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Enhancing the Performance of Microbial Fuel Cells by Installing an Air Pump to the Cathode Chamber

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Abstract

The microbial fuel cells (MFCs) are biochemical devices in which bacteria create electrical power by oxidizing simple compounds such as glucose as well as complex organic matter in wastewater. In this study, pumping air into the cathode chamber and its effect on microbial fuel cell performance was investigated. The metabolism of bacteria existed in wastewater was responsible for the generation of bioelectricity. The developed MFC system was designed by utilizing phosphate buffer to operate the system at controlled pH equal 7 and at a stable temperature of 30^{o}C. It was found that increasing oxygen supply to the cathode chamber has a positive effect on the cell performance by increasing the voltage value. Generally, the efficiency of microbial fuel cell was enhanced in the case of cathodic chamber aeration in comparison to the case of no aeration was applied. It was found that the voltage increased in the case of oxygen supply to reach 0.45 mv with a stability over the 138 h of the experiment compared to the case of no aeration was applied where the voltage reached only 0.2 mV with stability in one case and 0.4 mV after 78 h of operation with instability in the second case. Therefore, the performance of the microbial fuel cell improved. It can be concluded that oxygen concentration affects both reaction kinetics and final power efficiency.

Keywords: Microbial fuel cells; cathodic chamber aeration; bioelectricity generation; wastewater treatment.

1. Introduction

The growth in using fossil fuels (e.g., coal, oil, natural gas) in recent years has caused the global energy crisis and further increased the focus on environmental problems, such as green-house gas emissions, ozone depletion. Meanwhile, energy is an important factor in the advancement and development of human society. The limited and unstable supply of fossil fuels are not in line with the need for sustainable development [1, 2]. To solve the problem of environmental pollution and energy shortage, human beings continue to explore new pollution control technologies and alternative energy sources. Renewable energy is thus considered as a sustainable way to improve the increasingly serious global crisis [2].

One of the promising solutions for figuring out the energy and environmental problem is to utilize potential energy abundant in wastewater [3]. The traditional methods for treating wastewater such as physical and chemical methods have some shortcomings because of their high cost, serious secondary pollution, and non-reusability. Microbial fuel cell (MFC) is a novel electrochemical technology which is capable of decomposing organic compounds with a simultaneous electricity generation using microorganisms as the catalysts [4].

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MFC system is a unique sustainable biotechnology that is able to generate electricity through biodegradation of various organic compounds. MFC has received increasing research interests in broad fields: biochemistry, biochemical engineering and wastewater treatment. MFC has been recognised as a potential technology for the integration of electricity generation with wastewater treatment. MFC system relies on exoelectrogenic microorganisms to catalyse the electrochemical reactions occurring on electrode surfaces. To date, the applications of a number of pure or mixed cultures including Clostridium [6, 8], Pseudomonas [6, 7], Shewanella [6, 8] and Geobacter [6, 9] species have been reported.

Bacteria can be used in MFCs to produce electricity while doing the biodegradation of organic matters or wastes [10, 11]. This has attracted many researchers [10, 12]. MFCs comprise anodic and cathodic chambers isolated by a proton exchange membrane (PEM). Microbes present in the anodic compartment of a MFC oxidize substrates and produce electrons and protons. Dissimilar to a direct combustion technique, the electrons are absorbed by the anode and are transferred to the cathode through an external circuit. The protons go through the cathodic chamber and unite with oxygen to form water after crossing a PEM or a salt bridge [10, 13]. Electric current generation is attained by separating microbes from oxygen or any dissimilar end terminal acceptor without the anode and this requires an anaerobic anodic chamber [10].

MFCs are an attractive option to produce bioelectricity by utilizing various waste materials [10, 14]. The MFC is a device that uses microbial catabolic activities to generate electricity from organic matter [10, 15]. In the technology of MFCs, the alteration of stored energy in chemical bonds of organic compounds into electrical energy is carried out through the catalytic reactions by microorganisms. Standard electrode reactions are displayed below using acetate as a model substrate:

Reaction at anode:

$$CH_3COO + 2H_2O \xrightarrow{\text{Microorganisms}} 2CO_2 + 7H^+ + 8e \quad (1)$$

Reaction at cathode:

$$O_2 + 4e + 4H^+ \longrightarrow 2H_2O \quad (2)$$

Scheme 1: Standard anode and cathode reactions.

In general, reaction is the conversion of the substrate into carbon dioxide and water with an associated production of electricity as a by-product. On the basis of the electrode reaction couple above, a MFC bioreactor can produce electricity from the electron current from the anode to the cathode in the exterior circuit [10, 16].

There are several advantages of MFCs over anaerobic biogas technology. First, electricity is the most suitable form of energy for human activities. Second, MFCs can be useful to some wastewater types that are not appropriate for biogas processes, as well as low- strength wastewater [10, 17].

Alongside electricity generation [10, 18], MFCs have other applications: biosensors [10, 19], wastewater treatment [10, 20] and biohydrogen production [10, 21].

Many biochemical and systematic factors need to be considered in the development of MFC technology, including MFC design, microbial communities, electrodes and substrate chemistries [6, 9]. Chemicals involved in the MFC system as catholytes, substrate, nutrients and reagent for pH control could have significant impact on the bio-electrochemical reactions and overall performance of the MFC system [6].

Although a large amount of research has been conducted on microbial fuel cell (MFC) technology, MFC's application in commercial scales is limited due to some bottlenecks in the process. Cathode and electrolyte resistances are evaluated to be the major factors limiting electricity generation by MFCs [22]. Electrodes conductivity is a critical factor affecting the microbial fuel cells performance, where prototyping electrodes having high electrical conductivity and low resistance to electric current is a key issue in the scientific research and development endeavors in this field [23]. Anode biofilm is a crucial component in microbial fuel cells for electrogenesis. Better knowledge about the biofilm development process on electrode surface is believed to improve microbial fuel cell performance [24]. On the other hand, Rabaey and Verstraete [25] mentioned that the potential losses during electron transfer in a MFC are: (1) loss owing to bacterial electron transfer, (2) losses owing to electrolyte resistance, (3) losses at the anode, (4) losses at the MFC resistance -useful potential difference- and membrane resistance losses, (5) losses at the cathode, and (6) losses owing to electron acceptor reduction.

As a result, making improvements to cathode architecture presents the most immediate need in order for practical application of MFCs for wastewater treatment to be realized. Among the different types of cathodes that have been used in MFCs, air cathodes have demonstrated the capability of generating high power densities in MFCs, representing a great potential for practical applications [23].

This study aims to highlight to compare the cathode performance with and without oxygen supply through the air pump. Two chamber air cathode MFC was investigated in this study through applying air pump to determine the potential of this design as a biomass fuelled MFC. The appropriate interpretation of the MFC electric response to substrate concentration changes was demonstrated.

2. Materials and methods

2.1. MFC construction, inoculation and operation

Four H-type microbial fuel cells (MFCs) consisted of two chambers, an anaerobic anode chamber and an aerated cathode chamber were used to determine the microbial fuel cells performance without and with the air pump. The MFC was constructed using two plexiglass bottles (1000 mL) connected with each other using a salt bridge (Figure 1). The materials used for the anode and cathode were graphite. Both electrodes were connected to a multimeter (Fulk, 289 FVL). Each MFC has an elevation of 15 cm and 10×10 cm for the section (Figure 2). All MFC tests were operated at a fixed external circuit resistance (80 kΩ). The MFCs (anodic chambers) were inoculated with activated sludge samples from Zenein Wastewater Treatment Plant (Zenein, Bulaq Dakrur, Giza Governorate). The anodic chamber contained 0.1 M phosphate buffer or normal tap water and the cathodic chamber contained 0.5 M phosphate buffer or normal tap water. The experimental temperature was kept at 30°C. All experiments were conducted in duplicate.

Fig. 1: A photograph showing one of the installed MFCs.

Three replicates of the experiment were conducted. The experiment has two treatments, with and without the air pump. Whereas, 1 L of activated sludge, media and nutrients were added to the anodic chamber, and air was removed by using a syringe. The cathodic chamber was filled with phosphate buffer solution. Each 0.1 M of buffer solution contained (61.5 ml K_2HPO_4 and 38.5 ml KH_2PO_4) in 1 L distilled water. The experiments were conducted at ambient temperature (31 ± 1 °C). The experiments were conducted in two modes (with and without aeration), and the results were compared. In case of using a pump, and airflow rate of 3.5 L min^{-1} was applied.

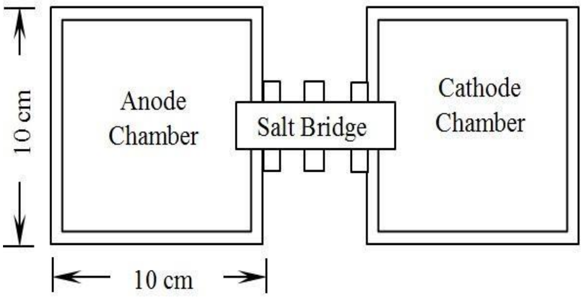

Fig. 2: Plan view of the manufactured microbial fuel cells.

2.2. Experiments

3. Results and discussion

3.1. With oxygen supply (with air pump)

Figure 3 shows the effect of air supply on the bioelectricity production from microbial fuel cells. The aeration was constantly applied. The output voltage in the first treatment initially started with 0.3 mV and decreased to 0.025 mV after 6 h and increased to 0.4 mV from 6 h to 90 h from the start of the experiments then showed stability from 90 h to 138 h. In the second treatment, the output voltage had a little increase during the first 24 h from 0.4 to 0.45 mV, then it showed a stability from 24 h to 72 h of the experiments then it decreased to 0.35 from 72 h to 96 h then increased to 0.4 mV from 96 h to 138h.

3.2. Without oxygen supply (without air pump)

Figure 4 shows the effect of not applying aeration on the bioelectricity production from microbial fuel cells, where all the conditions were the same except that the cathode aeration was stopped. The voltage dropped under zero during the first 24 h in the first treatment, then it increased from 24 h to 78 and reached a peak value of 0.4 mV after 78 h of operation. The curve continued to fluctuate between 0.35 mv and 0.4 mv to 138 hours of operation which is the end of the experiments. In second treatment, the output voltage reached 0.25 mV after 15 h of operation, then it falls to 0.18 mV at 24 h. After 36 h of operation the curve has reached a steady state at 0.2 mV. As shown in Figure 4, the drop in the voltage is in fact an indication of oxygen reduction (the final electron-acceptor terminal). Oxygen concentration affects both reaction kinetics and final power efficiency.

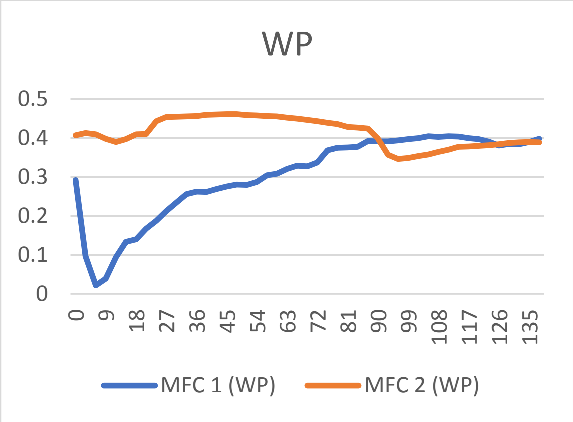

Fig. 3. Voltage-time relationship with the air pump.

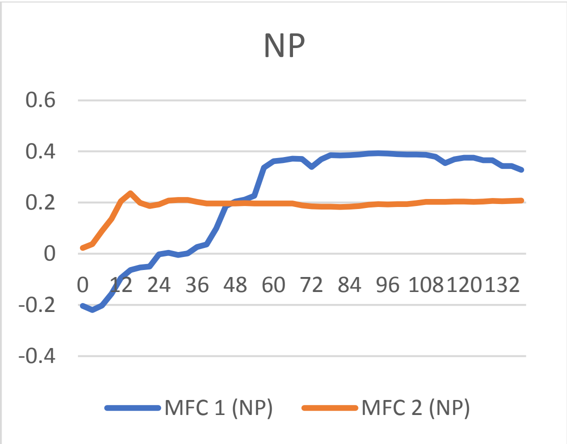

Fig. 4. Voltage-time relationship without the air pump.

The results of this study are in agreement with Fornero et al. [26] who stated that power densities are often constrained by the oxygen reduction reaction rate on the cathode electrode. One important factor for this is the normally low solubility of oxygen in the aqueous cathode solution, which creates mass transport limitation and hinders oxygen reduction at the electrocatalyst. In the present study, it was found that increased the air in the cathode chamber increases its solubility and consequently the availability of oxygen which agrees with the statements of Fornero et al. [26] and Hussein [27].
Future research will focus on the implementation of laser radiation as well as trace metals, in form of nanomaterials, to enhance the performance of microbial fuel cells, where the laser radiation and nanotechnology were implemented in biogas and biohydrogen production [28-36] but a very few studies in microbial fuel cells were conducted.

4. Conclusion

The supply of oxygen to the cathode chamber using the air pump has a positive effect on the cell performance, where it was observed that the voltage increased in the case of oxygen supply to reach 0.45 mv with a stability over the 138 h of the experiment compared to the case of no aeration was applied where the voltage reached only 0.2 mV with stability in one case and 0.4 mV after 78 h of operation with instability in the second case. Therefore, the performance of the microbial fuel cell improved. It can be concluded that oxygen concentration affects both reaction kinetics and final power efficiency.

5. Conflicts of interest

There are no conflicts to declare.

6. Funding sources

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