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Membrane fouling in a submerged membrane bioreactor with focus on surface properties and interactions of cake sludge and bulk sludge

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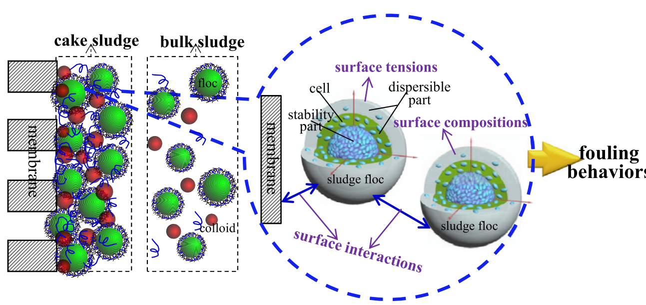
HIGHLIGHTS

- Specific filtration resistance of cake sludge was 5 times of that of bulk sludge.
- Cake sludge was more hydrophilic and had worse aggregation ability than bulk sludge.
- Cake sludge possessed more hydrocarbon, less O and N moieties than bulk sludge.
- Surface composition caused fouling behaviors difference of cake and bulk sludge.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, the fouling behaviors and surface properties of cake sludge and bulk sludge in a submerged membrane bioreactor (MBR) were investigated and compared. It was found that the specific filtration resistance (SFR) of cake sludge was about 5 times higher than that of bulk sludge. Two types of sludge possessed similar extracellular polymeric substances (EPS) content, particle size distribution (PSD) and zeta potential. However, their surface properties in terms of surface tensions were significantly different. Further analysis showed that cake sludge was more hydrophilic and had worse aggregation ability. Moreover, cake sludge surface possessed more hydrocarbon, less oxygen and nitrogen moieties than bulk sludge surface. It was suggested that, rather than EPS and PSD differences, the differences in the surface composition were the main cause of the great differences in SFR and adhesion ability between cake sludge and bulk sludge.

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1. Introduction

Membrane bioreactor (MBR) technology has recently attracted remarkable attention due to its advantages over conventional activated sludge process, stricter discharge standards, growing demand for water reclamation and steady decline of membrane costs (Meng et al., 2009; Svojitka et al., 2009; Lin et al., 2012; Hong et al., 2013). In spite of this, widespread applications of MBR technology must overcome the problem of membrane fouling (Le-Clech et al., 2006; Meng et al., 2009; Farquharson and Zhou, 2010; Lin et al., 2014). To date, lots of studies have been conducted, which have achieved considerable knowledge regarding the characteristics, causes and mechanisms of membrane fouling in MBRs (Le-Clech et al., 2006; Meng et al., 2009; Farquharson and Zhou, 2010; Lin et al., 2011b). The sufficient accumulation of this knowledge is essential for better membrane fouling control.

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Continuous operation in MBR would eventually cause a cake layer formed on the surface of membrane. Cake formation was generally reported to be the major form of membrane fouling (Zhang et al., 2006; Wang et al., 2007; Lin et al., 2009). The filtration resistance of cake layer accounted for 80–98% of the total filtration resistance (Lee et al., 2001; Lin et al., 2009; Wu et al., 2011). Due to the predominant role of cake layer formation in membrane fouling, considerable attention has been devoted to investigation of cake layer. It was reported that cake layer possessed complicated physical, chemical and biological structures (Gao et al., 2011). While cake sludge was mainly originated from bulk sludge in sludge suspension (Wang et al., 2007), their components in terms of extracellular polymeric substances (EPS) and metallic elements (mainly Ca element) were significantly different (Lin et al., 2011a). Wang et al. (2007) reported that cake layer possessed an unusually high filtration resistance as compared with dewatering sludge. They further attributed this phenomenon to the presence of higher content of biopolymer clusters (BPC) in cake layer. Furthermore, several studies reported that the microbial communities of cake layer were different from that of bulk sludge in sludge suspension (Gao et al., 2010; Lin et al., 2011c). In spite of the improved understanding of membrane fouling in MBRs achieved, these studies mainly focused on identification of membrane foulants or microbial communities in cake layer.

Recently, Hong et al. (2013) reported that cake formation in MBRs is a thermodynamic process which depends on the interactions between surfaces of membrane and foulants. The extended Derjaguin–Landau–Verwey–Overbeek (XDLVO) theory can be used to describe these interactions (Hong et al., 2013; Wang et al., 2013), and thus may provide a new approach to reveal the cake layer fouling mechanisms in MBRs (Zhang et al., 2014). The cake layer apparently is a porous media whose filtration resistance could be described through Carman–Kozeny equation (Bai and Leow, 2002). Cake layer characterization showed the calculated specific filtration resistance (SFR) of cake layer fell into magnitudes from 10^9 to 10^{11} m^{-1} kg^{-1} according to Carman–Kozeny equation (Zarragoitia-González et al., 2008; Gao et al., 2011). Whereas, experiments demonstrated that cake layer possessed an SFR ranged from 10^{13} to 10^{15} m^{-1} kg^{-1} (Wang et al., 2007; Lin et al., 2009, 2011c; Su et al., 2013). The main cause of this great difference has not been previously explored, and deserves further study. Su et al. (2013) have recently compared the aggregation ability between cake sludge and bulk sludge. They further intuitively suggested that membrane fouling potential of sludge could be reflected by sludge aggregation (Su et al., 2013). As aggregation ability is the tendency of sludge foulants to flocculate, above study is apparently unable to explain the cake formation process and the great resistance difference between experimental results and calculating results. However, that study provided a clue that surface properties of sludge might play key roles in these interactions and the filtration resistance of cake layer. A comparative investigation of the sludge surface properties and interactions may improve the understanding of membrane fouling caused by cake layer.

Taking into account the information above, the current study aims to investigate the relevance of surface properties of sludge to membrane fouling. Accordingly, the filtration behaviors, EPS content, particle size distribution (PSD), and the surface properties of cake sludge and bulk sludge were examined. Furthermore, the surface tensions, aggregation ability, interfacial interactions and surface compositions of cake sludge and bulk sludge were compared and discussed. Roles of surface properties in adhesion ability and filtration resistance of sludge flocs were also analyzed.

2. Methods

2.1. MBR system

The schematic of a lab-scale submerged MBR (sMBR) apparatus used in current investigation is presented in Fig. 1. The sMBR mainly consisted of a tank with 65 L effective volume (0.54 × 0.30 × 0.40 m height × length × width) where a flat sheet polyvinylidene fluoride (PVDF) membrane module (Shanghai SINAP Co. Ltd., China) was submerged. The average size of membrane pores was 0.3 μm, and a total 0.5 m^2 area of membrane was used. The effluent was intermittently sucked through the membrane module by a peristaltic pump (Baoding Longer, China) with an

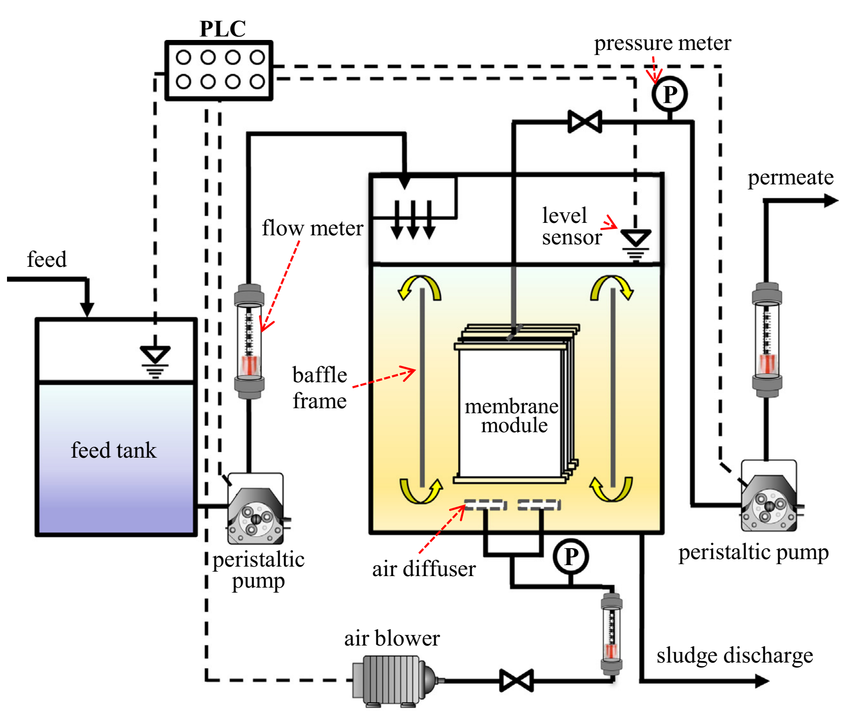

Fig. 1. Schematic of the submerged MBR and experiment setup.

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