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Single chamber microbial fuel cell with spiral anode for dairy wastewater treatment

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ABSTRACT

This study reports on the fabrication of a novel annular single chamber microbial fuel cell (ASCMFC) with spiral anode. The stainless steel mesh anode with graphite coating was used as anode. Dairy wastewater, containing complex organic matter, was used as substrate. ASCMFC had been operated for 450 h and results indicated a high open circuit voltage (about 810 mV) compared with previously published results. The maximum power density of 20.2 W/m^3 obtained in this study is significantly greater than the power densities reported in previous studies. Besides, a maximum coulombic efficiency of 26.87% with 91% COD removal was achieved. Good bacterial adhesion on the spiral anode is clearly shown in SEM micrographs. High power density and a successful performance in wastewater treatment in ASCMFC suggest it as a promising alternative to conventional MFCs for power generation and wastewater treatment. ASCMFC performance as a power generator was characterized based on polarization behavior and cell potentials.

1. Introduction

In microbial fuel cells (MFCs), microorganisms act as a biocatalyst to catalyze the oxidation reactions of organic matters in the anodic chamber. In general, microbial fuel cells consist of anaerobic anodic chamber and aerobic cathodic chamber that may be separated by a selective membrane limiting diffusion of oxygen into the anode chamber (Logan and Regan, 2006; Logan et al., 2006; Luo et al., 2010; Li et al., 2010). Electrons and protons produced from redox reactions are transported to cathode from different paths and electrochemically react with oxygen as electron acceptor to produce water. This way, electrical energy is generated while unwanted organic matters are removed. MFCs are able to generate power and at the same time remove organic wastes. By now, several types of MFCs, such as double chamber MFCs (Antonopoulo et al., 2010; Chae et al., 2010), single chamber MFCs (Cheng and Logan, 2011), tubular MFCs (Kim et al., 2010), up flow MFC (Zuo et al., 2010), and multi-anode/cathode MFCs (Jiang et al., 2010a) have been developed. However, single chamber microbial fuel cells (SCMFCs) are believed to be superior because of their simple design, flexibility, low internal resistance, and relatively low cost (Du et al., 2007).

Electrodes materials play an important role in the cost and performance of MFCs. Several types of electrodes have been used; including carbon cloth (Zhuang et al., 2010), carbon felt (Martin et al., 2010), graphite brush (Zuo et al., 2007; Logan et al., 2007; Cheng and Logan, 2011), graphite foam (Chaudhuri and Lovley, 2003), graphite granule (Feng et al., 2010), RVC (He et al., 2005), and granular activated carbon (Jiang and Li, 2009; Zhang et al., 2011a). The anode electrode materials should possess a good electrical conductivity, low resistance, strong biocompatibility, chemical stability, large surface area and an appropriate mechanical strength (Zhou et al., 2010). Carbon cloths are widely used in MFCs because of their higher porosity and mechanical strength in comparison with other electrode materials. Disadvantage of current commercially available carbon cloth is high cost (ca. $ 1000 m^2) (You et al., 2011).

MFCs represent a promising candidate as a new method for wastewater treatment, because of high efficiency, electricity generation, and low cost in comparison with other methods of wastewater treatment (Logan, 2008). Several types of wastewater such as domestic wastewater (Ahn and Logan, 2010), brewery wastewater (Wen et al., 2010), bakery wastewater (Velasquez-Orta et al., 2011), dairy wastewater (Mohan et al., 2010), etc. (Cercado-Quezada et al., 2010; Mathuriya and Sharma, 2009) have been used as feed in MFCs. 1–5 l of wastewater are produced per liter of milk processed in dairy plants (Klemeš et al., 2008). Dairy wastewater contains complex organics such as polysaccharides, proteins, and lipids which on hydrolysis form sugars, acids, and fatty acids (Demirel et al., 2005). In comparison with other wastewaters, dairy wastewater with low degradation rate produces lower power density in MFCs (Velasquez-Orta et al., 2011; Mathuriya and Sharma, 2009).

This study reports the fabrication of a novel single chamber MFC (SCMFC) assembly by using graphite coated stainless steel mesh as anode electrode with spiral geometry in SCMFC. Two objectives

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were followed in this study. First, a cheap graphite coated stainless steel mesh anode was developed as porous surface for biofilm growth to compare its performance with previously reported expensive electrodes. Second, the power generation of the annular single chamber MFC (ASCMFC) with spiral anode was compared with conventional air cathode MFCs to investigate the effects of this configuration on MFC performance.

2. Materials and methods

2.1. MFC assembly

ASCMFC with spiral anode was constructed using a Plexiglas cylindrical chamber as the main body. Dimensions of the chamber were 3 cm in height, 7.1 cm internal diameter and 8 cm external diameter. The volume of anaerobic chamber was 90 cm^3. The anode electrode (63 cm × 2 cm) was made of graphite coated stainless steel mesh (mesh 300). The graphite-modified stainless steel mesh was fabricated by coating the graphite on the stainless steel mesh. Graphite coating was done by spraying graphite paint on the surface of stainless steel mesh. Because of spiral geometry, the anode area was increased per unit volume and electrode spacing was reduced in comparison with other single chamber microbial fuel cell configurations. The cathode cylinder with 3 cm length and 12 cm diameter was made of carbon cloth type B (30% wet-proofing; E-Tek, USA) and treated according to the procedures reported previously (Cheng et al., 2006a,b) to achieve 0.5 mg cm^{-2} Pt loading. Poly tetra fluoro ethylene (PTFE) layers were coated on the air-side of the carbon base cathode to reduce the water loss through the cathode (Cheng et al., 2006b). The cathode was located axially in the main cylinder. The schematic diagram of ASCMFC with spiral anode is shown in Fig. 1.

2.2. Inoculation and operation of ASCMFC

Dairy wastewater (2500–5000 mg/L COD, pH 9.5–11.5, 2500–3200 μS/cm Conductivity, 190–300 NTU Turbidity) was collected from Pegah–Isfahan Dairy Industrial Corporation. Due to the high cost and very controlled operation environment, pure cultures are impractical for the real-world engineering operations. Mixed cultures (i.e., soil, wastewater) containing significant amounts of electrogenic bacteria can be used as the cost-effective inoculum for MFCs (Jiang et al., 2010b). Dairy wastewater-fed MFCs produce diverse microbial communities. Characterization of the anode biofilm from the MFC fed dairy wastewater showed that the microbial community was dominated by *Clostridium* (17%), *Thauera* (17%), *Pelobacter carbinolicus* (14%), *Parabacteroides* (10%), *Acholeplasma* (10%), and *Geobacter* sp. (7%) Kiely et al. (2011). The ASCMFC has been inoculated with activated sludge as a mixed culture collected from dairy wastewater treatment plant of Pegah–Isfahan Dairy Industrial Corporation for 2 months. Inoculation process was done with a 50:50 volume mixture of inoculum and dairy wastewater as medium. During the Inoculation, the microorganisms in the ASCMFC were fed dairy wastewater every two days by removing 30 ml of the anolyte and replacing it with fresh medium. Moreover, the ASCMFC was fed by buffer solution (pH = 10) to inhibit acidification of anaerobic chamber. After achieving stabilized performance, inoculum was allowed to settle down and exhausted wastewater was replaced with diluted raw dairy wastewater with COD of 1000 mg/l. The feed solution was replaced when the measured voltage between electrodes dropped below 20 mV, completing one cycle of operation.

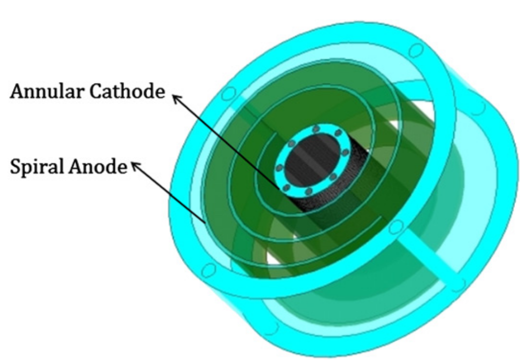

Fig. 1. Schematic diagram of annular single chamber microbial fuel cell (ASCMFC) with spiral anode.

2.3. Calculations and analysis

Cell voltage (V) was recorded every 15 min across a variable external resistance (30–50,000 Ω) using a data acquisition system connected to a personal computer. Current (I), power ($P = IV$), and Coulombic Efficiency (C_E) were calculated as previously described (Logan et al., 2006) and normalized by the projected anaerobic volume. An external resistance was applied to polarize the cell and the current variation under closed circuit conditions was monitored to obtain polarization and power density curves. The ohmic resistance (i.e., internal resistance) collectively referring to the resistance of electrodes, electrolytes, and interconnections to electron and proton transport processes, was calculated from either the slope of polarization curve at the linear (ohmic) region or from the maximum in power density curve where the internal and external resistances are equal (Logan 2008; Fan et al., 2008; O'Hayre et al., 2009)

The coloumbic efficiency can be calculated for a fed-batch system as (Logan, 2008):

$$C_E = \frac{8 \int I dt}{F V_{An} \Delta COD}$$

where ΔCOD depicts change in COD concentration over the batch cycle, F is Faraday's constant, I is the output current, and V_{An} is the volume of liquid in the anode compartment.

3. Results and discussion

3.1. Open circuit voltage (OCV)

Influence of external resistance on the accumulated active biomass and energy gain of the biofilms formed during the starting-up period were investigated by Zhang et al. (2011b). It was indicated that in a lower external resistance, more active biomass was established. The biofilm formed at higher external resictance appeared quite uniform. Uniform morphology of biofilm facilitates electron generation and transfer. By starting up of ASCMFC at open circuit conditions in this study, uniform biomass was formed on the anode surface.

Fig. 2 depicts OCV during the operation period of the ASCMFC. Four feed injections were performed during MFC operation. 30 cm^3 of the wastewater in the anodic chamber was replaced with fresh wastewater (COD of 1000 mg/l). Feed injections are marked in the figure by arrows. Interestingly, this figure shows a very high OCV compared with previously published results for dairy wastewater. Maximum OCV of ASCMFC is more than 2.5 fold of the reported OCV by Mohan et al., (2010) and Velasquez-Orta et al. (2011) investigated dairy wastewater treatment in the conventional single chamber MFCs.

With increasing the substrate concentration (injection of fresh wastewater), open circuit voltage significantly increased