Bioresource Technology 156 (2014) 35–41

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Effects of ionic strength on membrane fouling in a membrane bioreactor

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HIGHLIGHTS

- Ionic strength had no apparent effect on pore clogging resistance.
- Adhesion of sludge flocs on membrane surface must overcome an energy barrier.
- There exists a critical ionic strength above that the energy barrier will disappear.
- Cake resistance was not affected by ionic strength, but highly depended on SMP.

ARTICLE INFO

Article history:
Received 26 November 2013
Received in revised form 2 January 2014
Accepted 4 January 2014
Available online 11 January 2014

Keywords:
Membrane fouling
Membrane bioreactor
Critical ionic strength
Energy barrier

ABSTRACT

In this study, the effects of ionic strength on membrane fouling in a membrane bioreactor (MBR) were investigated. Ionic strength in range of 0.005–0.05 mol/L exerted no apparent impacts on the resistance of virgin membrane, fouled membrane and pore clogging. Thermodynamic analysis showed existences of a secondary energy minimum and an energy barrier in the process of the sludge flocs approaching to membrane surface. Increase in ionic strength could significantly reduce the energy barrier. It was revealed that there existed a critical ionic strength above that the energy barrier would disappear, facilitating adhesion of the foulants. Cake resistance was not significantly affected by the ionic strength, but highly depended on SMP in supernatant. The high cake resistance caused by SMP could be explained by the osmotic pressure mechanism. The obtained results provided new insights into membrane fouling in MBRs.

1. Introduction

Membrane bioreactor (MBR) technology has emerged as one of the most promising processes for wastewater treatment and reuse in the last decades due to its distinct advantages (Rajesh Banu et al., 2009; Lin et al., 2012). It was reported that MBR market has significantly increased with an annual growth rate of about 11% since 2005 (Lesjean and Huisjes, 2008; Meng et al., 2012), and more than 2500 MBR plants have been in operation worldwide now (Meng et al., 2012). Nevertheless, membrane fouling is still the major longstanding challenge for its further development (Ng and Ng, 2010; Lin et al., 2011a,d; Do et al., 2012; Robles et al., 2013). Therefore, there are urgent needs to investigate mechanisms and influencing factors of membrane fouling in order to develop effective fouling control strategies in MBRs.

Water chemistry of feed has been considered to crucially affect fouling in membrane processes. Ionic strength is one of the primary water chemistry parameters of feed. Some industrial sections, such as food, petroleum, textile and leather industry would produce streams with different salinity (Lin et al., 2012). Treatment of these streams with MBRs may suffer from certain variation of ionic strength. To date, many efforts have been devoted into investigating the effects of ionic strength on fouling in membrane processes. It was reported that membrane flux decreased with the ionic strength when filtrated suspension of model particles such as silica (Elzo et al., 1998) and spherical polystyrene latex (Chang et al., 1995). Faibish et al. (1998) further reported that particle cake thickness, porosity and permeability increased with a decrease in solution ionic strength. Meanwhile, inconsistent phenomena have been also reported. van den Brink et al. (2009) found that an increase in ionic strength had no impact on fouling rate in low fouling experiments, but decreased fouling with 66–72% at high fouling conditions when alginate was used as a model foulant. The inconsistent results indicate that effects of ionic strength on membrane fouling are complex, and require further research.

Current available articles regarding the effects of ionic strength on membrane fouling were mostly reported on conventional membrane processes and model foulants, while less focused on MBR systems. Sludge suspension in MBRs was a complex system which is significantly different from suspension of model foulants. It is therefore reasonable to expect that membrane fouling caused by

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0960-8524/$ - see front matter
http://dx.doi.org/10.1016/j.biortech.2014.01.014

ionic strength in MBRs is much more complicated than that in conventional membrane processes. Meanwhile, effects of ionic strength were mostly studied qualitatively by visual comparison of the flux or filtration resistance. The quantitative identification and underlying mechanisms regarding effects of ionic strength on membrane fouling have not been well documented in MBRs. Finally, MBRs treating real wastewater would generally encounter moderate variation of ionic strength (e.g. from 0 to 0.05 mol/L) (Lin et al., 2012). However, there have been no specific studies aimed to investigate the effects of ionic strength in such a range on membrane fouling in MBRs.

Membrane fouling in MBRs is a general conception, which can actually be further distinguished as several sub-processes such as pore clogging, cake layer formation and changes of cake layer. Ionic strength may affect these sub-processes to different extent, or even with opposite trends, and then take a complicated role in membrane fouling. Essentially, cake layer formation is the main cause of membrane fouling in MBRs (Wang and Li, 2008; Lin et al., 2011b). Cake layer formation on membrane surface is a thermodynamic process (Hong et al., 2013) which was traditionally described through the extended Derjaguin–Landau–Verwey–Overbeek (XDLVO) theory (Feng et al., 2009; Nguyen et al., 2011). Therefore, XDLVO theory may provide a new approach to resolve the effects of ionic strength on membrane fouling. Furthermore, ionic strength may also affect the formed cake layer. A systematic analysis and assessment of ionic strength effect is essential to better understand membrane fouling and facilitate to develop strategies for membrane fouling mitigation in MBRs.

The aim of this study was to investigate the effects of ionic strength on membrane fouling caused by pore clogging, sludge flocs' adhesion and the formed cake layer in a submerged MBR. A laboratory scale MBR was continuously operated. Series filtration tests were performed to investigate effects of ionic strength on pore clogging resistance and cake resistance. The surface properties of membrane and sludge were determined. Thereafter, the thermodynamic interactions between membrane and sludge flocs, as well as roles of ionic strength based on XDLVO approach, were comprehensively analyzed. This study would give significant insights into membrane fouling in MBRs.

2. Methods

2.1. Experimental setup and operation

A bench scale submerged MBR (SMBR) was constructed in this study. The schematic of the setup is presented in Fig. 1. The SMBR mainly consisted of a tank with 65 L effective volume ($0.54 \times 0.30 \times 0.40$ m height $\times$ length $\times$ width) where a flat sheet polyvinylidene fluoride (PVDF) membrane module (Shanghai SINAP Co. Ltd., China) was submerged. The membrane module had total 0.5 m^2 area of membrane with normalized pore size of 0.3 μm. Use of this membrane module is a representative selection because it is one of the mainstream membrane products used in MBR applications in China. The membrane module was intermittently sucked by a peristaltic pump (Baoding Longer, China) to obtain effluent with an intermittent mode (4-min-on and 1-min-off). Synthetic wastewater simulating municipal wastewater was used as the influent. The composition of the synthetic municipal wastewater was displayed as follows: 300 mg COD/L glucose plus the following mineral medium: $(NH_4)_2SO_4$ (27 mg N/L); KH_2PO_4 (7 mg P/L, 9 mg K/L); Na_2CO_3 (46 mg Na/L, 50 mg CO_3/L); $NaHCO_3$ (23 mg Na/L, 50 mg CO_3/L); $CaCl_2$ (6 mg Ca/L); $MgSO_4$ (7 mg Mg/L); $FeCl_3$ (4 mg Fe/L); $MnSO_4$ (0.04 mg Mn/L); $ZnCl_2$ (0.11 mg Zn/L); $CuSO_4$ (0.03 mg Cu/L); $CoCl_2$ (0.1 mg Co/L) and $NaMoO_4$ (0.02 mg Na/L, 0.07 mg Mo/L). It is a common operation using synthetic wastewater to test new concepts or study general aspects of membrane fouling (Lin et al., 2013). Continuous aeration (about 50 L min^{-1}) was supplied through the air diffuser underneath the membrane module to provide oxygen for the microorganisms and shear force on the membrane surface. In this study, membrane flux was controlled by adjusting the pump speed and two calibrations were made each day. With such an operational mode, the membrane flux can always be maintained at about 30 L m^{-2} h^{-1}, which corresponded to a hydraulic retention time (HRT) of approximate 5.5 h. The MBR set-up was continuously run for over 300 days. The sludge suspension in the last operation period (day 250–300) was used for the following experiments. The sludge concentration indicated as mixed liquid suspended solids (MLSS) was maintained in the range of 10–15 g/L during this period.

2.2. Analytical methods

Extraction of bound extracellular polymeric substances (EPS) of sludge flocs was based on cation exchange resin method. The supernatant was obtained by centrifuging the sludge suspension for 5 min at 2500×g (GTR16-2 high-speed refrigerated centrifuge, Beijing Era Beili Centrifuge Co., Ltd., China). The organics in supernatant were considered to be mainly soluble microbial products (SMP) because of the easy degradability of influent organics. The EPS and SMP were normalized as the sum of proteins and polysaccharides which were colorimetrically measured by using phenol/

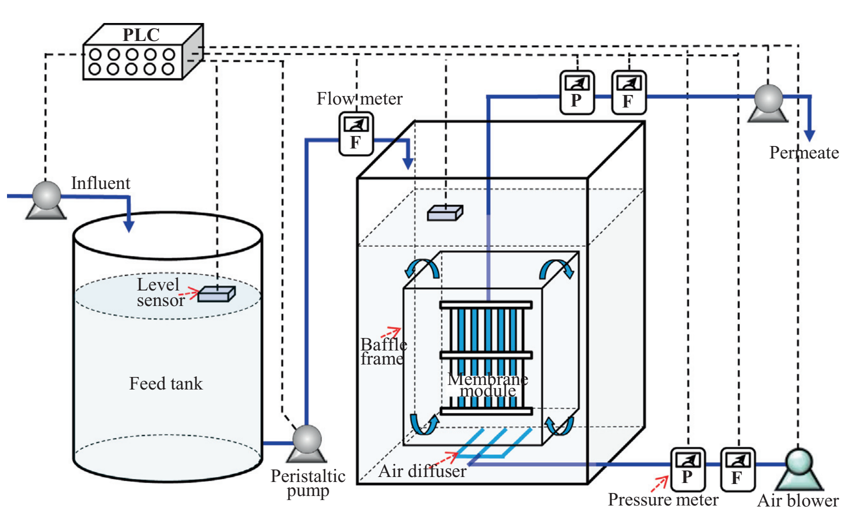

Fig. 1. Schematic design of the bench scale SMBR.