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Integration of microbial fuel cell with independent membrane cathode bioreactor for power generation, membrane fouling mitigation and wastewater treatment

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ABSTRACT

A microbial fuel cell (MFC) was integrated with flat sheet membrane bioreactor (MBR) and studied for electricity generation, membrane fouling mitigation and artificial wastewater treatment. The cell potential was ~0.2 V with 100 Ω external load during closed circuit operation. Batch tests identified that the sludge properties and aeration in cathodic chamber were the main affecting factors on electricity generation. Integration of microbial fuel cell can significantly alleviate membrane fouling, under closed circuit condition, membrane filtration lasted 21 days – 27 days and under the open circuit condition it lasted only 13 days - 15 days, before the transmembrane pressure (TMP) reached 0.03 MPa. The calculated electrostatic repulsion force between membrane surface and membrane foulant was about 2.5×10^{-14} N in this integrated reactor. The chemical oxygen demand (COD), ammonia nitrogen, phosphorus and offensive smell could be effectively removed by the sequential anaerobic-aerobic treatment system. The effluent pH was neutral and turbidity was very low.

Introduction

Microbial fuel cells (MFC) can extract energy directly from wastewater [1]. This attractive technology is regarded revolutionary in environmental engineering, which could reduce energy-input in wastewater treatment plants by beneficially generate bio-electricity More and more liter-scale and new structure microbial fuel cells had been proposed for practical application and electricity generation [2–4].

As one of the potential wastewater treatment technologies [5,6], the effluent from MFC anaerobic anode needs to be treated further before discharge, because the turbidity,

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ammonia, phosphate and organic matters in anaerobic effluent cannot meet the discharge standards. Therefore, hybrid system integrating MFC with membrane separation had been proposed to overcome the above-mentioned limitation and enhance the effluent qualities [7]. However, the commonly used membrane bioreactors (MBRs) system have special operation requirement, such as regular membrane cleaning [8], which may increase the operational complexity and affect the operation efficiency. Moreover, in this complex reactor, membrane cleaning might affect the anode of MFC and disturb the electricity generation if the cathode membrane was dependent on anode. So it is very necessary to develop a simple reactor structure with independent cathode membrane for scale up and practical application.

In our previous reports, the external electric field from power source [9] and internal electric field generated by galvanic cell [10] were adopted for conductive membrane fouling mitigation in MBR. But the additional consumption of energy and sacrificial iron anode limited the development, so the anaerobic biological anode was adopted to replace the sacrificing anode to form an MFC in MBR system.

Therefore, a novel bioelectrochemical membrane reactor (BEMR) system with independent flat sheet stainless steel mesh membrane was developed for electricity generation and wastewater treatment. In this BEMR system, the reactor was separated to anaerobic anode chamber and aerobic cathode chamber by filter cloth. The stainless steel mesh membrane modules were used as cathode and filtration unit, which could be disassembled and cleaned independently without affecting anode chamber. After anaerobic biological treatment, the water permeated through filter cloth into the aerobic cathode chamber was further treated under aerobic condition by active sludge. The final effluent was filtrated by membrane modules in aerobic cathode chamber.

The transmembrane pressure (TMP) values in the alternatively closed or open circuit operational cycles were investigated to compare the membrane fouling. The profiles of cell potential and electrodes potential were recorded, which reflect the electricity production in this BEMR. The electrostatic repulsion force between membrane surface and membrane foulant was calculated. The qualities of water samples (influent, effluent and from the anaerobic zone) were analyzed to evaluate the treatment efficiency in this sequential anaerobic-aerobic system.

Experimental procedures

Structure and operation of the reactor

A cubic polymethyl methacrylate reactor (length 21 cm × width 25 cm × height 46 cm) was separated into 3 chambers using porous polymethyl methacrylate spacer (741 pores, 3 mm in diameter, uniformly distributed in each spacer) covered with one layer of terylene filter cloth (pore size: 22 μm). The top of the spacer (5 cm) was not covered by filter cloth for liquid overflow in case the separator became fouled or blocked. The middle anaerobic zone (5.7 L) was filled with graphite granules (diameter: 4 mm, length: 5 ~ 10 mm) as the anode, resulting in an anode liquid volume of ~2 L. Two aerobic cathode chambers, with a total volume of 8.2 L, were each equipped with one membrane module made of stainless steel mesh with a pore size of 15 μm. The total area of the cathode was 800 cm^2 (10 cm × 20 cm × 4 pieces).

Three 15 cm carbon tubes (external diameter: 9 mm, internal diameter: 4 mm) were inserted into the graphite granules to conduct the electrons. The stainless steel wire and copper wire were used to connect the carbon tube and cathode membrane modules respectively to the 100 Ω external resistance load under closed circuit condition. The schematic of the whole system were shown in Fig. 1A and B.

The graphite granules were immersed in the suspended sludge for one week and excess nutrient substances were added to culture the exoelectrogens. The suspended sludge was taken from iron anode surface in our previous reactor. After that, the sludge taken from Chunliu Wastewater Treatment Plant (Dalian, China) was added to the two cathode chambers, and those graphite granules were added to the anode chamber to start the experiment. No sludge was discharged from cathode zones during each filtration cycle and the initial mixed liquor suspended solids (MLSS) was set to $3.29 \pm 2.26\ g\ L^{-1}$, $3.75 \pm 0.88\ g\ L^{-1}$, $4.15 \pm 0.65\ g\ L^{-1}$ and $3.18 \pm 0.50\ g\ L^{-1}$ for the four filtration cycles, respectively. Those were the average values from two cathode chambers

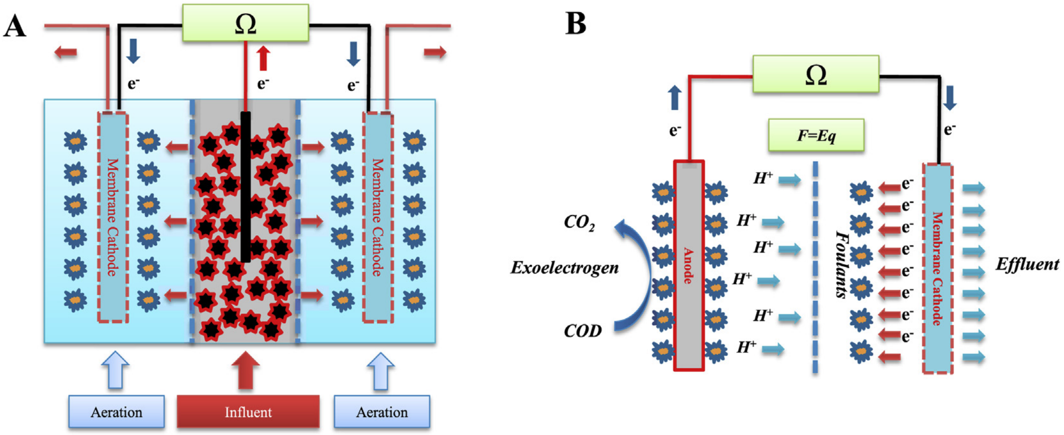

Fig. 1 – The schematic diagram of the BEMR reactor (A) and working mechanism of electric field on membrane fouling mitigation (B).