate pH on voltage, electricity and power generation was investigated.

2. Materials and Methods

2.1 Construction of MFC

A dual-chamber MFC was constructed using the materials purchased from local markets. The anode and cathode chambers were constructed using glass sheets. The volume of both chambers was identical, which was 0.005 m^3. Two chambers were connected by a small PVC pipe filled with an agar salt bridge (prepared by soaking surgical cloths in 0.1M agar solution). The anode was made from thin zinc plate with a surface area of 15 cm × 3 cm (length × width), providing a total area of 0.0045 m^2. The cathode was constructed from thin copper plate of identical dimensions (10 cm × 5 cm). Electrodes were scrabbed with sandpaper and thoroughly cleaned prior to use. Both anode and cathode were placed vertically in the anode and cathode chamber, respectively. It was ensured that there is no leakage in the chamber. The anode chamber and the cathode chamber were filled with collected drain water and tap water, respectively. Beforehand, the drain water was cultured/inoculated using cow dung and sugar. The experimental set up is depicted in Fig. 1.

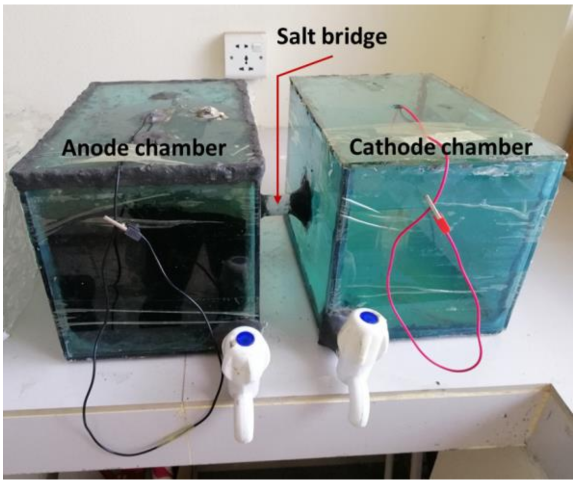

Fig. 1 Bench-top experimental set up of MFC.

2.2 Substrate preparation and experimentation

Drain water with sludge from the campus of Jashore University of Science and Technology was collected for carrying out the experiment. This water (5 L) was cultured for growth of microorganism in it. The process of culture was accomplished by mixing cow dung (100 g) and sugar (50 g) with collected drain water. Cow dung was collected from a nearby village of the university. Sugar was purchased from the local market. The mixture was kept in an aerobic condition for 48 h for culture/inoculation. After that time, the mixture was poured into the anode chamber. The operating pH was adjusted by adding small amounts of HCl or NaOH. On the other hand, the cathode chamber was filled with tap water. The ends of the electrodes were connected to a digital multimeter to measure the current and voltage produced by the microbial activity inside the MFC.

2.3. Data collection and analytics

From the setup, current (I (Amp) and voltage (V (volt) were measured on a daily basis. These measurements provided the raw data required for analyzing the performance of the system over time. Based on the recorded current and voltage values, several key performance parameters such as, power (P (watt), current density (C_{den} (mA/m^2)), power density (P_{den} (mW/m^2) etc. were determined using the following equations (Eq. 1-3). These calculated parameters were plotted against time to observe trends and analyze the performance of the MFC over the course of the experiment. This approach allowed to assess the efficiency and stability of the microbial fuel cell in terms of energy generation under the stated conditions.

$$P = V \cdot I \quad (1)$$

$$P_{den} = P/A \quad (2)$$

$$C_{den} = I/A \quad (3)$$

3. Results and Discussion

3.1. Effect of pH on voltage generation in MFC

The effect of pH on voltage generation in a double chamber microbial fuel cell (MFC) was investigated. At pH higher than 9, the microbial activity declines, leading to reduced performance of a microbial fuel cell (Banarjee et al., 2023). Typically, a pH range between 6.5 and 8.0 is considered the most suitable for the operation of MFCs using substrates. However, the exact optimal pH can vary depending on factors such as microbial activity, electrochemical reactions, substrate degradation, and electrode stability. Therefore, conducting thorough experiments to evaluate MFC performance across different pH levels is essential.

The used substrate was cow dung and wastewater, which were collected from the nearby village and from the drain in the university campus, respectively. The variation of voltage at different pH of the substrate was recorded on a daily basis and the result is depicted in Fig. 2. The pattern of the plot exhibited that the pH of the substrate influenced the voltage produced. It is obvious from the figure that the voltage increased for first few days in case of pH 8 and pH 10. The maximum voltage was recorded to be 875 mV in day 3. Thereafter the voltage started to decrease and gradually decreased for the rest of investigation time. For pH 7 the maximum voltage did not reach even 800 mV. The obtained maximum extent of the voltage is much better than other studies reported in the literature. Harshitha et al. (2019) fabricated a two-chambered microbial fuel cell (a laboratory scale two separate plastic containers of 4 L capacity each) and obtained a maximum voltage of 230 mV for a MFC operated with cow dung and municipal sludge with drain water.

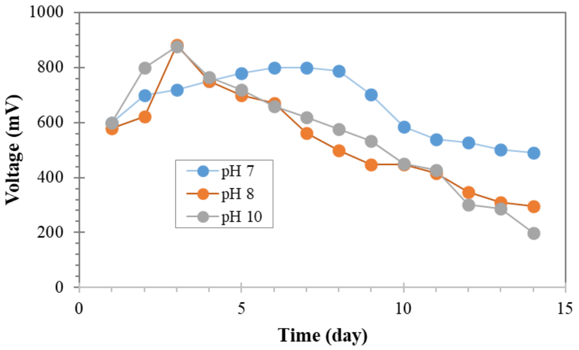

Fig. 2 Effect of pH on voltage generation in dual-chamber MFC.

3.2. Effect of pH on current density in MFC

The effect of current density at varying pH was studied over a time period of 14 days in this research. The results are shown in Fig. 3 from where it is evident that the extent of current density increases in first few days of the operation at all studied pH. The highest current density was measured to be 270 mA/m^2 for pH 8 at day 2. After reaching the peak value the extent of current density gradually decreases throughout the experiment. These findings suggest that the pH level is a critical factor influencing the performance of the MFC, as it significantly impacts the microbial activity and, consequently, the current density. The observed trends underscore the importance of optimizing the pH to achieve maximum efficiency in MFC operations.

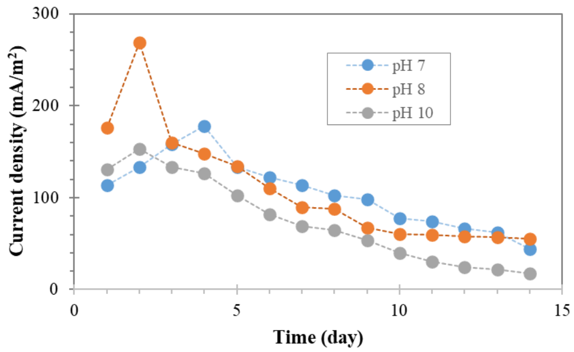

Fig. 3 Effect of pH on current density in dual-chamber MFC filled with cow dung and wastewater.

3.3. Effect of pH on power density in microbial fuel cell

This study investigated the impact of pH on power density in a double-chamber Microbial Fuel Cell (MFC) using cow dung and drain water as substrates. Over a period of 14 days, power generated by the MFC was recorded daily and plotted to observe trends in power density at different pH levels. As illustrated in Fig. 4, there was a noticeable increase in power density during the initial days of the experiment across all studied pH levels. Specifically, the highest power densities for pH 8 and pH 10 were recorded on the second day, while the peak power density for pH 7 occurred on the fourth day.

After reaching these maximum values, the power density gradually decreased over the rest of the experimental period. The highest recorded power density was 167 mW/m^2 at pH 8, indicating that this pH level is optimal for the MFC's performance. The observed trends suggest that the pH significantly influences the electrochemical activity and microbial interactions within the MFC, affecting its power generation capability. This study highlights the importance of adjusting pH conditions to enhance the efficiency and effectiveness of MFCs in practical applications, particularly for sustainable energy production and wastewater treatment.

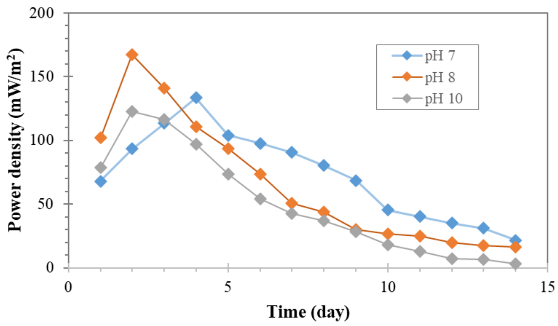

Fig. 4 Effect of pH on generated power density in dual-chamber MFC.

3.4. *Effect of pH on cumulative power density in microbial fuel cell*

In this study, the effect of pH on the cumulative power density of a microbial fuel cell (MFC) was studied over a 14-day period. The cumulative power density, which represents the total power output over time, was recorded for different pH levels and plotted in Fig. 5. The results indicated an obvious difference in performance based on the pH of the substrates.

Specifically, the substrate maintained at pH 10 exhibited the lowest cumulative power density compared to those at pH 7 and pH 8. This lower performance at higher pH levels suggests that microbial activity and electrochemical processes were less efficient under these conditions. Furthermore, after day 10, the cumulative power density at pH 10 showed minimal increase, indicating a stabilization or decline in system efficiency.

In contrast, the substrates operated at pH 7 and pH 8 displayed comparable acclimatization periods, with pH 8 showing superior performance up until day 8. During this initial phase, the substrate at pH 8 achieved higher power density, reflecting optimal conditions for microbial metabolism and energy generation. However, after day 8, the substrate at pH 7 exhibited a slight improvement in cumulative power density, suggesting that it may have provided more stable long-term conditions for sustained power output.

These observations highlight the essential role of pH in shaping the performance and efficiency of MFCs. By optimizing pH levels, cumulative power density can be increased, which in turn boosts both energy generation and the wastewater treatment effectiveness of MFC systems.

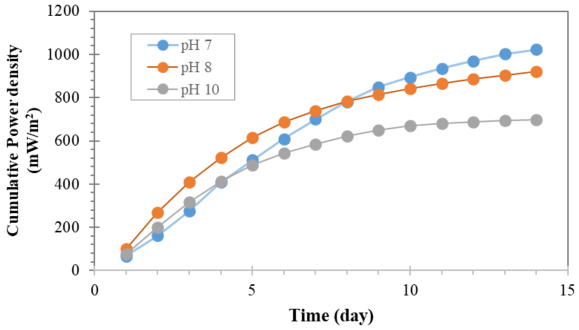

Fig. 5 Effect of pH on cumulative power density over the time period in dual-chamber MFC.

3.5. *COD removal from the collected drain water*

Chemical Oxygen Demand (COD) is a critical parameter that measures the amount of organic pollutants in water, indicating the potential environmental impact of the effluent. The wastewater collected from the campus drain, with an initial COD of 418 mg/L, underwent treatment in a Microbial Fuel Cell (MFC). This treatment aimed to both generate bioelectricity and treat the wastewater. The treatment's efficacy varied with pH levels: achieving 88.3% COD removal at pH 7, 90.2% at pH 8, and 84.4% at pH 10 (as shown in Fig. 6). These results indicate that the MFC treatment was most effective at pH 8, showcasing its potential as a dual-purpose technology for enhanced pollutant removal and energy production, underscoring its potential for scalable environmental applications.

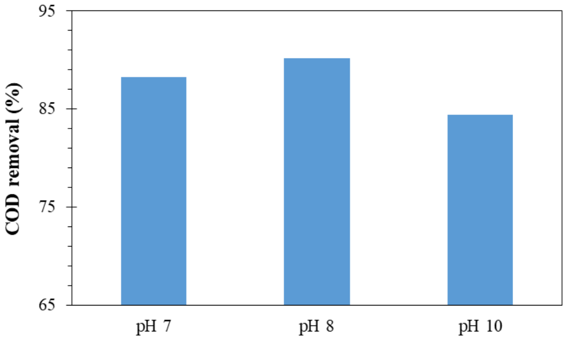

Fig. 6 COD removal at different operational pH in the MFC.

4. Conclusion

In this study, a bench-top dual-chamber microbial fuel cell (MFC) was constructed using locally sourced materials provided valuable insights into its potential for both bioelectricity generation and wastewater treatment. The use of cow dung and wastewater substrates demonstrated significant power generation (in the form of voltage, current density, and power density) from drain water in batch mode was found feasible. Experiments were performed at different pH (e.g., 7, 8, 10) at room temperature for 14 days at a stretch. The electrolyte pH had a great influence on the electricity harvesting, with optimal performance observed around pH 8. At this pH the maximum extent of voltage (881 mV), current density (270 mA/m^2), and power density (167 mW/m^2) were achieved. This study also highlighted the MFC's efficiency in reducing Chemical Oxygen Demand (COD), achieving a maximum COD removal of 90.2% at pH 8. The results underscore the MFC's promise as an effective, scalable solution for sustainable energy production and environmental remediation, provided that further optimization and studies on long-term stability are conducted.

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