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Research article

Influence of glass wool as separator on bioelectricity generation in a constructed wetland-microbial fuel cell

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ABSTRACT

To figure out the impact of the separator on the electrical performance of the newly established constructed wetland-microbial fuel cell (CW-MFC), two parallel upflow CW-MFC systems, with and without glass wool (GW), were set up in this study. System performances in terms of bioelectricity production were monitored for more than 4 months. Results showed that the highest voltage was achieved in non-separator (NS) system (465.7 ± 4.2 mV with electrode spacing of 5 cm), which is 48.9% higher than the highest value generated in GW system (312 ± 7.0 mV with electrode spacing of 2 cm). The highest power density was produced in NS system (66.22 mW/m^2), which is 3.9 times higher than the value in GW system (17.14 mW/m^2). The diffusion of oxygen from the open air was greatly hindered by the biofilm formed under the cathode. This kind of biofilm can be severed as the "microbial separator", playing the same role in a real separator.

1. Introduction

Microbial fuel cells (MFCs), which provide a sustainable and carbon-neutral source of energy, have drawn increasing attentions among the chemists and microbiologists during the last decade (Ge et al., 2013; Logan, 2008; Logan et al., 2015; Wang et al., 2015). However, compared to the pure MFCs, the integrated processes working in synergy with MFCs revealed more possibilities in practical applications (Li et al., 2014; Xu et al., 2016a). As a good example, constructed wetland-microbial fuel cell (CW-MFC), with the integration between traditional CW and MFC (Corbella et al., 2015; Doherty et al., 2015a; Fang et al., 2015; Oon et al., 2017; Yadav et al., 2012; Zhao et al., 2013), provides a more promising approach for updating the traditional CW. It has been shown by several studies that this kind of integration can not only enhance the pollutants removal efficiency in CWs, but also own the ability in directly extracting waste energy within the flux of wastewater into electricity and thus presenting a potential energy output wastewater treatment process (Doherty et al., 2015b; Fang et al., 2013; Srivastava et al., 2015; Villasenor et al., 2013; Wei et al., 2015).

Generally, MFC consists of a pair of anode and cathode with the separator between them. As a critical part of traditional MFCs, separator plays an important role in maintaining their normal operation. The two main functions of the separator are to prevent oxygen diffusion from cathode to anode chamber and to avoid the short circuit when the electrodes getting closer. A number of previous studies were emphasized in selecting a suitable separator in MFCs which can simultaneously control the oxygen intrusion from the cathode to anode and facilitate the proton transfer from the anode to cathode (Kim et al., 2007; Zhang et al., 2009, 2010). In addition, the work conducted by Liu and Logan (2004) also revealed that a non-proton exchange membrane (PEM) system could achieve a higher maximum power density (MPD) compared to a PEM system. However, the inexistence of membrane will greatly reduce the coulombic efficiency (CE) due to the diffusion of oxygen from air-cathode to anode.

In terms of CW-MFC, due to its relatively larger scale than pure MFCs (normally bottle-size scale), CW-MFC seems not feasible to adopt those membrane separators used in pure MFC regarding the architecture and cost. Thus, low price materials like glass wool were usually used as the separator in CW-MFC (Yadav et al., 2012; Zhao et al., 2013). Significantly, the argument seems existed in CW-MFC as the adoptions of separator and non-separator are both employed in the literature (Fang et al., 2015; Oon et al., 2015; Zhao et al., 2013), while no attention has been paid on it. Moreover, the operation mode of CWs is significantly different from the pure MFCs.

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Take upflow CW as the example, the treated water usually goes through the system from bottom to the top, which indicates that the outflow from anodic compartment will directly flow to cathodic compartment in CW-MFC. However, in pure MFCs, these two compartments are usually working separately to avoid the negative influences from both sides. In addition, since the internal resistance of CW-MFC is significantly higher than pure MFC, while the most efficient and direct method for internal resistance reduction should be the reduction of the electrode spacing. However, separator seems a necessity when the electrode spacing is quite small. With regards to these considerations, figuring out the role or the influence of separator in CW-MFC systems (especially when the electrode spacing is smaller) is necessary to further study the joint technology of CW-MFC as it is still in its infant stage of development.

Herein, two parallel CW-MFC systems were set up, one with a separator (glass wool) and the other is a non-separator system, for the first time of clarifying the influence of separator on the electrical performance of the CW-MFC. The influence derived from the existence of separator on electrical performances was investigated in terms of different embedded depth of anode (different electrode spacing). These results can hopefully give some insights to the future development of CW-MFC.

2. Materials and methods

2.1. CW-MFC systems set-up

A schematic illustration of the CW-MFC system was showed in Fig. 1. Two polyvinyl chloride (PVC) columns were built with a height of 600 mm and 100 mm in internal diameter to simulate the unplanted CW. The net liquid volume of both CWs is around 2 L and dewatered alum sludge (DAS) with an average particle size of 10–15 mm was used as the main wetland substrate, which has been intensively studied and demonstrated as promising low-cost adsorbent/substrate (Babatunde et al., 2010; Xu et al., 2016b; Zhao et al., 2013). At the bottom, a depth of 30 mm gravel with an average diameter of 5 mm was filled as the support layer to improve the distribution of wastewater/influent in the system. Carbon felt (100 mm in diameter) was used as the electrode material for both anode and cathode electrode. In each system, the cathode was located at the water-air interface on the top, while three anodes were embedded under cathode with the electrode spacing of 2 cm, 5 cm and 10 cm, respectively, making the systems as the CW-MFC. The only difference between the two systems is that one with glass wool (GW, CAS RN: 65997-17-3, ACROS ORGANICS) (with thickness around 20 mm) as the separator underneath cathode while the other does not. The two systems were wrapped in black plastic to prevent algae growth. Both the systems were inoculated with the active sludge (with MLSS of around 2 g/L) sourced from Malahide Wastewater Treatment Plant in Dublin, for three weeks before the electrical data were collecting.

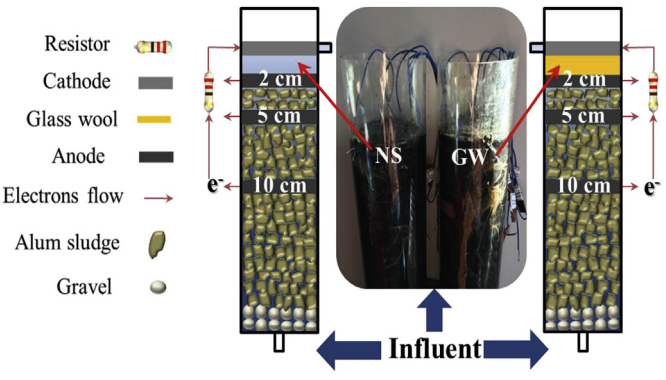

Fig. 1. Schematic description of the two parallel unplanted CW-MFC systems.

2.2. Operation and measurements

The two CW-MFC systems were continuously fed with synthetic wastewater as follow (g/10 L): CH_3COONa (6.42), NH_4Cl (1.14), $CaCl_2 \cdot 2H_2O$ (0.16), $MgSO_4$ (0.12), KH_2PO_4 (0.14) and 1 mL concentrated trace element solution as reported by (Wang et al., 2013a). The synthetic wastewater was pumped at the bottom through peristaltic pumps with controlled HRT of around 1 d. The overall operation period can mainly be divided into two main stages, from 0 to 90 day and 91–131 day. The first stage (0–90 day) consists of 3 small stages, which are 0–21 day, 21–46 day and 46–90 day. During which, cathode electrode was sequentially connected to each anode (in the sequence with the electrode spacing increased from 2 cm, 5 cm–10 cm), which corresponds to the 3 small stages. Afterward, the cathode was connected with anode with the reversal order (i.e. back to 5 cm (91–111 day) and then to 2 cm (111–131 day)) during the second stage (91–131 day), till to its initial state. For all stages, external resistance was kept at 1000 Ω. The changes of the output voltage were determined by recording the voltage drop (V) across the external resistor using a digital handheld multimeter or a data logger (USB-6000, NI Instrument). Power densities (P) were determined through basic electrical calculations as: $P = U^2/RA$, mW/m^2, where U is the voltage (V), R is the external resistance (Ω) and A is cross-section area of the column (m^2). To obtain the polarization curve, external resistance was varied over a range from 10 KΩ to 20 Ω and the steady-state voltage across the resistors was measured. The electrode potentials were determined against a saturated Ag/AgCl electrode (Mettler Toledo). All experiments were conducted at room temperature (20 ± 2 °C).

2.3. Determination of oxygen diffusion

To clarify the influence of glass wool on oxygen diffusion from the cathode to anode, oxygen diffusion rate was determined before the start-up and after the long period operation (131 days) for both NS system and GW system. The oxygen concentration was measured through a Microprocessor Oximeter (WTW, OXI 96), which was placed at 2 cm beneath the cathode, i.e. around the first anode electrode. Each measurement was duplicated with a continuous recording for 6 h. The oxygen mass transfer coefficients (K_0, cm/s) were calculated using $K_0 = -v/At \cdot \ln[c_{1,0} - c_2/c_{1,0}]$, where v is the liquid volume, A is the cross-sectional area, $c_{1,0}$ is the dissolved oxygen (DO) in the cathodic area while c_2 is the DO in the anodic area at time t.

3. Results and discussion

3.1. Influence of glass wool on electricity generation with different electrode spacing

After inoculation, voltages across the external resistance (1000 Ω) of the two systems were monitored and illustrated in Fig. 2. It can be seen that two different patterns were presented between GW system and NS system. In terms of the GW-system, the output voltage (with electrodes spacing of 2 cm) reached over 400 mV firstly and then gradually stabilized around 300 mV. In comparison, the output voltage of NS-system gradually increased since the beginning, to about 450 mV. This trend is consistent with the results revealed by Zhang et al. (2013), which suggested that the using of glass fiber membrane in MFC can shorten the start-up time