H₂O₂ AS ELECTRON ACCEPTOR IN DOUBLE CHAMBER MICROBIAL FUEL CELLS

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ABSTRACT

A variety of substrates have been explored relative to the anode substrate which takes the form of any wastewater with some amount of COD. Several modification methods have been developed to improve power generation at the anode level, but the cathode system and configuration have also been a challenge in most researches. The choice of cathode substrate is one of the greatest challenges in fabricating MFCs. In this study a DC-MFC with H₂O₂ cathode has been fabricated. A maximum voltage of 448 mV (OCV) for DC-MFC was observed at an ambient temperature of 25 °C which is much higher than 200 mV obtained from SC-MFC.

Keywords: MFC = Microbial Fuel Cell; SC-MFC = Single Chambered MFC; DC-MFC = Double Chambered MFC; OCV = Open Circuit Voltage

INTRODUCTION

Recently, Opoku-Donkor et. al. [1] has studied oxygen as electron acceptor in SC-MFCs. The main challenge in constructing an MFC is first to identify materials and architectures that maximize power generation and coulombic efficiency, but the next challenge is to minimize cost and create architectures that are inherently scalable [2]. Logan et al have shown that power densities can be increased by choosing high-energy catholytes such as ferricyanide or permanganate, but concluded that the use of these materials are not sustainable or cost effective. In most MFCs oxygen is used as the electron acceptor and as such all cathodic substrates is selected to achieve maximum acceptor level. The model performance of a MFC depends on the electrochemical reactions that take place between the organic substrate at a low potential such as glucose and the final electron acceptor with a high potential, such as oxygen [3]. However, its model cell voltage is vague because the electrons are transferred to the anode from the organic substrate through a complex respiratory chain that varies from microbe to microbe and even for the same microbe when growth conditions differ. Though the
respiratory chain is still inadequately understood, the key anodic reaction that determines the voltage is between the reduced redox potential of the mediator or the final cytochrome in the system for the electrophile/anodophile. For those bacterial type that are not capable of releasing electrons to the anode directly, a redox mediator is needed to transfer the electrons directly to the anode [4]. The search for anode substrate is still on-going, although species such as Geobacter sulfurreducens, is speculated to form an electrical conductive biofilm capable of electron transfer in the system a replacement would be necessary. In this study we chose to experiment diluted H$_2$O$_2$ at the cathode chamber. The composition of the oxidation chamber, as done by Borah et al [5] was phosphate buffer. Their maximum voltage was found to be 440 mV. Others have tried ferricyanide and ferric sulfate in solution. Devasahayan et al, have used ferricyanide in their 4 phased studies as oxidation agent to produce voltage between 285 to 779 V [6]. Park and Zeikus (2003) examined power generation using a single-chamber system with a Fe$^{3+}$-graphite cathodes exposed to air and had the current density of 788 mW/m$^2$, but were not sure whether iron reduction contributed to power generation [7].

The main objective of this study is to replace mixture of chemicals, with a simple sourced cathodic substrate which is H$_2$O$_2$.

**MATERIALS AND METHODS**

Two cells were constructed with each cell volume of 1.8 L. Both SC-MFC and DC-MFC have PEM as the partition (Fig. 1a and 1b).

![Fig. 1: a) Single-Chamber MFC b) Double-Chamber MFC](image)

The anode electrode for the SC-MFC is 6 cm from the PEM and the two electrodes in the DC-MFC, each 9.5 cm apart from the PEM. We used only two types of substrates: Domestic wastewater as anodic substrate and Hydrogen Peroxide as cathodic substrate. We assumed H$_2$O$_2$ has excess oxygen to share with the outflow of hydrogen from the anode. The electrodes are of graphite and submerged surface area of 87.6 cm$^2$. 
WASTEWATER

Wastewater was collected from a Wastewater Treatment Plant (KNUST, Kumasi - Ghana). This is wastewater coming from the university halls of residence containing faecal, urine, kitchen liquid, bath and others. COD was 1275 mg/L as measured at the GGBL. \( \text{H}_2\text{O}_2 \) was bought from a nearby chemical store in 200 mL bottles (ECL’S, Solution of Hydrogen Peroxide B.P. 20 Volumes – Contains 6% w/v of \( \text{H}_2\text{O}_2 \) with a stabilizer, made in Ghana by Ernest Chemists Ltd.). This was then diluted to 1:4 by part with distilled water. For physics point of view we thought any substrate that readily accept hydrogen from the anode through the cathode exchange membrane can be used, so we selected \( \text{H}_2\text{O}_2 \) which is readily available in nearby chemical shops. We therefore considered its strong oxidizing property.

HYDROGEN PEROXIDE - \( \text{H}_2\text{O}_2 \)

Hydrogen peroxide is the simplest peroxide. It is also a strong oxidizer. Hydrogen peroxide is a clear liquid, slightly more viscous than water. In dilute solution, it appears colorless.

- **Formula:** \( 2(\text{HO}) \)
- **Density:** 1.45 g/cm\(^3\)
- **Melting point:** -0.43 °C
- **Boiling point:** 150.2 °C
- **IUPAC ID:** dihydrogen dioxide
- **Molar mass:** 34.0147 g/mol
- This was to 1:4 by part with distilled water. [8]

PROTON EXCHANGE MEMBRANE (PEM)

The partition has been made from Nafion117. This was taken through the usual washing and pressed onto the container by means of bolt and nuts to make it water-tight for both single and double chamber MFC (Fig. 1a and 1b)

**Single Chamber Cell**

We used graphite rod inside the anode substrate connected to copper conductor outside. Air cathode through platinum doped carbon paper bridged to a copper strip conductor (Fig. 1a).

**Double Chamber Cell**

Graphite rods of dimension 1.2 cm x 3 cm x 10 cm were used in both chambers, thus making the submerged surface area of 87.6 cm\(^2\) as shown in Fig. 1b.

RESULTS AND DISCUSSION

In order to compare the performance of the two cells, both MFCs were operated under ambient conditions; same temperature and pressure (25 ± 0.5, 1 atm). The cells were connected to the Campbell Scientific Datalogger (CR10X) to measure the differential voltage. Data from the two cells were collected every minute for 30 days. Significant portions of the data are shown Fig. 2. The DC-MFC with \( \text{H}_2\text{O}_2 \) cathode performed better and comparatively much higher OCV than SC-MFC using air cathode.

Polarization curves were obtained by varying external resistances from 0 to 10,000 \( \Omega \). Voltage and current in the MFC were measured with a Digital Multimeter (Peak Tech® 2010DMM).
Fig. 3 indicates that generation of current in the double chamber cell is much higher in a relation to the use of H$_2$O$_2$ as an oxidizer.

![Graph showing variation of cell voltage with external resistance.](image)

**Fig. 2.** Electricity generation by single-chamber and double-chamber MFCs

The variation of cell voltage with current density are also shown in Fig. 4. This is based on the fact that the PEM operation surface areas and substrate volumes were the same for both cells. The maximum power occurred at 7.57 mW (6008 mW/m$^2$ base on the operational PEM area) for DC-MFC and 0.46 mW (367 mW/m$^2$ base on the operational PEM area) for SC-MFC respectively. The peak power was obtained at an external resistance of 5000 $\Omega$ and 7000 $\Omega$ for DC-MFC and SC-MFC respectively. This means the internal resistances are equivalent to 5000 $\Omega$ for DC-MFC and 7000 $\Omega$ for SC-MFC as well. Although the distance between the PEM and electrodes for DC-MFC (9.5 cm) is more than that for SC-MFC the cation affinity of H$_2$O$_2$ on the cathode side tends to minimize the internal resistance of DC-MFC as in Fig. 5.
Coulombic Efficiency ($C_E$) for DC-MFC = 9.20 % and for SC-MFC = 1.88 % based on the method proposed by Logan [9]. The efficiency for DC-MFC is thus about 5 times higher than SC-MFC. This indicated that the maximum power produced was as a result of the cathodic $\text{H}_2\text{O}_2$ as portrayed the graphs.

CONCLUSION

The difference between the two cells is that SC-MFC takes oxygen directly from the atmosphere and the DC-MFC derives oxidation from the $\text{H}_2\text{O}_2$. As the anode substrates are from the same source in SC-MFC as well as in DC-MFC, one can conclude that $\text{H}_2\text{O}_2$ might have accounted for the increment in power production.
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REFERENCE