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A comparison study on membrane fouling in a sponge-submerged membrane bioreactor and a conventional membrane bioreactor

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HIGHLIGHTS

- Less SMP and bound EPS in activated sludge in the SSMBR induced lower R_C and R_P.
- Lower biomass growth and sludge viscosity contributed to lower R_C in the SSMBR.
- Larger sludge flocs, higher zeta potential and RH led to lower R_T in the SSMBR.
- Sponge could prevent pore blocking and cake layer formation.
- Sponge addition could reduce SMP_C and EPS_C through adsorption and biodegradation.

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ABSTRACT

This study compared membrane fouling in a sponge-submerged membrane bioreactor (SSMBR) and a conventional membrane bioreactor (CMBR) based on sludge properties when treating synthetic domestic wastewater. In the CMBR, soluble microbial products (SMP) in activated sludge were a major contributor for initial membrane fouling and presented higher concentration in membrane cake layer. Afterwards, membrane fouling was mainly governed by bound extracellular polymeric substances (EPS) in activated sludge, containing lower proteins but significantly higher polysaccharides. Sponge addition could prevent cake formation on membrane surface and pore blocking inside membrane, thereby alleviating membrane fouling. The SSMBR exhibited not only less growth of the biomass and filamentous bacteria, but also lower cake layer and pore blocking resistance due to lower bound EPS concentrations in activated sludge. Less membrane fouling in SSMBR were also attributed to larger particle size, higher zeta potential and relative hydrophobicity of sludge flocs.

1. Introduction

In the past decades, membrane bioreactor (MBR) has emerged as a considerably alternative to the conventional activated sludge treatment system for water reclamation and reuse. This technology has some superior merits, such as high effluent quality, small footprint, complete liquid–solid separation, high biomass content, absolute control of sludge retention time (SRT) and hydraulic retention time (HRT), and low sludge production (Guo et al., 2009). However, membrane fouling, especially biofouling, is the most obstacle in wide application of the MBR technology. Generally, biofouling is referred to as undesirable accumulation of microorganisms at a phase transition interface, which may occur by deposition, growth and metabolism of bacteria cells or flocs on the membranes (Guo et al., 2012). As one of the most serious operational problems in membrane applications, biofouling causes severe flux decline, reduces membrane efficiency, increases membrane replacement and operational and maintenance costs.

Various strategies have been employed to reduce membrane fouling in the MBRs. Ngo and Guo (2009) found that an aerated submerged MBR (SMBR) system with addition of a very low-dose green bioflocculant (GBF) could achieve near zero membrane fouling after 70 days of operation as well as less backwash frequency. A chemical cleaning-in-place (CIP) was investigated by Wei et al. (2011) in a long-term operation of pilot-scale submerged MBR

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for municipal wastewater treatment. They reported that the chemical CIP, in both transmembrane pressure (TMP) controlling mode and time controlling mode, effectively removed the fouling in terms of membrane pore blockage and gel layer caused by colloids and soluble organic substances. Wu and He (2012) suggested that the low irreversible fouling was found in the cyclic aeration mode, which could be ascribed to the floc destruction and re-flocculation processes. During the short high aeration period, the preservation of the strong strength bonds within activated sludge flocs caused less release of soluble and colloidal material in the supernatant. The weak strength bonds damaged in the high aeration period could be recovered in the re-flocculation process in the low aeration period.

In addition, using biomass carriers (e.g. plastic media, powdered activated carbon (PAC), sponge) in MBR is an effective and promising method to control membrane fouling. Jin et al. (2013) suggested that biomass flocs were less easily broken up with addition of relatively light and large-sized suspended carriers (AnoxKaldnes, K1 carriers) in ceramic SMBR. Moreover, both extracellular polymer substances (EPS) and soluble microbial products (SMP) were lower in the SMBR with carriers than those in the SMBR without carriers. Ng et al. (2013) indicated that higher concentration of fresh PAC in the SMBR could provide better simultaneous adsorption, decomposition, and biodegradation effects for the reduction of fouling components in the supernatant of the mixed liquor such as EPS, fine colloids and planktonic cells. As an idea attached growth media, sponge has also exhibited excellent performance during biological treatment due to its advantages of high internal porosity and specific surface area, high stability to hydrolyses, light weight and low cost (Ngo et al., 2006). When employing in MBRs, it can act as a mobile carrier for active biomass, reduce cake layer formation on the membrane surface and retain microorganisms by incorporating both their attached growth and suspended growth (Ngo et al., 2008). Guo et al. (2008) investigated the effects of sponge addition on sustainable flux and membrane fouling. They found that compared to SMBR alone, the suspended sponge cubes in the sponge-submerged membrane bioreactor (SSMBR) with sponge volume fraction of 10% could significantly reduce the membrane fouling as well as improve sustainable flux by 2 times. Nguyen et al. (2012) also confirmed that SSMBR had lower TMP development than that of conventional SMBR during primary effluent treatment. Meanwhile, SSMBR could maintain good microbial activity and constant sludge volume index value.

Overall, previous studies have highlighted the advantages of sponge addition in MBRs for improving treatment performance as well as membrane fouling reduction in terms of sustainable flux or permeate flux. However, the effects of sponge on sludge characteristics and membrane fouling have yet to be investigated in MBR systems. Therefore, a comparison study was conducted to evaluate the performance of a SSMBR and a conventional MBR (CMBR) based on sludge characteristics, such as zeta potential, apparent viscosity, relative hydrophobicity (RH), EPS and SMP. The cake layer formation on membrane surface was also analysed.

2. Methods

2.1. Wastewater

The experiments were conducted using a synthetic wastewater to avoid any fluctuation in the feed concentration and provide a continuous source of biodegradable organic pollutants such as glucose, ammonium sulphate and potassium dihydrogen orthophosphate. It was used to simulate domestic wastewater just after primary treatment. The synthetic wastewater has dissolved organic carbon (DOC) of 100–130 mg/L, chemical oxygen demand (COD) of 330–360 mg/L, ammonium nitrogen (NH_4-N) of 12–15 mg/L and orthophosphate (PO_4-P) of 3.3–3.5 mg/L. $NaHCO_3$ or H_2SO_4 was used to adjust pH to 7.

2.2. Experimental setup and operating conditions

A SSMBR and a CMBR with the same effective working volume were operated in parallel to compare the performance and membrane fouling behaviour. For each MBR, a polyvinylidene fluoride (PVDF) hollow fiber membrane module with a pore size of 0.2 μm and surface area of 0.1 m^2 was used. Both MBRs were filled with sludge from a local Wastewater Treatment Plant and acclimatised to synthetic wastewater. They were started with identical seeding activated sludge with similar initial sludge concentration (7.03 g/L for SSMBR, 6.98 g/L for CMBR). No sludge was withdrawn from both MBRs. The reticulated porous polyester-polyurethane sponge (PUS) was used in SSMBR system. The PUS has density of 28-45 kg/m^3 and cell count of 45 cells/in (45 cells per 25.4 mm). The dimensions of the sponge cubes are 10 mm, 10 mm, and 10 mm in length, width and thickness, respectively. The sponge volume fraction was 10% in the SSMBR in this study, which was determined according to previous study of Guo et al. (2008). Before running the experiments, the sponge cubes were acclimatised to synthetic wastewater for 25 days. Synthetic wastewater was pumped into the reactor using a feeding pump to control the feed rate while the effluent flow rate was controlled by a suction pump. A pressure gauge was used to measure the TMP and a soaker hose air diffuser was used to maintain air flow rate at 9 L/min. The filtration flux of both MBRs was kept constant at 10 L/m^2 h by adopting a suction cycle of 59-min on and 1-min off (relaxation). For chemical cleaning of the membrane, the membrane was soaked in chemical solutions using the three following steps: 6 h in 0.5% citric acid, 6 h in 0.4% sodium hydroxide, 6 h in 0.8% sodium hypochlorite.

2.3. Analysis methods

DOC of the influent and effluent was measured using the Analytikjena Multi N/C 2000. The analysis of COD was according to Standard Methods (APHA, AWWA, WEF, 1998). NH_4-N and PO_4-P were measured by photometric method called Spectroquant® Cell Test (NOVA 60, Merck).

Fouling resistance was measured through various fluxes with distilled water at the end of the experiment. The resistance-in-series model was applied to evaluate membrane filtration characteristics by using Darcy's law. The model was expressed as follows (Choo and Lee, 1996):

$$J = \Delta P/\mu R_T \quad (1)$$

$$R_T = R_M + R_C + R_P \quad (2)$$

where J is the permeate flux; ΔP is the TMP; μ is the viscosity of the permeate; R_T is total resistance; R_M is the intrinsic membrane resistance; R_C is the cake resistance; and R_P is the pore blocking resistance.

At the end of the experiment, the membrane was taken out from the bioreactor. Cake layer on membrane surface was collected and then dissolved in 30 mL of distilled water. The extraction procedures and analysis methods of EPS and SMP of cake layer were in the same manner as described below. The EPS extraction protocol was modified from Frølund et al. (1996). 30 mL of mixed liquor were taken from the MBRs and then centrifuged at 3000 rpm for 30 min. After that, the supernatant was centrifuged at 3000 rpm for 30 min and filtered through 0.45 μm Phenex-NY (Nylon) syringe filter to obtain SMP. The pellets remaining in the centrifuge tube were suspended in phosphorus buffer solution up to 30 mL,