The Application of Cows Rumen for Electricity Generation Through The Implementation of A Ceramic-Based Microbial Fuel Cell System

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ABSTRACT

The growth in population is not adequately matched by the corresponding increase in energy demand. The imperative for prioritizing the exploration of alternative energy sources that possess attributes of safety, affordability, and ample access to raw materials cannot be overstated. An energy source with significant potential is a microbial fuel cell (MFC)-based energy source. This study aims to investigate the utilization of cow rumen as a substrate and source of nutrition in the bioenergy system of microbial fuel cells (MFCs). The present study aims to investigate the impact of substrate concentration and bacterial incubation duration derived from bovine rumen bacteria on the attainment of optimal power density. The research employed a Dual Chamber Microbial Fuel Cell (MFC) device using a Proton Exchange Membrane (PEM) constructed from ceramic materials. Daily observations were conducted over a period of 30 days. The performance of MFC was assessed utilizing the polarization technique. The findings indicated that altering the proportion of bovine rumen bacterial substrates and the duration of bacterial incubation had an impact on the power density seen in the Microbial Fuel Cell (MFC) system. The optimal conditions were attained when the substrate concentration reached 3640 ppm and after 7 days, resulting in a maximum power density of 864 mW/m^2.

Keywords: MFC, cow rumen, PEM, ceramic, power density.

INTRODUCTION

Finding appropriate and sustainable sources of organic matter to feed electricity-producing microorganisms is a fascinating problem in the development of microbial fuel cells (MFCs) (Liu et al., 2022), (Logan, 2009). The plant matter that is partially digested in a cow's stomach, known as bovine rumen, is a plentiful and renewable waste that can be utilized as a substrate for MFC (Thulasinathan et al., 2022). Numerous proteins, carbohydrates, and lipids can be broken down by different bacteria and archaea in the cow rumen (Mizrahi et al., 2021), (Li et al., 2020). These microbes' metabolic processes can result in the production of electrons, which can then be transmitted to electrodes and converted into electric current (Logan et al., 2019). In this approach, cow rumen can be utilized as a great resource for the creation of eco-friendly electricity.

More than 200 huge animals are murdered in a large slaughterhouse every single day, and around 40,000 animals are slaughtered every single year (Jothinathan et al., 2018). This results in a waste production of between 6 and 7 tonnes per day. Microbial fuel cells are an option that can be utilised in order to transform this waste into energy in an effective manner.

The cow's rumen possesses a distinct advantage as a substrate in microbial fuel cells due to its capacity to generate electrical energy via an anaerobic fermentation process facilitated by microorganisms (Besharati et al., 2022). This characteristic sets it apart from alternative substrates. Furthermore, it should be noted that the rumen of cows harbors a diverse array of microorganisms which have the potential to convert organic compounds into more compact sensing materials (Nagaraja, 2016; Newbold & Ramos-Morales, 2020). This process has the ability to enhance the efficiency of energy generation in microbial fuel cells.

Besharati states that the production power of cow rumen microorganisms was assessed at different times. These microorganisms can be used as a bacterial population in the anode section of a microbial fuel cell with graphite anode to create power (Besharati et al., 2023). The performance of the microbial fuel cell and in vitro gas production were also contrasted in the study. As the incubation time progressed, the alfalfa hay produced the least amount of gas in comparison to the other treatments, according to the results. Alfalfa exhibited a higher power output voltage during 2–24 hours of incubation than the other treatments. However, in comparison to other treatments, soybean meal demonstrated higher levels in the subsequent incubation hours (24 to 120 hours).

The utilization of cow rumen as a substrate for microbial fuel cells (MFCs) is not the sole option available (Bretschger et al., 2010), (Thulasinathan et al., 2022). Microbial fuel cells (MFCs) are electrochemical devices that harness the metabolic activities of microbes to facilitate the conversion of organic materials into electrical energy (Mahmoud et al., 2022). Additional potential substrates encompass food waste, sewage sludge, animal manure, and agricultural wastes. The aforementioned wastes possess a substantial quantity of organic components that are susceptible to decomposition by various strains of bacteria and archaea (Soni & Devi, 2022). The release of electrons by microorganisms is a consequence of their metabolic processes, and these electrons can be harnessed by an electrode to generate electrical current (Zhao et al., 2021). By utilizing these waste materials as substrates, microbial fuel cells (MFCs) have the potential to generate sustainable and environmentally friendly electricity while simultaneously mitigating the adverse effects of pollution on the environment (Slate et al., 2019).

The rumen is an essential component for the successful implementation of microbial fuel cells. Because of its one-of-a-kind microbial community and fermentation processes, it is able to convert organic materials into electrical energy in an effective manner. In addition, the capacity of the rumen to support a wide variety of microorganisms contributes to an improvement in the overall efficiency and stability of microbial fuel cells. The researchers are encouraged by how far they have gone in the past two years, and they are continuing their efforts to enhance the amount of power that these microbial fuel cells are capable of producing. Despite the fact that the technology is still in its infancy, the researchers have made significant progress. The researchers believe that microbial fuel cells have the potential to transform renewable energy sources in the future if additional breakthroughs are made in the technology (Logan et al., 2006). They are also investigating a variety of various tactics with the goal of increasing the commercial viability of these cells and improving their overall efficiency.

The results of this study provide an overview of the energy generation that is carried out by earthenware ceramic-based MFC rumen microorganisms. The parameters of rumen concentration, which serve as a supply of substrate and bacteria, as well as the length of incubation, were investigated for their influence on power density.

METHODS

Preparation of Dual Chamber Microbial Fuel Cell

The design of the Dual Chamber Microbial Fuel Cell used consists of anode and cathode chambers separated by an earthenware membrane as shown in Figure 1. In the cathode chamber with a Carbon Veil thickness of 1 cm which has been divided into 2 sides and placed on the inside of the earthenware membrane wall. One side of the cathode Carbon Veil sheath is smeared with a mixture of 80 grams of activated carbon powder and 60 grams of PTFE, while the other side is only coated with PTFE. The activated carbon layer is positioned attached to the earthenware membrane wall. The earthenware membrane used has a thickness of 0.5 cm and an outer diameter of 8 cm which functions as a separator for the anode and cathode spaces. The anode chamber will contain active paddy sludge from rice plants and substrate solution according to the specified variation. The chamber is composed of a Carbon Veil sized to fit the outer wall of the earthenware membrane and NiChrome wire stuck to the inside of the anode electrode. The NiChrome wire has a function as a connecting medium for electrodes between spaces (anode and cathode) with a digital multimeter so that the voltage and electric current values are known and the optimum power density value can be calculated.

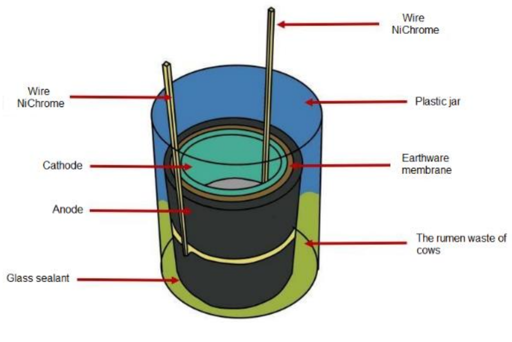

Figure 1. Design of a Dual Chamber Microbial Fuel Cell

Preparation of Substrates from Sediment and Cow Rumen Waste

The primary components of the Microbial Fuel Cell (MFC) system consist of substrate and sediment. The research utilised cow rumen waste as the substrate, and rice field mud obtained from the researcher's hamlet of Sumber Ketempa, Kalisat, served as the sediment. The research sample comprised of one control sample and six experimental samples, each with a volume of 200 mL and varying concentrations. Each of these concentration variations consists of three samples. Subsequently, the Total Dissolved

Solids (TDS) are quantified in every sample as a means of ascertaining the concentration of solid substances present in the sample under examination.

Acquisition and polarization methods

A Sanwa PC5000a data acquisition unit is used to monitor the voltage output in relation to the passing of time. Every minute, a record is made of the measurements. The software version Microsoft Excel 2019 was used to do processing and analysis on the recorded raw data. The polarization scanning was done by hand, and the values of the resistive load varied from 2,000 ohms all the way down to 10 ohms (Mulyono, 2020). The connection between each resistor is maintained for a period of five minutes.

RESULTS AND DISCUSSION

The rumen, the first chamber of the ruminant stomach, contains a rich microbial community that can degrade plant biomass and produce volatile fatty acids. These acids can be used as a catolyte or substrate for microbial fuel cells, which convert chemical energy into electrical energy. Several studies have investigated the power density that can be achieved using rumen fluid as a catolyte in different types of microbial fuel cells. Yashiro et al have studied the erformance of MFC using rumen with a power density of 600 mW/m^2 (Yashiro et al., 2023). Followed by Call et al, the power density produced by MFC is 24 W/m^2 (Call et al., 2009). Rismani et al produced a power density of 55 mW/m^2 (Rismani-Yazdi et al., 2007). The three researchers used MFC and did not use ceramic membranes. So the resulting MFC performance is less than optimal.

The power density value produced in the microbial fuel cell (MFC) is influenced by various factors, such as the type and concentration of substrate, the pH and temperature of the anode chamber, and the incubation time of the inoculum. In this study, we investigated the influence of incubation time for cow rumen bacteria as the inoculum on the power density value of the MFC. We used a dual-chamber MFC with a graphite electrode and a cation exchange membrane. We incubated the cow rumen bacteria for different periods of time (0, 1, 2, 4, and 4 weeks) in a medium containing glucose as the carbon source. We measured the power density value of the MFC every week using a polarization method. The results showed that the power density value increased with the incubation time of the inoculum, reaching a maximum of 910 mW/m2 at 1 weeks of incubation. This indicates that the longer incubation time enhanced the growth and activity of the electrogenic bacteria in the cow rumen inoculum, which improved the electron transfer and power generation in the MFC. The results suggest that incubation time is an important factor to consider when using cow rumen bacteria as the inoculum for MFCs.

Figure 2. Depicts a graph illustrating the relationship between power density and time (day), where the data points represent the average measurements recorded during a given day. The power density value exhibits temporal variability as the duration of time (measured in days) increases. The association between control (0 ppm) and rumen content, as measured in total dissolved solids (TDS), is shown graphically in the following graph. The power density generated by MFC in the presence of a substrate, such as rumen, is, on average, significantly more than that generated by MFC in the absence of a substrate. This leads one to believe that the contents of the rumen provide the MFC with a useful supply of energy, which in turn considerably improves its capacity to generate power. Because of the large variation in power density, it is essential for MFC systems to make use of substrates in order to make the most of their efficiency and the number of applications to which they are potentially applicable.

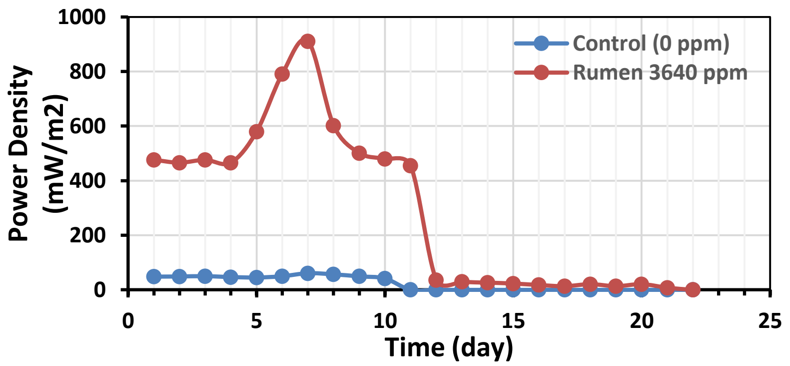

Figure 2. Time profile of bacterial incubation in the ceramic microbial fuel cell

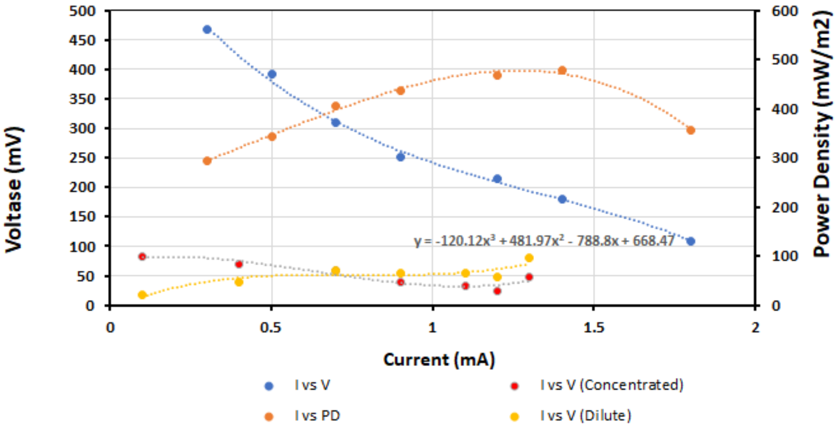

Figure 3. Difference in performance of MFC with concentrated cow rumen and diluted cow rumen

The aforementioned profile provides insights into the most favorable duration for bacterial incubation in ceramic microbial fuel cells, specifically on the seventh day. In contrast, the microbial fuel cell designated as the 'control' did not exhibit a discernible augmentation. This observation implies that the ceramic microbial fuel cells offer a conducive setting for bacterial proliferation and the generation of energy. Additional investigation may be warranted to explore the precise elements within the ceramic material that facilitate bacterial activity, hence enhancing the efficacy of microbial fuel cells.

Furthermore, the collection of power density data for each specific substrate concentration variation also exhibits distinct characteristics. According to the data presented in Figure 1, the graph illustrates the relationship between dilution variations and total dissolved solids (TDS) values. The orange line represents a dilution factor of 0 (no dilution), resulting in a TDS value of 3640 ppm. Meanwhile, the blue line shows the control media, which has a TDS value of 0 ppm because there is no addition of rumen solution.

The effect that the concentration of the substrate has on the power density produced by microbial fuel cells. When it comes to microbial fuel cells, the concentration of the substrate plays an essential part in the calculation of the power density. When there is a higher concentration of the substrate, there is also an increase in the activity and metabolic rates of the microbes, which results in a greater amount of electron transfer and power generation. However, after a certain threshold, an excessive concentration of substrate can cause substrate inhibition, which in turn results in a decreased power density. Therefore, determining the appropriate concentration of the substrate is vital if one wishes to achieve maximum power output from microbial fuel cells.

Performance measurement of ceramic microbial fuel cells

The utilization of the polarization approach proves to be highly advantageous in the determination of power density within microbial fuel cells. The procedure entails the quantification of voltage and current produced by the microbial fuel cells, which are subsequently utilized to determine the power production (Mulyono et al., 2022). Furthermore, the utilization of polarization analysis enables researchers to get insights into the constraints on performance and enhance the configuration of these cells to achieve optimal efficiency.

The Figure 3. Generated through the use of the polarization technique demonstrates a significant correlation between the introduction of cow rumen and the power density observed in microbial fuel cells. This finding implies that the presence of cow rumen greatly improves the efficacy of microbial fuel cells in electricity generation. Moreover, the graph illustrates a favorable link between the quantity of cow rumen administered and the corresponding rise in power density, hence emphasizing the potential to enhance this approach for enhanced energy generation.

CONCLUSIONS

The power density value is influenced by fluctuations in substrate concentration. As the concentration of the substrate increases, there is a corresponding increase in the power value, leading to a greater density. The research findings indicate that the highest power density value was achieved when utilizing a substrate concentration of 3640 ppm of cow rumen waste bacteria. The duration of incubation period for bacteria has a direct impact on the outcomes of the power density value. The power density value exhibits temporal variability as the duration of time (measured in days) increases. This phenomenon occurs due to the fact that bacteria undergo four distinct growth phases within a specific timeframe. The maximum power density value attained on the seventh day was recorded as 864 mW/m^2.

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