Enhanced Biological Nutrient Removal by a Single Stage Sponge-Submerged Membrane Bioreactor in Wastewater Treatment for Reuse

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Annotation
Sponges not only can reduce membrane fouling and maintain a balance of suspended-attached microorganisms in membrane bioreactor (MBR), but also enhance dissolved organic matter and nutrient removal. This study investigated the performance of three different sizes of sponge (S_{28-30}/45R, S_{28-30}/60R and S_{28-30}/90R) associated with continuous aerated submerged-MBR. A laboratory-scale single stage sponge-submerged MBR showed high performance for removing dissolve organic matter (>96%) and PO_4-P (>98.8), while coarse sponge, such as S_{28-30}/45R, S_{28-30}/60R could achieve more than 99% removal of NH_4-N. When sponge was mixed with the ratio S_{28-30}/45R:S_{28-30}/60R:S_{28-30}/90R of 1:1:1 and in conjunction with two kinds of membranes (0.1 µm hollow fiber and 2 µm nonwoven), the sponge MBR system has proved its generic merits of superior treated effluent quality and less membrane fouling. The NH_4-N and PO_4-P removal were found excellent, which were more than 99.8% and over 99% respectively. Molecular weight distribution also indicated that major fractions of organic matter could be successfully removed by sponge MBR.

Keywords
Biological nutrient removal; fouling control; hollow fiber membrane; nonwoven membrane; sponge submerged membrane bioreactor; wastewater treatment for reuse

INTRODUCTION

Nowadays, nutrients removal has attracted great attention in wastewater treatment for reuse. A number of biological processes, which apply various combinations of anaerobic, anoxic and aerobic or multiple compartments, have been developed to remove nutrients [1]. In particular, there is a growing interest in using low-pressure membrane bioreactor (MBR) coupled with microfiltration (MF) or ultrafiltration (UF) for simultaneous organic and nutrient removal.

MBR is the key element in wastewater treatment for reuse and ready to advance water sustainability. The main feature of MBR is a compact treatment technology which has several advantages over conventional biological systems, such as high effluent quality, excellent microbial separation ability, absolute control of sludge and hydraulic retention times (SRTs and HRTs), high biomass content, low-rate biomass production, small footprint and flexibility in operation [2]. In MBR applications, biological nitrogen removal can be achieved by two types of MBR systems: the single-reactor-type MBR and the modified Luzack-Ettinger (MLE)-type MBR. The single-reactor-type MBR introduced the alternating aerobic and anoxic conditions to a submerged MBR by intermittent aeration in the aerobic tank. However, filtration operation in this type of MBR is limited during only the aeration period due to minimize fouling of the membrane. Therefore, the MLE-type MBR (a continuous aerated MBR together with a separated anoxic tank) was developed for continuous filtration operation, in which the mixed liquor is recycled continuously from aerobic zone to anoxic zone [3, 4]. Although these MBRs have shown improved nitrogen removal with almost complete nitrification, phosphorus has not been removed significantly through these systems. Thus, some modified MBR systems have been developed and evaluated to enhance phosphorus removal, such as vertical submerged MBR with anoxic and aerobic zones (78% removal) [1], alternating of anoxic and anaerobic MBR process (AAAM, 94.1% removal) [4], sequencing anoxic/anaerobic MBR (SAM, 93% removal) [5], sequencing batch membrane bioreactor (SBMBR, 90% removal) [6], anoxic/aerobic MBR with addition of clinoptilolite powder followed by rapid coagulation process (92-96%) [7], nevertheless, the higher removal efficiencies were hardly achieved.

To solve this problem, attached growth bioreactors using specific material bioreactors have been used to modified biological processes. Sponge has been considered as an ideal attached growth media because it can act as a mobile carrier for active biomass, reduce the cake layers formed on the surface of membrane and retain microorganisms by incorporating a hybrid growth system (both their attached and suspended growth) [8, 9, 10]. Deguchi and Kashiwaya [11] have reported that the nitrification and denitrification rate coefficients of a sponge suspended biological growth reactor were 1.5 and 1.6 times respectively higher than the coefficients of conventional activated sludge reactor.

In this study, an innovative of sponge-submerged membrane bioreactor (SSMBR) has been developed at UTS for improving simultaneous phosphorus and nitrogen removal, alleviating membrane fouling and enhancing permeate flux. The main objective of this study is to evaluate the significance and practical use of a novel single stage SSMBR for wastewater treatment and reuse. The performance of SSMBR was assessed in terms of the removal efficiencies of ammonium nitrogen (NH_4-N), orthophosphate (PO_4-P), dissolved organic carbon (DOC), chemical oxygen demand (COD) and transmembrane pressure (TMP).

METHODS

Wastewater

The experiments were conducted using a synthetic wastewater containing glucose, ammonium sulphate, potassium dihydrogen phosphate and trace nutrients [12]. It was used to simulate high strength domestic wastewater (just after primary treatment process). The synthetic wastewater has DOC of 130-145 mg/L, COD of 340-390 mg/L, NH_4-N of 15-20 mg/L and PO_4-P of 3.5-4.0 mg/L. $NaHCO_3$ or H_2SO_4 were used to adjust pH to 7.

Sponge

Different pore sizes of reticulated polyester urethane sponge (S_{28-30}/45R, S_{28-30}/60R and S_{28-30}/90R) from Joyce Foam Products, Australia, were used in SSMBR system. The dimensions of the sponge cubes are 10×10×10 mm. The predetermined volume of acclimatized sponge cubes were added directly into the SSMBR reactor before the experiments.

Sponge-submerged membrane bioreactor (SSMBR) set-up

The schematic diagram of the SSMBR is shown in Figure 1. 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 TMP and a soaker hose air diffuser was used to maintain a high air flow rate (12 L/min). After each experiment, membrane was cleaned by chemical cleaning method and filtrate backwash was adopted for physical cleaning of the membrane during the operation. The SSMBR was filled with sludge from local Wastewater Treatment Plant and acclimatized to synthetic wastewater. In all cases, the systems were operated at activated sludge mixed liquor suspended solids (MLSS) of 15 g/L. Sponge volume fraction of 10% (bioreactor volume) was employed in this study, which was determined according to previous sustainable flux experiments [14].

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 [13]. For measuring MLSS and biomass, three samples were taken each time and the average values were then calculated. NH_4-N and PO_4-P were measured by photometric method called Spectroquant® Cell Test (NOVA 60, Merck). High pressure size exclusion chromatography (HPSEC, Shimadze, Corp., Japan) with a SEC column (Protein-pak 125, Waters, Milford, USA) was used to determine the Molecular weight (MW) distributions of organics. The equipment was calibrated using the standards of MW of various polystyrene sulphonates (PSS: 210, 1800, 4600, 8000 and 18000).

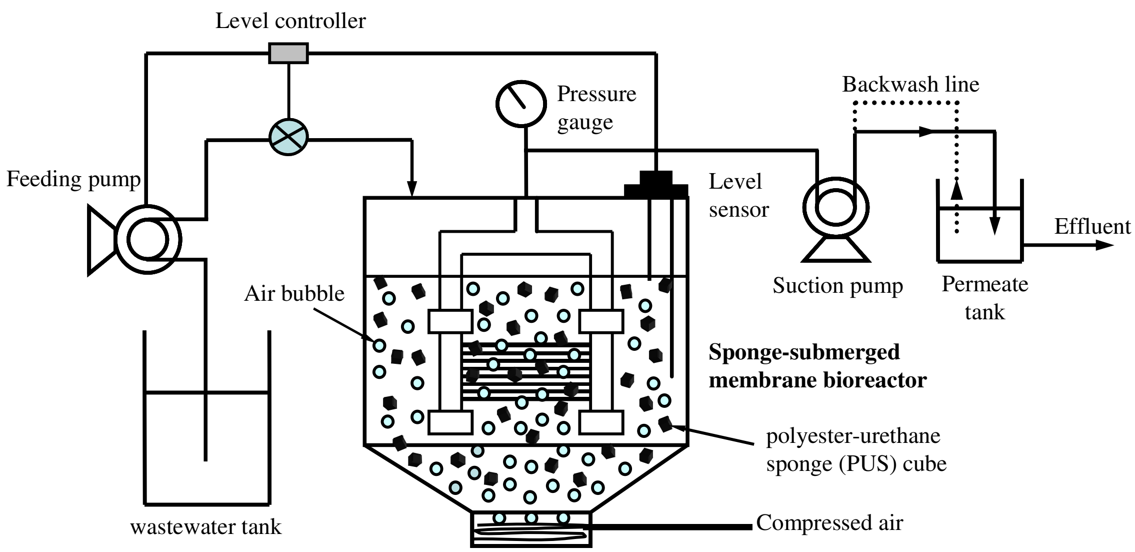


Figure 1: Experimental set-up of SSMBR

RESULTS AND DISCUSSION

The performance of sponges with different pore sizes

After acclimatizing of sponge to synthetic wastewater, the biomass attached on the different pore sizes of sponge cubes, namely S_{28-30}/45R, S_{28-30}/60R and S_{28-30}/90R (density of 28-30 kg/m^3 with 45 cells per 25 mm, 60 cells per 25 mm, 90 cells per 25 mm, respectively), were measured. Three samples were taken for each size and the average values were then calculated. The results indicated that sponge is an ideal attached growth media for MBR system as an active mobile carrier for active biomass. S_{28-30}/90R and S_{28-30}/60R had the higher biomass of 1.37 $g_{biomass}/g_{sponge}$ and 1.35 $g_{biomass}/g_{sponge}$ respectively, while S_{28-30}/45R only had 1.09 $g_{biomass}/g_{sponge}$ of biomass. The performance of three different sponges was investigated through a submerged hollow fiber MBR (membrane pore size of 0.1 μm and surface area of 0.1 m^2, Mitsubishi-Rayon, Japan) operating at a constant permeate flux of 20 L/m^2.h for 15 days. The effective volume of the bioreactor was 6 L and the MLSS was maintained at 15 g/L. The results are summarized in Table 1. In spite of different pore sizes, all of the sponges could help in achieving excellent phosphorus removal, which resulted in the PO_4-P of effluent less than 0.05 mg/L. Meanwhile, S_{28-30}/45R and S_{28-30}/60R could lead to better NH_4-N removal (over 99%) when compared to that of S_{28-30}/90R.

Table 1. The effluent quality of S_{28-30}/45R-SMBR, S_{28-30}/60R-SMBR and S_{28-30}/90R-SMBR (Influent DOC =130-145 mg/L; NH_4-N = 15-20 mg/L; PO_4-P = 3.5-4.0 mg/L; bioreactor MLSS = 15 g/L; HRT = 3 hours; SRT = 35 days; backwash = one minute every hour at 30 L/m^2.h; aeration rate = 12 L/min)

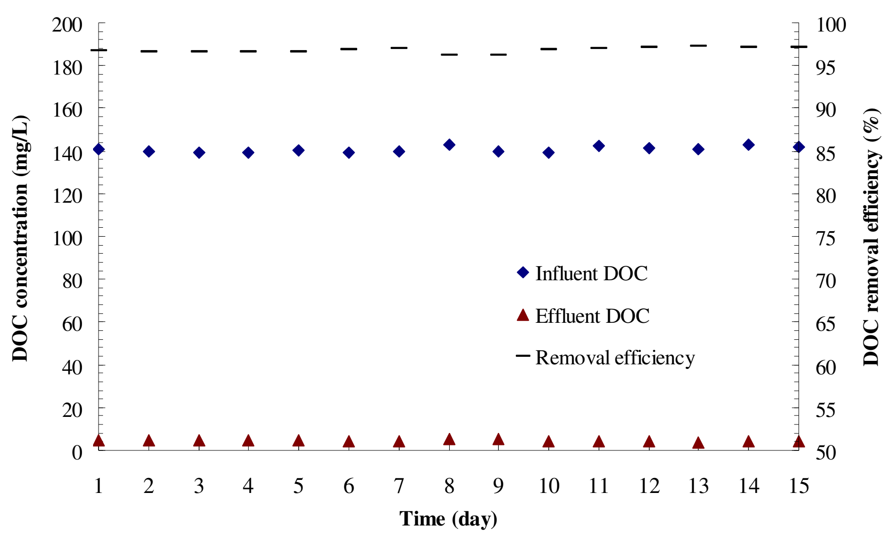
System	DOC		NH_4-N		PO_4-P	
	Effluent (mg/L)	Removal efficiency (%)	Effluent (mg/L)	Removal efficiency (%)	Effluent (mg/L)	Removal efficiency (%)
S_{28-30}/45R-SMBR	<5.0	>96.5	<0.05	>99.4	<0.04	>98.9
S_{28-30}/60R-SMBR	<5.1	>96.3	<0.05	>99.4	<0.04	>98.9
S_{28-30}/90R-SMBR	<5.4	>96.1	<1.65	>90.5	<0.04	>98.8

SSMBR performance with mixed sizes of sponge

According to the different capacity to remove ammonium nitrogen and phosphorus, three configurations of sponge cubes were mixed with volume ratio of 1:1:1. The mixed-SSMBR was then evaluated through two membranes (0.1 µm hollow fiber membrane and 2 µm nonwoven membrane), which were operated under the high filtration flux of 30 L/m^2.h.

Mixed-SSMBR with hollow fiber membrane

The hollow fiber membrane used has a total surface area of 0.195 m^2 (Mitsubishi-Rayon, Japan) and the effective volume of the bioreactor was 8 L. Figure 2 illustrates the influent quality, effluent quality and removal efficiency of the mixed-SSMBR during 15 days operation. The system resulted in superior recycled water quality. The organic removal was stable and excellent (DOC removal >96% and COD removal > 97%) with low TMP development of 23 kPa (Figure 3). The complete PO_4-P removal (effluent PO_4-P<0.01 mg/L) and high performance of nitrification (effluent NH_4-N < 0.04 mg/L) in this system also implied that enhanced biological phosphorus release as well as excess phosphorus uptake could be achieved by the anoxic/anaerobic condition inside the sponge cubes. In addition, the biomass attached on sponge and in mixed liquid has contributed partially to remove phosphorus biologically because P is one of the essentials for biomass growth [4].



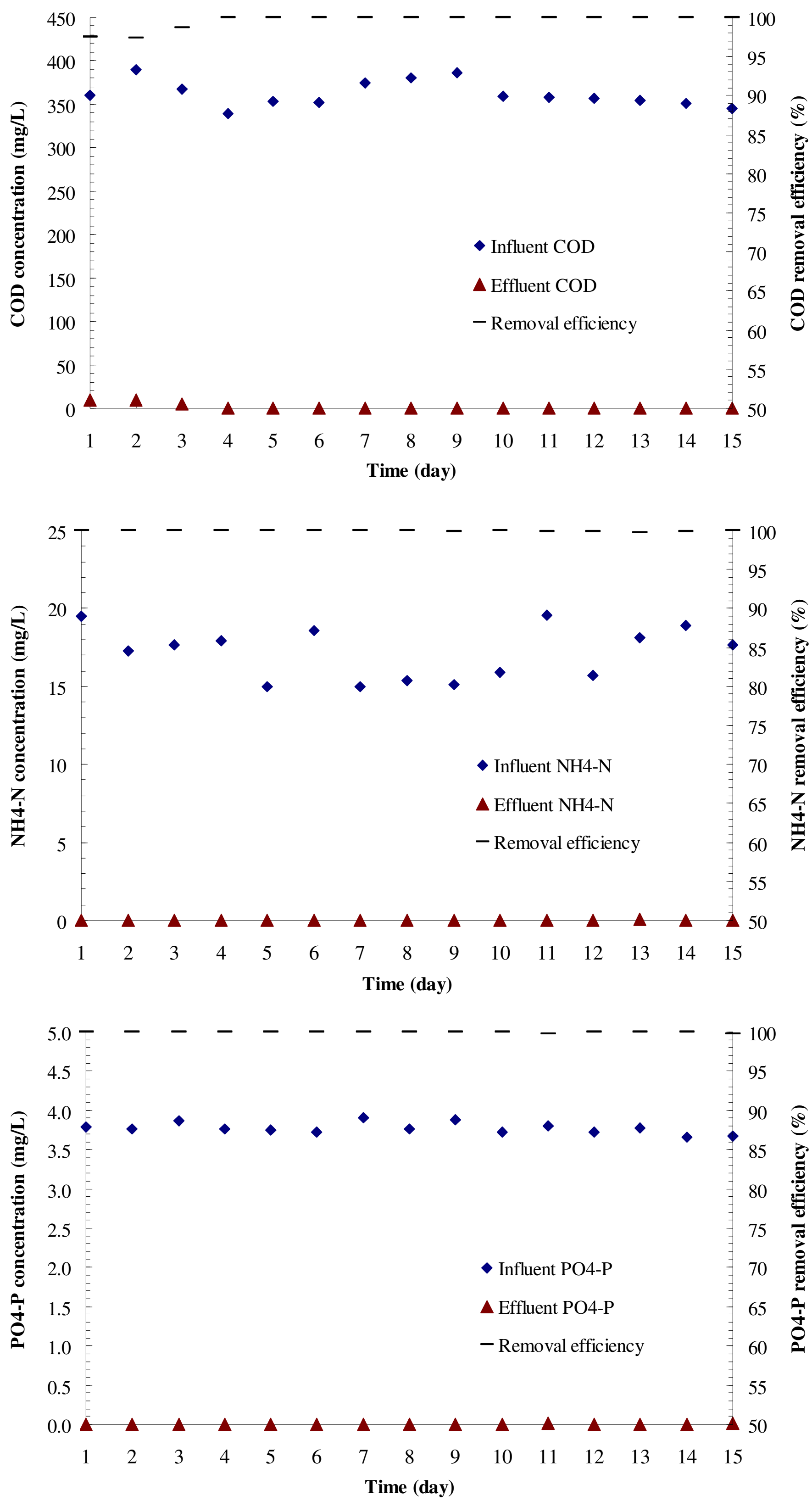


Figure 2: Overall treatment performance of mixed-SSMBR with 0.1 µm hollow fiber membrane (filtration flux = 30 $L/m^2.h$; backwash rate = 30 $L/m^2.h$; backwash = 1 minute every half an hour; MLSS = 15 g/L; HRT = 1.4 hours; SRT = 30 days)

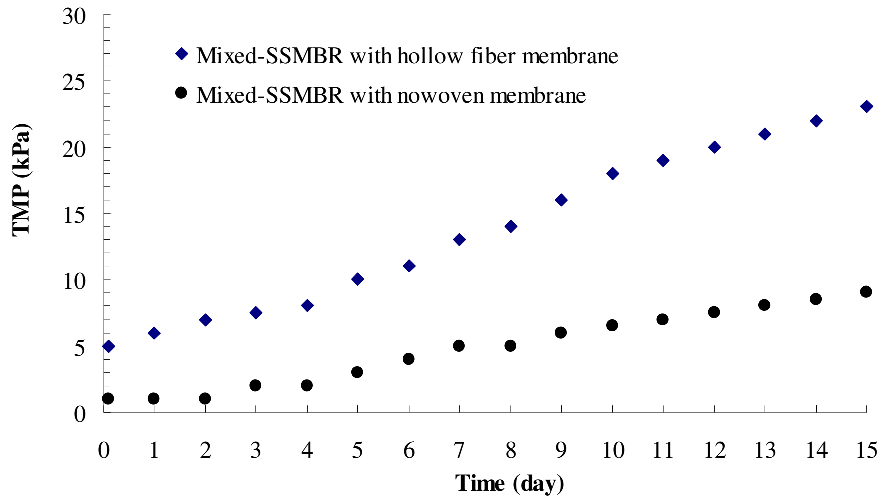


Figure 3: TMP development in mixed-SSMBR system with two different membranes

Mixed-size of sponge showed the excellent ability to reduce membrane fouling with low TMP development. Thus, MWD measurement was carried out to show which MW range of organic matter could be removed by the Mixed-SSMBR (Figure 4). The synthetic wastewater consists of dissolved organic matters with the MW fractions of 1530, 730, 390 and 90 Daltons. Both of the Mixed-SSMBRs could remove the MW fractions (1530, 390 and 90 Daltons) completely from the wastewater. However, a small portion of low MW molecules (730 Daltons) still remained in the effluent of both systems. Mixed-SSMBR with hollow fiber membrane presented better results compared to the MW removal of Mixed-SSMBR with nonwoven membrane, and this is mainly due to the bigger pore size of nonwoven membrane. The MWD results could correspond to the DOC and COD removals of the two mixed-SSMBRs.

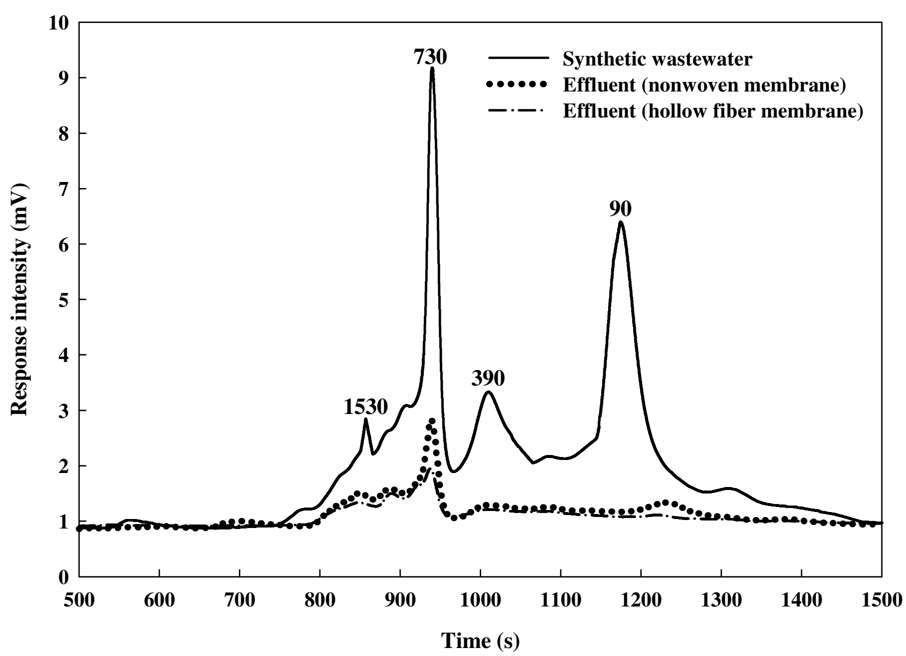


Figure 4: The MWD of SSMBR system with different membranes
(filtration flux = 30 L/m^2.h; backwash rate = 30 L/m^2.h; MLSS= 15 g/L)

Mixed-SSMBR with nonwoven membrane

Nonwoven (NW) fabric materials are extensively used of the removal of particles larger than 1μm in decontamination process, especially for airfiltration and sludge thickening. Recent research has considered nonwoven as a substitute for microporous membrane in MBR application because it has the merits of cheaper capital cost compared to membrane, high permeated flux and low filtration resistance [15]. In this study, a flat sheet nonwoven membrane (KNH Enterprise Co. Ltd., Taiwan) was in conjunction with mixed-sponge to treat the synthetic wastewater. The total surface area of nonwoven membrane was 0.04 m^2 and the bioreactor volume was 8 L. The removal efficiencies of DOC, COD, NH_4-N and PO_4-P are shown in Figure 5. Although the pore size of nonwoven membrane is much bigger than hollow fiber membrane, the results indicate that mixed-SSMBR with nonwoven membrane could exhibit high treated effluent quality (DOC removal >95%, COD removal >94%, PO_4-P removal >99%), especially, the absolute 100% nitrification gave nonwoven another credit for ammonium nitrogen removal. As can be seen in Figure 3, the development of TMP was lower than that of hollow fiber membrane (e.g. 9 kPa compared to 23 kPa over 15 days of operation).

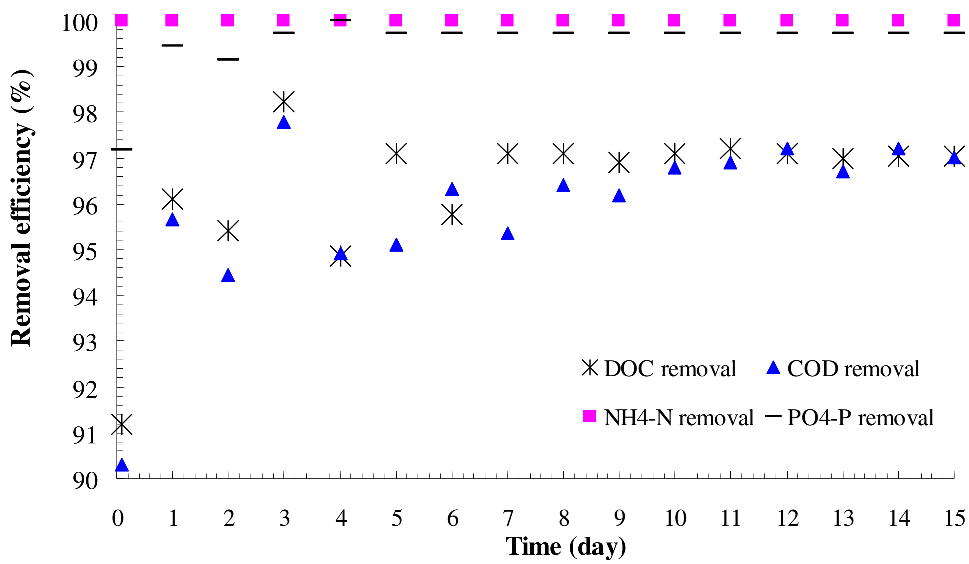


Figure 5: The performance of mixed-SSMBR with 2 μm nonwoven membrane (filtration flux = 30 $L/m^2.h$; backwash rate = 30 $L/m^2.h$; backwash = 1 minute every hour; MLSS = 15 g/L; HRT = 6.7 hours; SRT = 60 day)

CONCLUSIONS

Three different sizes of polyester urethane sponge (S_{28-30}/45R, S_{28-30}/60R and S_{28-30}/90R) were evaluated through the performance in SMBR in terms of the removal efficiencies of NH_4-N, PO_4-P DOC, COD and biomass concentration. The results indicate that the denser is the sponge, the more biomass can grow on the sponge. All of the sponges showed excellent DOC, PO_4-P removal ability whereas S_{28-30}/45R and S_{28-30}/60R could eliminate more than 99% NH_4-N in wastewater. When mixing sponge in conjunction with hollow fiber MBR and nonwoven MBR, mixed sponge with the ratio S_{28-30}/45R:S_{28-30}/60R:S_{28-30}/90R of 1:1:1 exhibited superior NH_4-N removal (over 99.8%) associated with over 99% of PO_4-P removal and low TMP development during 15 days of operation. Two mixed sponge-SMBRs could removal the major MW fractions (90-1530 Daltons) presented in the synthetic wastewater.

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