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Effect of gradual transition of substrate on performance of flat-panel air-cathode microbial fuel cells to treat domestic wastewater

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HIGHLIGHTS

- FA-MFCs were operated by substrate transition from acetate to domestic wastewater.
- Coulombic efficiency in acetate was similar to that in domestic wastewater.
- Maximum power density had higher correlation with acetate than with COD.
- FA-MFCs could maintain low internal resistance and overcome decreasing conductivity.

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ABSTRACT

In order to confirm the effects of the low conductivity and biodegradability of wastewater, flat-panel air-cathode microbial fuel cells (FA-MFCs) were operated by supplying substrates with different volume ratios of domestic wastewater mixed with an artificial medium: the artificial medium only, 25% wastewater, 50% wastewater, 75% wastewater, 100% of wastewater with 500 mg-COD/L by adding acetate, and raw domestic wastewater (230 mg-COD/L). With the increase of wastewater ratio, the maximum power density and organic removal efficiency decreased from 187 to 60 W/m^3 and 51.5 to 37.4%, respectively, but the Coulombic efficiency was maintained in the range of 18.0–18.9%. The FA-MFCs could maintain their low internal resistances and overcome the decreasing conductivity. The acetate concentration was more important than the total organics for power production. This study suggests that the FA-MFC configuration has great applicability for practical applications when supplied by domestic wastewater with low conductivity and biodegradability.

1. Introduction

The conventional activated sludge (CAS) process was used worldwide to treat domestic wastewater in the last century because of its operational convenience despite requiring tremendous amounts of energy. The energy cost for aeration in the CAS process can reach 30–55% of the total electricity cost (McCarty et al., 2011; Oh et al., 2010). Domestic wastewater has an energy potential of 1.23 kWh/m^3 in biodegradable organics (suspended organics: 0.67 kWh/m^3; dissolved organics: 0.56 kWh/m^3); hence, the collection of this energy to remove organic matter will enable sustainable wastewater treatment (McCarty et al., 2011).

Recently, processes using microbial fuel cells (MFCs) have received considerable attention to substitute for the CAS process because they can treat wastewater while simultaneously generating electricity (Ahn and Logan, 2010; Feng et al., 2014; Liu et al., 2004; Min and Logan, 2004; Pandey et al., 2016; Ren et al., 2014; Yu et al., 2012; Zhang et al., 2013). Among the various types of MFCs, air-cathode MFCs have a significant advantage in wastewater treatment because they can use oxygen directly from the air as electron acceptors without requiring aeration (Cheng and Logan, 2011; Fan et al., 2007; Logan et al., 2007; Yang et al., 2013; Zhu et al., 2011). Optimizing the configuration to overcome the low conductivity and biodegradability of domestic wastewater is the most important factor for applying an air-cathode MFC for wastewater treatment.

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The separator electrode assembly (SEA) has commonly been used to overcome the low conductivity of domestic wastewater (Ahn and Logan, 2013; Ahn et al., 2014; Hays et al., 2011). In addition, the cathode specific surface area (calculated as the ratio of cathode surface area to working anode volume) showed a linear function with the maximum power, which is an important indicator for the scale-up of MFCs in terms of increasing power (Cheng and Logan, 2011). Therefore, a higher cathode specific surface area, including shorter distance between SEAs, should be incorporated in the MFC design for maximizing power generation from domestic wastewater.

While the acetate has been widely used as an acclimation substrate to stimulate the sufficient growth of exoelectrogenic microbes, the sudden change of substrate from acetate to domestic wastewater mostly led rapid decrease of electricity production in many previous studies of MFC to treat wastewater. Therefore, it is needed to test whether the gradual transition of substrate from acetate to domestic wastewater can reduce the negative effect on the electricity production in the MFC. Recently, we developed a flat-panel air-cathode MFC (FA-MFC) comprising two SEAs with high cathode specific surface area (400 m^2/m^3) and interior baffles for guiding the water flow. In order to confirm the effects of the low conductivity and biodegradability of wastewater on the power production of FA-MFCs, it was operated with a gradual transition from substrate with different volume ratios (0–100%) of domestic wastewater to an artificial medium based on acetate. This study evaluated the performance of FA-MFCs including electricity generation, organic removal, and Coulombic efficiency (CE), and possible effective factors like chemical oxygen demand (COD), phosphate concentration, and conductivity during more than 3 months of operation.

2. Materials and methods

2.1. FA-MFC construction

The FA-MFC consisted of two cells that shared one anode chamber (volume: 150 mL), with four internal baffles for guiding the water flow (Fig. 1). According to computational fluid dynamics analysis, the presence of baffles allows for a good distribution of water flow over the electrode area (Kim et al., 2014). The inlet was located on the top of the anode chamber, and the outlet and solid removal port were located on the top and bottom of the opposite side, respectively. Owing to this configuration, we expected the particulate materials in the domestic wastewater to be easily removed from the bottom of the anode chamber.

Each FA-MFC has two SEAs that minimized the space between the anode, separator, and air-cathode (size: 150 × 200 mm) with a high cathode specific surface area of 400 m^2/m^3. The anode and cathode electrodes were made of graphite felt and 30% waterproof carbon cloth (E-Tek, BASF Fuel Cell, Inc., USA) with a platinum catalyst (0.5 mg/cm^2) using a 5% Nafion solution (Cheng et al., 2006), respectively. A polypropylene non-woven fabric (Korea Non-Woven Tech. Co, Ltd., Korea) was used as the separator because it showed high performance in a previous study (Yu et al., 2014).

2.2. FA-MFC operation

Seven FA-MFCs were operated for performance analysis at different hydraulic retention times (HRTs), external resistances, and substrate conditions. The anode chamber was inoculated with activated sludge obtained from a domestic wastewater treatment plant in Busan, Korea and was operated in batch mode with a synthetic medium for 13 days. The synthetic medium with a COD of 500 mg/L and a phosphate buffer of 50 mM contained CH_3COONa (0.64 g/L), K_2HPO_4 (4.35 g/L), KH_2PO_4 (3.4 g/L), NH_4Cl (0.23 g/L), NaCl (0.04 g/L), $MgSO_4{\cdot}7H_2O$ (0.01 g/L), KCl (0.02 g/L), and yeast extract (0.005 g/L). After batch operation, the synthetic medium was supplied into the FA-MFCs with various HRTs from 4 to 0.5 h (phase S-1, Fig. S1). After a 44-day operation, the external resistance was decreased stepwise from 500 Ω to 5 Ω for high current production (phase S-2). In order to test whether the gradual transition of substrate from acetate to domestic wastewater can reduce the negative effect on the electricity production in FA-MFC, the synthetic medium was mixed with domestic wastewater to obtain several ratios from 25 to 100% (volume of domestic wastewater/volume of synthetic medium) where the influent COD was maintained at 500 mg/L by adding acetate (phases W-1, W-2, W-3, and W-4). After 78 days, all FA-MFCs were operated with domestic wastewater (phase W-5) from the primary clarifier effluent at a wastewater treatment plant in Busan, Korea. In phase W-5, the external resistance-switching test was performed at 5 and 10 Ω. The operating conditions of the FA-MFCs are presented in Table 1. The FA-MFCs were operated at ambient temperature (15–25 °C) during the whole period.

2.3. Chemical and electrochemical analyses

The voltage (E, V) measured using a data acquisition system (Model 7700, Keithley Instruments Inc., USA) was recorded on a

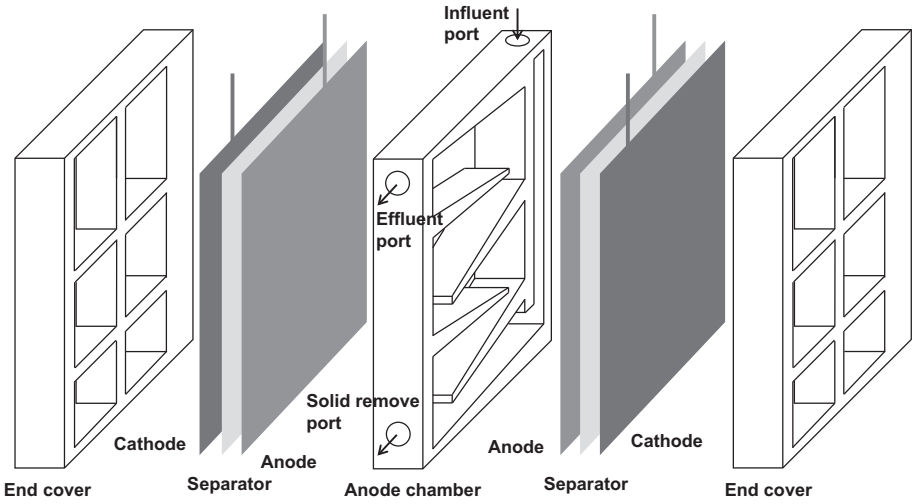

Fig. 1. Schematic diagram of FA-MFCs consisting of two separator electrode assemblies (SEAs) sharing the same anode compartment.