Separation and Purification Technology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Membrane fouling reduction and improvement of sludge characteristics by bioflocculant addition in submerged membrane bioreactor

Lijuan Deng [a], Wenshan Guo [a], Huu Hao Ngo [a,*], Mst. Farzana Rahman Zuthi [a], Jian Zhang [b], Shuang Liang [b], Jianxin Li [c], Jie Wang [d], Xinbo Zhang [e]

[a] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology, Sydney, Broadway, NSW 2007, Australia
[b] Environmental Science and Engineering, Shandong University, Jinan 250100, China
[c] State Key Laboratory of Separation Membranes and Membrane Processes, School of Materials Science and Engineering, Tianjin Polytechnic University, Tianjin 300387, China
[d] School of Environmental and Chemical Engineering, Tianjin Polytechnic University, Tianjin 300387, China
[e] Department of Environmental and Municipal Engineering, Tianjin Key Laboratory of Aquatic Science and Technology, Tianjin Chengjian University, Jinjing Road 26, Tianjin 300384, China

ARTICLE INFO

Article history:
Received 15 August 2015
Received in revised form 12 October 2015
Accepted 14 October 2015
Available online xxxx

Keywords:
Submerged membrane bioreactor (MBR)
Bioflocculant
Membrane fouling
Cake layer
Modeling

ABSTRACT

The effectiveness of a green bioflocculant (Gemfloc®) on enhanced performance of a submerged membrane bioreactor (SMBR) was evaluated in terms of membrane fouling reduction and sludge characterization. Two MBRs were operated parallelly in this study, namely conventional MBR (CMBR) and MBR with Gemfloc® addition (MBR-G). Results showed mitigated membrane fouling through Gemfloc® addition in terms of cake layer formation and pore blocking. When compared to the CMBR, in spite of more extracellular polymeric substances (EPS) presented in activated sludge, the MBR-G demonstrated less soluble microbial products (SMP), larger sludge flocs, higher zeta potential and greater relative hydrophobicity of sludge flocs, which decreased cake layer resistance and pore blocking resistance. The reduced cake layer resistance in the MBR-G could be also ascribed to less growth of suspended biomass, lower sludge viscosity, as well as less EPS, SMP and biopolymer clusters in the cake layer. In addition, a modified resistance-in-series model was employed by considering SMP and mixed liquor suspended solids. The simulated results implied that the model could predict the influence of sludge characteristics on membrane fouling behavior of the SMBR.

1. Introduction

Membrane bioreactor (MBR) has become an innovative and promising option for treatment and reuse of municipal, industrial wastewater and landfill leachate due to its distinct advantages (i.e., high effluent quality, small footprint, low sludge production) over the conventional activated sludge process [1–3]. However, membrane fouling is a long-lasting and inevitable issue along its development, which increases the hydraulic resistance to fluid flow, resulting in less permeability for constant pressure mode or transmembrane pressure increment for constant flux mode [4]. So far, numerous studies have been devoted to the mechanism and causes of membrane fouling and control strategies. Among six principal fouling mechanisms, biofouling has attracted a significant concern as it is a major cause of fouling in MBRs. Biofouling occurs through deposition and accumulation of undesirable microorganisms and bacterial cells or flocs at membrane surface [5,6]. It can lead to cake layer formation, which has been found to be the main contributor to total membrane resistance [4,5,7]. For a given MBR, biofouling and membrane filterability as well as cake layer formation are directly associated with sludge characteristics, such as mixed liquor suspended solid (MLSS) concentration, sludge viscosity, floc size, extracellular polymeric substances (EPS), soluble microbial products (SMP) and biopolymer clusters (BPC).

Currently, much more efforts have focused on addition of flocculants (e.g. inorganic flocculants, organic synthetic polymer flocculants and naturally occurring biopolymer flocculants) to MBRs for membrane fouling alleviation by modifying the characteristics of mixed liquor and cake layer. Table 1 summarizes the main factors affecting membrane fouling reduction in batch tests and short-term dead or cross-flow filtration tests. Studies on membrane fouling mitigation in terms of adding flocculants directly into submerged MBR have been investigated. Guo et al. [8] investigated the impacts of flocculants addition on the short-term performance of a submerged MBR. They reported that more stable sludge

* Corresponding author.
E-mail address: h.ngo@uts.edu.au (H.H. Ngo).

http://dx.doi.org/10.1016/j.seppur.2015.10.034
1383-5866/© 2015 Elsevier B.V. All rights reserved.

Table 1
Flocculant addition induced membrane fouling reduction in batch tests and short-term dead end or cross-flow filtration tests.

Factors for membrane fouling reduction[a]	Flocculants[b]	References
Increasing EPS and decreasing SMP in mixed liquor	MPL30, MPE50, KD452, Poly-1 (Nalco®), Poly-2 (France Chitin®), CPE; PAM, Chitosan, Starch, CGMS, PAM–MGMS; $Al_2(SO_4)_3$, $FeCl_3$, PAC, PFS	[9,14,16,17,19,20]
Enlarging floc size	MPL30, MPE50, KD452, Poly-1 (Nalco®), Poly-2 (France Chitin®), CPE; PAM, Chitosan, Starch, CGMS, PAM–MGMS; $FeCl_3$, PAC	[9,14,16–20]
Enhancing charge neutralization	MPL30, MPE50, KD452, CPE; $Al_2(SO_4)_3$, $FeCl_3$, PAC, PFS	[14,16,17,19,20]
Increasing sludge hydrophobicity	CPE; $Al_2(SO_4)_3$, $FeCl_3$, PAC, PFS	[14,16,17]
Reducing gel layer and forming more porous and high permeable cake structures on membrane surface	CPE, Poly-1 (Nalco®); Chitosan	[16,18,20]

[a] EPS = extracellular polymeric substances, SMP = soluble microbial products.
[b] CGMS = modified corn starch, CPE = organic cationic polyelectrolyte, MGMS = modified corn starch, PAM = polyacrylamide, PAC = polyaluminium chloride, PFS = polymeric ferric sulfate.

volume indexes and higher specific oxygen uptake rates were obtained by adding natural organic flocculants such as chitosan, while inorganic flocculants (e.g. $FeCl_3$, polyaluminium chloride (PACl)) reduced SMP as well as lowered membrane fouling rates. Long-term filtration experiments were conducted by Iversen et al. [9] to investigate the effect of cationic polymers (NALCO MPE50, ADIPAP KD 452) and starch (TATE & LYLE Mylbond 168) on the performance of a pilot-scale plant. The results suggested that two cationic polymers could mitigate membrane fouling, while starch addition led to more serious fouling phenomena. Wu and Huang [10] reported that addition of polymeric ferric sulfate (PFS) could decrease the formation rate of gel layer on membrane surface due to the removal of high molecular weight organics, thereby retarding membrane fouling in long-term operation of the MBR system. Moreover, PFS also increased sludge floc size by supplying positive charges for organic particles and enhancing charge neutralization. PFS addition did not induce direct deposition of exotic Fe and severe inorganic fouling on membrane surface. For organic flocculants, submerged MBR with MPE50 addition exhibited significant improvement of the sustainable flux and membrane fouling reduction [11]. A more recent study conducted by Zhang at al. [12] mentioned that the addition of organic flocculant (MPE50) was an effective approach to membrane fouling control at high salt shock due to increase in floc size, relative hydrophobicity and bound EPS (especially proteins). Additionally, combined flocculants have also been exploited recently. A new combined inorganic–organic flocculant (CIOF) of $FeCl_3$ and MPE50 prepared by Nguyen et al. [13] was added to an aerated submerged MBR. The results indicated that the CIOF was successful in alleviating membrane fouling while maintaining stable SVI and low transmembrane pressure (TMP) development rate. Ji et al. [14] investigated the performance of modified starch (MGMS) and its polyacrylamide–starch composite flocculant (PAM–MGMS) on fouling minimization for submerged MBRs. It was shown that the flocculant had long effect duration on reducing SMP concentration, as well as prolonged the decrease in floc size due to irreversible breakage of aggregates (de-flocculation) caused by continuous shear stress in MBR and the degradation of the modified starches.

Although above-mentioned flocculants have their own merits for membrane fouling reduction, the development of a safe biodegradable natural flocculant is essential in order to have less impact on the environment and produce less ‘secondary pollutants’ through wastewater reclamation and reuse processes. Ngo and Guo [15] developed a new green bioflocculant (GBF) which was modified from a natural starch-based cationic flocculant (HYDRA Ltd., Hungary). It was found that GBF could significantly reduce membrane fouling (TMP increment of 2.5 kPa after 70 days of operation) and energy consumption (less backwash frequency) of a conventional submerged MBR. Based on this research, Gemfloc® was patented by University of Technology, Sydney (UTS). However, membrane fouling behavior related to sludge properties by Gemfloc® addition has not been well understood and explored yet. Therefore, in this study, the effectiveness of Gemfloc® on fouling reduction in the lab-scale submerged MBR under long-term sustainable operation was evaluated. Furthermore, fouling reduction through modifying the characteristics of mixed liquor as well as cake layer were also investigated in terms of SMP, EPS, BPC, zeta potential, apparent viscosity, relative hydrophobicity (RH), and floc size.

2. Materials and methods

2.1. Wastewater

Both MBRs were fed with synthetic wastewater simulating primarily treated domestic wastewater. The synthetic wastewater contains glucose, ammonium sulfate and potassium dihydrogen orthophosphate, which provides a continuous source of pollutants. Dissolved organic carbon (DOC), chemical oxygen demand (COD), ammonium nitrogen (NH_4-N), and orthophosphate of synthetic wastewater were 100–130 mg/L, 330–360 mg/L, 12–15 mg/L, and 3.3–3.5 mg/L, respectively. Sodium hydrogen carbonate or sulfuric acid was employed to adjust pH to 7.

2.2. Experimental setup and operating conditions

Two submerged MBRs with identical effective working volumes of 8 L, namely MBR-G (MBR with Gemfloc® addition) and CMBR (control MBR), were operated in parallel. A hollow fiber membrane module (polyvinylidene fluoride (PVDF), pore size 0.2 μm, surface area 0.1 m^2) was submerged into each MBR. Activated sludge collected from a local Wastewater Treatment Plant was added into both MBRs, and synthetic wastewater was used for acclimatization afterward. During the operation period, no sludge withdrawal was performed (infinite SRT) except sampling activated sludge for analysis. Gemfloc® was supplied to the MBR-G at a dosage of 1 g/day (net weight). A feeding pump consistently delivered synthetic wastewater into both MBRs. Permeate through the submerged membrane module was withdrawn continuously and maintained at a constant flux of 12 L/m^2 h using a suction pump, corresponding to a HRT of 6.67 h. Membrane fouling was monitored by measuring TMP using a pressure gauge. 9–10 L/min air was supplied using a soaker hose air diffuser at the bottom of the reactor. During the experiment, the membrane was only backwashed two times/day with duration of 2 min/time by pumping a fraction of permeate back through the membrane module at a flow rate of 36 L/m^2 h. When TMP reached 35 kPa, the filtration experiments were stopped, and the membrane modules were taken out from the MBRs thereafter. Chemical cleaning was conducted by immersing each tested membrane in 0.5% citric acid for 6 h, followed by 0.4% sodium hydroxide for 6 h and 0.8% sodium hypochlorite for 6 h.

Please cite this article in press as: L. Deng et al., Membrane fouling reduction and improvement of sludge characteristics by bioflocculant addition in submerged membrane bioreactor, Separ. Purif. Technol. (2015), http://dx.doi.org/10.1016/j.seppur.2015.10.034