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## Electrostatically enhanced performance of a yeast-based microbial fuel cell

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### Key words

Microbial fuel cells  
Biofuel cells  
Yeast fuel cells

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## Abstract

An electrically insulated electrode was connected via a voltage source to the anode of a compact two-compartment microbial fuel cell, which employed yeast as the anode catalyst. Applying a dc voltage of 0.5 V between the anode and the insulated electrode caused the open-circuit voltage of the cell to increase from 0.3 V to 0.47 V. The dc voltage also extended the operation current and increased the power output of the fuel cell. Since no current was induced in the insulated electrode-anode circuit, therefore no power was delivered by the voltage source to the fuel cell system. The electrostatic method appears as an additional parameter in the design of biofuel cells.

A goal in microbial fuel cell (MFC) research is to use MFCs to generate electricity directly from organic or inorganic matter so that they can be used as power supplies<sup>1</sup>. However, the performance of current MFCs makes the research to achieve this goal remain challenging<sup>2</sup>. The power output and energy output of MFCs critically depend on electron transfer from the microbe to the fuel cell anode, a process that electrically connects the microbe to the electrical hardware<sup>3</sup>. Different approaches have been used to enhance electron transfer in MFCs. Pores and channels on the bacterial membrane created using a chemical method have improved the electron transfer rate and power density of MFC due to increased mediator excretion and enhanced direct electron transfer through the bacterial membrane<sup>4</sup>. It was found that the presence of the anode of a MFC stimulated *P. aeruginosa* to produce pyocyanin to improve electron transfer<sup>5</sup>. A significant amount of previous MFC studies use mediators to transfer

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electrons from the microbe to the anode<sup>1</sup>. The present work was inspired by a recent demonstration that enhanced glucose metabolism in yeast can be caused by applying an external voltage to an electrochemical system with a yeast-immobilized working electrode<sup>6</sup>. The present work shows that the performance of a MFC, which employs yeast, a model microorganism<sup>7</sup>, and glucose as the anode catalyst and substrate, respectively, can be improved by applying an external voltage via an additional electrode to the anode. Figure 1 (a) and (b) show the essential components and the additional electrode-anode system of the MFC, respectively. The applied voltage was observed to improve the MFC's performance by enhancing the fuel cell's open-circuit voltage (OCV), current density and power density.

A double-compartment compact fuel cell with a volume of 100 mL of each compartment was used in this work. The compartments were separated by a Nafion membrane (DuPont 117) with an effective area of 10 cm<sup>2</sup>. The anode and the cathode were each made of a 10 cm<sup>2</sup> rectangular piece of carbon cloth (TP1-120, Toray, Inc.) Current density was calculated based on the area of the anode, which is approximately the same as that of the Nafion membrane. The distance between the anode and the cathode was 2 cm. A reference electrode (Ag/AgCl) was installed in the anode chamber. A voltage source  $V_{\text{appl}}$  was applied between the anode and an additional electrode, which was formed by bending a 0.7 mm-diameter insulator (enamel)-coated copper wire to form multiple turns. Positive  $V_{\text{appl}}$  values are applied between the additional electrode and the anode. Figure 1 (a) shows the schematic structure of the MFC and Figure 1(b) is a cross-sectional view of the additional electrode-anode system.

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*Saccharomyces cerevisiae* or baker's yeast (YSC1, Sigma Aldrich) was used as the biocatalyst for the anode. Dried yeast was cultured for 20 h at 30 °C in a solution containing glucose and peptone. A volume of 80 ml of the cultured medium was mixed with 120 mM glucose, adjusted to pH 7.0 using phosphate buffer saline (PBS) and used as the anolyte. Methylene blue at 50 mM was added to the anolyte as the mediator. The catholyte was 70 mL of PBS with 50 mM of potassium ferrocyanide as the mediator. Initially, the anolyte was purged with dry nitrogen for 50 min. Then, the anode potential and the OCV were measured versus the reference electrode until they became stable. The cathode potential was calculated by subtracting the measured anode potential from the measured OCV without applying  $V_{\text{appl}}$ . The polarization curve was obtained by measuring the cell voltage and the cell current using a multimeter while changing the load resistance. The power was calculated according to power = current x voltage. De-ionized water (18.2 M $\Omega$ -cm) was used to prepare PBS. All measurements were made at room temperature. No current was observed to flow in the additional electrode-anode (secondary) circuit as measured by inserting an ammeter in this circuit during the operation of the fuel cell for the  $V_{\text{appl}}$  used.  $V_{\text{appl}}$  was applied in the absence of yeast and in the presence of lysed cells and no changes in OCV and power density were observed.

Electrochemical measurements were made using a conventional three-electrode electrochemical cell. A commercial Ag/AgCl (3 M KCl) electrode was used as the reference electrode, and a platinum wire was used as the counter electrode. The cell was driven by a

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commercial electrochemical controller (CHI 660C Work Station). A potential scan rate of 20 mV/s was used in recording cyclic voltammograms (CV). Phosphate buffer solution (PBS, 0.1M at pH 7) was prepared using de-ionized water (18.2 M $\Omega$ -cm). All measurements were made with deaerated PBS at room temperature. Reproducible results were obtained by repeating each measurement multiple times.

Cyclic voltammetry of a yeast-immobilized electrode was carried out with the system shown in Figure 1 (b) as the working electrode to study the effect of  $V_{\text{appl}}$ . Figure 2 shows the cyclic voltammograms (CVs) obtained using a yeast-immobilized graphite electrode in a glucose solution under different conditions. CV1 was obtained in PBS whereas CV 2 was obtained with glucose added to the PBS. CV1 and CV2 show a pair of weak redox peaks indicated by the arrows with a formal potential at 100 mV vs. Ag/AgCl. These peaks are the redox peaks of yeast<sup>8</sup>. The new pair of redox peaks in CV3 is due to adding the mediator to the anolyte. With  $V_{\text{appl}} = 0.5$  V and 0.7 V, this pair of peaks becomes progressively enhanced due to enhanced cellular electron transfer as the result of charge polarization induced by  $V_{\text{appl}}$ . This possibility is described below. Therefore,  $V_{\text{appl}}$  appears to cause an increase in the mediated glucose oxidation current. Previously, the increased glucose oxidation current caused by a voltage applied to yeast immobilized on a working electrode was shown to be the result of enhanced glucose metabolism in yeast<sup>6</sup>.

The properties of the MFC were characterized by measuring its OCV, polarization curve and power curve. Figure 3 (a) shows the anode potential, the cathode potential and the OCV of the

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MFC. The cathode potential was shown to be 0.57 V with and without  $V_{\text{appl}}$ . The anode potential and OCV measured with  $V_{\text{appl}} = 0$  V is 0.27 V and 0.3 V, respectively. With  $V_{\text{appl}} = 0.5$  V, the anode potential was measured to be 0.10 V and the OCV 0.47 V. Figure 3 (b) shows the polarization curve (voltage vs. current) and the power curve (power vs. current) of the MFC for three values of  $V_{\text{appl}}$ . The application of  $V_{\text{appl}} = 0.5$  V appears to have extended the maximum operation current density of the MFC from 9.5 mA/m<sup>2</sup> to 22 mA/m<sup>2</sup>. Both polarization curves show insignificant activation loss presumably due to the use of the mediators. The polarization curves show that the extended operation current is accompanied by a reduced concentration loss.  $V_{\text{appl}}$  caused the peak power density to shift from 6.5 mA/m<sup>2</sup> to 14 mA/m<sup>2</sup> and boosted the magnitude of the peak power from 145 mW/m<sup>3</sup> to 200 mW/m<sup>3</sup>. No current was measured in the secondary circuit that contains  $V_{\text{appl}}$ . Therefore no power was delivered by the voltage source to the fuel cell system.

The improved performance of the MFC is believed to be due to enhanced electron transfer caused by  $V_{\text{appl}}$  within the anode compartment. This presumption is evidenced by the lowered anode potential and by the extended MFC operation from 9.5 mA/m<sup>2</sup> to 22 mA/m<sup>2</sup>. Previously, it was demonstrated that applying an external voltage from an insulated electrode to a glucose oxidase (GOx)-immobilized working electrode of a modified three-electrode electrochemical cell resulted in enhanced glucose oxidation current<sup>9</sup>. The effect was explained as enhanced electron transfer between the active site of GOx and the electrode due to the reduced height of the polypeptide tunnel barrier. The applied voltage re-arranged the ionic charge distribution at the solution-electrode interface inducing an electric field about the enzyme. The field reduced

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the tunnel barrier height and therefore increased electron transfer rate<sup>10</sup>. A recent work shows that an external voltage similarly applied to yeast immobilized on an electrode causes enhanced rate of glucose metabolism<sup>6</sup>. Cellular glucose metabolism involves different redox enzymes such as dehydrogenases. Envisioned scenarios are the reduction of NAD<sup>+</sup> to form NADH by glyceraldehyde-3-phosphate dehydrogenase in glycolysis or by alcohol dehydrogenase for maintaining redox balance of the cell<sup>11</sup>, either or both processes being influenced by the induced field. The enhanced electron transfer caused by the induced field results in rapid recycling of the NADH/NAD<sup>+</sup> redox couple due to its interaction with the enzymes. In the present work,  $V_{\text{appl}}$  may have caused similar modification to electron tunnel barrier in several processes in the anode compartment by causing polarization in the yeast, resulting in enhanced electron transfer leading to enhanced glucose metabolism.

This work shows that applying a dc voltage to the anode of the yeast-based MFC enhances the cell performance. The improved performance is reflected in OCV, the polarization curve and the power curve. Since the improved performance does not require the dc voltage to supply extra energy on the fuel cell, the electrostatic method appears to be a viable way to boost up the output of MFCs. The method is applicable to generic MFCs. This work indicates that the applied voltage functions as an additional operation parameter and should be considered in the design of biofuel cells. Our on-going study of the effect is focused on the scaling-up of MFCs.



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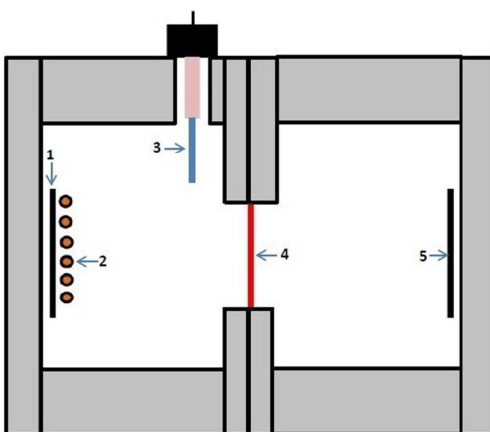
## References

## Captions

Figure 1 (a) A schematic description of the MFC, showing the essential components. (b) A schematic description of the additional electrode-anode system.  $V_{\text{appl}}$  is applied between the anode and the additional electrodes, which are electrically connected.

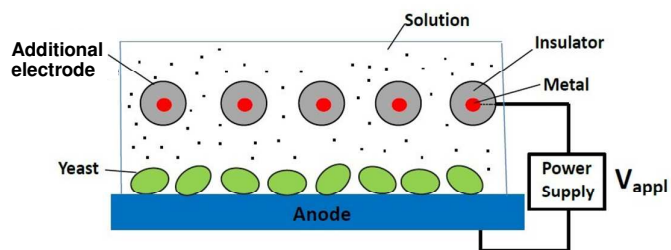
Figure 2 CVs of yeast-immobilized electrode under different conditions.

Figure 3 Characterization of MFC: (a) Anode potential, cathode potential and OCV, (b) Polarization curve and power curve.



- 1 Anode                      2 Additional electrode  
3 Reference electrode      4 Proton exchange membrane  
5 Cathode

(a)



(b)

Figure 1

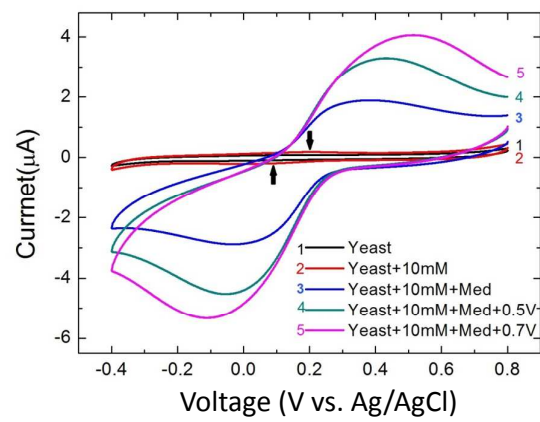


Figure 2

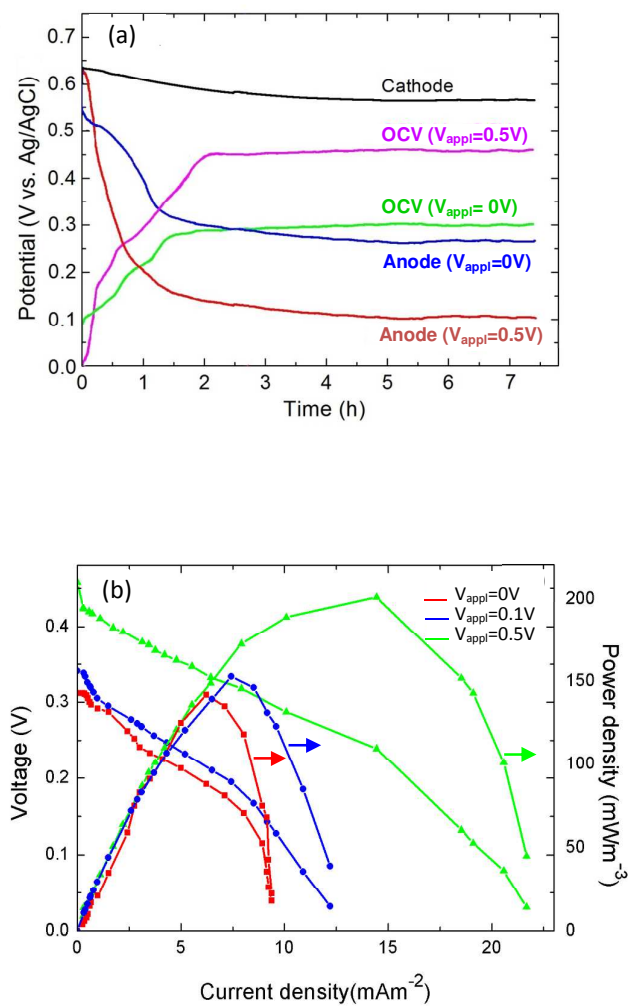


Figure 3

The performance of a yeast MFC is improved by applying a dc voltage  $V_{\text{appl}}$  to its anode without causing extra energy spent on the MFC.

