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Short communication

The electrochemical behavior of three air cathodes for microbial electrochemical system (MES) under meter scale water pressure

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HIGHLIGHTS

- A 3 m test system was built to investigate the effect of water pressure.
- The cathodes of Pt-CC, Pt-CM, and AC-MM showed various responses under pressure.
- The AC-MM functioned stable and achieved the best water pressure tolerance.
- The mechanical properties of cathodes close related to their performance responses.

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ABSTRACT

To produce cathodes with high water pressure tolerance for the practical application of microbial electrochemical system (MES), a 3-m test configuration is set up. Three kinds of cathodes, including Pt-CC (carbon cloth with platinum carbon), Pt-CM (carbon mesh with platinum carbon), and AC-MM (metal mesh with activated carbon), are investigated. The electrochemical performances of these cathodes are tested with linear sweep voltammetry under varied water pressures. Current densities of Pt-CC and Pt-CM increase with the rising water pressures till the maximum endurable water head, which are 100 cm for Pt-CC and 130 cm for Pt-CM. Yet electrochemical performances of AC-MM remained stable under the tested water pressure range from 0 to 30 KPa. The deformation of cathodes under varied water pressures causes the changes of cathode performances. The curvature degrees of cathodes relate to their mechanical properties. Elastic modulus of AC-MM is $4 \pm 0.4 \times 10^3$ MPa, which is over 10 times larger than that of Pt-CM and over 60 times larger than that of Pt-CC. The best mechanical properties prevent AC-MM from the substantial deformation and the consequent lacerations and water flooding of diffusion layers.

1. Introduction

Microbial electrochemical system (MES) is considered as a promising technology for wastewater treatment [1]. In MES, organic pollutants were oxidized by anode exoelectrogens, and the released electrons were finally combined with electron acceptors at the cathode [2,3]. Great efforts have been made in the past decade to increase the maximum power density by optimizing the reactor structure [4], constructing the energy harvest external circuit [5], and enhancing the performance of electrodes [6,7]. However, there remained some challenges when considering the scaling up and the practical application of MES. Till now, most of the scaled-up systems were associated to the enlargement in liter-scale [4,8,9] and the height of MFC was in centimeter-level to decimeter-level [10]. The performances of cathodes were found to be affected under higher water pressure [11,12]. It is obviously important to enlarge the system to meter-scale in real application and the cathode could function stable under meter-level water pressure is of great significance.

Carbon cloth cathode with platinum catalyst (Pt-CC) was widely used for oxygen reduction [13] and carbon mesh cathode with Pt catalyst (Pt-CM) was used as a less expensive alternative of Pt-CC [6]. Recently, activated carbon cathode with metal mesh (AC-MM) was found to possess comparable catalytic properties with

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platinum carbon cathodes [14]. In these cathodes, hydrophilic catalysts layers were usually fixed on to the conductive supporting materials by various binders and diffusion layers were applied as thin layers using hydrophobic polymers, such as polytetrafluoroethylene (PTFE) [15] or polydimethylsiloxane (PDMS) [16]. These cathodes were widely investigated and optimized in previous works for the purpose of obtaining high power density output [14] and low manufacturing cost [6]. These air cathodes were considered to be promising in the practical application of MES, especially the carbon mesh (CM) cathode [10] and activated carbon cathode with stainless steel mesh (AC-MM) [17]. However, the impacts of water pressure on the performances of these cathodes were still unknown. In order to find out suitable cathodes for practical application, their maximum endurable water pressures should be examined.

In this study, to investigate the service life of different cathodes under different water pressures and to find out a suitable cathode with high water pressure tolerance, the cathodes of Pt-CC, Pt-CM and AC-MM were included as research targets. The relationships between cathode performances and the diffusion layer deformation under various water pressures, and mechanical properties of cathode structure were analyzed.

2. Experiment and methods

2.1. Test system

A 3-m test system was composed by two parts. The lower part was a 1.5 m height plexiglass rectangle column with an inner size of 4 cm (length) × 4 cm (width). Fifteen pairs of cathode fixed sites were placed on both sides of the column. A plexiglass tube (Φ 3 cm) was glued on the top of the plexiglass rectangle column to extend the test range from 1.5 m to 3 m (Fig. 1 and Fig. S1). The water pressures were calculated based on the height between the upper edge of the cathodes and the highest liquid surface. The effective diameter of the cathodes was 2 cm.

The 30% wet proofed carbon cloth (CC, type B, E-TEK), 10% PTFE wet proofed 3K carbon mesh (CM, Toray, 3K plain-weave carbon mesh) and corrosion resistant type 304 stainless steel mesh (SS, 60 mesh) were chosen as the conductive substrate of the tested cathodes followed previous reported methods [6,13,17]. The Pt-CC and Pt-CM were made followed the same process and coated with Pt/C catalyst layer with a loading rate of 0.5 mg Pt cm^{-2}. The activated carbon loading rate of AC-MM was 40 mg cm^{-2}. The PTFE loading rate in the diffusion layer of these cathodes was set at 25 μL cm^{-2} and the manufacturing processes were shown in Fig. 1.

2.2. Electrochemical analysis

The linear sweep voltammetry (LSV) was performed at a scan rate of 0.1 mV s^{-1} on the cathodes with a smooth bright Pt plate of 1 cm^2 apparent area as counter electrode and an Ag/AgCl reference electrode (195 mV vs. SHE, Spsic-Rex Instrument Factory, China) using a potentiostat (WonATech WMPG 1000, Korea). The test system was filled with 50 mM PBS (Na_2HPO_4, 4.58 g L^{-1}; $NaH_2PO_4 \cdot H_2O$ 2.45 g L^{-1}; conductivity of 6.9 mS cm^{-1}). The performances of cathodes under different water pressures were obtained by controlling water head in the test system. Prior to LSV test, the examined cathodes were stabilized under the certain water level for 24 h. The LSV tests under each water level were repeated until the curves obtained from three adjacent tests were overlapped. The LSV curves obtained in the last time were exhibited in this paper.

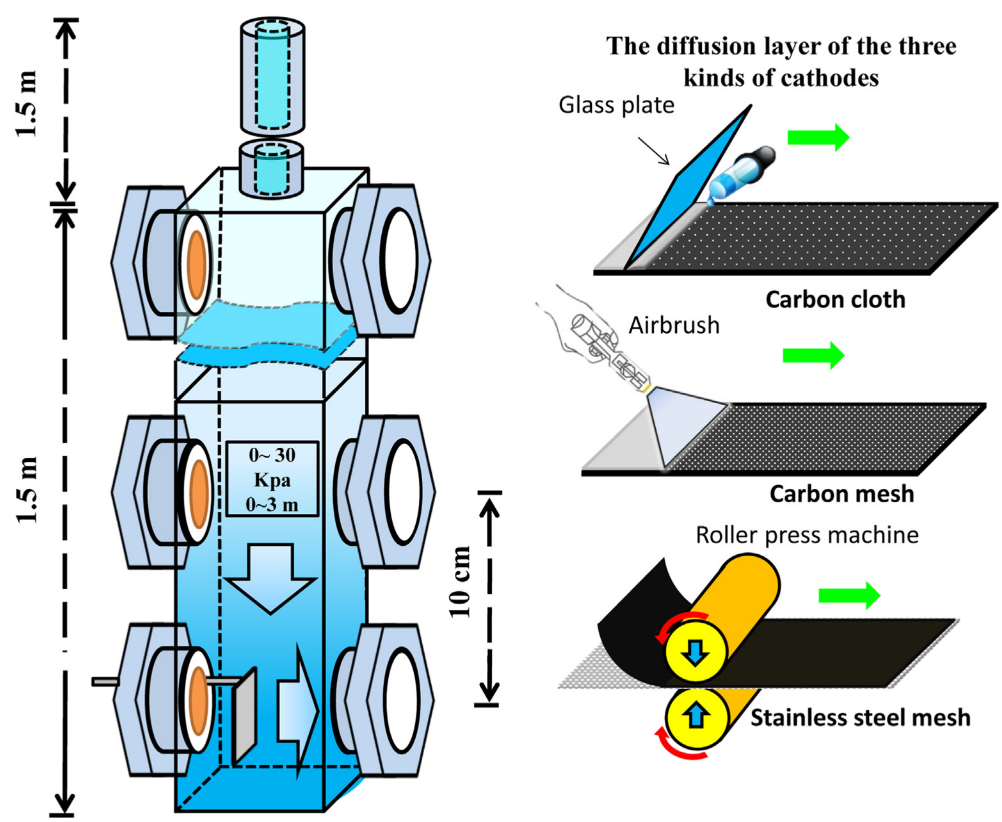

Fig. 1. Test system for water pressure influences on MES cathode performances (left) and schematic diagram of Diffusion layer fabrication for the three researched cathodes (right), smeared for Pt-CC, sprayed for Pt-CM and pressed for AC-MM.