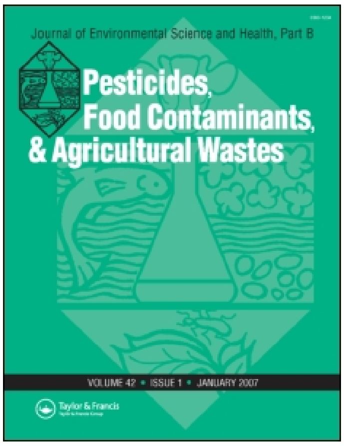

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Removal of nitrogen and phosphorus from swine wastewater by intermittent aeration processes

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REMOVAL OF NITROGEN AND PHOSPHORUS FROM SWINE WASTEWATER BY INTERMITTENT AERATION PROCESSES

KEY WORDS: Piggery wastewater, Intermittent aerations, Nitrification/denitrification, Phosphorus removal, T-N/TOC ratio.

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ABSTRACT

Nitrogen and phosphorus removal in a methane fermentation plus activated sludge method type pig

farm (M-III) with an intermittent aeration process (IAP) was evaluated in comparison with a continuous aeration process (CAP) based on the full-scale and bench-scale experiments. Operation conditions for the treatment system were the same except for the aeration program (in the CAP), a consecutive 24-hr aeration was used, whereas in the IAP, the aeration and non-aeration periods were alternated at intervals of 3:1 hr. BOD and TOC removal efficiencies with the intermittent aeration were as high as those with the continuous operation (92-98%). In the removal of nitrogen and phosphorus, large differences between IAP and CAP were observed. At an influent T-N/TOC ratio of 0.1, removal efficiencies for T-N in the bench-scale IAP was 70%, and for T-P was 22%, respectively. At an even higher influent T-N/TOC ratios of 0.3-1.0, the removal efficiencies for T-N were decreased to about 59-61%, whereas that for T-P were -0.3-13%. In a full-scale plant, removal efficiencies for T-N with IAP and CAP were 42% and -0.09%, respectively. The results of this study show the successful performance of a simple IAP for piggery wastewater: simultaneous, one-sludge denitrification with nitrification in single-activated sludge reactor in a pig farm.

INTRODUCTION

Pig farms are forced to purify the wastewater while keeping within very strict limits imposed by the law. Treatment plants today, however, are difficult to operate and have high running costs. The reasons for this may be found in the characteristics of the wastewater itself: its high organic and nutrient content as well as inbalanced carbon:nitrogen:phosphorus ratio.

The law is extremely restricting in its limits and, with current technology, respecting these limits means facing up to high costs which can not be supported. One feasible solution is to improve the present purification plants whose purpose is obligatory treatment of this wastewater.

Simplified technology, however, must be researched which can remove the nutrients while minimizing investment and running costs. Such a viewpoint is the basic for this paper.

In the last two decades, much effort has been made to study not only the anaerobic digestion of animal wastewater but also the aerobic degradation treatment, obtaining high removal efficiencies for BOD, TOC, and SS. Only a few studies, however, have dealt with nitrogen and phosphorus removal from animal wastewater, which are currently of great interest in terms of eutrophication of streams and lakes.

The previous research (Liao et al., 1992) has shown that the activated sludge process with continuous aeration is effective for swine wastewater: high removal efficiencies for BOD and TOC were achieved. It could not satisfied, however, the effluent standard for nitrogen because swine wastewater contains a large amount of nitrogen which corresponding to 20-40% of BOD (Liao et al., 1992). The results also show that during the continuous aeration process, the nitrification activity decreased gradually, as the pH of treated wastewater dropped due to the resultant oxidized nitrogen (NO_x-N). To attain a higher removal efficiency for nitrogen, another aeration program was adopted: the intermittent aeration process (simultaneous nitrification/denitrification process), to avoid accumulating NO_x-N and affecting BOD removal and nitrification activity.

In any system that performs simultaneous nitrification/denitrification, three type of biological reactions occur. The first type of reaction is the usual aerobic, heterotrophic oxidation of organic matter, or carbonaceous BOD ($C_5H_9ON + 3O_2 + 0.4H^+ \rightarrow 2CO_2 + 0.6C_5H_7O_2N + 0.4NH_4\text{-}N + 1.8H_2O$). Aerobic bacteria use O_2 as the terminal electron acceptor in oxidation of the organic matter. The reaction provides energy that is used to produce more bacteria. The second reaction is nitrification, also an aerobic reaction ($NH_4\text{-}N + 1.8O_2 + 0.2CO_2 \rightarrow 0.96NO_3\text{-}N + 0.04C_5H_7O_2N + 1.64H^+$). NH_4-N which is originally present in piggery wastewater and is released by the heterotrophic reaction. Because nitrifying bacteria use only CO_2 as a carbon source, they are autotrophs. The third reaction is denitrification, which is heterotrophic reaction that uses NO_3-N as the terminal electron acceptor instead of O_2 ($C_5H_9ON + 3.36NO_3\text{-}N + 3.92H^+ \rightarrow 1.68N_2 + 0.36C_5H_7O_2N + 3.2CO_2 + 3.92H_2O + 0.64NH_4\text{-}N$). Nitrogen gas (N_2) is the main sink for nitrogen (N); nitrogen (N) is removed through loss N_2 to the atmosphere. The two heterotrophic reactions use organic matter (C_5H_9ON) as the electron donor and carbon source. Aerobic processes use O_2 as electron acceptor, while denitrification uses NO_3-N. All three reactions produce cells ($C_5H_7O_2N$).

Autotrophic nitrifiers are distinct from heterotrophic bacteria. Nitrification is a two-step process that involves two groups of organisms. The first step is oxidation of NH_4-N to NO_2-N; Nitrosomonas is the most common genus that mediates this reaction. The second stage, oxidation of NO_2-N to NO_3-N, is carried out by Nitrobacter, Nitrospira, Nitrococcus, and Nitrolystic, Nitrobacter is the most common.

Because denitrifying bacteria are facultative aerobes, a sufficiently high concentration of DO prevents the use of NO_3-N as the terminal electron acceptor. Because bacteria in actual treatment plants are aggregated as floc or attached films, rapid denitrification can occur when the DO concentration in the bulk liquid is considerably greater than 0.1 to 0.2 mg l^{-1}. Numerous reports verify aerobic denitrification in a variety of treatment systems: 0.5 mg l^{-1} in activated sludge (Krul and Veeningen, 1977); less than 1.0 mg l^{-1} in an intermittently aerated oxidation ditch (Murray et al., 1975); and 0.3 to 1.5 mg l^{-1} in semi-batch activated sludge (Jansen and Behrens, 1980).

A control program on a plant for treating piggery wastewater is presented. Various modifications were made to the system and, as a result, a higher removal of nitrogen and simultaneous nitrification/denitrification seemed to occur. Therefore, the purpose of this field study was to evaluate the hypothesis that simultaneous nitrification/denitrification occurs in a intermittently activated sludge plants without the need for complicated operating procedures. One full-scale piggery wastewater treatment plant was extensively monitored to document denitrification.

In specific terms, the purposes of this paper are: (1) to evaluate the effectiveness of swine wastewater treatment system concentrated on the nitrogen and phosphorus removal, and (2) to deal with the intermittent aeration process for swine wastewater in an attempt to evaluate the advantage of the intermittent aeration operation to typical wastewater in swine production units based on a full-scale and a bench-scale experiments.

MATERIALS AND METHODS

Description of M-III Wastewater Treatment Plant

M-III pig farm, located at the south Taiwan regions was denitrification extended its practical capacity, and reduced energy use. The flow chart and

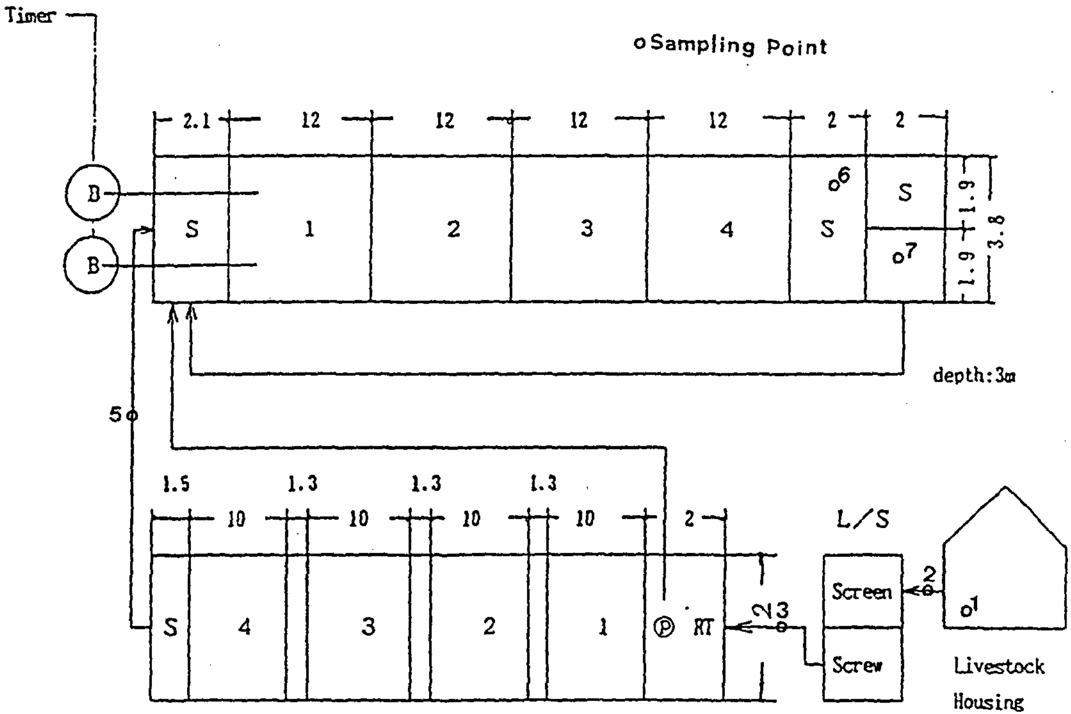


FIGURE 1. Layout of M-III Full Scale Swine Treatment Plant

layout of the plant are shown in Figure 1. First, all waste is gathered in a raw wastewater tank (5.5 m^3, 50 m^3day^{-1}) inside of which is a loading pit to rotating screen type liquid/solid separator. A submerged centrifugal pump is placed in the pit. It can pump approximately 3 m^3 hr^{-1}. The screened wastewater together with the excess sludge from the final clarifier, is collected in a balancing tank (8 m^3). From here a system regulates the flow of the wastewater into 4-RMP methane fermentors (160 m^3). The screened solid is stored in a tank and used for agricultural purposes (e.g., composting). After about 3 days retention, the mixed liquor goes to a sedimentation tank (24 m^3). Part of the sludge which collects at the hopper-shaped bottom of the sedimentator, together with the returned sludge goes to an activated sludge reactors (576 m^3, blower capacity is 1.34 m^3 min^{-1}). Next the mixed liquor continues to the final clarifier (48 m^3) from which the clarified water is then discharged. Part of the excess sludge is sent back to the balancing tank, as mentioned previously.

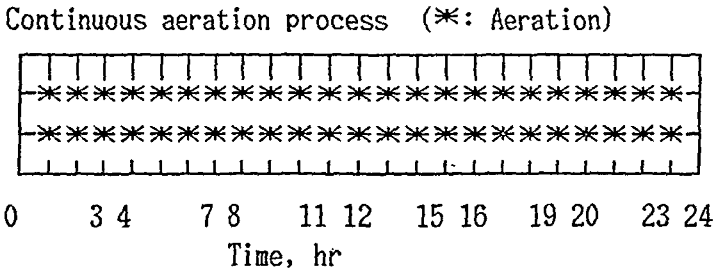
Experimental Objectives

The plant was subjected to a two-phase period in order to ascertain efficiency of the purification under different working conditions. The experiment was done in such a way as to check if DO values of less than 1.0 mg l^{-1} allow: (1) denitrification with nitrification process can take place, (2) simultaneous nitrification/denitrification within the biological floc according to alternate phases, and (3) improvement in the purifying efficiency.

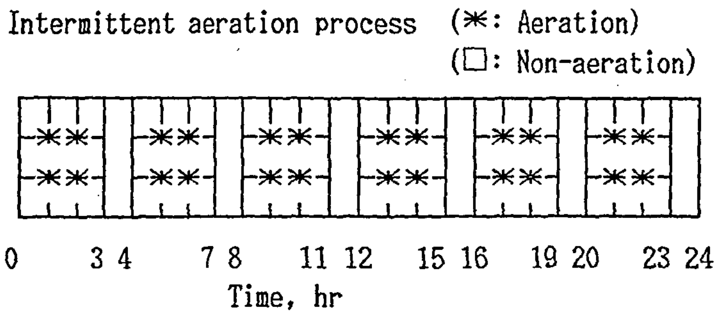
Such effects have already been described in the literature. The addition of a denitrifying process to a nitrifying one can be advantageous in several ways compared to only nitrification: more efficient removal of nitrogen, enhanced phosphorus removal, reduction in O_2 demand for aeration (therefore energy saving), higher capacity for supporting excess loads and reduced consumption of alkalinity (Rittmann and Langeland, 1985). Simultaneous nitrification/denitrification during aerobic treatment of pig slurry was observed by Smith and Evans (1982).

Description of the Experiment

The first phase (February - May, 1991) was characterized by a high content of DO in activated sludge plant (average temperature is 20°C) (Liao et al., 1992). The DO concentration was deliberately kept constantly above about 2 mg l^{-1}, the value of DO



(a)



(b)

FIGURE 2. Time Chart of Experimental Operation: (a) Continuous Aeration Process, (b) Intermittent Aeration Process

normally used in the aerobic treatment of pig slurry in order to guarantee a suitable supply of O_2 both to the microorganism that destroy the organic substance and to the nitrifying organisms (Owen et al., 1973; Van Staen et al., 1976).

The second phase (January - April, 1992), on the other hand, was characterized by DO concentration between 0.4 and 2.6 mg l^{-1} in the anoxic period via an intermittent and aeration and non-aeration periods were alternated at interval of 3:1 hr day^{-1} (average temperature is 23°C) (Figure 2).

The plant thus can be accessed through a determination of the parameter variation caused by the alternating mode of operation. An experimental plan monitoring variations over cycles and over a complete 24-hour period in order to encompass the effects of the operation scheme was then designed.

During the first phase, samples were taken at the following point of the plant (Figure 1);

1 -- collection pit: plant loading,

2 -- inside the raw wastewater tank outlet,

3 -- solid/liquid separator liquid outlet,

4 -- solid/liquid separator solid outlet,

5 -- methane fermentor outlet,

6 -- activated sludge reactor outlet,

7 -- final clarifier outlet.

During the second phase, samples were taken from the input and output of the activated sludge reactors; from the effluent according to the intermittent aeration/non-aeration timing of 3:1 hr day^{-1}; pH, temperature and DO concentration were, however, measured in all samples.

The analytical determinations were carried out according to official methods (APHA, 1985). DO concentration was measured by means of a polarimetric probe (KRK KDO-5151, Japan).

Bench-Scale Experiment

The purpose of bench-scale experiment is to evaluate the nitrogen and phosphorus removal with an intermittent aeration process (simultaneous nitrification/denitrification) based upon the T-N/BOD or T-N/TOC ratio using the actual swine wastewater.

1. Apparatus.

(1) Vessel: total volume is 5 liters, and working volume is 4 liters.

(2) Monitoring and control system is shown in Figure 3. DO concentration should be maintained within 3 - 8 mg l^{-1}.

(3) sampling points: (i) Aerobic stage: Basically, any point can be sampled, while stationary point should be stirred up before sampled. (ii) As the aeration stopped, settling phenomena need to check up. It will take 30 - 50 minutes for the insoluble solid goes down to the bottom. (iii)

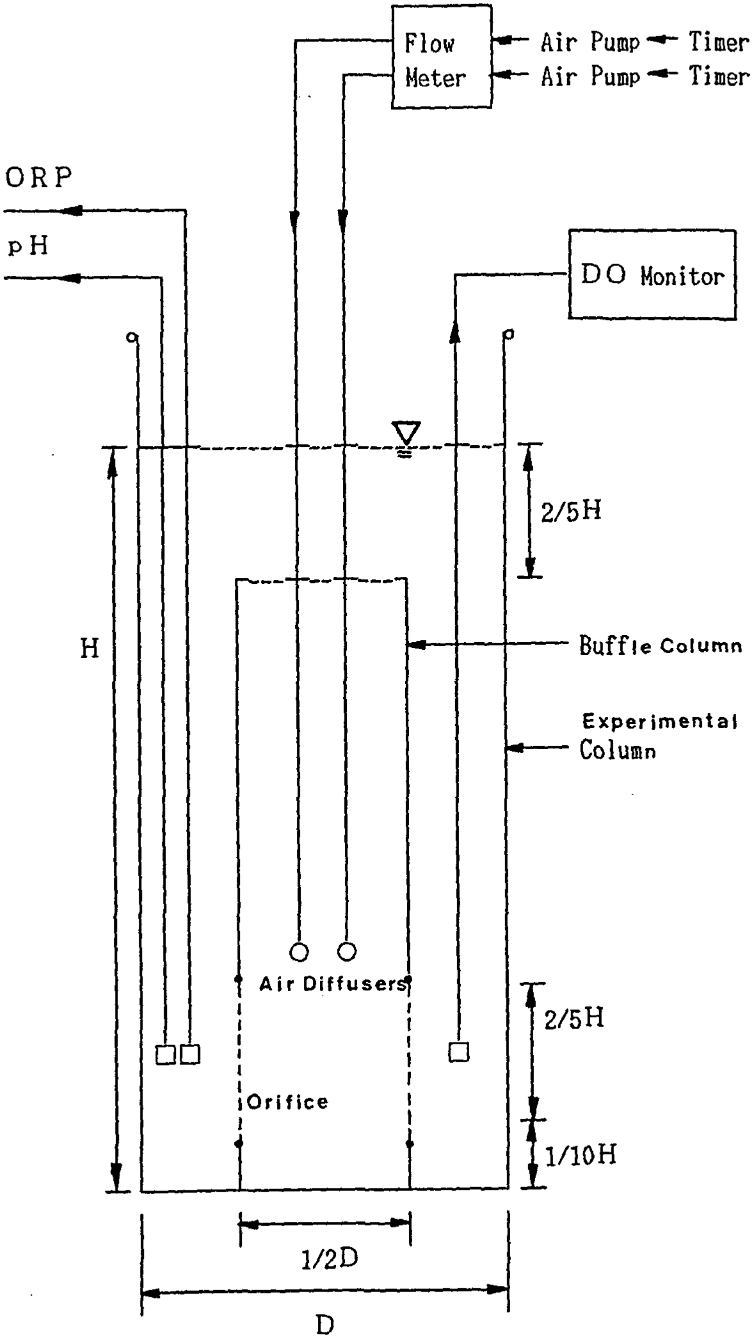


FIGURE 3. Monitoring and Control System of Bench-Scale Experiment

Sampling point: About 1/10 height of the column. Sampling volume is within 200 ml. (iv) Sampling timing may be set at 0 hr, 12 hrs (11:30 - 11:50) and 24 hrs (23:30 - 22:50).

2. Raw wastewater arrangement.

(1) Raw wastewater sampling method: Raw wastewater should be sampled at FARM M-III during the swine wastewater was discharged from the pig housing or when pump in the raw wastewater tank is working.

(2) Sampling volume: (i) Supernatant of raw wastewater tank should be sampled at the volume of 18 - 20 liters then stored in a PE vessel (may be referred to as sample A). (ii) Separated liquid by secondary separator should be sampled at the same volume mentioned above (may be referred to as sample B). Samples A and B should be filtrated via a screen of 100 mesh (0.02 mm).

(3) Storage and preservation: Samples A and B must be stored in refrigerator at the temperature ranged from 2 to 4 °C.

(4) T-N/BOD or T-N/TOC ratio adjustment: (i) The following ratio of T-N/BOD or T-N/TOC is prepared for the purpose of this work: 0.1, 0.2, 0.3, 0.5, and 1.0, respectively. (ii) Carbon source application: Organic hydrocarbon ($(CHO)_n$) or bycarbonate (HCO_3^-)

can be seen as a carbon source for denitrification. Water quality of samples A and B should be analyzed initially including pH, TOC, BOD, NH_4-N, NO_3-N, NO_2-N, TKN, TS, and VS.

(5) Equations for adjustment of T-N/TOC: In convenience of experiment, both MOH and HCO_3^- (from marble stone mixed up with HCl solution) can be adopted as carbon sources.

EXP. I: MOH (methyle alcohol):

$$R = T\text{-}N^*/(TOC^* + MOH \times 0.375) \quad (1)$$

$$MOH = 1/0.375(T\text{-}N^*/R - TOC^*) \quad (2)$$

where:

MOH = TOC content (12/32=0.375),

$T\text{-}N^*$ = original total nitrogen,

TOC^* = original total organic carbon,

$R = T\text{-}N^*/TOC^*$ (0.1 - 1.0).

If CH_3COOH (acetic acid) is used as a carbon source, the content of carbon becomes 32/70=0.486.

EXP II: Bicarbonate (HCO_3^-):

$$Marb = 1/0.196\ (T\text{-}N^*/R - TOC^*) \quad (3)$$

where: Marb is the concentration of HCO_3^- (carbon content is 12/61=0.196).

3. Assimilation Procedure.

(1) The experimental reactor should be operated first for the growing nitrification/denitrification

microbes under 0.1 of T-N/TOC ratio. This assimilation operation needs at least one week using MOH liquid as a carbon source. Before assimilation, samples A and B are mixed with 1:1 each other. This mixed one may be referred to as sample C.

(2) The T-N*/TOC ratio of sample C should be adjusted to 0.1 by MOH using equation (2).

(3) Preoperation for assimilation: (i) The 4 liter of sample C of the corrected T-N*/TOC ratio is putted together with 200 mg of the vegetable cultured soil into the experimental reactor. (ii) Aeration program: aeration was intermittently and aeration and non-aeration periods were alternated at interval of 3:1 hr. (iii) If the monitored DO concentration is not within the range of 3 - 8 mg/l (average is 5 mg/l), the aeration capacity should be increased.

(4) Assimilation: (i) After every batch treatment, 200 ml of liquid is sampled and then 2 liters of supernatant is immediately discharged, and the 3 liters of correct sample C (R=0.1) is filled and continued this operation for a week. (ii) The sampled 200 ml of treated liquid should be analyzed for TS, VS, TKN, NH_4-N, and NO_3-N and NO_2-N. The VS and organic nitrogen can be monitored as the existent evidence of microbes.

4. Actual Operation.

(1) The 18 liters of samples A and B were once again sampled from FARM M-III, respectively, and kept them in a refrigerator at temperature ranged from 2 - 4 °C. Sample A should be filtrated by a 200 mesh screen.

(2) Chemical analyses include TOC, TKN, NH_4-N, NO_3-N, NO_2-N, and T-P.

(3) The arrangement of T-N*/TOC ratio can be calculated from MOH/Biocarbonate.

(4) Time schedule and adjustment of R: 1st day, R=0.1 (MOH); 2nd day, R=0.2 (MOH); 3rd day, R=0.3 (MOH); 4th day, R=0.5 (MOH); 5th day, R=1.0 (MOH).

(5) Feeding and sampling volume: (i) Feeding: 2.5 liter (stationary volume is remained at 1.5 liters). (ii) After 11:30 - 11:50: 500 ml (supernatant). (iii) After 23:30 - 23:50: 500 ml (supernatant). (iv) Discharged of treated liquid: 1.5 liters (remained 1.5 liter). (v) Repeating procedures from (i) to (iv).

(6) The 2.5 l/day of feeding volume should be prepared and added up to 4 liters as a working volume.

TABLE 1. Characteristics of the Input Wastewater and Effluent from Final Clarifier During the First Phase Test Period

Parameters	Point 1[a]		Point 7[a]	
	x	s	x	s
pH	7.82	0.3	7.06	0.64
TS mg/l	3024	1678	1590	370
VS mg/l	1574	984	466.3	289
BOD mg/l	1265	455	28.8	12
DO mg/l	0.22	0.09	2.74	0.62
NH_4-N mg/l	440	283	20	10.9
NO_3-N mg/l	68	45	204	101
T-P mg/l	1.86	1.07	37.2	23.1

x = Average, s = standard deviation, number of samples = 5.
[a]See Figure 1.

RESULTS AND DISCUSSION

First Phase: Continuous Activated Sludge Method

Table 1 shows the average qualitative characteristics of the input wastewater and effluent from final clarifier found at sample points no. 1 and 7 (Figure 1) during the first phase experimental period. For the mixed wastewater treated, the ratio between organic matter (as BOD), nitrogen (N), and phosphorous (P) was 100:38:0.2. Table 2 shows that the nitrogen concentrations present in different forms at the activated sludge reactor input (sample point no. 5) and the reactor output (sample point no.

TABLE 2. Nitrification and Denitrification of the Full-Scale Continuous Activated Sludge Reactor Input (Point 5) and Output (Point 6)

Date	Sample point number[a]	Parameters (mg/l) NH_4-N	NO_3-N	NO_2-N
2/12/91	5	352	27	ND[b]
	6	18	351	ND
2/21/91	5	210	13	ND
	6	13	198	ND
3/04/91	5	336	23	ND
	6	29	310	0.1
4/22/91	5	291	12	95
	6	11	135	18
5/06/91	5	261	11	ND
	6	78	303	0.05

[a]See Figure 1.
[b]ND = Not detected.

6). Table 2 indicates that how the sharp reduction in NH_4-N at the reactor output coincides with the increase in the nitrification process when the DO concentration were larger than 2 mg l^{-1} in the biological section. Only one denitrification process was found (in point no. 5, 4/22/1991) when NO_2-N was 95 mg l^{-1}. Generally, NO_2-N was constantly less than 0.1 mg l^{-1}. Figure 4 shows the trends of T-N, NH_4-N, NO_3-N, and T-P for each sample point number (Figure 1) during the first phase test period.

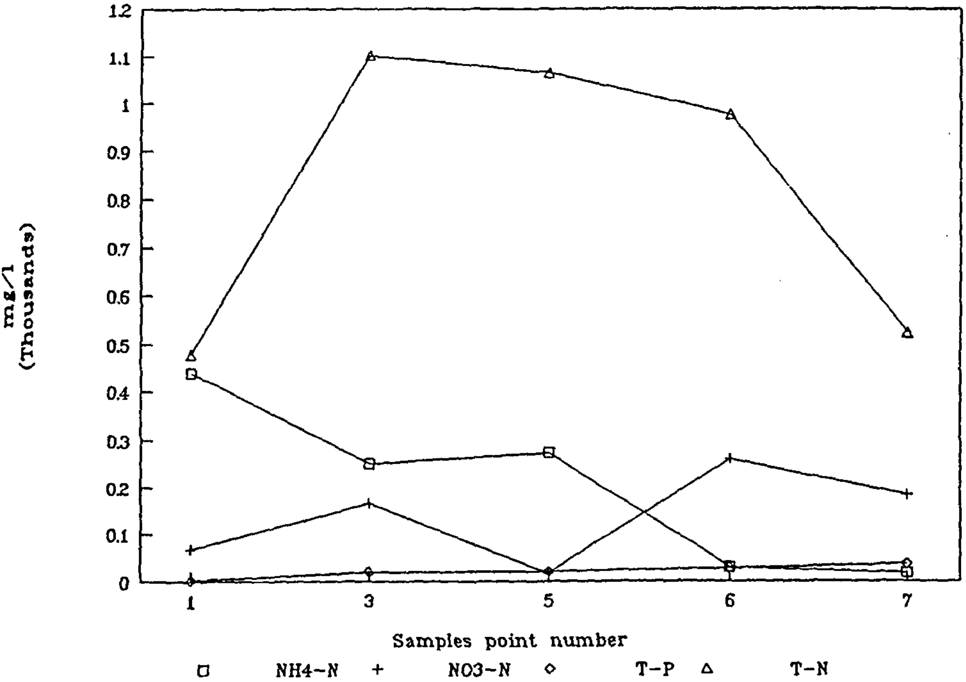


FIGURE 4. T-N, NH_4-N, NO_3-N, and T-P Trends in Each Sample Point During the First Phase Test Period

A material balance calculation (Table 3) indicates that TS and VS of outlet from methane fermentor is higher than that of inlet. This shows that the treatment processes slightly abnormal. A good performance occurs in methane fermentor (points no. 3 and 5) regarded to the removal of BOD concentration. In activated sludge method, T-N removal ratio is around 46% even T-N/BOD ratio is 34.

TABLE 3. Material Balance for M-III During The First Phase

Stage[a]	Q m^3/d	TS	VS	BOD	T-N	T-P
		---------	mg/l		-------------	
1	50	3024	1574	1265	480	1.86
2	50	5482	3483	2363	1102	41.5
3	49.04	1412	663	202	1064	20.3
4	0.96	43400	14.8			
5	49.04	1810	6810	29.2	975	28.1
6	49.04	1518	511	18	522	37.2

Remarks:
(1) Separator efficiency = 72%.
(2) BOD removal ratio = 98%.

[a]See Figure 1.

Material balance on FARM M-III as the hypothesis that intermittent aeration process is added to improve the present plant is shown in Table 4. Table 4 indicates that supernatant of raw wastewater tank can be used as the carbon source to the intermittent aeration process to enhance T-N and T-P removal efficiencies by addition of denitrification to a nitrification process. The hydraulic retention time of methane fermentor should be shorten to be 1/3 of the present system. As a result, T-N and T-P removal efficiencies become 75 and 83% of the input, respec-

TABLE 4. Material Balance for Improved M-III During the First Phase

	Q	TS		VS		BOD		T-N		T-P	
stage[a]	m^3/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d
1	50	3024	151	1574	79	1265	63	480	24	1.86	0.093
1'	25	1550	39	515	15	595	15	410	10	0.3	0.0075
2	25	4480	112	2523	63	1963	48	540	19	3.42	0.086
2'	6.5	163200	82	92200	46						
3	24.5	1240	30	7035	17	695	23	197	4.82	1.24	0.03
4	24.5	890	21.8	280	6.9	416	10.2	180	4.42	1.24	0.03
4'	1.23	13333	16.4	4179	5.14						
5	23.29	231	5.38	73.9	1.72	328.7	7.65	47.3	1.1	0.34	0.008
6	47.77	93.48	4.18	35.3	16.7	472	22.6	240	11.4	0.324	0.02
7	47.77	67.4	32.2	10.7	5.14	142	6.76	119	5.7	0.324	0.02

Remarks: Improving points for FARM M-III
(1) Point 1': Receiver tank, put a cutter pump.
(2) Point 2: First separator (presently existed)
(3) Point 3-4: Methane fermentor, try to make HRT half.
(4) Point 4': Second separator.
(5) Point 6: T-N/BOD ratio = 0.5.
(6) point 7: T-N and T-P removal efficiencies are 75 and 83% of the input, respectively.

[a]See Figure 5.

tively. Therefore, the results of this study then suggest that the continuous activated sludge method should be modified to a simple process for denitrification with nitrification: intermittently activated sludge method in this particular case (Figure 5): (1) Add a cutter pump in raw wastewater tank. (2)

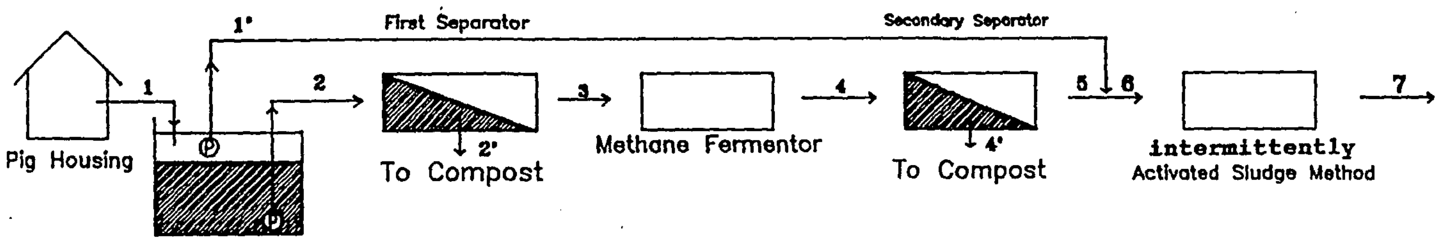


FIGURE 5. Improved M-III Plant Flow Sheet

Add a screen type separator between the processes of methane fermentor and intermittently aerated reactor. (3) Increase blower capacity to 2 times of present one. (4) Add a timer-relay system to activated sludge reactors to achieve the intermittent aerations.

Second Phase: Intermittently Activated Sludge Method

Table 5 lists the comparison of the actual operation data during the first phase with the observed experimental data in the second phase and estimated data based on the material balance in the aeration tank. For the mixed wastewater treated, significant differences in the characteristics of the slurry in the two different experimental periods were not found (Student's t-test).

The only differences between two phases were to do with the DO concentration and the concentration of biomass in the aerators, and therefore of the TOC/(NO_3+NO_2)-N ratio in the biological treatment section (from sample points 5 to 6, Figure 1). The TOC/(NO_3+NO_2)-N ratio of the input to the biological section is 3.76. High removal efficiencies (88-92%) for BOD were obtained with both continuous and intermittent aeration processes in all runs.

TABLE 5. Comparison of the Actual Operation Data in 1991, with the Observed Experiment Data in 1992, and Estimated Data Based on the Material Balance in Aeration Tank

Sample	TS	VS	BOD	T-N[a]	T-P[b]	Operation conditions
Influent	1810	672	29.2	975	28.1	Continuous aeration[c]
Effluent	1585	511	18.0	522	37.2	
Influent	1606	805	240	333	30.0	Intermittent Aerobic/anaerobic = 3/1 hr[d]
Effluent	908	354	105	277	30.0	
Influent	93.59	35.8	472	240	0.32	Intermittent Aerobic/anaerobic = 1/1 hr[e]
Effluent	67.40	10.7	142	119	0.32	

[a]Initial T-N=480 mg/l.
[b]Initial T-P=1.86 mg/l.
[c]Average data on the full-scale operation of the Farm-III in 1992.
[d]Full-scale experiment of wastewater treatment in the intermittent process on the Farm-III in 1992.
[e]Improved treatment layout on the Farm-III for the nitrification and denitrification based on the material balance.

Figure 6 shows a 24-hour variation in nitrogen concentrations present in different forms at the biological section. NO_2-N is not shown because it was negligible. Notices how the sharp reduction in NO_3-N at the plant output coincides with the increase in removal of nitrogen (N) in all its forms exactly when

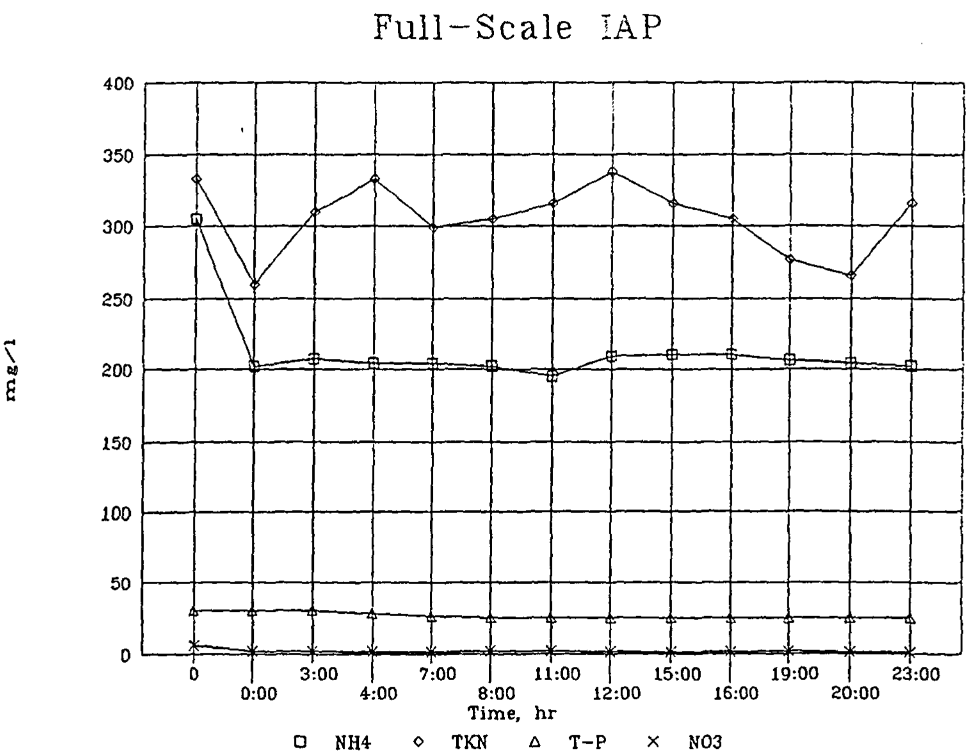


FIGURE 6. 24-hr Variations of Nitrogen in Different Forms and T-P at Activated Sludge Reactor During the Second Test Period

DO concentrations were reduced and the TS increased in the biological section. In Table 5 the most important results from the in- and outlet are summarized. The pH value in the plant ranged from 7.6-8.2 and the temperature averaged 21°C, and the DO concentration averaged 1.2 mg l^{-1}.

In addition of following may be noted: the low pH value in the first phase, indicating a high level of nitrifying activity not followed by an equal level denitrifying activity; the high quality effluent in COD terms in the second phase and the good sedimentation characteristics of the sludge (low value of the TS concentration of the discharge) in the second phase despite the lower DO concentration. The results show a higher removal efficiency of the plant with low DO concentration and high TS concentration in the biological section.

The nitrogen mass balance allowed calculation of the nitrogen removed by denitrification in the second phase test period of 43% of the input nitrogen of 480 T-N mg l^{-1}. Compared with the first phase of -0.09% of the T-N removal efficiency, the increase in amount removed was therefore considerable. The disappearance of the nitrogen noted in the second phase, may be attributed to a simultaneous nitrification/denitrification process, because if the reduced concentration of NO_3-N was due to a drop in nitrifying activity, an increase in T-N should occur (Evans et al., 1979; Muck and Streenhuis, 1982); since this was not the case.

Thus, higher removal efficiencies for total organic substance, nitrogen and enhanced phosphorus removal in swine wastewater were simultaneously

TABLE 6. Characteristics of Swine Wastewater of Bench-Scale During Assimilation Period

Date 1992	NH_4-N	NO_3-N	TKN	TS (mg/l)	VS	Inorg-N	T-N
5/19	33.6	14.7	190	2204	41.4	156.4	204.7
5/20	25.2	14.9	146	1276	37.3	120.8	160.9
5/21	30.8	11.7	179	1208	36.8	148.2	190.7
5/22	25.2	11.9	137	1104	35.5	111.8	148.9
5/23	36.4	13.8	151	1346	37.0	114.6	164.8
5/24	33.6	14.9	162	2366	34.1	128.4	176.9
5/25	25.2	14.7	174	1462	39.3	148.8	188.7
5/26	30.8	16.0	185	2346	42.1	154.2	201

obtained in the full-scale FARM M-III plant by the intermittent aeration process. Therefore, simultaneous nitrification/denitrification in a single reactor seems a realistic possibility for the treatment or pretreatment of wastewater with a high concentration of nitrogen and phosphorus.

Bench-Scale Experiment: Intermittent Aeration Process

Two types of data were obtained. The first was the set of routine data from samples collected from the first week assimilation period at steady-state operation (DO concentration = 5 - 8 mg l^{-1}) (Table 6). The other data were collected along the time course of actual treatments (Table 7). The profile of NH_4-N, NO_x-N, and VS concentrations changing with time during assimilation period is shown in Figure 7.

TABLE 7. Characteristics of Swine Wastewater of Bench-Scale Experiment During Actual Operation

Date 1992	pH	NH3	NO3	TKN	BOD	TOC	DO
05,26PM	8.36	25.2	10.5	28	2600	1190	3.2
05,27AM	8.39	22.4	10.5	28	2457	982	3.2
05,27PM	8.33	28.0	12.0	34	2000	879	3.1
05,28AM	8.27	25.2	12.0	34	2200	870	3.6
05,28PM	7.66	33.6	14.5	39	660	524	3.8
05,29AM	7.88	25.2	14.0	39	750	506	3.1
05,29PM	7.53	30.8	15.0	36	895	309	3.4
05,30AM	7.58	25.2	14.5	36	755	303	3.5
05,31AM	8.93	22.4	11.0	28	240	103	3.8
05,31PM	8.84	30.8	11.0	39	320	331	3.7
06,01AM	8.96	19.6	10.5	28	240	84	3.3

Date	TS	VS	T-P	T-N	T-N[a] (Removal Ratio)	T-P[b] (Removal Ratio)
05,26PM	1276	44.5	2.3	38.5	70.38461	0.0
05,27AM	1774	43.2	1.8	38.5	70.38461	21.7
05,27PM	1288	47.5	2.0	46.0	64.61538	13.0
05,28AM	1292	46.7	2.2	46.0	64.61538	4.3
05,28PM	1498	48.9	2.0	53.5	58.84615	13.0
05,29AM	1420	48.3	2.2	53.0	59.23076	4.3
05,29PM	1584	44.9	2.0	51.0	60.76923	13.0
05,30AM	1478	45.3	2.5	50.5	61.15384	-0.087
05,31AM	1660	42	2.0	39.0	70.00000	13.0
05,31PM	1782	47.1	2.5	50.0	61.53846	-0.087
06,01AM	1658	43.1	3.0	38.5	70.38461	-0.304

[a]Initial T-N=130 mg/l
[b]Initial T-P=2.3 mg/l

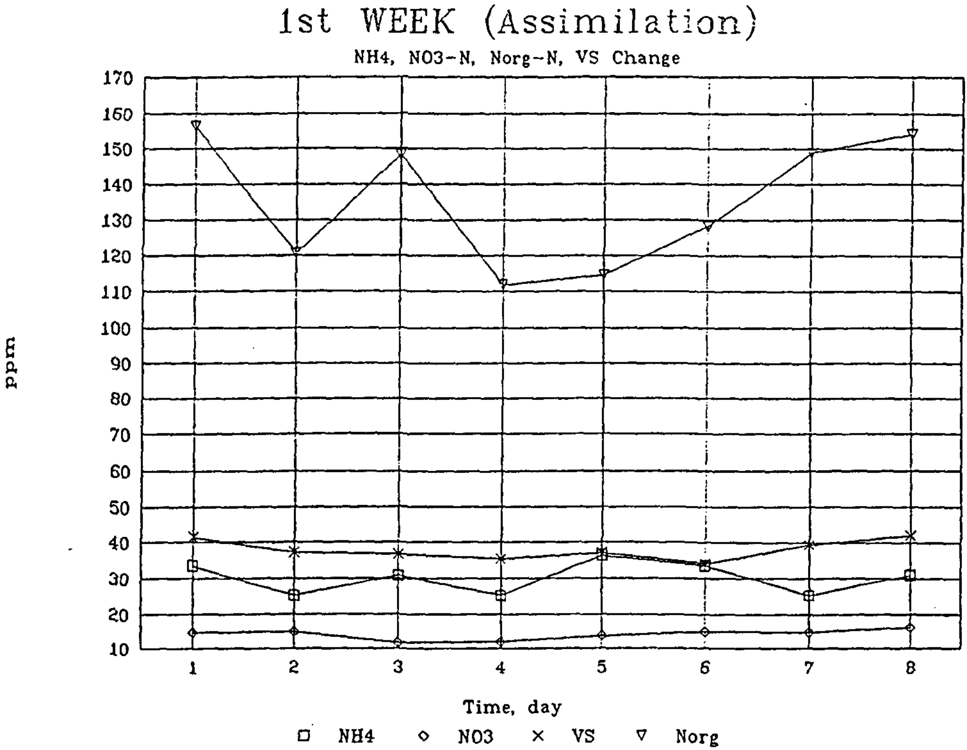


FIGURE 7. Changes of NH_4-N, NO_3-N, Organic-N, and VS During Assimilation in Bench-Scale Experiment

High removal efficiencies (91 - 93%) for BOD and TOC were obtained in all runs. High TS concentration in the bench-scale column may explain the above performance. TOC, DO and pH profiles are presented in Figure 8. TOC reduction occurred immediately after the aeration and the reduction was observed even at the first non-aeration period in the intermittent aeration process.

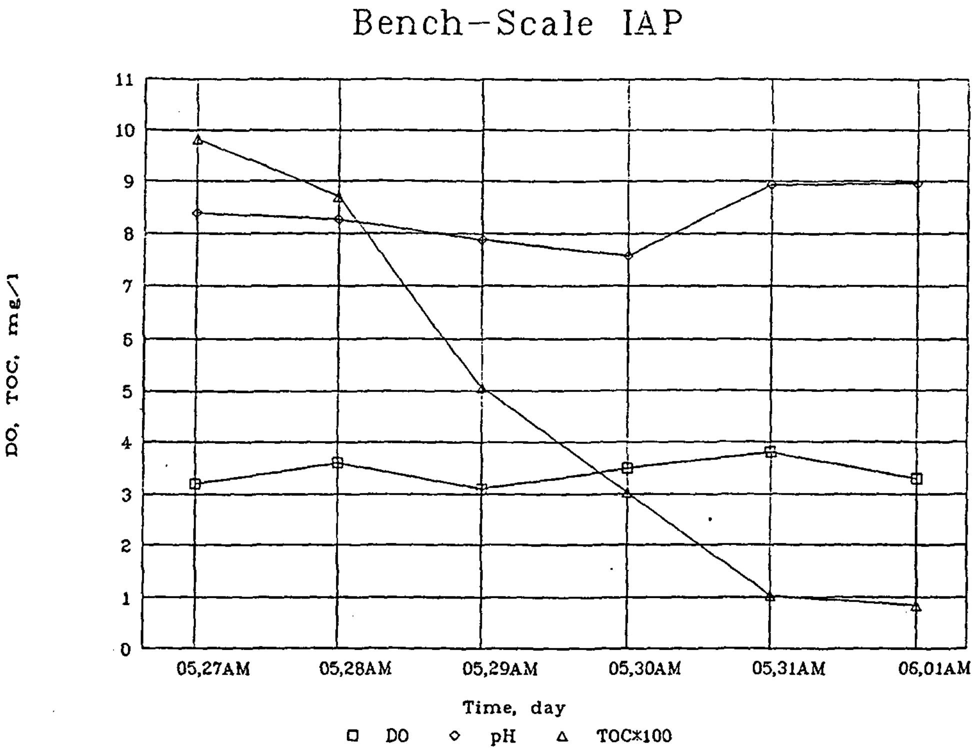


FIGURE 8. Changes of pH, DO, and TOC During Actual Operation in Bench-Scale Experiment

Large differences in the removal of nitrogen were observed between intermittent and continuous aeration processes (Tables 3 and 7). Removal efficiencies of the intermittent aeration (59 - 60%) were much higher than that of the continuous one (-0.09%). During the continuous aeration process, though organic nitrogen and NH_4-N in influent were readily oxidized, a noticeable decrease of T-N did not occur.

When the T-N/BOD (or T-N/TOC) ratio of influent was increased to 0.31, NH_4-N was not readily oxidized, due to the accumulation of NO_x-N and the concomitant drop in pH (Haga et al., 1989). The incorporation of the intermittent non-aeration period in the bench-scale experiment avoided the accumulation of NO_x-N to obtain high nitrogen removal.

Figure 9 shows the change profile of nitrogen in different forms during the bench-scale experiment. NO_x-N produced during an aeration period was immediately reduced in the subsequent non-aeration period to nitrogen gas, and nitrification in the aeration periods occurred smoothly (Figure 9) under an almost stable pH condition (Figure 8). Thus, along with the proceeding NH_4-N oxidation, T-N and NO_x-N decreased in the intermittent aeration process.

Denitrification occurs in anoxic conditions with the existence of organic matter as electron donor. Methyle alcohol added to as an organic matter in the influent has been used for this objective. Thus, in the case of the intermittent aeration process, denitrification might occur mainly at the earlier stage of the non-aeration period in the operation where organic material in the influent still remain in the mixed liquor. The results also show that denitrifi-

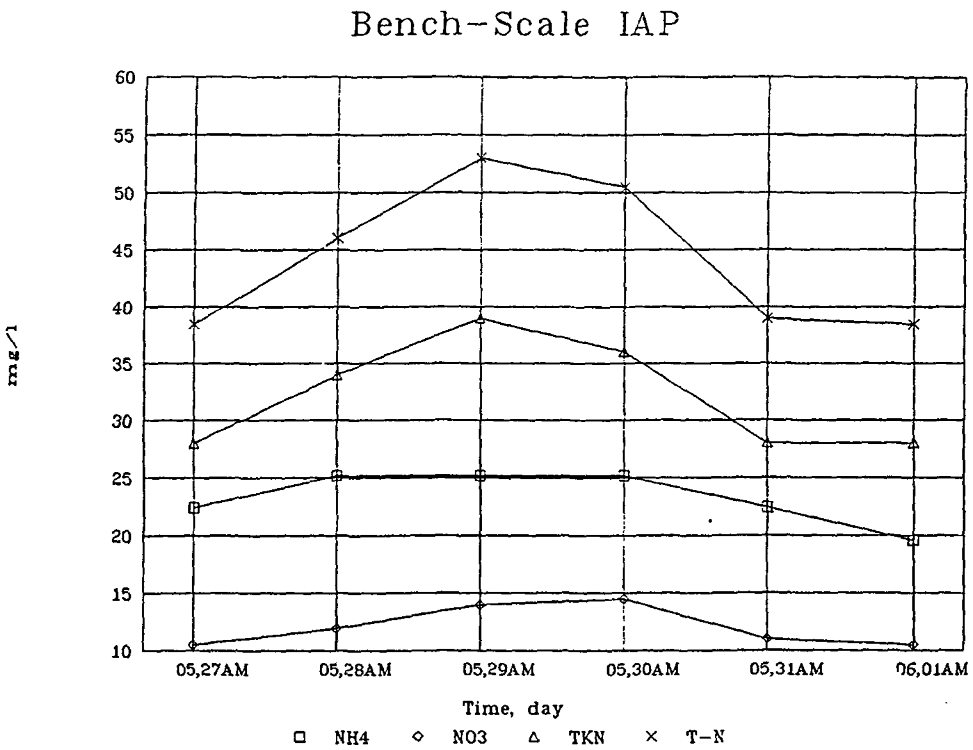


FIGURE 9. Changes of Nitrogen in Different Forms During Actual Operation in Bench-Scale Experiment (Initial T-N = 130 mg/l)

cation occurs mainly at the TOC profile at the beginning of high level of TOC concentration (Figures 8 and 9). Investigation of organic matters in swine wastewater is necessary to assess the limitation for nitrogen removal without any supplemental carbon sources.

Nitrogen was mainly decreased during the aeration period in the early stage of the bench-scale actual operation when the DO concentration stayed at a low level (Figures 8 and 9). Applegate et al. (1980) assumed that most of the denitrification occurred in the first two channels under low oxygen concentration (DO = 0.1 - 0.9 mg l^{-1}) in a multi-channel oxidation ditch system. What types of nitrogenous gases were released during the denitrification process remains unsolved.

Removal efficiencies for phosphorus with the intermittent aeration process in a bench-scale were higher than those with the continuous ones (Tables 5 and 7). A high rate of removal of 22% was achieved as T-N/TOC ratio of 0.1. When the T-N/TOC ratio of the influent increased to 0.5 and 1.0, phosphorus removal efficiencies decreased to 13 and -0.09%, respectively. This phenomena may can be explained as: the presence of NO_x-N disturbed the release of phosphorus during the non-aeration period, as did the presence of molecular oxygen, and diminished the uptake of phosphorus during the aeration period.

Therefore, accumulation of phosphorus in activated sludge should be guaranteed in both intermittent and continuous processes. The results therefore show that gradual increase of phosphorus in the wastewater treated by the continuous aeration process

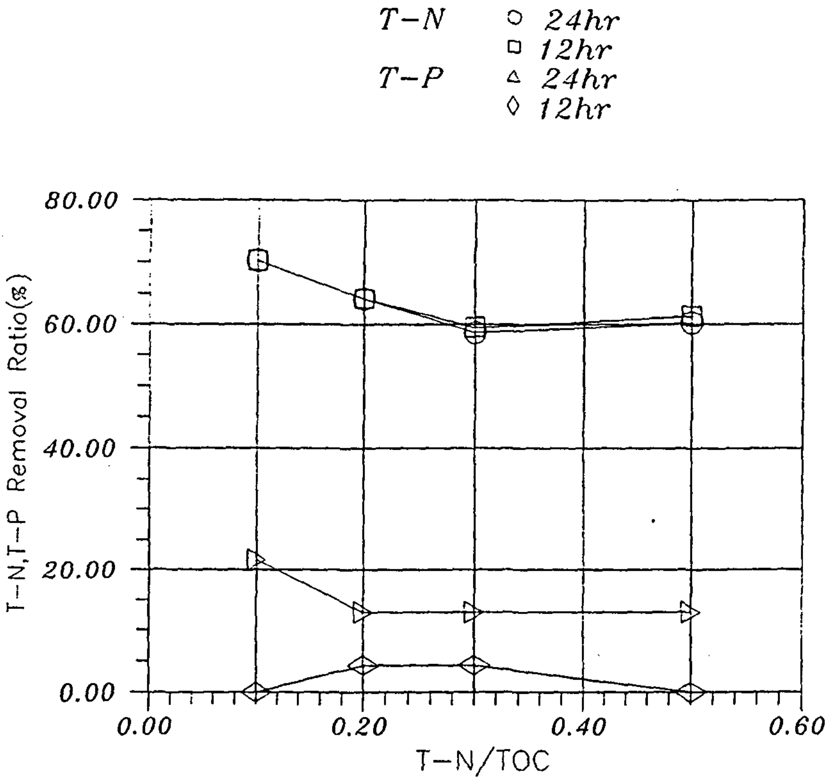


FIGURE 10. Effect of T-N/TOC Ratio of Influent Wastewater on the Removal Efficiencies of T-N and T-P in the Bench-Scale Experiment

(Table 3) seemed to result from the release of phosphorus from activated sludge. The phenomena contents during intermittent full-scale and bench-scale operations show the same tendency as that of the continuous aeration operation (Table 7).

The relationship between the T-N/TOC ratio of the swine wastewater and the removal of nitrogen is summarized in Figure 10. Nitrogen removal efficiencies were sharply decreased to a T-N/TOC ratio of 0.3 (70 - 59%), and decreased with an increased in the ratio. As the T-N/TOC ratio of swine wastewater was estimated to be 0.2 - 0.4 (Haga et al., 1989), the application of the intermittent aeration process for swine wastewater treatment might anticipate the removal of nitrogen to satisfy the effluent standards.

By adopting an adequate aeration program for individual swine wastewater treatment, this system will provide a promising means for nitrogen and phosphorus control.

CONCLUSION

The experiments in a methane fermentation plus activated sludge method type pig farm (M-III) have been performed with the continuous and intermittent aeration processes on the removal of nitrogen and phosphorus in the full-scale and bench-scale operations. The following results were obtained.

1. From the theoretical point of view, this particular case, or referred to as the one-reactor

denitrification with nitrification system (intermittent aeration process), has two possible advantages: (1) the frequent cycling of the mixed liquor creates a very high mixed liquor recycle rate that provides NO_3-N for anoxic oxidation of incoming BOD; and (2) the flexibility in O_2 transfer capacity (turning individual aerators on or off) allows carefully matching of O_2 transfer capacity to the required rate.

2. From the process design point of view, this system is unnecessary to establish anoxic zones therefore it would significantly simplify design and operation of such systems. The main control parameters to achieve denitrification would be the O_2 transfer rate, which would equal the O_2 demand for nitrification and for carbonaceous BOD not removed through denitrification, and an average DO concentration suitable for formation of anoxic and aerobic microzones within the floc.

3. BOD and TOC removal efficiencies with the intermittent aeration process were as high as those with the continuous aeration operation, though the total aeration period in the intermittent aeration process were nearly one-third of that of the continuous one.

4. In the removal of nitrogen and phosphorus, large differences between the intermittent and continuous aerations were observed without pH stabilizers.

5. At an influent T-N/TOC ratio of 0.1, removal efficiency for T-N in the bench-scale experiment was 70%, and for T-P were 22%, respectively.

6. At an even higher influent T-N/TOC ratios of 0.3 - 1.0, the removal efficiencies for T-N were decreased to about 59 - 61%, while that for T-P was -0.3 - 13%.

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