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Electricity generation and microalgae cultivation in microbial fuel cell using microalgae-enriched anode and bio-cathode

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ABSTRACT

In this study, a microbial fuel cell (MFC) was developed to treat waste, produce electricity and to grow microalgae simultaneously. Dead microalgae biomass (a potential pollution vector in streams) was used as a substrate at anode. CO_2 generated at anode was used to grow freshwater microalgae at cathode. The performance of microalgae-fed MFC was compared with acetate-fed MFC. The maximum power density of 1926 ± 21.4 mW/m^2 (8.67 ± 0.10 W/m^3, at $R_{ext} = 100\ \Omega$) and Coulombic efficiency (CE) of $6.3 \pm 0.2\%$ were obtained at 2500 mg COD/L of microalgae powder (0.5 g/L). Microalgae captured CO_2 (5–14%, v/v) to produce a biomass concentration of 1247 ± 52 mg/L. However, microalgae could not grow in acetate-fed (0.5 g/L) MFC (acetate-control) and without anodic CO_2 supplying MFC (CO_2-control).

1. Introduction

Microalgae are considered as promising feedstocks for the production of biofuels. Currently, the scale-up applications of algae-derived biofuels are not economical yet [1–3]. One obvious way to reduce the cost of biofuels is to integrate them with other technologies such as waste treatment and electricity generation. Microbial fuel cells (MFCs) offer such a potential to treat waste, generate electricity and produce biofuels simultaneously [4,5]. In MFCs, fuels, mostly organic substrates, are oxidized, electrons are generated and deposited on the anode electrode [6–8]. MFC employs biocatalyst, i.e., electrochemically active bacteria existing in the form of biofilm on the surface of anode electrode. These microbes, termed *exoelectrogens* are capable of directly transferring and depositing electrons on the anode [9–11].

A substrate, both its type and concentration, is a crucial component in bio-electrochemical systems, affecting the composition of a microbial community and thus, power output [12]. In terms of power output and handling easiness, simple organic compounds including acetate are used [13,14]. To produce substantial amount of electricity, however, far cheaper yet massively available feedstock should be explored. In this regard, microalgae biomass can be used. Microalgae cause pollution in the streams. They are the main sources of eutrophication. A large quantity of microalgae biomass is obtained during wastewater treatment around the world. Direct discharge of microalgae into sewer system can threaten the human health. Therefore, microalgae must be skimmed from the water bodies and disposed off. Microalgae biomass is used for biofuels production. However, the bio-fuels production from microalgae biomass is not economical yet. Alternatively, microalgae can be used as a substrate in MFC. This approach serves dual purpose, waste treatment and electricity generation. Thus, the use of microalgae biomass has two way benefit, pollution control and feedstock for MFC. Microalgae biomass contains high level of proteins (32%) and carbohydrates (51%) which are readily degradable by the electrogens to produce electricity [15]. Velasquez-Orta et al. [38] obtained the maximum power density of 0.98 W/m^2 (277 W/m^3) using *Chlorella vulgaris* (a microalgae) powder as a substrate [15].

Traditionally, expensive catalysts (e.g. Pt, CuO) are used to enhance the performance of cathode. The alternate way is to circulate water containing adequate concentration of dissolved oxygen. The concentration of dissolved oxygen should be equivalent to the oxygen produced by the catalysts. However, continuous pumping of water poses additional cost on MFC operation. Replacing catalysts with photosynthetic microalgae species is a promising approach to improve cathodic performance. Microalgae release oxygen during its growth, which serves as terminal electron acceptor. Another advantage of using microalgae at cathode is carbon fixation.

In MFC operation, the electrogens produce CO_2. Microalgae at cathode use CO_2 as a carbon source and promote its growth. Biomass produced by the cultivation of microalgae can be further used to extract fuels (bio-hydrogen, biodiesel, and bioethanol) out of it.

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To prove this concept, microalgae-based MFC is developed. Dead microalgae biomass is used at anode as a nutrients source. Activated sludge is used as an inoculum at anode. Microorganisms present in the sludge use dead microalgae biomass as a nutrients source to generate electrons. Live microalgae are grown at cathode. CO_2 released at anode is directed towards cathode to be used by microalgae for its growth. A synergetic relationship between biomass degradation and CO_2 emission at anode, and microalgae growth at cathode was developed. Microalgae grown at cathode could be further used to extract biodiesel. However, this work is limited to microalgae growth only. To explore the effectiveness of microalgae-based MFC, the objective of this study were set as follows: (1) to investigate microalgae biomass as a feedstock for electricity generation (2) to grow microalgae at cathode (3) to fix CO_2 using microalgae-enriched bio-cathode (4) to compare microalgae-based MFC with acetate-based MFC.

2. Material and methods

2.1. Microalgae biomass pretreatment

Microalgae biomass (*Scenedesmus*, a green algae) was provided in powder form by Korea Research Institute of Bioscience and Biotechnology (KRIBB, Republic of Korea). The dry biomass was ground (particle size 106–140 μm), sieved, and dried at 45 °C until constant weight. After desiccation, the biomass was stored in hermetic bags to keep the same moisture content before testing. Microalgae biomass (named *Scenedesmus* powder) was stored at room temperature.

Chlorella vulgaris (C. vulgaris) AG30007 UTEX 0000265 obtained from University of Texas at Austin (USA) was used as a bio-cathode. For inoculum preparation, *C. vulgaris* was cultivated photoautotrophically in 250 ml sterilized Erlenmeyer flasks containing BG-11 medium at pH 6.0 [11]. The flasks were placed in a shaking incubator at 140 rpm, temperature 25 ± 2 °C, and under the illumination of white Light Emitting Diodes (LED). *C. vulgaris* from these flasks was transferred into cathode at desired level of concentration (10–400 mg/L).

2.2. MFC reactor fabrication

Four cubical dual-chamber reactors made of acrylic with each electrode chamber holding a volume of 112.5 mL (5.0 cm × 5.0 cm × 4.5 cm) were constructed (Fig. 1). Both, anode and cathode, had working volume of 100 mL each with a headspace of 6 mL. The chambers were purged with N_2 gas to remove oxygen. Each reactor was separated by a piece of cation exchange membrane (CEM, CMI-7000, Membrane International, Inc. USA) with an effective surface area of 25 cm^2 (5.0 cm × 5.0 cm). A silicone tube was connected to transfer CO_2 from the anode to the cathode compartment. A carbon fiber brush (2.5 cm L, 2.5 cm D, titanium wire) was used as an anode. A carbon cloth (3.0 cm × 3.0 cm = 9.0 cm^2, B-1 Designation B, 30% wet-proofing, Clean Fuel Cell Energy) connected with titanium wire was used as a cathode following the procedure described in the literature [16,17]. 0.35 mg Pt/cm^2 Pt catalyst (20 wt% Pt/C power, Alfa Aesar) was coated on both sides of the carbon cloth but one side was placed closely on the membrane surface so as to expose only one surface to the solution. Membrane-electrode assembly was formed without hot pressing treatment.

2.3. Operation

PBS medium, containing 4.264 g/L NaH_2PO_4, and 9.150 g/L Na_2HPO_4 (conductivity 10.75 mS/cm, pH 7.05) and BG-11 medium containing (per liter of de-ionized water) $MgSO_4{\cdot}7H_2O$ 0.075 g, $CaCl_2{\cdot}2H_2O$ 0.036 g, citric acid 0.006 g, ferric ammonium citrate 0.006 g, EDTA (disodium salt) 0.001 g, Na_2CO_3 0.02 g, H_3BO_3 2.86 mg, $MnCl_2{\cdot}4H_2O$ 1.81 mg, $ZnSO_4{\cdot}7H_2O$ 0.222 mg, $Na_2MoO_4{\cdot}2H_2O$ 0.39 mg, $CuSO_4{\cdot}5H_2O$ 0.079 mg, $Co(NO_3)_2{\cdot}6H_2O$ 0.0494 mg were added at cathode [3]. PBS was used as catholyte whereas BG-11 medium was required for microalgae growth. Before adding BG-11 into the cathode, live microalgae cells of various concentrations (10–400 mg/L) were also added. N_2 was purged for 15 min in cathode to remove oxygen from the medium. A continuous illumination of white light LED (light intensity of 2000 lux) was employed around the cathode, along with magnetic stirring (400 rpm). The carbohydrates present in microalgae biomass are degraded by the microbes present in the sludge. Various gases are produced at by anaerobic digestion of microalgae biomass. However, in most of the MFC work it is reported that the major gas is CO_2. A small quantity of methane may also be produced, which identifies that methanogens does not play their role. The use of acetate instead of microalgae biomass also produce CO_2. The quantity of CO_2 released depends upon substrate concentration. The released CO_2

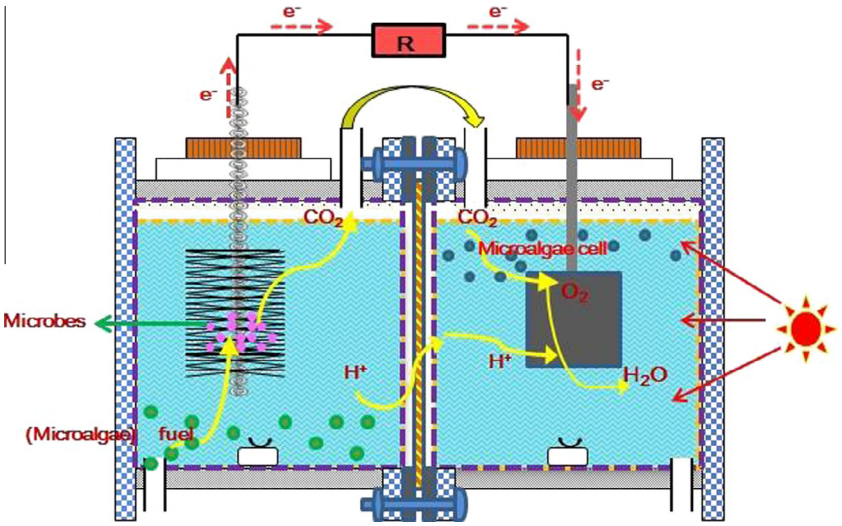

Fig. 1. Schematic diagram of MMR (microalgae biomass-enriched anode and microalgae-based biocathdoe reactors) for simultaneous bioelectricity production, microalgae cultivation, and CO_2 sequestration. *Scenedesmus* powder was used as fuel by microbes and the CO_2 released by the degradation of *Scenedesmus* powder. The CO_2 was transported through silicon tube, fixed on the chambers.