Non-woven fabric filter separation activated sludge reactor for domestic wastewater reclamation

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Abstract A non-woven fabric filter was experimentally evaluated for solid-liquid separation in an activated sludge reactor as an alternative membrane. A polypropylene fabric filter (70, 50 and 35 g/m^2) was used for the experiment. The pilot system was operated in A/O (Anaerobic/Oxic) type in which the filter module was submerged into the oxic compartment. The filtration module consists of 10 plate type rectangular filter elements with effective filtration area, 2 m^2. Gravity filtration was carried out for solid-liquid separation by changing the water head 0.05–0.5 m without backwashing during the system operation. Initial permeate flux was set at 0.4 m/d. C/N ratio of raw wastewater was controlled at 4.5 in terms of BOD/T-N. The fabric filter system showed a good performance enough for domestic wastewater treatment. Effluent solid concentration was 3.2 mg/L (93.5% removal). COD removal efficiency was 91.6% producing an effluent concentration around 13 mg/L. 66% of total nitrogen removal could be obtained at the adjusted C/N ratio of influent wastewater. However phosphorus removal was very low at 23%. It was found that the initial flux of 0.4 m/d should be maintained for stable performance of the system.

Keywords Activated sludge process; dynamic filtration; gravity flow; non-woven fabric filter; nutrient removal; wastewater reclamation

Introduction

Recently membrane separation technology is widely used for water and wastewater treatment. Especially micro-filtration (MF) has been commonly used in combination with activated sludge process to enhance the degree of purification in domestic wastewater treatment (Chiemchaisri *et al*., 1993; Seo *et al*., 2000). Since the membrane process has perfect solid-liquid separation ability, stable performance of the activated sludge process could be achieved regardless of sludge bulking or rising, and shock loading, etc. However, the membrane is hardly applicable for a small community sewage treatment because of its high cost and energy requirement. Fouling of the membrane requires regular chemical cleaning, and makes its operation complex and expensive. Properly applying non-woven fabric filter could be an alternative to the membrane for solid-liquid separation in an activated sludge reactor.

The non-woven fabric filter was applied originally for sludge thickening. Recently its application is expanded to wastewater treatment in conjunction with the activated sludge process since it has the following major characteristics, 1) inexpensive cost of filter material compared to membrane, 2) high permeate flux and low filtration resistance, 3) gravity filtration without energy requirement. Although limited researches have been conducted, it was suggested that the fabric filter has a high potential to replace membrane (MF) in a hybrid membrane bioreactor for wastewater treatment (Kitao *et al*., 1991). Kitao *et al*. (1998) also reported from their long time operation of the filter system that a water head of 1 cm was enough to get a comparable flux of MBR. They found also that the lower compressed part of the sludge cake layer on the filter surface was the main reason for filtration resistance. Since, however, the fabric filtration is dynamic, there are operational difficulties in the fabric filter system. In this study, the ability of a non-woven fabric filter was investigated for separation of activated sludge particles. An evaluation of the fabric filter separation activated sludge system was conducted for small community domestic wastewater treatment in the ruler area.

Materials and methods

Fabric filter separation of activated sludge

The activated sludge separation characteristic of the fabric filter was evaluated with three types of filter in a batch experiment. 70, 50 and 35 g/m^2 filters were investigated at different pressure as shown in Table 1. The initial flux was controlled with the water head, 1 m^3/m^2/day for 0.1 m and 25 m^3/m^2/day for 0.5 m. A filter element with filtration area of 0.054 m^2 was submerged in an activated sludge reactor with MLSS 1,800 mg/L. The specification of the fabric filter is described in Table 2. Particle size of sludge at the inlet and outlet as well as flux variation was measured at different water heads. The process of sludge cake formation on the filter surface was also observed.

Pilot experiment

System description. A pilot scale experimental apparatus was installed at a small domestic wastewater treatment plant in Changwon, Korea. As shown in Figure 1, the system consists of a storage tank, anoxic (0.28 m^3) and aerobic (0.47 m^3) reactors, fabric filter module, internal recycling pump, and mixing pump. Effective filtration area of the filter module is 2 m^2 and the module has ten rectangular elements made with a porous plastic spacer inserted between two sheets of fabric filter. The filter module is submerged into the aerobic reactor for gravity filtration. Influent wastewater is supplied to the anoxic reactor and is controlled by a level sensor installed at the aerobic reactor to prevent over flow. MLSS is recycled from the aerobic to the anoxic reactor at 100–300% of influent flow. Solid-liquid is separated by the fabric filter in gravity flow. As shown in Table 3, an experiment with 70 g/m^2 and 35 g/m^2 filters was performed at water heads 0.5 and 0.05 m, respectively.

Wastewater. Since organic concentration of the domestic wastewater was relatively low (67 mg/L as BOD) compared to nitrogen and phosphorus concentration (38–40 mg/L as T-N and 5 mg/L as T-P), 10% glucose was added to adjust nutrient balance. Average BOD and COD_{cr} concentration was controlled at 180 mg/L and 320 mg/L giving C/N ratio of 4.5 On average.

Results and discussion

Separation characteristics of activated sludge

Flux decline at water head 10 and 50 cm is shown in Figure 2 and Figure 3. The initial flux was set at 1 m/day and 25 m/day for water heads 0.1 and 0.5 m, respectively. It was identified that the

Table 1 Experimental condition of fabric filter separation

Parameters	Condition
Type of filter (g/cm^2)	70, 50, 35
Water head (m)	0.5, 0.3, 0.1, 0.05
Filtration area (m^2)	0.054

Table 2 Characteristics of non-woven fabric filter

Weight (g/m^2)	Thickness (mm)	Tensile strength (kg/2.5 cm)	Material
70	0.42	18.0	Polypropylene
50	0.36	13.8	
35	0.26	8.1	

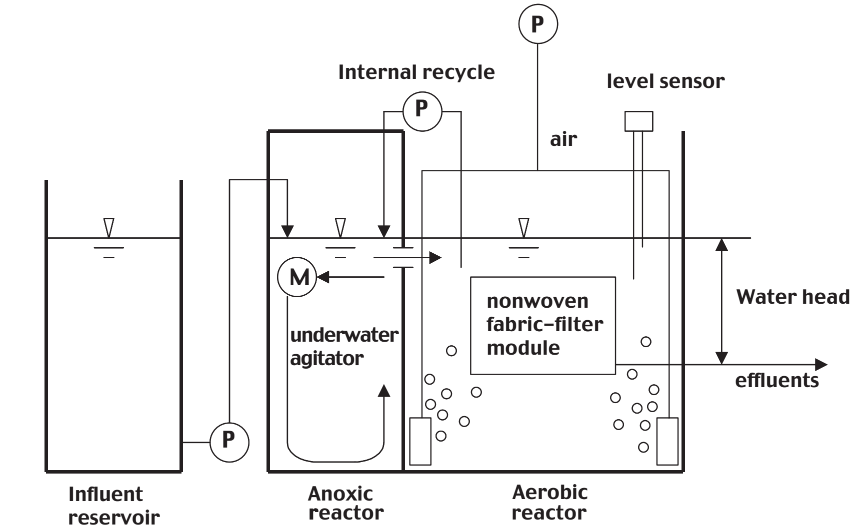

Figure 1 Schematic diagram of experimental apparatus

Table 3 Operating condition

Run	Filter weight (g/m²)	Water head (m)	Operation period (days)	MLSS (mg/l)	C/N ratio*
1	70	0.5	28	1346–2175	4.5
2	35	0.05	29	1789–2458	4.5

* C/N ratio is based on BOD/T-N

weight of the filter has a significant effect on flux. At water head 0.1 m, rapid flux decline was observed for a 70 g/m^2 filter. It was decreased to 70% of the initial flux after 40 minute. However 35g/m^2 filter was maintained for 160 minutes at the same head. Therefore a lighter filter seems to produce stable flux at lower filtration pressure. When the water head increased to 0.5 m, the initial flux, 25 m/d declined to around 5 m/d in 160 minutes for all filters. A similar pattern of filtration was observed for 0.3 m. Hamata and Nakatsuka (1999) reported rapid initial flux (25 m/d) decline to 2 m/d in 5 hours and complete recovery of the flux by water backwashing once a day in their fabric filter separation experiment.

The SS of initial permeate is significantly high. It was in the range 81–480 mg/L at 0.5 m water head and 33–91 mg/L at 0.1 m. The high SS might be caused by the leakage of MLSS. The SS in the initial permeate increased as the water head was increasing and filter weight decreasing. However the leakage of MLSS stopped at 20 minutes after filtration showing SS concentration less than 10 mg/L.

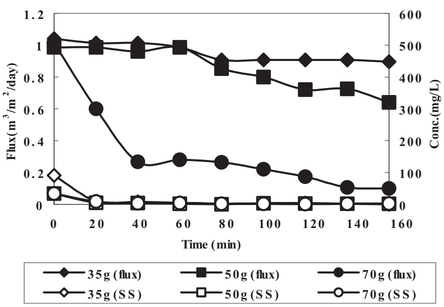

Figure 2 Flux variation at 0.1 m water head

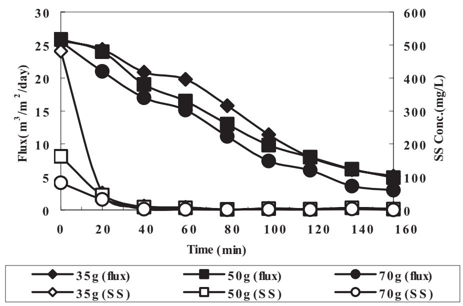

Figure 3 Flux variation at 0.5 m water head

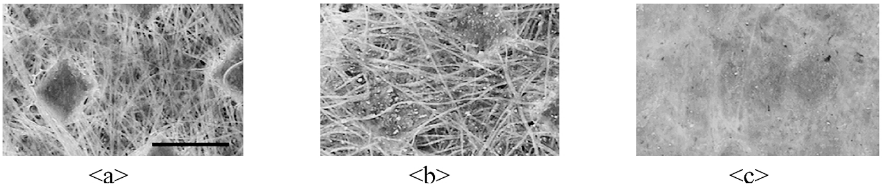

Figure 4 Process of activated sludge cake layer formation on the filter surface (microscope 80×, (a): after 5 min., (b) after 15 min., (c) after 20 min.)

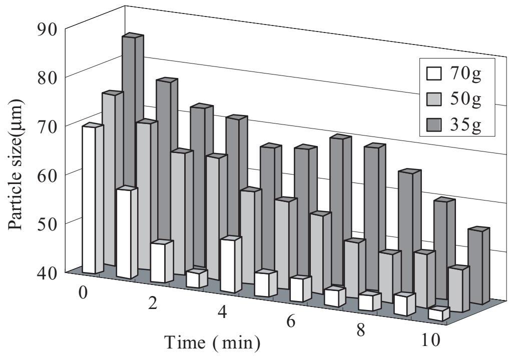

Figure 5 Average particle size of SS in filtrate

Since it is dynamic filtration, the fabric filter itself has no separation ability unless there is sludge cake formation on the filter surface. 20 minutes was taken to get separation ability by sludge cake layer as shown in Figure 4. The initial leakage was much reduced at water head 0.05 m even though the flux declined to less than half. On the basis of the experimental result, it is important to control both filtration pressure and weight of filter for stable operation of the system. Lighter fabric filter and lower pressure are desirable if the required flow rate is obtained.

Figure 5 shows the particle size variation of SS in permeate for initial 10 minute filtration. The particle size is gradually decreased as the sludge cake layer is formed on the filter surface.

System performance

Removal of organic matter and SS. Figure 6 and Figure 7 show the experimental results on organic and SS removal by the system. Average organic removal in terms of COD is 91.6%. The effluent COD, 13–15 mg/L is comparable to that of a membrane bioreactor, less than 10–20 mg/L (Chiemchaisri *et al*., 1993 and Trouve *et al*., 1994). It was identified that the 84% of removed COD was consumed in the anaerobic chamber as a carbon source for denitrification.

During the initial stage of each run before sludge cake layer is formed, leakage of MLSS was observed through the filter pore causing high SS concentration in effluent. However the leakage decreased and the effluent SS concentration was maintained at an average 3.2 mg/L giving removal efficiency 93.4%.

Nutrient removal. Daily observation of total nitrogen and phosphorus removal is shown in Figure 8 and Figure 9. When the initial flux of 0.4 m/d was maintained in run 1, around 80% T-N removal efficiency was obtained during the period (5 to 20 day). However the T-N removal efficiency was decreased to 49.4% as the permeate flux declined. The decreasing

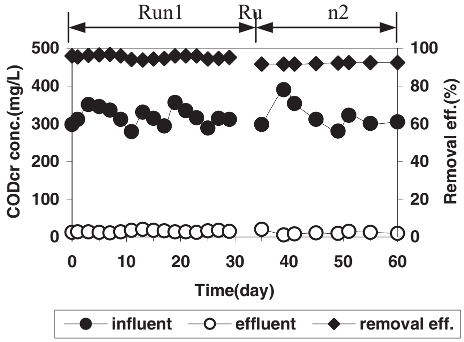

Figure 6 Daily variation of effluent CODcr concentration and removal rate

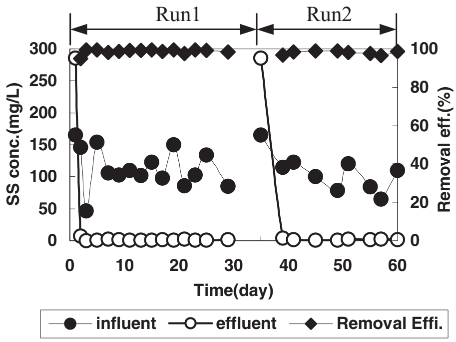

Figure 7 Daily variation of effluent SS concentration

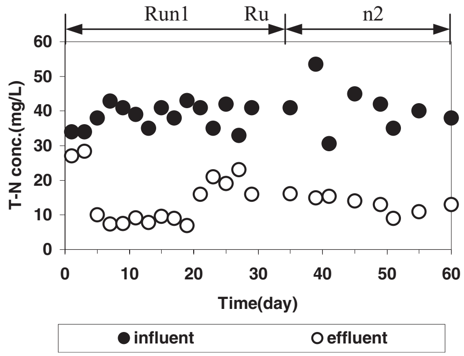

Figure 8 Daily variation of effluent T-N concentration

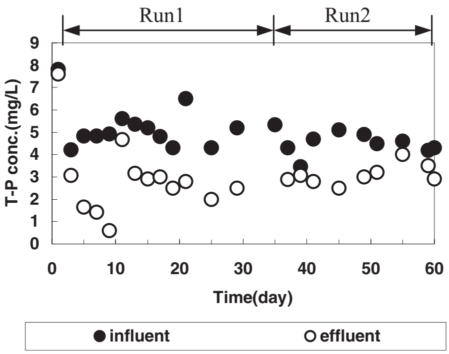

Figure 9 Daily variation of effluent T-P concentration

T-N removal efficiency was caused by insufficient supply of organic matter to the anoxic reactor for dentrification. In addition the initially fixed internal recycling ratio changing from 100% to 300% could be another reason for the reduced efficiency. In run 2 of the consequent system operation with 35 g/m^2 filter at 0.05 m water head, the removal efficiency was slightly improved. The influence of flux on the removal was observed too. Average 66.6% removal was obtained during this period.

Biological nitrification and denitrification was clearly observed in the system. The inlet concentration of NH_4-N (34.1–40.6 mg/L) decreased to less than half by dilution in the anoxic reactor and oxidized mostly in the aerobic one. The organic consumption in the anaerobic reactor provided an efficient nitrification in the aerobic reactor. The oxidized nitrogen is recycled to the anaerobic reactor for denitrification. The T-P removal efficiency of 23% was obtained, which is the removal efficiency of the activated sludge process. An appropriate condition might not be established in the anaerobic reactor for phosphorus release.

Flux variation. Figure 10 is the variation of flux at different experimental conditions. The initial flux was controlled at 0.4 m/d as a design flow rate of the filtration system for one household. The initial flux of 70 g/m^2 filter could be maintained for 12 days at 0.5 m head and it declined gradually to less than 0.2 m/d. In the second run, a 35 g filter was used for the experiment at 0.05 m water head. The flux was rapidly decreased to 0.1 m/d in 10 days operation. This implies that the water head of 0.05 m is insufficient for a 35 g/m^2 filter. Higher water head than 0.05 m is required for a 35 g/m^2 filter for the extended period of initial flux.

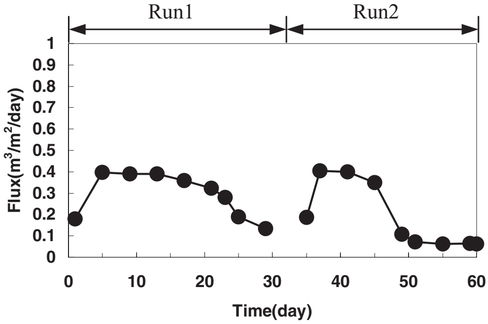

Figure 10 Daily variation of flux

Conclusion

On the basis of the experimental investigation, it was identified that the non-woven fabric filter could be used for domestic wastewater treatment in combination with an activated sludge system. The following conclusions were reached.

1. Both weight of fabric filter and filtration pressure were important parameters for stable operation of the fabric filter separation activated sludge system. At the same water head, a lighter filter produced higher flux but the initial SS concentration of effluent was also high. However, the leakage of MLSS was much controlled by the sludge cake layer formed in 20 minutes.
2. Average SS concentration was 3.2 mg/L showing 93.4% removal. Organic removal was 91.6% in terms of COD. The 84% of removed COD was removed in the anaerobic reactor. Stable effluent quality, 13–15 mg/L in COD, was obtained.
3. Around 80% T-N removal efficiency could be obtained during the initial flux (0.4 m/d) maintenance for a 70 g/m^2 filter at a water head of 0.5 m. However the T-N removal efficiency decreased to 49.4% as the flux declined. T-N removal of 66.6% was obtained for a 35 g/m^2 filter at 0.05 m water head. Only 23% T-P removal was obtained, which is the level of the conventional activated sludge process.
4. The initial flux of 0.4 m/d was maintained for 12 days with a 70 g/m^2 filter at water head 0.5 m and 7 days with a 35 g/m^2 filter at a water head of 0.05 m. Getting the optimum point between the filter weight and water head is important to extend the operation period at the initial flux, which is the design flow rate of the system.

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