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Effect of temperature variation on membrane fouling and microbial community structure in membrane bioreactor

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HIGHLIGHTS

- SMPs and EPS in mixed liquor increased conspicuously as temperature decreased.
- Lower temperature resulted in higher polysaccharide content in SMPs.
- Temperature variation displayed a great influence on microbial community.
- Microbial community would be ultimately responsible for membrane fouling.

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ABSTRACT

This study aimed to investigate the effect of temperature variation on membrane fouling and microbial community in a membrane bioreactor (MBRs). The results indicated that extracellular polymer substances (EPS) and soluble microbial products (SMPs) increased due to decreasing temperature, which triggered membrane fouling as evidenced by the trans-membrane pressure (TMP) increase rate. Moreover, fluorescent intensity variations in the excitation–emission matrix (EEM) fluorescence spectroscopy of SMPs were closely related to rapid increase in TMP, suggesting that they might be used to monitor SMPs variations and indicate membrane performance. In addition, 16S rRNA clone library and sequence analyses results demonstrated the predominant phyla were always *Proteobacteria*, *Nitrospira* and *Bacteroidetes*. However, at lower temperature, *α-proteobacteria* and some filamentous bacteria such as *Actinobacteria*, *Haliscomenobacteria* and *Thiothrix* were relatively rich. At higher temperature, *Zoogloea* showed its presence. Detrended correspondence analysis (DCA) and Mantel test results also demonstrated that temperature had strongly influence on microbial community.

1. Introduction

In recent years, membrane bioreactors (MBRs) have been widely applied for the treatment of wastewater treatment plants (WWTPs) in China because of their distinct advantages, such as excellent effluent quality, small footprint and space reduction (Judd, 2006). However, the MBR WWTPs in north of China have been having low operational efficiency due to the severe membrane fouling in winter months. Therefore, a better understanding of membrane fouling in cold temperatures is essential for improving and optimizing the MBR wastewater treatment processes.

Membrane fouling was a major obstacle in the wide spread application of MBR process, which resulted from various physico-chemical interaction between membrane and sludge mixed liquor (Le-Clech et al., 2006). Amounts of papers have been devoted to properties of foulants, factors influencing fouling and fouling mechanism, as well as to the fouling mitigating strategies (Le-Clech et al., 2006; Meng et al., 2009; Drew, 2010). It was generally accepted that feed water characteristics, membrane material, mixed liquor characteristics and operation parameters were responsible for the membrane fouling (Le-Clech et al., 2006; Meng et al., 2009).

Temperature could influence the production of extracellular polymeric substances (EPS) and soluble microbial products (SMPs). EPS and SMPs were composed of a variety of organic substances that released from microorganisms as a result of their metabolic activity and biomass decay, which were proved to be the major fraction of membrane foulants (Drews et al., 2007; Kimura et al., 2009). So far, several researches had been devoted to the effects of temperature on membrane fouling. Rosenberger et al. (2006) observed the filtration properties in two parallel MBRs, and

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elucidated that higher polysaccharide concentration in the mixed liquor suspension of MBRs during low-temperature periods resulted in a higher fouling rate in MBRs. Similar results had been reported by Drews et al. (2007) and van den Brink et al. (2011). Wang et al. (2010) identified that the concentration of EPS, polysaccharides, and proteins increased in the case of low temperature operation, which led to the increase of biopolymers attached to membrane surfaces and in turn cause severe membrane fouling. Miyoshi et al. (2009) investigated the seasonal variation of membrane fouling in MBRs treating municipal wastewater. They indicated that physically reversible fouling was more significant in low temperature period. The development rates of physically reversible fouling maybe correlated to the concentration of dissolved organic matters in the mixed liquor suspension, the polysaccharide-like and humic acid-like substances. While physically irreversible fouling developed more severe in high temperature period, which resulted from the nature of the dissolved organic matter, not depended on the concentration of dissolved organic matter. The protein composition was dominant in the mixed liquor suspension in high temperature period, and the same result was identified in the membrane foulants.

These investigations suggested that the decrease in the ambient temperature could affect the biomass to release more EPS and SMPs, which impacted on membrane fouling significantly. Concomitantly, EPS and SMPs concentration and characteristics would determine its fouling propensity. Those intensive efforts mentioned above were helpful to understand the correlations of EPS and SMPs components with membrane fouling and on their corresponding fouling mechanism. However, comprehensive understanding of the influence of low temperature on EPS, SMPs and their compositions, on microbial community structure in membrane reactor and in turn on membrane fouling was still very limited. The objects of this study were to investigate how temperature variation influenced EPS, SMPs properties and microbial community structure, and further to predict their relative contributions to membrane fouling.

2. Methods

2.1. Experimental set-up

Fig. S1 presented the pilot-scale submerged membrane bioreactor used in this study. The MBR located in Huairou Municipal WWTP of Beijing. The membrane tank was equipped with two hollow fiber polyvinylidene fluoride membrane module (Originwater Co., Ltd., China) with filtration area of 2.85 m^2. The membrane nominal pore size is 0.1 μm. Continuous aeration was monitored by a flow-rate meter and supplied through the air diffuser which was below membrane modules in order to supply oxygen demanded by the microorganisms and to induce a cross-flow velocity. The influent pump was controlled by a water level sensor to maintain a constant water level in the bioreactor. The membrane effluent was intermittently extracted with a suction pump connected to the membrane modules. Filtration operation of the pilot-scale MBR was conducted with a constant flow-rate mode, and a suction cycle of 10 min followed by 2 min relaxation (no suction) was applied. The effluent flow rate and the trans-membrane pressure (TMP) were monitored by a flow-meter and a pressure sensor, respectively. A programmable logic controller (PLC) automatically and continuously controlled all electronic devices. The hydraulic retention time (HRT) was 4.9 h, and sludge retention time (SRT) was maintained at 40 d by discharging the mixed liquor from the bioreactor once a day. The system had been operated for 3 years. During the investigating period, the temperature was in the range of 8.7–19.7 °C. Chemical cleaning was carried out when TMP reached about 60 kPa to remove membrane foulants and recover the membrane permeability.

2.2. Determination of filtration resistance

Different types of membrane filtration resistances could be applied to evaluate the degree of membrane fouling, which can be calculated using the resistance-in-series model and Darcy's equations:

$$R_t = R_m + R_f + R_c \quad (1)$$

$$R_t = \mathrm{TMP}/(\eta_T J) \quad (2)$$

where J is the membrane permeate flux ($m^3/m^2/h$), TMP is the trans-membrane pressure (Pa), η_T is the viscosity of permeate (Pa s), R_t is the total resistance (m^{-1}), R_m is the intrinsic membrane resistance (m^{-1}), R_c is the cake layer resistance and R_f is the fouling resistance (m^{-1}) caused by irreversible adsorption and pore blockage.

R_m was determined from measuring the water flux of Milli-Q water using original membrane. R_t was calculated by the recorded data at the end of filtration operation. A temperature correction to 20 °C was used to account for the dependence of permeate viscosity, according to the following equation (Rosenberger et al., 2006)

$$\eta_T = \eta_{20} \cdot e^{(T-20)} \quad (3)$$

with the temperature T in degree of celsius. For the calculation of $R_m + R_f$, the fouled membranes were rinsed with tap water in order to drain off the cake layer, and then Milli-Q water was filtrated through the membrane to determine $R_m + R_f$ by using Eq. (2). R_c was evaluated by subtracted the $R_m + R_f$ from the R_t according to Eq. (1).

2.3. Extraction of EPS

Many methods had been proposed for EPS extraction, including heating, cation exchange, extraction by EDTA chelating and formaldehyde–NaOH (Liu and Fang, 2003; Sheng et al., 2010). The extraction of EPS was performed according to the thermal extraction method in this study. A sludge suspension was first dewatered by centrifugation in a 50 mL tube at 4 °C, 4000g for 5 min and the supernatant were filtered by glass–fiber membrane (0.70 μm, GF/F, Whatman, UK). Herein the yielded fraction was termed MBR supernatant (containing SMPs). The residual sludge was resuspended by adding 15 mL of 0.05% NaCl solution at room temperature, and then was diluted with the NaCl solution up to 40 mL, which was pre-heated to 70 °C to ensure that the sludge suspension reached an immediate warm temperature of 50 °C. Without any delay, the sludge suspension was then agitated by a vortex mixer (QL-861, Kylin-Bell) for 1 min, followed by centrifugation at 4 °C, 4000g for 5 min. The organic matter in the supernatant was readily extractable EPS, and was regarded as the LB-EPS of the biomass.

EPS constituents were determinated by measuring the concentration of proteins (PNs), polysaccharides (PSs) and humic-like substances by means of conventional colorimetric methods. The PNs and HSs were analyzed by a UV/VIS spectrophotometer (DR5000, HACH) following the modified Lowry method (Frølund et al., 1995) using bovine serum albumin and humic acid (Sigma) as the standards, respectively. The phenol–sulfuric acid method (Dubois et al., 1956) was applied for determination of polysaccharides. All the above analyses were conducted in duplicate, and their average values were reported.