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Substrate cross-conduction effect on the performance of serially connected microbial fuel cell stack

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ABSTRACT

This study presented a new design of scalable, air-cathode microbial fuel cell (MFC) stack that shared a common fuel feed passage. As two individual cells were electrically connected in series by metal wires and hydraulically joined by conductive substrate flow, the performance degradation phenomenon was observed. The open circuit voltage (OCV) and low current behavior of stacked MFC were lower than should be expected. This energy loss was proposed to be a consequence of parasitic current flow due to the substrate cross-conduction effect and can be likely minimized through controlling the distance between the anode electrodes or/and the cross-sectional area of substrate flow. The unique and simple water distribution system of the tubular MFC stack would contribute to the further scale-up and implementation of MFC technologies, especially for wastewater treatment.

1. Introduction

At present, the greatest challenge in MFCs research is to use MFCs for real application, which requires high energy production, low cost, simple construction and easy maintenance. The technologies including air-cathode [1], ion exchange membrane cathode [2] and non-Pt cathodic catalyst [3] have significantly reduced the cost of MFC and allowed easy construction and operation. Stack reactors [4–6] are devised to increase the voltage output since a single MFC can only produce a maximum working potential of 0.3–0.7 V due to the thermodynamic constraints [7], which mainly limits the scale-up and implementation of MFC technologies.

Aelterman et al. [5] stacked six individual continuous MFC units in series, electrically connected by cooper wires between the electrodes, in which the influent was separately fed to the individual MFCs. The stacked MFC enabled an increase of the voltages (2.02 V at 228 W m^{-3}). Ieropoulos et al. [8] tested the connection configuration of MFC units in series, parallel or series-parallel under a continuous-flow mode for optimizing the power output. Although the above designs of stacked MFCs boosted the voltage, each MFC cell required an individual recirculation loop for substrate feed and discharge. Such water distribution system for influent and effluent was too delicate and undeniably inapplicable for scale-up of MFC technologies, especially for wastewater treatment.

Here, we presented a stackable air-cathode MFC design, in which all individual MFC units shared a common feed passage and the fuel was push-flowed through each cell and finally discharged through a terminal unit. This concept avoids the requirement of a complicated water distribution system to pump substrate individually to different reactors and discharge separately, thereby providing an approach for easy construction and implementation. Under the continuous-flow mode, as two MFC units were electrically connected in series by metal wires and hydraulically connected by substrate flow, we observed a performance degradation phenomenon that the open circuit voltage (OCV) and low current behavior of such MFC stack were lower than should be expected. In this paper, we focused on the experimental evidences for the voltage loss and further discussed the potential methods to minimize it.

2. Experimental

2.1. Configuration of MFC stack

Two tubular air-cathode MFCs were connected in series, as shown in Fig. 1. Each MFC was built with a 0.2 cm-thick polyvinyl chloride (PVC) plastic tube (I.D. 7.5 cm × 11 cm). The PVC tube, serving as the framework of anode chamber, was punched with evenly distributed pores (I.D. 1 cm), giving an opening area ratio of 12.55%. A tubular membrane cathode assembly (MCA) used in this experiment was constructed by hot-pressing carbon fiber cloth (11.0 cm × 26.0 cm) containing a MnO_2 catalyst (8.0 mg/cm^2) [9] to a same size cation exchange membrane, and then wrapped the MCA around the outer surface of the anode chamber. A 0.5 cm-thick graphite felt (11.0 cm × 23.6 cm) was nested inside the

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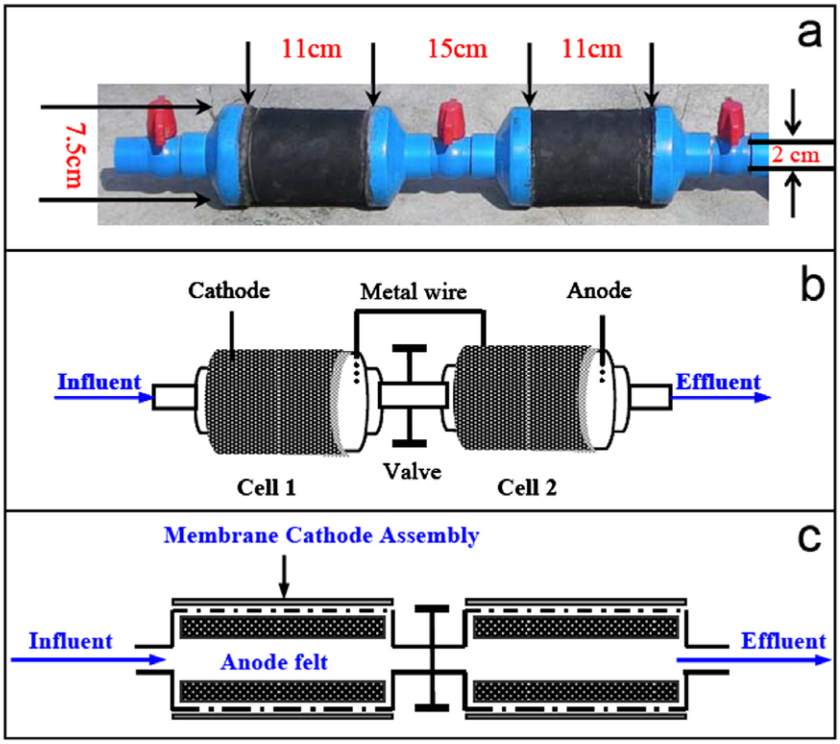

Fig. 1. Stacked MFC (twin-cell): (a) photograph; (b) schematic configuration; (c) cross-sectional view.

chamber as anode (Fig. 1c). A twin-cell was built by joining two MFC cells via a ball valve (I.D. 2 cm), which was employed to control the substrate flow between MFCs. The void volume of a twin-cell was approximately 1500 mL. To electrically connect them in serial configuration, the cathode of cell 1 was connected to the anode of cell 2 by titanium wires (Fig. 1b). All MFC experiments were conducted at 30 °C.

2.2. Reactor inoculation and calculation

The twin-cell MFC was inoculated using pre-acclimated microbial community from another MFC that has been running in the fed-batch mode over 12 months. The reactor was initially incubated in the fed-batch mode with brewery wastewater containing 1% NaCl (%wt) (pH = 7.5, conductivity = 6900 μs/cm, BOD = 3090 mg/L). After a repeatable cycle of power generation, the system switched to continuous-flow mode. The wastewater was continuously fed to the MFC stack by a peristaltic pump at 62.5 mL h^{-1} corresponding to a volumetric loading rate of 4.25 g COD L^{-1} d^{-1}, which ensured the substrate sufficiency. The polarization and power density curves as a function of current density were obtained by varying the external resistance over a range from 10 to 5000 Ω when the voltage output reached a plateau [1].

3. Results and discussion

3.1. Performance degradation of MFC stack

As shown in Table 1, in the case of electrically and hydraulically unconnected states, the individual cell 1 and cell 2 produced the OCVs of 652.2 and 654.1 mV, respectively. When the two cells were electrically connected, the OCVs for each cell remained at similar potential, and the OCV of twin-cell almost equaled to the mathematical sum of individual cells, which demonstrated the successful serial connection. In this experiment, we employed a ball valve to control the hydraulic connection. It was found that when the ball valve was open (i.e. hydraulically connected), the OCV in the both cells significantly reduced to 378.7 and 586.3 mV, respectively. The voltage drop phenomenon is consistent and instantaneous. If the hydraulic connection was blocked (i.e. close the valve), the OCVs of both cells rebounded. When keeping the twin-cell in hydraulic connection but removed the metal wires between the individual cells, the voltage potentials resumed to the values of unconnected state. In summary, a decrease in MFC performance would occur in the case of both electrical and substrate fluidic connections, the sole fluidic connection or electrical connection would not result in the voltage loss.

Table 1
Open circuit voltage (OCV) of individual cells and the twin-cell (unit: mV).

Conditions	Cell 1	Cell 2	Twin cell
Hydraulically isolated + electrically isolated	652.2	654.1	–
Hydraulically isolated + electrically connected	652.9	655.3	1307.7
Hydraulically connected + electrically connected	378.7	586.3	964.2
Hydraulically connected + electrically isolated	651.5	654.8	–

3.2. Evidences for substrate cross-conduction effect

As the hydraulic connection mode of the twin-cell switched from unconnected to connected, the OCV of the twin-cell dropped to 0.96 V from 1.31 V. The decrease in OCV suggested the presence of an internal short current flow because no external current can flow through the twin-cell under the open circuit conditions. As shown in Fig. 2, the electrical connection by metal wires between the cathode of cell 1 and the anode of cell 2, integrated with the electrolytic connection through conductive substrate flow, formed an internal, parasitic fuel cell. As a consequence, a parasitic cross current was generated within the parasitic cell and flowed through the closed loop, driving the drop of voltage in both cells. The par-