INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–8

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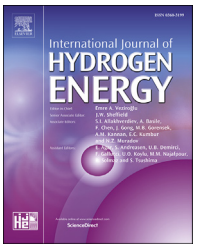

Effects of brush-anode configurations on performance and electrochemistry of microbial fuel cells

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ARTICLE INFO

Article history:
Received 31 March 2017
Received in revised form
21 June 2017
Accepted 22 June 2017
Available online xxx

Keywords:
Microbial fuel cell
Anode configuration
Brush anode
Maximum power density
Electrochemical impedance spectroscopy
Regression analysis

ABSTRACT

For practical implementation of MFC, increasing power generation is important because it is closely related with energy production rate and wastewater treatability. However, it is not known which relative arrangement of anode and cathode gives the best performance, and it is necessary to know electrochemical reference point of the brush anode for this. Five different brush-anode configurations were tested in a single-chambered cubic MFC. By merely changing a brush anode configuration, power and current densities were increased by 20% and 30%, respectively. The horizontally-positioned anode configuration (H1) with the closest anode-cathode distance produced the highest power and current. EIS showed that anode impedance and full-cell impedance were decreased by 60% and 49%, respectively. CE and EE were not significantly affected by the anode-cathode distance, but the horizontal type cells showed relatively higher CE, EE and COD removal rate and shorter batch time. The center of a titanium current collector and the center of carbon fibers of a brush-anode were found to be statistically-significant reference points for MFC electrochemistry.

Introduction

A microbial fuel cell (MFC) is being developed for energy positive wastewater treatment system for generating electricity from organic waste stream by treating detrimental pollutants in it. For practical implementation of MFC for bioelectrochemical wastewater treatment application, increasing power generation is crucial because it is closely related with energy production rate and wastewater treatability [1]. Currently, researchers are developing MFC technology by using scientific knowledge from investigating

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http://dx.doi.org/10.1016/j.ijhydene.2017.06.181
0360-3199/

system architecture, electrochemistry, materials, catalysts, biology, and etc [2–4].

MFC performance can be enhanced by simply changing anode location. For example, power increases with decreasing distance between the anode and the cathode in general [5]. However, in an extremely close distance, oxygen diffused from the air cathode can be detrimental to anode performance, so that overall power density could be reduced [6–9]. It is still not known which relative arrangement of an anode to a cathode gives the best performance of MFCs. Moreover, it is insufficiently understood how performance and electrochemistry of MFCs are affected by anode configurations and distance between anode and cathode, and their quantitative electrochemical relationships are also poorly understood.

The brush anode of MFC is made up of a titanium-current-collector for facilitating electron transfer and carbon fibers for holding high amount of microbial communities. Therefore, its volume is larger than that of the cathode. It is necessary to quantitatively describe the relative positions of the brush anode and the cathode in order for efficient arrangement of the brush anode. To this end, we need to know a electrochemical reference point of the brush anode. At present, it is not known which point is good for a electrochemical reference point of the brush anode.

In this experiment, vertical and horizontal arrangement of the brush anode and relative distance between the electrodes were varied, and the performance and electrochemical characteristics of the MFC were analyzed. A single-chamber cubic MFC, the most commonly used reactor type in the MFC field, was used. Based on these results, we found electrochemical reference points of the brush anode and the relative arrangement of the brush anode for maximizing MFC performance. In addition, relationships between relative arrangements of the brush anode and electrochemical parameters were quantitatively described.

Materials and methods

MFC construction and operation

The MFC reactor was constructed from polycarbonate cut to produce a cylindrical chamber 4 cm long by 3 cm in diameter. A brush anode were made from carbon fibers (25 mm diameter × 25 mm length; fiber type: T700, TORAYCA) twisted between two titanium wires (length: 7 cm; 17 gauge; #2 grade; Seoul Titanium). This brush anode was heat-treated 450 °C for 30 min in a furnace (FX/FHX, Daihan Scientific, Wonju, South Korea). The inoculated brush anode was operated for over six months at a fixed external resistance (1000 Ω) in a constant temperature room (30 °C) [10,11]. Medium for MFC operation contained 1.0 g/L of sodium acetate in a 50 mM phosphate buffer solution (NaH_2PO_4, 2.34 g/L; Na_2HPO_4, 4.33 g/L; NH_4Cl, 0.31 g/L; KCl, 0.13 g/L; trace minerals, 10 ml/L and vitamins, 10 ml/L). Air cathodes were made of stainless steel mesh (60 × 60, type 304, projected cross sectional area of 7 cm^2) spread with the catalytic mixture (300 mg of activated carbon powder, 30 mg of carbon black and 1 ml of 10% PVDF solution) [12]. A titanium plate (10 mm × 25 mm, G2, Seoul Titanium, Siheung, South Korea) was used as a current collector.

To investigate influence of relative configuration of an anode to a cathode on performance and electrochemistry of MFC, five different anode configurations were tested. The anode core rod was placed horizontally to the cathode in 12 mm (H1) and 28 mm (H2), and vertically to the cathode in 1 mm (V1), 6 mm (V2) and 11 mm (V3) (Fig. 1 and Table 1). In the H1 configuration, non-woven fabric (E-210, R&B, Gwangju, South Korea) was used as a separator to prevent the electrical short circuit [13]. As a preliminary test, a separator effect on power generation was performed in the other anode configurations (H2 and V1–3), and power densities decreased. Since one of our goals was to find the best anode configuration for increasing power production, a separator was not added except for the H1, where a separator was inevitable in order to prevent short circuit. Because large variations are observed commmonly in performance of different anodes, the same bioanode was used throughout the experiment. Ag/AgCl reference electrode (RE-1B, ALS, Japan; −0.209 V vs. SHE) was installed very closely to the bioanode and used for electrochemical measurement.

Electrochemical tests

The cell voltage was recorded at 1-min interval using a system switch multimeter (Model 3706A, Keithley Instrument, USA). Measurements of polarization, EIS and CV were performed using a potentiostat/galvanostat/impedance analyzer (ZIVE SP1, Wonatech, Seoul, South Korea). For polarization tests, the MFC reactor was operated in open circuit for 90 min, and its circuit was connected to ZIVE SP1 with the following programming: rest time 30 min, scan rate 1 mV/s and potential range from OCP to 0 V versus Ag/AgCl. Potentiostatic anode EIS tests were done in a three electrode configuration: a cathode as the working electrode, anode as the counter electrode and Ag/AgCl as the reference electrode. Potentiostatic full cell EIS tests were done in a two electrode configuration: a cathode as the working electrode and anode as the counter electrode. MFCs for EIS measurement were poised at each optimal potential for 30 min to make them produce a stable current. EIS was performed at each bias potential with the following conditions: amplitude 10 mV, initial frequency 10^5 Hz, final frequency 10 mHz, 10 points/decade of data acquisition [14–16]. Electrochemical values were reported after normalizing by using the cathode area of 7 cm^2.

Measurements of CE (coulombic efficiency) and EE (energy efficiency)

For CE and EE measurements, CODs of medium samples taken from the beginning and final batch were measured. When voltage reached ~30 mV, MFC operation was stopped and a sample was taken for COD measurement. 2 ml of suspension was taken and filtered through a syringe filter (HD-04513, CTK, Daejeon, Korea) to remove suspended solids, and its filtrate was tested by COD kit (X-100, C-MAC) to measure its COD.

CE was calculated as

Please cite this article in press as: Kang H, et al., Effects of brush-anode configurations on performance and electrochemistry of microbial fuel cells, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.06.181