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Effects of the presence of sheet iron in freshwater sediment on the performance of a sediment microbial fuel cell

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ABSTRACT

In this study, we demonstrate the effect of iron sheet on the output power of sediment microbial fuel cells (SMFCs). An SMFC with iron sheet present, but not in the circuit (SMFC-GF-iron) displayed a maximum power density of 63 mW m^{-2}, whereas we find 37 mW m^{-2} for that SMFC with the iron sheet not present (SMFC-GF). Furthermore, the SMFC with an iron sheet in the circuit (SMFC-iron) had a maximum power density of 170 mW m^{-2}. The effect of sheet iron, out of the circuit, was to improve the iron reduction microbial activity, while, within the circuit, it produced a large number of electrons from the electrochemical corrosion yielding higher power production. The study suggests that the addition of iron sheet to an SMFC is an easy and effective method for enhancing the output power of SMFCs.

Introduction

A Microbial fuel cell (MFC) is a device that uses bacteria to directly convert chemical energy presented in organic substrates [1,2] into electricity. The sediment microbial fuel cell (SMFC) is a type of MFC configuration, which harvests electricity from organic matter present in aquatic sediments. SMFCs typically consist of an anode embedded in the anaerobic sediment and a cathode suspended in the aerobic water column above the anode [3]. SMFCs could be used as power sources for instruments deployed in marine and lake

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environments for long-term monitoring [4–6], due to their simple design and the rich organic matter available in the sediments. In addition, SMFCs could be applied for in situ sediment remediation, augmenting the removal of organic matter from these sediments [7–9].

The performance of a SMFC might be affected by various factors. For the cathode in SMFCs, the low oxygen reduction rate is one of the important limiting factors. In order to increase the output power, the application of a catalyst can be performed at the cathode [10] to improve the oxygen reduction rate. Alternatively, the oxygen availability can be increased by rotating the cathode [11] or by use of an algae-assisted cathode [12]. The low mass transfer rate in the anode region is one of the major limiting factors for output power. Several methods have been demonstrated to improve SMFC performance, by either increasing the organic content via addition of plant rhizodeposits [13], biomass like chitin [14] or cellulose [15], or the improvement of sediment conductivity by the addition of graphite flakes [16] or the in situ formation of silica colloids [17].

The iron reduction pathway is an important biogeochemical process in freshwater sediment [18]. Kato et al. [19] reported that sediment contained iron minerals in different oxidation states and that the iron oxides could mediate electron transfer using microbes as electron conduits [20]. Based on this hypothesis, Zhou et al. [21], improved SMFC performance by amendment of colloidal iron oxyhydroxide into these sediments and concluded that high Fe(II) concentration in the pore water of these sediments led to higher power production.

Iron sheet may rust in aqueous solution, and produce ferrous iron or iron oxide [22]. Therefore, the addition of iron sheet might have an interesting effect on the performance of the SMFC. In this study, iron sheets were added into the SMFCs in a variety of ways. All the SMFCs were operated for about three months. The performance differences of these SMFCs are explained through in-depth analyses.

Materials and methods

SMFCs construction and operation

The sediments (0–10 cm below the sediment–water interface) were obtained from the sediment–water interface of a stream in Nanjing Tech University, China and passed through a 0.5 cm sieve to remove coarse debris. Plexiglass columns with an inner diameter of 110 mm and a height of 150 mm were used for constructing SMFCs. In total, 6 SMFCs, including 3 pairs of SMFCs, with their various anode conditions, were set up in this study. Each SMFC contained 700 g wet sediment and 500 mL water. In each, the anode was buried below the sediment–water interface and the graphite felt cathode was suspended in the overlying water. In the set called SMFC-GF-iron, graphite felt was used as anode and placed along a polyvinyl chloride cylindrical holder (31.8 cm^2 EFA). 16 pieces of sheet iron (15 mm × 50 mm) were inserted into the sediment around the polyvinyl chloride cylindrical holder (about 10 mm distant), but out of the circuit. In the set called SMFC-iron, 16 pieces of sheet iron (15 mm × 50 mm) was placed along a polyvinyl chloride cylindrical holder inserted into the sediment and used as the anode. In the set called SMFC-GF, the graphite felt was used as the anode, without the addition of sheet iron. Sediment without the SMFC was used as a control. The SMFCs were operated at a fixed external resistance of 1000 Ω and maintained at 25 °C.

Analysis

The voltages produced by the SMFCs during the experiments were recorded at an interval of 30 min, using a precision multimeter and a data acquisition system (Keithley Instruments 2700, USA). The external resistor was varied over the range of 50–2000 Ω to obtain polarization curves. Voltage was converted to power density based on the footprint area of the anode [23]. Tafel plots (log [Current density] versus overpotential, η) were used to evaluate the electrode electrochemical characteristics by a CHI660C electrochemical workstation (CH Instruments, Chenhua Instrument Co., China) with a three-electrode system, consisting of the sediment imbedded anode as the working electrode, an Ag/AgCl (saturated KCl) reference electrode, and the cathode in the overlying water as counter electrode. Tafel plot testing was performed by sweeping voltages from 0 to 0.1 V at 1 mV s^{-1}. The loss on ignition (LOI) of the sediment was determined by weighing the sample before and after combustion at 550 °C for 4 h [8]. Potential ferric reduction rate (FeR) was measured according to literature report [21].

Results

Electricity generation from SMFCs

The voltages of both the SMFC-GF and the SMFC-GF-iron were low during the first day of operation and increased quickly during the initial period of 15 days (Fig. 1). This phenomenon might be due to the formation of an electrochemically active biofilm on the anode surfaces during the initial reaction phase. Although the voltage of the SMFC-GF-iron and the

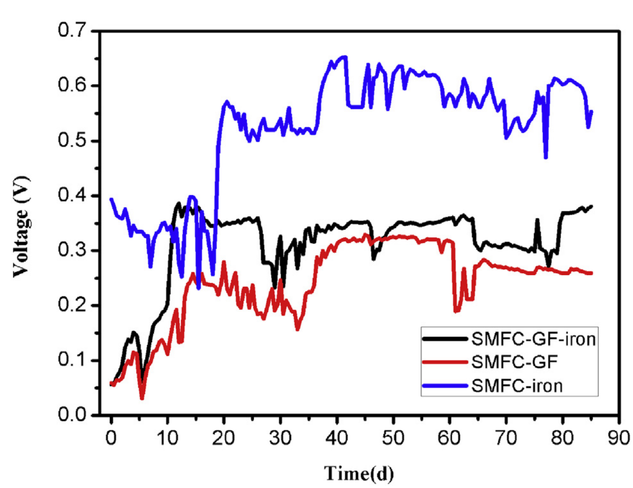

Fig. 1 – Voltage generation produced by the SMFCs with different anodes.