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Effect of inert particle concentration on the operation of a microbial fuel cell

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ABSTRACT

Considering the promising application of microbial fuel cells (MFCs) in the wastewater treatment, the inherent solid particles in the wastewater may affect the MFC performance. In this paper, the effect of inert particle concentration on the operation of MFCs is investigated by adding silicon dioxide (SiO_2) particles into the anolyte. The results show that the existing SiO_2 particles in the anolyte result in a decreased active biomass and a reduced electrochemical activity of the biofilm. The anode ohmic resistance is almost the same for MFCs with various SiO_2 particle concentrations in the anolyte, while an increase in the charge transfer resistance is observed. A small amount of inert particles have little influence on the MFC. However, when the MFC is operated with the anolyte containing more than 500 mg L^{-1} SiO_2 particles, the performance decreases significantly due to the low electrochemical activity and high internal resistance of the anode.

Introduction

Microbial fuel cells (MFCs) have attracted much attention because of its unique advantage of simultaneous wastewater treatment and electricity production [1–4]. In recent years, much effort has been made to improve the power density of MFCs on aspects including anodic electron transfer mechanism [5,6], biofilm formation [7–9], electrode materials [10–12], operating conditions [13,14] and configuration design [15]. However, the commercial application of MFCs is still hindered by low power output and high cost [16,17].

The organic substrates in wastewater, which serve as the carbon and energy source in MFCs, are biologically oxidized by microorganisms to generate electricity. Therefore, the characteristics of the wastewater, especially the chemical composition and the concentrations of components, play an essential role in the efficiency and economic viability of MFCs [18,19]. A great number of substrates can be used as fuels for MFCs including pure compounds (such as acetate, lactate and glucose) and complex mixtures of organic matter in industrial and domestic wastewater. It has been reported that not only the anodic biofilm communities but also the Coulombic efficiency (CE) and power output vary with different substrates [20]. Liu et al. [21] also found that the operational performance and electrical response of MFCs depended on the carbon source fed. Compared with butyrate, acetate was demonstrated as a preferred substrate for electricity production in a

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single-chambered MFC [22]. Besides the variety of the substrate, the concentration of the substrate influences the performance of MFCs as well. Generally speaking, the power output is enhanced by increasing the substrate concentration [23]. However, the substrate inhibition effect may occur at excessively high concentrations of the substrate [24,25].

Owing to the complexity of components in the real wastewater, pure organic compound is always used in most experimental studies of MFCs [7,8,10–12,14,16,20–22,24,25], while synthetic or real wastewater is becoming increasingly popular in recent investigations [13,15,23,26,27]. It is pointed out that although employing similar design, the MFC with acetate seems to achieve higher power density than that with swine wastewater or domestic wastewater [18]. Besides organic and inorganic matters, there are many inherent inert solid particles in real wastewater. In the wastewater treatment plants, larger solid particles can be removed by deposition and filtration, while the smaller ones may suspend in the wastewater and further affect the MFC performance significantly. Therefore, it is necessary and important to understand the effect of inert suspended solids on the operation of a MFC.

In this study, silicon dioxide (SiO_2) particles were added into the substrate during the operation of MFCs to simulate the inert suspended solids in the real wastewater. The morphology of the anode biofilm was analyzed via scanning electron microscope (SEM) images. The electrochemical activity and internal resistance of the anode were characterized by cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) tests, respectively. The effect of SiO_2 particle concentration on the performance of the MFC was finally discussed.

Materials and methods

MFC construction and operation

Five flat plate two-chamber MFCs were constructed in this study. Each MFC comprised a Nafion® 117 proton exchange membrane, two carbon cloth electrodes (5 cm × 5 cm) and two fixture plates, which were made of plexiglass and a serpentine flow channel (volume, 2.7 mL) was machined on its surface. The electrodes were connected to an external resistor box by titanium wires.

MFCs were inoculated simultaneously from the effluent of an acetate-fed MFC. The culture medium, containing 0.68 g CH_3COONa (COD of 500 mg L^{-1}), 6 g Na_2HPO_4, 3 g KH_2PO_4, 0.5 g NaCl, 0.1 g NH_4Cl, 0.1 g $MgSO_4 \cdot 7H_2O$, 15 mg $CaCl_2 \cdot 2H_2O$ and 1.0 mL trace elements solution per liter, was fed to the anode. After successful start-up, SiO_2 particles (D50 = 4.738 μm) were added into the culture medium. MFCs operated with culture medium containing 0, 200, 500, 1000 and 2000 mg L^{-1} SiO_2 particles were denoted as MFC-0, MFC-200, MFC-500, MFC-1000 and MFC-2000, respectively. Before flowing into the anode, the culture medium with SiO_2 particles was dispersed by a magnetic stirrer all the time. A 50 mM potassium ferricyanide solution was supplied to the cathode in the experiment. During the start-up process and the steady state operation, an external resistance of 50 Ω was used. The anolyte (culture medium with or without SiO_2 particles) and catholyte were supplied continuously by two peristaltic pumps at a flow rate of 1.5 L day^{-1}, respectively. To determine whether the MFC voltage reached steady state, fed-batch tests were conducted, in which the effluent anolyte was recycled to the anode. However, during the operation and performance test, to maintain adequate substrate for the anode, the effluent anolyte was not recycled but expelled directly from the anode. Two Ag/AgCl reference electrodes were employed at the anode and cathode to obtain the individual electrode potentials. All the experiments were conducted at 30 ± 1 °C in a temperature-controlled chamber and repeated three times.

Analytical methods

The surface and cross-section morphology of the biofilm under different SiO_2 particle concentrations was analyzed by a scanning electron microscope (SEM) (Nova 400, FEI). The SiO_2 content in the biofilm was determined by dissolving the carbon cloth with biofilm in aqua regia. The active biomass content in the biofilm was evaluated by the phospholipid analysis [28]. The phosphate concentration released from the phospholipid was measured by a spectrophotometer (Leng Guang 756 mc, China) at 610 nm.

The cell voltage (U) and electrode potentials of the MFC were collected by an Agilent 34,970 data acquisition unit. To obtain polarization curves, the external resistance was varied in a range of 2–10^5 Ω. The voltage of the MFC was recorded until the fluctuation of the voltage was less than 1 mV in 5 min and the steady time kept at least 20 min. Current (I) can be determined by Ohm's law and output power density by the following equation: $P = U \times I/A$, where A was the surface area of the electrode. Unless specified otherwise, the electrode potentials were quoted versus Ag/AgCl reference electrode.

Cyclic voltammetry (CV) and Electrochemical Impedance Spectroscopy (EIS) tests were conducted by a Zennium electrochemical workstation (Zahner, Germany). CV experiments were performed on the anode in the potential range from −0.4 V to 0.3 V (vs. SHE) at a scan rate of 1 mV s^{-1}. Electrochemical Impedance Spectroscopy (EIS) was carried out on the anode using the anode as the working electrode and the cathode as the counter electrode and the reference electrode. Nyquist plots were recorded under the closed circuit with an external resistance of 1000 Ω. The AC amplitude was 10 mV and frequency was varied from 100 kHz to 10 mHz.

Results and discussion

Cell voltage

After startup, MFCs were operated with the culture medium containing different SiO_2 particle concentrations. Cell voltages reached stable after 5 days, which was demonstrated in the fed-batch test and the result is shown in Fig. 1. It can be seen that the maximum cell voltage of each MFC remains almost the same from the second to the fourth feeding cycle, suggesting the biofilm has reached the steady state again after adding SiO_2 particles into the culture medium. In addition, when SiO_2 particle concentration is higher than 500 mg L^{-1}, an obvious drop in the maximum output voltage is observed