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# Evaluation of Glucose-Infused Ceramic Separators in Microbial Fuel Cells

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## Abstract

Recently, global energy demand has been increasing. Most of the energy is produced from fossil fuels. Since fossil fuels are finite and produce greenhouse gases during energy creation, alternatives are needed. Microbial fuel cells (MFCs) are a promising source of renewable energy. These cells utilize ceramic separators, and enhancing the performance of these separators is crucial for increasing the power output of MFCs. In this experiment, ceramic separators were fabricated with varying volumes of glucose. During the firing process, the glucose dissolves, resulting in separators with porous properties. The performance of MFCs with these glucose-infused separators was evaluated. The results showed that ceramic separators mixed with glucose had significantly more small holes in their surface compared to those without glucose. This increased porosity enhances proton transport, thereby improving the performance of the separator. Consequently, MFCs using these separators demonstrated higher power output, with the cathode performing better as the glucose content in the separator increased. This indicates that glucose-infused ceramic separators are effective in improving MFC performance.



***Keywords***

*MFC; Ceramic separators; Glucose; Bokuju; Proton*

## 1. Introduction

Currently, there is a growing global demand for energy, with most of it being produced from fossil fuels. However, fossil fuels have significant drawbacks, such as greenhouse gas emissions and resource scarcity, making their continued use problematic. Therefore, alternative energy production methods are urgently needed. (Muhammad et al., 2021) This is why renewable energy has garnered so much attention in recent years. Renewable energy harnesses power from sources that are constantly available in nature, such as sunlight, wind, and geothermal energy, which can be used indefinitely without depletion. One promising renewable energy source is the microbial fuel cell (MFC), which generates power through the activity of microorganisms and is gaining attention as a new sustainable energy solution. (Kurniawan et al., 2022; Rojas-Flores et al., 2022)

Microorganisms that release electrons when decomposing organic matter, known as electron-producing bacteria, are abundant in nature. Microbial fuel cells (MFCs) harness the electrons released by these bacteria. (Boas et al., 2022) The principle of MFCs is as follows: When electron-producing bacteria break down organic matter, they produce electrons and protons. The electrons are captured at the anode electrode of the MFC and move through an external circuit to the cathode electrode. Meanwhile, the protons travel through the electrolyte to the cathode electrode. At the cathode, the reaction between electrons, protons, and oxygen produces water. This is the fundamental mechanism by which MFCs operate. (Soichiro et al., 2023)

Separators are often used in microbial fuel cells (MFCs) to ensure stable power generation. Among these, ceramic separators made from natural sources are gaining attention. However, MFCs using ceramic separators typically have low output, necessitating further improvements for practical electricity generation. This has led to various studies on enhancing ceramic separators. (Anina, 2022, Gowthami et al., 2023) One such separator is created by mixing starch with clay, the primary material used in ceramic separators. During the firing process, the starch burns off, resulting in a more porous structure that improves proton exchange. This enhanced porosity is crucial for increasing the efficiency and output of MFCs utilizing ceramic separators. (Siti et al., 2020)

Glucose is an inexpensive and readily available substance. When mixed with clay and fired, the glucose dissolves, resulting in a ceramic separator with a porous structure. In this experiment, ceramic separators were created by combining glucose with clay, and their performance in microbial fuel cells (MFCs) was evaluated. The results demonstrated that the inclusion of glucose improved the separator's performance, enhancing the overall efficiency of the MFCs.

## 2. Materials and Methods

### 2.1. Preparation of ceramic separators

Clay (purchased from Art Publishing Educational Inc., Tokyo, Japan) was used in the ceramic separator for this experiment. D-glucose (Sigma-Aldrich Japan G.K., Tokyo, Japan) was also used as a fine powder in a mortar. Glucose was mixed with 30 g of clay to form sheets measuring 20 x 20 x 2 mm. The glucose was added in varying volume ratios of 0%, 10%, 20%, and 30% (as shown in Table 1). The sheets were then baked at 900°C for 3 h.

Table 1: Separator preparation (Source: the authors)

| **Materials** | **0%** | **10%** | **20%** | **30%** |
|---|---|---|---|---|
| Clay | 30g | 30g | 30g | 30g |
| Glucose | 0g | 1.68g | 3.77g | 6.46g |

Figure 1 shows photos of the 0% and 30% separators after fabrication. It can be seen that the 0% separator has a smooth surface, whereas the 30% separator has an uneven surface. This indicates the effect of glucose on the separator structure.

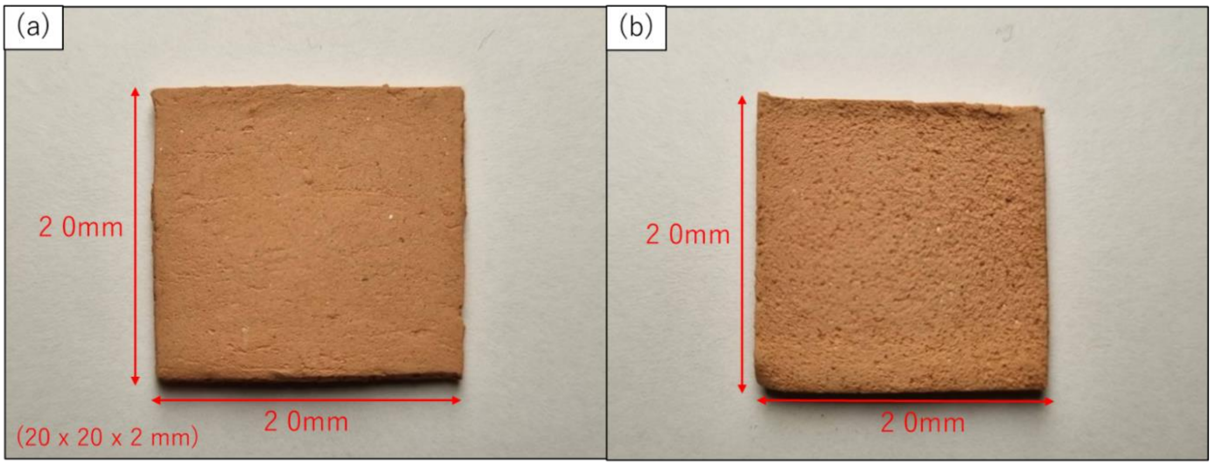


Figure 1: Photos of the fabricated ceramic separator: (a) 0% and (b) 30%. (source: by authors)

## 2.2. Preparation of MFC electrodes

Carbon felt (10 x 10 x 5 mm) was used as the anode electrode. The anode electrode was placed in paddy soil (Shiga, Japan) for 2 days prior to installation in the MFC to facilitate biofilm adhesion. Urethane (20 x 20 x 9 mm) (U.E.S. Inc., Osaka, Japan) and sumi ink (Kuretake Co., Ltd., Nara, Japan) were used as cathode electrodes. Bokuju is a traditional ink used in Japan and can be obtained at an affordable price. Bokuju was used in this case as a binder to connect the cathode electrode to the ceramic separator.

## 2.3. Preparation of LB medium

LB medium was used as an electrolyte in this experiment. To prepare it, 5 g of tryptone, 2.5 g of yeast extract, and 5 g of sodium chloride were dissolved in 500 ml of purified water. Then, 2.5 mL of a solution containing 0.5 g of sodium hydroxide, mixed with 50 mL of purified water, was added to adjust the pH of the LB medium. For the electrolyte used in MFC power generation, 100 mL of LB medium was prepared by mixing 500 mL of tap water with 1 mL of soil water collected from paddy fields.

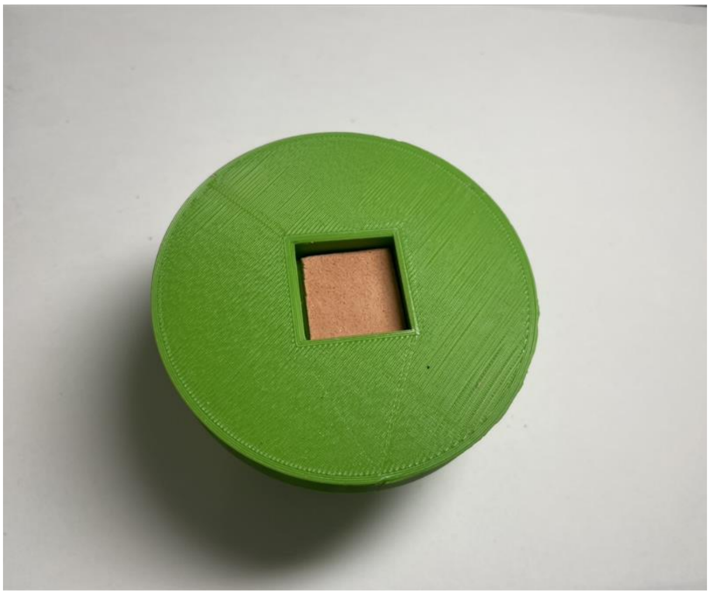

Figure 2: The photo image of a float MFC with a separator. (source: by authors)

## 2.4. Operation of the MFC

Figure 2 shows a floating MFC with a separator attached. The ceramic separator was connected to the float using an adhesive. The cathode electrode is also created on this separator and fixed by drying the binder, Bokuju. MFCs were operated in a float type, as shown in Figure 3, with the ceramic separator placed in close contact with the cathode electrode. The distance between the electrodes was 35 mm, the external resistance was connected to 47 kΩ, and the external temperature was stabilized at 28°C ± 1°C. Tap water was added daily to the MFC electrolyte to maintain a stable water level.

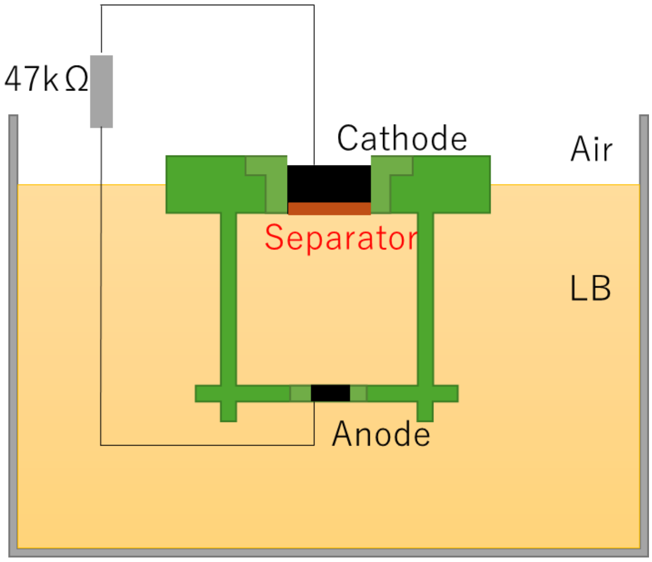


Figure 3: Diagram of float-type MFC.(source: by authors)

## 3. Experimental results

### 3.1. Surface observation of the separator

After the ceramic separators were prepared, their surfaces were examined using a scanning electron microscope (SEM, S-4300, Hitachi, Ltd., Japan). Figure 4 shows those created containing (a) 0% and (b) 30% glucose. The 30% surface is more porous than the 0% surface. The use of separators with higher porosity improves the power generation in MFC as more protons are transported. Therefore, this ceramic separator has the potential to be an effective separator for MFCs.

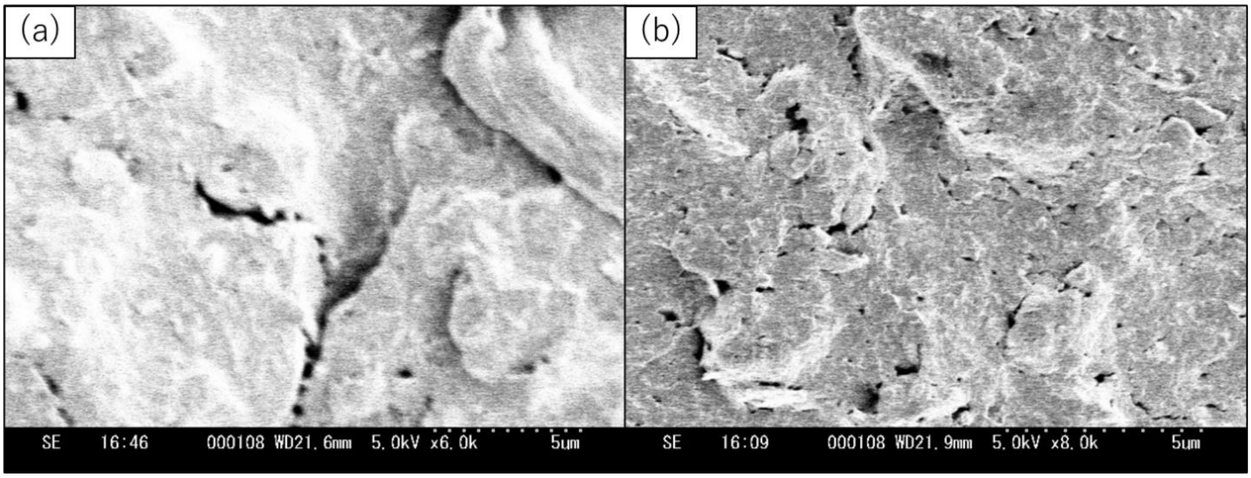


Figure 4: Ceramic separator surface (a) 0% and (b) 30%.(source: by authors)

### 3.2. Performance of each electrode

Ag/AgCl reference electrodes were used to evaluate the performance of the anodes and cathodes in each MFC. These reference electrodes were made by soaking the surface of an Ag wire with AgCl ink and allowing it to dry. The voltage of each electrode relative to the Ag/AgCl reference electrode was measured using a digital multimeter. Figure 5(a) shows the anode potential, with all anode electrodes stabilizing at approximately 500 mV. This indicates stable power generation by the microorganism at the anode electrode. Figure 5(b) displays the cathode potential, where the cathode electrodes in MFCs with 0%, 10%, 20%, and 30% glucose stabilized at -10, 10, 15, and 25 mV, respectively. This indicates that the function of the cathode in MFCs improves with the addition of more glucose to the ceramic separator.

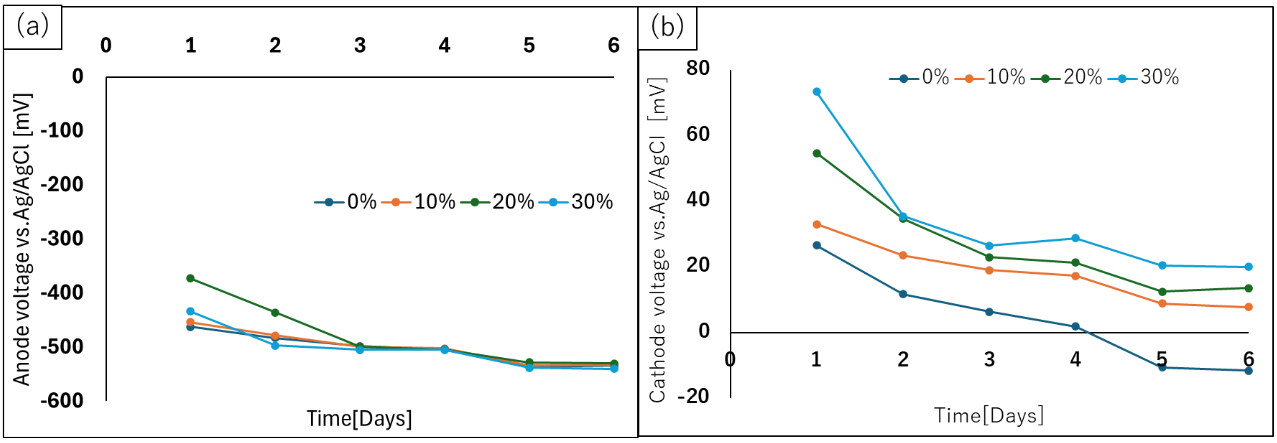


Figure 5: Voltage of each electrode relative to the Ag/AgCl reference electrode: (a) Anode and (b) Cathode.

## 3.3. Power generation performance of each MFC

Figure 6 shows the power and current densities on day 5 for the 0% and 30% MFC. The external resistor connected to the MFC, 47 kΩ, was removed, and a variable resistor was connected in its place. The variable resistor varied from 47 kΩ to 12 kΩ, and the voltage was measured. The power density and current density were calculated from the resistance and voltage values. The maximum power density of the 0% MFC was 9.95 μW/㎠$cm^2$, whereas the 30% MFC was 13.27 μW/$cm^2$, representing an approximately 33% increase in power output. It can be said that ceramic separators made by mixing glucose are effective in increasing the power output of MFCs.

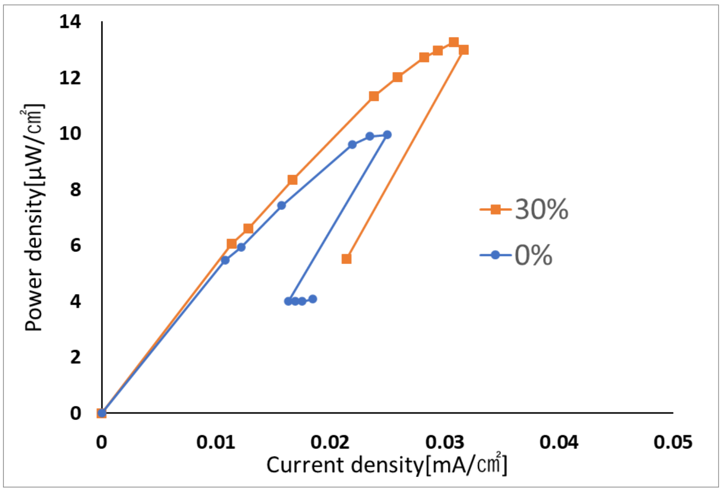


Figure 6: Power density and current density of MFC.(source: by authors)

## 3.4. Observation of electrode surfaces

After running the 30% MFC, the anode electrode was removed from the float-type MFC and placed in alcohol for one day to kill any microorganisms on the electrode. The electrodes were then placed in ethanol for 30 minutes to dehydrate them and subsequently dried. A gold coating was applied to the dried electrode surface by sputtering to enhance its conductivity. The electrode surface was then observed using SEM. As shown in Figure 7, a significant amount of biofilm was formed on the electrode surface, confirming that power generation is due to microbial activity.

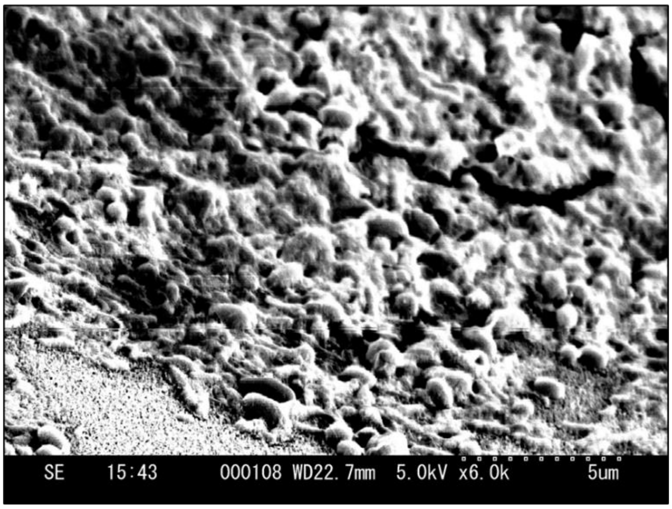


Figure 7: Electrode surface after MFC operation. (Source: by authors)

## 4. Conclusion

To enhance the functionality of ceramic separators used in microbial fuel cells (MFCs), we evaluated the performance of ceramic separators prepared by mixing glucose. The surfaces of these glucose-infused ceramic separators were more porous compared to those without glucose. The evaluation of the cathode electrode potential with respect to the Ag/AgCl reference electrode, as well as the power density and current density in MFCs, demonstrated that the inclusion of glucose improved MFC performance. However, creating separators with even higher percentages of glucose could increase porosity but might also provide a habitat for microorganisms, potentially negatively impacting cathode function. Therefore, future studies aim to determine the optimal percentage of glucose for these ceramic separators.

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**Ethics Approval**

Not applicable.

**Conflict of Interest**

The authors declare there is no conflict.

**References**

Boas, J., Oliveira, V., Simões, M., Pinto, A. (2022). Review on microbial fuel cells applications, developments and costs. Journal of Environmental Management, *307*, 114525.

Muhammad Imran Din, Amna Ghulam Nabi, Zaib Hussain, Rida Khalid, Mahroosh Iqbal, Muhammad Arshad, Adnan Mujahid, Tajamal Hussain. (2021). Microbial fuel cells—A preferred technology to prevail energy crisis. International Journal of Energy Research. Volume 45. 8117-9712.

Kurniawan TA, Othman MHD, Liang X, Ayub M, Goh HH, Kusworo TD, Mohyuddin A, Chew KW. (2022). Microbial Fuel Cells (MFC): A Potential Game-Changer in Renewable Energy Development. Sustainability. 14(24), 16847.

Soichiro Hirose, Dang Trang Nguyen, Kozo Taguchi. (2023). Development of low-cost block-shape anodes for practical soil microbial fuel cells. Energy Reports. Volume 9.

Anina James. (2022). Ceramic-microbial fuel cell (C-MFC) for waste water treatment: A mini review. Environmental Research, Volume 210.

Gowthami Palanisamy, Sadhasivam Thangarasu, Ranjith Kumar Dharman, Chandrashekar S. Patil, Thakur Prithvi Pal Singh Negi, Mahaveer D. Kurkuri, Ranjith Krishna Pai, Tae Hwan Oh, (2023). The growth of biopolymers and natural earthen sources as membrane/separator materials for microbial fuel cells: A comprehensive review. Journal of Energy Chemistry. Volume 80. 402-431.

Siti Mariam Daud, Wan Ramli Wan Daud, Mimi Hani Abu Bakar, Byung Hong Kim, Mahendra Rao Somalu, Andanastuti Muchtar, Jamaliah Md Jahim & S. A. Muhammed Ali. (2020). Low-cost novel clay earthenware as separator in microbial electrochemical technology for power output improvement. Bioprocess Biosyst Eng 43, 1369–1379.

S. Rojas-Flores, M. De La Cruz-Noriega, R. Nazario-Naveda, Santiago M. Benites, D. Delfín-Narciso, W. Rojas-Villacorta, and Cecilia V. Romero. (2022). Bioelectricity through microbial fuel cells using avocado waste". Energy Reports. Volume 8. 376-382.