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Effects of online chemical cleaning on removing biofouling and resilient microbes in a pilot membrane bioreactor

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ABSTRACT

Membrane biofouling in membrane bioreactor (MBR), resulted from microbes and their associated extracellular polymeric substances (EPS), is a primary challenge for wide application of MBR. However, the dynamic change of microbes attached on membrane remains little understood. In the study, a pilot MBR was constructed to estimate the effects of online chemical cleaning on membrane biofouling and meanwhile to study the microbial compositions and dynamic change before and after online chemical cleaning. Results showed that the trans-membrane pressure (TMP) increased with running time and online chemical cleaning temporarily eased TMP. Using the scanning electron microscopy, it was clearly observed that the microbes adhered into the EPS and formed biofilm before online chemical cleaning, and the biofilm was disrupted and most microbes on the membrane surface were removed after online chemical cleaning. EPS assay results showed that online chemical cleaning removed most protein and humic substances, but only a little part of polysaccharide. Microbial phylogenetic cluster displayed that some microbes attached on the membrane were clustered together and obviously separated from those in the mixed liquor sludge, indicating the special property of the microbes on the membrane. The microbial community dynamic analysis demonstrated that the dominant group on the membrane was changed from *Burkholderiaceae* to *Flavobacteriaceae* and *Saprospiraceae* after online chemical cleaning. Furthermore, some microbes such as *Acinetobacter*, *Xanthomonas*, *Cloacibacterium* and *Flavobacterium* were found to repeatedly cause the membrane fouling. The results might be helpful for developing biological-based cleaning method and antifouling strategies in the future.

1. Introduction

Compared to the conventional wastewater treatment, membrane bioreactor (MBR) has advantages with higher effluent quality, smaller footprint, and less sludge production, which has been increasingly favored in wastewater treatment and reclamation (Friha et al., 2014; Xiao et al., 2014; Phan et al., 2015). However, the membrane fouling in MBR limits its widespread application (Malaeb et al., 2013). Membrane fouling could cause severe flux decline, and thus frequent membrane cleaning or replacement is required, which would increase high energy consumption and maintenance costs. To address this problem, lots of researches have been done to investigate the membrane fouling mechanisms, and many of them focused on physical or chemical factors of membrane fouling (Tsuyuhara et al., 2010; Yu et al., 2015). Nevertheless, microbes are the major components of activated sludge, and amounts of biomass and their soluble microbial products (SMPs) can interact with membrane and cause membrane biofouling in MBR (Ivnitsky et al., 2007; Zuthi et al., 2013). Therefore, biofouling control is deserved to pay more attention in MBR plant operation. Understanding of the microbes attached on membranes will be helpful to design cleaning protocols as well as to develop biological-based antifouling strategies (Jahangir et al., 2012; Li et al., 2012; Malaeb et al., 2013; Nguyen et al., 2015).

In MBR, the microbial community of mixed liquor and their relations with operational parameters has been extensively studied (Sun et al., 2014). Nevertheless, the microbes that cause membrane biofouling were relatively less concerned. Currently, studies found that food/microorganisms (F/M) ratio, sludge characteristics, operation conditions such as sludge retention time, oxygen and calcium concentration influence the microbes on membranes (Kim and Jang, 2006; Zhang et al., 2007; Huang et al., 2008; Meng et al., 2010; Xia et al., 2010), and further study disclosed the correlation

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Table 1
The sampling and online chemical cleaning time distributions during the operation process of MBR.

Treatment	Sample ID*	Sampling time	Online chemical cleaning time
Before chemical cleaning	BL1/BM1	21st day	
	BL2/BM2	29th day	
	BL3/BM3	36th day	
After chemical cleaning			41st day
	AL1/AM1	44th day	
			52nd day
	AL2/AM2	53rd day	
			59th day
			62th day
	AL3/AM3	63rd day	

BL: mixed liquor samples before online chemical cleaning; BM: membrane samples before online chemical cleaning; AL: mixed liquor samples after online chemical cleaning; AM: membrane samples after online chemical cleaning.

between microbial quorum sensing and membrane biofoulings (Kim et al., 2013). Noticeably, the studies about membrane biofouling mostly have used synthetic wastewater in laboratory-scale systems, which were quite different from the actual wastewater in wastewater treatment plants (Bereschenko et al., 2011; Calderón et al., 2011). Furthermore, it is still unclear what happens to the microbes attached on the membrane after online chemical cleaning. Microbes and their extracellular polymeric substances (EPS) are the major reasons of membrane biofouling. However, few studies suggested the dynamic changes of microbial community and EPS with time and online chemical cleaning. Therefore, this study addressed the development and changes of membrane biofouling with time and online chemical cleaning, which will provide more useful information to prevent membrane biofouling in MBR operation.

In this study, online chemical cleaning was used in a pilot-scale MBR with actual wastewater. The primary objectives were 1) to illustrate the effects of online chemical cleaning on membrane biofoulings; 2) to compare dynamic microbial development between the mixed liquid and the membrane; 3) to identify the key microbes that resulted in membrane biofoulings in MBR with actual municipal wastewater.

2. Materials and methods

2.1. MBR operations

A pilot-scale submerged MBR was constructed at Qinghe municipal wastewater treatment plant, Beijing, China. The MBR with a volume of 2.24 m^3 was operated with the wastewater from the primary sedimentation basin. The MBR was equipped with hollow-fiber microfiltration membrane modules, which were made of polyvinylidene fluoride (PVDF) with a total surface area of 20 m^2 and a nominal pore size of 0.1 μm (Beijing Scinor Membrane Technology Co. Ltd, China). The outer and inner diameters of the fibers were 1.6 mm and 1.1 mm, respectively. The permeate was extracted from the membrane at a constant flux (15 $l\ m^{-2}h^{-1}$) by a peristaltic pump. Membrane filtration was carried out with an intermittent suction cycle of 7 min on and 1 min off. Aeration was continuously carried out at the flow rate of 150 $m^3\ m^{-2}h^{-1}$. The mixed liquor suspended solid (MLSS) concentration in the reactor was maintained at 6–9 $g\ l^{-1}$ by discharging the excess sludge. The reactor ran totally for 63 days, and the online chemical cleaning was carried out since the 41st day. Thereafter the membrane module was cleaned using online chemical cleaning method, and it was carried out about once a week with sodium hypochlorite (1000 ppm) for 2 h.

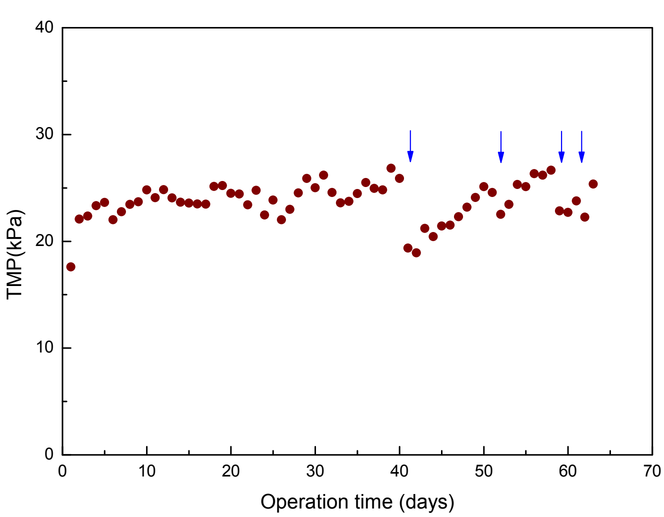

Fig. 1. The variations of TMP during operation process (Arrows indicated online chemical cleaning of membrane performed).

2.2. Sampling

The biofilm on the membrane and the parallel mixed liquor samples for bacterial analysis were taken simultaneously from the MBR at different time-points. The samples were collected once a week for the operation process without online chemical cleaning. When online chemical cleaning was performed, the samples were taken after online chemical cleaning. The detailed sampling and cleaning time information are listed in Table 1. The membrane fibers were taken from various locations on the fouled membrane module. The hollow-fiber membranes were cut into pieces (10 mm) using sterile steel knife and then mixed them to form a sample. After sampling, the membrane fibers and mixed liquor samples were quickly shipped to the lab for the further analysis.

2.3. Microbial morphology on the fouled membranes

The microbial morphology on the fouled hollow-fiber membranes was analyzed by scanning electron microscopy (SEM). The fouled membrane surfaces without online chemical cleaning were taken on the 36th day. After cleaning the membranes were taken on the 44th day. The membrane samples' pretreatment was required before further analysis. The vacuum freeze dryer was pre-frozen at −80 °C for 4 h, and then the samples were frozen at 1 Pa vacuum for 24 h. The dried samples were coated with platinum and palladium, and examined under a SEM (QUANTA 200 FEG, FEI, Netherlands) at 15.0 kV.