Effect of Crude Glycerin on a Membrane-less Single-chamber Microbial Fuel Cell

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Abstract

A microbial fuel cell (MFC) is a novel electrochemical system that can operate on various energy sources. Some prospective renewable sources include wastewater and crude glycerin waste from biodiesel production. We investigated the effect of using crude glycerin as a supplementary nutrient for bacteria in a membrane-less single-chamber MFC. The cathode of the MFC was made of aluminum mesh, coated with silicone mixed with carbon black. The silicone layer allowed oxygen to diffuse through but prevented water inside the MFC chamber from leaking out. The anode was made of activated carbon granules in an aluminum mesh container. In each cycle of operation, which lasted about 36 hours, the MFC was filled with 1 litre of diluted activated sludge, and the output voltage was recorded over time. After the first 6-7 cycles, either 1 or 2 g of crude glycerin was mixed into the sludge solution. The addition of 1 g of crude glycerin decreased the power density from 0.34 to 0.29 mW/m^3 and increased the Coulombic efficiency from 4.6 to 5.2 %. The addition of 2 g of crude glycerin decreased the power density from 0.44 to 0.01 mW/m^3 and decreased the Coulombic efficiency from 2.7 to 0.7 %. The single-chamber MFC seemed to be able to utilize crude glycerin at the lower amount of 1 g per 1 litre of the sludge solution.

Keywords: microbial fuel cell; single chamber; glycerin; biodiesel waste; silicone.

1. Introduction

As a public knowledge, our dependence on fossil fuel must be reduced, while the search for clean and renewable sources of energy must continue. A microbial fuel cell (MFC)[1], a novel technology that combines principles of electrochemistry and microbiology, is one such energy source. In place of chemicals used in conventional batteries, a proper system of an electrochemical cell containing liquid cultures of bacteria, can produce electricity. MFCs typically come with two chambers, of anode and cathode, separated by a proton exchange membrane (PEM). Another common configuration is a membrane-less MFC with a single chamber containing an anode electrode and a liquid culture of bacteria [2].By living and attaching on the anode surface, the bacteria are responsible for transferring electrons from organic molecules, consumed by the bacteria, to the anode. One side of the cathode of the MFC is in contact with the liquid, while the other side is directly exposed to air. In this manner, oxygen in the air can passively diffuse through the cathode. The oxygen molecules then obtain the electrons, which migrate from the anode to the cathode. An intensive energy task of liquid aeration is not required, thus saving cost and energy. A PEM is quite expensive and can obstruct the flow of the protons from the anode chamber to the cathode. A study [2] showed that an air-cathode MFC produced higher power output in the absence of the membrane.

The bacteria in a microbial fuel cell can consume a variety of nutrients, such as organic matters in wastewater. This process can be applied as wastewater treatment with a simultaneous production of electricity. Crude glycerin, as a by-product of biodiesel production process, is another promising substrate for the bacteria. Crude glycerin can be used by the fuel cell without the purification process [3]. This utilization of crude glycerin by MFCs can synergistically boost the biodiesel production industry.

In this work, a membrane-less single-chamber MFC was built from inexpensive local materials. We studied the possibility of using crude glycerin, a by-product of biodiesel production, as a supplementary nutrient for the bacteria.

2. Materials and Methods

2.1 MFC design and operation

A conceptual design and an actual experimental setup of our MFC are shown in Fig. 1(a) and 1(b). Following the design, an aluminum mesh was used to construct parts of the MFC, as shown in Fig. 2(a). For the anode, an aluminum mesh was shaped to be a cylindrical container of packed activated carbon granules and also behaved as a current collector to mediate the electron movement from the anode to cathode. For the cathode, a cylindrical mesh was coated with a mixture of silicone and carbon black (a weight ratio of 4:1), as shown in Fig. 2(b). The carbon black was added to encourage electrical conduction. The mixture was diluted with toluene for easy application on the mesh, and then the prepared cathode sat overnight waiting for the silicone layer to be cured.

The MFC operated in batch cycle. We started each cycle by replacing the liquid in the MFC chamber with 1 litre of 10 % v/v activated sludge. The anode and cathode meshes were connected to each other via a 100-Ω resistor. The MFC was covered and secured with tape to prevent air from entering the chamber. The liquid was continuously stirred with a magnetic bar. Each cycle lasted approximately 36 hours, while the output voltage of the MFC was recorded every minute by a volt meter. At the end of each cycle, the liquid was poured out, but the activated carbon granules were not replaced, and kept being used for all of the cycles. When testing the effect of crude glycerin, we followed the above procedure, except that either 1 or 2 g of crude glycerin was mixed into the sludge solution. The addition of crude glycerin happened after the first 6-7 cycles without crude glycerin.

2.2 MFC performance calculation

Performance of the MFC was evaluated based on two parameters; power density and Coulombic efficiency[1, 4]. The power density was calculated on the basis of the liquid volume by,

$$P_V = \frac{E_{cell}^2}{VR_{ext}} \tag{1}$$

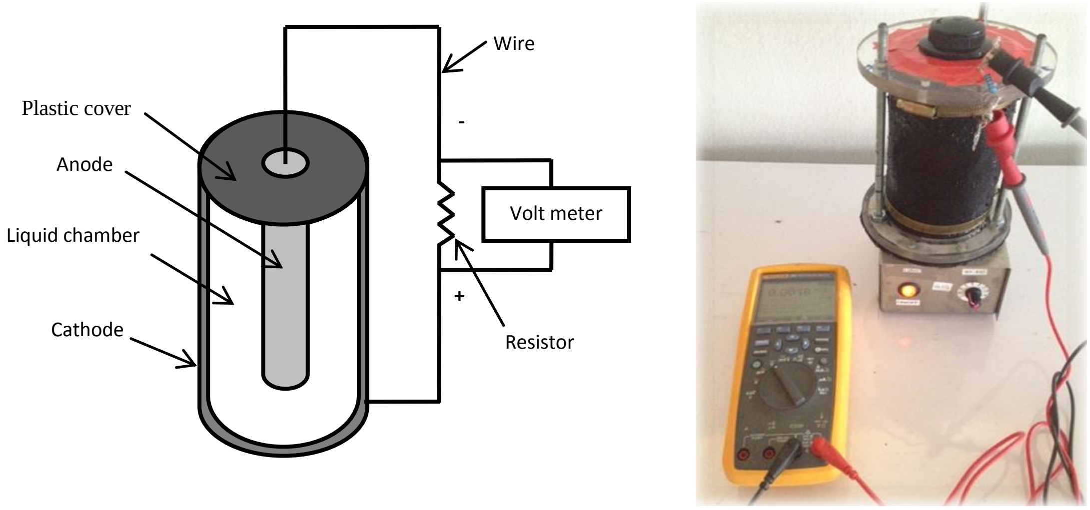
where

P_V = power density per liquid volume, W/m^3

E_{cell} = measured output voltage of MFC, V

V = total liquid volume, m^3

R_{ext} = external resistor across which the output voltage was measured, Ω



(a) **(b)**

Fig. 1. (a) a design of our MFC; (b) an experimental setup of the MFC operation.

(a) **(b)**

Fig. 2. (a) the MFC with aluminum meshes as a frame; (b) the mesh was coated with a mixture of silicone and carbon black to become the cathode.

The Coulombic efficiency was defined as the ratio of total electrical charges actually transferred from the substrate to the anode, to the maximum possible charge transferred if all the substrate consumption produced electrical current [1]. The Coulombic efficiency for a fed-batch MFC running over time t_b was thus calculated by,

$$\epsilon_{Cb} = \frac{M \int_0^{t_b} I dt}{FbV \Delta COD} \quad (2)$$

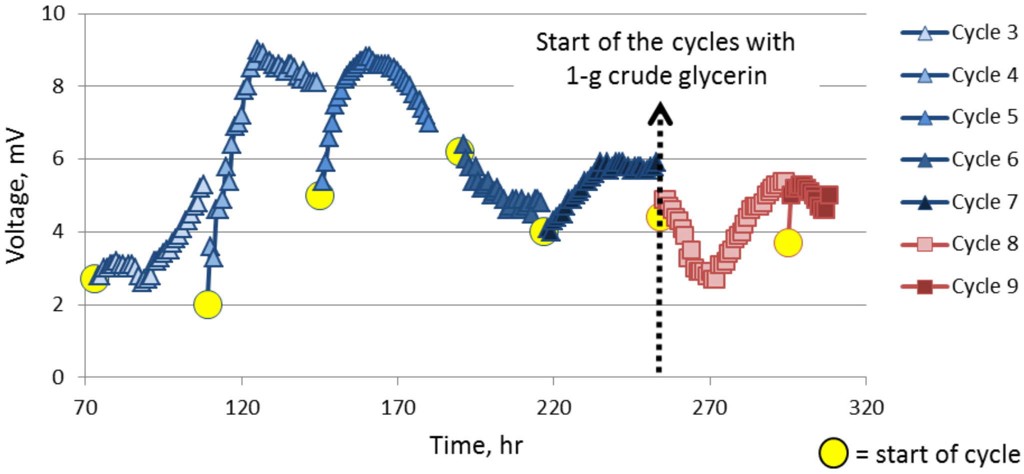
where

ϵ_{Cb} = Coulombic efficiency
M = 32 = molecular weight of oxygen
t_b = period of running time of fuel cell, s
I = measured output current of MFC, A
F = 96485.3 C/mol = Faraday's constant
b = 4 = number of electrons exchanged per mole of oxygen
ΔCOD = change in COD over time t_b mg/L

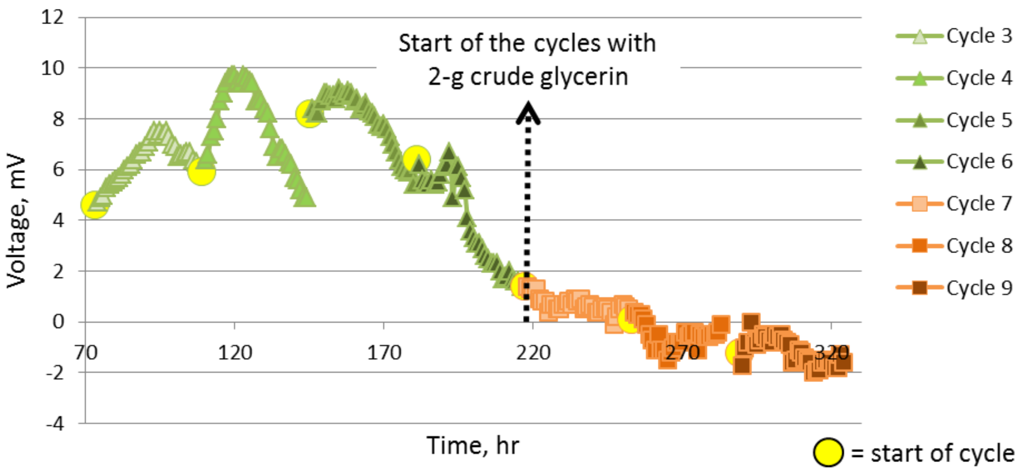
3. Results and Discussions

We investigated the possibility of using crude glycerin as a supplementary energy source. In the first experiment, starting at the 8th cycle, the liquid solution of only activated sludge was replaced with a mixture of activated sludge and 1 g of crude glycerin. In the second experiment, starting at the 7th cycle, 2 g of crude glycerin was used. The additions of crude glycerin reduced the average output voltage from 7.0 to 5.2 mV and 8.2 to 0.4 mV for the first and second experiments, as shown in Fig. 3(a) and 3(b), respectively.

As shown in Fig. 4, the addition of 1 g of crude glycerin resulted in the power density decreasing from 0.34 to 0.29 mW/m^3, but the Coulombic efficiency increasing from 4.6 to 5.2 %. Although the power dropped slightly, a small increase in the efficiency can imply that crude glycerin was a more efficient energy source than the organic matters in the activated sludge. The addition of 2 g of crude glycerin resulted in significant decreases in the power density, from 0.44 to 0.01 mW/m^3, and the Coulombic efficiency, from 2.7 to 0.7 %. We suspect that the liquid with the high concentration of crude glycerin was not a suitable environment for the bacteria to live. The power outputs of the MFC were too low for practical use, so further improvement of the system is required.

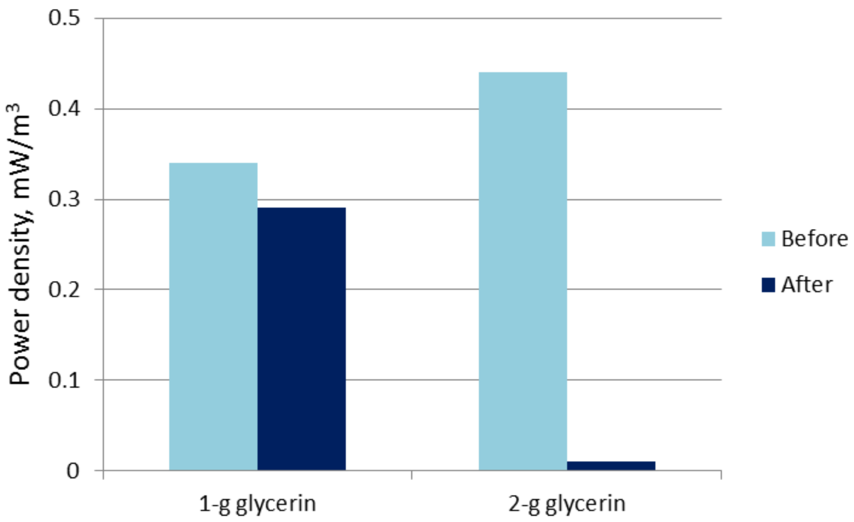


(a)

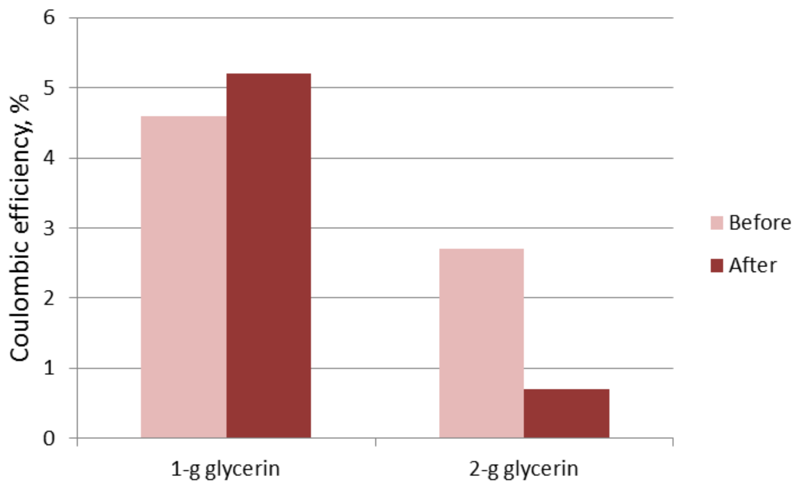


(b)

Fig. 3. (a) the effect of 1-g crude glycerin and (b) the effect of 2-g crude glycerin on the output voltages of the MFC.



(a)



(b)

Fig. 4. Comparison of (a) the power densities and (b) the Coulombic efficiencies before and after the additions of crude glycerin.

4. Conclusion

Our membrane-less single-chamber MFC had aluminum mesh coated with silicone for the cathode, and activated carbon granules in an aluminum mesh container for the anode. The MFC seemed to be able to utilize 1 g of crude glycerin per 1 litre of the sludge solution. The MFC yielded the power density of about 0.3 mW/m^3 and the Coulombic efficiency of about 5 %.

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