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Effect of different flocculants on short-term performance of submerged membrane bioreactor

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ABSTRACT

This study aims at evaluating the impacts of flocculant addition to a submerged membrane bioreactor (SMBR). Three types of common flocculants ($FeCl_3$, PACl and chitosan) were tested based on the performance of organic and nutrients removal, respiration test and fouling control. The data showed that all of the flocculants not only could keep high removal efficiencies of DOC and COD (>90%) compared to SMBR alone, but also exhibited different advantages and disadvantages according to the properties of the flocculants. For instance, inorganic flocculants strongly affected the nitrification process and organic flocculant addition slightly reduced the phosphorus removal efficiency in SMBR. After adding $FeCl_3$ and PACl, NH_4-N removal decreased to 31.9% and 11.1%, while T-N removal dropped to 22% and 0.5% respectively. Although flocculants addition improved sludge settleability and oxygen transfer to some extent, organic flocculant obtained more stable sludge volume indexes (SVI) and specific oxygen uptake rates (SOUR) than those of inorganic flocculants. Inorganic flocculants, on the other hand, led to more reduction of soluble microbial products (SMP) present in mixed liquor and lower membrane fouling rates (1.3 and 2.6 kPa/day for $FeCl_3$ and PACl respectively).

1. Introduction

The accumulation of nitrogen and phosphorus compounds by discharge of wastewater is one of the main causes for eutrophication in water bodies. Thus, these substances have to be removed from wastewater for reducing their harmful impact on environment [1]. Biological processes based on suspended growth (i.e. activated sludge processes) are effective for organic and nutrient removal from municipal wastewater. However, the removal efficiency mainly depends on sludge characteristics, hydraulic retention time (HRT) of the reactor and sludge retention time (SRT). Especially the first one could give rise to serious operating problems such as increase of suspended solids, nitrogen and phosphorus in the effluent and decrease of biomass activity in the system [2].

Membrane bioreactor (MBR) utilizing membrane filtration and activated sludge process into one compact unit is the most promising technology for wastewater reclamation and reuse. The outstanding merits of MBR over the conventional activated sludge systems include small footprints, complete solids removal, high effluent quality, high biomass concentration and improved sludge ages in the bioreactor [3]. However, MBR technology is currently facing some research and development challenges such as membrane fouling, high membrane cost and pretreatment. Membrane fouling is the most difficult challenge, which increases operational cost and shortens membrane life [4]. Three approaches have been used to control membrane fouling: (i) fouling control by operating membrane system below critical flux, (ii) pretreatment of the feedwater, and (iii) membrane backwashing and cleaning [5].

The main objective of the membranes in MBR is to filter the sludge mixed liquor. The characteristics of the mixed liquor govern the filterability and the membrane fouling. Recently, various trials have been carried out to minimizing membrane fouling by a promising method, coagulating/flocculating the activated sludge by adding chemicals, increasing the floc size and decreasing concentration of soluble foulants in the bulk phase [6]. Thus, organic flocculants (i.e. MPE50, chitosan and starch) and metal salts (i.e. $FeCl_3$, polyaluminium chloride and alum) have been tested for fouling control of MBRs. However, most of the studies mainly focused on modifying the mixed liquor characteristics through batch or jar tests. Koseoglu [6] conducted batch shaker tests to evaluate the effectiveness of seven different chemicals (three cationic polymers (MPL30, MPE50, KD452), a biopolymer (chitosan), a starch and two metal salts ($FeCl_3$, PACl)) on filterability and fouling reduction in MBR mixed liquors. The optimum dosages of chemicals were determined in terms of soluble microbial products (SMP) removal. The results elucidated all tested chemicals were able to remove SMP at

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different extent and all cationic polymers, starch and chitosan significantly reduced fouling rates and increased permeability values. Similarly, Yoon et al. [7] reported that MPE (membrane performance enhancer) could reduce SMP level significantly. A decrease of polysaccharide level from 41 mg/L to 21 mg/L was observed with 100 mg/L of MPE. Iversen et al. [8] also investigated the effects of 13 different flux enhancing chemicals ($FeCl_3$, polyaluminium chloride (PACl), two chitosans, five synthetic polymers, two starches and two activated carbons) on respirometric characteristics and nitrogen removal for MBR mixed liquor. They found that only few additives showed strong influences on respirometric characteristics and nitrification/denitrification performance under the considered optimum dosages. The tested PACl strongly impacted on nitrification (−16%) and denitrification rate (−43%). In addition, Song et al. [9] evaluated the membrane fouling control and removal of phosphorus by the addition of alum and $FeCl_3$ directly into aerobic tank of a pre-anoxic nutrient removal system. It was found that addition of alum had positive effects on phosphorus removal and membrane filtration resistance without any deterioration in nitrogen removal efficiency. $FeCl_3$ was efficient in the reduction of specific resistance, but it led to decrease in pH than that of alum.

Besides, there are a few documents about chemicals addition in real MBR system. Yoon and Collins [10] indicated that 300 mg/L of MPE50 could increase the long-term daily flux by 150% of fouled membranes in a small municipal MBR plant. With 400 ppm MPE50, a full-scale municipal MBR plant (2300 m^3/day) could be operated at an average flux of 47.25 LMH, which is 39% higher than the critical flux (34 LMH). Moreover, the cake formed on membrane surface exhibited 1.26 times greater porosity than that in the control reactor with the dosing of a cationic polymeric material [11]. Zhang et al. [12] employed $FeCl_3$ (concentration of 0–1.6 mM) to a hybrid MBR in order to mitigate membrane fouling. The addition of Fe(III) to the MBR system reduced the larger molecular weight fraction (>10 kDa) in the SMP and the 1–10 μm particles in the flocs. Another study by Wu and Huang [13] also stated that the addition of polymeric ferric sulfate formed a gel layer on membrane by removing organics with high molecular weight from supernatant. This resulted in improving membrane filterability of the mixed liquor.

Therefore, it is necessary to study the impact of flocculant addition on MBR performance in a real MBR system in terms of biomass activity, and organic and nutrient removal. In this study, three kinds of flocculants were applied to a submerged membrane bioreactor (SMBR). The performance of SMBR was examined in terms of sludge characteristics, organic and nutrients removal, as well as membrane fouling. Oxygen uptake rate (OUR) and specific oxygen uptake rate (SOUR) were used to assess the impact of flocculants on biomass activity or oxygen transfer.

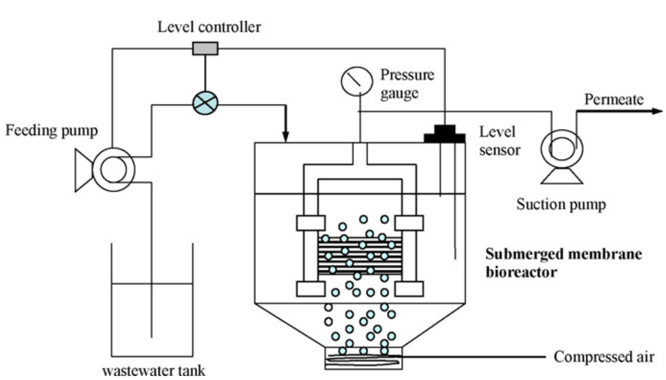

Fig. 1. Experimental set-up of SMBR.

Table 1
Organic matter removal with different flocculants (influent DOC = 135–160 mg/L, COD = 350–400 mg/L).

Flocculant	Dosage (g/day)	DOC removal efficiency (%)	COD removal efficiency (%)
No flocculant	–	96.5 ± 0.3	96.7 ± 1.0
$FeCl_3$	0.9	97.6 ± 0.7	96.1 ± 0.9
PACl	1.0	97.1 ± 0.8	92.1 ± 3.2
Chitosan	1.0	96.0 ± 1.0	93.0 ± 3.7

2. Material and methods

2.1. Wastewater

A synthetic wastewater was used to simulate high strength domestic wastewater (just after primary treatment process). The synthetic wastewater contains glucose, ammonium sulfate, potassium dihydrogen orthophosphate and trace nutrients, which has dissolved organic carbon (DOC) of 135–160 mg/L, COD of 350–400 mg/L, total nitrogen (T-N) of 17–20 mg/L and total phosphorus (T-P) of 3.6–4.0 mg/L. $NaHCO_3$ or H_2SO_4 were used to adjust pH in SMBR reactor to a constant value of 7. The synthetic wastewater used in this study does not contain any colloidal and suspended particles. It contains only soluble organic matter.

2.2. SMBR set-up and flocculants

A polyethylene hollow fiber membrane module was used with the pore size of 0.1 μm and surface area of 0.1 m^2. The schematic diagram of the submerged hollow fiber microfiltration system is shown in Fig. 1. The effective volume of the bioreactor was 8 L. 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. Level sensor was used to control the wastewater volume in the reactor. A pressure gauge was used to measure the transmembrane pressure (TMP) and a soaker hose air diffuser was used to maintain a high air flow rate (8 L/min or 4.8 $m^3/m^2_{(\text{membrane area})}$ h). For physical cleaning of membranes, filtrate backwash was used two times per day for 2 min duration at a backwash rate of 30 L/m^2 h. Once the TMP reached up to 30 kPa, chemical cleaning was conducted. The permeate flux of SMBR was kept constant (10 L/m^2 h) with a hydraulic retention time (HRT) of 8 h. As SRT has great effect on SMBR performance, especially nitrogen removal, SMBRs were operated at initial MLSS concentration of 5 g/L and SRT was kept indefinite (no sludge withdrawal during the experiment) in order to compare the relative merits of each flocculant. Initially, SMBR was filled with acclimatized sludge and the seeding sludge from a Wastewater Treatment Plant in Sydney was inoculated to synthetic wastewater.

Three different kinds of flocculants were employed to SMBR, including two metal salts flocculants ($FeCl_3$ and PACl) and one biopolymer flocculant (Chitosan). Chitosan (Aldrich) used in this study is natural low-molecular weight deacetylated chitin extracted from the sea shrimp or crab shell. The dosages of $FeCl_3$, PACl and chitosan were 0.9, 1, and 1 g/day respectively (Table 1), which responded to 37.5, 41.7 and 41.7 mg/$L_{(\text{wastewater})}$. The inorganic flocculants of $FeCl_3$ and PACl were added on a continuous basis to the SMBR by a dosing pump (to minimize the effect of pH variation). In contrast, chitosan was added by dosing to SMBR directly two times per day. The flocculants were added mainly to agglomerate the biomass and reducing membrane fouling. Moreover, the flocculant has no direct flocculation effect on the feed solution as it has no colloidal and suspended solid fraction.