Environ. Eng. Res. Vol. 9, No. 3, pp. 113~118, 2004
Korean Society of Environmental Engineers

# PILOT-SCALE INVESTIGATION OF TWO-STEP BIOFILTRATION FOR MUNICIPAL WASTEWATER TREATMENT

**Won-kwon Lee, Woo-Keun Bae, Daewon Pak*,†**

Department of Civil and Environmental Engineering, Hanyang University

*Water Environment and Remediation Research Center, Korea Institute of Science and Technology, P.O.Box 131 Cheongryang, Seoul, 130-650, Korea

(received January 2004, accepted June 2004)

**Abstract** : Pilot plant of two-step biofiltration, a pre-denitrification step followed by a nitrifying step (CN-biofilter), was designed to treat the primary settled municipal wastewater. Performance of the two-step biofiltration was evaluated and compared with the one-step biofiltration (CN-biofilter only). The two-step biofiltration was more effective in removing COD and BOD from municipal wastewater. The pre-denitrification step reduced significantly the organic loading to the following step, CN-biofilter. Therefore, in the CN-biofilter, nitrification rate was enhanced. An important factor affecting the performance of two-step biofiltration is the recirculation ratio. The recirculation ratio determines SCOD/$NO_3$-N in the pre-denitrification step. In order to maximize total nitrogen removal, SCOD/$NO_3$-N ratio has to be maintained at 6.

**Key Words** : Biofilter, two-step biofiltration, pre-denitrification, municipal wastewater, nitrogen removal

## INTRODUCTION

Biological aerated filter (BAF) is a downflow or upflow granular media reactor with air sparging to support high biological oxidation rate. The reactor also functions as a filter and requires no additional suspended solid removal step. BAF has been used as a high-rate biological process for a variety of domestic and industrial effluents at a full scale.[1~4]

Increasingly, nitrogen removal from wastewaters is required to protect receiving waters. In the BAF, since nitrogen removal was limited due to aerobic environment provided by air sparging, a step has to be added as pre- or post-denitrification to increase nitrogen removal. Pre-denitrification, when compared to the post-denitrification, was more attractive from both economic and environmental point of view. By achieving simultaneously pre-denitrification and nitrification in two reactors, it enabled the development of two specific types of biomass. In the pre-denitrification reactor, nirate was reduced by denitrifier using organic substrates in the influent wastewater. This could reduce the requirement of an external carbon source and the organic loading to the following reactor. Due to a lowered flux of carbonaceous substrate coming from the pre-denitrification reactor, heterotrophic /autotrophic competition for oxygen can be significantly reduced. This produced an enhanced nitrification and less air consumption in the process.

† Corresponding author
E-mail: daewon@kist.re.kr
Tel: +82-2-958-5835, Fax: +82-2-958-5839

In this study, the pilot plant of two-step biofiltration, a pre-denitrification biofilter followed by CN-biofilter, was designed to evaluate the performance in treating the primary settled municipal wastewater. CN-biofilter is a BAF where COD removal and nitrification take place. The two-step biofiltration was compared with one-step biofiltration consisting of CN-biofilter only in removing COD, BOD, suspended solid and nitrogen. The factors affecting the performance of the two-step biofiltration was also investigated to optimize the operating conditions.

# MATERIALS AND METHODS

## Pilot Plant

Pilot plants of the two-step biofiltration and one-step biofiltration were designed and operated in parallel as shown in Figure 1. The CN-biofilter was the column type reactor of 0.5 m in diameter. Ceramic beads with effective diameter of 3 to 6 mm were used to charge the filter to a bed height of 2 m and 4 m in the pre-denitrification biofilter and CN-biofilter, respectively. The respective filtering volumes were 0.4 $m^3$ for the pre-denitrification biofilter and 0.8 $m^3$ for the CN-biofilter. Density and surface area of ceramic media were 1.3 and 1000 - 4000 $m^2/m^3$, respectively. The primary settled municipal wastewater was fed to the pre-denitrification biofilter in the two-step biofiltration and CN-biofilter in the one-step biofiltration. The characteristics of the primary settled municipal wastewater and operating conditions were listed in Table 1 and Table 2, respectively. Backwashing of biofilter was undertaken nor-

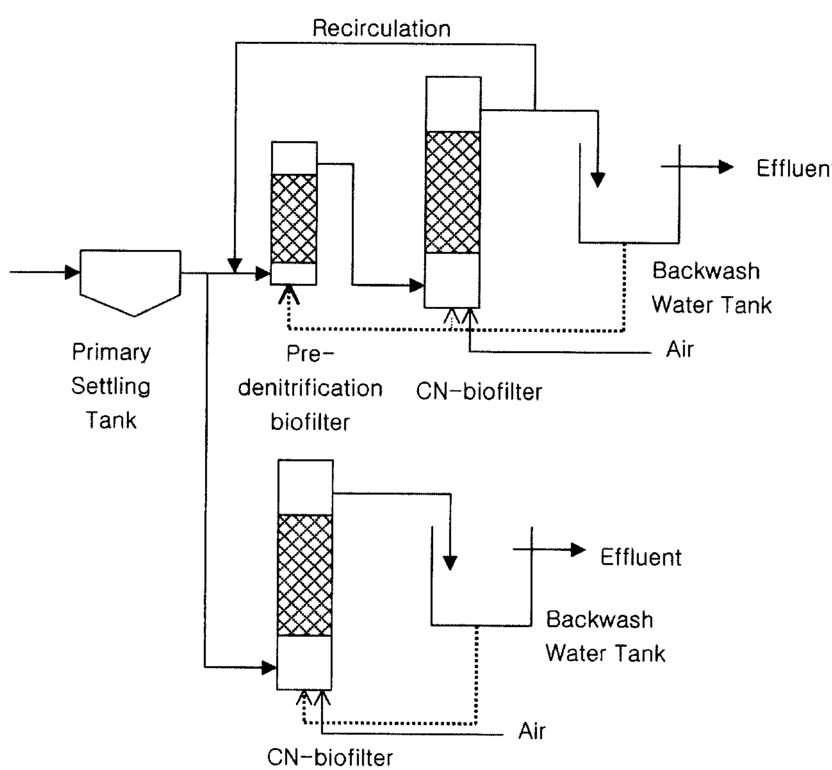


Figure 1. Pilot plant of the two-step biofiltration (pre-denitrification biofilter followed by CN-biofilter) and the one-step biofiltration system (CN-biofilter only).

Table 1. Characteristics of the primary settled municipal wastewater

| Constituent | Mean value (mg $l^{-1}$) |
|---|---|
| TCOD | 88 |
| SCOD | 27 |
| TBOD | 50 |
| SS | 51 |
| TKN | 13 |
| $NH_4$-N | 11 |
| $NO_3$-N | 2 |
| T-P | 1.6 |
| Alkalinity | 130 |

Table 2. Operating conditions of pilot plant

| Parameter | Range |
|---|---|
| Flow rate ($m^3$/day) | 10 - 45 |
| Emty bed contact time (hr) | |
| Two-step biofiltration | 0.5 - 3.0 |
| One-step biofiltration | 0.4 - 2.0 |
| Backwashing interval (hr) | 24 - 48 |
| Process air flow rate ($m^3$/hr) | 1.8 |
| Recycle ratio (%) | 100 - 300 |

mally once a day to ensure a specific volumetric throughput rate of wastewater by using air scour and backwash. Air scour and backwash water rates were 0.4 $m^3$ air/$m^3$ media/min and 0.35 $m^3$ water/$m^3$ media/min, respectively.

### Analysis

COD, BOD, $NH_4$-N, T-N, T-P, TKN, $NO_3$-N, alkalinity and SS were measured according to the Standard Methods.[5] In addition, the temperature and pH were also monitored.

## RESULTS AND DISCUSSION

### Comparison Between The Two-Step Biofiltration And BAF

Figure 2 shows COD removal rate as a function of COD loading rate in the two-step biofiltration system and one-step biofiltration. The COD loading rate varied less than 1 kg COD/$m^3$/day to 6 kg COD/$m^3$/day. As you can see, the COD removal rate increased linearly with the organic loading in both biofiltration systems. Average COD removal rate of the two-step biofiltration system was 85%, which was greater than that of one-step biofiltration. It

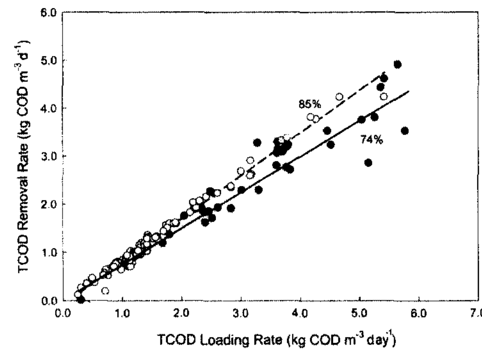


Figure 2. COD removal rate as function of COD loading rate.
( ●: one-step biofiltration, ○: two-step biofiltration)

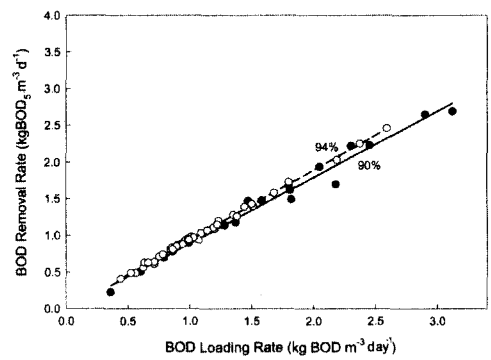


Figure 3. BOD removal rate as function of BOD loading rate.
( ●: one-step biofiltration, ○: two-step biofiltration)

seemed that most of organic matter was removed in the pre-denitrification biofilter of the two-step biofiltration. In the pre-denitrification biofilter, nitrate was reduced by denitrifiers using organic substrates in influent wastewater. Therefore this could reduce the organic loading to the following CN-biofilter. The following CN-biofilter could remove the remaining organic substance. This resulted into an enhanced organic removal by the two-step biofiltration. Figure 3 shows BOD removal rate as a function of BOD loading rate. BOD loading rate varied from 0.5 to 3 kg BOD/$m^3$/day. BOD removal rate was 94% and 90% for the two-step biofiltration and the one-step biofiltration, respectively. From the result of COD and BOD removal data, the pre-denitrification step makes the biofilter system more effective in removing organic substance from municipal wastewater.

There was no significant enhancement in suspended solid removal by the two-step biofiltration compared with the one-step biofiltration. Figure 4 shows the suspended solid removal rate as function of suspended solid loading rate. The suspended solid loading rate varied from less than 0.5 kg SS/$m^3$/day to 3.5 kg SS/$m^3$/day. The suspended solid removal rate increased linearly with suspended solid loading rate. The average suspended solid removal rates were 91% for the two-step biofiltration and 89% for the one-step biofiltration. It seems that, for the two-step biofiltration, most of suspended solids was removed in the pre-denitrification biofilter. The following CN-biofilter could not make significant difference in suspended solid removal.

However, the two-step biofiltration makes some difference in nitrification rate. Figure 5 shows $NH_4^+$-N removal rate as a function of $NH_4^+$-N loading rate. $NH_4^+$-N loading rate varied from 0.1 kg $NH_4^+$-N/$m^3$/day to 0.8 kg $NH_4^+$-N/$m^3$/day. $NH_4$-N removal rate increased linearly with $NH_4$-N loading rate. $NH_4$-N removal rates were 95% for the two-step biofiltration and 88% for the one-step biofiltration. This enhanced nitrification was made possible by the pre-denitrication step reducing the organic loading to

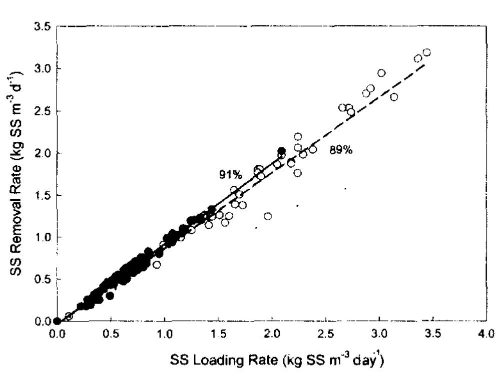


Figure 4. SS removal rate as function of SS loading rate.
(○: one-step biofiltration, ●: two-step biofiltration)

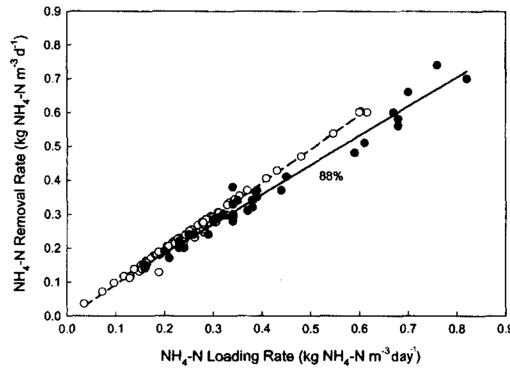


Figure 5. $NH_4$-N removal rate as function of $NH_4$-N loading rate.
(●: one-step biofiltration, ○: two-step biofiltration)

the following CN-biofilter. Elevated organic loading was reported to affect nitrification, especially *Nitrobacter acivity.*[7,8] Working with elevated organic loadings, the researchers found that Nitrobactor activity would be retarded. In the two-step biofiltration, organic matters were used as electron donor for denitrification in the pre-denitrification step. This can reduce significantly the organic loading to the following CN-biofilter. This is why nitrification rate was enhanced in the two-step biofiltration.

## Factors Affecting The Performance Of Two-Step Biofiltration

The performance of the two-step biofiltration, especially total nitrogen removal efficiency, depends on the recirculation ratio. Figure 6 shows the relationsip between the recirculation ratio and total nitrogen removal rate. The maximum removal rate of total nitrogen was obtained at between 150% and 200% of recirculation ratio. When the recirculation ratio increased more than 200%, total nitrogen removal efficiency decreased. This might attribute to high oxygen supply and short rentention time in the pre-denitrification biofilter caused by recirculation from CN-biofilter. The purified water being recirculated from the C/N biofilter had dissolved oxygen at almost saturation level. The recirculation ratio determined the loadings of oxygen and the retention time in pre-denitrification biofilter. If the oxygen loading to the pre-denitrification increases, SCOD has to be used to scavenge oxygen before denitrification. In pre-denitrification biofilter, SCOD will be removed more than theoretically required for denitrification. In addition, an increase of recirculation ratio reduces the retention time in the pre-denitrification biofilter. When the recirculation increases more than 200%, the retention time in the pre-denitrification biofilter is insufficient for denitrification.

The recirculation rate also determines the nitrate loading to the pre-denitrification step. In order to remove nitrate, a sufficient amount of electron donor has to be provided for denitrification. Figure 7 shows SCOD removal rate as function of $NO_3$-N removal rate. SCOD

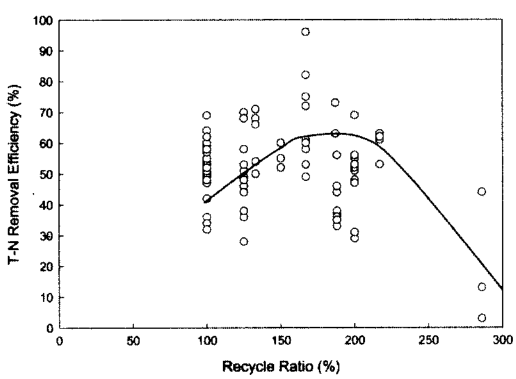


Figure 6. Total nitrogen removal as function of recycle ratio of the two-step biofiltration.

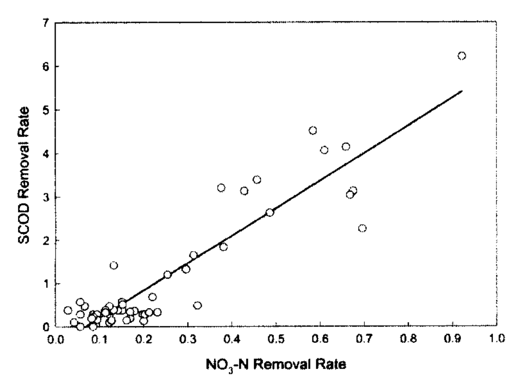


Figure 7. SCOD removal rate as function of $NO_3$-N removal rate of the two-step biofiltration.

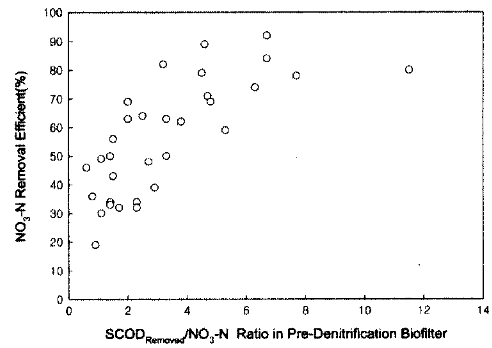


Figure 8. $No_3$-N removal efficiency as function of SCOD/$NO_3$-N ratio of the two-step biofiltration.

removal rate increased linearly with $NO_3$-N removal rate. As a general rule, 4 g of COD is needed per g of nitrate reduced.[6] However the actual value will depend on the system operating conditions and type of electron donor used for denitrification. An expression that can be used to determine the SCOD/$NO_3$-N ratio is developed from a steady-state SCOD balance.[6]

$$SCOD_u = SCOD_{syn} + SCOD_o \quad (1)$$

where $SCOD_u$ = SCOD utilized, kg COD/day
$SCOD_{syn}$ = SCOD incorporated into cell synthesis, kg COD/day
$SCOD_o$ = SCOD oxidized, kg COD/day.

For cell synthesis, the $SCOD_{syn}$ is calculated from the net biomass yield ($Y_n$) and the ratio of 1.42 kg $O_2$/kg VSS. $SCOD_o$ is the SCOD oxidized and is equal to the oxygen equivalent of the $NO_3$-N used for SCOD oxidation.

$$SCOD_{syn} = 1.42\ Y_n\ SCOD \quad (2)$$

$$SCOD_o = 2.86\ NO_3\text{-}N \quad (3)$$

Substituting Eq(2) and Eq(3) into Eq(1)

$$SCOD/NO_3\text{-}N = 2.86/(1-1.42\ Y_n) \quad (4)$$

Typical yield coefficient for denitrifying bacteria is 0.18 - 0.2 kg VSS/kg COD.[6] If this value is substituted into Eq (4), then SCOD/

$NO_3$-N ratio becomes 4. This indicates that 4 kg COD is needed per kg of $NO_3$-N. In the two-step biofiltration system, the daily nitrate removal rate by the pre-denitrification biofilter was calculated and related to the influent SCOD load. Figure 8 shows the relationship between nitrate removal rate and SCOD/$NO_3$-N ratio in pre-denitrification biofilter. Nitrate removal rate increased as SCOD/$NO_3$-N ratio increased up to 6. When SCOD/$NO_3$-N ratio increases to greater than 6, there is no further increase in nitrate removal rate. This value is greater than that calculated by using Eq(4) because some SCOD was used for scavanging dissolved oxygen in the pre-denitrification step. Therefore the recirculation ratio has to be maintained at greater than 6 of SCOD/$NO_3$-N ratio to maximize the nitrate removal.

## CONCLUSIONS

The performance of the two-step biofiltration was evaluated and compared with the one-step biofiltration. The two-step biofiltration, a pre-denitrification step followed by a nitrifying step, showed enhanced performance in removing COD and BOD. The pre-denitrification biofilter could significantly reduce organic loading to the following CN-biofilter. This led to higher nitrification in the CN-biofilter. An important factor affecting the performance of the two-step biofiltration was the recirculation ratio. The optimum range of the recirculation ratio was between 150% and 200%. The recirculation ratio determined SCOD/$NO_3$-N ratio in the pre-denitrification step of the two-biofiltration. SCOD/$NO_3$-N ratio has to be maintained at 6 to maximise total nitrogen removal rate.

## REFERENCES

1. Pak, D. and Chang, W., "Factors affecting phosphorous removal in two biofilter system treating wastewater from car-washing facility," *Water Sci. Technol.*, **41**(4-5), 487-492 (2000).
2. Rogalla, F., Payraudeau, M., Bacquet, G., Bourbigot, M. M., Sibony, J., and Gilles, P., "Nitrification and phosphorous precipitation with biological aerated filters," *WPCF*, **62**(2), 169-176 (1990).
3. Pujol, R., Canler, J. P., and Iwema, A., "Biological aerated filters: an attractive and alternative biological process," *Water Sci. Technol.*, **26**, 693-702 (1992).
4. Canler, J. P. and Perret, J. M., "Biological aerated filters: assessment of the process based on 12 sewage treatment plants," *Water Sci. Technol.*, **29**, 13-22 (1994).
5. APHA/AWWA/AWEF, Standard Methods for the Examination of Water and Wastewater. 19th edition, Washington, D.C (1995).
6. Metcalf and Eddy, Wastewater Engineering - Treatment and Reuse, 4th edn, Mcgraw-Hill (2003).
7. Alleman, J. E., "Elevated nitrite occurrence in biological wastewater treatment system," *Water Sci. Technol.*, **17**, 409-419 (1984).
8. Balmelle, B., Nguyen, K. M., Capdeville, B., Cornier, J. C. and Deguin, A., "Study of factors controlling nitrite build-up in biological processes for water nitrification," *Water Sci. Technol.*, **26**, 1017-1025 (1992).