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Electrochemical performance and community structure in three microbial fuel cells treating landfill leachate

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ABSTRACT

Electrochemical performances and pollutants removal characteristics of synthetic landfill leachate were investigated using three dual-chambered microbial fuel cells (MFCs). An open circuit MFC, aerated MFC and non-aerated MFC were used to compare the performance of the different modes. Results showed that aerated MFC was superior to the open circuit MFC and the non-aerated MFC in generating electricity and removing pollutants. High-throughput sequencing of the bacterial and archaeal communities revealed that electricigen of *Enterobacter* and *Comamonas* was found in three MFCs. *Methanobacterium* was the genus of archaea present at the highest proportion in the open circuit MFC, non-aerated MFC and aerated MFC, at 56.67%, 51.62% and 58.37%, respectively. Diversity of the bacterial and archaeal community in open circuit MFC is higher than that of closed circuit MFC. Richness goes by contrary. The circuit connections and growth conditions can help to control the species of biomass and change the performance of MFCs.

1. Introduction

Landfill leachate is made up of rain that has percolated through a landfill site, liquids that are generated by the biodegradation of the wastes and inherent water from the refuse itself (Wiszniowski et al., 2006; Zhang et al., 2013; Renou et al., 2008). Hence landfill leachate is highly contaminated with a wide range of complex dissolved organic matter, inorganic macro-components, heavy metals and xenobiotic compounds (Zhang et al., 2015a; Kjeldsen et al., 2002; Christensen et al., 1994; Puig et al., 2011).

A microbial fuel cell (MFC) is an electro-biochemical reactor capable of directly converting the energy in organic matter or inorganic substances into electricity as long as a substrate and oxidant are available (Logan et al., 2006; Khera and Chandra, 2012; Zhang et al., 2015b). In recent years, there has been much research on the treatment of landfill leachate by MFCs. MFCs can generate electricity without requiring additional organic matter or chemical substances to be added, while the high concentrations of chemical oxygen demand (COD) and ammonia nitrogen in the leachate allow the MFC to maintain a high electrical conductivity and low internal resistance (Puig et al., 2011; Iskander et al., 2016). Prior studies also demonstrated that MFC system can recover resource from landfill leachate while combining with membrane technologies (Iskander et al., 2016; Qin et al., 2016). In a dual-chamber MFC, COD in the landfill leachate could be removed because oxygen diffusion from the cathode was reduced by aerobic or anoxic bacteria in the anode chamber, leading to substrate and ammonium nitrogen loss (You et al., 2006). Both an activated carbon anode and a biochar anode have been used to treat landfill leachate by a semi-continuous operation MFC (Ganesh and Jambeck, 2013).

Different operating modes can have a substantial impact on MFCs. MFCs in either the open or closed circuit mode may have helped control the amount of biomass and enhanced MFC performance (Yu et al., 2015a). Closed circuit, open circuit and sealed off cathode reactors were used to understand how oxygen transfer affects the microbial community structure (Shehab et al., 2013). COD removal rates and resistance were higher in the closed circuit mode when compared to the open

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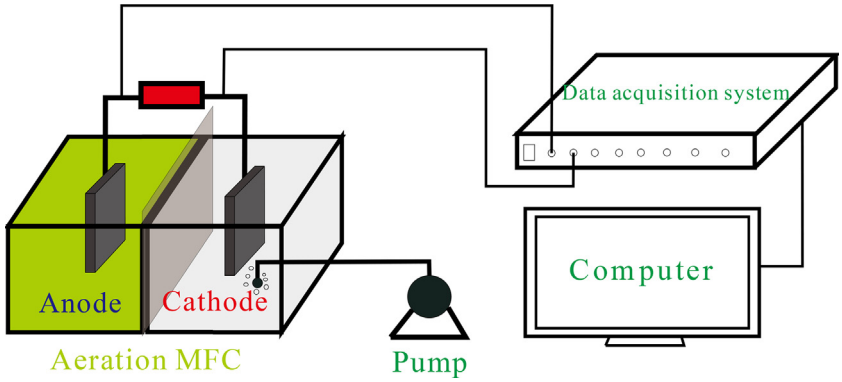

Fig. 1 – Schematic diagram of the aeration MFC.

circuit mode (Sevda et al., 2014). When the cathode chamber was aerated, the maximum achievable voltage, current and COD removal rate were higher than when the cathode was operated under anaerobic conditions (Amari et al., 2015).

The abundances of bacterial species were dependent on the operational conditions. The MFC community was mainly dominated by *Geobacter*, *Shewanella* and *Clostridium* species (Cetinkaya et al., 2016). The viability of anodic biofilms was sustained in the closed circuit MFC but decreased in an open circuit MFC (Yang et al., 2011). The closed circuit MFC anode was enriched in several microorganisms related to known electrochemically active and dissimilatory Fe(III) reducing bacteria, mostly *Geobacter* spp., to the detriment of *Bacteroidetes*, which is abundant in the open circuit MFC anode (de Carcer et al., 2011). In the closed circuit MFC, the microbes most similar to *Geobacter* were predominant on the anodes, but the most abundant bacteria was *Azoarcus* in the open circuit MFC. Hydrogenotrophic methanogens were most predominant, with sequences most similar to *Methanobacterium* in the closed circuit reactor and *Methanocorpusculum* in the open circuit reactors (Shehab et al., 2013). Ammonium was oxidized to nitrate at the aerated cathode of the MFC, and ammonium oxidation was mainly carried out by phylotypes belonging to the *Nitrosomonadales* and *Nitrospirales* genera (Wei et al., 2015).

At present, few studies have compared the effects of an open circuit MFC, aerated MFC and non-aerated MFC on the treatment of landfill leachate, and most of the research has focused on bacteria, and less on archaea. In this study, in order to further clarify the influence of the different operating modes on the performance of MFCs, the effects on power generation performance, treatment and community structure were investigated in an open circuit MFC, an aerated MFC and a non-aerated MFC.

2. Materials and methods

2.1. MFC setup and operation

Three reactors (an open circuit MFC, an aerated MFC and a non-aerated MFC) were prepared by using plexiglass dual-chamber MFC. One 10 cm × 10 cm sheet of cation exchange membrane (Qianqiu Co. Ltd, Jinyun,China) was used as a separator between the anode and the cathode chambers. The volume of each chamber was 1000 mL. Carbon felt (Wuxi Kuntai Co. Ltd, China) with a projected area of 49 cm^2 (7 cm × 7 cm) was used as the anode and cathode. For the aerated MFC and non-aerated MFC,the electrodes were connected by a copper wire through a 500 Ω external resistance for voltage recording. For open circuit MFC, the anode and cathode were not connected. In the cathode chamber of the aerated MFC, an air pump was used to provide dissolved oxygen. The system configuration of the MFC is illustrated in Fig. 1.

The anode chamber bacteria were inoculated from a lab-scale MFC that had been continuously operated for over one year. The anode chamber was fed with synthetic landfill leachate, which contained (per L): sodium acetate, 2.14 g; glucose, 2.14 g; NH_4Cl, 9.81 g; urea, 0.15 g; nutrient broth, 0.15 g; KH_2PO_4, 2.95 g; $K_2HPO_4{\cdot}3H_2O$, 6.6 g; KCl, 0.13 g. COD was 4000 mg L^{-1}, ammonia nitrogen concentration was 3000 mg L^{-1} and the pH was 7.13. All chemicals were purchased from Sinopharm Chemical Reagent Co. Ltd, Shanghai, China, and were used without further purification. All experiments were performed in duplicate at room temperature (22 ± 5 °C) in fed-batch mode.

2.2. Analytical methods

Total organic carbon (TOC) was measured using a TOC analyzer (TOC-V CPH/CPN). COD, NH_4^+-N and total nitrogen (TN) were estimated according to the standard methods (GB 11914-89).

Voltage across the external resistor was continuously recorded by a data acquisition system (CT2001A, Land, China). The current (I) was calculated from Ohm's law ($I = V/R$). When the voltage of the MFC became stable, polarization curves and the power density were obtained using an external adjustable resistance box (Dongmao, Shanghai). The external resistance was gradually reduced from 8000 Ω to 30 Ω. Power density was calculated according to Ohm's law ($P = U^2/R$) and normalized by the projected area of the electrode.

2.3. High-throughput sequencing analysis

Samples were collected from the surface of the anode carbon felt in different operation modes (open circuit MFC, non-aerated MFC and aerated MFC) for DNA extraction using the Soil DNA Kit according to the manufacturer's instructions (Sangon Biotech Co. Ltd., Shanghai China). Primers 341F (5′-CCTACGGGAGGCAGCAG-3′) and 805R (5′-GACTACCAGGGTATCTAATC-3′) were used to amplify the variable V3–V4 region of the bacterial 16S rDNA of the samples (Baker et al., 2003). After PCR, the products were detected by agarose gel electrophoresis. For PCR products amplified from bacteria and archaea and PCR products with normal amplicons above 400 bp, a magnetic beads-to-sample volumetric ratio of 0.6× was used for DNA purification and recovery. For PCR products and other amplified products less than 400 bp, a magnetic beads-to-sample ratio of 0.8× was used for DNA purification and recovery. The recovered DNA was accurately quantified using the Qubit 2.0 DNA Assay Kit with convenient 1:1 mixing and complete shaking. The mixed sample was used for subsequent sample preparation and sequencing.