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Effect of anaerobic digestion on the high rate of nitritation, treating piggery wastewater

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Abstract

The amount of piggery wastewater as domestic livestock is increasing. The volume of piggery wastewater produced is less than the volume of other wastewaters, but piggery wastewater has a heavy impact on wastewater streams due to an extremely high concentration of nitrogen and COD. In this study, laboratory reactors were operated using piggery wastewater and the effluent of anaerobic digester from piggery wastewater plants. The purpose of this study was to induce the nitritation process, which is an economically advantageous nitrogen removal method that converts ammonium nitrogen into nitrite. The results showed that the effluent of anaerobic digester from piggery wastewater was more efficient than raw piggery wastewater in terms of inducing nitritation. It can be deduced that nitritation is largely affected by an organic fraction of piggery wastewater. It can also be concluded that a small amount of biodegradable organic matter in piggery wastewater is efficient in inducing nitritation.

Key words: piggery wastewater; anaerobic digestion; nitritation; nitrogen

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Introduction

A very small amount of piggery wastewater is flowing into municipal wastewater treatment plants (MWTP), but it contains a high concentration of contaminants. Economic development, which results in more livestock consumption, leads to livestock generating larger amounts of piggery wastewater. According to the South Korea Ministry for Food, Agriculture, Forestry and Fisheries (2008), the number of cows increased about 30% in 2008 (when compared to data in 2001), while the number of pigs increased approximately 10%. According to the data of the South Korea Rural Development Administration (2007), the volume of piggery wastewater in 2006 was reported to be 43,915,000 ton/year. Piggery wastewater has high concentrations of organic matter and nutrients such as nitrogen (N) and phosphorus (P), and when it flows into the water bodies, it is known to be the cause of eutrophication. When it comes to the treatment process of piggery wastewater, contaminants are normally removed through a piggery wastewater treatment plant or transported to an adjacent MWTP, but more effective treatment processing and resources are being studied (Choi et al., 2001; Gali et al., 2008; Shin, 2010; Wang et al., 2010; Zhang et al., 2009). In general, the biological nitrogen removal is accomplished by converting ammonium nitrogen to nitrate which is reduced to nitrogen gas in the process of nitrification-denitrification. The process of nitrification-denitrification has been dominant in the field of wastewater treatment. However, studies on nitritation have been actively undertaken in recent years and started to draw attention (Abma et al., 2010; Cui et al., 2005; Gil, 2006; Hellinga et al., 1998; Lee, 1998; Li et al., 2010a, 2010b; Maite and Yuan, 2010). The reason that the nitritation has gained popularity is because of the economic advantages. In the nitritation process, 25% of oxygen and 40% of carbon source can be saved (Han et al., 1998; Siegrist, 1996). In addition, if the effluent occurs with stable accumulation of ammonium nitrogen to nitrite within the piggery wastewater by nitritation, the anaerobic ammonium oxidation (ANAMMOX) process can be applied to the effluent. The ANAMMOX process is an innovative biological nitrogen removal process that converts ammonium nitrogen and nitrite to nitrogen gas in an anaerobic condition (Gil, 2006; Hellinga et al., 1998; Henze, 1991; Cui et al., 2005; Lee, 1998; Li et al., 2010a). In this study, the laboratory scale nitritation reactor was operated with wastewater from Y and H piggery wastewater treatment plants and the effluent of digester from the H piggery wastewater treatment plant. The high concentration of ammonium nitrogen in piggery wastewater was induced to accumulate into nitrite through

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the efficiency nitrogen removal process on nitritation. In addition, this research was analyzed to find the optimum conditions to successfully induce the nitritation on the basis of the operational results for each piggery wastewater.

1 Materials and methods

1.1 Materials

The piggery wastewater was obtained by taking samples from the raw piggery wastewater from Y and H piggery wastewater treatment plants and the effluent stream from the anaerobic digester located in the H piggery wastewater treatment plant. The characteristics of the piggery wastewaters are presented in Table 1. Sodium bicarbonate ($NaHCO_3$) was added to the inflow to keep the theoretical alkalinity/ammonia nitrogen ratio required for the nitritation at 7.14 or higher. In addition, the ammonium nitrogen influent concentration during the operation period was 1500 mg/L or higher, and more than 70% of total nitrogen (TN) was detected as ammonium nitrogen. The raw piggery wastewater and the effluent of anaerobic digester in the piggery wastewater treatment plant showed the greatest difference of the BOD_5 value.

1.2 Experiment

The laboratory scale reactor used in this study was operated in the batch type, and the influent and the effluent were tested at the same time. In addition, aeration was continuously maintained to prevent a shortage of oxygen supply to nitritation. The nitritation reactor was a cylinder-shaped acryl with a volume of 8 L with spare space. In order to maintain an optimum temperature of 35°C, the reactor exterior was made with a water-jacket for the heater and the cooler. The water quality must be homogeneous in the reactor, so the sample will represent the concentration inside the reactor. There are several methods to analyze COD fraction, but in a number of previous studies, the respirometric method was recommended most frequently (Dricks et al., 1999; Wentzel et al., 1999). Using the oxygen uptake rate (OUR)-Test based on the respirometric method, the COD fraction analysis was implemented in the piggery wastewater. For the OUR-Test, the sludge in the endogenous respiration phase was used to mix with the sample in the aeration tank, and a flow control pump was used to pump it into a dissolved oxygen (DO) measurement at a certain interval to measure DO. In the aeration tank, the sample went through the continuous aeration to maintain DO sufficiently for microbial activity. For preventing experimental deviation, the nitrification control agent, 1-Ally 1-2-thiourea, was added to the aeration reactor to prevent DO consumption resulting from nitrification. Additionally, the DO measurement was done in a closed system to prevent external air from interfering with the analysis. The pH meter (Accumet AB15, USA) and DO meter (YSI-550A, USA) were used. DR2800 (HACH company, USA) was used to measure ammonium nitrogen and Ion Chromatorgraphy (Dionex ICS-1000, USA) was used to measure the nitrite and nitrate. For TSS filtering, a Whatman GF/C glass fiber filter was utilized. Alkalinity, COD, BOD_5, and TN were analyzed with Standard Methods (APHA et al., 1998).

2 Results and discussion

2.1 COD fraction analysis

By the OUR-Test of each sample of piggery wastewater used in this study, the results on the COD fraction analysis is shown in Fig. 1. The COD fraction is classified into four ingredients: SI (soluble inert), SS (soluble biodegradable), XS (suspended biodegradable), and XI (suspended inert). By the analysis of the piggery wastewater influent from the treatment plant in Fig. 1a and b, it was observed that the biodegradable organic matter (BDCOD) on average takes about 70% or more. However, as shown in Fig. 1c, the effluent of anaerobic digester from piggery wastewater is likely to contain non-biodegradable organic matter (NBDCOD). As it went through the nitritation, the BDCOD was removed, and in addition, the removal of the BDCOD affected the nitritation of the influent of piggery wastewater and the effluent of anaerobic digester from piggery wastewater.

2.2 Reactor operation in laboratory scale

The overall operation is summarized in Table 2. Figure 2 shows the alkalinity and ammonium nitrogen concentration in the raw piggery wastewater of Y piggery wastewater treatment plant (R), the raw H piggery wastewater treatment plant (Q), and the effluent of anaerobic digester from H piggery wastewater treatment plant (D). Figure 3 shows the concentration of nitrite and nitrate in the effluent, the amount of ammonium nitrogen concentration removed, and the result of the operation condition for each period. Figure 2 presents artificial alkalinity along the concentration of influent ammonium nitrogen. This is to

Table 1 Characteristics of influent piggery wastewater in Y and H piggery wastewater treatment plants and effluent of anaerobic digester in H piggery wastewater treatment plant

Parameter	Influent of Y plant		Influent of H plant		Effluent of anaerobic digester in H plant	
	Concentration range	Average	Concentration range	Average	Concentration range	Average
pH	7.5–8.7	8.3	7.4–8.3	8.1	7.2–8.4	7.9
Alkalinity (mg/L as $CaCO_3$)	12,400–18,740	16,428	13,270–14,090	13,950	11,860–13,800	12,740
COD_{Cr} (mg/L)	11,520–16,840	13,155	9600–11,420	10,430	5230–8320	6742
BOD_5 (mg/L)	7280–9690	8952	7630–9870	6970	520–840	682
NH_4^+-N (mg/L)	1680–3940	2770	1870–1960	1920	1650–1920	1830
TN (mg/L)	2170– 680	3282	3140–3620	3320	2870– 3120	2960

TN: total nitrogen.

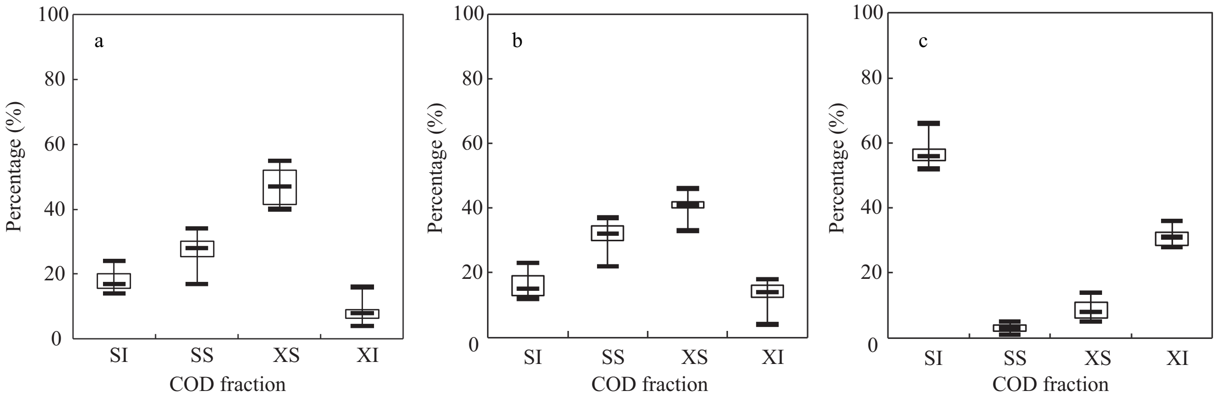

Fig. 1 COD fraction of piggery wastewater. (a) using raw wastewater of Y or H plant; (b) piggery wastewater treatment plant; (c) using effluent of anaerobic digester from H piggery wastewater treatment plant. Data are expressed as mean ± SD. COD fraction: SI: soluble inert; SS: soluble biodegradable; XS: suspended biodegradable; XI: suspended inert.

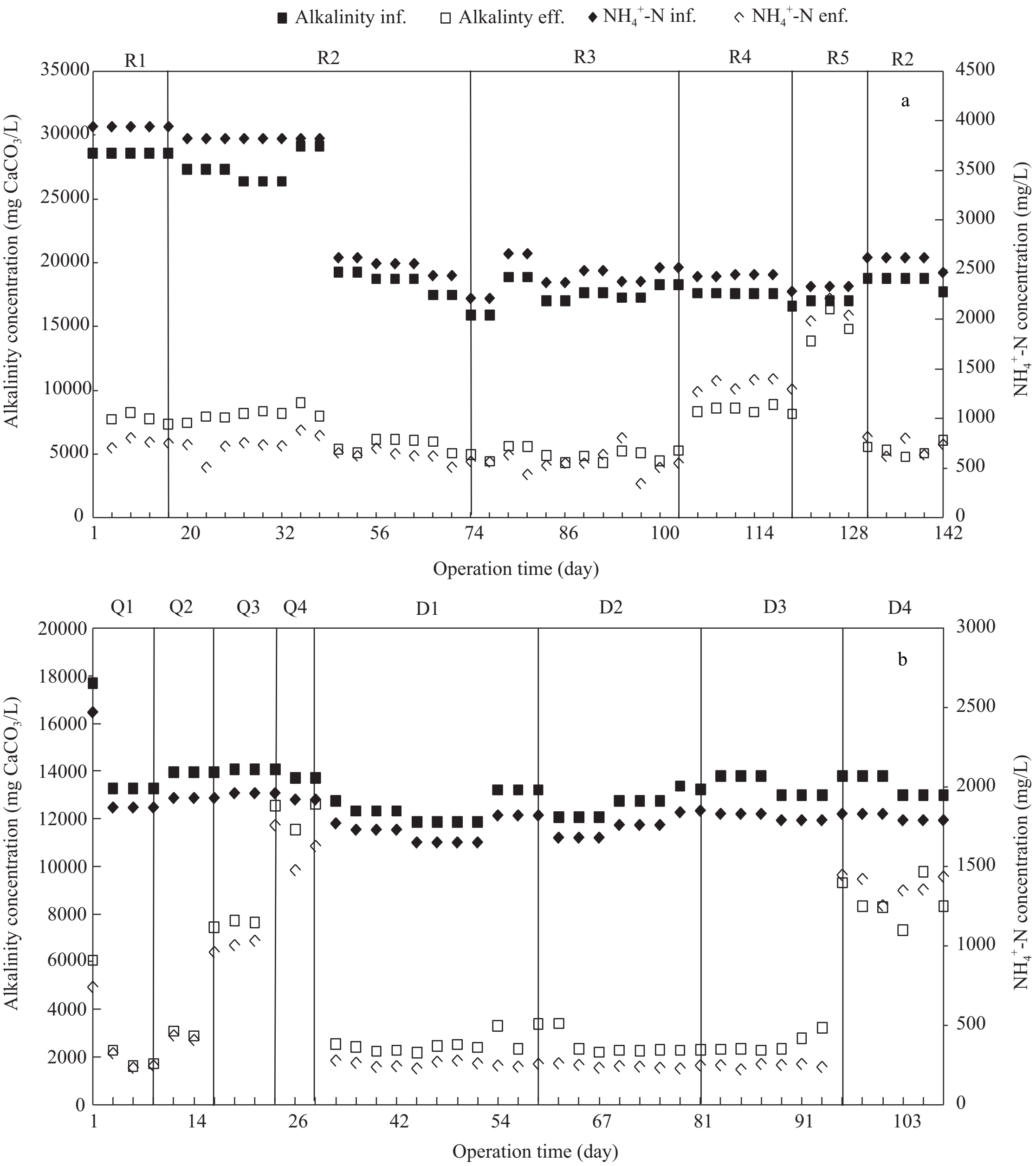

Fig. 2 Influent and effluent alkalinity and NH_4^+-N in the reactor. (a) using raw wastewater from Y piggery wastewater treatment plant, (b) using raw wastewater and effluent of anaerobic digester from H piggery wastewater treatment plant. The periods of R, Q, and D are referred to Table 2.

Table 2 Change of SRT, ammonia removal rate, nitrite conversion rate during the operation periods

Influent	Period	SRT (day)	Ammonia removal rate (%)	Nitrite conversion (%)
Raw wastewater of H plant (R)	R1	16	80.9	0
	R2	8	77.1	46.6
	R3	6	77.7	58.6
	R4	4	44.6	49.4
	R5	2	12.5	26.7
Raw wastewater influent of H plant (Q)	Q1	16	85.9	5.1
	Q2	8	78.4	55.2
	Q3	4	48.9	47.6
	Q4	2	16.3	25.5
Effluent of anaerobic digester from H plant (D)	D1	8	85.5	10.0
	D2	6	86.4	35.6
	D3	4	86.6	78.2
	D4	2	23.9	40.6

SRT: solid retention time.

consistently maintain the ratio of alkalinity and ammonium nitrogen, therefore, the ratio is not influenced during the operation period. In the effluent, an increase in the removal rate of the ammonium nitrogen causes an increase in the exhaust amount of the alkalinity, and a decrease in the removal rate of the ammonium nitrogen causes a decrease in the exhaust amount of the alkalinity. In the period of R, approximately 40 days in the early operation period, 4000 mg/L of ammonium nitrogen concentration was streamed in for analyzing the reactor's efficiency when there is a high concentration of ammonium nitrogen. The reactor operation controls the ammonium nitrogen concentration in the piggery wastewater to begin with solid retention time (SRT) with the gradual decrease of SRT. During R and Q periods, the raw piggery wastewater treatment plant operates the reactor, and for the period operated with SRT of 4 days or longer, it shows a stable ammonia removal rate of 70% or more. However, under SRT 4 days, the ammonia removal rate was reduced to 50%, and if the operation condition of SRT would become shorter, the efficiency would be drastically reduced. The D period exhibited a stable ammonia removal rate in all zones, except D4. In the D4 period, there was a low ammonia removal rate of approximately 20% similar to R5 and Q4, and the D3 period had a higher ammonia removal rate in comparison compared to the R4 and Q3 periods for the same SRT condition.

Looking into the D1–D3 periods of Fig. 3b, 1500 mg/L

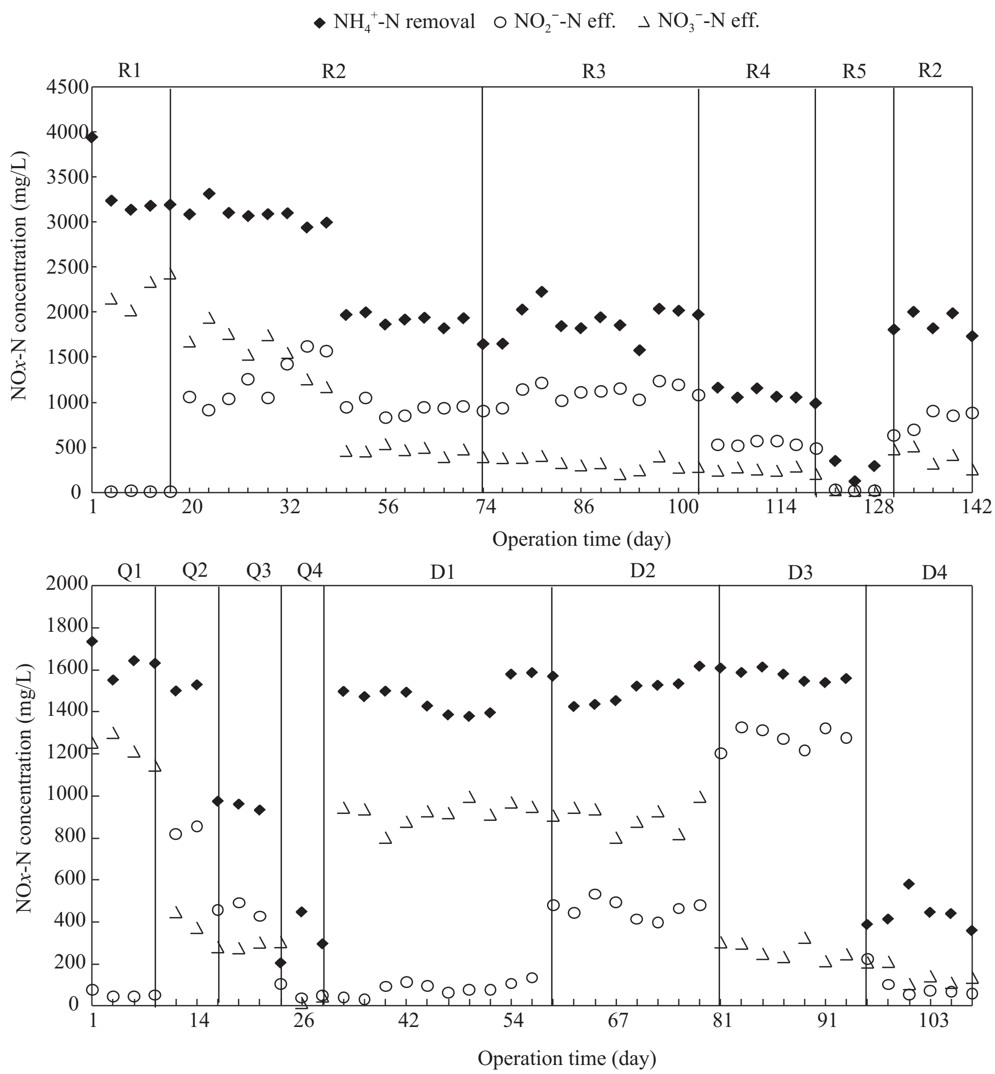

Fig. 3 NH_4^+-N removal and effluent NO_2^--N and NO_3^--N in the reactor. (a) using raw wastewater from Y piggery wastewater treatment plant piggery wastewater treatment plant, (b) using raw wastewater and effluent of anaerobic digester from H piggery wastewater treatment plant.

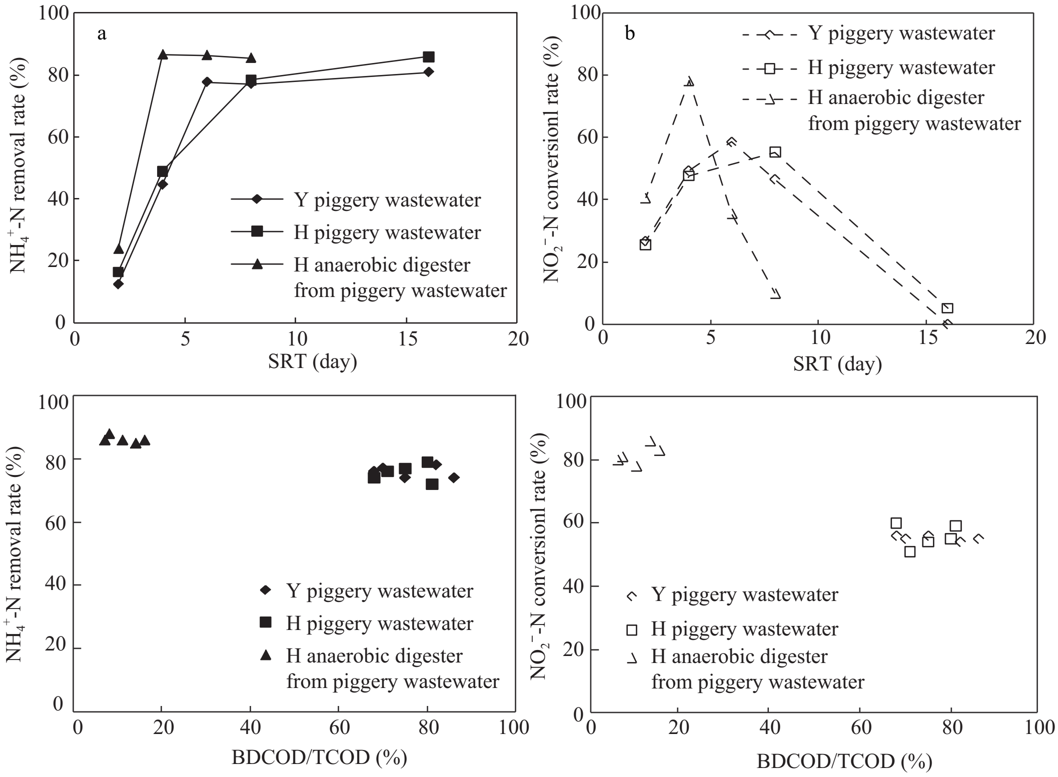

Fig. 4 Ammonia removal rate (a) and nitrite conversion (b) according to SRT and ammonia removal rate (c) and nitrite conversion (d) according to biodegradable organic matter (BDCOD)/total COD (TCOD).

of ammonium nitrogen was removed, but the nitrite was converted during the D1 and D2 periods, and the nitrate was converted during the D3 periods. Through D1–D3, in the periods that the ammonium nitrogen removal was consistent, the concentrations of nitrite and nitrate were changed. In the period that high concentration of nitrate of the effluent was detected, the reactor was operated in longer SRT to induce the nitrification. In addition, the SRT range to induce the nitritation was narrower than the SRT to remove the ammonium nitrogen, and to artificially induce the nitritation through the SRT control. For each influent, the results show a stable ammonia removal rate and high nitrite conversion for R3 (58%), Q2 (55%), and D3 (78%). In spite of operating with SRT, the shortest D3 had the highest nitrite conversion operation result. By using the effluent of anaerobic digester from piggery wastewater, the nitritation would be induced more than in the influent of piggery wastewater. As shown in Fig. 1, BDCOD is affected by the nitritation in the influent.

Figure 4a, b shows the average ammonia removal rate and nitrite conversion of the effluent following the SRT of each reactor. When the reactor SRT was maintained for a certain period, an approximate ammonia removal rate of 80% was secured. In ammonium nitrogen removal, the effluent of anaerobic digester from piggery wastewater had required a shorter SRT than influent of piggery wastewater. The change of the nitrite conversion rate was greater depending on SRT, and the effluent of anaerobic digester from piggery wastewater showed the shortest SRT with the highest nitritation efficiency. Analysis of the results of using the nitration to dispose of the piggery wastewater shows that piggery wastewater can obtain a stable ammonia removal rate for operating with a certain SRT or more, but the piggery wastewater needs to maintain a certain SRT or more to accumulate the nitrite. Therefore, the accumulation of the nitrite is influenced by SRT, and the effluent of anaerobic digester from piggery wastewater would be more successful in inducing the nitritation.

Figure 4c, d shows the ammonia removal rate and nitrite conversion in the period with the highest nitrite conversion for the reactor with the influent of BDCOD/TCOD (total COD) (BDCOD ratio from the total COD). For the effluent of anaerobic digester from piggery wastewater, the portion of BDCOD was 20% or less while the portion of influent of piggery wastewater was 70% or more. According to the increase in BDCOD/TCOD, the ammonia removal rate and nitrite conversion were reduced. In addition, the nitrite conversion was greatly reduced in comparison to the ammonia removal rate. This may be attributable to the BDCOD having an effect on the ammonium nitrogen removal and nitrite conversion. If the BDCOD in the piggery wastewater is removed through the anaerobic digestion, nitritation is induced more successfully. The effluent of anaerobic digester from piggery wastewater had a shorter SRT required for nitritation compared to the raw piggery wastewater, and this is due to the influence of a small BDCOD/TCOD ratio in the influent. Therefore, nitritation of piggery wastewater with the removal of BDCOD is more effective than nitritation of the raw piggery wastewater.

2.3 Inhibition of FA and FNA

Factors leading to the accumulation of nitrite, such as high pH, high temperature, and low DO density, were presented by several researchers (Ruiz et al., 2003; Turk

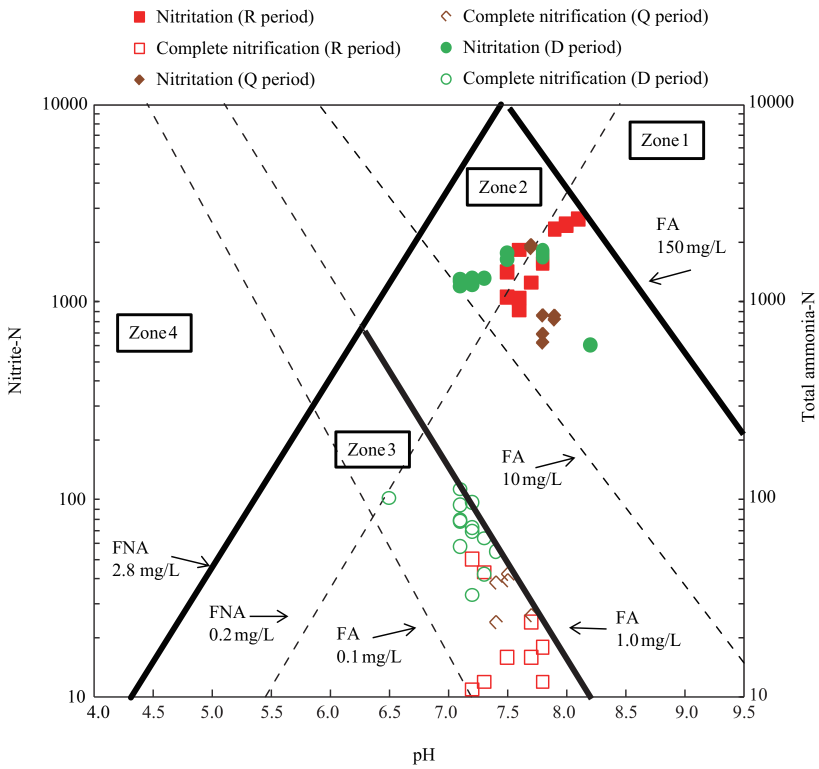

Fig. 5 Inhibition condition graph in the laboratory reactor. FA: free ammonia; FNA: free nitrous acid.

and Mavinci, 1989; Kuai and Verstraete, 1998; Hellinga et al., 1998). In particular, Anthonisen et al. (1976) concluded that the cause of nitrite accumulation was due to inhibition on the FA (free ammonia) and FNA (free nitrous acid). A system diagram is present that shows the effects of pH, nitrite, and ammonium nitrogen on each zone as follows: Zone 1: FA inhibition to *Nitrobacter* and *Nitrosomonas*; Zone 2: FA inhibition to *Nitrobacter*; Zone 3: complete nitrification; Zone 4: FNA inhibition to *Nitrobacter*. FA as NH_3 (mg/L) and FNA as HNO_2 (mg/L) can be calculated through Eqs. (1) and (2).

$$FA = \frac{[TNH]_3 \times 10^{pH} \times \frac{17}{14}}{e^{\frac{6344}{(273+T)}} + 10^{pH}} \quad (1)$$

$$FNA = \frac{46}{14} \times \frac{[NO_2^- \text{-N}]}{e^{\frac{-2300}{(273+T)}}} \quad (2)$$

where, $[TNH_3]$ (mg/L) is total ammonia amount as N; T (K) is temperature.

The operation results of the R, Q, and D periods in Fig. 5 were applied to the system control diagram. When it was applied to the system control diagram of the zone, the removed ammonium nitrogen converted into the nitrite that was located in Zone 2. Nitrification was located in Zone 3 in this case. In this research, FA was found to cause inhibition to *Nitrobacter* to cause the accumulation of the nitrite.

3 Conclusions

The raw piggery wastewater in the Y and H piggery wastewater treatment plants and the effluent of anaerobic digester from the H piggery wastewater treatment plant were used to study nitritation. For the raw piggery wastewater, it had XS as the biggest portion of COD, and for the effluent of anaerobic digester from piggery wastewater, SI was the biggest portion. This was an important factor to be considered when selecting the process to remove the nitrogen in piggery wastewater. As a result of implementing the nitritation reactor operation using influent of piggery wastewater, the critical SRT for a stable ammonium nitrogen removal was 4 days, and a high nitrite conversion was 6 to 8 days of SRT. In the case of the effluent of anaerobic digester from the piggery wastewater treatment plant, the SRT required for the ammonium nitrogen removal was 2 days and the SRT for the nitrite conversion was 4 days. For treating wastewater with lower BDCOD, the SRT for nitritation was shorter. The operation condition to induce a stable nitritation was related to the COD fraction of the influent of piggery wastewater. The nitrite conversion in the reactor was found to have the nitrite to accumulate the FA to cause the inhibition on *Nitrobacter*. Therefore, FA is considered an important factor for inducing effective nitritation. When stable nitritation is induced, the efficiency of the piggery wastewater through the nitritation is high. This is due to the effect of BDCOD in piggery wastewater. For inducing the nitritation of the piggery wastewater, the effluent of anaerobic digester from piggery wastewater was more effective than the influent of piggery wastewater.

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