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Production of algal biomass (*Chlorella vulgaris*) using sediment microbial fuel cells

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ABSTRACT

In this study, a novel algal biomass production method using a sediment microbial fuel cell (SMFC) system was assessed. Under the experimental conditions, CO_2 generation from the SMFC and its rate of increase were found to be dependent on the current generated from the SMFC. However, the CH_4 production rate from the SMFC was inhibited by the generation of current. When *Chlorella vulgaris* was inoculated into the cathode compartment of the SMFC and current was generated under 10 Ω resistance, biomass production from the anode compartment was observed to be closely associated with the rate of current generation from the SMFC. The experimental results demonstrate that 420 mg/L of algae (dry cell weight) was produced when the current from the SMFC reached 48.5 mA/m^2. Therefore, SMFC could provide a means for producing algal biomass via CO_2 generated by the oxidation of organics upon current generation.

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1. Introduction

Recently, a significant amount of attention has been focused on renewable energy sources that might help satisfy the ever-increasing demand for energy consumption and environmental protection (Choi et al., 2010; De Schamphelaire and Verstraete, 2009). Among possible renewable energy sources, microalgae have gained increased attention as they contain a significant quantity (e.g. 20–50% dry cell weight) of neutral lipids for biodiesel production (Hu et al., 2008). Various methods for the cultivation of algae have been proposed ever since Harder and von Witsch proposed the mass cultivation of diatoms to produce urgently needed fat during World War II (Liang et al., 2009). In recent years, significant efforts have expended toward the development of biological aspects (i.e. strain selection and/or improvement, etc.) and non-biological aspects (i.e. light source, fermentor design, cultivation method, etc.) for use in algal production (Brennana and Owendea, 2010). Despite recent efforts to improve the production yield of algal biomass, there remain some technological barriers to overcome before the economic production of a stable energy source becomes feasible. Among these technological barriers, CO_2 is one of the critical factors in photosynthesis, along with light, water, and nutrients. Particularly in the case of high-density cultures of algal biomass in a bioreactor, effective CO_2 supply is recognized as a crucial factor. In the case of open pond-type cultures such as raceway-type ponds or lakes, quality control, slow growth, and low CO_2 partial pressure constitute major obstacles (Brennana and Owendea, 2010).

Along with the problems listed above, the presence of organic bottom lake sediment is associated with the generation of CH_4, which has serious greenhouse gas effects. To remove CH_4 generation from conventional lake or swamp sediment, a variety of methods, including ultrasonication, O_2 feeding, heat treatment, and acid/base treatment, have been proposed for the treatment of sediment (Elbeshbishya et al., 2010). In particular, it has been reported that the addition of inorganic electron acceptors to sediment inhibits CH_4 generation (Scholten and Stams, 1995). In a previous study, a microbial fuel cell (MFC) using lake sediment as an electron donor for electrochemically active bacteria was examined, and it was determined that this method could be used successfully to reduce the organic matter content of the sediment (Hong et al., 2008).

In the present study, we demonstrate a novel algal production system using a sediment microbial fuel cell (SMFC) capable of decreasing CH_4 generation capability of organic rich-lake sediment, which was divided into two parts. First, using organic-rich sediment obtained from a natural lake, correlations between current generation and gas (CO_2 and CH_4) production in the SMFC were established. Secondly, the algal production capability of the SMFC and the applicability of algal culture for SMFC operation without any external oxidant were investigated.

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2. Methods

2.1. Algal strain, medium, and sediment for SMFCs

The *Chlorella vulgaris* strain (KCTC AG10002) was provided by the Korean Culture Type Collection (Daejun, Korea). The medium for cultivation of *C. vulgaris* was Bold's Basal Medium (BBM, pH 6.8) (Lima et al., 2010). The cells were grown in 250 ml Erlenmeyer flasks on an orbital shaker set at 150 rpm at 25 °C under constant florescence light. Sediment for the construction of SMFCs was obtained from Ilgam lake, an artificial lake at Konkuk University, Seoul, and a typical hypereutrophic lake in Korea (collection date: June 2010). The average amounts of organic matter in the sediment as measured by the loss on ignition (LOI) and readily oxidizable organic matter (ROOM) methods were 10.4% LOI and 3.52% ROOM, respectively (Hong et al., 2008).

2.2. SMFC construction

Fig. 1 shows a schematic diagram of the sediment microbial fuel cell (SMFC) employed in this study. The SMFC consisted of an anode and cathode positioned at opposite sides of a poly-acrylic plastic cylindrical chamber (d = 110 mm, h = 250 mm, t = 2 mm). Both the anode (d = 80 mm, t = 2 mm) and cathode (d = 90 mm, t = 2 mm) consisted of graphite felt (GF series, GEE graphite Ltd., UK). Electrodes were connected externally with concealed copper wire. The sediment (775 g wet weight) was initially added to the chamber (ca. 50 mm in thickness), and the anode was placed in the middle of the sediment layer. The sediment was then covered with sterilized sand (638 g wet weight). For direct collection of the gas generated from the anode compartment (i.e. sediment), a funnel type gas collector (d = 80 mm) was placed on the surface of the sediment of the SMFC and connected to a gas sample bag (232 series, SKC, USA). Four sets of the SMFC system were used in this study.

2.3. SMFC operation

The SMFCs were operated in a fluorescence light (light intensity of 81 μmol/m^2 s) incubator at constant temperature of 25 °C. To investigate the effect of external resistance on current and gas generation, the cathode compartment was initially filled with BBM, and the cathode was aerated at a rate of 200 ml/min. The connection between the anode and cathode was made via external load resistors. BBM containing 1% glucose (w/v) as a fuel for operation of the SMFCs was supplied to the system (0.04 ml/min) with a peristaltic pump. When the system set-up was completed, the current generated from each SMFC was monitored with a digital multimeter (model 2000, Keithley, USA) (Choi et al., 2010). The gas generated during operation (15 days) of the SMFCs was collected via the gas collector and stored in the sample bag. Sampling for bicarbonate analysis was made via the sampling port (Fig. 1).

For algae cultivation in the SMFCs, the gas collector in the cathode compartment was removed and the precultured algae inoculated (20% v/v) into the cathode compartment. During algal cultivation, aeration to the cathode was stopped. Cultivations were carried out for 15 days in the SMFCs with different load resistors. To prevent bacterial contamination, the SMFCs were irradiated with UV light (λ_{max} = 204 nm) eight times a day (10 s every 3 h at 200 μmol/m^2 s intensity) (Seo et al., 2009). All experiments were conducted at least in duplicate.

2.4. Analysis

Gaseous CO_2 and CH_4 generated from the SMFCs were analyzed via gas chromatography as described previously (Holland et al., 1999). CO_2 dissolved in the cathode compartment was measured via the acid/base titration based on the bicarbonate concentration (Fresenius et al., 1988). The dry weight of the algal culture sample was determined by drying 50 ml of the algal suspension at 80 °C in a drying oven for 24 h after filtration through pre-dried and pre-weighted 0.45 μm filter paper.

3. Results and discussion

3.1. Effect of external resistance on generation of current, CO_2, and CH_4

After the SMFCs with different external load resistors were set up, electrical current and gas generation from the SMFCs were monitored. The current gradually increased over 15 days, upon which it achieved steady state. Fig. 2 shows the relationships among electrical current generation, CO_2 generation, and CH_4 generation from the SMFCs connected with different external load resistors.

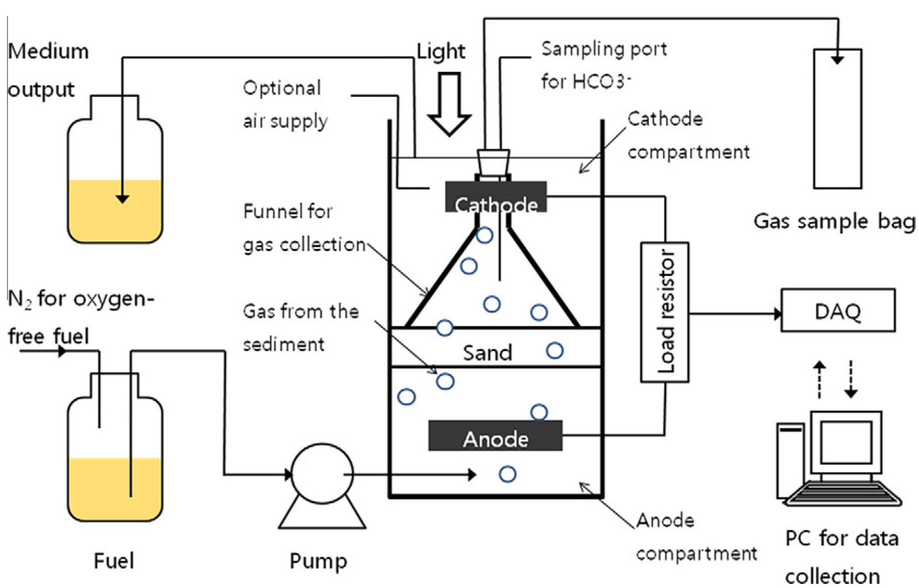

Fig. 1. Schematic diagram of the algal culture system using SMFC.

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