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TREATMENT OF NITROGEN IN ANIMAL WASTEWATER WITH NITRIFYING PELLETS

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ABSTRACT

Enhanced nitrification of ammonia (NH_4-N) is an important consideration for improved systems of animal waste treatment. One of the most effective processes uses large populations of nitrifying microorganisms entrapped in polymer pellets. The process is used in Japan in municipal wastewater treatment plants and has shown conversion rates that are much faster than those occurring in conventional waste treatment systems. We evaluated whether this technology could be adapted for treatment of higher-strength animal wastewater. A prototype plant was set up in a swine operation in North Carolina for nitrification treatment of lagoon wastewater. The liquid contained, on the average, 330 mg NH_4-N/L, 420 mg TKN/L, and 220 mg BOD/L; but values varied significantly throughout the year. The unit consisted of a 0.34-m^3 contact aeration tank used to lower influent BOD, a 0.18-m^3 sedimentation tank, and a 1.3-m^3 aerated fluidized tank used for nitrification treatment. The unit was instrumented with pH and DO controllers. Polyethylene glycol (PEG) pellets containing 2% activated municipal sludge were added in the nitrification tank at 10% (v/v) concentration. Pellets were successfully acclimated to swine wastewater during the first 3-month period in which the ammonia loading rate was increased by decreasing the hydraulic retention time (HRT). At the initial 48-h HRT, nitrification activity of pellets increased from 0.02 to 2.0 g N/L-pellet/d in 30 d. Nitrification activity further increased to 3.2 and 4.3 g N/L-pellet/d at HRT's of 32 and 24 h, respectively. Performance of the unit was tested under a range of ammonia loading rates (237 to 1070 g N/m^3 tank/d) and water temperatures (4.9 to 33.3°C) during the subsequent nine months. Nitrification rates during winter months (Dec.-Feb.) were 40 to 80 mg N/m^3 tank/day and increased considerably when water temperature raised above 10°C. The nitrification rate obtained in March (20°C) was 380 g N/m^3 tank/day using HRT of 19 h and further increased during summer months. In August (30°C), the nitrification rate obtained was 650 g N/m^3 tank/day with a 12-h HRT. All the ammonia-N removed was nitrified without losses of N by volatilization. Our results indicate that immobilized pellets can rapidly nitrify animal wastewater. One of their first applications may be the retrofit of anaerobic swine lagoons for fast and efficient removal of ammonia.

KEYWORDS

Swine Lagoons, Ammonia Removal, Nitrification, Immobilized Nitrifiers, Animal Wastewater Treatment

INTRODUCTION

Animal waste treatment is a significant agricultural and environmental challenge that needs additional options as a result of expanded and confined animal production. Interest has greatly increased in finding alternative methods that are functional and affordable for nutrient management of confined animal production. For nitrogen, this need ranges from new technologies that reduce ammonia emissions from existing operations to the design of new systems without lagoons such as the use of liquid/solids separation and aerobic treatment of the liquid effluent. Although biological removal of N through the process of nitrification and denitrification is regarded as the most efficient and economically feasible method available for removal of N from municipal wastewaters, the application to animal systems is difficult because of the inhibition of nitrifying bacteria by high-ammonia concentration typical of these effluents.

Another problem is that nitrifying bacteria have a slow growth rate compared to heterotrophic microorganisms, and with effluents containing high BOD concentration, the nitrifiers tend to be overgrown or washed out of reactors. Thus, recycling of surplus activated sludge in an aerobic reactor or long hydraulic retention time (HRT) is required to retain slow growing autotrophic nitrifiers. Unfortunately, in the absence of enriched nitrifying populations, aerobic treatment of high-ammonia animal wastewater can potentially add to problems by stripping ammonia into the atmosphere (Burton, 1992; Vanotti and Hunt, 1998). The efficiency of the nitrification process can be improved by increasing the nitrifiers' retention time independent from the wastewater retention time (Wijffels et al., 1993). In most cases, this is done by immobilization via spontaneous attachment of cells to the surface of inert support materials. Applications of attached growth for treatment of swine wastewater have been developed by Ciaccolini et al. (1984) and St.-Arnaud et al. (1991) who reported improved nitrification rates when compared to systems where microorganisms were in suspension. However, higher nitrification rates are feasible because of advances in biotechnology that use immobilization entrapment of cells in polymer gels.

NITRIFYING PELLET TECHNOLOGY

Through the immobilization process, the nitrifying microorganisms are provided with a very suitable environment to perform at optimal effectiveness. The nitrifiers are entrapped in 3- to 5-mm pellets made of polymers that are permeable to NH_3, oxygen, and carbon dioxide needed by these microorganisms. Tanaka et al. (1991) reported nitrification rates three times higher than those of the conventional activated sludge process. Typical materials are polyethylene glycol (PEG) and polyvinyl alcohol (PVA); these pellets are functional for more than 10 years. Vanotti and Hunt (1998) reported that this technology can be adapted for fast and efficient removal of NH_4^+ contained in anaerobic lagoons by using acclimated microorganisms. Nitrifying bacteria were cultivated in a medium containing 300 mg NH_4^+ N/L, immobilized in PVA polymer pellets, and then used for nitrification of swine lagoon wastewater containing ~230 mg NH_4^+ N/L. Nitrification efficiencies of more than 90% were successfully obtained in bench experiments, even at both short HRT of 12 h and an NH_4^+ loading rate of 420 mg N/L-reactor/day. High-ammonia nitrifying bacteria were also successfully immobilized in polymer pellets to treat swine wastewater containing 350 to 2600 mg N/L (Vanotti et al., 1999). In batch treatment, ammonia removal rates of 915 to 990 mg N/L-reactor/day were obtained with 97 to 100% nitrification efficiency. Although these bench studies showed the magnitude of the capacity for ammonia removal from animal wastewater by nitrifying pellets, pilot-scale testing was required to evaluate the most efficient operating strategy for a full-scale nitrification reactor.

PILOT EXPERIMENT

The reactor used in the pilot experiment **(See Figure 1 "Pilot-scale experimental reactor for the continuous nitrification of swine lagoon liquid by immobilized nitrifiers")** was modeled after the Pegasus process (Takeshima et al., 1993). The unit was set up in a swine operation near Kenansville in Duplin Co., North Carolina. It consisted of a 0.34-m^3 contact aeration tank used to lower influent BOD, followed by a 0.18-m^3 sedimentation tank, and a 1.3-m^3 aerated fluidized tank for nitrification. The unit was designed to treat 1.0 m^3 of lagoon liquid per day and remove 280 g NH_4-N at a water temperature of 15°C. The contact aeration tank was packed with PVC crossflow media (CF-1900, Brentwood Industries, Inc, Reading, PA). The nitrification tank contained 10% (130 liters) of polyethylene glycol (PEG) nitrifying pellet cubes of 3- to 4-mm size. The PEG pellets were produced in Japan by the Hitachi Plant Engineering & Construction Co. using a sheet polymerization technique (Aoki et al., 1989) and contained 2% activated municipal sludge. A 1-mm wedge-wire screen was installed at the outflow of the nitrification tank to separate the pellets and activated sludge and retain the pellets inside the nitrification tank. The pellets were shipped to the field site immediately after production in Japan. Air was provided to the bottom of both tanks with a compressor and fine air diffusers (8.6% efficiency). The air flow was controlled through proportional solenoid valves in the air lines responding to dissolved oxygen (DO) concentration in the tanks. An average air flow rate of 50 L/min was applied to the contact aeration tank and 80 L/min to the nitrification tank. This flow rate ensured appropriate fluidization of the pellets and maintained DO concentration of the mixed liquor at more than 3 mg/L. The process pH in the nitrification tank was kept between 7.5 and 8.0 with a pH controller and chemical tank containing NaOH. The unit was instrumented with instrumentation to monitor pH, DO, water temperature, and air and water flow. Wastewater samples were obtained via an automated, refrigerated water sampler.

Swine Lagoon Wastewater

The wastewater used was an effluent from a single-stage anaerobic lagoon of 4100-m^3 volume which provided treatment and storage of flushed swine manure from 2600 pigs. The lagoon liquid contained, on the average, 331 mg NH_4-N/L and 421 mg Total Kjeldahl N/L, but actual concentration varied markedly throughout the year **(See Table 1 "Swine lagoon wastewater characteristics")**. Most of the variation in lagoon wastewater characteristics shown in Table 1 was associated with normal pig growing cycles in the farm operation and not associated with seasonal weather changes, except for COD and BOD where higher concentrations were associated with cold temperature months.

ACCLIMATION OF NITRIFYING PELLETS TO SWINE WASTEWATER

The PEG pellets were manufactured using municipal activated sludge from a municipal wastewater treatment plant as the source of nitrifiers. Therefore, we conducted an acclimation procedure to adapt the nitrifiers for swine wastewater which contained 10 to 20 times more ammonia-N than municipal systems. The evolving activity of the nitrifying pellets was determined frequently through laboratory tests. Samples of the pellets were transported to the laboratory and tested for nitrification and oxygen consumption rates. Nitrification activity was determined in 1-L aereated reactors during a 4-h period using a synthetic medium (pH 8.3) containing 300 mg NH_4-N/L and 10% (v/v) pellet concentration. Nitrification rate was calculated from the slope of a regression line relating the increase in NO_3-N concentration and time. Oxygen consumption activity was determined using a DO probe in a closed glass chamber (128 mL) containing 20 mL of pellets and the synthetic medium. Oxygen consumption rate was calculated from the slope of a regression line describing the relationship between the decrease of DO concentration in the liquid and time **(See Figure 2 "Nitrification activity and oxygen consumption tests")**.

The pellets were successfully acclimated to lagoon effluent during a 3-month period in which the ammonia loading rate was increased with higher flow rates. The flow rate was increased into the next level when the NH_4-N concentration of the nitrified effluent was approximately 100 mg/L. At the initial 48 h HRT, nitrification activity of pellets increased from 21 to 200 g N/m^3 tank/d (0.02 to 2.0 g N/L-pellet/d) in about 30 d. Nitrification activity further increased to 319 and 433 g N/m^3 tank/d (3.2 to 4.3 g N/L-pellet/d) at HRT's of 32 and 24 h, respectively **(See Figure 3 "Nitrification activity of nitrifying pellets during acclimation to swine wastewater")**. Nitrification activity further increased during the subsequent 3-month period and stabilized at about 750 to 900 g N/m^3 tank/d. Oxygen consumption rate of pellets also increased with time and corresponded with the nitrification activity. Typically, 1.5 to 2.0 g of O_2 was consumed by the pellets in the laboratory tests per g of ammonia-N removed.

NITRIFICATION TREATMENT PERFORMANCE

Data in this paper show evaluation of the pilot unit after acclimation from December 1997 to August 1998 and include cold, mild, and warm water temperatures **(See Table 2 "Treatment of lagoon swine wastewater with nitrifying pellets")**.
The evaluation consisted of consecutive runs; each run was conducted at a constant HRT and lasted three to four weeks. The HRT was adjusted by changing the influent flow rate so that: 1) the rates of nitrate production could be compared at similar

ammonia loading values across temperature regimes, and 2) optimum nitrification conditions could be determined. A 24-hr composite sample was collected every 3.5 d from the influent, the effluent of the contact aeration tank, and the effluent of the nitrification tank. Samples were stored in a refrigerated sampler in the field at 4.0°C and kept cold until chemical analyses. Rates of nitrification were significantly affected by seasonal water temperature. Nitrification rates were generally low during winter months (Dec.-Feb.) when water temperatures were lower than 10°C. In addition to low temperatures affecting the activity of nitrifiers, the influent wastewater during this period contained a higher proportion of organic materials. Under these conditions, average nitrate efficiency was 28% at ammonia loading rate of 237 g N/m^3 tank/d and HRT of 33 hr (Run No. 2). The activity of the pellets remained high in laboratory tests at 20°C during the same winter period **(See Figure 3 "Nitrification activity of nitrifying pellets during acclimation to swine wastewater")**. This indicates that high BOD present in the winter did not deteriorate the pellets and that nitrification performance during winter months may be improved with insulation or external heat.

Nitrate production rates significantly increased with water temperatures >10°C **(See Table 3 "Nitrification efficiency of pilot unit")**. Nitrification efficiencies of more than 80% were obtained during early spring with ammonia loads of 476 g N/m^3 tank/d and HRT of 19 hr (Run No. 5) and during summer months with ammonia loading rates of 615 to 626 g N/m^3 tank/d and HRT of 16 to 12 h (Runs No. 8 and 10). In all cases, the ammonia-N removed was entirely converted into nitrate-N forms without losses of ammonia by volatilization (Table 3). Higher than optimum loading rates affected nitrate production rates and increased variability **(See Figure 4, "Nitrification performance of pilot unit during summer")**. In contrast, the use of loading rates that matched the nitrification capacity of the pellets resulted in higher rates and consistent nitrification performance.

The contact aeration tank was very effective in reducing organic load. For example, data for June 8 through July 2, 1998, (HRT = 16 hrs, Run No. 8) indicate that 82% of the total BOD_5 reduction in the unit took place in the contact aeration tank **(See Table 4 "Water quality of nitrified lagoon liquid by nitrifying pellets")**. On the other hand, 99% of the nitrate produced was due to the activity of the pellets in the nitrification tank. Although the alkalinity concentration in swine lagoon wastewater is high, it is usually not enough for complete nitrification of ammonia, and it needs to be supplemented in order to achieve high nitrification efficiencies. Data in Table 4, for example, show an initial alkalinity of 1930 mg/L, which can provide for approximately the oxidation of about 270 mg N/L assuming 7.14 mg alkalinity/mg N.

CONCLUSIONS

Nitrification of ammonia is a critical component for improved systems of animal wastewater treatment. One of the most effective processes uses nitrifying microorganisms encapsulated in polymer pellets. The use of large populations of nitrifying bacteria entrapped in polymer resins offers the potential for ammonia removal rates that are much faster than those occurring in conventional waste treatment systems based on activated sludge. Although this technology has been successfully used in Japan for treating municipal wastewaters, their municipal wastewaters have lower concentration of nitrogen and organic carbon compared to liquid animal manure. There was a concern that concentrated animal waste may be harmful to the immobilized bacteria, specifically because of high free ammonia and BOD. A pilot-scale unit was constructed in a pig operation in North Carolina to evaluate whether the use of nitrifying pellet technology has applicability to animal systems.

The pellets were successfully acclimated to swine wastewater through a stepwise procedure in which ammonia load was gradually increased by decreasing the hydraulic residence time from 48 h to 24 h. Performance of the unit was tested under a range of ammonia loading rates and temperatures during the subsequent nine months. Nitrification rates during winter months (Dec.-Feb.) were 40 to 80 mg N/m^3 tank/day and increased considerably when water temperature raised above 10°C. The nitrification rate obtained in March (20°C) was 380 g N/m^3 tank/day using HRT of 19 h and further increased during summer months. In August (30°C), the nitrification rate obtained was 650 g N/m^3 tank/day using HRT of 12 h. All the ammonia-N removed was nitrified without losses of N by volatilization.

Our results indicate that immobilized pellets can rapidly nitrify animal lagoon wastewater with rates comparable to those found in Japan in municipal systems. Thus, immobilized pellets are a useful technology for fast and efficient removal of ammonia contained in swine lagoons. They may be very useful in the retrofit of existing lagoons.

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Figure 1. Pilot-scale experimental reactor for the continuous nitrification of swine lagoon liquid by immobilized nitrifiers

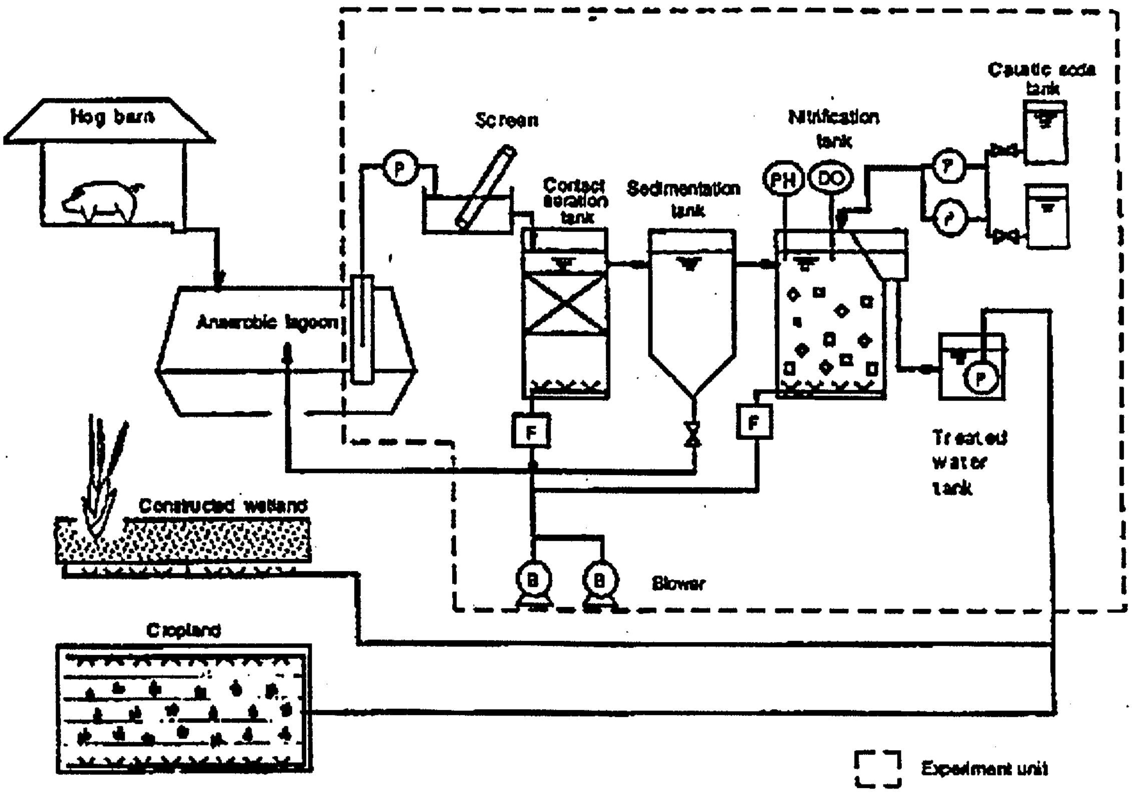

Figure 2. Nitrification activity and oxygen consumption tests

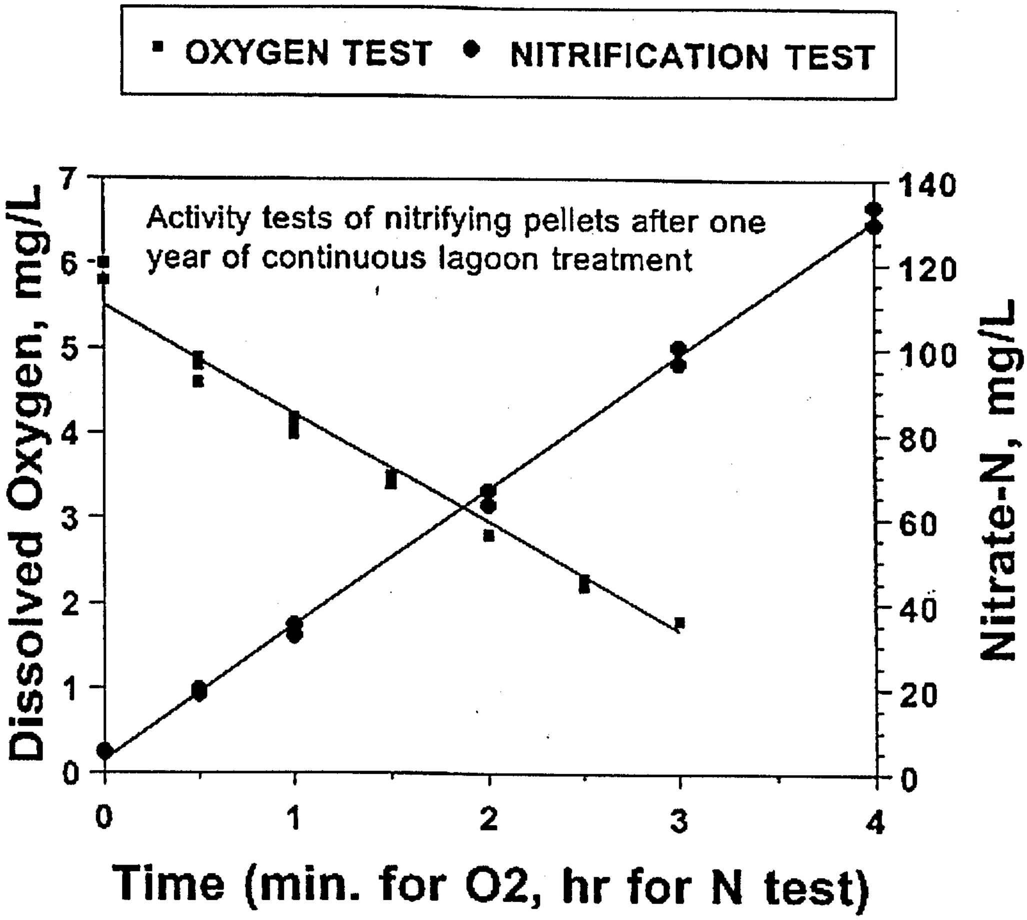

Figure 3. Nitrification activity of nitrifying pellets during acclimation to swine lagoon wastewater

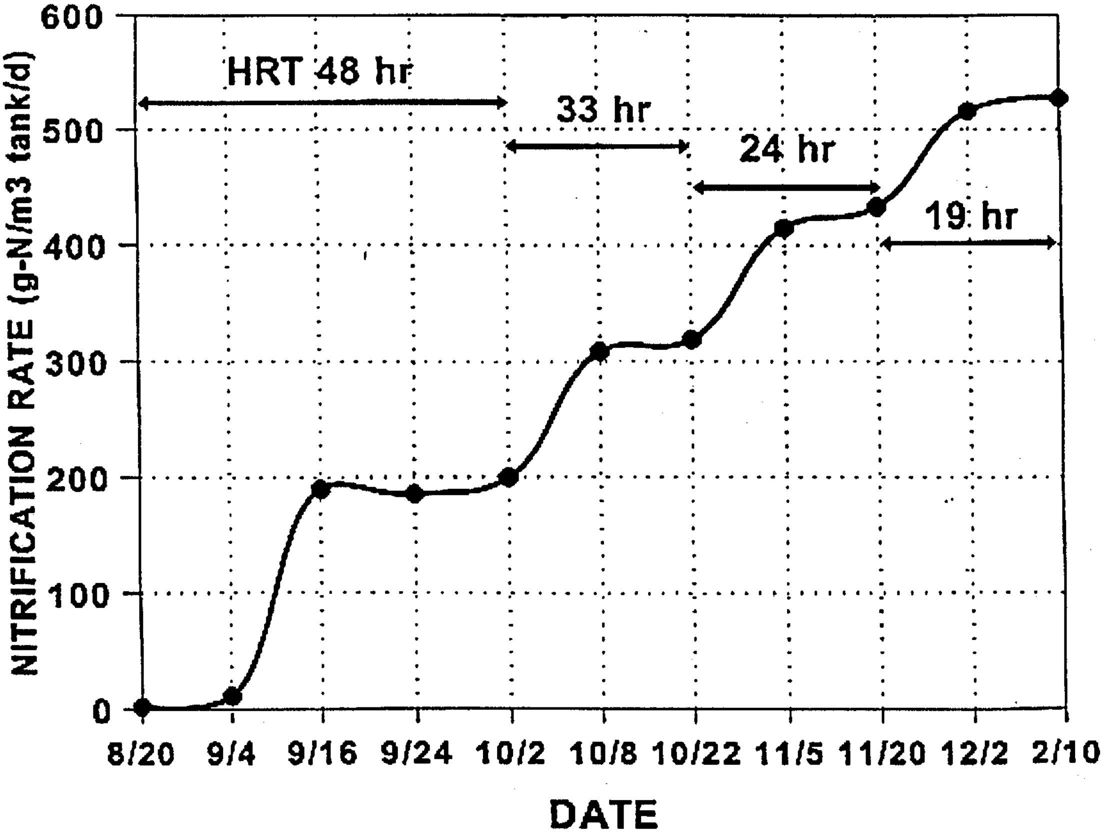

Figure 4. Nitrification performance of pilot unit during summer (avg. water temp = 30.2°C)

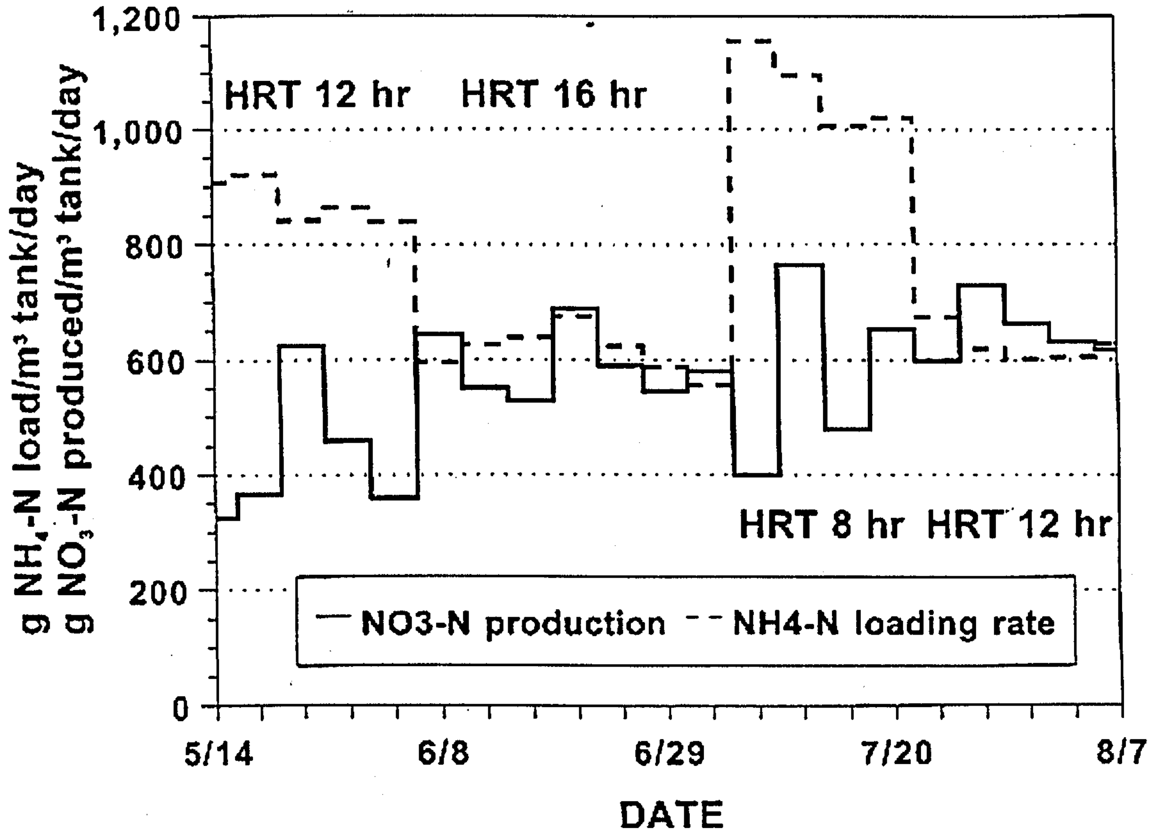

Table 1. Swine Lagoon Wastewater Characteristics

	Average[1]	Range	
		Minimum	Maximum
pH	7.96	7.40	8.59
Alkalinity, mg/L	1,846	1,462	2,375
Total Solids, mg/L	1,812	1,200	4,362
Suspended Solids, mg/L	456	187	2,790
COD, mg/L	1,107	495	3,430
BOD_5, mg/L	223	61	780
NH_4-N, mg/L	331	224	461
NO_3-N, mg/L	0	0	1
Kjeldahl-N, mg/L	419	270	566
TP, mg/L	81	45	126
O-PO_4-P, mg/L	45	28	81

[1] One year data, n=80 (8-20-97 through 8-7-98)

Table 2. Treatment of Lagoon Swine Wastewater with Nitrifying Pellets

			Influent Quality			Effluent Quality		
Run no.[1]	Water Temp	HRT[2]	BOD_5	Alkalinity	NH_4-N	BOD_5	Alkalinity	NO_3-N
	°C	hour	mg/L Concentration					
	December - February, Avg. Water Temperature = 8.3°C							
1	4.9	24	186	1,679	255	80	1,396	38
2	8.6	33	460	2,037	326	277	1,514	90
3	9.2	19	634	2,099	343	246	1,634	61
	March - April, Avg. Water Temperature = 16.9°C							
4	11.6	24	238	1,935	403	59	638	256
5	19.4	19	128	1,896	377	61	337	302
6	20.1	16	131	2,073	387	32	665	211
	May - August, Avg. Water Temperature = 30.2°C							
7	28.9	12	173	2,190	437	52	794	214
8	29.2	16	210	1,931	410	79	333	394
9	33.3	8	165	1,992	357	66	800	183
10	30.5	12	138	1,777	313	55	501	324

[1] Each run consisted of a 3- to 4-week period at a constant HRT.

[2] HRT = Hydraulic retention time of nitrification tank.

Table 3. Nitrification Efficiency of Pilot Unit

Run No[1]	Water Temp	HRT[2]	Ammonia Loading Rate	Ammonia Removal Rate	Nitrate Production Rate	Ammonia Removal Efficiency	Nitrification Efficiency
	°C	hour	----------g N/m³ tank/day----------			-------%-------	
	December - February, Avg. Water Temperature = 8.3°C						
1	4.9	24	255	54	38	21	15
2	8.6	33	237	77	65	32	28
3	9.2	19	433	91	77	21	18
	March - April, Avg. Water Temperature = 16.9°C						
4	11.6	24	403	247	256	61	63
5	19.4	19	476	378	381	79	80
6	20.1	16	581	311	316	54	54
	May - August, Avg. Water Temperature = 30.2°C						
7	28.9	12	875	418	427	48	49
8	29.2	16	615	555	590	90	96
9	33.3	8	1,070	543	550	51	52
10	30.5	12	626	558	648	100	100

[1] Each run consisted of a 3 to 4 week period at a constant HRT.

[2] HRT = Hydraulic retention time of nitrification tank.

Table 4. Water Quality of Nitrified Lagoon Liquid by Nitrifying Pellets.[1]

	Influent Quality	Effluent Quality	
		Contact Aeration Tank	Nitrification Tank
pH	8.14	8.28	7.67
Alkalinity, mg/L	1,931	1,839	333
Suspended Solids, mg/L	460	302	205
COD, mg/L	898	599	517
BOD_5, mg/L	210	108	79
NH_4-N, mg/L	410	404	40
NO_3-N, mg/L	0	4	396
Kjeldahl-N, mg/L	494	480	88
Total N	494	484	482

[1]Average data for Run No. 8, June 8 to July 2, 1998; HRT of nitrification tank = 16 hours; NH_4-N Load = 615 mg N/m^3 tank/day.

