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In situ investigation of processing property in combination with integration of microbial fuel cell and tubular membrane bioreactor

Jie Wang [a,b,*], Yawen Zheng [b], Hui Jia [a], Hongwei Zhang [a]

[a] State Key Laboratory of Hollow Fiber Membrane Materials and Processes, Tianjin Polytechnic University, Tianjin 300387, China
[b] School of Environmental and Chemical Engineering, Tianjin Polytechnic University, Tianjin 300387, China

HIGHLIGHTS

- A bio-cathode MFC with tubular membrane was integrated to construct a MFC–TMBR system.
- The MFC–TMBR was able to produce electricity while degrade organic concentration.
- The performance of MFC–TMBR system was affected by the concentration of MLSS.
- Low-cost materials were used for reactor construction.

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ABSTRACT

Microbial fuel cell (MFC) presents a novel method for simultaneous energy recovery and wastewater treatment. In this study, a bio-cathode MFC with tubular membrane assembly was integrated to construct a MFC–TMBR system, which combined the advantages of each individual module. To examine the feasibility of MFC–TMBR integrated process, both electricity generation and wastewater treatment were investigated. Maximum voltage output of 0.8 V and maximum power density of 0.040 W/m^2 were obtained in the 30th day of operation. The MFC–TMBR system achieved organic removal of 94%, as well as the ammonia nitrogen removal of more than 80%. Membrane fouling mitigation was realized using cross-flow filtration with tubular membrane in the MFC–TMBR, without any physical cleaning during the 30-day operation. Lower MLSS concentration and higher DO could potentially support this system. Low-cost materials were adopted for reactor construction. The results demonstrate that this system is an energy-efficient and cost-effective approach for wastewater treatment.

1. Introduction

Producing electricity from renewable organic matter via microbial fuel cell (MFC) has been studied since 1960s. However, it is only recently that microbial fuel cells have been increasingly used for providing possible opportunities in practical application (Herrero-Hernandez et al., 2013; Logan et al., 2006). MFC is a promising technology for wastewater treatment. But to achieve practical application, there are still many technical obstacles to be overcomed (Wang et al., 2012). One approach to conquer barriers and optimize processes structure is to combine with membrane technology. An integration of MFC with conventional activated sludge process was first reported by Cha et al., (2010) and Min and Angelidaki, (2008). In this system, an aeration tank was directly used as the cathode chamber, where the aerobic biofilm developed on the cathode served as low-cost and self-sustainable catalyst. The aeration tank was followed by a clarifier to support a continue-flow operation, and excess sludge was returned in succession. Nevertheless, this setup produced extra cost for the clarifier construction. From the point of this view, an integration system, combining MFC with membrane, seems to be more attractive in wastewater treatment. Cathode chamber and membrane constitutes a membrane bioreactor (MBR), and the MBR is an effective wastewater treatment technology in which membrane separation is coupled with biodegradation. The MBR recently has played a significant role in the field of wastewater treatment. Nowadays, the development of MBR shows the advantages of low-cost operation, high processing efficiency and widespread application (Zheng et al., 2013; Hasan et al., 2012). So, with no doubt, MFC–MBR system will become one of the key methods in environmental manipulation sooner or later.

Currently, some suggestions (Logan, 2008) and studies (Wang et al., 2011) about combining membrane separation with MFC for enhancing the effluent quality have been widely reported. Liu et al. used membrane as cathode in MFC integrated with MBR

* Corresponding author. Address: School of Environmental and Chemical Engineering, Tianjin Polytechnic University, Tianjin 300387, China. Tel./fax: +86 022 8395 5673.

E-mail address: wangjiemailbox@163.com (J. Wang).

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(Liu et al., 2013). In their study, negative charge accumulated in membrane surface and enhanced electrostatic repulsion force between membrane and foulants. Cathode membrane fouling in MBR was reduced in such featured reactor, although the power output was not high. In addition, Wang et al. developed a MFC–MBR integrated process, in which the aeration tank of a MBR was used as cathode chamber, and anode chamber was directly submerged in the bioreactor (Wang et al., 2012). The performances of continuous wastewater treatment and power generation were investigated. However, the condition of membrane fouling was not examined. Taking electricity generation and membrane fouling mitigation into consideration, bio-cathode MFC requires connecting with a kind of membrane which possesses high resistance to contaminant.

Microfiltration membrane and ultrafiltration membrane, including hollow fiber membrane, plate membrane, ceramic tubular membrane, etc. are increasingly used to separate activated sludge in MBR technology. For wastewater contaminated with high concentration of suspended substances, the membrane flux of hollow fiber membrane and plate membrane is low. The flux decline is caused by neutral hydrophilic fraction of organics, which plugs membrane pore easily. Moreover, this kind of membrane is not easy to clean when fouled. And the ceramic tubular membrane is not satisfied with the criteria of low-cost. Therefore, PVDF tubular membrane, with advantages of low-cost, high mechanical strength and strong antipollution ability, garners attention. Due to tubular membrane's unique structure, it has the following distinct characteristics (Seo and Vogelpohl, 2009): (1) with a new type of concession runner, and liquid flows turbulently in it; (2) tubular membrane allows less preprocessing requirements because it can maintain larger flux under higher sludge concentration; (3) it has the advantages of good surface-to-volume ratios, low shear stress, and high cell densities; (4) easy cleaning is supposed as tubular membrane's outstanding advantages containing both chemical cleaning and mechanical cleaning.

First, the microbial fuel cell–tubular membrane bioreactor (MFC–TMBR) system using MFC combined with tubular membrane was integrated in this study. And then, to optimize reactor structure and reduce membrane fouling, integrated with bio-cathode MFC, a continuously operated side-stream tubular membrane cross-flow filtration system was developed. Side-stream TMBR has potential advantages over submerged MBR such as higher permeate flux and easier membrane replacement and cleaning. But to our best knowledge, there is no report about MFC–TMBR.

Integrated microbial fuel cell with tubular membrane technology made the MFC–TMBR system have the superior characteristics in both energy recovery and wastewater treatment. The aim of the series of tests in this study is to investigate the interrelationship between MFC electricity generation and TMBR membrane fouling under different operation conditions and the feasibility of a MFC–TMBR integrated system for continuous wastewater treatment and power generation. Carbon felt without any pre-treatment was used as the electrode to favor biofilm development. In order to further reduce the investment and operating cost, low-cost ultrafiltration membrane was adopted here as separate material. The cell voltage and polarization curves were also studied in diverse conditions. The effluent qualities were investigated to protect environment from pollution.

2. Methods

2.1. Integrated MFC–TMBR system

The MFC–TMBR system was constructed with a bio-cathode MFC and single tubular membrane, as shown in Fig. 1a. The ultrafiltration membrane (PES: MWCO = 30k; Shanghai SINAP Membrane Tech Co., Ltd., China) separated the anode and the bio-cathode. The two chambers (2.5 L, 10 cm $*$ 10 cm $*$ 25 cm) were filled with 2.2 L liquid. The anode and cathode electrode each was a piece of carbon felt (126 cm^2, Beijing Honghaitian Tech Co., China) without any pretreatment. The cathode chamber was directly used as the aeration tank. The anode and cathode were connected through a 1000 Ω resistor. The cell voltage and electrode potential were recorded automatically every 5 min using a data acquisition system (USB-FS1208, Measurement Computing™, Hungary). Saturated calomel electrode (type of 232, 0.2244 V as SHE, Shanghai Leici, China) was set in the corner of reactor as reference electrode for electrode potential measurement, and its distances from anode and cathode was 3 cm and 3 cm, respectively. For the TMBR section, the single tubular membrane (10 cm, polyvinglidene fluoride with an average pore size of 0.1 μm, Tianjin Motimo Membrane Tech Co., China), as shown in Fig. 1b, with a filtration area of 37.68 cm^2 was placed out of the aeration tank. Aeration unit was placed at the bottom of the chamber. The aeration flow rate was 78 L/h and the influent flow rate was 0.3 L/h. Peristaltic pumps (BT100-2 J, Baoding Langer pump company, China) rotating at 6 rpm with 10.5 l/m^2 h flux were used to conduct the control of constant flow for drawing out effluents, the hydraulic retention time (HRT) was about 10 h. The transmembrane pressure (TMP) was measured by pressure sensors (Danfoss, MBS 3000, Denmark) for monitoring membrane fouling. Tubular membrane was washed with sodium hypochlorite (0.5%) for 1 h and back-flushed with tap water for 3 h.

2.2. Operating conditions

4.4 g/L KH_2PO_4, 3.4 g/L K_2HPO_4, 0.5 g/L NaCl, 0.1 g/L NH_4Cl, 0.05 g/L $MgCl_2$, 0.05 g/L $CaCl_2$, and 1 g/L glucose were dissolved

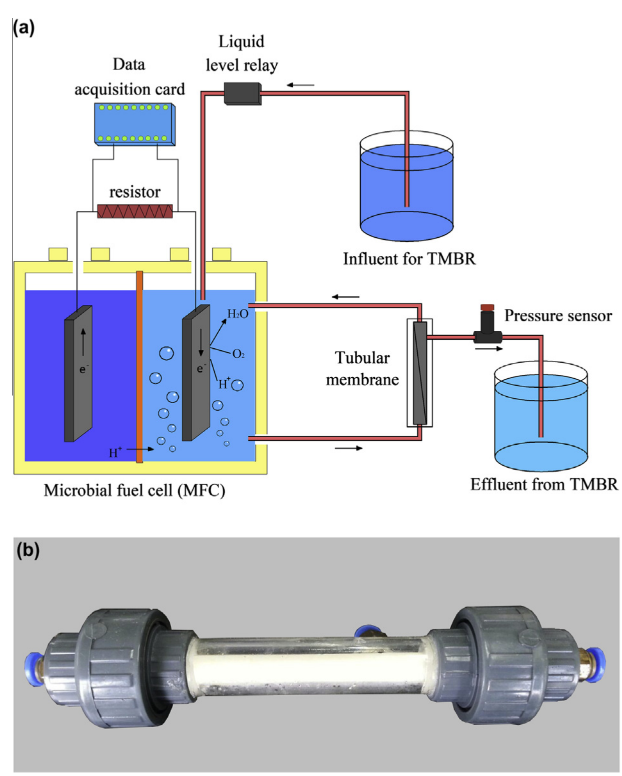

Fig. 1. (a) Schematic of the MFC–TMBR integrated system; (b) the picture of tubular membrane.