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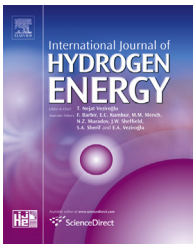

Factors that influence the performance of two-chamber microbial fuel cell

Qibo Jia, Liling Wei, Hongliang Han, Jianquan Shen**

Beijing National Laboratory for Molecular Sciences (BNLMS), Key Laboratory of Green Printing, Institute of Chemistry, Chinese Academy of Sciences, Beijing 100190, PR China

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ABSTRACT

The two-chamber microbial fuel cell (MFC) was operated in batch mode, using acclimated hydrogen-producing mixed bacteria as the anodic inoculum, artificial sucrose wastewater as the substrate (sucrose concentration 10.0 g/L). The performance of the MFC was analyzed at different anodic pH microenvironments, such as the initial pH of the anolyte of 8.57, 7.3, 7.0 and 6.0, respectively, while anodic pH-controlled of 7.3 and 7.0. It showed that the best performance was obtained when the MFC was carried out at anodic pH-controlled of 7.3. Taking the interaction of factors into consideration, we adopted response surface methodology (RSM) to investigate the effects of sucrose concentration, operating temperature and ferrous sulfate concentration on the performance of MFC. The optimum condition for maximum output voltage of the two-chamber MFC (external resistance 1000 Ω) was thus obtained.

Introduction

In our energy-based society, the value of any energy-rich matters is increasing. Consequently, the high organic load in wastewater is no longer seen as waste, but instead as a valuable energy resource. The simultaneous production of energy and the degradation of contaminants in wastewater can provide economic and environmental benefits from microbial fuel cells (MFCs) [1–3].

Two-chamber microbial fuel cell consists of anode and cathode chamber, separated by a proton exchange membrane (PEM). Microorganisms grow in the anode chamber, and the organic matter is oxidized by microbes to produce electron. In this case, anodic operating conditions play a significant role in the overall performance of MFC. Among those operating conditions, the selection of anodic pH value is critical, which will ensure not only the growth and reproduction of microorganism under the best condition but also the efficient movement of protons through PEM [4–6].

Researches [7,8] shown that the maximum current of the MFC was generally obtained at the anodic pH value of 7–8, but the current decreased when the anodic pH value exceeded 9 or was below 6. Raghavulu et al. [9] indicated that acidophilic pH (pH = 6) in anodic chamber showed effective performance with respect to power output compared with the corresponding neutral (pH = 7) and alkaline (pH = 8) operations. Similarly, Liu et al. [10] believed that the optimal pH value for the growth and reproduction of anaerobic microbial is about 6. While, according to our previous work, we also found an effect of anodic environment on the generation and movement of protons [11]. For these reasons, it is particularly important to study the impact of anodic pH value on the electricity generation.

* *Corresponding authors*. Tel.: +86 10 61934539; fax: +86 10 62559373.
E-mail addresses: weill@iccas.ac.cn (L. Wei), jqshen@iccas.ac.cn (J. Shen).
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Many factors can influence the performance of MFC. The present researches are mostly based on a single condition, ignoring the interaction of various factors. Therefore accurate optimization results cannot be obtained. Response surface methodology (RSM), a collection of mathematical and statistical techniques for empirical model building, can be used to analyze the interaction of different factors on the MFC output voltage. Teng et al. [12] studied the effect of mixed volatile fatty acids (VFAs) (acetic acid, propionic acid and butyric acid) on the electricity generation of microbial fuel cell, utilizing RSM to explore the relative contribution to the electricity generation of the three kinds of acid and the interaction of them. He found that formation of the anode biofilm is rapid when using mixed VFAs as substrate. According to our previous work [11,13,14], we believe it is necessary to use RSM to investigate the effects of the interaction of sucrose concentration, operating temperature and ferrous sulfate concentration on maximum output voltage and the optimal operating conditions of two-chamber MFC, though it is not an often used method in MFC researches [15–17].

Materials and methods

MFC configuration

The two-chamber MFC consisted of two plexiglass bottles, serving as an anode and a cathode, each with an operating volume of 1 L. The carbon paper (5 × 5 cm each), proton exchange membrane (PEM), adjustable resistor and data acquisition system (DAS) were used in the system as previously described [11,13,14].

MFC inoculation and operation

The hydrogen-producing mixed bacteria were taken from a completely stirred tank reactor (CSTR) producing fermentative H_2 that treated artificial sucrose wastewater for more than one year [18,19]. The acclimated mixed cultures were used as inoculum in the anode chamber of MFC for electricity generation, operating in batch mode. In the anode chamber, sucrose was degraded by mixed bacteria to produce electrons, protons and fatty acids, and no biogas was detected at a steady state condition. Experiments were divided into two series in order to study the effects of different anodic pH microenvironments on the electricity-generation characteristics of MFC and the interaction of sucrose concentration, operating temperature and ferrous sulfate concentration on maximum output voltage.

To explore the effect of different anodic pH microenvironment on MFC performance, the MFC was operated at six different initial pH of the anolyte of 8.57, 7.3, 7.0 and 6.0, or anodic pH-controlled of 7.3 and 7.0, identified as $M_{pH}1$, $M_{pH}2$, $M_{pH}3$, $M_{pH}4$, $M_{pH}5$ and $M_{pH}6$, respectively. After addition of 200 mL inocula and 800 mL medium to the anode chamber, the air was removed from the headspace by argon gas sparging for 5 min. The culture medium composition used in the system is derived from the patent [20]. 1 L of culture medium consisted of sucrose 10.0 g; NH_4HCO_3, 3770 mg; Na_2CO_3, 2000 mg; K_2HPO_4, 125 mg; $MgCl_2{\cdot}6H_2O$, 100 mg; $CuSO_4{\cdot}5H_2O$, 5 mg; $MnSO_4{\cdot}4H_2O$, 15 mg; $FeSO_4{\cdot}7H_2O$, 25 mg; $CoCl_2{\cdot}6H_2O$, 0.125 mg. The bottles were then capped with rubber septum stoppers and placed in an incubator at a temperature of 35 °C. Bacterial concentration in anode chamber was determined by measuring the optical density at 660 nm (OD_{660}) with a UNICO7200 spectrophotometer (UNICO Co., Shanghai, China). The pH was measured with a pH meter (PHB-9901-3C, Shanghai, China). The initial OD_{660} of the anolyte was 0.744. The cathode chamber was filled with phosphate buffer solution (PBS). The initial pH of PBS was adjusted to 7, and 1 L of catholyte consisted of Na_2HPO_4, 20.7492 g; NaH_2PO_4, 3.1167 g, $K_3Fe(CN)_6$, 32.93 g. The MFC was operated in a batch mode. Each experiment was repeated at least three times, with all data reported as the average of replicate experiments. The external resistance of the set was initially 100 kΩ and then changed to 2000 Ω after 48 h of operation. After the internal resistance test (the time period between 50 and 75 h), the external resistance was changed to 1000 Ω and all tests were operated under this condition for 525 h.

A central composite design (CCD), with three variables, was used to determine the optimum operating conditions of two-chamber MFC (external resistance 1000 Ω) based on the maximum output voltage. The effect of the independent variables X_1 (sucrose), X_2 (temperature) and X_3 (ferrous sulfate), at five variation levels on maximum output voltage, is shown in Table 1. The composition of anolyte and catholyte are the same as above-mentioned except the cathodic electron acceptor of potassium permanganate. In addition, the initial OD_{660} and pH of the anolyte were 0.462 and 9.16. The external resistance of the set was 1000 Ω. Maximum output voltage value was an average of 2 days' data after output voltage reached maximum.

For statistical calculations, the natural variable X_i was coded as x_i according as the Eq. (1).

$$x_i = (X_i - X_i^*)/\Delta X_i \quad (1)$$

where x_i is a dimensionless coded value of the variable X_i, X_i^* is the value of X_i at the center point and ΔX_i is the value of the step change.

The average yield of the triplicate values obtained was taken as the dependent variable or response, Y. The model proposed for the response is given below:

$$Y = \beta_0 + \sum \beta_i x_i + \sum \beta_{ii} x_i^2 + \sum \beta_{ij} x_i x_j \quad (2)$$

where Y is the desirable response, β_0 is an offset term, β_i is the liner effect, β_{ii} is the squared effect and β_{ij} is the interaction effect.

Analysis

Voltage was continuously measured by a multimeter with a data acquisition system. Current (I) was calculated from the voltage (V) by $I = V/R_e$, where R_e is the external resistance. Power (P) was calculated as $P = IV$. Power density was obtained according to $P_A = IV/A$, where A is the anode surface area. Volatile fatty acids (VFAs, C2–C5) and the alcohols were measured by a gas chromatograph (GC 14B, SHIMADZU Co., Japan) using a flame ionization detector (FID) and a 2-m glass column packed with GDX-203 (30/60 mesh). The concentration