Nutrient removal from low strength domestic wastewater in sequencing batch biofilm reactor

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Abstract Nutrient removal was investigated in a packed bed column, which was operated by changing of aerated and non-aerated periods. Good removal efficiencies for nitrogen and phosphorus were obtained at long aeration period. Highest nitrification efficiency was observed in run3 because the aeration period was enough to allow nitrification. NO_3 concentration was not significantly changed during the cycle, because of simultaneous denitrification during aerobic stage. Nitrogen and phosphorus removal efficiencies reached to 71 and 74% in run3 respectively. Effluent concentrations of TKN, Tot.P, NH_4 and NO_3 were found as 3.8, 3, 1 and 2.5 mg/l respectively.

Keywords Biofilm; nutrient removal; sequencing batch reactor

Introduction

Nutrient removal from wastewater has become important in order to protect water bodies from eutrophication, especially in lakes and highly enclosed bays. Modified SBR systems incorporating alternating aerobic and anoxic/anaerobic stages either in suspended or attached culture have been used to obtain good removal of organics, SS and nitrogen by nitrification-denitrification processes. SBR activated sludge processes are seen to have several advantages over conventional continuous flow systems. It is well known that nitrogen and phosphorus removal is possible in a single tank SBR if operating conditions are properly selected to introduce anaerobic, aerobic and anoxic reactions during a cycle without any addition of separate reactors, recycling lines or clarifiers.

Success of system efficiency mainly depends on strength of wastewater, reactor configuration, cycles etc. The SBR also reduces the need for continuous control of parameters such as inlet flow, sludge conditions etc. (Vuoriranta *et al*. 1993; Rusten and Eliassen, 1993; Bortone *et al*., 1994). The cycle that typically consists of five periods such as fill, react, settle, decant and idle can be altered to accommodate for specific operating conditions and to yield the desired results (Sheker *et al*., 1993).

Denitrification has been observed (Vuoriranta *et al*., 1993) in filling and anaerobic/anoxic stage after nitrification stage was completed in suspended culture. Since simultaneous nitrification-denitrification has particularly been occurring (Siebritz *et al*., 1983; Munoz-Colunga and Gonzalez-Martinez, 1996; Pastorelli *et al*., 1999), inhibition effects of nitrate on P removal have been not a problem in anaerobic stage in biofilm SBR system. The removal of COD and TKN has been found as 95% and 92% respectively. Tot. P reduction has been found between 66.9–90% depending on operational conditions (Farchill *et al*., 1993; Marklund, 1993; Subramanian *et al*., 1994). Highest removals for COD and PO_4 rates have been found with 12-hour cycles in biofilm SBR (Munoz-Colunga and Gonzalez-Martinez, 1996). The nitrogen removal efficiency has ranged (Farchill *et al*., 1993) from 74.5 to 83.9% with HRT about 12 hour.

In this study, effectiveness of packed bed column for carbon, nitrogen and phosphorus removal was investigated by changing the periods of anaerobic, aerobic and anoxic conditions and hydraulic retention time.

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Materials and methods

Figure 1 shows the schemes of the column with settling tank used in the present work. During the experimental studies the settled sludge in the tank was continuously recycled to the system. The column has a volume of 21 l and was packed with 1 in. size pall rings of specific area 190 m^2/m^3; thus the packing provided a total surface area of 3.95 m^2. Temperature was held at 20±1°C in the laboratory.

Supplying of air and returning of the wastewater to the column respectively provided mixing in the column in aerated and non-aerated cycles. Pumps provided feeding, returning and recycling. The system was worked at 2 HRTs. Synthetic sewage was used as a feeding solution. The experiment was divided into four runs having 6 cycles. Operative cycles of the column are given in Table 1. Analyses of total organic carbon, TKN, NH_4, NO_2-NO_3 and Tot.P have been carried out according to *Standard Methods*.

Dissolved oxygen concentration during the aeration period was held around 4 mg/l . Samples were taken from the effluent line of the settling tank. The reactors were firstly seeded with sludge from domestic sewage treatment plant and then operated by feeding of synthetic sewage for about 4 months to develop a biofilm on plastic media and to obtain rich biomass population which can work under anaerobic/anoxic/aerobic conditions. During the experiments, settling period was not applied before drawing because the system contained very low amount of suspended solids.

Acetate has been found (Sheker *et al*., 1993) an efficient carbon substrate after propionate was added to the system to enhance denitrification. However, it has been found (Farchill *et al*., 1993) that the presence of acetate under aerobic conditions might contribute to deterioration of the phosphorus efficiency. The ratio of TOC to NO_3 was adjusted to 15, 24 and 15 by adding of acetate as a carbon source at the start of the second non-aerated period in runs1, 2 and 3 respectively. Acetate was only added at the start condition in run4. The ranges for the main parameters of the feeding solution for each run are given in Table 2.

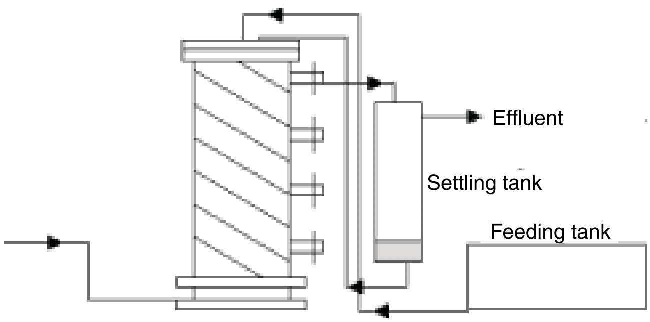

Figure 1 Schematic representation of the packed bed column

Table 1 Operating cycle of SBR system

Reaction sequence (hours)	Run1	Run2	Run3	Run4
Fill	0.2	0.2	0.2	0.2
Non-aerated	4	2	2	3
Aerated	3.5	6	2	2
Non-aerated	16.5	16	3	1
Aerated	0.5	0.5	16.5	2.5
Draw	0.2	0.2	0.2	0.2

Table 2 Influent concentrations of wastewater for four experimental runs

Parameters mg/l	Run1	Run2	Run3	Run4
TOC	52	52	52	84
Tot.P	10	14	12	17.9
TN	20.4	18.6	15	14

Results and discussions

SBR was operated at 4 runs by changing the periods of anaerobic/anoxic/aerobic conditions. Cycle duration was 24.5 and 8.5 hours for first 3 runs and last run respectively. After the anaerobic pretreatment of wastewater with retention time of 2–4 hours, the reactor was cyclically exposed to aerobic, anaerobic and aerobic conditions. Total aerated time was 4, 6.5, 18.5 and 4.5 hours in the experimental runs with number from 1 to 4 respectively. Samples were taken at the start of each stage and also at the end of the cycle from the effluent. The reactor was operated for at least 2 months to complete the adaptation period and also to get the stable condition at new situation for the each run.

Phosphorus and TOC removal

Figure 2 shows Tot.P and TOC profiles obtained in one cycle for 4 experimental runs. In run1 P concentration was not changed in first unaerated period whereas P release was highly marked in the second anaerobic stage of 16.5 hours. Removal of P from 10 to around 2 mg/l was seen during 3.5 hours of aeration period. Uptake of P was very low, because of short aeration time. TOC was removed from 52 mg/l to around 14 mg/l in first 7.5 hours. At the start of anaerobic stage, TOC concentration was increased to 38 mg/l with addition of acetic acid for denitrification and it was removed to the concentration of 18 mg/l at the end of the cycle (Figure 2a).

Contrary to run1, P was slightly released in the first 2 hours of the anaerobic stage and significantly removed down to the concentration of 3.6 mg/l at the end of first aerobic stage in run2. Than it only decreased to 9.7 mg/l after release to 15.4 mg/l in the anaerobic stage. Finally, removal efficiency only remained at 31%, which was the lowest value among the other runs because of insufficient aeration period. This could be explained by relatively high TOC loading compared to the run1. Removal was not good, because the last aeration time of 0.5 hour for the uptake was not long enough. TOC was removed from 52.5 to 11.2 mg/l at the end of the second stage, at which point it was increased to 72 mg/l by acetate addition. During 16 hours of the anaerobic stage, TOC was removed to the concentration of 37 mg/l (Figure 2b).

In run3, little removal was observed in the first 2 hours of anaerobic stage instead of releases in Tot.P. It was than removed rapidly in the next aerobic stage during two hours. Final P concentration declined to 3 mg/l after the end of last aerobic stage within 16.5 hours. Highest P removal efficiency was found as 74% among the other runs. TOC was removed from 52 to 8.8 mg/l in first anaerobic and the aerobic stage that was 4 hours. TOC increased to 27 mg/l, then was treated to 13 mg/l at the end of aerobic stage (Figure 2c). The reactor was operated at longer aerobic periods in run3 than that in other runs. In run4 important changes in Tot.P were not observed in first anaerobic and aerobic conditions. Removal was mostly realized at last aerobic part in this run (Figure 2d). Total removal efficiency for P was calculated as 40%. TOC removal was mostly observed at aerobic period too. However it was the highest value with 86% with comparing to the other runs.

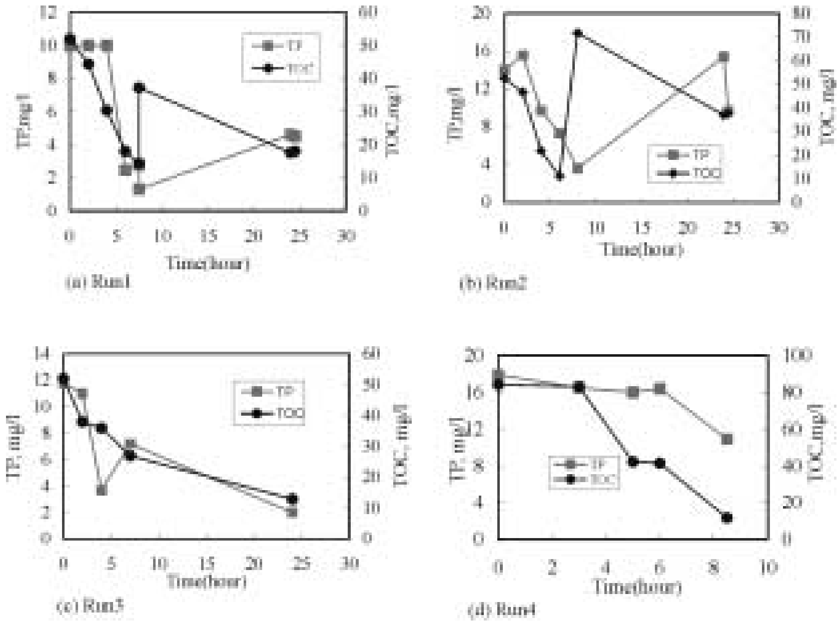

Figure 2 Changes of Total P and TOC concentrations with time at different operational conditions

Nitrogen removal

Figure 3 shows the changes of TKN, NH_4, and NO_3 with time in one cycle. NO_3 concentration was not significantly changed during the one cycle, because of simultaneous denitrification during the aerobic stage. TKN was removed from 17.5 mg/l to 12 mg/l at first anaerobic and aerobic stage in first 7.5 hours of cycle in run1. The concentration decreased to 7.5 mg/l at the end of cycle. Initial NH_4 concentration of 10.5 mg/l was only decreased to 7 mg/l at the effluent. However, nitrification rate was calculated as 12.7 mg/l .d according to the N mass balance. Removal efficiency for TN was found as 46% (Figure 3a).

In run2, TKN values dropped from initial 16.8 mg/l to 8.7 mg/l. TKN removal efficiency was found as 48%. Little accumulation in NH_4 concentration was observed at first 6 hours of aeration stage. However, it removed from 8 to 6 mg/l at the end of cycle. Removal rate of NH_4 was about 10 mg/l .d. Nitrification was lower than that in run1 in spite of increased aeration period in this run. This could be explained with inhibition of the increased TOC loading.

In run3, TKN removal efficiency reached to 71% and 16.2 mg/l .d of NH_4 was converted to NO_3. Highest nitrification efficiency was observed in this run because of highest aerobic period. Two reasons to achieve almost complete nitrification were identified:

1) the organic loading was lower than run2 and it probably caused lower inhibition effects,
2) the aeration period was enough to allow nitrification. Most of the nitrogen was converted sequentially from TKN to NH_4, NO_3 and finally N_2. Significant N change as TKN, NH_4 and NO_3 was not observed in the system in run4.

TKN removal was not observed in Run4. Nitrification and denitrification reactions were also not realized in this case (Figure 3d).

Table 3 gives the overall results measured during one cycle of runs 1 to 4. (a) TOC removal efficiency was varied from 28 to 86%. The lower removal efficiency in TOC could be explained by addition of high amount of acetate in the run2 to enhance anaerobic condition. (b) The highest nitrogen removals were achieved with aeration period of 18.5 h in run3. TKN removal efficiency was found as 71%, and removal rate of NH_4 was 16.2 mg/l.d in this run. (c) NO_3 concentrations of the effluent were ranged between 1.6–3.3 mg/l for all of the runs. (d) Highest P removal was found as 74% in run3.

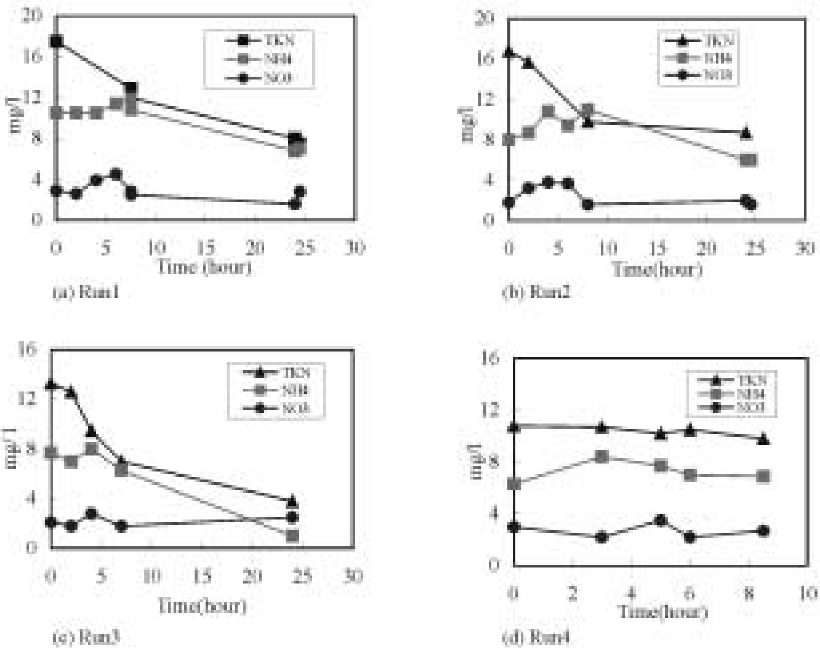

Figure 3 Changes of TKN, NH_4 and NO_3 concentrations with time at different operational conditions

Figure 4 shows monthly average data obtained during the experimental studies. Cycle duration was hold at about 24 hours during the experiments except for 8th and 10th month. Concentration of Tot.P in the influent ranged between 27–10 mg/l . Effluent concentrations varied between 3–18 mg/l depending on operational conditions (Figure 4a).

Tot. P concentrations were ranged between 10–27 mg/l in the influent. It was found decreasing to 3–18 mg/l in the effluent (Figure 4a). Initial TOC values decreased from 52–162 mg/l to 12–81 mg/l in the effluent (Figure 4b). Removal of TKN was not very high, however it reduced as low as 3.8mg/l in the effluent (Figure 4c). Removal of NH_4 was good in some operational cases; best removal in NH_4 was observed in 15th month. It was reduced to 1 mg/l in the effluent (Figure 4d). NO_3 concentration in the effluent generally remained at low level. Influent and effluent concentration for NO_3 did not show big difference. The concentration in the effluent was between 1.6–4.7 mg NO_3/l (Figure 4e).

Conclusions

Effect of anaerobic, anoxic and aerobic periods on nutrient removal was investigated by using packed bed column. In present study, the column was completely based on attached growth reactor and the system produced very low amount of suspended sludge. The main conclusions are as follows.

Table 3 Experimental results

Run No	Tot. Aero. Period hours	Tot. Anae. Period hours	Effluent concentrations (mg/l) TOC	TKN	NH_4	NO_3	Tot.P	Total removals (%) TOC	TKN	NH_4 (mg/l.d)	Tot.P
1	4	20.5	21	7.5	7	3.5	4.6	60	57	12.7	54
2	6.5	18	37.6	8.7	6	1.6	9.7	28	48	10	31
3	18.5	5	13	3.8	1	2.5	3	75	71	16.2	74
4	4.5	4	12	9.8	7	2.7	11	86	9	–	40

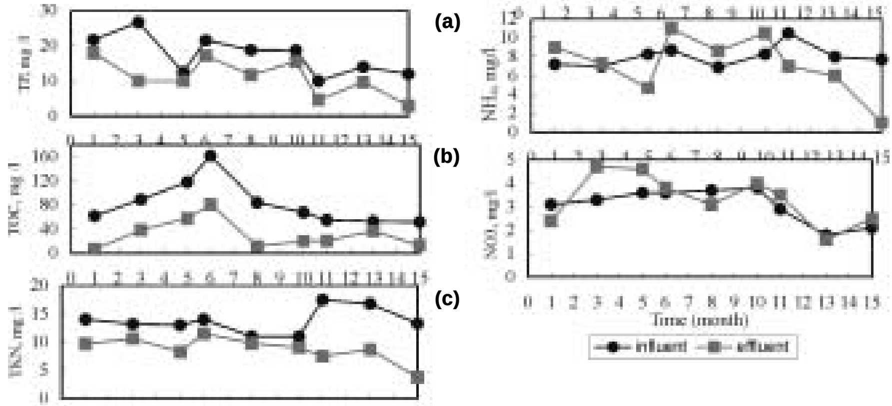

Figure 4 Monthly average data

a) Degradation rate of NH_4 and TKN mostly became the limiting reaction in the case of insufficient aeration period. Comparison of the results in run1 and 3 showed that decrease of total aerated time affected total nitrogen removal by limiting the reaction time, which was necessary for the degradation of TKN and nitrification. Accumulation of NH_4 was not observed during the anaerobic pretreatment and first aerobic stage for run1, however in run 2, NH_4 accumulated from 8 to 11 mg/l as a result of TKN degradation (Figure 4b). Duration of aerobic period in run3, which was selected as 18.5 h, was sufficient for TKN degradation and nitrification reaction. Nitrification is also affected by applying of comparably high TOC concentration in run2 and 4. In run4, high degree of anaerobic pretreatment did not show good results in nutrient removal.

b) Important NO_3 accumulation was not observed since denitrification simultaneously occurred even under aerated stage.

c) Highest P release was observed in the longest anaerobic phase in run2 however removal efficiency was only reached to 31%. Highest P removal was achieved in run3; this means that longer aerobic periods improve P removal. Operating results from the run3 can be used to achieve high effluent quality particularly in nutrients.

d) In run4, the system only removed TOC and Tot.P at the efficiency of 86% and 40% respectively.

References

Bortone, G., Malaspina, F., Stante, L. and Tilche, A. (1994). Biological nitrogen removal and phosphorus removal in an anaerobic/anoxic sequencing batch reactor with separated biofilm nitrification. *Wat. Sci. Tech.*, **30**(6), 303–313.

Farchill, D., Goldstein, M., Kanarek, A. and Aharoni, A. (1993). Biological nutrient removal in a single sludge plant. *Wat. Sci. Tech.*, **27**(7–8), 63–70 (1993).

Marklund, S. (1993). Cold Climate Sequencing Batch Reactor Biological Phosphorus Removal-Results 1991–92. *Wat. Sci. Tech.*, **28**(10), 275–282.

Munoz-Colunga, A. and Gonzalez-Martinez, S. (1996). Effects of population displacements on biological Phosphorus removal in biofilm SBR. *Wat. Sci. Tech.*, **34**(1–2), 303–313.

Pastorelli, G., Canziant, R., Pedrazzi, L. and Rozzi, A. (1999). Phosphorus and nitrogen removal in moving-bed Sequencing batch biofilm reactors. *Wat. Sci. Tech.*, **40**(4–5), 169–176.

Rusten, B. and Eliassen, H. (1993). Sequencing Batch Reactors for Nutrient Removal at Small Wastewater Treatment Plants. *Wat. Sci. Tech.*, **28**(10), 233–242.

Sheker, R.E., Aris, R.M. and Shieh, W.K (1993). The effects of fill strategies on SBR performance under Nitrogen deficiency and rich conditions. *Wat. Sci. Tech.*, **28**(10)**,** 259–266.

Siebritz, I.P., Ekama, G.A. and Marais, G.V.R. (1983). A parametric model for biological excess phosphorus removal. *Wat. Sci. Tech.*, **15**(3/4), 127–152.

Subramanian, K., Greenfield, P.F., Ho, K.M., Johns, M.R. (1994). Efficient Biological Nutrient Removal in High Strength Wastewater Using Combined Anaerobic-Sequencing Batch Reactor Treatment. *Wat. Sci. Tech.*, **30**(6), 315–321.

Vuoriranta, P., Mariam, D.H. and Kautia, E. (1993). Organic Carbon and Nitrogen Removal from Wastewater of Single Houses and Small Separate Establishments Using a Simple Sequencing Batch Reactor. *Wat. Sci. Tech.*, **28**(10), 243–249.