Membrane fouling control and enhanced phosphorus removal in an aerated submerged membrane bioreactor using modified green bioflocculant

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Abstract

This study aims at developing a modified green bioflocculant (GBF) for membrane fouling control and enhanced phosphorus in a conventional aerated submerged membrane bioreactor (SMBR) to treat a high strength domestic wastewater (primary sewage treated effluent) for reuse. The GBF was evaluated based on long-term operation of a lab-scale submerged membrane bioreactor (SMBR). The results showed that SMBR system could achieve nearly zero membrane fouling at a very low dose of GBF addition (500 mg/day) with less backwash frequency (2 times/day with 2-minute duration). The transmembrane pressure (TMP) only increased by 2.5 kPa after 70 days of operation. The SMBR could also remove more than 95% and 99.5% dissolved organic carbon (DOC) and total phosphorus (T-P) respectively. From the respiration tests, it was evident that GBF not only had no negative impact on biomass but also led to high OUR (>30 mg O_2/L.h) and stable SOUR. The results also indicated that GBF had no effect on nitrogen removal and nitrification process.

Keywords: Bioflocculant, Submerged membrane bioreactor; Membrane fouling control; Organic and nutrient removals

1. Introduction

Membrane bioreactors (MBRs) are ready to advance water sustainability. The technology encourages wastewater reuse and provides safe water to the community (DiGiano, 2004). 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 unavoidable challenge, which increases operational cost and shortens membrane life (Yang et al., 2006).

The common strategies for fouling control include optimizing the hydrodynamic conditions in bioreactor, operating membrane system below critical flux, pre-treating the feedwater, or conducting air scour, membrane backwashing and cleaning (Tchobanoglous et al., 2003). The innovative methods involve membrane coating (Bae et al., 2006), the addition of porous carriers for attached growth (Ngo et al., 2008), flocculation of the activated sludge by adding additives (Song et al., 2008), and modification of the suspension by adsorption (Guo et al., 2008). Recently, various chemicals including synthetic or natural polymers, metal salts, resins, granular or power activated carbon have been tested for filterability and fouling reduction in MBR mixed liquors through batch test and dead-end filtration process (Koseoglu et al., 2008). However, besides the membrane fouling control, the aspects (such as toxicity and biodegradability) of the chemicals addition to real MBR system and their effects on organic and nutrient removal need to be documented by further investigation.

Flocculating agents are generally categorized into inorganic flocculants, organic synthetic polymer flocculants and naturally occurring bio-polymer flocculants. Although the organic synthetic polymer flocculants have been used together with inorganic flocculants because of low cost, easy handling and high efficiency, some of them can give rise to environmental and health risk during the degradation (Shih et al., 2001). In addition, nonbiodegradable property presents another major drawback of polymeric flocculant, which will lead to "secondary pollution" for environment. Hence, the safe biodegradable natural flocculant which has less ecological impact becomes more attractive in wastewater reclamation and reuse.

In this study, a modified green bioflocculant (GBF) was explored and tested in a lab-scale SMBR. The performance of SMBR was assessed in terms of removal efficiencies of DOC, T-P and T-N, as well as membrane fouling based TMP development and SVI. OUR and SOUR was used to assess the impact of GBF on biomass activity or oxygen transfer.

2. Materials 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 DOC of 145-160 mg/L, T-N of 16-19 mg/L and T-P of 3.6-3.9 mg/L. $NaHCO_3$ or H_2SO_4 were used to adjust pH in SMBR reactor to a constant value of 7.

2.2. Green bioflocculant

A new green bioflocculant (GBF) has been developed and modified from a natural starch-based cationic flocculant (HYDRA Ltd., Hungary). GBF offers inherent advantages over inorganic and synthetic polymer flocculants such as being derived from a renewable source of raw materials, very low cost, and easily degradable in the environment after use. In SMBR, microorganisms also can utilize the carbon source from flocculated bioflocs for microbial activity. The trial dose of the GBF in this study was 1000 mg/day at the first 10 days and 500 mg/day afterwards.

2.3. Submerged membrane bioreactor (SMBR) set-up

A polyethylene hollow fiber membrane module was used with the pore size of 0.1 μm and surface area of 0.195 m^2 (Mitsubishi-Rayon, Japan). The effective volume of the bioreactor was 10 L and the permeate flux was maintain at 10 $L/m^2.h$. Filtrate backwash was conducted two times per day for 2 minutes duration at a backwash rate of 30 $L/m^2.h$. A pressure gauge was used to measure the TMP and a soaker hose air diffuser was used to maintain the air flow rate. The SMBR was filled with sludge from local Wastewater Treatment Plant and acclimatized to synthetic wastewater. The initial mixed liquor suspended solids (MLSS) and biomass (mixed liquor volatile suspended solids, MLVSS) concentration were 5 g/L and 4.4 g/L respectively.

3. Results and Discussion

3.1. Organic and nutrient removals

The operation of SMBR was divided into three phase, Phase I (biomass growth phase), Phase II (phosphorus removal recovery phase), and Phase III (steady phase).

The results of DOC, NH_4-N, T-P and T-P removals are shown in Figure 1. During Phase I (1-36 days run), the SMBR was operated with complete sludge retention. The biomass mass increased gradually from 4.4 to 14.2 g/L with high DOC and T-P removal efficiency (>95% and >99.5% respectively). However, as the cell growth associated mass balance of phosphorus decreased from 0.81 to 0.27 mg $P/g_{\text{biomass synthesis}}$, the phosphorus removal broke down after 36-day run. In Phase II (37-54 days run), the system had the highest MLVSS concentration of 15.4 g/L on 40^{th} day, but only 91.4% of T-P was eliminated. Therefore, sludge was withdrawn from the system for next 13 days (up to 53^{th} day) and the MLSS dropped to 10 g/L. On the 54^{th} day, 4 $g/L_{\text{(reactor volume)}}$ fresh sludge was added into the reactor, which gained the MLSS of 14 g/L and led to high T-P removal again (99.7%). In spite of changing mixed liquor conditions, the organic removal of the system was not affected and the removal still retained as high as before. Starting from Phase III (55-70 days run), sludge has been wasting from the system according to the biomass growth, which resulted in a sludge retention time (SRT) of 40 days. The system has been running steadily with consistently high DOC and T-P removal (>96.5% and >99.7% respectively) and more finding will be reported in future full research paper.

Compared with DOC and T-P removal, the system could not achieve high nitrogen removal. At the first 20 days, the bioreactor was supplied with 10 L/min air. With the biomass growth, nitrification reduced rapidly due to dissolved oxygen (DO) decreasing in suspension. Thus, the aeration rate was adjusted up to 12 L/min from 20th day in order to restore nitrification rate. After 30 days, the nitrification rate could maintain constantly around 20-30 mg NH_4-N/L.h with ammonia removal of 80-90%.

Nevertheless, the system had moderate T-N removal which was kept at 40-50 % up to 70-day operation.

Fig. 1. DOC, NH_4-N, T-N and T-P profiles of SMBR system with GBF addition (influent DOC = 145-160 mg/L; T-N = 16-19 mg/L, T-P = 3.6-3.9 mg/L, filtration rate = 10 L/m^2.h; backwash rate = 30 L/m^2.h; backwash = 2 times per day for 2 minutes duration; HRT = 5.1 hours)

3.2. Respiration test and SOUR

Respiration tests were conducted using SI 5300 Biological Oxygen Monitor for testing the impact of GBF on microbial activity or oxygen transfer. Mixed liquor has been taken from the bioreactor periodically in order to measure DO consumption rate, oxygen uptake rate (OUR) and specific oxygen uptake rate (SOUR). As shown in Table 1, the initial DO consumption was only 48% in accordance with low OUR and SOUR (15.21 mg O_2/L.h and 3.5 mg O_2/gMLVSS.h respectively). With GBF addition, the DO consumption and OUR increased dramatically and could keep at high consumption level during the Phase I and Phase III. On the other hand, the values of SOUR were dropped associated with biomass growth in Phase I and then kept constant (>2.6 O_2/gMLVSS.h) in Phase III. The experimental data elucidated that GBF is friendly to biomass activity and non-biotoxic to biomass.

Table 1
Respiration tests for DO consumption, OUR and SOUR

3.3. SVI and membrane fouling

In this study, sludge volume index and TMP were investigated as indicators of membrane fouling. Compared to SMBR with GBF addition, SMBR without applying bioflocculant was carried out at the same operation conditions. Within 6 days operation, the SVI of mixed liquor retained around 50 mL/g and TMP increased up to 30.2 kPa. In contrast, SMBR with GBF addition resulted in lower SVI (22.6 mL/g) on 6th day, which indicates the predominance of flocs in sludge suspension. In addition, the system exhibited excellent fouling control through TMP development. The TMP of the system only increased from 3.5 to 6 kPa after 70 days operation without any cleaning processes except filtrate backwash two times per day with 2 minutes duration. The results clarified that GBF could significantly reduce membrane through modifying the mixed characteristics.

Fig. 2. SVI and TMP development of SMBR system with GBF addition (influent DOC = 145-160 mg/L; T-N = 16-19 mg/L, T-P = 3.6-3.9 mg/L, filtration rate = 10 L/m^2.h; backwash rate = 30 L/m^2.h; backwash = 2 times per day for 2 minutes duration; HRT = 5.1 hours)

4. Conclusions

The conventional aerated SMBR with low dose GBF addition led to high organic and T-P removals (>95% and >99.5% respectively). The most important merits of GBF could apparently be seen through its ability to significantly reduce membrane fouling (TMP development of 2.5 kPa after 70 days of operation) and energy consumption (less backwash frequency). GBF could enhance microbial activity of activated sludge with high DO consumption, high OUR and stable SOUR, suggesting GBF is applicable for biological treatment. As expected, GBF was not able to improve nitrogen removal in aerated SMBR (e.g. T-N and ammonia removal of lees than 50% and 90% respectively). Even though this short communication has convinced well the success of GFC, further study on the better way to make GBF sustainable during biological treatment and the optimization of the GBF-SMBR system is necessary.

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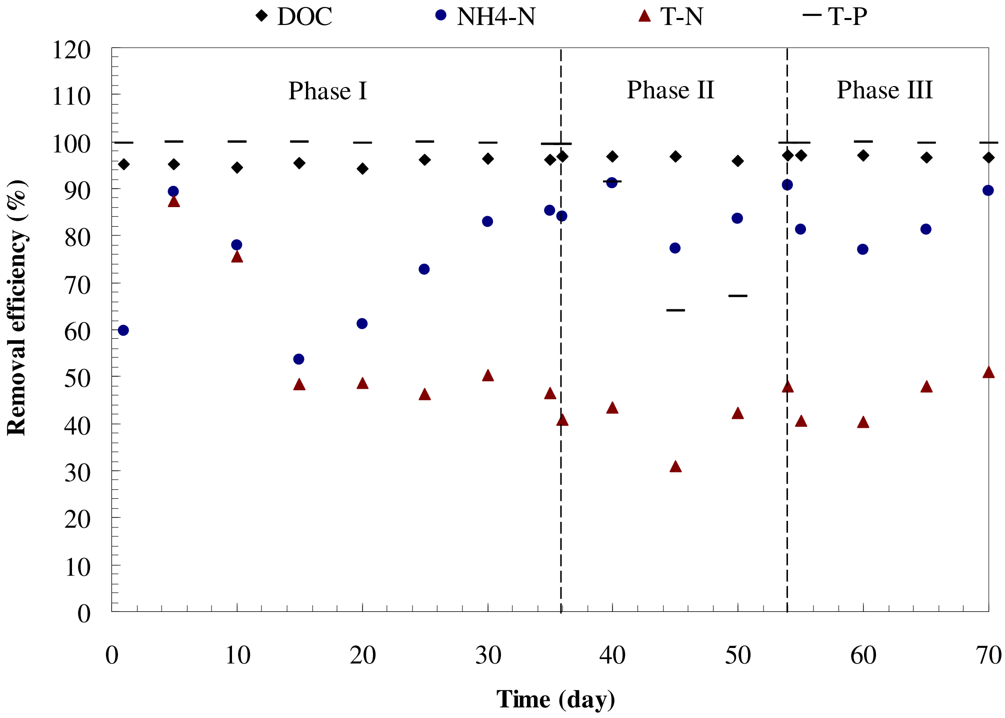
Table 1
Respiration tests for DO consumption, OUR and SOUR

Time (Day)	DO consumption for 16 mins (%)	OUR (mg O_2/L.h)	SOUR (mg O_2/gMLVSS.h)
0	48.0	15.21	3.50
5	99.8	31.62	4.90
10	98.7	31.27	4.67
20	97.3	30.83	3.19
30	91.9	29.12	2.37
40	96.4	30.55	1.98
50	87.3	27.66	2.13
60	98.1	31.08	2.74
70	98.4	31.18	2.62



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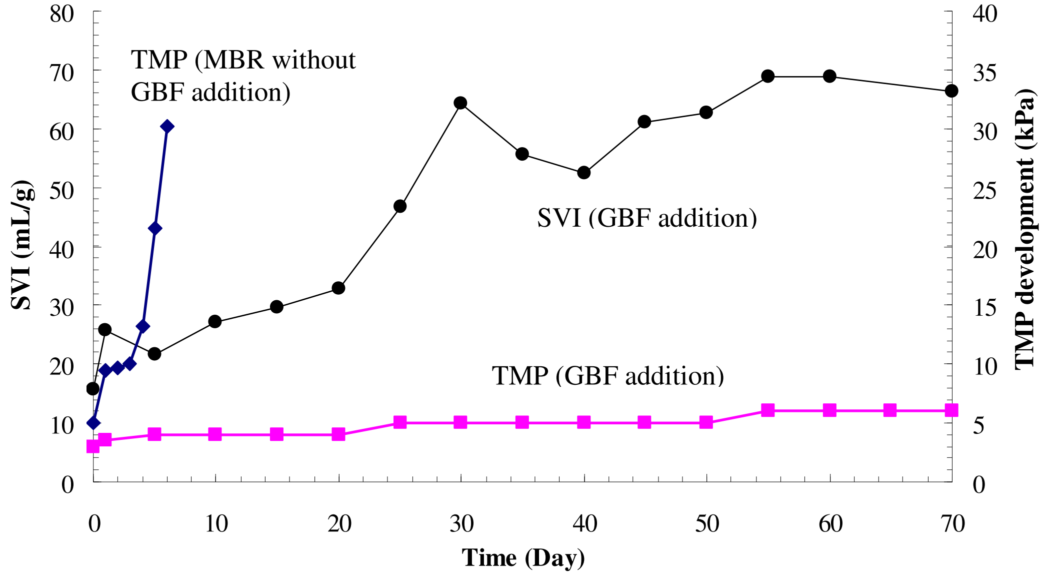

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