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Improved performance of the microbial electrolysis desalination and chemical-production cell with enlarged anode and high applied voltages

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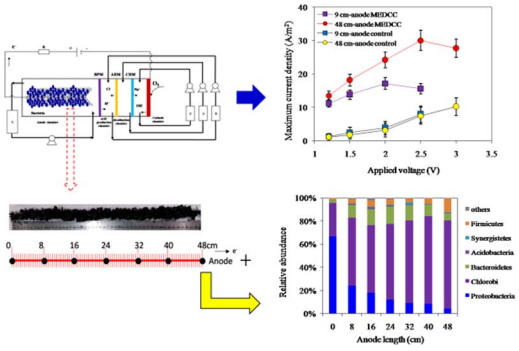
GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this study was to improve performance of the microbial electrolysis desalination and chemical-production cell (MEDCC) using enlarged anode and high applied voltages. MEDCCs with anode lengths of 9 and 48 cm (i.e., the 9 cm-anode MEDCC and 48 cm-anode MEDCC, respectively) were tested under different voltages (1.2–3.0 V). Our results demonstrated for the first time that the MEDCC could maintain high performance even under the applied voltage higher than that for water dissociation (i.e., 1.8 V). Under the applied voltage of 2.5 V, the maximum current density in the 48 cm-anode MEDCC reached 32.8 ± 2.6 A/m^2, which is one of the highest current densities reported so far in the bioelectrochemical system (BES). The relative abundance of *Geobacter* was changed along the anode length. Our results show the great potential of the BES with enlarged anode and high applied voltages.

1. Introduction

In the bioelectrochemical system (BES), electrochemically active bacteria (EAB) are utilized to catalyze different electrochemical reactions. With external electrical power, BESs can be used to produce various value-added chemical products, such as hydrogen, alkalis, and acids (Logan, 2009; Rozendal et al., 2008). The value-added BESs include microbial electrolysis cell (MEC), microbial electrolysis and desalination cell (MEDC), microbial electrolysis and chemical production cell (MEDCC), and others (Chen et al., 2012a; Logan et al., 2015; Mehanna et al., 2010). According to the life cycle or cost-effective assessment, the value-added BESs are shown to be more promising in practices than microbial fuel cell (Foley et al., 2010; Logan & Rabaey, 2012; Rozendal et al., 2008). The performance of the value-added BESs

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is greatly affected by the applied voltage. Hydrogen production rates in the MEC have been shown to be a linear function of applied voltages from 0.2 to 0.8 V (Call & Logan, 2008). However, chemical oxygen demand (COD) removal and biogas yield in the MEC can be greatly reduced with the applied voltage above 1.0 V, mainly because of low EAB growth rate and metabolic activity (Ding et al., 2016). Our previous results demonstrated that the maximum current density of MEDCC increased from 10.3 to 11.0 A/m^2 with applied voltages from 1.0 to 1.2 V, but decreased to 3.8 A/m^2 with 1.3 V (Chen et al., 2012 b). The applied voltages in the BESs have been always set up to be lower than that for water dissociation (i.e., close to 1.8 V) (Liu et al., 2005b). If water dissociation occurs in the BES, oxygen may be produced on the anode ($2H_2O \rightarrow O_2\uparrow + 4e^- + 4H^+$, $E^0 = +1.229$ V), which inhibits the activity of EABs, such as *Geobacter* (Bond & Lovley, 2003) and *Shewanella* (Lu et al., 2017). So far it has not been reported for the BES to be able to operate at applied voltages higher than that for water dissociation.

The current density in the BES has been greatly improved by several orders of magnitude in recent years (Fan et al., 2012). However, the maximum current densities are still much lower in the BESs than in the conventional electrochemical systems, such as fuel cell (Rinaldi et al., 2008) and electrodialysis with bipolar membrane (EDBM) (Huang & Xu, 2006). The current density in the BESs can be increased via reduction of internal resistance or increase of applied voltage according to the Ohm's law. Through the constructed optimization, the internal resistance of MEC or MEDCC has been reduced to ten to hundreds Ohms (Call & Logan, 2008; Liu et al., 2015). Application of high voltages should be an alternative to increase the current density in the BES.

Many microorganisms can survive at very high electric field. *Escherichia coli* and *Staphylococcus aureus* are viable almost by 100% under a vertical electrical field of 2.5 kV/cm applied for 0.25 h (Jain et al., 2015). Although the colony-forming unit per cm^2 of viable biofilm cell of *Pseudomonas aeruginosa* on stainless steel elements is greatly reduced with a direct current treatment (10 V and 10 mA) within 24 h, it can be recovered to the pretreatment level within 48 h (Costerton et al., 1994). Moreover, the anode potential could be kept stable at $-0.200 \sim -0.500$ V in the matured MEC(Call & Logan, 2008), MEDC(Mehanna et al., 2010) or MEDCC(Chen et al., 2012a), indicating that the anode potential may be determined by the colonized EABs instead of the anode electrode material. Therefore, we hypothesize that EABs can survive and be capable to keep the anode potential as low as –0.200 V even at an applied voltage higher than that for water dissociation in the BES. The oxygen production at the anode electrode may not take place due to low anode potential. Thus, high current density can be achieved because of EABs in the anode. In addition, a larger surface area of the anode in the MFC should be favorable for EAB biomass development on the anode biofilm and boost substrate utilization, which can enhance electricity generation (Fan et al., 2008; Logan et al., 2007). Therefore, it is expected that an enlarged anode should result in high current density.

The objective of this study was to investigate the feasibility to improve performance of the MEDCC using high applied voltages and enlarged anode. Performance of the MEDCC, including maximum current density and desalination rate, was characterized. The effect of high applied voltages and enlarged anode on the bacterial community in the anode biofilm was discussed.

2. Materials and methods

2.1. MEDCC setup and operation

The MEDCC reactor was constructed with four chambers, i.e., an anode chamber, an acid-production chamber, a desalination chamber, and a cathode chamber, which were separated successively using bipolar membrane (BPM, Fumasep-FBM, Fumatech, German), cation exchange membrane (CEM, Ultrex CMI-7000, MI, USA), and anion exchange membrane (AEM, Ultrex AMI-7001, MI, USA). The effective area of each membrane was 7 cm^2. Carbon fibers were cut into 3 cm long, which were used to make carbon brush anodes. Two types of anodes were prepared with lengths of 9 and 48 cm, respectively, and total carbon fiber lengths of the two anodes were 72 and 384 cm, respectively. After pretreated with 450 °C for 30 min, the carbon brush anodes with lengths of 9 and 48 cm were used in the MEDCCs, denoted as 9 cm-anode MEDCC and 48 cm-anode MEDCC, respectively (Xin et al., 2009). The activated carbon (SPC-01, Xinsen, China) was used as cathodic catalyst and the cathode was made following Dong et al. (2012). The spacings among BPM, CEM, AEM, and the cathode were about 1.0 mm, resulting in the same effective volumes of the acid-production, desalination, and cathode chambers (i.e., 1 mL). Effective volumes of the anode chambers in the 9 cm-anode and 48 cm-anode MEDCCs were 112 and 336 mL, respectively. An external resistance of 10 Ω was connected between the negative lead of the power supply (Itech, IT6700, China), and the positive lead of the power supply was connected to the anode.

The MEDCCs were operated in a recirculation mode (Fig. 1). A plastic magnetic pump (MP-6R, Shanghai Magnetic Pump manufacture Co. Ltd., China) was used to recycle the flow in the anode chamber with a flow rate of 2.8 L/min. The hydraulic retention time (HRT) was 2.4

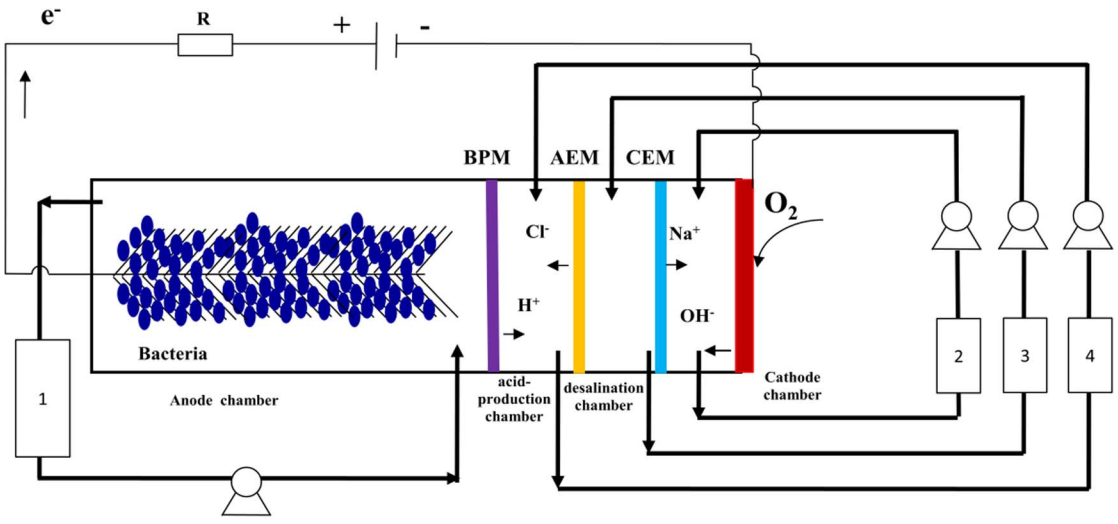

Fig. 1. Schematic diagram of the reactor setup. Numbers 1, 2, 3, and 4 represent the anode storage tank, acid-production storage tank, desalination storage tank, and cathode storage tank, respectively.