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Effect of hydrogen producing mixed culture on performance of microbial fuel cells

*Jeongdong Choi, Youngho Ahn**

Department of Civil Engineering, Yeungnam University, Gyungsan 712-749, Republic of Korea

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ABSTRACT

This study examined the influence of H_2-producing mixed cultures on improving power generation using air-cathode microbial fuel cells (MFCs) inoculated with heat-treated anaerobic sludge. The MFCs installed with graphite brush anode generated higher power than the MFCs with carbon cloth anode, regardless heat treatment of anaerobic sludge. When the graphite brush anode-MFCs were inoculated selectively with H_2-producing bacteria by heat treatment, power production was not improved (about 490 mW/m^2) in batch mode operation, but for slightly increased in carbon cloth anode-MFCs (from 0.16 to 2.0 mW/m^2). Although H^+/H_2 produced from H_2-producing bacteria can contribute to the performance of MFCs, suspended biomass did not affect the power density or potential, but the Coulombic efficiency (CE) increased. A batch test shows that propionate and acetate were used effectively for electricity generation, whereas butyrate made a minor contribution. H_2-producing mixed cultures do not affect the improvement in power generation and seed sludge, regardless of the pretreatment, can be used directly for the MFC performance.

Introduction

Worldwide energy consumption has increased dramatically. Fossil fuels are the most widely used energy source, but eventually will be depleted by human activity, leading to the production of environmental pollutants. Therefore, improving renewable bioenergy technology is crucial for reducing the dependence and environmental effect of fossil energy sources [1,2]. One promising technology with great potential is the microbial fuel cell (MFC), which converts renewable biomass to electricity *via* electricity-producing microorganisms. Bacteria, which can transfer extracellular electrons, oxidize organic matter and transport the electrons to the anode. The protons produced in the anode migrate to the cathode, where water is produced by the reduction of oxygen. The mechanisms of extracellular electron transfer in MFCs are summarized as follows: (a) direct electron transfer from the outer surface of c-type cytochromes to the electrode [3]; (b) electron shuttle of soluble redox molecules to mediate electron transfer between the bacteria and electrode [4]; and (c) nanowires that promote electron transfer through the multilayer biofilm on anodes [5].

As microorganisms are actively catalyzed for electron transfer from the substrate to the anode, an active microbial population producing high levels of electricity is of great importance in MFCs. Some papers have reported power production using pure cultures, such as *Geobacter* sp. [6,7] and *Shewanella* sp. [8,9]. On the other hand, many studies have shown that the reactor performance is normally superior in

* *Corresponding author*. Tel.: +82 53 810 3511; fax: +82 53 810 4622.
E-mail address: yhahn@ynu.ac.kr (Y. Ahn).
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MFCs using mixed species consortia [10,11]. In an attempt to increase power generation, the selective inoculation of MFCs from the anodic community of other MFCs was reported to be an ultimate enrichment procedure from cultivation on the anode [12,13]. Venkata Mohan et al. [14] studied bioelectricity generation in MFC using selectively-enriched H_2-producing mixed culture under acidophilic microenvironment and showed acidophilic contribution to the activity of acidogenic bacteria along with inhibiting methanogenic bacterial activity. Nevertheless, the influence on a mixed inocular of MFCs is not completely understood. In addition, the role of H_2-producing cultures is still questionable, even though organic matter is biodegraded by H_2-producing bacteria that are capable of producing protons and electrons.

Clostridium butyricum, which is one of the widely known H_2-producing bacteria, was used as a biological material to generate hydrogen in a biological fuel cell by glucose fermentation [15]. Other studies reported that H_2-producing bacteria can be beneficial for MFCs with respect to power generation and electron transfer [16,17]. Park et al. [18] isolated *C. butyricum* EG3, which was electrochemically active and Fe(III)-reducing in MFCs. Therefore, the adoption of a selectively-enriched H_2-producing culture might improve electricity generation and organics removal in MFCs. MFCs inoculated from anaerobic mixed consortia producing H_2 in a laboratory scale biofilm bioreactor showed power generation and wastewater treatment [19]. No studies, however, reported the effect of a pretreatment of seed sludge in MFCs, which enhances H_2-producing cultures, even though many pretreatment methods have been attempted to enhance biological hydrogen production [20,21].

This study examined the contribution of H_2-producing mixed cultures by heat treatment for seed sludge in a single chamber air-cathode MFC. The performance of batch mode MFCs was compared according to the anode materials and seed sludge treatment. The effect of suspended biomass was also examined despite biomass attached to the anode playing a significant role in producing electricity. Moreover, continuous sequencing batch mode was performed using the selected MFCs that produced the highest Coulombic and energy efficiencies.

Materials and methods

Substrate and seed sludge

A sucrose (2.8 g/L) solution in phosphate buffer saline (PBS, 200 mM) [22] was used in the batch mode experiment. Anaerobic sludge from a local brewery wastewater treatment plant (Gwangju, S. Korea) was collected and stored at 4 °C prior to use. The concentration of anaerobic sludge was 26 g VSS/L with 0.88 VSS/TSS ratio. The anaerobic sludge was used as the seed sludge with or without heat treatment. For the heat treatment, the anaerobic sludge was baked at 105 °C for 2 h before seeding.

MFC configuration

Single chamber air-cathode MFCs without a membrane were used for the experiment (Fig. 1). Two types of anode were prepared; a graphite brush treated with ammonia gas [23] and carbon cloth (without wet proofing; E-Tek, USA). The surface areas of the anode were 0.22 m^2 and 7 cm^2 for the graphite brush and the carbon cloth, respectively. The air-cathode was a 30% wet-proof carbon cloth containing 0.5 mg/cm^2 of a Pt catalyst. The MFCs were comprised of a plastic cylindrical chamber, 4 long by 3 cm in diameter, with a 28 mL liquid volume. Titanium wires were used as the electrode connectors for the anode and cathode.

Biohydrogen production activity test

The experiment for hydrogen production was examined using MFC reactors not connected to an electrical circuit (no connection with resistance and wire) (Fig. 2). The MFCs (including control) assembled with brush and carbon cloth anodes, respectively, were used to collect hydrogen. The heat-treated anaerobic sludge (2 g in wet weight) was inoculated and a sucrose solution (22–25 mL) was added to the reactors (no sucrose addition for the control). The gas collection bag (100 mL) was connected to the top of the reactors and the reactors were placed in temperature-controlled room (35 ± 1 °C). For the batch cycle, the supernatant was discarded after gas production was stopped and then the substrate mixture was replenished for the next cycle. The collected biogas volume was measured using 5–100 mL syringes.

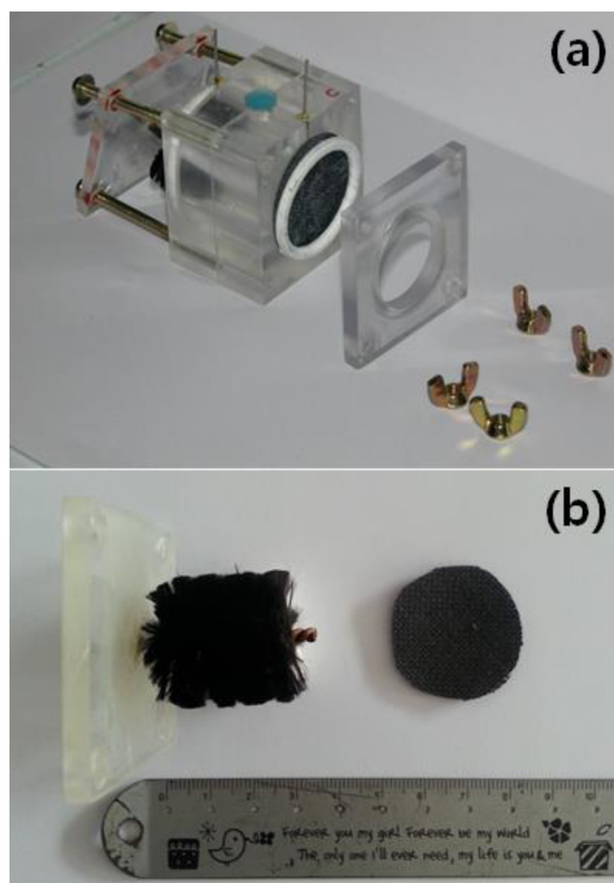

Fig. 1 – MFC image and anodes used in this study. Each anode in left and right shows graphite brush and carbon cloth.

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