

Fabrication and Operation of a Novel Membrane-less Microbial Fuel Cell as a Bioelectricity Generator

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Abstract: Nowadays, traditional sources of energy are near exhaustion and alternative sources of energy are considered. One of the newest resources of energy is microbial fuel cell (MFC). MFC is a bioreactor that converts chemical energy in bonds of organic substrate to bioelectricity. The active biocatalysts such as microorganisms or enzymes, in the anode compartment, utilize substrate for growth maintenance; as a result electrons are supplied. Electrons and protons are produced by oxidation of substrate where electrons move from external resistance to the cathode surface while protons move across membrane to the cathode surface as well. Electrons and protons, with solution oxygen, combine to form water. In this study, this process is achieved by a new membrane-less MFC (MLMFC) which is low in cost when compared to other dual chamber MFCs. Maximum power produced by MLMFC was 40.43 mW/m² while COD removal was 66%. Open circuit voltage of 790 mV has been achieved after 96 h of operation. This study presents a new configuration of MLMFC as an electron generator. The key factor of this configuration is: low cost of design and lack of membrane bio fouling that is common in H-type configuration.

Key words: Bioelectricity; Continuous process; Membrane-less cell; Microbial fuel cell; Power generation.

INTRODUCTION

Use of fossil fuel, especially oil and gas, has accelerated in recent decades and this brings about a global energy crisis [1, 2]. Renewable bioenergy is viewed as one of the new ways to alleviate the current global warming crisis [3, 4]. Power production from renewable resources that does not produce carbon dioxide emission is desired [5].

A microbial fuel cell (MFC) is a novel technology, which has a number of potential uses [6–9]. The first and most clear are producing bioelectricity as a power source. Essentially any organic material can be used as electron donors. MFCs could be installed to waste water treatment plants. The active microorganisms in anaerobic anode compartment would utilize waste material from the water and generate bioelectricity for the plant. The gains to be made from doing this are: MFCs are very clean and an efficient method of energy production. MFCs also use energy more efficiently than standard combustion engines, which are limited by the Carnot Cycle [10]. It is also a challenging technology because of its current situation of low output but high in cost. The utilization of noble metal catalyst and ion exchange membrane contributes to a large proportion of the MFC configuration expense [11].

A traditional MFC consists of two chambers: anodic chamber and cathodic chamber. The MFC may

be improved by several key process factors, which are critical in its operation. These factors are: (I) metabolism of cells, (II) transfer of produced electrons to anode surface, (III) performance of proton exchange membrane, (IV) internal and external resistances, and (V) oxidation in cathode. Most of the process factors have great effects on electron transfer and bioelectricity generation [12, 13].

Two individual chamber in traditional MFCs are separated by special membranes such as proton exchange membrane [11, 14] cation exchange membrane and anion exchange membrane [15] but these membranes are high in cost, so some researchers tried to reduce the cost of MFCs by using cheaper membrane (e.g., glass fiber) or by removing of the membrane [16]. However, non-membrane means more oxygen diffusion to the anode chamber that will inhibit anaerobic condition and microbial growth and thus decrease the columbic efficiency [3, 17] so using cheaper membrane seems to be an appropriate method. Viridis and his coworker has made the loop model MFC to remove carbon and nitrogen compounds from wastewater, which some H⁺ and NH₄⁺ ions could transfer from the anode chamber to the cathode chamber through the electrolyte loop [18]. In the common anaerobic/oxic or anaerobic/anoxic/oxic wastewater treatment process [19], wastewater flows from the anaerobic tank to the aerobic tank. Substrate can be transfer via the flow.

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So MFCs can operate with continuous electrolyte stream (from anode chamber to cathode chamber) instead of the used ion exchange membrane to accomplish H^+ transfer [11]. This is a new configuration of membrane-less MFC (MLMFC), which the anode and cathode chambers are connected together by a control valve.

MATERIALS AND METHOD

ML-MFC was constructed with two chambers, which consists of anodic and cathodic compartments. Each chamber is 1000 cm^3 ($10 \times 10 \times 10\text{ cm}$). Three baffles were designed for both the anode and cathode chambers to help mixing. Two chambers are

connected together by a valve and pipe, which can control the amount of flow (refer to Fig. 1). Carbon paper was used as the electrode. The electrodes were connected with a copper wire, and the produced voltage and current were recorded with an online data logger. Aquarium pump with an air sparger was used to aerate the cathode chamber. This design is able to prevent oxygen diffusion into the anode chamber and on the other hand it can prevent mixing of anode and cathode solution. The fabricated ML-MFC with axial equipment is shown in Fig. 1. The prepared substrate is transferred by a peristaltic pump (Thomas, Germany) from the feed tank to the anode chamber and then passes through the valve to the cathode chamber.

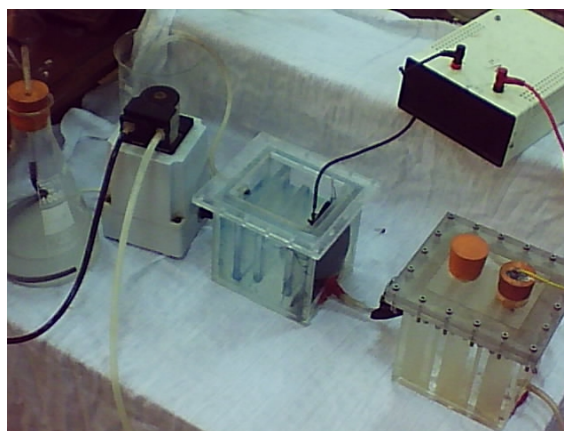


Fig. 1: Membrane-less microbial fuel cell with auxiliary equipments.

Inoculation and operation: ML-MFC was inoculated with anaerobic sludge collected from the food industry and the cheese whey was obtained from Gella in Amol. Samples are withdrawn from each chamber every day. COD analyses were carried out using the closed reflux method according to standard method.

Polarimetry technique was adapted to analyze the cell electrical performance. Polarization curves were obtained using an adjustable external resistance. Power and current were calculated based on following equations (1) and (2):

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

$$I = \frac{E}{R_{ext}} \quad (2)$$

Where P is the generated power and E the measured cell voltage; R_{ext} denotes external resistance and I indicates produced current. The surface area of the used membrane normalized the online-recorded current and power. Analog digital data acquisition was fabricated to record data every 4 min. Measurements were carried out at variable resistances imposed to the MFC. The current in the MFC was automatically calculated and recorded dividing the obtained voltage by the specified resistance. The system also provided power calculation by multiplication of voltage and current. These provisions were provided for online

observation of polarization curve showing the variation of power density and MFC voltage with respect to current. The online system had the ability to operate automatically or manually. While it operates in auto-mode, the assembled relays were able to regulate the resistances automatically. Voltage of MFC was amplified and the data were transmitted to a microcontroller by an accurate analog to digital converter. The microcontroller was also able to send the primary data to a computer by a serial connection. In addition, a special function created using Matlab 2007a (ver. 7.4, MathWorks, USA) was used to store and display synchronically the obtained data. The computer connected to the system also automatically recorded the power, current and voltage.

RESULTS AND DISCUSSION

Microorganisms in the anodic chamber of an MFC oxidize the added substrates and generate electrons and protons in the process. Four experiments were performed with different feeds of COD content (2000–3500 mg/L) and loading rate of 0.7 mL/min. Fig. 2 depicts variation of voltage with time for different feeds of COD contents for a period of 4 days. The

voltages varied with time and reached a steady state level after almost 2 days of operation. The maximum voltage of 790 mV was obtained with COD of 3500

mg/L and lowest voltage 750 mV was obtained with feed COD of 2000 mg/L.

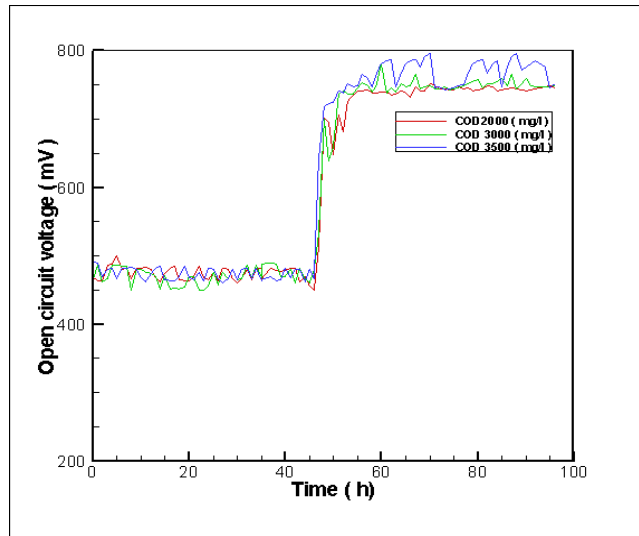


Fig 2: Open circuit voltage of the MLMFC.

When COD concentration in the feed stream was 3500 mg/L, a probably balanced nutritional requirement of the microorganisms yields the highest of COD removal and electron NADH formation. At low feed COD contents, the rate of metabolism was limited by the availability of organic compounds. Variation of COD concentration with time for different feed COD concentration between 2000–3500

mg/L is depicted in Fig. 3. COD concentration decreases with time. At a feed COD concentration of 2000 mg/L the final COD was nearly 700 mg/L and COD removal was around 65%. High feed of COD contents resulted in high biomass concentration in the MFC yielding high COD removal. Fig. 4 shows the percentage of COD removal for the MLMFC.

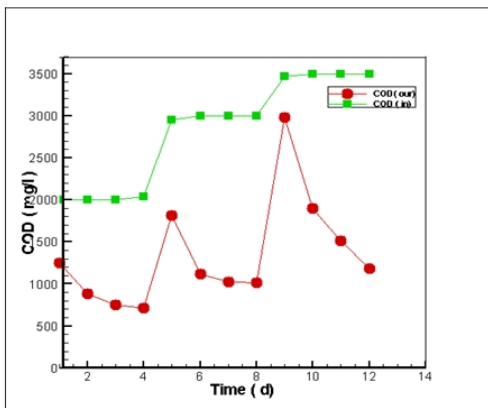


Fig. 3: Different amounts of COD and COD removal.

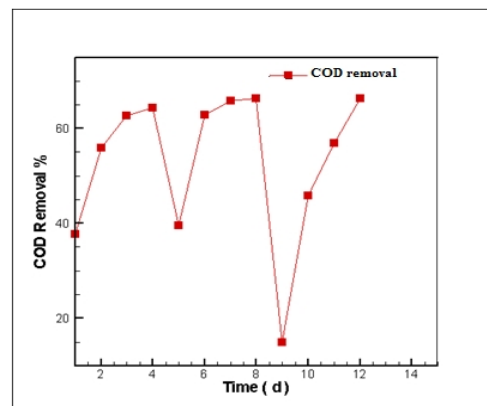


Fig. 4: COD removal percentage of cheese whey.

Effects of hexacyanoferrate ($K_3[Fe(CN)_6]$) on power and current density of MFC: One of the important factors that effect power of microbial fuel cell is type and amount of catholyte because catholyte

can decrease cathode losses. Thus, in this experiment, it was used at different amounts. Maximum power and current density were obtained at 40.43 mW/m^2 and 172.66 mA/m^2 . Fig. 5 and Fig. 6 show variations of

power versus current density and also voltage obtained

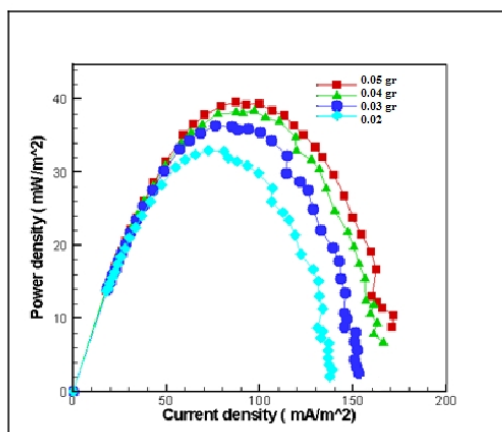


Fig. 5: Power versus current density for different amounts of $K_3[Fe(CN)_6]$.

CONCLUSIONS

MFC is a new technology that converts chemical energy in bonds of waste to electricity and treats wastewater simultaneously. The use of active biocatalyst is an interesting point in MFCs. A new configuration of MLMFC was used for COD removal of cheese whey. Fermentation of substrate for power production was successfully carried out in the dual chamber of the fabricated MLMFC. Graphite was selected in the fabricated MLMFC as the electrode. Maximum COD removal obtained was 66%. Maximum power and current densities obtained were 40.43 mW/m^2 and 172.66 mA/m^2 . The MFC is a good alternative for production of restricted power from different sources. The important features of this configuration are: low cost of design and no membrane bio fouling.

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by different amounts of hexacyanoferrate.

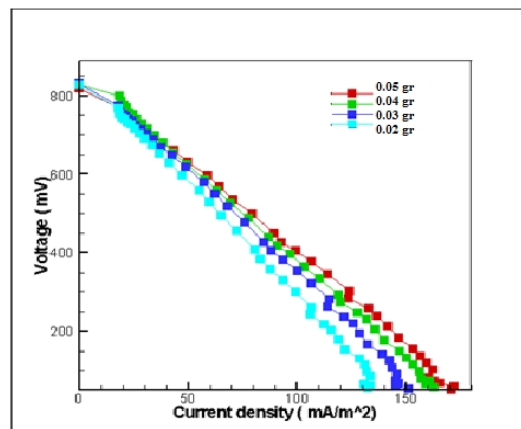


Fig. 6: Voltage versus current density for different amounts of $K_3[Fe(CN)_6]$.

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