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Effective control of membrane fouling by filamentous bacteria in a submerged membrane bioreactor

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ABSTRACT

Two identical submerged membrane bioreactors (MBRs) for synthetic wastewater treatment were operated in parallel under different dissolved oxygen (DO) levels for over 3 months in this study. The digital biological microscopy, particle size distribution (PSD) analysis, gel filtration chromatography (GFC), three-dimensional excitation-emission matrix (EEM) fluorescence spectroscopy, and column chromatographic method, etc. were used to identify the difference between bulking sludge (BS) caused by filamentous bacteria (low DO operation, about 0.4 mg/L) and normal sludge (NS) (high DO operation, about 4.0 mg/L) and to obtain a comprehensive insight into the behaviours of filamentous bacteria in MBRs. Test results showed that the MBR with bulking sludge (BS-MBR) exhibited a better filtration performance and a reduced membrane fouling compared to the MBR with normal sludge (NS-MBR). It was found that the mitigation of membrane fouling by the abundant filamentous bacteria in the BS-MBR could be attributed to the larger PSD, lower hydrophobic contents in SMP, and the retention effects of a special fouling layer induced by filamentous bacteria.

1. Introduction

The conventional activated sludge (CAS) process is the most commonly used technology for wastewater treatment, which is comprised of a biochemical stage (aeration tank) for the degradation of contaminants by activated sludge and a physical settling stage (secondary clarifier) for solid/liquid separation and biomass recirculation. However, bulking sludge (BS), as a common problem in CAS systems, leads to biomass loss and poor effluent quality [1]. The overgrowth of filamentous bacteria has been often identified as the main reason causing sludge bulking [2].

In recent years, membrane bioreactors (MBRs), being an efficient technology for municipal and industrial wastewater treatment, have gained increasing popularity. MBRs, in which solid/liquid separation is performed by membranes, successfully solve the biomass separation problem occurring in CAS systems; however, a major obstacle for the applications of MBRs is the rapid decline of membrane flux as a result of membrane fouling [3–5]. In submerged MBRs, membrane fouling is influenced by a variety of factors, such as operational parameters (flux value, operational modes, etc.), membrane materials, sludge properties and so on [3]. Sludge properties are closely related to the physiological behaviours of microorganisms. If the species and/or dominant colony are changed, it will lead to different physiochemical characteristics and abnormal conditions of mixed liquor which could accordingly influence membrane fouling behaviours. Some recent studies reported that bulking sludge had significant negative effects on membrane fouling and might reduce the sustainable operation time of MBRs [3,6,7]. It was reported by Choi et al. [8] that severe membrane fouling occurred under a sludge bulking condition. Chang et al. investigated the ultrafiltration performance of various kinds of activated sludges and found that the order of the fouling potential was normal sludge (NS) < pinpoint sludge < bulking sludge [9]. With regard to the fouling mechanism of bulking sludge in MBRs, Meng et al. [6,7] insisted that severe membrane fouling under the excess growth of filamentous bacteria was caused by the change of physical and chemical properties of the activated sludge, and other researchers argued that the floc morphology of the bulking sludge had more important influences on membrane fouling [9]. However, according to the study of Li et al. [10], the effect of filamentous bacteria density on the membrane fouling rate was negligible even though filamentous bacteria could change the floc morphology. In our study, however, we interestingly found that the submerged MBR with excess growth of filamentous bacteria achieved better membrane permeability compared to a parallel submerged MBR with negligible filamentous bacteria, which is controversial to the above researches. It is very essential to investigate the membrane fouling mechanisms caused by

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the growth of filamentous bacteria and to analyze the difference between our study and other researchers' findings.

In this study, two identical submerged MBRs were operated in parallel under different dissolved oxygen (DO) levels for over 3 months. The digital biological microscopy, particle size distribution (PSD) analysis, gel filtration chromatography (GFC), three-dimensional excitation–emission matrix (EEM) fluorescence spectroscopy, and column chromatographic method, etc. were used to identify the difference between bulking sludge caused by filamentous bacteria and normal sludge and to obtain a comprehensive insight into the behaviours of filamentous bacteria in MBRs. The positive effects induced by the growth of filamentous bacteria on membrane fouling were discussed and the mechanisms for enhancing membrane filtration operation were proposed. The results obtained in this study are expected to provide a sound and all-round understanding of the role of filamentous bacteria in membrane fouling of MBRs.

2. Materials and methods

2.1. Experimental setup

As shown in Fig. 1, the experimental system consisted of two identical MBRs that were operated in parallel. Each reactor had an effective volume of 68.4 L, in which three membrane modules were mounted vertically between two baffle plates located above the air diffuser. The membranes were made of polyvinylidene fluoride (PVDF) membrane with a mean pore size of 0.20 μm and an effective filtration area 0.175 m^2 for each module. Air was monitored by a rotameter and supplied through the air diffuser which was below the membrane modules in order to supply oxygen demanded by the microorganisms and to induce a cross-flow velocity (CFV) along membrane surfaces. The characteristics and constituents of the influent wastewater are shown in Table 1. It is obvious that the influent wastewater was rich in COD, but short of nutrients, i.e., nitrogen and phosphorus, which was used to simulate some wastewater with poor nutrients (for instance, some water polluted by alcohol-distillery wastewater). The influent pump was controlled by a water level sensor to maintain a constant water level in the bioreactor over the experimental system. The membrane-filtered effluent was then obtained by suction using a pump connected to the modules. The effluent flow rate and transmembrane pressure (TMP) were monitored by a water meter and a pressure gauge, respectively.

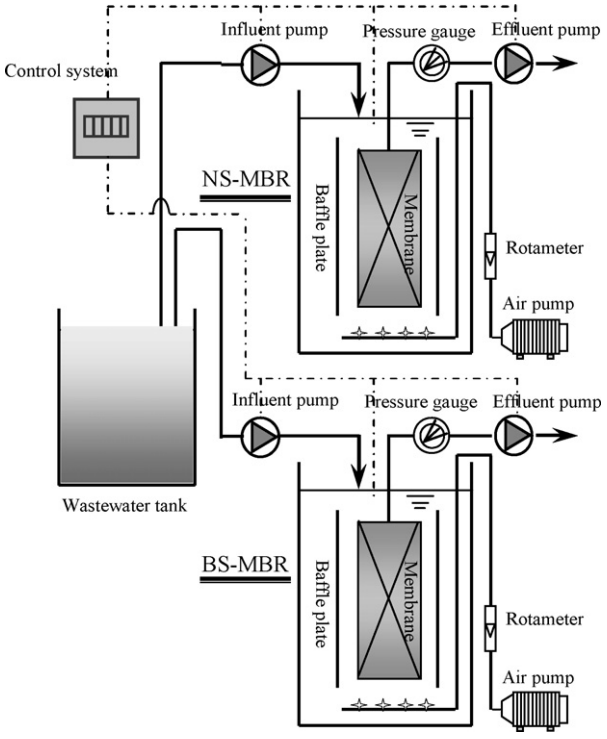

Fig. 1. Flow diagram of two parallel submerged MBRs.

Table 1
Components and characteristics of influent water.

Components	Concentration (mg/L)	Influent water parameters	Concentration (mg/L)
Glucose	450	COD	432–480
NH_4Cl	15	NH_4^+–N	3.7–3.9
KH_2PO_4	5	TP	1.0–1.1
$NaHCO_3$	200	pH	6.7–7.2
$MnSO_4$	5		
$FeCl_3$	2		
$MgSO_4$	2		

2.2. Operating conditions

The membrane flux of the two MBRs was kept constant at about 20 L/(m^2 h), which is lower than critical flux value as determined by step-wise method, during the experiment. A suction cycle of 10 min followed by 2 min relaxation (no suction) was employed. The suction mode was adopted based on our previous research and proven to be effective for controlling membrane fouling. The hydraulic retention time (HRT) and sludge retention time (SRT) were maintained at 7.8 h and 20 d, respectively. The only difference in the two MBRs was dissolved oxygen (DO) concentration in the mixed liquors by varying the supplied air flow rate. DO concentrations of 4.0 ± 0.4 and 0.6 ± 0.4 mg/L were maintained in the two MBRs, respectively. The two MBRs were seeded with activated sludge of a municipal wastewater treatment plant (WWTP) of Shanghai and acclimated for about 1 month before the filtration was begun (the TMP profiles were recorded in the following 2 months). Afterwards, the filtration experiment and a series of measurements were carried out. The steady-state mixed liquor suspended solids (MLSS) concentrations in the two MBRs were 8.5 ± 0.5 g/L (high DO operation) and 8.3 ± 0.4 g/L (low DO operation), respectively. The MBRs were operated with temperature in the range of 14–24 °C. Chemical cleaning-in-place procedure (0.5% (v/w) NaClO solution, 2 h duration) was carried out in order to recover membrane permeability if the TMP reached about 30 kPa during the operation.

2.3. Analytical methods

2.3.1. Digital biological microscope analysis

A mixed liquor sample was taken from one of the submerged MBRs by a pipette, and a little drop of the mixed liquors was placed on the center of a clean glass slide and then covered with a cover glass. It should be ensured that there were no gas bubbles trapped between the glass slide and the cover glass. The prepared sample was examined by a phase contrast digital microscope (Leica DMRME, Leica Microsystems, Germany). The Leica Qwin QG2-32 software was employed to process and analyze the images, which could create JPEG image format files of the microscopic examination samples. The microscopic examination of a mixed liquor sample was conducted in triplicate. The microorganisms in the two submerged MBRs were examined by the microscope at the same operational period (on the day 60) and the differences between them were compared.