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# Characterization of soluble microbial products in 10 large-scale membrane bioreactors for municipal wastewater treatment in China

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ABSTRACT

In order to fill the knowledge gaps between lab/pilot-scale and full-scale operations and contribute basic information to long-term and stable operation of large-scale membrane bioreactors (MBRs), a systematic investigation was first conducted focused on soluble microbial products (SMPs) in 10 large-scale MBRs (capacity over 10,000 $m^3$/d) for municipal wastewater treatment distributed in 4 different areas of China from fall to winter. The majority of these MBR plants had been operated stably for at least 1 year. Fundamental properties of SMPs were investigated, including composition, molecular weight distribution, hydrophobicity, fluorescent characteristics and fouling potential. The results showed that the concentration of SMPs ranged roughly from 5 to 25 mg TOC/L, with the major component being polysaccharides (ca. 3–18 mg/L) followed by humic substances (ca. 2–10 mg/L); while the protein concentration was relatively low ( $<5$ mg/L). The SMPs presented a broad molecular weight distribution from smaller than 1 kDa to over 100 kDa. About half of the SMPs were hydrophilic substances mainly contributed by polysaccharides; humic substances were concentrated in hydrophobic fractions while proteins showed a relatively wide distribution. The fluorescent properties were found to be affected appreciably by the influent quality. The batch fouling tests indicated that the initial fouling rate correlated significantly with SMPs concentrations, which was particularly the case for hydrophilic and large-molecular-weight fractions. These findings may contribute to better understanding of membrane fouling in engineering conditions and assist in long-term and stable operation of full-scale MBRs.



## 1. Introduction

Since the introduction of membrane bioreactor (MBR) into the field of wastewater treatment in the 1980s, great progress has been achieved on both research and application of this technology in China and worldwide [1–5]. In light of its remarkable advantages over conventional activated sludge process, MBR technology has been commercially applied to treat different types of wastewater and provide high-quality reclaimed water. In the recent years, this technology has been increasingly employed in large-scale wastewater treatment plants (WWTP), particularly owing to the reduction of both membrane and operational cost. To date, there are more than 30 installations of large-scale ( $>10{,}000$ $m^3$/d) MBRs in China treating municipal wastewater, petrochemical wastewater, chemical wastewater, etc. [1]. A number of surveys and analyses [1,3,4] have highlighted the potential markets for large-scale MBR application in the field of wastewater treatment in the following decades.

Alongside the development of MBR, membrane fouling is a long-lasting and inevitable issue. Numerous papers have been devoted to the characterization and cause of fouling, as well as to the strategies for mitigating fouling [6–8]. It is generally accepted that the following factors are responsible for fouling [6,7]: feed characteristics, mixed liquor properties, membrane materials, module configurations and operational conditions. Soluble microbial products (SMPs) in the mixed liquor, which are composed of hydrolysis products of extracellular polymeric substances (EPS) [9] and decay products of active cells [10], have been proved to be the major source of membrane foulants [11,12]. Studies on SMPs have covered many aspects: physical and chemical properties [12–15], effect of operating conditions [12,16], occurrence and fate [17], fouling mechanisms [18,19], and modeling [20,21]. However, the majority of these studies were confined to lab/pilot-scale operations; very few studies focused on large-scale MBRs [22,23]. Many scientific questions still remain unanswered in terms of SMPs' occurrence (e.g., typical concentration range), behaviors (e.g., accumulation and degradation patterns) and fouling propensities in large-scale operations. As noted by Drews in the latest review on membrane fouling in MBR [8], large distinctions exist in design, operation and surroundings between lab/pilot-scale and large full-scale systems. Therefore, the extrapolation of knowledge from lab/

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pilot-scale reactors to full-scale plants might lead to conflicting results [22,24], due to our limited understanding of large-scale MBRs. It is important that a representative survey with deep insight into SMPs under real conditions in large-scale MBRs be conducted.

In order to improve the practical knowledge about large-scale MBRs, understand fouling phenomenon in full-scale operations, and contribute credible and valuable information to future design and operation, a systematic investigation into SMPs in 10 large full-scale MBRs were first conducted in this study. These plants, each with a capacity over 10,000 $m^3$/d, are located at different places of China. The survey refers to all the fouling-related physical and chemical properties such as the composition, molecular weight, hydrophobicity and fluorescent characteristics. The fouling potential was also evaluated via batch filtration tests, followed by analyses of its correlation with the physical and chemical properties of SMPs. Furthermore, a brief interpretation was put on the difference between our findings for large-scale MBRs and those in literature for lab/pilot-scale MBRs.

## 2. Materials and methods

### 2.1. Full-scale MBRs

Ten large-scale municipal MBRs located at different places of China (Fig. S1 in the Supporting Information) were selected in this study, each having a capacity over 10,000 $m^3$/d and combined with a common nutrient-removal activated sludge system(e.g., the anaerobic–anoxic–oxic process). Among them, four plants (B1, B2, B3 and B4) were located in Beijing, northern China; another four plants (W1, W2, W3 and W4) were situated in Wuxi, Jiangsu Province, eastern China; S1 plant was in Hubei Province, central China; and K1 plant was in Yunnan Province, southwestern China. The membrane information, process parameters and operational conditions are presented in Tables 1 and 2. The majority of these MBRs had been operated stably for at least 1 year.

### 2.2. Sampling date

The sampling of SMPs was undertaken from October, 2010 to January, 2011, in the order of B1, B2, B3, B4, W1, W2, W3, W4, S1 and K1 at an interval of approximately 2 weeks. The properties of SMPs in fall and winter seasons could thus be reflected by this study. In addition, since the MBRs were commissioned at different dates (Table 1), to some extent the samples could stand for SMPs at different operational time of MBR.

### 2.3. Sampling and pretreatment

For the sampling at each plant, the mixed liquors obtained from the membrane tanks were filtrated by a filter paper and a glass-fiber membrane (0.7 μm, GF/F, Whatman, UK) in succession to remove the suspended solids. Herein the yielded fraction was termed MBR supernatant (containing SMPs). The samples were

**Table 1**
Processes and membrane information of 10 large-scale MBR plants for municipal wastewater treatment in China.

| WWTP[a] | Process[b] | Membrane suppliers | Membrane parameters (μm) | Capacity ($m^3$/d) | Wastewater type | Commissioned |
|---|---|---|---|---|---|---|
| B1 | $A_1$—$A_2$—O—MBR | Siemens, Memcor, Germany | Hydrophilic PVDF, 0.04 | 60,000 | Domestic | 2007.11 |
| B2 | $A_1$—$A_2$—O—MBR | Asahi Kasei, Microza MUNC-620A, Japan | Hydrophilic PVDF, 0.1 | 35,000[d] | 80% domestic+20% industrial | 2007.11 |
| B3 | $A_1$—$A_2$—O—MBR | Mitsubishi Rayon, Sterapore SADF, Japan | Hydrophilic PVDF, 0.4 | 40,000[d] | 80% domestic+20% industrial | 2010.05 |
| B4 | $A_1$—$A_2$—O—MBR | Mitsubishi Rayon, Sterapore SADF, Japan | Hydrophilic PVDF, 0.4 | 30,000[d] | Domestic | 2009.11 |
| W1 | —$A_1$—$A_2$—O—MBR | GE/Zenon, ZeeWeed 500d, USA | Hydrophilic PVDF, 0.04 | 30,000 | 40% domestic+60% industrial | 2009.05 |
| W2 | $A_1$—$A_2$—O—MBR | Siemens, Memcor, Germany | Hydrophilic PVDF, 0.04 | 20,000[d] | 40% domestic+60% industrial | 2009.09 |
| W3 | $A_1$—$A_2$—O—$A_2$—MBR | Mitsubishi Rayon, Sterapore SADF, Japan/ OriginWater, China | Hydrophilic PVDF, 0.4/0.1[c] | 20,000[d] | 40% domestic+60% industrial | 2009.11 |
| W4 | $A_1$—$A_2$—$A_2$—O—MBR | OriginWater, China | Hydrophilic PVDF, 0.1 | 50,000 | 60% domestic+40% industrial | 2010.01 |
| S1 | $A_1$—$A_2$—O—MBR | OriginWater, China | Hydrophilic PVDF, 0.1 | 110,000[d] | Domestic | 2009.11 |
| K1 | $A_1$—$A_2$—O—$A_2$—MBR | OriginWater, China | Hydrophilic PVDF, 0.1 | 60,000 | Domestic | 2010.08 |

[a] WWTP: wastewater treatment plant.
[b] $A_1$: anaerobic; $A_2$: anoxic; O: oxic; MBR: membrane bioreactor.
[c] W3 municipal plant applies both products of Mitsubishi Rayon and OriginWater; PVDF: polyvinylidene fluoride.
[d] These plants' actual capacity is around 40–80% of the design. Other plants reached full-capacity operation.