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Novel microbial fuel cell design to operate with different wastewaters simultaneously

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ABSTRACT

A novel single cathode chamber and multiple anode chamber microbial fuel cell design (MAC-MFC) was developed by incorporating multiple anode chambers into a single unit and its performance was checked. During 60 days of operation, performance of MAC-MFC was assessed and compared with standard single anode/cathode chamber microbial fuel cell (SC-MFC). The tests showed that MAC-MFC generated stable and higher power outputs compared with SC-MFC and each anode chamber contributed efficiently. Further, MAC-MFCs were incorporated with different wastewaters in different anode chambers and their behavior in MFC performance was observed. MAC-MFC efficiently treated multiple wastewaters simultaneously at low cost and small space, which claims its candidature for future possible scale-up applications.

Introduction

Microbial fuel cells (MFCs) hold a promising future in wastewater treatment as an emerging system, capable of removing contaminants and producing electricity simultaneously. These are the devices, which convert chemical energy of chemical compounds, directly into electrical energy using catalytic activities of microorganisms. The essential components of a MFC include: an anode, a cathode, an electrolyte medium that connects the two electrodes, an external circuit, and microorganisms (Cheng et al., 2006a; Mathuriya and Sharma, 2009a; Mathuriya and Yakhmi, 2014). A prototype two-chamber MFC has been studied most extensively (Cheng et al., 2006a, 2006b; Shukla et al., 2004; Mathuriya and Sharma, 2009b). This MFC consists of anaerobic anode and aerobic cathode chamber separated by a cation/proton exchange membrane. At the anode, microorganisms generate electrons through degrading organic compounds. Electrons travel through external circuit to cathode while protons through membrane. At the cathode, they react with oxygen to form water. Therefore, the electricity generated by MFC can be harvested by an external resistor placed between the anode and the cathode (Jiang et al., 2010).

Over the past few years, MFCs witnessed intense research and development and proved to be superior over other competing conventional wastewater treatment technologies, in many aspects, including enhanced conversion efficiency due to direct conversion of substrate's chemical energy into electricity; capability to treat low-strength wastewaters that are not suitable for anaerobic digestion (Rittmann, 2008; Watanabe, 2008); safe and quite performance; ability to operate at ambient temperature (Mathuriya and Sharma, 2009a); and generation of 50%–90% less solids to be disposed of (Du et al., 2007). Moreover, MFCs produce mainly carbon dioxide (CO_2) that has no useful energy content and comparatively less harmful, thus not requiring much further treatment (Jang et al., 2004). In recent years power densities in MFCs reached over 4200 mW/m^3 (Sharma and Li, 2010) and chemical oxygen demand (COD) and other contaminants removal up to 100% (Luo et al., 2011).

The structural parameters draw crucial effects on the overall performance of a fuel cell (Larminie and Dicks, 2000).

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In past, many MFC designs have been tested to increase power density or wastewater treatment efficiency (Kaewkannetra et al., 2011; Qian et al., 2011; Huang et al., 2012). In additions, various attempts have been made to minimize MFC operational costs (Buitrón and Cervantes-Astorga, 2013). Novel configurations *viz.* single-chamber (Yokoyama et al., 2006), column (Powers et al., 2011), tubular, (Rabaey et al., 2005) and high efficiency electrode materials (non-platinum coated cathodes, brush anodes, granular activated carbon anodes) have been developed till date (Rabaey et al., 2005; Cheng et al., 2006a,b; He et al., 2007; Logan et al., 2007; Zou et al., 2008; Sharma et al., 2008). However, most MFCs studies were conducted at lab scales (less than 1 L) and it was observed that the power density decreased during scale-up (Keller and Rabaey, 2008). In addition, these MFCs were able to treat only one type of wastewater at a time (Mathuriya and Sharma, 2009a; Rabaey et al., 2005). In order to make MFCs suitable for practical applications, it is critical to achieve high power density at large scale along with real time wastewater management capabilities. In present investigation, a novel multiple anode chamber and single cathode chamber MFC design (MAC-MFC) was fabricated which operated as a fed batch system to optimize power output from wastewater and its performance was compared with the standard single-anode/cathode chamber MFC (SC-MFC) for power production and chemical oxygen demand (COD) removal. Further, efficiency of MAC-MFC was studied with different wastewaters in each anode chamber to prove its ability in treating different wastewaters simultaneously, a possible situation in many waste treatment plants.

1. Materials and methods

1.1. Wastewaters

Dairy wastewater was collected from primary effluent collection tank from a local dairy plant at Agra, India. Potato wastewater was collected from local potato chip unit Agra, India. Paper wastewater was collected from a paper processing plant at Agra, India. The artificial wastewater was prepared by modifying previous method (Jang et al., 2004). The composition was (g/L): 15.0 g glucose, 450.0 mg $NaHCO_3$, 100.0 mg NH_4Cl, 10.5 mg K_2HPO_4, 6.0 mg KH_2PO_4, 64.3 mg $CaCl_2{\cdot}2H_2O$, 18.9 mg $MgSO_4{\cdot}7H_2O$, 10.0 mg $FeSO_4{\cdot}7H_2O$, 6.0 mg $MnSO_4$, 0.5 mg $ZnSO_4{\cdot}7H_2O$, 20.0 mg $CoCl_2{\cdot}6H_2O$, and 0.65 mg $CuSO_4{\cdot}5H_2O$. Spot samples of all wastewaters were transported to laboratory for physicochemical analysis. These parameters include pH, total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solids (VSS), color, odor, COD, and biological oxygen demand (BOD). Each sample was left undisturbed for 24 hr at 4°C under anaerobic conditions to settle the solid particulate contents. Wastewater samples were kept in refrigerator at 4°C, when not in use. The plain wastewaters (without any modifications such as addition of nutrients, mediator, and any other microbial inoculum or trace metals) with constant COD value of 1500 mg/L were used as the inoculum for all MFC tests (except as indicated). COD values of various wastewaters were adjusted by diluting wastewaters with de-ionized water. Experiments were conducted at 30°C, pH 7.0 and stagnant condition (without stirring).

1.2. MFC designs

Standard single chamber MFCs (SC-MFCs) were constructed from two glass chambers with total inner volume of 3000 mL and working volume of 2100 mL. The anode and cathode chambers were separated using a glass plate frame having 6 × 6 cm hole. The hole was tightly sealed by a proton exchange membrane (PEM-Nafion™ 117, DuPont Co., USA). Plain carbon paper (7 × 7 cm) and graphite plate (7 × 7 cm) were used as anode and as cathode (Fig. 1a). The electrodes (both anode and cathode) were connected to copper wire and exposed copper metal surface at the joints, were tightly sealed with non conductive epoxy resin. Both anode and cathode were suspended in their respective chambers. The anodic chamber was filled with 2100 mL dairy wastewater. The anodic chamber was continuously flushed with a mixture of N_2/CO_2 (80:20, V/V) to maintain anaerobic conditions. On the other hand, cathode chamber was filled with 700 mL of 100 mmol/L phosphate buffer and pH was maintained to 7.0 by 0.5 mol/L NaOH. Air was percolated in the cathode chamber through a 0.45 μm pore size filter to provide molecular oxygen as electron acceptor for cathode.

Multiple anode chamber MFC design (MAC-MFC) was constructed from three media bottles and one water bottle. Each media bottle had a total working volume of 1000 mL while water bottle was of 5000 mL capacity. The media bottles were developed as anode chambers and water bottle as cathode. All anodes and cathode bottles were joined by a non-conductive resin with 6 × 6 cm PEM, separating the passage between the bottles (Fig. 1b). Electrode arrangements consisting of plain carbon paper (7 × 7 cm) as anode and three parallel graphite plates (7 × 7 cm) as cathode were used. The anodes and cathodes were suspended from the top cover, which was tightly sealed. The anodes were continuously flushed with N_2/CO_2 (80:20, V/V) to maintain anaerobic conditions. Cathode chamber was filled with 100 mmol/L, 2100 mL phosphate buffer and pH adjusted to 7 by 0.5 mol/L NaOH. Cathode chamber was provided with air that was passed through a 0.45 μm pore size filter to provide molecular oxygen as electron acceptor for cathode. The electrodes were attached to copper wire with all exposed metal surfaces sealed with a nonconductive epoxy. One sampling ports were tapped in the side of the anodes and cathode chamber to permit withdrawal and addition of medium solution.

1.3. MFC operations

After the attachments were completely dried, both the cathode and anode electrodes were soaked in deionized water for 1 hr before assembling the MFCs. The anode chambers were filled (700 mL) with wastewater for study. Initially MFCs were inoculated with artificial wastewater containing glucose as carbon source. After two cycles, feed solution containing 50% artificial wastewater and 50% dairy wastewater sample, inoculated into MFCs separately. After four cycles, feed solution was switched to dairy wastewater sample.

The experimental setup was run in fed-batch mode with dairy wastewater as anolyte except as indicated. The performance of all the MFCs was evaluated by measuring current, current density, potential, open circuit voltage (OCV), and power density along with COD removal efficiency. Stable voltage output was