A new sponge tray bioreactor in primary treated sewage effluent treatment

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Abstract

The new attached growth sponge tray bioreactor (STB) was evaluated at different operating conditions for removing organics and nutrients from primary treated sewage effluent. This STB was also assessed when using as a pre-treatment prior to micro-filtration (MF) for reducing membrane fouling. At a short hydraulic retention time (HRT) of 40 minutes, the STB could remove up to 92% of DOC and 40-56% of T-N and T-P at an organic loading rate (OLR) of 2.4 kg COD/m^3 sponge.day. This OLR is the best for the STB as compared to the OLRs of 0.6, 1.2 and 3.6 kg COD/m^3 sponge.day. At 28 mL/min of flow velocity (FV), STB achieved the highest efficiencies with 92% of DOC, 87.4% of T-P, and 54.8% of T-N removal. Finally, at the optimal OLR and FV, the STB could remove almost 90% of organic and nutrient, significantly reduce membrane fouling with HRT of only 120 min.

Keywords: Sponge tray bioreactor, organic and nutrient removal, pre-treatment for micro-filtration, primary treated sewage effluent.

1. Introduction

Biological treatment of organic and nutrient polluted wastewaters is an accepted process for water purification and water reuse. The popular biological methods include activated sludge process or treatment using wetland; however, these approaches often demand a large land area due to the requirement for high hydraulic retention time (HRT). For example, a conventional activated system requires 4-8 h, while an extended aeration process needs 24-40 h of retention time. In addition, high input energy for aeration, sludge management difficulties, are also the obstacles. To overcome most of these problems, a simple, compact, and efficient attached growth reactor has been evaluated.

In order to select an appropriate support media, the rapid and stable attachment of microorganism to a porous media surface is one of the most important criteria (Chae et al., 2008). Sponge has been considered as an ideal attached growth media because it can act as a mobile carrier for active biomass. Polyurethane sponge and some of the other porous media have been successfully applied for attached growth systems. Ngo et al. (2006) developed the first generation of attached growth sponge bioreactor (AGSB) at the University of Technology, Sydney. This study considered the detailed design of AGSB including sponge type, sponge shape, and inclination slope of the sponge tray. The results concluded that a sponge type of 70-90 cells/in^2; triangular shape of sponge; and designated slope of sponge tray of 10 degrees led to the highest pollutant removal.

In addition, the sponge bioreactor could be applied effectively in an economical manner to produce a high quality effluent that meets the standards of wide range of water reuse (e.g. NH_4-N = 0.04 mg/L, PO_4-P <0.01 mg/L and COD < 1 mg/L). Nguyen et al. (2010) studied the effect of polyurethane sponge size and type on the performance of an up-flow sponge bioreactor using different sponge cube sizes (1×1×1 cm, 2×2×2 cm and 3×3×3 cm) and types of sponge ($S_{28\text{-}30}$/45R, $S_{28\text{-}30}$/60R, $S_{28\text{-}30}$/80R, $S_{28\text{-}30}$/90R). The results indicated that under aerobic condition the system could remove more than 95% of DOC, 90% of T-P and 65% of T-N. The simple-designed system was efficient in pollutant removal even with low HRT of only 2.62h. A combined up-flow anaerobic sludge blanket (UASB) down-flow hanging sponge (DHS) system for sewage treatment was successfully evaluated (Tawfik et al., 2006). The study indicated that a combined UASB-DHS system appears an appropriate solution as a compact, low cost, and low energy requirement for sewage treatment. In addition, the system could achieve relatively high removal efficiency of 90% COD, 98% BOD_5, 86% NH_4-N and 99.92% of coliform. Another study on DHS was also conducted in laboratory scale (Chuang et al., 2007). The results showed a high ammonium removal rate at a maximum of 1.46 kg NH_4^+-N m^3/day, even in limited oxygen concentration. It was also observed that the partial nitrification was satisfactorily accomplished under limited oxygen condition at around 0.5% in the gas phase (0.2 mg DO/L). Yang et al. (2008) used a reticulated polyurethane sponge material as a support media in a single layer rotating drum biofilter (RDB), a multi-layer RDB, and a hybrid RDB for removal of VOCs. The results of this study indicated that VOCs removal efficiency of the systems was over 50%. Xing et al. (1995) investigated the feasibility of the treatment of artificial sewage in two fluidised bed bioreactor (FBBR) employing polyurethane cubes as a carrier media for enhancing simultaneous nitrification-denitrification process. The study concluded that at HRT of 4h the system could eliminate of 40% total nitrogen. The advantages of attached growth system using sponge over the conventional activated sludge were also reported (Deguchi and Kashiwaya., 1994). The results showed 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 activated sludge system.

The objectives of this study are to evaluate the optimal conditions (OLR, FV and HRT) of STB on: (i) the removal efficiencies of organics (chemical oxygen demand COD and total organic carbon TOC) and nutrients (total nitrogen TN and total phosphorus TP) and (ii) quality of the treated wastewater as pre-treatment for micro-filtration.

2. Materials and methods

2.1. Synthetic wastewaters

The experiments were conducted using a synthetic wastewater to avoid any fluctuation in the feed concentration and provide a continuous source of biodegradable organic pollutants such as glucose, ammonium sulfate and potassium dihydrogen orthophosphate. This was used to simulate high strength domestic wastewater (just after primary treatment process). The synthetic wastewater consists of DOC of 120-130 mg/L, COD of 330-360 mg/L, ammonium nitrogen (NH_4-N) of 12-15 mg/L and orthor-phosphate (PO_4-P) of 3.3-3.5 mg/L (COD:N:P = 100:5:1). The composition of synthetic wastewater used in this study is shown in Table 1 (Lee et al., 2003).

Table 1
Characteristics of the synthetic wastewater

2.2. Sponge tray bioreactor description

The laboratory-scale sponge bioreactor designed in this study was constructed with a number of prism-shaped polyester-urethane sponge trays with designated slope of 10 degrees. This slope was obtained from previous study of Ngo et al. (2006) about attached growth sponge bioreactor. Reticulated porous polyester-urethane sponge (PUS) named S28-30/90R (density of 28-30 kg/m^3 with 90 cells per 25 mm) was used in the study. The sponges were provided by Joyce Foam Australia Company. The STB was 40 cm width and 120 cm height. The synthetic wastewater was pumped from the top of the STB and the treated wastewater was collected from the bottom. The recirculation of the treated wastewater was also applied in the experiment of different HRT.

2.3. Analysis

DOC of the influent and effluent was measured using the Analytikjena Multi N/C 2000. T-N and PO_4-P were measured by photometric method using Spectroquant ® Cell Test (NOVA 60, Merck). For measuring the biomass of sponge, the identified part of sponge was squeezed and washed with Mili-Q water. Biomass in the collected water, monitored as mixed liquor volatile suspended solid, was determined according to APHA Standard Method. The experimental set up for the MFI experiment is shown in Fig. 1. The filter holder unit consisted of a cylindrical cell (internal diameter of 55 mm) with the membrane at the bottom supported on porous base. The advantage of such holder was the need for an additional outlet for air purging. Nitrocellulose membrane (Millipore, USA) with a pore size of 0.45 µm was used as filter with a diameter of the rubber 'O' ring of 47 mm diameter. All the membranes were soaked in deionised (DI) water for more than 24 hours prior to experiment. To increase hydrophilic property, the membrane was soaked in the 5% ethanol for about 5 minutes before fixing the membrane in the cell. Nitrogen gas was used as a source of pressure for the dead end filtration. Feed tank consisted of a stainless steel pressure vessel fitted with pressure gauge and a pressure release valve. The vessel is connected to the filtration cell by pipe system through control box. Control box is equipped with a more accurate pressure gauge and a one way valve. The data logging for the filtration permeate consisted of electronic balance connected to computer which records cumulative filtrate volume every 3 second.

Fig. 1. Experimental set up for MFI tests

3. Results and discussion

3.1. Effect of organic loading rate on the performance of sponge tray bioreactor

The effect of four different OLRs on pollutant removal and MFI is showed in Table 2. At OLR of 1.2 and 2.4 kg COD/ m^3.sponge.day, the system achieved more than 92 % of organic carbon, whereas less than 86 % is removed when operating at OLR of 0.6 and 3.6 kg COD/ m^3.sponge.day. Similar results were also found in several previous studies, rotating biological contactor (RBC) could remove approximate 90% of organic at the optimal OLR before started decreasing (Najafpour et al., 2005; Palma et al., 2003). In terms of nutrient removal, the system could eliminate only 20.9 % of PO_4-P with the lowest OLR; it slightly increased to 30.2 % at 1.2 kg COD/ m^3.sponge.day OLR. The highest removal efficiency was observed at OLR of 2.4 kg COD/

m^3.sponge.day with the value of 56.0 %, whereas the system achieved only 49.7 % at the higher OLR. Previous studies have also proved that attached growth systems could not achieve high removal efficiency at certain OLR. Wang et al (2000) described that the percentage of COD removed decreased linearly with increased OLRs over the range in a hybrid biological reactor. Data of NH_4-N and T-N also showed the optimal performance of the system when operating at OLR of 2.4 kg COD/ m^3.sponge.day with 40.2 and 41.9 % removal, respectively. The removal mechanism of nitrogen was the process of nitrification and denitrification. Nitrification took place on the surface of sponge whereas anaerobic condition inside the sponge provided environment for denitrification (Nguyen et al. 2010). The quality of treated effluent wastewater in terms of pre-treatment for micro-filtration also indicated the optimal OLR of 2.4 kg COD/ m^3.sponge.day with MFI value is 2.3×10^4 s/L^2. The conclusion of this set of experiment is, based on the results above, the most appropriate OLR for this lab-scale STB is 2.4 kg COD/ m^3.sponge.day.

Table 2
Performance of the sponge tray system at different OLRs (Influent DOC = 90 – 100 mg/L; PO_4-P = 3.1 – 3.2 mg/L; NH_4-N = 16.5 – 17.5 mg/L; flow velocity = 40 mL/min; HRT = 40 min)

3.2. Effect of flow velocity on the performance of sponge tray bioreactor

At the optimal OLR of 2.4 kg COD/ m^3.sponge.day obtained from first experiment, the system was assessed at the different flow velocities of 4, 8, 20, 28, 40 mL/min. The results indicated that flow velocity did not significantly effect on DOC removal (Table 3). At all of the flow velocities, the system could successfully achieve more than 90% of DOC. PO_4-P removal efficiency tended to increase when operating at higher flow velocity. The system eliminated only 49.5% of PO_4-P at the starting velocity of 4 mL/min and it was increasing to 72.1 and 87.4% at 20 and 28 mL/min, respectively. There was a drop of PO_4-P removal efficiency at the highest flow velocity to 56.0%. The highest NH_4-N removal efficiency was also indentified at 28 mL/min velocity with the value of 52.9%. T-N removal efficiency was increasing from 27.9 to 40.2% when increasing flow velocity from 4-20 mL/min. It reached the peak of 54.8% at 28 mL/min, followed by a slump to 41.9% at the highest operating rate. Finally, in terms of MFI value, the best index was observed at 28 and 40 mL/min with the value of 2.3×10^4 s/L^2. It can be explained by the correlation between the quality of treated water in terms of organic concentration and membrane fouling (Javeed et al., 2009; Shon et al., 2009). It is proved that at flow velocity of 28 mL/min, the system obtained the highest performance in terms of pollutant removal and reducing membrane fouling.

Table 3
Performance of the sponge tray system at different flow velocities (Influent DOC = 90 – 100 mg/L; PO_4-P = 3.1 – 3.2 mg/L; NH_4-N = 16.5 – 17.5 mg/L; HRT = 40 min)

3.3. Effect of hydraulic retention time on the performance of sponge tray bioreactor

The experiment of the effect of HRT on the performance of sponge tray bioreactor was conducted at the optimal OLR and FV of 2.4 kg COD/ m^3.sponge.day and 28 mL/min, respectively. Four different HRTs were considered for the experiment including 40, 80, 120, and 180 min (Table 4). DOC removal efficiency results showed that at higher HRT of 120 or 180 min the system could achieve more than 95% of DOC, while it was slightly slower at HRT of 40 and 80 min. Normally, higher HRT provides longer contact time between support media and wastewater, and enhances pollutant removal efficiency (Najafpour et al., 2006; Gavana et al., 2006). There was no significant difference in terms of PO_4-P removal as it increased less than 4% between the lowest and the highest HRT. At 40 and 80 min the system eliminated 87.4-87.5% of PO_4-P, and 91.0-91.1% was removed when operating at HRT of 120 and 180 min. Nevertheless, NH_4-N removal efficiencies were well correlated with HRTs. In detail, 52.9% of NH_4-N was removed at starting HRT of 40 min, and then it was increasing to 70.7 and 88.2% at 80 and 120 min HRT, respectively. A number of studies have also proved the effect of HRT on NH_4-N removal. Liu et al. (2010) reported that increasing HRT from 2 h to 4 h could enhance NH_4-N removal from 47.2% to 98.1%. There was no significant improvement from HRT of 120 to 180 min when the highest operating mode could eliminate 89.5% of NH_4-N. Similarly, the results also proved that at HRT of 120 and 180 min, STB achieve the highest T-N removal. It was 71.6 and 70.8% removal efficiency at HRT of 120 and 180 min, respectively. The relevant results were also reported from other studies. Krumins et al (2002) found that nutrient removal efficiency increased from 73% to 92% when HRT changed from 3 h to 24 h. The effect of HRT on MFI data was also presented in Table 4. The results indicated that the system could produce better treated water effluent in terms of reducing membrane fouling as increasing HRT. The MFI value of the lowest HRT of 40 min was 2.2×10^4 s/L^2, while at higher HRT of 120 and 180 min, the fouling index reduced to only 1.3×10^4 s/L^2. The results proved that at higher HRT the system performed better; however, there was no significant improvement from HRT of 180 min as compared to 120 min. Therefore, HRT of 120 min could be the optimal HRT for the system.

Table 4
Performance of the sponge tray system at different HRTs (Influent DOC = 90 – 100 mg/L; PO_4-P = 3.1 – 3.2 mg/L; NH_4-N = 16.5 – 17.5 mg/L)

3.4. Biomass growth on sponge

Biomass growth on sponge at different HRT is also discussed. In order to analyse the sponge biomass, a part of sponge from the top tray of STB was taken and washed out the biomass. The results indicated that the amount of biomass was limited by the low HRT. It was only 0.24 g biomass/ g sponge at the lowest HRT of 40 min, while at HRT of 120 and 180 min the biomass was more than double, resulting at 0.56 and 0.57 g biomass/g sponge, respectively. It could be explained by the effect of contact time on the growth of biofilm on the surface of support media, the more contact time the more biomass developed. The result of this study also indicated the high performance of STB in terms of biomass growth compared to previous studies. Nguyen et al. (2010) investigated the effect of sponge sizes and sponge types on the up-flow sponge bioreactor and found that the maximum biomass attached on the sponge was only 0.1 g biomass/ g sponge. Ryu et at. (2010) studied the relationship between biomass, pressure drop and performance in polyurethane biofilter. The data of this study showed that there was only thin biofilm growth on the support media after 10 days of operation, with the value of only 0.2 g biomass/ g media.

4. Conclusions

The results of this experiment concluded that the simple, compact STB system can produce the high quality treated effluent. In order to achieve a very excellent performance, the system needs to operate at the optimal conditions of OLR, FV and HRT. In addition, STB provided suitable condition and support media for biomass to grow on it. The results also indicated that using STB is a promising pre-treatment method for micro-filtration. Further study of the pilot scale STB on treating domestic and industrial wastewater will be experimented to verify the ability of the system.

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Table 1
Characteristics of the synthetic wastewater

Compound	Chemical formula	Concentration (mg/L)
Organics and nutrients		
Glucose	$C_6H_{12}O_6$	280
Ammonium sulfate	$(NH4)_2SO_4$	142
Potassium phosphate	KH_2PO_4	26
Trace nutrients		
Calcium chloride	$CaCl_2.2H_2O$	0.368
Magnesium sulfate	$MgSO_4.3H_2O$	5.070
Manganese chloride	$MnCl_2.4H_2O$	0.275
Zinc sulfate	$ZnSO_4.7H_2O$	0.440
Cupric sulfate	$CuSO_4.\ 5H_2O$	0.391
Cobalt chloride	$CoCl_2.\ 6H_2O$	0.42
Sodium molybdate dihydrate	$Na_2MoO_4.2H_2O$	1.26
Ferric chloride anhydrous	$FeCl_3$	1.45
Yeast extract		30

Table 2
Performance of the sponge tray system at different OLRs (Influent DOC = 90 – 100 mg/L; PO_4-P = 3.1 – 3.2 mg/L; NH_4-N = 16.5 – 17.5 mg/L; flow velocity = 40 mL/min; HRT = 40 min)

OLR (kg COD/m^3 sponge. day)	0.6	1.2	2.4	3.6
DOC RE (%)	83.2	92.9	92.3	85.7
PO_4-P RE (%)	20.9	30.2	56.0	49.7
NH_4-N RE (%)	6.3	33.9	40.2	36.2
T-N RE (%)	4.1	21.1	41.9	31.4
MFI (s/L^2)	4.1×10^4	3.4×10^4	2.3×10^4	4.5×10^4

RE: removal efficiency

Table 3
Performance of the sponge tray system at different flow velocities (Influent DOC = 90 – 100 mg/L; PO_4-P = 3.1 – 3.2 mg/L; NH_4-N = 16.5 – 17.5 mg/L; HRT = 40 min)

Flow velocity (mL/min)	4	8	20	28	40
DOC RE (%)	>90	>90	>90	>90	>90
PO_4-P RE (%)	49.5	50.5	72.1	87.4	56.0
NH_4-N RE (%)	27.5	35.8	42.1	52.9	40.2
T-N RE (%)	27.9	35.6	40.2	54.8	41.9
MFI (s/L^2)	4.4×10^4	3.0×10^4	3.2×10^4	2.3×10^4	2.3×10^4

RE: removal efficiency

Table 4
Performance of the sponge tray system at different HRTs (Influent DOC = 90 – 100 mg/L; PO_4-P = 3.1 – 3.2 mg/L; NH_4-N = 16.5 – 17.5 mg/L)

HRT (min)	40	80	120	180
DOC RE (%)	>90	>90	>95	>95
PO_4-P RE (%)	87.4	87.5	91.0	91.1
NH_4-N RE (%)	52.9	70.7	88.2	89.5
T-N RE (%)	54.8	68.8	71.6	70.8
MFI (s/L^2)	2.2×10^4	1.7×10^4	1.3×10^4	1.3×10^4

RE: removal efficiency

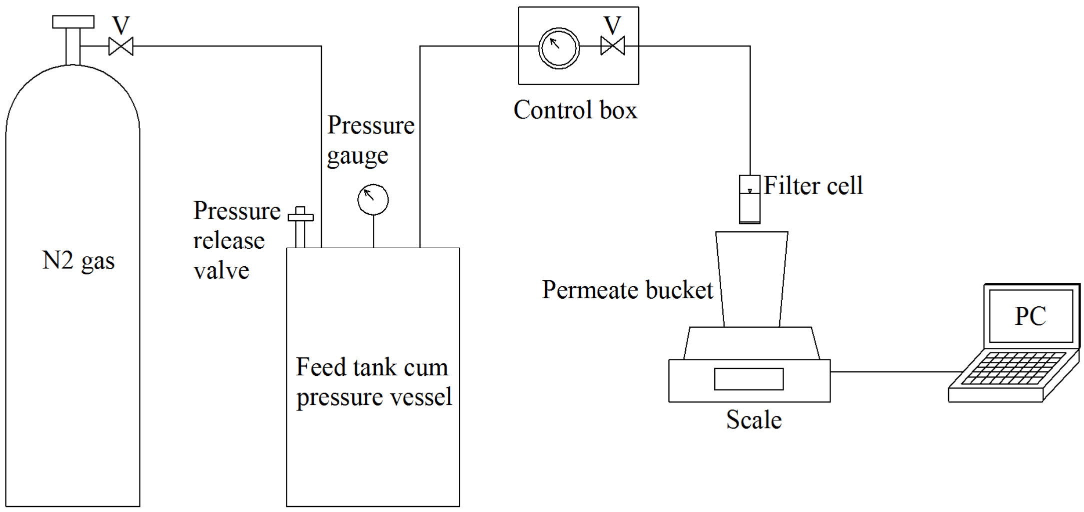

Fig. 1. Experimental set up for MFI tests