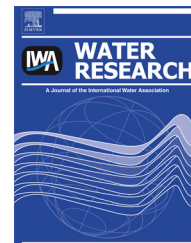


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In-situ utilization of generated electricity in an electrochemical membrane bioreactor to mitigate membrane fouling

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ABSTRACT

How to mitigate membrane fouling remains a critical challenge for widespread application of membrane bioreactors. Herein, an antifouling electrochemical membrane bioreactor (EMBR) was developed based on in-situ utilization of the generated electricity for fouling control. In this system, a maximum power density of 1.43 W/m³ and a current density of 18.49 A/m³ were obtained. The results demonstrate that the formed electric field reduced the deposition of sludge on membrane surface by enhancing the electrostatic repulsive force between them. The produced H₂O₂ at the cathode also contributed to the fouling mitigation by in-situ removing the membrane foulants. In addition, 93.7% chemical oxygen demand (COD) removal and 96.5% NH₄⁺ – N removal in average as well as a low effluent turbidity of below 2 NTU were achieved, indicating a good wastewater treatment performance of the EMBR. This work provides a proof-of-concept study of an antifouling MBR with high wastewater treatment efficiency and electricity recovery, and implies that electrochemical control might provide another promising avenue to in-situ suppress the membrane fouling in MBRs.

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1. Introduction

With an ever-decreasing cost and improving performance, membrane bioreactor (MBR) processes are gaining increasing popularity for wastewater treatment in recent years (Meng et al., 2009; Wang et al., 2006). However, membrane fouling still presents a big headache for the long-term operation of such processes. During the operation, some dissolved organic matters and suspended solids in reactor would gradually deposit on the membrane surface or the pore walls, leading to diminished effective pore size or even complete pore blocking, and thus decrease the reactor performance. Therefore, the key to membrane fouling control is to mitigate the deposition of

various foulants on membrane and/or to timely remove them from the membrane surface.

In respect of mitigating deposition, most of previous efforts have been focused on reducing the affinity between foulants and membrane by employing membrane materials with improved surface properties (Won et al., 2012). Recently, several studies suggest that electrochemical techniques may offer another viable option to directly control the membrane surface properties (Akamatsu et al., 2010; Bani-Melhem and Elektorowicz, 2010; Liu et al., 2013). For example, the usage of an intermittent electrical field has been demonstrated to suppress the membrane fouling of an MBR (Akamatsu et al., 2010). This fouling alleviation is mainly attributed to a static

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electric respelling force imposed by the external electric field, which reduces the deposition of negatively-charged sludge onto the equally negatively-charged membrane surface. However, this method requires application of an external electric field, which not only increases energy input, but also adds up to system complexity. At the same time, the usage of iron anodes assisted by an internal or external electrical field has been reported to reduce membrane fouling by changing the physical, chemical, and biological properties of the filtration sludge through electrocoagulation process (Bani-Melhem and Elektorowicz, 2010; Liu et al., 2013). However, this method requires iron consumption, which increases the cost. Also, the discharge of chemical precipitates might have potential environmental risk. Moreover, the impact of the ferric hydroxide precipitation on sludge properties, such as biomass community and biomass metabolism bioactivity (Iversen et al., 2009), should be further evaluated.

In terms of foulant removal, some highly-oxidative chemicals, such as sodium hypochlorite and hydrogen peroxide (H_2O_2), have been frequently used to ease the membrane fouling, either ex-situ or in-situ (Grelot et al., 2008). However, external dose of such progressive chemicals increases extra costs and might damage the membrane materials (Judd, 2008). In addition, some chemicals like sodium hypochlorite may raise environmental and ecological concerns (Grelot et al., 2008). Therefore, effective methods are still lacking to control membrane fouling in MBRs.

From an engineering point of view, in-situ control of membrane fouling is highly desirable but very challenging. Fortunately, the recent finding that H_2O_2 could be generated in-situ in a bioelectrochemical system provides new opportunities (Fu et al., 2010; Rozendal et al., 2009). Here, we propose a novel concept for in-situ mitigation and cleaning of membrane fouling in an electrochemical membrane bioreactor (EMBR). This process utilizes the bioanode-derived electric energy for in-situ membrane fouling control for the stainless steel mesh filter, which also serves as a cathode in the EMBR. Such a unique process might offer dual benefits: 1) an electric field formed at the vicinity of cathode to suppress sludge deposition; 2) H_2O_2 could be continuously generated to clean the already deposited foulants in-situ. In this study, we investigated the system performance in terms of membrane fouling mitigation, power generation and nutrient removal, and elucidated how the membrane fouling was suppressed in this system.

2. Materials and methods

2.1. Reactor setup

A tubular EMBR with the same configuration as reported in our previous study was used (Wang et al., 2011). The anodic chamber was filled with granular graphite and a graphite rod was inserted as the electron collector. The total volume and effective volume of the anodic chamber were 210 mL and 109 mL respectively. A stainless steel mesh of 40- μ m pore size was used as the cathode without treatment (Huayang Iron-ware Co., China). The total projected surface area of the cathode was 494 cm^2 . The electrode assembly was submerged

in a column-type reactor (height 50 cm, diameter 10.4 cm, working volume 2.3 L), which also acted as the cathodic chamber. The spacing between stainless steel mesh cathode and graphite rod anode was 3.1 cm. In this EMBR system, a nonwoven cloth (400 g/m^2) pretreated with poly(tetrafluoroethylene) was employed as the separator between anode and cathode.

2.2. Inoculation and operation conditions

The anodic chamber was inoculated with 100 mL of anodic effluent from another laboratory-scale EMBR. The cathodic chamber was inoculated with activated sludge from a municipal wastewater treatment plant in Hefei, China. The initial mixed liquor suspended solids (MLSS) concentration was 3.8 g/L.

Wastewater was continuously pumped into the anodic chamber using a peristaltic pump (1515X, Lange Co., China). The feed rate was kept at 0.68 L/h, resulting in a filtration flux of 13.8 $L/m^2/h$. The HRTs of the anodic chamber and cathodic chamber were 0.16 h and 3.4 h, respectively, which are calculated from the net effective volume of the anodic chamber and cathodic chamber and the influent flow rate. Then, the effluent from the anodic chamber continuously flew into the cathodic chamber, passed through the stainless steel mesh, and was finally discharged. The composition of the synthetic wastewater was: $CH_3COONa \cdot 3H_2O$, 0.64 g/L; NH_4Cl , 114 mg/L; $K_2HPO_4 \cdot 3H_2O$, 44 mg/L; $CaCl_2$, 11.5 mg/L; $MgSO_4$ 12 mg/L and 10 mL of trace element solution. The composition of the trace element solution (in μ g/L) was: EDTA, 50, $ZnSO_4 \cdot 7H_2O$, 22, $CaCl_2 \cdot 2H_2O$, 8.2, $MnCl_2 \cdot 4H_2O$, 5.1, $FeSO_4 \cdot 7H_2O$, 5.0, $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$, 1.1, $CuSO_4 \cdot 5H_2O$, 1.8, $CoCl_2 \cdot 6H_2O$, 1.6.

The reactor was operated at 25 °C during the experimental period. Fine-bubble aeration was provided at the bottom of cathodic chamber. The dissolved oxygen (DO) concentration was maintained at 4–5 mg/L.

2.3. Experimental design

To identify the impacts of electrochemical parameters on this system, the electricity generation and wastewater treatment performance as well as the development of mesh fouling under various conditions were evaluated. According to the operating conditions, the entire experimental period was divided into 5 stages: Stages 1 and 4, extended from day 1st to day 8th and day 44th to 48th without connecting the circuit (reference stages, simulating the conventional MBR); Stages 2–3 (simulating the EMBR system) lasting from day 9th to 43rd when the circuit was connected with 1000 Ω or 10 Ω external resistance and Stage 5 lasting from day 49th to 61st when a 1 V of external voltage was applied. The detailed operating conditions and parameters of each stage are summarized in Table 1.

At the operating mode of constant influent flux, the membrane fouling degree could be indicated by the rise of the trans-membrane pressure (TMP) across the steel mesh. Once the TMP reached 1 kPa, the mesh surface was washed off-line with running tap water to remove the deposited sludge cake and resume its permeability.

During the entire operating period, no excess sludge was discharge except for the purpose of MLSS analysis. Thus,

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