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Characteristics of wastewater and mixed liquor and their role in membrane fouling

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HIGHLIGHTS

- ▶ Effect of wastewater characteristics on membrane fouling was studied.
- ▶ Colloidal content in feed and mixed liquor plays dominant role in controlling fouling.
- ▶ The ratio of proteins to polysaccharides in SMPs is important in controlling fouling.
- ▶ Characterization of feed and mixed liquor may be used as a tool for fouling prediction.

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ABSTRACT

Effects of wastewater and mixed liquor characteristics on membrane fouling in both a submerged anaerobic membrane bioreactor and a thermophilic submerged aerobic membrane bioreactor were studied with four types of industrial wastewaters. Significant differences in particle size distribution, colloidal content, the protein to polysaccharide ratio, and soluble compounds molecular weight distribution were observed among the four types of wastewaters and mixed liquors. Differences in wastewater and mixed liquor characteristics were correlated to the changes in membrane filtration behavior in both systems. The colloidal content in feed and mixed liquor plays a dominant role and is more important than the quantity of total suspended solids in controlling membrane fouling. The ratio of proteins to polysaccharides is more important than the total quantity of soluble organic substances in controlling membrane fouling. A full characterization of feed and mixed liquor may be used as a tool to predict membrane performance.

1. Introduction

Membrane bioreactor (MBR) has received considerable attention in recent years. It has been well implemented in treating both municipal and industrial wastewater (Le-Clech, 2010; Smith et al., 2012). The MBR system has many advantages over the conventional activated sludge process in terms of its excellent effluent quality, high removal efficiency of chemical oxygen demand (COD), small footprint, and integration of biological treatment and filtration (Abeynayaka and Visvanathan, 2011; Akram and Stukey, 2008; Jeison et al., 2009). However, the loss of the membrane performances due to membrane fouling remains a major obstacle in the extensive application of MBRs. Membrane fouling results in a rapid reduction of permeation flux or an increase in trans-membrane pressure, energy consumption, frequent membrane cleaning, and replacement, thus increasing the operation cost of the process.

Membrane fouling is directly or indirectly affected by a number of factors, such as wastewater characteristics, sludge properties, operating and environmental conditions as well as hydrodynamic conditions (Drews, 2010; Meng et al., 2009). Although extensive studies have been conducted on the effects of sludge properties (Tian et al., 2011; Wu and Lee, 2011) and operating and environmental conditions (Dvorák et al., 2011; Miyoshi et al. 2009) on membrane fouling, the importance of wastewater characteristics in MBRs has not been well studied. There are only a few studies that addressed the effect of wastewater characteristics (Arabi and Nakhla, 2008; Park et al., 2006) on membrane fouling in MBRs. Therefore, it is highly desirable to understand the role of wastewater characteristics on membrane fouling in both submerged anaerobic membrane bioreactor (SAnMBR) and submerged aerobic membrane bioreactor (SAMBR) systems.

To gain more insight into the optimization of MBRs design, this study focused on the three fractions, i.e., total solids, colloids, and soluble organic materials, of the wastewater and mixed liquor and their effects on the membrane fouling. Moreover, no comparative studies have been reported to date on the effects of different industrial wastewaters on membrane fouling despite the evidence to the

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significant role played by the mixed liquor in membrane fouling. The objective of this study was to provide a comprehensive characterization of four types of industrial wastewaters and the mixed liquor, to correlate the wastewater characteristics and mixed liquor properties to the observed differences in membrane fouling in both SAnMBR and SAMBR system (each system treating two types of wastewaters).

2. Methods

2.1. Lab-scale membrane bioreactors

The study was conducted using a lab-scale SAnMBR and a lab-scale thermophilic SAMBR (TSAMBR) system. Each system (SAnMBR or TSAMBR) treated two types of industrial wastewaters with significant difference in characteristics. The working volume of the SAnMBR and the TSAMBR is 10 L and 6 L, respectively. Both systems were equipped with a flat sheet microfiltration membrane module (0.03 m^2, 10 cm width × 15 cm length × 2, Shanghai SINAP Membrane Science and Technology Co. Ltd., China). The material of the membrane and the molecular weight cut off (MWCO) were polyvinylidene fluoride (PVDF) and 70,000 Daltons, respectively. The pore size of the membrane is 0.3 μm. Biogas and air was used for sparging to control membrane fouling in the SAnMBR and TSAMBR system, respectively. The pH values (7.0 ± 0.1) of the two systems were automatically controlled by a pH regulation pump and a pH electrode (Thermo Scientific, Beverly, MA). The operating temperatures were maintained by circulating warm water through the water jacket. Wastewater was pumped into the bottom of the bioreactor automatically by a feeding pump (Masterflex Model 7520-50, Barnant Co., USA) which was controlled by a level sensor (Madison Co., USA) and controller (Flowline, USA), and the sludge was continuously mixed by a magnetic stirrer located at the bottom of the reactor. Membrane flux was controlled by adjusting the speed of a peristaltic pump (Masterflex, C/L, Model 77120-70, Barnant, Co., USA). Intermittent suction with a cycle of 4 min run and 1 min pause was carried out for permeate production. The details of the experimental systems are described in previous publications (Gao et al., 2011a,b; Qu et al., 2012). The SAnMBR system was operated for about three months for each type of wastewater tested, while the TSAMBR system was operated for about one month for each type of wastewater tested.

The details of the operating conditions are provided in Table 1. For the TSAMBR system treating two types of wastewaters, the hydraulic retention time (HRT), solids retention time (SRT), mixed liquor suspended solids (MLSS) flux, specific organic loading rate (OLR) were kept the same. In the case of the SAnMBR system, it was operated for the purpose of no sludge wasting (infinite SRT). The calculated SRT was based on the volume of sludge taken for unavoidable MLSS measurement and sludge characterization and both SRTs were very large (220–350 days). The SAnMBR was started at the same flux for TMP pressate 1 and TMP whitewater treatment. However, different sustainable fluxes were maintained, due to the effect of wastewater characteristics. In spite of this, the specific OLR was almost the same for the two wastewaters.

2.2. Wastewater and mixed liquor characterization

The four types of industrial wastewaters were collected from different process locations of a local thermomechanical puling (TMP) mill: TMP pressate (named TMP pressate 1) and TMP whitewater were treated by the SAnMBR system, while TMP pressate (named TMP pressate 2) and a mixture of different TMP wastewaters (named TMP wastewater) were treated by the TSAMBR system.

The total suspended solids (TSS) in wastewaters were determined by filtration of the wastewater through a glass fiber filter circle (Particle Retention: 1.2 μm). Colloids in wastewaters were obtained by filtering the feed supernatant after centrifugation (18,700 g for 20 min) using a membrane with pore size of 0.45 μm (Durapore, Millipore). Additionally, a liquid sample containing only the soluble substances was obtained after filtration with 0.45 μm pore size membrane.

The mixed liquor suspended solids (MLSS) were obtained by the TSS method described above. Colloids in the mixed liquor were obtained from the supernatant by filtering the supernatant after centrifugation at 18,700 g for 20 min with a membrane (0.45 μm pore size). Also the liquid sample after the filtration of the supernatant by 0.45 μm pore size membrane contained only the solutes.

2.3. Molecular weight distribution of soluble organic substances

The soluble organic substances obtained from 0.45 μm pore size membrane filtration were characterized by molecular weight distribution (MWD). Ultrafiltration (UF) of the soluble organic substances in wastewaters and supernatants was performed with a 180 mL stirred filtration cell (Amicon, USA) at the room temperature (25 ± 1 °C). Three cellulose ultrafiltration membranes (Millipore) with nominal molecular weight limits (NMWL), also known as molecular weight cut-off (MWCO), of 100 k, 10 k, 1 kDa were used in series with the highest MWCO at first and the lowest MWCO at last. After the ultrafiltration, four molecular weight distributions (MWD) were obtained: The 100 kDa retentate, called as ">100 k"; the sample passed through 100 kDa membrane but retained by 10 kDa membrane, regarded as "10 k < MW < 100 k"; the retentate of 1 kDa, "1 k < MW < 10 k"; and the permeate of 1 kDa, "<1 k". Nitrogen was applied as pressure over the liquid in the stirred cell. The operating pressures were 0.689 bar for the membranes with NMWL of 100 kDa, 1.379 bar for the membranes with NMWL of 10 kDa, and 2.068 bar for the membranes with NMWL of 1 kDa(Leiviskä et al., 2008), respectively. All membranes were prepared according to the operating instruction before the

Table 1
Operating conditions of SAnMBR and TSAMBR.

Parameters	SAnMBR		TSAMBR	
Types of wastewater	TMP pressate 1	TMP whitewater	TMP pressate 2	TMP wastewater
Reactor Working Volume (L)	10	10	6	6
Temperature (°C)	37 ± 1	37 ± 1	51 ± 1	51 ± 1
pH	7.0 ± 0.2	7.0 ± 0.2	6.9 ± 0.1	6.9 ± 0.1
HRT (d)	2.5 ± 0.2	3.8 ± 0.2	1.1 ± 0.1	1.1 ± 0.1
SRT (d)	350	220	20	20
MLSS (g/L)	10.9 ± 0.5	8.7 ± 0.4	11.0 ± 0.5	11.0 ± 0.5
Flux (L/m^2/h)	6.9 ± 0.6	4.6 ± 0.3	9.2 ± 0.5	9.2 ± 0.5
Permeability (LMH/kPa)	0.25 ± 0.01	0.15 ± 0.02	2.45 ± 0.34	2.47 ± 0.46
Sparging Rate (L/min)	1.5	1.5	3.2	3.2
Specific Organic Loading Rate (kg COD/kg MLSS/d)	0.24	0.21	0.30	0.31