[Japanese Journal of Water Treatment Biology Vol.37 No.1 19-27 2001]

Effect of Step Feed Ratio and Temperature on Nitrogen Removal in an Anoxic-Oxic Activated Sludge Process

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Abstract

A step-feed anoxic-oxic activated sludge process is one of the most practical methods for the up-grading of existing conventional ones to enhance nitrogen removal efficiency, eliminating internal water recirculation and supplement of external carbon source for denitrification. In this study, effect of step-feed ratio on the biological nitrogen removal of the process was investigated by a kinetic model in pilot-scale experiments. The results showed that the optimal step-feed ratio for nitrogen removal depended on water temperature in the tanks. There was little effect of the step-feed ratio on T-N removal at relatively low temperatures around 17℃. As the water temperature became lower, the nitrification efficiency seriously decreased, and then the effect of the step-feed on denitrification would be canceled. On the other hand, the optimal step-feed ratio for T-N removal was around 0.4 at 20 to 30℃. At higher temperatures, denitrification process seemed to be rate limited at the lower step-feed ratios, while the nitrification process would be rate limited at higher step-feed ratios.

Key words : upgrading, step-feed ratio, biological nitrogen removal, nitrification, denitrification, kinetic model, simulation

INTRODUCTION

In Japan, 658 municipal sewage treatment plants out of 876 have adopted conventional activated sludge processes which are designed mainly for biochemical oxygen demand (BOD) removal[1)]. Nowadays nutrient removal is seriously demanded for conformance to environmental quality standard on nitrogen and phosphorus especially for Osaka Bay and Tokyo Bay[2)], so that sewage treatment plants should be enhanced nutrient removal efficiency. Upgrading the existing conventional process is one of the most cost-effective solutions for nitrogen removal[3-6)]. A step-feed anoxic-oxic activated sludge process consists of configuration of anoxic and oxic conditions in tanks in series and receives influent as an external carbon source for denitrification in anoxic tanks. Anoxic and oxic zones within the existing reactor are created and the step-feed configuration is made for upgrading of a conventional process if a reactor has enough capacity of maintaining enough nitrifiers. Main differences between the process and a conventional one are control of oxygen supply into tanks and providing other intake flows of influent, so that the concept of upgrading is easily applicable to the existing conventional plants. It was reported that a step-feed anoxic-oxic activated sludge process was more economical than the A_2O process, one of major processes for nitrogen removal, because the process requires recirculation of nitrified liquor[7]. Upgrading the conventional process to the A_2O process cannot be done without the expansion of reactor volumes and newly constructing a huge pump for recirculation of nitrified liquor.

However, the step-feed anoxic-oxic process has many factors in respect of nutrient removal such as the step-feed ratio[8, 9], water temperature[10], sludge retention time (SRT)[10, 11], oxygen supply, volume of the tanks[3, 8], and influent composition[8]. Among these factors, the step-feed ratio is most controllable for operation of the process. In this study, effects of the step-feed ratio with change of water temperature of mixed liquor were focused and examined by computer simulation analysis in an upgraded pilot-scale plant.

EXPERIMENTALS

Pilot plant An activated sludge pilot plant used in this study had a reactor of 240 *l* and a secondary settling tank of 98 *l* as depicted in Fig. 1. The reactor consisted of five tanks (Tanks 1 - 5) with the nearly same volume: anoxic condition in Tanks 1 and 4 and aerobic in Tanks 2, 3, and 5. Since this plant had been originally designed as a conventional activated sludge process with step-feed lines[12], it was easy to change its operation scheme from the conventional process to the anoxic-oxic process by reducing air supply in Tanks 1 and 4 where two influent lines led inflow.

The biological activities in an upgraded pilot plant are considered as follows. In Tank 1, denitrification is carried out by heterotrophs that utilize organic compounds in influent and nitrate nitrogen (NO_3-N) returned from the settling tank. Polyphosphate stored within the cells of activated sludge microorganisms is released as orthophosphate (PO_4-P) when the condition in the tank becomes anaerobic (without NO_3-N). BOD removal, nitrification, and luxury uptake of PO_4-P simultaneously take place in Tanks 2 and 3. In Tank 4, NO_3-N produced in Tanks 2 and 3 is denitrified with expense of organic compounds as an internal carbon source in the influent. Tank 5 receives ammonia nitrogen (NH_4-N) and organic compounds from the previous tank and removal of remaining BOD and nitrification are expected.

Synthetic sewage Synthetic sewage was used for eliminating the effect of variation of influent quality on nutrient removal. The concentrated synthetic sewage was restored in a refrigerator at 4℃ and its chemical composition was as follows : peptone 30 g/*l*, meat extract 20 g/*l*, NaCl 1 g/*l*, KCl 1 g/*l*, $CaCl_2 \cdot 2H_2O$ 1.32 g/*l*, $MgSO_4 \cdot 7H_2O$ 1 g/*l*, $Na_2HPO_4 \cdot 12H_2O$ 10 g/*l*, NH_4Cl 10 g/*l*, $NaHCO_3$ 20 g/*l*, and tap water 1 *l*. The sewage was diluted about 200 times with tap water before entering into Tanks 1 and 4 (Fig. 1). The influent quality after dilution was described in Table 1.

Operating conditions The seed activated sludge was taken from a full-scale plant in Suita, Osaka, and cultivated for more than two weeks for acclimatizing it to synthetic wastewater. As shown in Table 2, six experimental runs were performed by changing step-feed ratios from 0.00 to 0.75. Experimental runs in the pilot plant were conducted from September 1999 to February 2000 in the engineering laboratory at Osaka University. Basically the experiments were carried out without temperature control, but heaters were used in Runs 5 and 6 for maintaining the tanks at 17℃. It is known

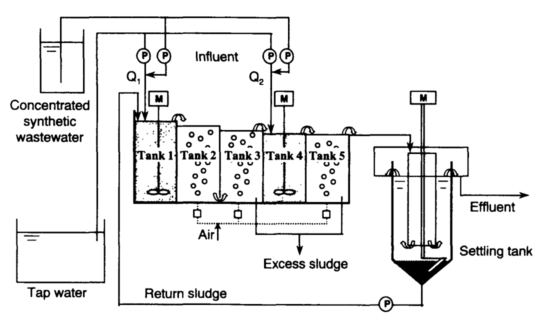

Fig. 1 Flow scheme of step-feed anoxic-oxic activated sludge pilot-plant. Two influent lines bring wastewater into anoxic tanks 1 and 4. Tanks 2, 3, and 5 are under oxic conditions.

that stable operation for continuous activated sludge processes in experiments using synthetic sewage is hard to be maintained because the bulking problem frequently occurs. Therefore, each run was carried out in the short period as possible as stable treatment performance was maintained. The step-feed ratio (r) was defined as $Q_2/(Q_1+Q_2)$, whereas Q_1 and Q_2 are influent flow rate for Tanks 1 and 4, respectively. During all experiments, dissolved oxygen (DO) in Tanks 2, 3, and 5 was maintained at 2 - 3 mg/l and total influent flow rate and return sludge flow rate were maintained constantly. The excess sludge was withdrawn from Tanks 3 and 5 and SRT was maintained 15 days at a constant.

Analytical methods Effluent samples were collected at one hour interval by auto-sampler (Sigma type 900, Tokyo) and composite samples were analyzed after filtration by 1.0-μm-pore-size glass microfiber filters (Whatman, Meidston). Mixed liquor in each tank was sampled analyzed two or three times in each run with the same manner for effluent. BOD and total organic carbon (TOC) concentrations were measured by BOD meter (DKK type 7161, Tokyo) and TOC analyzer (Shimadzu TOC-5000, Kyoto), respectively. Mixed liquor suspended solid (MLSS), total nitrogen (T-N), NO_3-N, NH_4-N, nitrite nitrogen (NO_2-N), total phosphorus (T-P), and PO_4-P were measured according to JIS (Japan Industrial Standards) K0102. Total Kjeldahl nitrogen (TKN) and organic nitrogen (Org-N) were calculated based on the values of T-N, NH_4-N, NO_3-N, and NO_2-N.

Table 1 Characteristics of influent

BOD (mg/l)	250
TOC (mg/l)	120
T-N (mg/l)	38
TKN (mg/l)	37
Org-N (mg/l)	9.7
NH_4-N (mg/l)	27
NO_3-N (mg/l)	1.0
T-P (mg/l)	6.7
PO_4-P (mg/l)	5.5
pH	7.2
Alkalinity (mg/l)	120

MODELING AND SIMULATIONS

Kinetic models The model developed by Ichikawa et al.[13] was applied to the operations in the pilot plant. The model was originally developed for simulating the nitrification-denitrification process with nitrified liquor recirculation treating synthetic sewage whose chemical composition was similar to that used in this study. Following assumptions were originally made:

(i) Denitrifiers were identified as heterotrophs,

(ii) Endogenous decay of heterotrops and nitrifiers led to the production of BOD and Org-N,

(iii) BOD removal was carried out by respiration for obtaining energy, by cell growth of heterotrophs, and by denitrification,

Table 2 Operating conditions and performance of the pilot plant

	Run 1 13 Oct– 28 Oct	Run 2 29 Oct– 10 Nov	Run 3 11 Nov– 27 Nov	Run 4 30 Sep– 12 Oct	Run 5 6 Dec– 15 Dec	Run 6 16 Dec– 25 Dec
Step feed ratio $r=Q_2/(Q_1+Q_2)$	0.00	0.25	0.40	0.50	0.60	0.75
Average water temperature in Tanks (℃)	21.7	19.4	17.6	25.8	17.0[a]	17.0[a]
Total influent rate Q_1+Q_2 (l/d)	600					
Return sludge flow rate (l/d)	570					
Waste sludge flow rate from the Tanks 3 and 5 (l/d)	10.4 and 5.6 (SRT 15d)					
TOC removal (%)	96±1	96±1	96±1	91±2	92±2	95±1
T-N removal (%)	49±5	49±2	55±2	61±7	54±4	46±3
T-P removal (%)	27±11	29±7	30±5	36±20	28±15	21±6

[a] Water temperature in the Tanks was controlled by a heater during Runs 5 and 6.

(iv) The cell growth of heterotrophs was not affected by DO concentration,

(v) BOD removal by cell growth and respiration led conversion of Org-N to NH_4-N, and

(vi) The chemical formula of synthesized bacterial cells was $C_5H_7NO_2$.

Reaction rate expressions were defined in Table 3. Temperature adjustments of the reaction rate expressions (1) - (4) were different from the original expressions[13].

Stoichiometry Stoichiometry for the reaction model was shown in Table 4. Parameter values were given as shown in Table 5 and coefficients of temperature θ_{AN}, θ_B, θ_d, and θ_{ON} according to the literature of Barker and Dold[14] for simulations. Parameter fitting was not carried out in this study.

Mass balance and simulation processing Mass balance was applied for the pilot-plant configuration. There were eight substrates in the kinetic models, therefore, eight differential equations were obtained for each tank in the reactor and the settling tank.

Following assumptions were made for simulations :

(vii) Each tank was completely mixed,

Table 3 Reaction rate expressions

(1) BOD removal rate by respiration for obtaining energy [a]

$$R_{BO} = -K_{BO}\,\theta_B^{\,T-15}\,\frac{S_O}{S_O+K_{OH1}}\,S_B X_H$$

(2) BOD removal rate by synthesis of new cells [a]

$$R_{BA} = -K_{BA}\,\theta_B^{\,T-15}\,S_B X_H$$

(3) Denitrification rate [a]

$$R_{AN} = -K_{AN}\,\theta_{AN}^{\,T-15}\,\frac{S_{NO}}{S_{NO}+K_{NO}}\,\frac{K_{OH2}}{S_O+K_{OH2}}\,S_B X_H$$

(4) Nitrification rate [a, b]

$$R_{ON} = -K_{ON}\,\theta_{ON}^{\,T-15}\,\frac{S_{NH}}{S_{NH}+K_{NH}}\,\frac{S_O}{S_O+K_{OA}}\,F_{PH} X_A$$

$$F_{PH} = 1-0.833(7.2-pH) \qquad 6.2 \leqq pH \leqq 7.2$$

$$pH = 1.514\exp(0.00232 S_{ALK})+5 \qquad 50 \leqq S_{ALK}$$

(5) Endogenous decay rate of heterotrophs [b]

$$R_{bH} = -b_{15}\,\theta_d^{\,T-15} X_H$$

$$b_{15} = b_A + (b_O - b_A)\frac{S_O}{S_O+K_{OH1}}$$

(6) Endogenous decay rate of nitrifier [b]

$$R_{bA} = -b_{15}\,\theta_d^{\,T-15} X_A$$

(7) Overall volumetric oxygen-transfer coefficient [a, b]

$$K_{LA} = 2.0$$

$$S_{OS} = 14.16-0.3943T+0.0007714T^2-0.0000646T^3$$

[a]This study, [b]Ichikawa et al., (1997).

Table 4 Process kinetics and stoichiometry for reaction model [a]

	S_B	S_{ORG}	S_{NO}	S_{NH}	X_H	X_A	S_O	S_{ALK}	Reaction rate
(1) BOD removal by respiration	1	C_N		$-C_N$			1	$-Y_{AN}C_N$	R_{BO}
(2) BOD removal by cell synthesis	1	C_N		$Y_{NB}-C_N$	$-Y_{XS}$			$Y_{AN}(Y_{NB}-C_N)$	R_{BA}
(3) Denitrification	Y_{SN}	$Y_{SN}C_N$	1	$-Y_{SN}C_N$				$-Y_{AN}(Y_{SN}+1)$	R_{AN}
(4) Nitrification			$-Y_{NO}$	1		$-Y_{XN}$	Y_{ON}	$Y_{AN}(1+Y_{NO})$	R_{ON}
(5) Decay of heterotrophs	$-Y_{OX}$	$-Y_{NX}$			1				R_{bH}
(6) Decay of nitrifier	$-Y_{OX}$	$-Y_{NX}$				1			R_{bA}
(7) Oxygen uptake							1		$K_{LA}(S_{OS}-S_O)$

[a]Ichikawa *et al.*,[13].

Table 5 Values of constant

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
b_A	0.01[a]	K_{NO}	0.1[a]	θ_{AN}	1.029[b]	Y_{OX}	1.42[c]
b_O	0.05[a]	K_{OA}	0.5[a]	θ_{ON}	1.123[b]	Y_{AN}	3.571[c]
K_{AN}	0.009[a]	K_{ON}	3.0[a]	θ_d	1.029[b]	Y_{XS}	0.8[c]
K_{BA}	0.025[a]	K_{OH1}	0.5[a]	Y_{NB}	0.0744[c]	Y_{NO}	0.98[c]
K_{BO}	0.025[a]	K_{OH2}	0.1[a]	YS_N	2.857[c]	Y_{ON}	4.48[c]
K_{NH}	0.1[a]	θ_B	1.029[b]	Y_{XN}	0.1227[c]	Y_{NX}	0.124[c]

[a]Ichikawa *et al.*,[13], [b]Barker and Dold[14], [c]Stoichiometry.

(viii) The organic substrates in the model was simply handled as BOD_5 although it was originally did as the ultimate ($BOD_U = BOD_5/0.7$)[13],

(ix) There was no change in quality of influent during the experiment,

(x) Solid/liquid separation was completely carried out and no reaction occurs in the settling tank, and

(xi) DO concentration in Tanks 2, 3, and 5 was 2.5 mg/l and K_{LA} values in Tanks 1 and 4 were 2.0.

These differential equations were solved by using the 4th order Runge-Kutta method in the simulations till it reached the steady state.

RESULTS

Performance of the pilot plant TOC, T-P, and T-N removals in Runs 1-6 were summarized in Table 2. The bulking problem occurred with prolonged operations in preliminary experiments as mentioned in operating conditions (data not shown). Therefore, each Run was carried out in the short period as possible as stable treatment performance was maintained although the results does not always show exact steady states for the operation conditions. In all Runs, TOC was removed sufficiently but removal of T-P was ineffective because Tank 1 was not kept under strictly anaerobic conditions by the disturbance of NO_3-N in return sludge. Concentrations of nitrogen species in effluent were summarized in Fig. 2. NO_2-N was negligible in all Runs. Nitrification rate was not high enough for complete nitrification in Runs 3, 5, and 6, resulting that NH_4-N concentration in effluent was relatively high. Low water temperatures (see Table 2) would be the reason for inhibition of nitrification process. T-N removal slightly increased from Run1 to Run 4 and reached the maximum value of 61% in Run 4 with step-feed ratio of 0.5 and decreased in Runs 5 and 6. The highest T-N removal in Run 4 would attribute to not only the effect of step-feed ratio but also the average water temperature which was the highest among all the runs.

Substrate profiles Figure 3 shows typical experimental and simulated results on the MLSS, BOD, and nitrogen concentrations in the tanks. Measured and computed plots of MLSS, Org-N, and NH_4-N showed a good agreement without any parameter fitting. TOC concentrations were measured instead of BOD, and the TOC and computed BOD values (S_B) also showed a good agreement. In case of NO_3-N (S_{NO}), the measured and computed values, especially, in Tanks 2, 3, and 5 in Runs 1, 2, and 3 showed difference.

In Run 1 with hydraulic retention time (HRT) of 10 hours, the nitrification process proceeded sufficiently according to Fig. 3, however, the denitrification process in Tanks 1 and 4 was restricted because of insufficient carbon sources. On the other hand, in Runs 2 - 6, the denitrification process successfully proceeded by the step-feed into Tank 4. These results suggested that the step-feed configuration was a promising method for upgrading the existing wastewater plants to enhance nitrogen removal efficiency.

Effect of step-feed ratio and water temperature on nitrogen removal Effects of the step-feed ratio and water temperature on TKN and T-N removal in the pilot plant were shown in Fig. 4. Computer simulation was done with the temperature of 10, 15, 17, 20, 25 and 30℃. The computed lines showed the lowest TKN and T-N removals at 10℃, the middle level at 15 to 25℃ and then the highest at 30℃. The measured data showed lower values than the computed lines especially Runs 1, 2, and 4. TKN removal increased with decrease in the step-feed ratio. There was little effect of the step-feed ratio on T-N removal at relatively low temperatures.

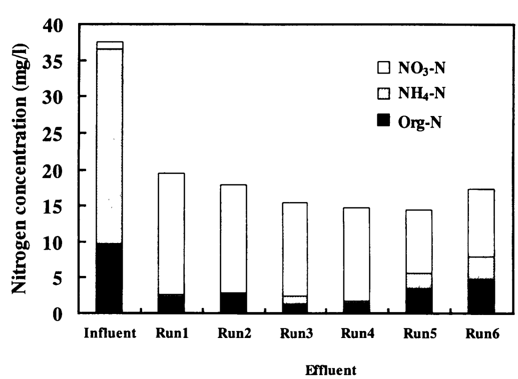

Fig. 2 Nitrogen concentration in influent and effluent in Runs 1-6

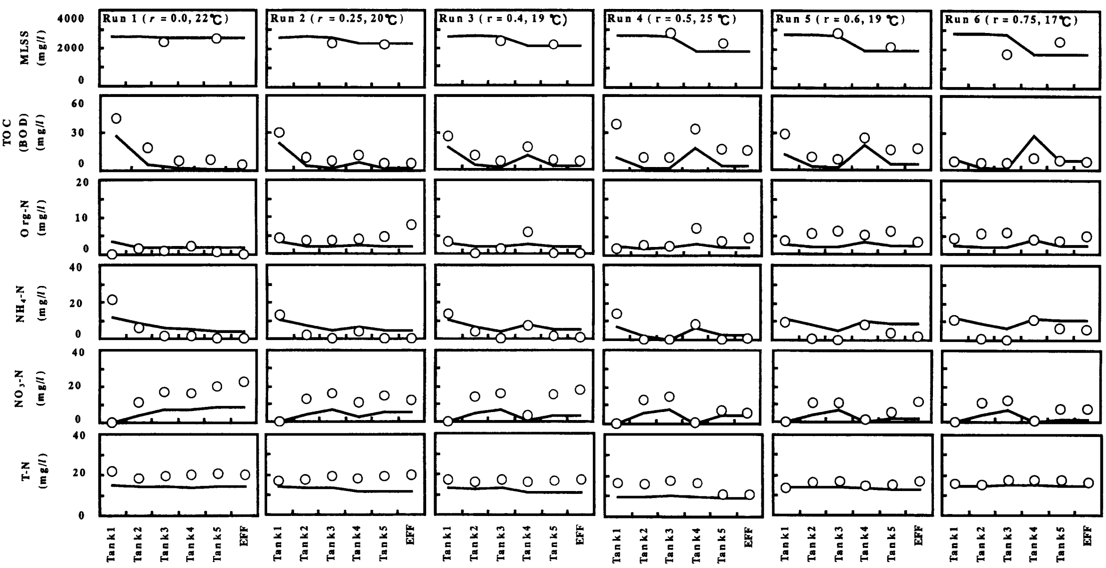

Fig. 3 Typical substrate profiles in pilot-plant in Run 1-6. Experimental data plots and computed lines are shown

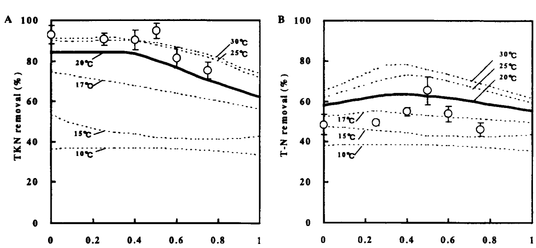

Fig. 4 Effect of step-feed ratio on TKN removal (A) and T-N removal (B). Experimental data plots with standard deviations and computed lines are shown.

However, T-N removal reached the peaks of the step-feed ratio at relatively high temperatures. The optimal step-feed ratio for T-N removal was around 0.4 at 20 to 30℃. At higher temperatures, denitrification process seemed to be rate limited at the lower step-feed ratios, while the nitrification process would be rate limited at higher step-feed ratios. As the water temperature became lower, the nitrification efficiency seriously decreased, and then the effect of the step-feed on denitrification would be canceled.

Simulation studies at the average water temperature in Osaka were performed. T-N removal efficiency with the calculated optimal step-feed ratio was shown in Fig. 5. Maximum T-N removal from June to November was observed at the step-feed ratio of about 0.4. On the other hand, the optimal step-feed ratio decreased as average water temperatures decreased, and the T-N removal also decreased. When T-N removal in February showed the lowest, the optimal step feed ratio was suggested to be 0. As simulation result in case of the conventional process was also shown in Fig. 5 (C). It was suggested by the simulation that the T-N removal of the conventional process which was without both anoxic zones and the step-feed remained about 30% throughout the year. T-N removal of a process without anoxic zones but with step-feed was also calculated, however, the simulation result showed that T-N removal gradually decreased from ca. 30% to ca. 28% with increase in the step-feed ratio (data not shown). The simulation result of T-N removal of an anoxic-oxic process without step-feed was also shown in Fig. 5 (C). As shown in Fig. 4 (B), the effect of step-feed was remarkable at higher temperatures. These results suggested that creation of anoxic zones enhance nitrogen removal of the

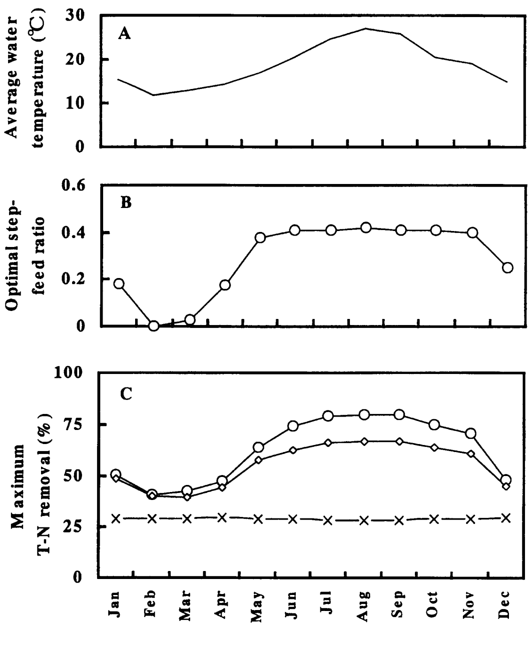

Fig. 5 Computed maximum T-N removal of the anoxic-oxic activated sludge process with the optimal step-feed ratio at Osaka (○). Typical average water temperature in the tanks (A), optimal step-feed ratio of the process (B), and maximum T-N removal with the optimal step-feed value (C) are shown. Computed T-N removals by a conventional activated sludge process (×) and an anoxic-oxic activated sludge process without step-feed (◇) were also shown.

process and the step-feed configuration is more effective during the months from June to November.

DISCUSSION

A step-feed anoxic-oxic activated sludge process is one of the most practical methods for the upgrading of existing conventional ones for nutrient removal. However, the step-feed anoxic-oxic process has many operating factors such as the step-feed ratio, water temperature, and SRT. In this study, effect of the step-feed ratio which is the most controllable among the factors on nitrogen removal was examined mainly by computer simulation analysis. To support the simulation results, experimental studies in an upgraded pilot-scale plant was carried out.

Because of the short period of each experimental run and insufficient number of runs, parameters values authorized by Ichikawa *et al.*[13] and Barker and Dold[14] were used for the simulation without any parameter fitting. However, validity of the model without parameter fitting was confirmed to a certain degree although the measured data of T-N removal showed slightly lower values than computed ones (Fig. 3). It was suggested that creation of anoxic zones in the reactor enhanced nitrogen removal efficiency (Fig. 5). Thus, the step-feed configuration brought drastic nitrogen removal, especially, at relatively high temperatures although further experimental verification is needed (Fig. 4).

Nakazawa *et al*[10] reported 63% T-N removal at a pilot-scale plant with step-feed ratio of 0.5. On the other hand, Funamizu *et al*[9] reported that change of the step-feed ratio could not improve nutrient removal (T-N removal about 60%) at a laboratory-scale process. The experiment was done in July in Sapporo, the northern part of Japan, and 20℃ was the average maximum water temperature for the month. Their results corresponded with the finding in this study that the step-feed ratio had less effect on nitrogen removal when the average water temperatures decreased (Fig. 4).

At lower temperatures, the nitrification rate was lowered and TKN removal decreased drastically with increase in the step-feed ratio, because nitrifiers are susceptive to water temperature and the retention time for sewage to pass the oxic tanks was not enough for occurrence of sufficient nitrification. The step-feed ratio in winter would be better to set at nearly 0 or would not be needed exact attentions. For maintaining a high nitrification rate, Nakazawa *et al*[10] suggested that aerobic sludge retention time (A-SRT) be an important parameter for controlling nitrogen removal in the process. Immobiliza- tion of nitrifiers onto media such as plastic materials with a large surface area would also help maintaining a high nitrification rate even when the temperature decreases.

On the other hand, it was suggested that the step-feed ratio in summer should be set at around 0.4 for effective nitrogen removal (Fig. 5). At higher temperatures, nitrification would proceed sufficiently with low step-feed ratios, therefore, denitrification is the rate limiting process for T-N removal. One of the options for further T-N removal is addition of an external carbon source for denitrification. More than 80% T-N removal by another pilot-plant with addition of methanol has already been reported by authors' group[15]. Wasted materials such as cellulose from newspapers[16] and volatile fatty acids from anaerobic digestion sludge[6] would be also utilized as external carbons in terms of cost reduction.

Besides the step-feed ratio, the process has many design and operation parameters for nitrogen removal, such as influent quality, oxygen supply, return sludge flow rate, SRT, and volume allocation of the tanks. Creation of strictly anaerobic zones in reactors is also needed for sufficient phosphorus removal. Activated sludge models[11,14,17] including the model used in this study can be used for predicting the performance of wastewater treatment plants, and computer simulations would be the powerful tool for their operation and design.

ACKNOWLEDGEMENTS

Authors thank the municipal wastewater treatment plant directors for providing the seed activated sludge, Dr. Keisuke Iwahori of Institute for Environmental Sciences, University of Shizuoka for valuable suggestions on the model modifications, and Mr. Mikihito Yasui of Sewage Works Bureau, Osaka Municipal Government, and Mr. Junichi Baba of Sewerage Engineering Department II, Takuma Co. Ltd., for helpful advice on the pilot-plant experiments.

NOMENCLATURE

b_A : Endogenous decay coefficient on anoxic, 1/d.
b_O : Endogenous decay coefficient on oxic, 1/d.
b_{15} : Endogenous decay rate at 15℃, 1/d.
C_N : NH_4-N/BOD ratio in tank.
F_{PH} : pH function on nitrification, -.
K_{AN} : Specific denitrification rate, l/mg/d.
K_{BA} : Specific removal rate of BOD for synthesis, l/mg/d.
K_{BO} : Specific removal rate of BOD for respiration, l/mg/d.
K_{NO} : NO_x half-saturation constant for denitrification, mg/l.
K_{NH} : NH_4-N half-saturation constant for nitrification, mg/l.
K_{OA} : DO half-saturation constant for denitrification, mg/l.
K_{OH1} : DO half-saturation constant for BOD removal, mg/l.
K_{OH2} : DO half-saturation constant for nitrification, mg/l.
K_{ON} : Specific nitrification rate, l/mg/d.
K_{LA} : Overall volumetric oxygen-transfer coefficient, -.
pH : pH, -.
Q_1 : Inflow rate into Tank 1, l/d.
Q_2 : Inflow rate into Tank 4, l/d.
R_{AN} : Reaction rate for denitrification, mg/l/d.
R_{BA} : Reaction rate for BOD removal by cells synthesis, mg/l/d.
R_{bA} : Reaction rate for decay of autotrophs, mg/l/d.
R_{BO} : Reaction rate for BOD removal by respiration, mg/l/d.
R_{bH} : Reaction rate for decay of heterotrophs, mg/l/d.
R_{ON} : Reaction rate for nitrification, mg/l/d.
r : Step-feed ratio, -.
S_{ALK} : Alkalinity, mg/l.
S_B : BOD, mg/l.
S_{NH} : NH_4-N, mg/l.
S_{NO} : NO_x (NO_3-N and NO_2-N), mg/l.
S_O : DO, mg/l.
S_{ORG} : Org-N, mg/l.
S_{OS} : Saturated DO, mg/l.
T : Water Temperature in tanks, ℃.
X_A : Nitrifier, mg/l.
X_H : Heterotrophs, mg/l.
Y_{AN} : Conversion constant alkalinity, -.
Y_{NB} : NH_4-N removal by cell synthesis, -.
Y_{NO} : Yield of NOx on nitrification, -.
Y_{NX} : Org-N yield of decay, -.
Y_{ON} : Oxygen utilization for nitrification, -.
Y_{OX} : BOD yield of decay, -.
Y_{SN} : BOD removal of denitrification, -.
Y_{XN} : Yield of nitrifier, -.
Y_{XS} : Yield of heterotrophs, -.
θ_{AN} : Coefficient for temperature for denitrification, -.
θ_B : Coefficient for temperature for BOD removal, -.

θ_d : Coefficient for temperature for endogenous decay, -.

θ_{ON} : Coefficient for temperature for nitrification, -.

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(Submitted 2000. 6. 27)
(Accepted 2000. 11. 11)