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NITROGEN AND PHOSPHORUS REMOVAL FOR SWINE WASTEWATER USING INTERMITTENT AERATION BATCH REACTOR FOLLOWED BY AMMONIUM CRYSTALLIZATION PROCESS

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Abstract—A process for the crystallized precipitation of ammonium by adding magnesium salt and phosphate were carried out in order to remove nitrogen and phosphorus as well as to improve the C/N ratio in swine wastewater. The optimal operation conditions were obtained as follows: reaction temperature (25°C), reaction time (1 h), pH (7.5) and the molar ratio of NH_4–N : PO_4–P : M_g = 1.0 : 0.9 : 0.9. Under these conditions, the maximum quantity of the crystallized precipitation occurred, the removal ratio of NH_4–N increased to more than 90% and the C/N ratio increased from 1.98 to more than 8, but phosphorus was not removed. On the other hand, when the molar ratio of NH_4–N : PO_4–P : M_g = 1.0 : 0.6 : 0.9, the ammonium and phosphorus removal ratio would be 79.32–87.45% and 40.3–88.5%, respectively. After completion of the crystallized precipitation of ammonium, an intermittent aeration process with an aeration to anaerobic time ratio of 1 : 1 h is used for this improved swine wastewater (T–N/BOD = 0.14, in which BOD = 8200 mg/l, T–N = 1166 mg/l, and NH_4–N = 519 mg/l). The results obtained from these experiments showed that the removal ratio of T–N and NH_4–N are 91 and 99%, respectively. T–P is not removed, while the removal ratio of PO_4–P is 60% when 3% $CaCl_2$ liquid is added.

Key words—Swine wastewater, nitrification, ammonium crystallization, denitrification, intermittent aeration

INTRODUCTION

The standards of discharged livestock wastewater have been strictly set to prevent eutrophication of rivers, lakes and marshes in Japan and Taiwan. Nitrogen and phosphorus will be included among these values which are controlled by these standards in the near future. Therefore, pig farms will be forced to purify wastewater while keeping within very strict limits imposed by the law. Based on this prospect, treatment plants for swine wastewater using activated sludge after methane fermentation will be disseminated in Japan and Taiwan. These methods are effective for the removal of BOD and COD but not for nitrogen and phosphorus (Liao *et al.*, 1992). So an intermittent aeration process has been extensively studied for the treatment of swine wastewater in which the C/N ratio is low (Liao *et al.*, 1992, 1993; Liao and Maekawa, 1994).

The intermittent aeration process is a batch treatment; aerobic and anaerobic conditions are alternately repeated over a certain period. This method is especially effective for gasification of ammonium nitrogen. But the C/N ratio of swine wastewater is generally so low that it causes a carbon source shortage requirement for denitrification. In general, methanol can serve as a carbon source in the denitrification process (Timmermans and Van Haute, 1983)

$$CH_3OH + 6/5\,NO_3^- \Rightarrow 3/5\,N_2 + CO_2 + 6/5\,OH^- + 7/5\,H_2O. \quad (1)$$

This method is very expensive. So to improve the C/N ratio, another method of removing ammonium by adding magnesium salt and phosphate to allow $MgNH_4PO_4{\cdot}6H_2O$ crystallization was used. The stoichiometric equation is as follows (Shinjikken kagaku koza, 1977)

$$Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \Leftrightarrow MgNH_4PO_4{\cdot}6H_2O\downarrow. \quad (2)$$

The crystallized precipitation may be dependent on the pH range of the solution, and is either acid soluble ($pH < 6$) or becomes $Mg_3(PO_4)$ in basic solution ($pH > 10$). Through the crystallized treatment, the effluent was also treated by an intermittent aeration process in a batch reactor.

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MATERIALS AND METHODS

Synthetic wastewater

Materials. Potassium hydric phosphate (KH_2PO_4) was dried for 3 h at 105°C in an electric dryer, and after that, a 0.1 mol./l solution is made. In addition, 0.1 mol./l solutions of NH_4Cl and $MgCl_2$ are also separately made.

Experimental operation. After adjusting the pH of the KH_2PO_4 and the NH_4Cl solutions using 1% NaOH solution at a selected concentration, 50 ml of each solution is added to a 500 ml flat-bottom flask and the experiments are began. The pH of the $MgCl_2$ could not be adjusted at the selected level because of $Mg(OH)_2$ sediment while NaOH was added. Each control factor and selected level are shown in Table 1.

Experiment design of $L_{27}(3^{13})$ is used to analyze these factors (Taguchi, 1976). Linear graphs in the orthogonal array table are used for setting each factor and the positions of their levels, and the order of the experimental operation is determined by using the method of partial execution and a table of random numbers.

Wastewater from pig housing

Materials. Raw swine wastewater was obtained from the pig farm of Tokyo Yoton Agricultural Cooperative located in Iwai city, Ibaraki, Japan. After scooping up the supernatant after centrifuging the raw swine wastewater at 3000 rpm for 3 min, it was stored at 4°C in a refrigerator. A 100 ml sample of supernatant liquid was sampled, then 10% (mol./l) KH_2PO_4 and $MgCl_2$ solutions were separately prepared.

Experimental operation conditions. (a) Temperature, 25°C, (b) stirring speed, 165 rpm, (c) reaction time, 1 h and (d) supernatant liquid quantity, 100 ml (composition: NH_4-N = 2500–2600 mg/l, and PO_4-P = 200–450 mg/l).

The concentration of phosphorus ions and magnesium ions were set at 0.9, 0.8, 0.7, and 0.6 times the molar numbers with which it can completely react with ammonium in the raw swine wastewater (including the concentration of phosphorus ions in the raw swine wastewater). The pH for the entire reaction liquid was set at 7.5, 8.0, 8.5, and 9.0. An experimental design of $L_{16}(4^5)$ was used (Taguchi, 1976). Table 2 shows the factors and the experimental levels.

Analytical method. Each crystallized solution of the synthetic wastewater and the swine wastewater were filtered through filter paper ($NO_{0.5}$ Toyo Filter Paper) soon after the reaction. The concentrations of PO_4-P, Mg, and NH_4-N were measured in the solution using standard methods (APHA, 1985). The weight of the crystallized sediment on the filter paper was measured using an electronic balance (Mettler PE300) after drying at 35°C in an electric dryer for 24 h. The crystallized sediment from the raw swine wastewater was again dried at 600°C in an electric oven for 3 h, then gradually cooled it for 24 h in a desiccator. The weight was then measured to confirm the purity of the crystallized precipitate.

The chemical reaction at high temperature is shown as follows:

$$2MgNH_4PO_4{\cdot}6H_2O \Rightarrow Mg_2P_2O_7 + 2NH_3\uparrow + 13H_2O\uparrow. \quad (3)$$

Table 1. Factors and levels set up for the crystallization of synthetic wastewater

	Level		
Factor	1	2	3
(A) Temperature (°C)	15	25	35
(B) Stirring speed (rpm)	125	145	165
(C) pH (—)	9.5	10	10.5
(D) Reaction time (min)	20	40	60

Table 2. Factors and levels set up for the crystallization of ammonium in the swine wastewater

	Levels			
Factor	1	2	3	4
PO_4-P[a]	0.9	0.8	0.7	0.6
Mg[a]	0.9	0.8	0.7	0.6
pH	7.5	8	8.5	9

[a] Stoichiometric ratio for the ammonium nitrogen.

Intermittent aeration experiments using four types of swine wastewater

Material and experimental operation. Activated sludge was brought from the activated sludge plant of Tokyo Yoton Agricultural Cooperative and was incubated in a 5 l of a cylinder type reactor (Fig. 1) using a raw swine wastewater for one month at 20°C. Raw swine wastewater was also brought from the same place and divided into 4 samples by dilution and crystallization: (a) raw swine wastewater, (b) 3-times diluted swine wastewater diluted with pure water, (c) 6-times diluted swine wastewater diluted with pure water, and (d) supernatant liquid obtained from filtering after crystallized treatment of the raw swine wastewater. These liquids were used when the molar ratio of $NH_4:PO_4:Mg = 1:0.6:0.9$, and the pH of the whole liquid was 7.5. The characteristics of the swine wastewater used are shown in Table 3.

Four operations were performed in the same reactor (Fig. 1) for the working volume of 3 l. The air was supplied by a sparger at the bottom of the reactor through an intermittent air pump at the rate of 2.0 l/min controlled by an electric timer. Excess sludge was adjusted and MLSS concentration was measured once a week. The intermittent aeration time ratios of *aerobic/anaerobic* were 1/1 h and 1.25/0.75 h. 2.5 l of the supernatant was scooped out from the reactor every day at 9:45 am, and the same quantity of the swine wastewater was added into the reactor. The reactor was operated at the same conditions for one week.

Analytical method. The sampled effluent from the reactor was centrifuged at 3000 rpm for 3 min. NH_4-N, PO_4-P of the supernatant were measured every day. pH, DO and oxidation-reduction potential (ORP) were monitored throughout the experiment. NH_4-N, NO_3-N, NO_2-N, PO_4-P, T-N, T-P were analyzed by an ion chromatography (TRAACS800 Analytical Console). NH_4-N, NO_3-N, NO_2-N, PO_4-P were also checked by standard methods

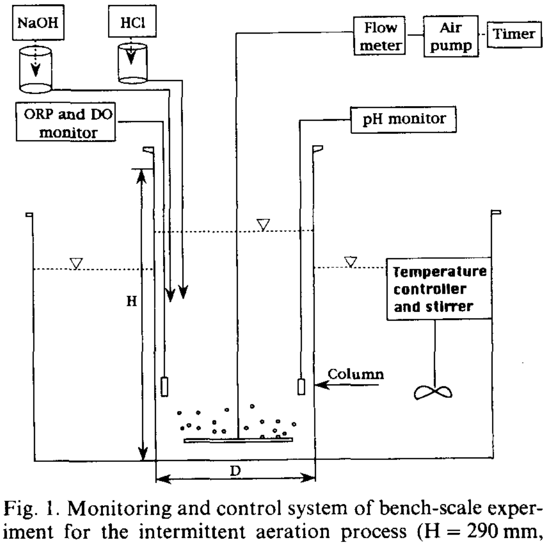

Fig. 1. Monitoring and control system of bench-scale experiment for the intermittent aeration process (H = 290 mm, D = 165 mm).

Table 3. The quality of swine wastewater

Items	Units	Swine wastewater (SWW)	3-times diluted SWW	6-times diluted SWW	Crystallized SWW
pH	—	8.48	8.42	8.45	7.51
BOD	mg/l	9500	3200	1600	8200
TOC	mg/l	4540	1648	866	3923
T–N	mg/l	5930	2864	2583	1166
NH_4–N	mg/l	2500	830	290	519
NO_x–N	mg/l	7.02	2.34	1.2	6
T–P	mg/l	360	138	158	108
PO_4–P	mg/l	302	112	115	91

(APHA, 1985). TOC was measured using a TOC Analyzer (TOC-5000 Analyzer, Meishinkogyo).

RESULTS AND DISCUSSION

The analysis results of variance for the residual NH_4–N concentration of the crystallized synthetic wastewater are shown in Table 4. From Table 4, it is obvious that the reaction time (D), reaction temperature (A) and interaction among temperature (A) and pH (C) have a great influence on the residual concentration of ammonium and its removal ratio. The residual ammonium concentration has the lowest value when the temperature, time and pH were 25°C, 60 min and 10, respectively.

The longer the reaction time, the more crystallized sediment, the lower residual ammonium and phosphate concentrations were obtained, so the crystallization needs a longer reaction time than that of the operation.

Table 5 shows the analysis results of variance for the residual NH_4–N concentration of the crystallized swine wastewater. From Table 5, it is clear that the initial phosphate concentration, magnesium ion and pH in the whole liquid during the reaction have a great influence on the residual ammonium ion. When the concentration ratios of the initial phosphate, magnesium ion and pH were 0.9, 0.9, and 7.5, respectively, the residual ammonium concentration has a minimum value, and the ammonium removal ratio was 91.42–91.98% (significant level: 5%). But phosphorus could not be removed. This would occur in the raw swine wastewater, since it contains various ions, it is necessary to consider how to make those ions interact effectively, i.e. there are general rules such as the complex ion effect, common ion effect and rule of Paneth–Fajans–Hahn (Day and Underwood, 1982), and some negative ions among those in the raw swine wastewater that make insoluble ammonium magnesium phosphate more adhesive.

So, for the crystallized influent of the following intermittent aeration experiments, the molar concentration ratio of the initial phosphate to ammonium diminished from 0.9 to 0.6, that is to say, while the initial molar ratio of NH_4–N:PO_4–P:Mg = 1.0:0.6:0.9, and pH is 7.5, the ammonium and phosphorus removal ratio was 79.32–87.45% (significant level: 5%) and 40.3–88.5% (significant level: 5%), respectively. The T–N concentration in the crystallized swine wastewater decreased from 5930 to 1166 mg/l.

Through microscopic inspection, it was found that the diameter of the crystal grains from swine waste-

Table 4. Analysis results of variance for the residual NH_4–N concentration of the crystallized Synthetic wastewater

Factor	S	f	V	F
A: Temperature	4121	2	2065.5	4.71[a]
B: Stirring speed	1968.8	2	984.4	2.25
e_1	1147.7	2	573.5	1.03 < 6.94(0.05)
C: pH	647	2	323.5	
D: Reaction time	5446	2	2723	6.224[a]
A*C: Interaction of A & C	7020.5	4	1755.1	4.01[a]
B*C: Interaction of B & C	5538	4	1385	3.16
C*D: Interaction of C & D	1244.6	4	311.15	
e_2	2210.6	4	552.5	
Pooled (e_3)	(5249.9)	12	437.49	

[a] $F^2_{12}(0.05) = 3.98$, $F^4_{12}(0.05) = 3.26$.
[b] $F^2_{12}(0.01) = 6.93$, $F^4_{12}(0.01) = 5.41$.

Table 5. Analysis results of variance for the residual NH_4–N concentration of the crystallized swine wastewater

Factor	S	f	V	F
A: concentration of phosphate ion	14181.5	3	4727.17	42.6[b]
B: concentration of magnesium ion	52435.2	3	17478.4	157.6[b]
C: pH	2460.2	3	820.1	7.39[a]
e	665.4	6	110.9	
Total	69742.3	15		

[a] $F^3_6(0.05) = 4.76$.
[b] $F^3_6(0.01) = 9.78$.

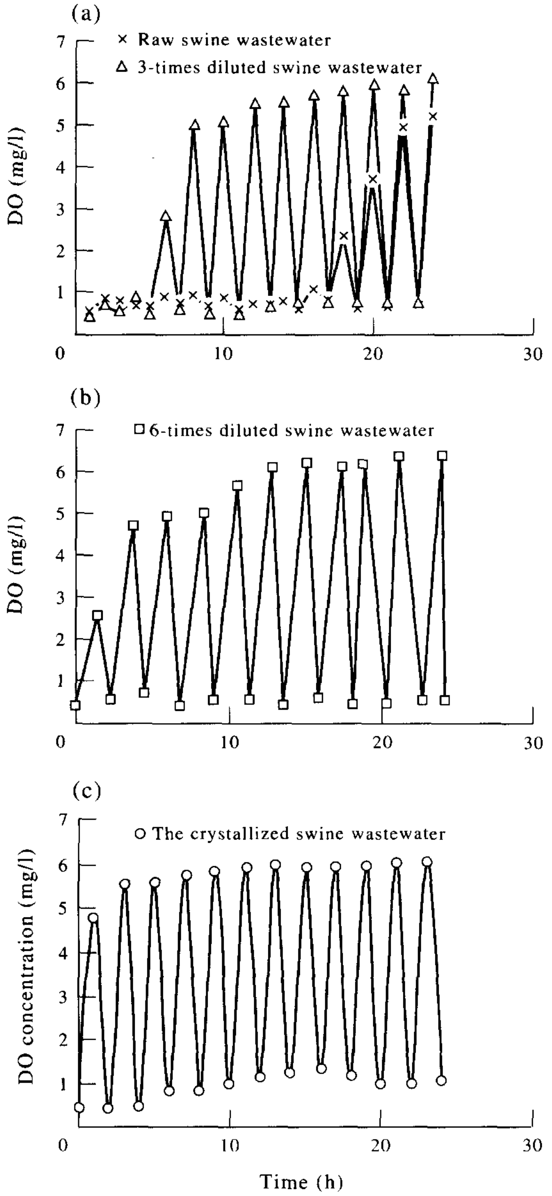

Fig. 2. The time–course changes of the DO concentrations at the intermittent time ratio of 1/1 h for the influent of (a), (c), and 1.25/0.75 h for the influent of (b).

water was smaller than that of synthetic wastewater. The reason is that swine wastewater contains various kinds of organic matter and break them into smaller pieces during stirring, such that the organic grains in the wastewater were drawn into the precipitate of the crystallized ammonium.

In these experiments, since the diameter of the precipitation obtained from raw swine wastewater were from 10 to 100 μm, so in practice, they could be filtered by an oscillating sieve, and could be used as fertilize.

Figure 2 shows the time-course change of the DO in the four types of swine wastewater. The time ratio of aerobic and anaerobic was 1/1 h for swine wastewater, 3-times diluted swine wastewater and crystallized swine wastewater, and 1.25/0.75 h for 6-times diluted swine wastewater.

The initial DO concentration under aerobic conditions reached 1.00 mg/l after 16 h in the raw swine wastewater, but for the 3-times diluted swine wastewater, the DO concentration reached 2.00 mg/l after only 3 h. Under anaerobic conditions, the DO concentration could not reach 1.00 mg/l even after 24 h for both the raw and 3-times swine wastewater.

In the crystallized swine wastewater, the initial DO concentration under aerobic conditions was 4.79 mg/l, and then reached 6.05 mg/l after 24 h. Under anaerobic conditions, the DO concentration started at 0.43 mg/l and increased to 1.00 mg/l after 10 h, then remained at the same level. Both initial and final DO concentrations for crystallized swine

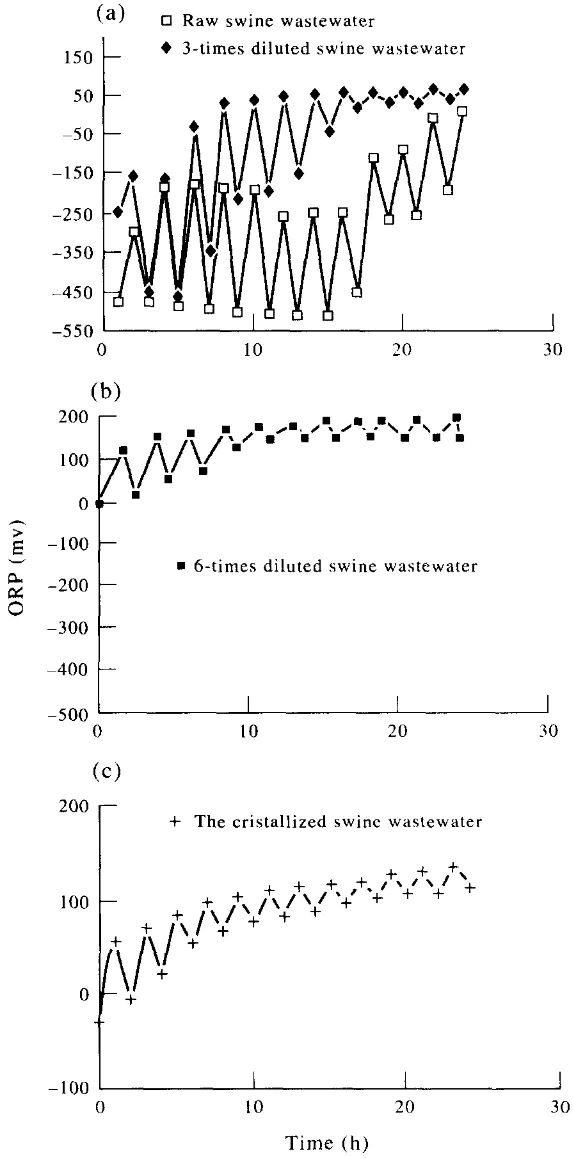

Fig. 3. The time–course changes of ORP in the four types of swine wastewater at the intermittent time ratio of 1/1 h for (a), (c), and 1.25/0.75 h for (b).

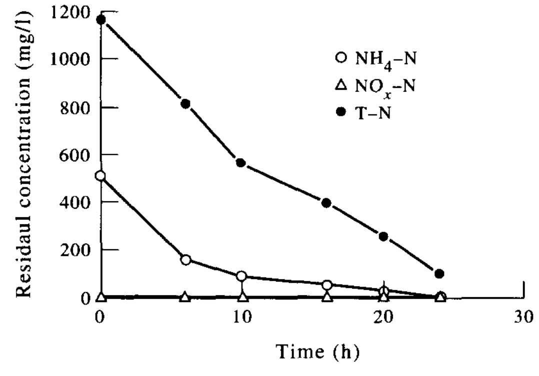

Fig. 4. The transition of the residual concentrations of T–N, NH_4–N, NO_x–N for the influent of crystallized swine wastewater at the intermittent time ratio of 1/1 h.

wastewater under aerobic and anaerobic conditions were higher than that of raw swine wastewater and 3-times diluted swine wastewater, that is to say, the crystallization process improved the C/N ratio of the raw wastewater increase to higher than 8 and makes the wastewater treated easy.

In the 6-times diluted swine wastewater, the initial DO concentration under aerobic conditions was 2.55 mg/l, and then reached 6.30 mg/l after 24 h. Under anaerobic conditions, the DO concentration started at 0.41 mg/l and increased to 0.53 mg/l after 5 h, then remained at the same level.

Figure 3 shows the time–course of ORP in the four types of swine wastewater. The ratio of aerobic and anaerobic time was 1/1 h for swine wastewater, the 3-times diluted swine wastewater and crystallized swine wastewater, and 1.25/0.75 h for the 6-times diluted swine wastewater.

For swine wastewater, the voltage of the ORP (using hydrogen standard electrode) started increasing to 0 mV after 20 h under aerobic conditions. Under anaerobic conditions, it increased to −158 mV after 24 h.

For the 3-times diluted swine wastewater, the voltage of the ORP started increasing to 34 mV after 8 h under aerobic conditions. Under anaerobic conditions, it increased to 44 mV after 24 h.

For the 6-times diluted swine wastewater, the voltage of the ORP started increasing from 118 mV up to 196 mV under aerobic conditions and started at −9 mV and increased to 151 mV under anaerobic conditions after 24 h respectively.

For crystallized swine wastewater, the voltage of the ORP started increasing from 57 mV up to 133 mV under aerobic conditions. Under anaerobic conditions, it started at −29 mV and increased to 113 mV, and the change was smaller than that for the 6-times diluted swine wastewater. After 10 h of treatment, the change in ORP under aerobic and anaerobic conditions was maintained between 20 and 33 mV.

From Fig. 3, it is clearly that since the crystallization process improved the C/N ratio of the raw wastewater and decrease the organic loading of treatment, so that both initial and final ORP value for crystallized swine wastewater under aerobic and anaerobic conditions were higher than that of raw swine wastewater and 3-times diluted swine wastewater.

Figure 4 shows the transition of the residual concentrations of T–N, NH_4–N, and NO_x–N in the crystallized swine wastewater. The ratio of aerobic and anaerobic time was 1/1 h. The initial residual T–N concentration was 1166 mg/l, which then decreased to 103 mg/l after 24 h. The average removal rate and ratio of T–N was 44.3 mg/l·h and 91.2%, respectively. The NH_4–N concentration started with 519 mg/l then decreased to 2 mg/l after 24 h. The average removal rate and ratio was 21.2 mg/l·h and 99.6%, respectively. The NO_x–N concentration decreased from 7.75 to 1.32 mg/l, and it showed that denitrification was successful. This result was the same as the best result in the references concerning the nitrification/denitrification of livestock wastewater under similar condition.

Figure 5 shows the transition of the T–P and PO_4–P concentrations in the crystallized swine wastewater. The ratio of aerobic and anaerobic time was 1/1 h. T–P decreased from 109 to 98.5 mg/l after 7 h, but gradually increased until it reached 142 mg/l after 24 h. PO_4–P decreased from 91.0 to 51 mg/l after 7 h, and gradually increased to 112 mg/l after 24 h. Under anaerobic conditions, when phosphorus in the sludge dissolved into the treated water and the DO increased to more than 1.00 mg/l, denitrifying bacteria used the oxygen and directly consumed the carbon source, and then the NO_x–N concentration in the effluent increased. At the same time, due to excessive uptake of phosphorus by phosphate-accumulated bacteria, phosphoric acid remains in the treated wastewater by these bacteria autolysis. By adding 45 ml of $CaCl_2$ (3%) into the treated water, the phosphoric acid decreased to 41 mg/l. This reaction was caused by sedimentation of $Ca_3(PO_4)_2$.

Figure 6 shows the time course of the TOC/T–N ratio and removal ratios of T–N and NH_4–N in the crystallized swine wastewater. TOC quickly

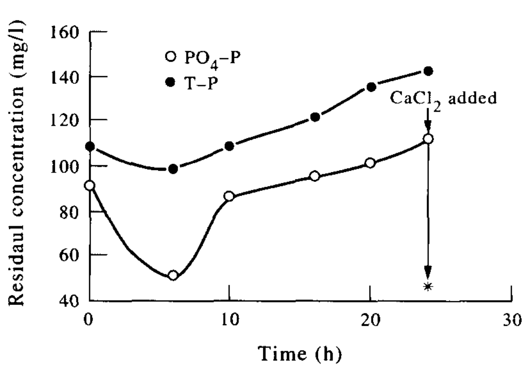

Fig. 5. The transition of the residual T–P, PO_4–P concentrations in the crystallized swine wastewater at the intermittent time ratio of 1/1 h (added $CaCl_2$ conc. and volume are 3% anf 45 ml, respectively).

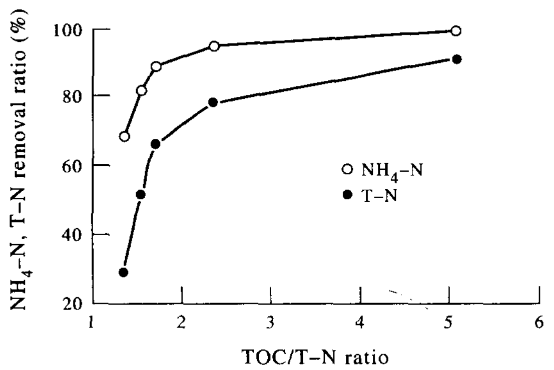

Fig. 6. The relationship of NH_4–N, T–N removal ratio to TOC/T–N ratio in the crystallized swine wastewater at the intermittent time rato of 1/1 h (initial quality of the wastewater was shown in Table 3).

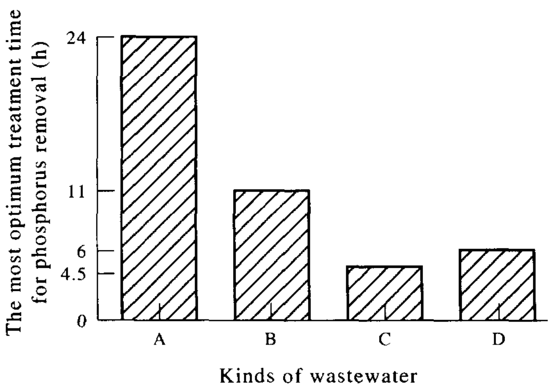

Fig. 8. The relationship between the kinds of influent wastewater and their most optimum treatment time for attaining the maximum T–P, PO_4–P removal value. A: Raw swine wastewater. B: 3-times diluted swine wastewater. C: 6-times diluted swine wastewater. D: The crystallized swine wastewater.

decreased in the first 6 h from 3923 to 1105 mg/l, and the TOC/T–N ratios in the whole treated wastewater temporarily decreased to 1.35, then TOC slowed down, and TOC/T–N ratio began to increase to 5.05 because T–N decreased, therefore the T–N, and NH_4–N removal ratio were also both increased.

Figure 7 shows the relation between the change in the TOC/NH_4–N ratio in each wastewater sample and removal ratios of T–N and NH_4–N after intermittent aeration treatment. The TOC/NH_4–N ratio in raw swine wastewater, the 3-times diluted swine wastewater, the 6-times diluted swine wastewater, and the crystallized swine wastewater were 1.86, 1.98, 2.98, 8.76, respectively. Accordingly, the removal ratios of T–N were 28.63, 31.2, 48.7 and 91.2%, respectively, while for NH_4–N they were 32, 45, 57 and 99%, respectively.

Figure 8 shows the relation between the kinds of influent wastewater and their most optimum treatment time for attaining the maximum T–P, PO_4–P removal ratio. For raw swine wastewater, the 3-times diluted swine wastewater, the 6-times diluted swine wastewater and the crystallized swine wastewater, the most optimum treatment time is 24, 11, 4.5 and 6 h, respectively. From these results, it is clear that for phosphorus and nitrogen removal, the most optimum treatment time is not the same if only depending on the biological reaction. In theory, during the nitrification process, for obtaining high nitrogen removal efficiency, the sludge residence time (SRT) has to be longer and longer, but for phosphorus removal, since it depends on the amount of excess sludge, so that the SRT would be shorten, if possible.

Based on these results, the following points have to be considered for the removal of nitrogen and phosphorus from swine wastewater using the intermittent aeration process.

(1) pH: it is very important to fix the pH value during the treatment because bacteria for nitrification and denitrification have their own suitable pH value (Murata *et al.*, 1977a, b); for common *Nitrosomonas*, it is 8.0–8.5, and for *Nitrobacteria*, it is 6.5–8.3. The change in pH influences not only nitrate and nitrite bacteria, but also the reduction of nitrogen. When the pH value increases to more than 9, denitrification efficiency significantly decreases. Delwiche (1956) indicates that the best pH value is more than 7.3, but when less than 7.3, more N_2O is generated. Warner

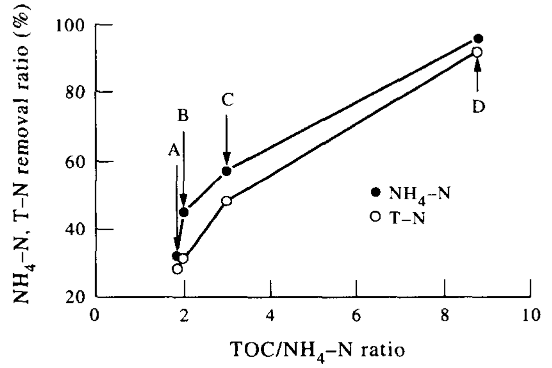

Fig. 7. The relationship between the change in the TOC/NH_4–N ratio and T–N, NH_4–N removal ratios for the four types of swine wastewater. A: Raw swine wastewater. B: 3-times diluted swine wastewater. C: 6-times diluted swine wastewater. D: The crystallized swine wastewater.

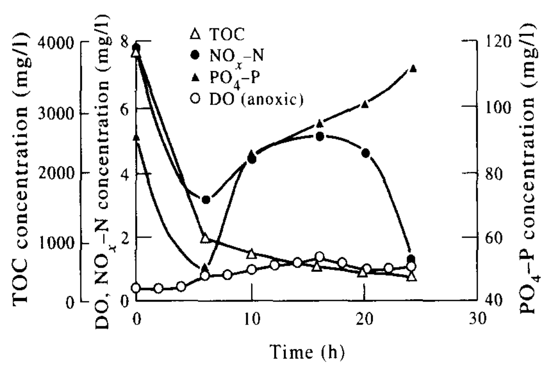

Fig. 9. The time–course changes of the residual TOC, NO_x–N, DO(anoxic), PO_4–P concentrations for the crystallized swine wastewater at the intermittent time ratio of 1/1 h (initial quality of the swine wastewater was shown in Table 3).

et al. (1986) and Osada *et al.* (1991) point out the importance of stabilizing the pH and alkalinity for aerobic/anaerobic digestion of excess sludge. In an experiment using intermittent aeration treatment after the crystallizing treatment, the pH in the liquid had the similar value.

(2) DO: it is very important to monitor the changes in DO concentration. Dowing *et al.* (1964) indicates that at least 0.5 mg/l of DO is required for the nitrification process. Toya (1970) indicates that DO has to be maintained at 3–4 mg/l to achieve a nitrification rate of 90% or more during nitrification. The results obtained from the experiment meet these requirements. As Fig. 9 shows, the removal ratio of ammonium nitrogen increased as the DO increased.

(3) Removal of nitrogen: by intermittent aeration treatment (the time ratio of aerobic/anaerobic time was 1/1 h) of swine wastewater in which the C/N ratio has been improved, the highest removal ratios of T–N and NH_4–N were 91%, and 99%, respectively. This result is similar to that of Liao and Maekawa (1994), and Osada *et al.* (1991).

(4) Inhibited phosphorus removal during the intermittent aeration treatment of crystallized swine wastewater: in the intermittently activated sludge method, the phosphoric acid concentration in the liquid decreases because the phosphate bacteria excessively consumes phosphoric acid in the wastewater while aerobic and anaerobic conditions are maintained. This phosphorus is stored in the activated sludge, and is finally removed as excess sludge. Thus, organic matters such as glucose or acetic acid must not be contained in the wastewater. Similarly, under anaerobic conditions, DO, NO_3–N, and NO_2–N must not be contained in the wastewater. When wastewater does not meet these requirements, removal of phosphorus is inhibited.

Figure 9 shows the time course changes of the PO_4–P concentration of the crystallized influent in the intermittent aeration process, and DO and NO_x–N concentration under anaerobic conditions. For the first 6 h, DO was as low as 1 mg/l and denitrification occurred. As the NO_x–N concentration decreased, the PO_4–P concentration also decreased. The DO then increased as the TOC decreased and the consumption of DO decreased. Because denitrifying bacteria consume part of the DO, denitrification is proceeded slowly and the NO_x–N concentration increased. These results might explain why phosphate-accumulated bacteria consumed PO_4–P in the liquid to inhibit the denitrification.

CONCLUSIONS

The obtained results are summarized as follows:

(1) In the synthetic wastewater: the results makes it clear that the reaction temperature (25°C), reaction time (1 h), and interaction between temperature and pH have a great influence on the quantity of the crystallized precipitate and the removal ratio of NH_4–N.

(2) In the swine wastewater: the case of the reaction temperature (25°C), reaction time (1 h) and pH (7.5), as well as the molar ratio of NH_4–N:PO_4–P:Mg = 1.0:0.9:0.9, the quantity of the crystallized precipitate is a maximum value, the removal ratio of NH_4–N increases to more than 90% and the C/N ratio increases from 1.98 to more than 8, except for phosphorus which could not be removed. For the molar ratio of NH_4–N:PO_4–P:Mg = 1.0:0.6:0.9, the ammonium and phosphorus removal ratio would be 79.32–87.45% and 40.3–88.5%, respectively.

(3) When crystallized effluent is treated by the intermittent aeration process, the NH_4–N concentration decreases from 519 to 2 mg/l, and the removal ratio increases to 99%. The T–N concentration decreases from 1166 to 102 mg/l, and the removal ratio increases to 91%.

(4) For the intermittent aeration process, during phosphorus and nitrogen removal, the most optimum treatment time is not the same if only depending on the biological reaction. The removal ratios of PO_4–P and T–P decrease in the order of raw wastewater, 3-times diluted swine wastewater, 6-times diluted swine wastewater, and crystallized swine wastewater. Phosphorus is not removed when crystallized swine wastewater is treated by the intermittent aeration process. The removal ratio of PO_4–P reaches 60% due to the flocculation and precipitation by adding $CaCl_2$.

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