Journal of Power Sources 253 (2014) 177–180

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Short communication

Promotion of anodic electron transfer in a microbial fuel cell combined with a silicon solar cell

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HIGHLIGHTS

- A traditional MFC and a silicon solar cell (SSC) are combined to build a novel MFC–SSC.
- Cell performances are significantly promoted by the SSC in MFC–SSC.
- Anodic microbial oxidation of organic substrate is enhanced in MFC–SSC.
- The SSC is compatible to promote the whole system without influencing anodic microbial reactions.
- Cooperation of anodic microorganisms and SSC improves electron transfer efficiency in the MFC–SSC.

ARTICLE INFO

Article history:
Received 25 September 2013
Received in revised form
23 November 2013
Accepted 9 December 2013
Available online 18 December 2013

Keywords:
Microbial fuel cell
Silicon solar cell
Electron transfer
Anode potential
Microbial oxidation

ABSTRACT

This study focuses on the promotion of electron transfer in microbial fuel cells (MFCs) by equipping a silicon solar cell (SSC) into the circuit. As compared to a sole MFC, a significant improvement of power output is observed in the MFC–SSC, that the maximum power density increases from 7.5 W m^{-3} –19 W m^{-3} by 2.53 times. A linear relationship between anodic potential and current has been observed when the current is below the limiting point of SSC. We estimate the electron transfer rate can be promoted in a MFC–SSC under the condition that the anodic microbial reactions are unaffected by the incorporation of a SSC. In this way, the anodic electrons are fully pumped and enter into the external circuit. This estimation is thereby demonstrated by the 24-h test, which shows the quantity of the electrons fluent in the circuit of a MFC–SSC is doubled and the microbial oxidation efficiency is improved to 341.6% as compared with a sole MFC.

1. Introduction

Microbial fuel cell (MFC) is a well-known bioelectrochemical device mainly used for power generation and contaminant remediation [1–4]. The efficiency of a MFC is influenced by many factors, such as electricigens, electrode material, electron donor and accepter species, equipment configuration, et al. [5–7]. In essence, all these factors are correlated with electron transfer processes. For examples, electricigens controls electrons transfer from organic substrates to anode electrode, and cathodic materials affect electrons transfer from cathode electrode to electron acceptors. Therefore, optimizing those factors to accelerate electron transfer rate would eventually improve the performance of MFCs [8]. Among those electron transfer processes, the anodic microbial electron transfer is critical to the whole MFC performance [9], principally because all electrons are produced from the oxidation of anodic "fuels" by microorganisms. Various methods have been applied to promote the microbial electron transfer rate, such as inoculating mixed microbial community, adding electron mediators, replacing electrode materials and optimizing electrode and cell design [10–13]. Specially, applying a potentiostat to fix the MFC's anode potential at a constant value was demonstrated to be an effective method to improve the electron transfer efficiency from microbes to anode [14,15]. However, it caused extra electric energy consumption, which is contradictory to the primary intention of operating a MFC in a cost-effective way.

Silicon solar cell (SSC), which is a stable, low cost and commercialized power generation device, can transform solar energy into electric energy. We previously found the combination of MFC with SSC could provide higher power output [16]. However, it has been so far unclearly known such a power promotion was achieved by what mechanisms. Moreover, the issues about the compatibility of SSC with MFC, the influences of SSC on anodic

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http://dx.doi.org/10.1016/j.jpowsour.2013.12.047

microorganisms of MFC, and the cooperating mechanisms of MFC with SSC were not discussed before. In this study, we optimized the MFC–SSC system by taking into consideration of the compatibility of SSC and MFC. In order to explore the electron transfer mechanisms, the performances of a sole MFC, a sterilized MFC–SSC and a MFC–SSC were compared in terms of power output, potential variation, anodic substrate oxidation efficiency and electron transfer efficiency. By virtue of the simple configuration and good performance, the MFC–SSC was believed to be highly applicable in practical fields of clean energy production and environmental remediation.

2. Experimental

2.1. Experimental setup construction and operation

A single-chambered MFC was used in this study, which was a U-shaped glass reactor with inner diameter of 5 cm and volume of 120 mL for each side. Both of anodic and cathodic electrodes were carbon felt (Sanye Carbon Co., Ltd, Beijing, China) of 0.5 (in thickness) × 10 (in width) × 10 (in length) cm^3 with 9 cm distance from each other. The cell was filled with a medium based on PBS, which contained 10.31 g L^{-1} $Na_2HPO_4{\cdot}12H_2O$, 3.31 g L^{-1} $NaH_2PO_4{\cdot}2H_2O$, 0.31 g L^{-1} NH_4Cl, 0.13 g L^{-1} KCl, 1.64 g L^{-1} CH_3COONa and 0.25 g L^{-1} yeast extract. The initial pH of the medium was 7.0 ± 0.2.

The anode was inoculated with anaerobic activated sludge (10% in volume ratio) which was collected from Gaobeidian Wastewater Treatment Plant (Beijing, China). It had been cultured for 1 month to make a stable biofilm attachment on the carbon felt. The cathodic chamber was slowly bubbled with sterile air to supply dissolved oxygen as electron acceptor. All experiments were carried out at 32 ± 2 °C to keep the microbial activity.

A commercial SSC and a resistor were in series connected with a MFC. The SSC's positive terminal was connected with the MFC's anode and the SSC's negative terminal was connected to the resistor and the MFC's cathode. A Xeon lamp with a UV and IR filter (PLS-LAX500, Trust Tech Co., Ltd, Beijing, China) was used as the light source and placed away from the SSC surface at a distance of 1 m. The illumination area of the SSC was 0.4 × 0.4 cm^2. When the illuminating intensity reached 1.8 mW cm^{-2}, the SSC could be fully activated and provide an open circuit voltage (OCV) at about 600 mV and a maximum current at about 3.3 ± 0.1 mA with an internal resistance of 20 Ω. Decreasing the illuminating intensity resulted in the part inactivation of SSC with an extreme large internal resistance, which would inevitably affect the performance of the cell system. Therefore, the illumination intensity was fixed at 2 mW cm^{-2} to ensure SSC can be fully activated and kept stable in the MFC–SSC system.

For all experiments, a MFC, a MFC–SSC and a MFC–SSC with sterile anode (called "sterilized MFC–SSC") were operated in parallel for performance comparison.

2.2. Electric data collection and potential analysis

The voltage of the external resistor was continuously monitored by a data-logger (ADC-16, Pico technology, UK) and recorded by a linked computer. The current was calculated by Ohm's Law. For polarization and power density analysis, the resistor was gradually alternated from disconnection to 0.1 Ω (nearly short circuit). After each resistance change, the cell was stabilized at least 10 min to allow the microbial adaptation [17]. The system resistance and the maximum power output were calculated from polarization curve and power density curve, respectively. In order to facilitate the comparison of MFC–SSC with SSC, current value was used as the *X*-axis instead of current density. For potential analysis, a saturated calomel electrode (SCE, 0.242 V vs. NHE, 25 °C) was placed closely to each electrode, and a UT-33B digital voltmeter was used to measure the electrode potential.

2.3. Calculation of microbial fuel oxidation and electron generation efficiency

To measure the anodic microbial fuel oxidation and electron pumping efficiency, the external resistor was fixed at 1000 Ω, and the MFC was operated in batch mode. When the performance of each batch got steady, it was refilled with fresh medium for the next operation.

5 mL sample were taken from the medium at 0 and 24 h, which were then filtered with 0.22 μm millipore filters and diluted to 1/3 for COD (chemical oxygen demand) measurements. COD was measured by potassium dichromate photometric method with a HATO CTL-12 COD analyzer (Chengde HATO environmental instrument Co., Ltd, China) at 600 nm. The resistor voltage was also monitored to get the current data, which was then converted into the numbers of electrons by integral operation. The COD values were also converted into the equal numbers of electrons by a 1:8 ratio because oxidation of 1 mol acetate to H_2O and CO_2 gives 8 mol electrons. The microbial oxidation efficiency (MOE) was defined as the oxidation rate of organic substrate (acetate in this study) by anodic microorganisms, which was calculated by measuring the decrease of acetate per unit time. The anodic coulomb efficiency was calculated basing on the ratio of the electrons in the real circuit and the equivalent electrons of COD.

3. Results and discussion

3.1. Power generation in MFC, sterilized MFC–SSC and MFC–SSC

The polarization and power density curves of MFC, sterilized MFC–SSC and MFC–SSC were shown in Fig. 1. The OCV of MFC–SSC was 1208 mV, which was nearly double of the value in sole MFC (665 mV). The system resistance of MFC–SSC (120 Ω) was a little higher than that of MFC (99 Ω), which was due to SSC itself has an internal resistance of 20 Ω under light. The maximum power density of MFC–SSC was 19 W m^{-3}, much higher than that of MFC (7.5 W m^{-3}), indicating a great improvement of electron transfer efficiency by incorporation of SSC into MFC.

It should be noticed that the OCV of MFC–SSC closely approximated the sum of MFC (665 mV) and SSC (600 mV), and its internal

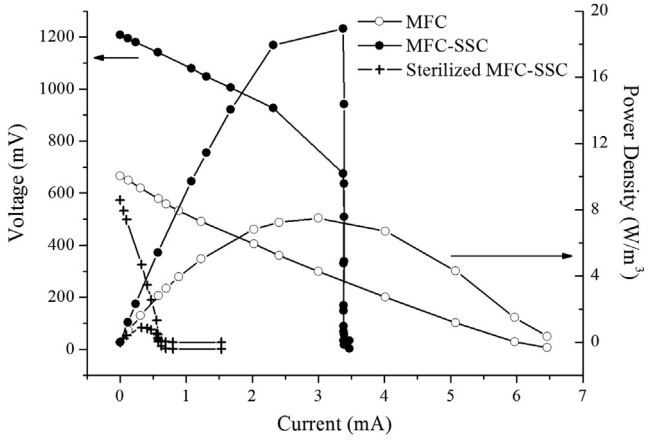

Fig. 1. Polarization and power density curves of MFC, MFC–SSC and sterilized MFC–SSC.