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 (FeCl₃, 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 FeCl₃ and PACl, NH₄-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 FeCl₃ and PACl respectively).

**Keywords:** Submerged membrane bioreactor (SMBR); Flocculant; Specific oxygen uptake rate (SOUR); Nutrients removal; Critical flux

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. FeCl₃, 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 7 different chemicals (3 cationic polymers (MPL30, MPE50, KD452), a biopolymer (chitosan), a starch and 2 metal salts (FeCl₃, 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 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), 2 chitosans, 5 synthetic polymers, 2 starches and 2 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$^3$/d) 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 $\mu$m 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.

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. NaHCO₃
or H₂SO₄ 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 m². 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$^2$.h). For physical cleaning of membranes, filtrate backwash was used 2 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 hours. 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.

**Fig. 1.** Experimental set-up of SMBR

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(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 are added mainly to agglomerate the biomass and reduce membrane fouling. Moreover, the flocculant has no direct flocculation effect on the feed solution as it has no colloidal and suspended solid fraction.

2.3. Analysis

DOC of the influent and effluent was measured using the Analytikjena Multi N/C 2000. The analysis of COD and the measuring of mixed liquor suspended solids (MLSS) and biomass (monitored as mixed liquor volatile suspended solids, MLVSS) were according to Standard Methods [14]. Nitrogen and phosphorus were measured by photometric method called Spectroquant® Cell Test (NOVA 60, Merck). The bacterial activity during operation of MBR can be evaluated by measuring the oxygen consumption (by respirometric procedure). YSI 5300 Biological Oxygen Monitor was used to measure oxygen uptake rate (OUR) and specific oxygen uptake rate (SOUR) in order to assess the impact of flocculants on biomass activity or oxygen transfer. The viscosity of activated sludge and the particle size distributions of flocculated activated sludge were determined using Brookfield Dial Reading Viscometer and Malvern 2600.

3. Results and Discussion

3.1. The performance of SMBR in terms of organic removal

Organic removals in SMBR were compared with and without additives (flocculants, in our case). Table 1 summarises the DOC and COD removal efficiencies with different flocculants together with the values of control SMBR. The temporal variation in DOC removal is shown in Fig. 2. As can be seen from the
results, there is only marginal difference between the removals with and without flocculants addition. FeCl₃ and PACl addition could slightly improve the DOC removal as compared to membrane alone (97.6±0.7% and 97.1±0.8% respectively). However, the DOC removals for chitosan was little bit lower than that of SMBR alone (96.5±0.3%), which means organic flocculant may have some negative effects on organic removal. COD removal results also showed the similar trend.

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

![Fig. 2. DOC removal efficiency of SMBR with different flocculants addition](image)

3.2. The performance of SMBR in terms of nutrient removal

Although several studies highlighted the role of flocculants on membrane fouling reduction in real MBR system [10, 11, 12, 13], there are little data about the influence of flocculants on nutrient removal. Thus, NH₄-N, NO₃-N, NO₂-N, TN (sum of NH₄-N, NO₃-N and NO₂-N) and TP concentrations in the influent and effluent were monitored during the experiments. Fig. 3 and Fig. 4 present the removal efficiencies of NH₄-N and T-N. The addition of flocculants improved the nitrification in SMBR. During the initial stage of operation (the first 4 days), the NH₄-N removal with SMBR alone decreased gradually, while it improved with the addition of flocculants (>87% removal). After 4 days, the inorganic flocculants inhibited the nitrification significantly. For example, NH₄-N removal dropped to 31.9% and 11.1% on 10th day with the addition of FeCl₃ and PACl respectively, whereas chitosan could keep the NH₄-N removal relatively constant around 82%. Similarly, T-N removal with inorganic flocculants followed the same trend as nitrification. With inorganic flocculants (FeCl₃ and PACl), T-N removal decreased to 22% and 0.5% respectively,
while T-N removal remained around 66.6% after 10 days run with the organic flocculant (chitosan) addition. The results elucidated that mineral additive flocculants could increase metal concentration in the mixed liquor and cause an adverse impact on nitrogen removal in SMBR. However, as an environmentally friendly biopolymer, chitosan possesses intrinsic characteristics such as non-toxicity and biodegradability that make it an effective flocculant for biological process [15].

**Fig. 3.** NH$_4$-N removal efficiency in SMBR with the addition of different flocculants

**Fig. 4.** T-N removal efficiency in SMBR with the addition of different flocculants

Recently, the phenomenon of simultaneous nitrification and denitrification (SND) has attracted the attention because SND may occur within microbial flocs as a result of DO concentration gradient and there may exist anoxic micro-zones in the center of sludge flocs that allow denitrification happen in traditional way [16, 17]. Thus, in this study, the efficiency of the SND in aerobic SMBR ($E_{SND}$, %) was calculated by Eq. (1):

$$E_{SND} = (1 - \frac{C_{\text{NO}_x\text{-produced}}}{C_{\text{NH}_4\text{-oxidized}}}) \times 100\%$$

(1)

Fig. 5 shows the efficiency of the SND with and without flocculants. The SND efficiency increased sharply up to 90% or above during the first 5 days of operation, but decreased afterwards. At the end of the 10$^{th}$ day, SND efficiencies were 71% and 83% with FeCl$_3$ and chitosan addition. The SND efficiency dropped dramatically on the 10$^{th}$ day (4.3%) due to the presence of abundant NO$_3$-N and NO$_2$-N in the SMBR effluent. Overall, chitosan is the only flocculant which had low impact on nitrogen removal compared to other flocculants used in this study.

**Fig. 5.** SND efficiency of SMBR with the addition of different flocculants
The phosphorus removal was also investigated during the operation of SMBR (Fig. 6). Since the MBR contained a low initial MLSS, the phosphorus could be removed nearly completely by metabolic function of microorganisms (cell growth) and the removal rate was maintained around 0.67 mg P/g biomass synthesis. During the application of flocculants, the inorganic flocculants exhibited no influence on T-P removal and resulted in excellent results (100%) through the experimental period. On the contrary, the addition of chitosan attenuated the phosphorus uptake by biomass metabolism and resulted in the decrease of T-P removal (98%) throughout the experiments.

**Fig. 6.** T-P removal of SMBR with the addition of different flocculants

### 3.3. Respiration test and SOUR

Oxygen uptake rate (OUR) and specific oxygen uptake rate (SOUR) tests of mixed liquor have been conducted periodically using YSI 5300 Biological Oxygen Monitor in order to investigate the impact of flocculants on microbial activity and oxygen transfer. To evaluate the enhancement of oxygen transfer by flocculant addition on oxygen transfer, SOUR increasing rates were calculated using Eq. (2):

\[
\text{SOUR increasing rate} = \left( \frac{\text{SOUR on 1st day}}{\text{SOUR on 0 day}} \right) \times 100\%
\]  

(2)

Table 2 summarizes the values of SOUR increasing rates, OURs and SOURs. Under the condition of no flocculant addition, the SOUR increased by 200% during the first day. Both of FeCl₃ and chitosan resulted in a higher increase (224% and 220%) as compared to that of PACl (169%), which indicated that PACl led to a less oxygen transfer due to the highly viscous nature of the flocculant [8]. However, regarding to OURs and SOURs, all three different additives showed significant improvements. In particular, the highest OURs and SOURs observed with chitosan supported why it
could maintain higher nutrients removal than other flocculants. These increased values also revealed that the flocculant addition could improve the sludge adaptation to glucose-containing substrate.

**Table 2**
SOUR increasing rate, OUR and SOUR values with standard deviation

### 3.4. Sludge settleability and particle size

Sludge settleability was determined by measuring the sludge volume index (SVI), which is the volume of MLSS after 30 min of settling. The SVIs measured during the experiments were displayed in Fig. 7. Without flocculant addition, the SVI firstly increased and kept stable around 50 mL/g. On the other hand, the use of flocculants improved the compressibility and settleability of the activated sludge in SMBR and lower SVIs were observed. On the first day, adding FeCl$_3$ and PACl resulted in lower SVIs compared to chitosan, which were 13, 19, and 29 mL/g respectively. This is mainly due to aluminum- or iron- based flocculants neutralize negatively charged flocs and colloids and allow them to flocculate with each other by electrostatic attraction [18]. After that, the SVIs increased gradually with time and reached up to 50 and 40 mL/g respectively in case of FeCl$_3$ and PACl addition because of the growth of biomass (Table 2). The addition FeCl$_3$ led to the highest biomass growth rate of 0.33 g/day and lowest MLVSS/MLSS ratio of 0.84, while PACl had a biomass growth rate (0.24 g/day) and MLVSS/MLSS ratio (0.86), which were similar to that of SMBR alone (0.23 g/day and 0.87) (Table 3). Nevertheless, the SVIs of chitosan dropped slightly and maintained at relatively constant values around 23 mL/g, which corresponded to its relatively low biomass growth rate (0.27 g/day) and the highest MLVSS/MLSS ratio (0.90). The results indicated FeCl$_3$ addition could lead to large volume of sludge production compared to other flocculants. Meanwhile, the results
also showed another merit of chitosan superior to inorganic flocculants which is outstanding chelation behaviour [14].

**Table 3**  
Biomass growth rate in SMBR reactor and the change of sludge viscosity after flocculant addition (initial MLSS = 5 g/L; initial MLVSS/MLSS = 0.87)

**Fig. 7.** SVI values of mixed liquor in SMBR with different flocculants addition

To further understand the change of SVIs, the sludge viscosities and particle size distributions using different flocculants were measured through the jar test. At the initial MLSS of 5 g/L, flocculants (same doses as added in SMBR) were added in 2-L jar and mixing for 24 hours before measurement. According to the results listed in Table 3 and 4, the sludge without any flocculant addition gained viscosity of 2.08 mPa.s after 24 hours mixing. 20.5 % sludge particles were between the lower particle range of 0-10 µm and 74.3 % ranged from 10 to 150 µm. Three kinds of flocculants increased the sludge viscosity and particle size by aggregating the sludge flocs. Therefore, the lowest SVIs achieved by chitosan could be owing to its ability of increasing the sludge viscosity (increased to 3.38 mPa.s) and particle size (89.5 % of 10-150 µm particles). In addition, the lowest rise of viscosity and the highest biomass growth rate of FeCl$_3$ could response to its increase in SVIs.

**Table 4**  
Particle size distributions (percentage) of mixed liquor with and without flocculant addition (initial MLSS = 5 g/L)

3.5. **Membrane fouling and critical flux**

Mixed liquor contains a variety of soluble organic compounds such as soluble microbial products (SMP) and they have larger fouling potential than suspended solids due to their interaction with the membrane material. Normally, TOC analysis usually can be adopted to characterize soluble organic contents by either filtration or
centrifugation methods [19]. In this study, the amount of SMP has been represented by TOC analysis of filtered mixed liquor (through 0.45 µm standard filter) (Fig. 8). Without flocculant addition, the SMP present in mixed liquor was around 19.4 mg/L. After adding the flocculants, the SMPs dampened in mixed liquor and the values were 8.2, 9.0 and 11.2 mg/L for flocculants FeCl$_3$, PACl and chitosan respectively. Although these ions enhance the filterability of the mixed liquor, the TMP reductions were not obvious due to the low backwash frequency. Since the increasing rate of TMP via a certain time can be the indicator as membrane fouling [20], the membrane fouling rates were computed based on TMP development each day (dTMP/day) through the experimental time (Table 5). Meanwhile, critical flux experiments were conducted after 10 days operation of each condition (lowest flux step started at 10 L/m$^2$.h) and the results were also stated in Table 5. The membrane fouling rate increased by 5 kPa/day for SMBR alone, while decreases of the TMP development were observed with flocculants addition. This is due to flocculants addition reduced some small particles and colloids (0-50 µm) presented in mixed liquor and increased the fraction between 50-150 µm, resulting in mitigation of membrane fouling [21, 22]. However, the enlarged floc size is only one of the important elements governs fouling minimization. Although FeCl$_3$ and PACl offered the lowest fouling rate of 1.3 and 2.6 kPa/day respectively, chitosan had the highest fouling rate of 3.7 kPa/day because of the increase in sludge viscosity. After 10 days of operation, critical flux could not be identified for SMBR alone and SMBRs with chitosan addition. In contrast, SMBRs adding FeCl$_3$ and PACl gave the existing critical fluxes of 17 and 12 L/m$^2$.h respectively. Therefore, in this study, the inorganic flocculants had better ability of mitigating membrane fouling and organic flocculant may require more backwash frequency when applying in SMBR system.
Fig. 8. SMP in mixed liquor in SMBR with different flocculants addition

Table 5
Membrane fouling rate and critical flux values after 10 days operation

4. Conclusions

The study evaluated the effects of three different flocculants on the performance of SMBR system through short-term experiments. The results indicated that the flocculants addition had little influence on organic removal in SMBR. However, they had more or less effects on other parameters. The most vital demerit of inorganic flocculants is they strongly affected the nitrification and nitrogen removal in SMBR. The NH$_4$-N and T-N removal dropped to 11.1% and 0.5 % on 10th day respectively when PACl was employed, whereas chitosan could retain the higher NH$_4$-N and T-N removal of 82% and 66.6% respectively.

In this study, although organic flocculant achieved lower SVI values and higher SOUR values, inorganic flocculants could eliminate SMP in mixed liquor and resulted in relatively low fouling rates. For example, FeCl$_3$ attained the highest SVI (50 mL/g) and lowest SOUR (4.11 mg O$_2$/g MLVSS.h), however, it led to lowest SMP concentration (8.2 mg/L) in the mixed liquor and TMP increasing rate (1.3 kPa/day). After 10 days of operation, only the SMBRs with inorganic flocculants addition showed a critical flux higher than operational filtration flux of 10 L/m$^2$.h. Although all of the three flocculants could improve sludge settleability and oxygen transfer, reduce SMP present in mixed liquor and minimise membrane fouling rates, inorganic flocculants gained superior in terms of fouling control. Thus, for long-term running of SMBR, use of both inorganic and organic flocculants together with more frequent
backwash may be a solution to enhance the performance and reduce membrane fouling.

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[6] H. Koseoglu, N.O. Yigit, V. Iversen, A. Drews, M. Kitis, B. Lesjean, M. Kraume, Effects of several different flux enhancing chemicals on filterability and fouling


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

<table>
<thead>
<tr>
<th>Flocculant</th>
<th>Dosage (g/day)</th>
<th>DOC removal efficiency (%)</th>
<th>COD removal efficiency (%)</th>
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<tr>
<td>No flocculant</td>
<td>–</td>
<td>96.5±0.3</td>
<td>96.7±1.0</td>
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<tr>
<td>FeCl₃</td>
<td>0.9</td>
<td>97.6±0.7</td>
<td>96.1±0.9</td>
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<tr>
<td>PACl</td>
<td>1.0</td>
<td>97.1±0.8</td>
<td>92.1±3.2</td>
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<tr>
<td>Chitosan</td>
<td>1.0</td>
<td>96.0±1.0</td>
<td>93.0±3.7</td>
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<tr>
<td>Flocculant</td>
<td>SOUR increasing rate (%)</td>
<td>OUR (mg O₂/L.h)</td>
<td>SOUR (mg O₂/g MLVSS.h)</td>
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<td>-------------</td>
<td>--------------------------</td>
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<td>------------------------</td>
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<tr>
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<td>220</td>
<td>25.07±6.26</td>
<td>4.88±0.50</td>
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Table 3
Biomass growth rate in SMBR reactor and the change of sludge viscosity after flocculant addition (initial MLSS = 5 g/L; initial MLVSS/MLSS = 0.87)

<table>
<thead>
<tr>
<th>Flocculant</th>
<th>Biomass growth rate (g/day)</th>
<th>MLVSS/MLSS ratio on 10th day</th>
<th>The change of viscosity after adding the flocculant (mPa.s)</th>
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<td>Particle size range (μm)</td>
<td>No flocculant</td>
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<td>PACl</td>
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<tr>
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<td>--------</td>
<td>-------</td>
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<td>0-10</td>
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Table 5
Membrane fouling rate and critical flux values after 10 days operation

<table>
<thead>
<tr>
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<th>Membrane fouling rate (kPa/day)</th>
<th>Critical flux after 10 days run (L/m².h)</th>
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<tr>
<td>No flocculant</td>
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<td>12</td>
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<tr>
<td>Chitosan</td>
<td>3.7</td>
<td>–</td>
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Fig. 1. Experimental set-up of SMBR
Fig. 2. DOC removal efficiency of SMBR with different flocculants addition
Fig. 3. NH₄-N removal efficiency in SMBR with the addition of different flocculants
Fig. 4. T-N removal efficiency in SMBR with the addition of different flocculants
Fig. 5. SND efficiency of SMBR with the addition of different flocculants
Fig. 6. T-P removal of SMBR with the addition of different flocculants
Fig. 7. SVI values of mixed liquor in SMBR with different flocculants addition
Fig. 8. SMP in mixed liquor in SMBR with different flocculants addition