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Preliminary Studies on Immobilized Cells-Based Microbial Fuel Cell System on its Power Generation Performance

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Abstract

Microbial fuel cell (MFC) is considered an alternative energy production technology that uses the degradation ability of microbes toward organic matters. The resultant products are electrons that will be transferred to electrode and flows to cathode of the MFC through an external circuit to produce current. The flow of electron and proton can be channeled to an external circuit to produce electricity. Although the MFC has many advantages, the power density produced is still low. This happens due to high internal resistance cause by electrolyte, the MFC design and the microbes itself. In order to overcome the restriction cause by internal barrier, the present research has focused on developing bio-based anode using microbial cells immobilized in alginate and activated carbon mixture (GAC). In addition, the power production performance was analyzed via MFC. Scanning electron microscopic (SEM) observation that the microbes have been successfully embedded into the matrix of alginate. Furthermore, using the immobilized activated, maximum open circuit voltage produce 403 mV during the MFC operation. This value was much higher compare to a control experiment (without GAC), which achieved 217 mV only after 200 hours operation. In addition, the maximum power densities achieved by the SCMFC are 0.184mW/m3 (immobilized system) and 0.0054mW/m3 (non-immobilized system).

Keyword: Activated carbon, Alginate, Bio-electrode, Immobilization, Scanning electron microscope (SEM).

1. Introduction

Energy sustainability becomes an issue throughout the world since it was predicted that fossil fuel would be depleted. Besides, the power generation through the combustion of fossil fuel also raises the pollution issue (such as global warming, etc.) due to the carbon emission. Therefore, renewable energy is considered as one of the solution to alleviate the current global warming crisis [1].

Generally, microbial fuel cell (MFC) is one of the alternative technologies that have been given much attention and altogether a promising way to overcome the dependency towards fossil fuel. Traditionally, MFC consists of anode and cathode, which are separated via a proton exchange membrane (PEM) to complete the circuit [2]. However, the power concentration generated via MFC has became an issue, and frequently debated due to its low power output [3]. Therefore, a lot of studies had been carried out to identify the factors that limit the power density of the MFC. In one study, researchers concluded that microbial catabolism is the rate-limiting step in MFC process [4]. In addition, electrode materials in the MFC also play an important role to enhance the power generation [5].

Many studies involves on investigating different conductive material as anodic or cathodic material, but to finally conclude the most perfect material could not be done. This is related to the difference in experimental conditions, such as temperature, pH, substrate and also the design of MFC. In contrast, bio-based electrodes has been largely implemented in MFC operations as it was later discovered that the bio-electrode that integrates into the MFC can further enhance the power productivity. However, the performance of bio-electrode in anode (also called bio-anode) is limited by several factors such as mass transfer between the substrate and the electrode, ohmic losses due to the resistance, electron- quenching process due to the bio-reaction, and activation losses due to the energy barrier of the biochemical reaction [6]. As a result, immobilization of cells onto electrode material as support has been proposed and is believed can further reduce the ohmic losses between the electrode and the microbes [6].

In this study, microbial cells have been immobilized through entrapment method onto activated carbon as support using alginate as a binder. Subsequently, MFC trials were carried out to produce the electricity via single chamber microbial fuel cell (SCMFC). A mix of two locally isolated microbes were added into MFC and operated under ambient condition with glucose as the substrate. In addition, the performance of the immobilized GAC based MFC system was evaluated through its voltage generated, calculated power and current densities.

2. Material and Methods

2.1. Immobilization of Microbes

2.1.1. Microorganism

Two microorganisms were used which were obtained from MFC enrichment culture in previous experiment [9]. The microbes were designated as E1 and E2 were maintained in commercial available Luria Bertani broth (MERCK) and cultured in the same medium to prepare pre-culture.

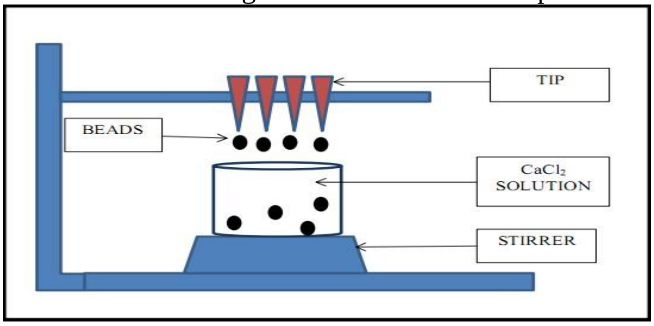
2.1.2. Microbial Immobilization

The cell suspension of E1 and E2, which reached optical density ($OD_{600\ nm}$) of more than 1.0 was collected and mixed to 1 to 1 ratio (volume of E1: volume of E2) and diluted with 0.1 M phosphate buffer (pH 7.0) to a final $OD_{600\ nm}$ of 2. The mixed suspension was then added into a beaker containing granular activated carbon, 10% (w/v) and stirred with a medium speed on the magnetic stirrer overnight. Next, sodium alginate, NaAlg (4% w/v) powders (Kanto Chemical Co. Inc.) were then dissolved in the mixed suspension. The sodium alginate was added little by little and stirred with slow speed homogenizer to prevent lump formation. The polymer-cell mixtures were poured into 5-mL pipette tip and gravitationally, dropped slowly into a bikre containing calcium chloride, CaCl2 (4% w/v) solution and left to harden in the solution with slow stirring for 30 minutes (Figure 2.1). The immobilized GAC beads were rinsed three times with steriled-distilled water before use. The beads are then acclimated in phosphate medium (pH 7.0) containing 1.0 % (w/v) glucose and incubated for 16 hours for the reactivation of microbes in the beads and then stored in room temperature for further usage.

2.2.1. Open Circuit Voltage Testing

In order to obtain roughly the maximum voltage can be achieved by the designed MFC configuration, open circuit voltage testing was carried out. According to Logan, the open circuit voltage (OCV) works under the condition without the presence of current. Therefore, it can reflect the electron motive force the MFC [7]. A multimeter was used for electrical measurement. The voltage was recorded every 2 hours until the maximum reading was recorded.

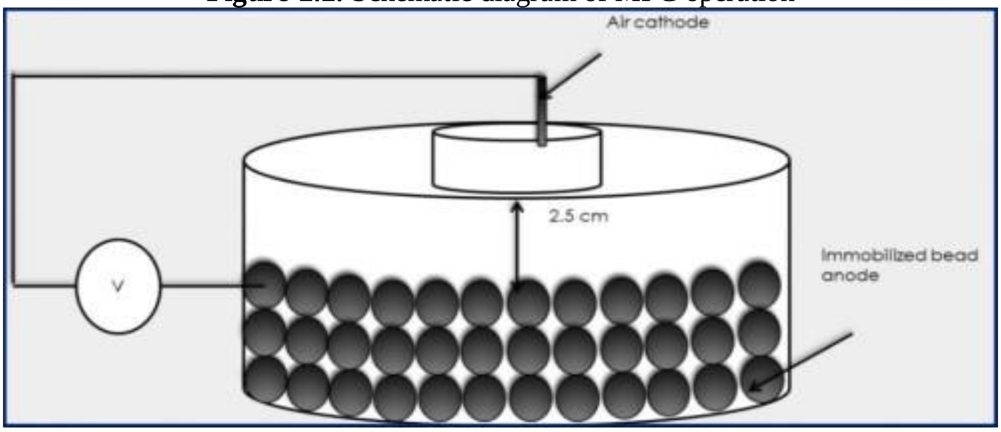
Figure-2.1. Schematic diagram of beads formation process



2.2.2. Closed Circuit Voltage Testing

The closed circuit voltage testing was carried out immediately after the maximum OCV has stabillized. The anode and cathode of the MFC were connected to a resistor box and voltage produced was obtained. The closed circuit voltage testing was repeated with different values of external resistant in the range from 100 Ω to 51000 Ω. The voltage reading was recorded until the reading became stable for five minutes before continuing with next load or resistance. The increase or decrease of the voltage was recorded for 5 consecutive reading. The power density and current density can be calculated and was plotted in MS Excel-based graphs.

Figure-2.2. Schematic diagram of MFC operation



2.3. Analysis

2.3.1. Scanning Electron Microscope (SEM) Scanning

The beads were characterized using scanning electron microscopy (SEM) images and an equilibrium swelling study. The SEM micrographs were taken to examine the morphology, surface structure and inside structure of microbes immobilized NaAlg at the required magnification at room temperature.

2.3.2. MFC Operation and Measurement

In principle, OCV is without the concern of the current present. Therefore, the OCV should approach the electromotive force (e.m.f.) of the fuel cell [7]. In a CCV configuration, the measured potential (V) was converted to current by the relationship of Ohm's law.

Where, V = Potential energy (Voltage) I = Current (Ampere)
$V = I \times R$
R = Resistance (Ohm)
The power density, P (W/m3) was obtained according to
P = IV/V
Where I(A) is the calculated current, V(V) is the measured voltage and V(m^3) is the projected working volume of the anode.

3. Results and Discussion

3.1. Immobilized GAC

3.1.1. Morphology of GAC

Figure 3.1 shows the morphology of the immobilized bead before the MFC operation. Indeed, the resultant immobilized GAC shows that the microorganism entrapped in the alginate gel matrix and adhered on the porous activated carbon. Furthermore, microscopic observation using SEM justified that the addition of the alginate does not give an agglomeration on the activated carbon surface but will cover the surface thoroughly. Therefore, porous structure of activated carbon remains and allows microbes to multiply and adhere on the porous surface of the activated carbon. In addition, microbial growth was observed both on the surface of GAC beads and internal (through cross-sectional view) of the GAC beads as shown in Figure 3.2. This phenomenon was probably due to the consumption of the glucose for expanding the microbial growth in the solution. However, the SEM images also reveals, that further reused of the bead might cause the leaking of microbes into the medium solution and pollute the solution, which will contributes to high internal resistant.

Figure-3.1. Morphology of immobilized bead (2.5K × magnification) before MFC operation (left) whole bead, (right) cross sectional bead.

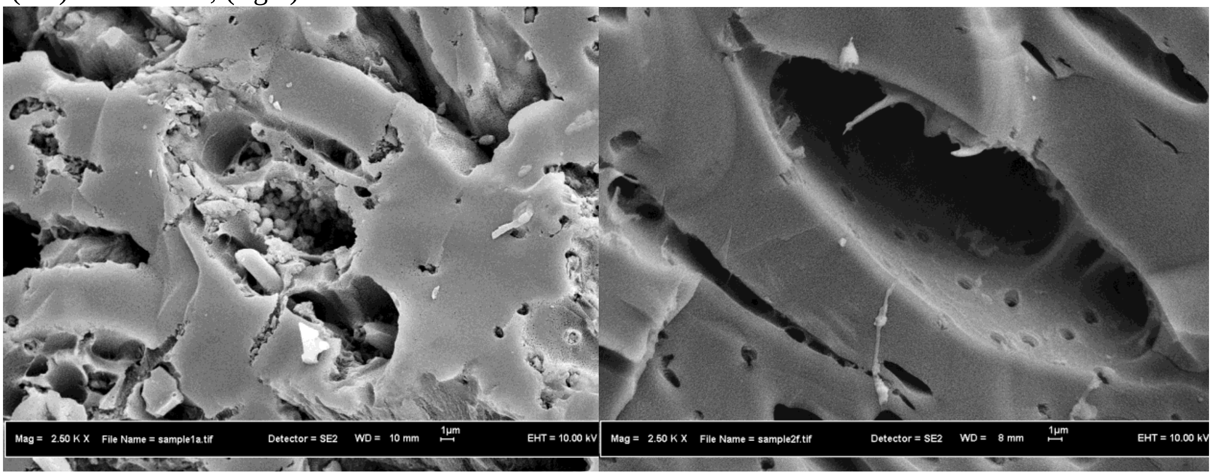
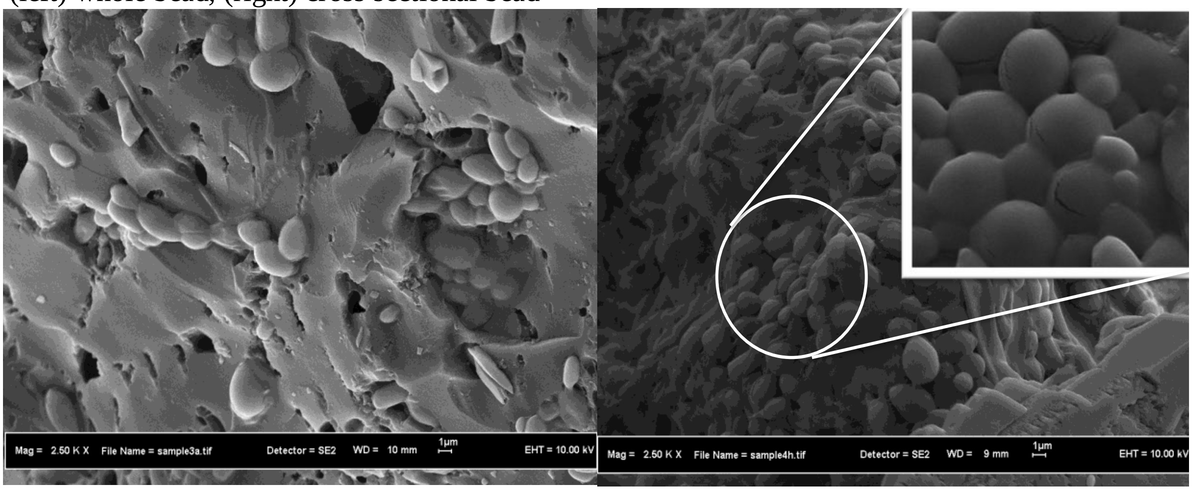


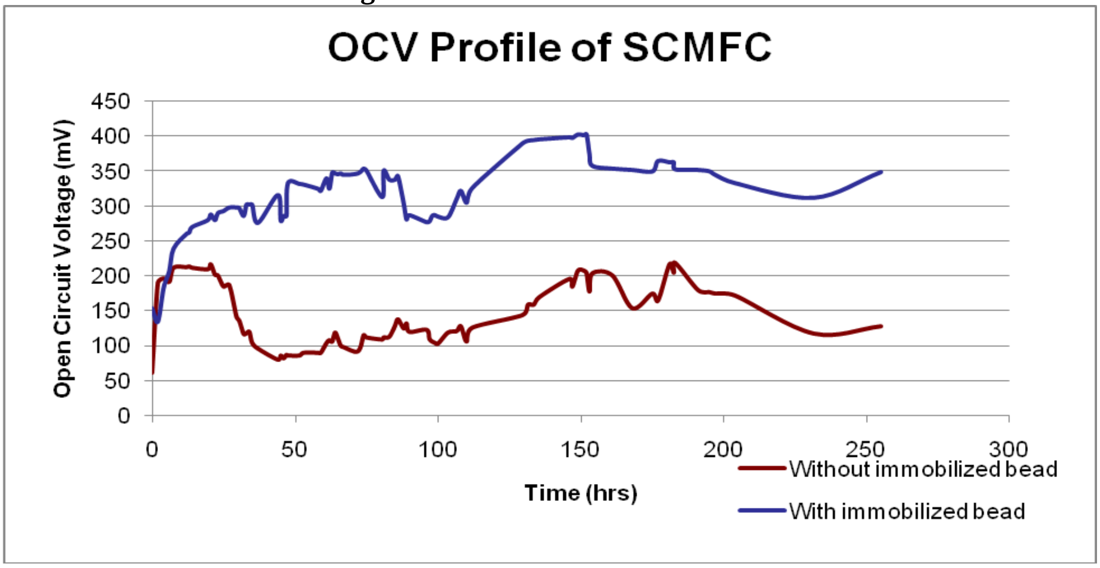
Figure- 3.2. Morphology of immobilized bead (2.5K × magnification) after MFC operation (left) whole bead, (right) cross sectional bead



3.1.2. OCV and CCV

The maximum value for OCV was achieved at approximately 403 mV (with immobilized bead) compared to 217 mV (without immobilized bead) (Figure 3.3). Both of the SCMFC shared the similar OCV profile and achieved the maximum open circuit voltage at the t = 150 hrs to t = 200 hrs. Indeed, the maximum OCV values amid differences that may suggest localization of the cells within the immobility has a close contact and resulted with more electron transfer.

Figure-3.3. OCV Profile of SCMFC



CCV data also reflects the same as shown in Figure 3.4. The power and current that obtained from the closed circuit analysis were usually normalized with the volume or area of electrode in anode compartment where the biological reaction occurs [7]. Figure 3.4 shows polarization curves, which shows the characteristic of power production of a MFC. By using MFC with immobilized bead has achieved maximum power of 0.184 mW/m3 with a corresponding current density of 4.898 mA/m3. Moreover voltage produced per se shows that ohmic losses were dominant. In contrast, MFC with the non-immobilized bead was 0.0054 mW/m3 with a corresponding current density of 0.626 mA/m3 with the voltage curve (Figure 3.5) suggests activation losses were largely affected the power production (e.g. a limitation of biological metabolism at the anode and oxygen reduction at the cathode [11]). This phenomenon prevails at the range of 0.6 to 1 mA/m3 of current density values, whereas ohmic losses were dominating the rest of the spectrum. According to Logan (2006), activation losses occur during the transfer of the electron from reacting compound (i.e. microorganism surface) at the electrode surface [7]. This experimental result agree with the hypothesis the immobilization method can further reduce the resistance between the transfer of electron from bacteria to the electrode.

Figure-3.4. Polarization (b) and power (a) curves of a microbial fuel cell operating on immobilized bead.

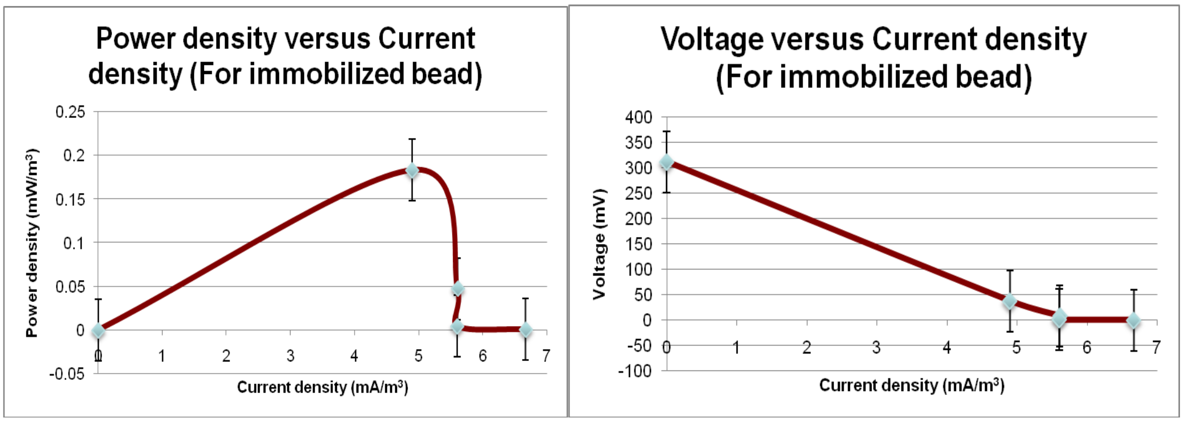
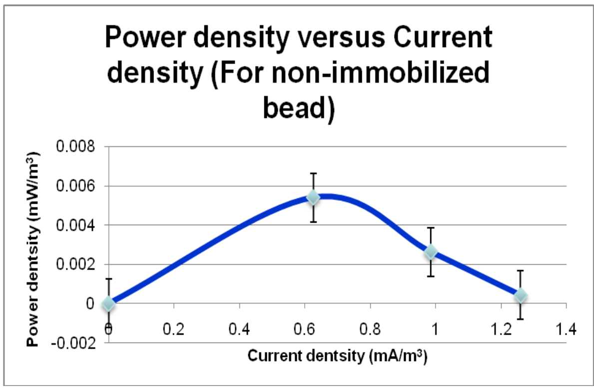
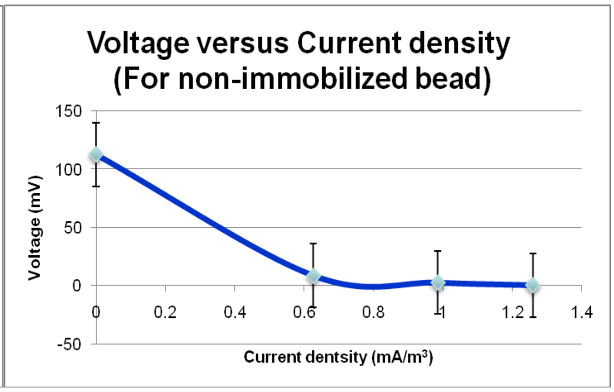


Figure-3.5. Polarization (b) and power (a) curves of a microbial fuel cell operating on non-immobilized bead.





4. Conclusion

In this study, immobilized cell was prepared in an attempt to improve the electron transfer from cell to electrode. The alginate-cell-activated carbon immobilization was successful developed and tested for power production using MFC. After a 200 hours operation of MFC, the immobilized system achieved 403 mV while the non-immobilized system achieved 217 mV. In addition, the power density of the immobilized system show a good respond as the internal resistant of the power source (SCMFC) was further decrease via the reduction of the activation losses during the MFC operation. However, in morphological view, improvement can be made for more efficient immobilization. In addition, with this immobilization bio-anode based MFC, further modification needed for enhancement of power produced.

5. Acknowledgements

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