Filtration characteristics of immersed coarse pore filters in an activated sludge system for domestic wastewater reclamation

G.T. Seo*, B.H. Moon*, Y.M. Park* and S.H. Kim**

*Department of Environmental Engineering, Changwon National University, Sarim-dong 9, Changwon, Gyeongnam 641-773, South Korea (E-mail: *gts@changwon.ac.kr*)

**Department of Environmental Engineering, Kyungnam University, Wolyong-dong 449, Masan, Gyeongnam 631-701, South Korea

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Abstract The filtration characteristics of two different module configurations with coarse pore filter (non-woven fabric) were investigated for sludge floc separation in an activated sludge reactor for domestic wastewater reclamation. A polypropylene non-woven fabric filter (35 g/m^2) was used for the two different module configurations, one flat and one tubular type, each with a filtration area of 0.052 m^2. The different module types, submerged in the oxic compartment of A/O (anaerobic/oxic) type reactors, were operated simultaneously. The filtration fluxes were gradually increased from 0.5 to 1.2 and 1.73 m/d. The filtration pressures were more stably maintained for the tubular type module than the plate type. The tubular type module installed horizontally with two-side suction showed less filtration pressures than the tubular type module installed vertically with one-side suction. The solid separation was significantly high showing less than 5 mg/L effluent solids. The organic and T-N removal efficiencies were around 95 and 50%, respectively. The 85% removal of T-P was achieved with 20 mg/L injection of PAC (poly-aluminum chloride).
Keywords Activated sludge; coarse pore filtration; domestic wastewater reclamation; solid separation

Introduction

The membrane bioreactor (MBR) is an immerging process for wastewater treatment enhancing effluent quality, requiring less footprint and sludge waste. However, expensive membrane modules lead to increased treatment cost. Bio-fouling of the membrane results in difficulties for stable operation of the system. A coarse pore filter could be an alternative to the membrane for solid-liquid separation in an activated sludge reactor. Compared to the membrane (MF), the coarse pore filter is inexpensive, with high permeation and low filtration resistance. Moghaddam *et al.* (2002) reported that the coarse pore filtration activated sludge system had an excellent performance in organic removal at flux; about 1 m/d. Kiso *et al.* (2000) investigated the coarse pore filtration for separation of MLSS in an activated sludge system and showed acceptable separation of sludge with good effluent quality.

Several researchers (Kitao *et al.*, 1991, 1998; Seo *et al.*, 2003a, b) have shown that a non-woven fabric filter activated sludge system for domestic wastewater treatment has a high potential to compete with membranes in the same process. Seo *et al.* (2003a, b) identified that a non-woven fabric filter could be used for domestic wastewater treatment in combination with an activated sludge system to produce treated water with a high enough quality for domestic reuse without human contact, such as stream restoration.

However, the hybrid system presented difficulties for stable operation in domestic wastewater treatment. Although an initial flux of 0.42 m/d could be maintained for 100 days by 2 min air backwashing once a day in long-term operation of the system with a 35 g/m^2 filter medium at water head 0.3 m, signs of flux reduction were still observed, e.g. residual particle accumulation on fibres of the filter. Even distribution of air in the filter

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element was a key factor for effective backwashing (Seo *et al.*, 2003a, b). Therefore further study is required to enhance the filtration by coarse pore filters in the activated sludge process. In this study, different module configurations of submersed type coarse pore filters coupled with activated sludge systems were investigated to identify system performance.

Materials and methods

Experimental apparatus

The experiment was conducted with a bench scale reactor (anoxic/oxic process) installed in a 20°C temperature controlled room. The system performance was evaluated with different types of filter modules each having a filtration area of 0.052 m^2. The filter material was non-woven fabric of 35 g/m^2. Figure 1 is the configuration of the filter element used in the experiment.

As shown in Figure 2, two sets of the reactor with different modules were operated in parallel. In stage 1, comparisons of flat and tubular module installed systems were operated. In stage 2, comparisons of vertical and horizontal tubular module installed systems were operated. Each system consisted of an influent storage tank, an anoxic (0.0072 m^3) and an aerobic (0.012 m^3) reactor, a filter module submerged in the aerobic reactor, an internal recycling pump and a mixing pump in an anoxic reactor. Since the filtration area of the filter modules was too small, suction types filtration was carried out using master flex pumps for experimental purposes. Influent was supplied to the anoxic reactor and its flow rate was controlled by a level sensor installed in the aerobic reactor to prevent overflow. MLSS is recycled from the aerobic to the anoxic reactor at 200% of influent flow. Air was supplied at the rate of 10 L/min from the bottom of the reactor.

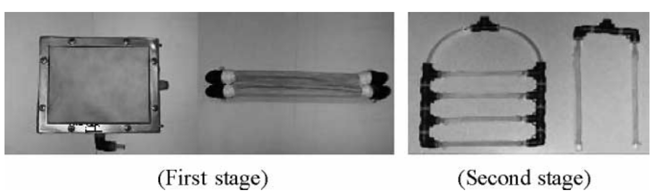


Figure 1 The configuration of module element

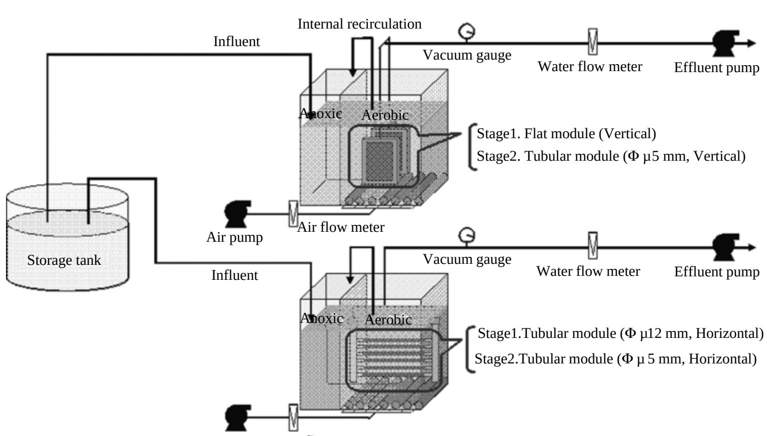


Figure 2 Schematic diagram of the experimental apparatus

Operation conditions and analytical method

The system operation conditions were HRT 5–8 h, MLSS 2,500–3,500 mg/L and internal recirculation was 200% of influent flow rate. Synthetic domestic wastewater was used as influent with a concentration of COD, T-N and T-P, 100 ± 5, 40 ± 0.5 and 6 ± 0.3 mg/L, respectively. Table 1(a) and (b) represents the operation conditions of the system. As shown in the table the system was operated in two stages. In the first stage, the filtration characteristics were compared for two different modules: flat plate and tubular type. Tubular modules in different configurations were evaluated at the second stage. The initial flux was controlled at 0.5–1.73 m/d in the first stage and 0.5–1.0 m/d in the second stage.

Analysis of organic matter and nutrients was carried out using the Korean standard method. Particle size distribution was measured by size analyser (Master Sizer, Malvern). Microscopic analysis was also conducted to identify the effect of sludge cake layer on the system performance.

Results and discussion

Filtration pressure at different flux levels

Filtration pressure increase of the flat plate and tubular (Φ12 mm) type filter modules was observed at different flux levels in the first stage experiment. As shown in Figure 3, the filtration pressure of the two modules was maintained at the same level during the operation period of flux 0.5 and 1.11 m/d. The pressure increased when the flux was set at 1.73 m/d but in different patterns for the two modules. The filtration pressure was maintained under 5 kPa for the tubular type module while it increased rapidly reaching 16 kPa for the flat plate type at 27 days of operation. There was a subsequent increase of the pressure to 21.3 kPa for the flat plate with a sharp increase to 17.3 kPa for the tubular module.

Table 1(a) Operation conditions of the system (Stage I)

Parameters	Type 1				Type 2 (Φ 12 mm)			
	Run 1	Run 2	Run 3	Run 4 (reoperation)	Run 1	Run 2	Run 3	Run 4 (reoperation)
Operation day	6 days	10 days	14 days	10 days	6 days	10 days	14 days	10 days
Configuration	Flat plate				Tubular (Φ 12 mm)			
Filtration area	0.052 m^2				0.051 m^2			
Installation of the filter	Vertical, One side suction				Horizontal, Two side suction			
Bath capacity	0.0192 m^3 (Anoxic 0.0072 m^3, Aerobic 0.012 m^3)							
Initial flux	0.5 m/d	1.11 m/d	1.61–1.73 m/d	1.11 m/d	0.5 m/d	1.11 m/d	1.61–1.73 m/d	1.11 m/d
MLSS	2,500–3,500 mg/L							

Table 1(b) Operation conditions of the system (Stage II)

Parameters	Type 1 (Φ 5 mm)			Type 2 (Φ 5 mm)		
	Run 1	Run 2 (physical washing)	Run 3 (reoperation)	Run 1	Run 2 (physical washing)	Run 3 (reoperation)
Operation day	2 days	5 days	7 days	2 days	5 days	7 days
Configuration	Tubular (Φ 5 mm)			Tubular (Φ 5 mm)		
Filtration area	0.035 m^2			0.035 m^2		
Installation of the filter	Vertical, One side suction			Horizontal, Two side suction		
Bath capacity	0.0192 m^3 (Anoxic 0.0072 m^3, Aerobic 0.012 m^3)					
Initial flux	1 m/d	0.4 m/d	0.3 m/d	1 m/d	0.4 m/d	0.3 m/d
MLSS	2,500–3,500 mg/L					

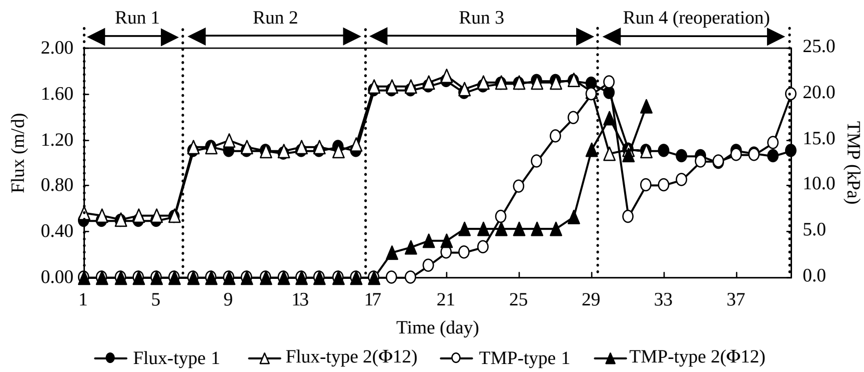


Figure 3 Comparison of filtration pressure increase at different flux levels between the flat plate and the tubular type filter module

After the 30th day of operation, the sludge cake on the filters was washed out for subsequent operation. However, the filtration pressure was not recovered completely by the physical washing. At flux 1.11 m/d, the pressure increased from 7 to 20 kPa in 10 days for the plate filter while it increased from 13 to 18 in one day for the tubular type filter. This means that filter pores were already clogged with sludge during 30 days operation without backwashing. Seo *et al.* (2003a, b) have reported a similar result in a long-term operation of a non-woven fabric filter activated sludge process. Although there was regular air backwashing, sludge particles were accumulated on the inner part of the filter fibre resulting in flux decline or filtration pressure increase. The difference in the filtration pressure could be evaluated by the solid cake structure formed on the filter surface, such as compression of the cake, and the size and shape of the particles.

Figure 4 is the amount of sludge attached to each filter surface. The attached sludge on the tubular type filter was more than twice that on the plate type. Since the tubular filter was set horizontally, the sludge cake could easily accumulate on the top of the tube element during the operation time. On the other hand, a thin biofilm-like cake layer formed on the plate type filter which is installed parallel to the air bubble. Such different cake formations may have an effect on the different patterns of filtration pressure increase between the two types of filter. The sludge cake on the top of the tube might be thick and uncompressed initially, maintaining low filtration pressure; however, the layer was compressed by operation time causing a sharp increase of the filtration pressure. Particle size and shape were also measured (Figure 5). There was not so much difference in particle size and shape.

Two sets of tubular (Φ 5 mm) filter module were compared for filtration performance in the second stage experiment. Here, one filter module was installed vertically with one side suction with the other one horizontally with two side suction. The results are shown in Figure 6(a). The filtration pressure increase is similar with both modules at various fluxes from 1.11 to 0.3 m/d. The faster increase of the pressure in the vertically installed module may be caused by the hydraulic head loss inside the tube. Figure 6(b) is a microscopic

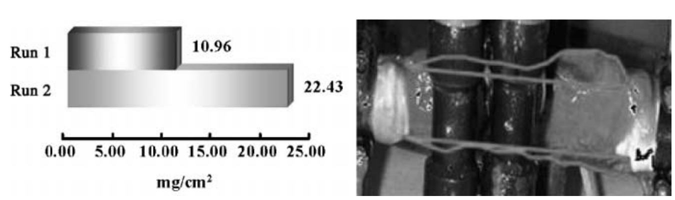


Figure 4 Comparison of the sludge accumulated on the filter module

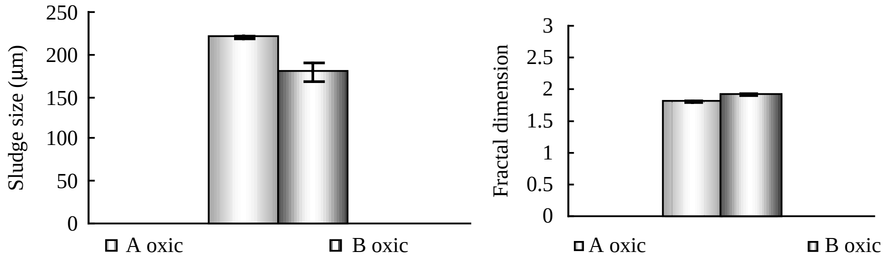
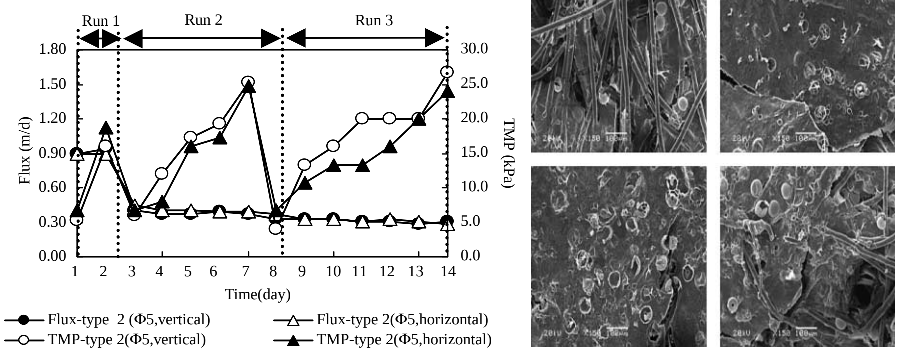


Figure 5 Particle size and fractal dimension of the two reactors



(a) Daily observation of filtration pressure (b) Microscopic observation of the filter surface

(Respectively Type2(Φ5, Vertical), Type2(Φ5, Horizontal) the center ×150, side ×150)

Figure 6 Comparison of filtration pressure of the tubular filter in different installations

photograph taken by SEM for the two tubular filter modules at the end of the operation. The vertically installed filter module has rather more sludge accumulation on the tip than the centre of the filter, while the horizontal one shows a relatively even distribution of sludge cake layer.

Organic removal

The system performance for organic removal was monitored in terms of TOC and BOD during the experimental period. The results are shown in Figures 7 and 8. The average effluent BOD concentration is 7.8 mg/L for the influent 90–130 mg/L, which shows 93%

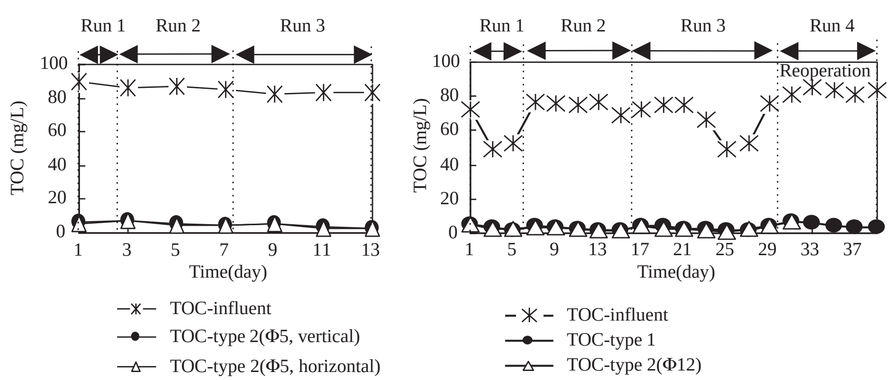


Figure 7 Daily observation of TOC removal by the system with different types of filter module

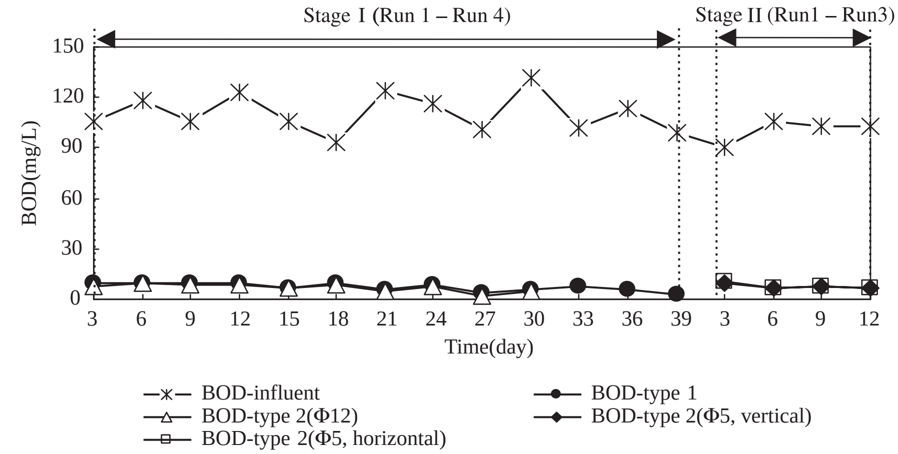


Figure 8 Daily observation of BOD removal by the system with different types of filter module

removal on average. This is comparable to the effluent quality of a membrane bioreactor, less than 10–20 mg/L (Chiemchaisri *et al.*, 1993; Trouve *et al.*, 1994). TOC removal was in the range of 93–98% for an influent concentration of 50–85 mg/L. Consequently, stable and high organic removal could be obtained by the system with various configurations of the coarse pore filter module.

MLSS in the reactor and SS release

Maintaining MLSS at high concentration is an important factor for the performance of the fabric filter combined activated sludge process. However, there was leakage of MLSS at the initial stage of operation before the sludge cake layer was formed (Seo *et al.*, 2003a, b). In this study MLSS was maintained at 2,500–3,500 mg/L initially. When the concentration decreased due to its attachment to the filter surface, stocked sludge was added to maintain the concentration. Regardless of the MLSS concentration in the oxic reactor, effluent SS concentration was stably maintained in the range of 3–7 mg/L as shown in Figure 9.

Nutrient removal

When the system was operated in the anoxic/oxic process with an internal recycle ratio 200% of influent flow rate, a relatively low T-N removal of 51.1% could be obtained. The effluent T-N concentration was 15.7 mg/L for the influent concentration of

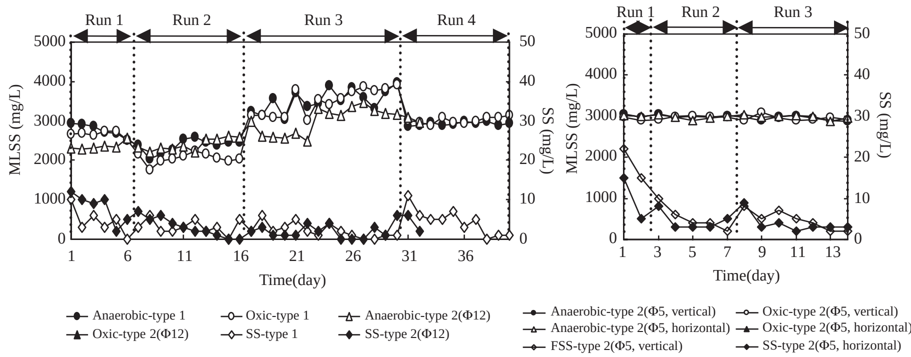


Figure 9 Daily variation of MLSS and SS concentration

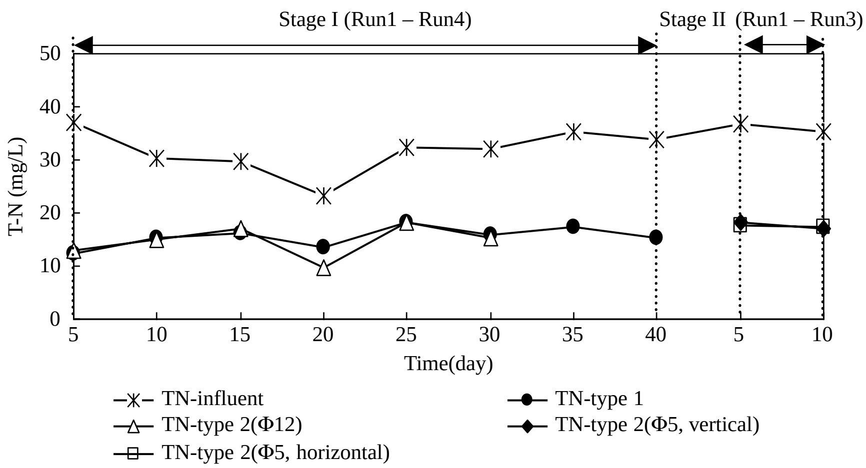


Figure 10 Daily variation of T-N concentration and removal rate

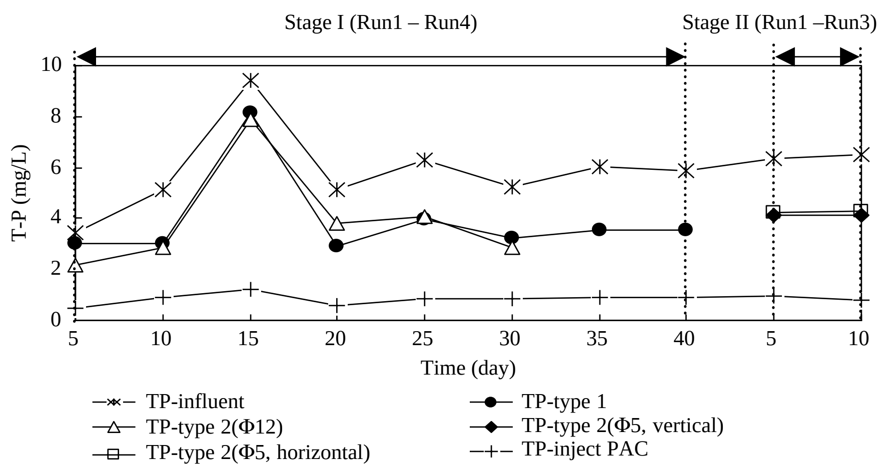


Figure 11 Daily variation of T-P concentration and removal rate

32.5 mg/L. As shown in Figure 10, nitrogen removal is similar for all the systems compared in this study. Enhanced removal of T-N could be expected by increasing the internal recycle ratio.

Figure 11 shows the removal of T-P by the system. A very low removal efficiency of 33.8% was observed for an influent concentration of 5.9 mg/L. Since it is difficult to maintain suitable conditions for biological phosphorus removal in this small system, chemical treatment could be considered. The removal efficiency of T-P was 85% with injection of PAC of 20 mg/L.

Conclusions

Two types of coarse pore filter module, flat plate and tubular, were tested in the activated sludge reactor for system performance and the following results were obtained. Although filtration pressure was maintained at the same level for the low flux 0.5–1.1 m/d, the tubular module (Φ 12 mm) was more stable than the flat plate type in terms of the pressure increase at flux 1.73 m/d. However, sludge cake formation on the top of the horizontally installed tube caused rapid increase of the pressure. Particle size and shape of the sludge particle in the two systems did not vary significantly. The filtration pressure increase did not vary much between the two sets of tubular filter module, vertical and horizontal installation in the reactor, at various fluxes from 1.11 to 0.3 m/d. The faster increase of the pressure in the vertically installed module might be caused by the hydraulic head loss inside the tube. The system performance to remove organics and SS was good enough to produce reclaimed water showing effluent BOD and SS 7.8 and 3.0 mg/L, respectively. However, operational modification of the system was required to enhance nitrogen and phosphorus removal.

Acknowledgements

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