Application of piggery waste to nightsoil plant towards sustainable development

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Abstract Organic loads have been significantly reduced in nightsoil plants along with the employment of sewage treatment plants. Nightsoil consisting of 10% septage and showing higher ratios of alkalinity and carbon to nitrogen helped nitrification and denitrification for those combined plants with weak piggery waste. However, alkalinity and carbon addition was necessary with the weak nightsoil consisting of 80% septage when the combined influent was less than 21 g/L COD. The piggery waste could be applied at a rate of 0.5 kgTKN/oxic m^3/d, but the organic load should be limited to 0.7 kgCOD/m^3/d with strong piggery waste during summer in order not to exceed the reactor temperature higher than 35°C.

Keywords Nightsoil plant; nitrogen removal; piggery waste; temperature

Water Science and Technology **Vol 47 No 10 pp 147–153** © IWA Publishing 2003

Introduction

Rapid population growth due to industrialization during the 1970s faced nightsoil (human feces) problems in urban areas in Korea. The nightsoil was collected by trucks and treated at centralized nighsoil treatment plants. Later, sewage treatment plants (STP) began to be constructed. Even today, there are about 200 nightsoil plants, but their roles have mostly been replaced by STP and their loads have been reduced.

At present, Korea is faced with piggery waste management problems. There are more than 8 million pigs and its land application practices have shown up as overloaded conditions in most areas. Thus, it was required to construct co-op or community piggery wastewater treatment plants to remove nutrients in addition to organics. This gives an idea on how much piggery waste could be applied to the existing nighsoil plants originally designed to remove organics.

Materials and method

The degritted and screened characteristics of piggery waste and nightsoil applied to laboratory and full-scale BNR (biological nutrient removal) plants are shown in Table 1. The strength of piggery waste varied with how to separate the solids at pig farms. Manual separation (clean operation) usually showed lowest solids content resulting in lower strength as shown in lab-scale unit P1, and scraper separation included some solids resulting in a higher strength as shown in lab-scale unit P2. The slurry type operation without solid separation resulted in a much higher strength. The influent strength of full-scale nightsoil plants (N1 and N2) also varied with the septage portions. N1 and N2 contained about 10% and 80% septage, respectively.

Combined influent with piggery waste (P) and nightsoil (N) was applied to PN units (or plants) with a volumetric P/N ratio of 3 to 1 as shown in Table 2. Lab-scale unit PN1 and full-scale plant PN2 were operated with the combined influent of P1 and N1, while full-scale plant PN3 was operated with the combined influent of P1 and N2. The influent was degritted, and screened or centrifuged prior to equalization as shown in Figure 1. Uniform

Table 1 Characteristics of wastes applied to lab and full-scale BNR plants (g/L except pH)

Constituents	Piggery		Piggery + nightsoil			Nightsoil	
	Lab-scale		Lab-scale	Full-scale		Full-scale	
	P1	P2	PN1	PN2	PN3	N1	N2
pH	8.2	7.6	7.7	7.6	8.3	7.9	7.6
Alkalinity	4.0	16.5	NA	8.4	4.9	19.8	5.6
TCOD	4.3	38.25	8.65	12.10	13.92	41.05	17.81
BOD	2.0	19.87	3.50	4.17	5.26	15.20	6.02
TKN	1.2	5.47	1.33	2.08	2.33	4.42	1.60
NH_4N	0.80	2.95	1.15	1.40	1.83	3.68	1.20
TCOD/TKN	3.5	7.0	6.5	5.8	6.1	9.3	11.1
BOD/TKN	1.7	3.6	2.6	2.0	2.3	3.4	3.8
Alk/TKN	3.3	3.0	NA	4.0	2.1	4.5	3.5

NA = not available

Table 2 Operating conditions of BNR plants

Operating conditions	Piggery		Piggery + nightsoil			Nightsoil	
	Lab-scale		Lab-scale	Full-scale		Full-scale	
	P1	P2	PN1	PN2	PN3	N1	N2
Q (m^3/d)	–	–	–	30	40	25	73
P/N ratios (m^3/m^3)	1/0	1/0	3/1	3/1	3/1	0/1	0/1
Temperature (°C)	25	25	20	32	36	17–43	28–33
HRT (days)	5	25	10	10	38	31–44	39–49
SRT (days)	5	25	25	25	38	31–44	39–49
Ox HRT (days)	3.3	10.4	5	5	25.3	15.5–22	26–32
Ax/Ox ratios	1/2	1/0.8	1/1	1/1	1/2	1/1	1/2
MLVSS (g/L)	1.4	8.3	5.8	6.3	6.9	8.0–12.0	3.7–4.8
COD loading rates (kgCOD/m^3/d)	0.8	1.53	0.9	1.2	0.37	0.89–1.49	0.32–0.40
TKN loading rates (kgN/oxic m^3/d)	0.34	0.53	0.27	0.42	0.09	0.2–0.32	0.04–0.05

feed was applied to each unit operated in sequencing batch reactor (SBR) or modified Ludzack and Ettinger (MLE) modes. The effluent was not easy to settle and hydraulic retention time (HRT) was the same as the solid retention time (SRT) except for PN1 and PN2 as shown in Table 2. The solid separation could be done by dewatering with chemical aids or membrane. After the solid separation, further treatment was employed for effluent polishing.

Various anoxic (Ax) and oxic (Ox) periods were used to optimize the removal efficiencies. The reactor temperatures of full-scale plants were higher even during winter due to the heat released from the microbial reaction. The applied organic and nitrogen loads were respectively 0.32 to 1.53 kgCOD/m^3/d and 0.04 to 0.53 kgTKN/oxic m^3/d.

Results and discussion

Waste characteristics

Nightsoil has shown high strength of organics and nitrogen as shown in the N1 plant of Table 1. However, flush toilets with septic tanks have been introduced in most houses and

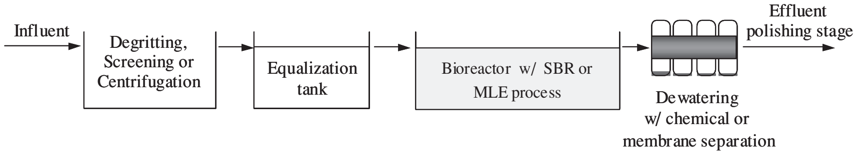


Figure 1 Representative schematic flow diagram of treatment process for nightsoil and piggery waste

the representative strength of screened nightsoil has been reduced to a low strength as shown in the N2 plant. Generally nightsoil presented higher alkalinity with higher TCOD/TKN ratio as shown in Table 1. This could make nitrification easier and denitrification faster when treated together with the weak piggery waste obtainable from clean operation. Non-biodegradable (NBD) organic portions of the combined influents were respectively 9 to 18% in particulate and 3 to 8% in soluble COD (SCOD), and 4 to 9% in particulate and 0.7 to 2% in soluble organic nitrogen. The NBD portions were generally higher in nightsoil.

Effluent COD

Table 3 presents the measured and predicted effluent SCOD and nitrogen concentrations of each plant. The effluent SCOD levels were generally increased as the organic loads increased except that PN3 and N2 operated at extremely low loads. The full-scale plant N1 operated at high temperature above 35°C showed higher effluent SCOD. The predicted COD concentrations (NBD SCOD) basically were well in agreement with those measured.

Effluent NH_4N

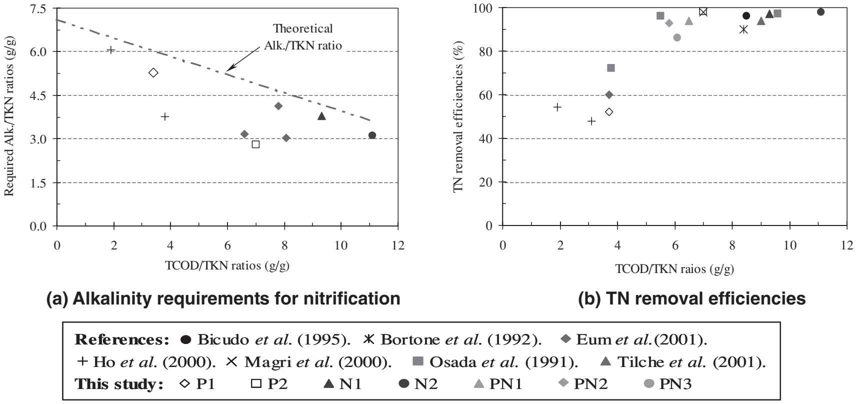
Significant temperature effects were observed for nitrification when the reactor temperature exceeded 35°C (Eum and Choi, 2001). Alkalinity was consumed during nitrification, and recovered during denitrification. In this regard, the TCOD/TKN ratio became important. Figure 2(a) shows the alkalinity requirements along with TCOD/TKN ratios. In order to achieve a complete nitrification, Alk/TKN ratio must be around 3 at higher TCOD/TKN ratio of 6. In fact, the effluent NH_4N level was reduced at PN1 and PN2 operated with the combined influent of P1 and N1, through which alkalinity and carbon were provided by nightsoil. However, the effluent NH_4N of PN3 was not improved because the nightsoil (N2 plant) used for this case included higher septage portion. Predicted effluent NH_4N, NO_2N and NO_3N levels in Table 3 were computed from mass balances of alkalinity with Figure 2 and NO_2N/NOxN fractions from Figure 3.

Denitrification

The efficiency of denitrification varied with the carbon available in a system. As shown in Figure 2(b), the nitrogen removal efficiencies increased as TCOD/TKN ratio increased. In order to maintain higher nitrogen removal efficiencies greater than 90%, the ratio must be

Table 3 Summary of measured and predicted effluents from each BNR units (mg/L except pH)

Effluent concentrations		Piggery		Piggery + nightsoil			Nightsoil		
		Lab-scale		Lab-scale	Full-scale		Full-scale		
		P1	P2	PN1	PN2	PN3	N1		N2
							Summer	Winter	
Measured	Temp. (°C)	25	25	20	32	36	43	25	28–33
	pH	7.2	8.6	7.2	7.8	6.6	8.2	7.9	6.8
	Alkalinity	175	1440	–	–	–	3960	1850	310
	SCOD	290	1050	405	590	787	1475	1120	735
	NH_4N	62	11	15	10	65	296	6	1
	NO_2N	319	17	0	86	0	3	1	0
	NO_3N	118	2	45	25	256	24	22	4
Predicted	Temp. (°C)	25	25	25	35	35	40	25	30
	SCOD	300	1100	460	600	700	1100	1100	780
	S org-N	10	40	20	30	35	40	45	30
	NH_4N	< 70	< 5	< 5	< 10	< 80	< 240	< 5	< 5
	NO_2N	< 350	< 10	< 6	< 75	0	0	< 10	0
	NO_3N	< 90	< 3	< 59	< 20	< 230	< 30	< 5	< 10



(a) Alkalinity requirements for nitrification **(b) TN removal efficiencies**

Figure 2 Alkalinity requirements and TN removal efficiencies with influent TCOD/TKN ratios

greater than 6. However, the pH must not exceed about 9 when the denitrification rate rapidly slowed down (Ho and Choi, 2000). In addition, nitrogen removal efficiencies were reduced at higher temperature and lower pH, which inhibited nitrification as indicated earlier. P1, PN1, PN2 and PN3 seemed to have limited carbon source resulting in higher NOxN in effluent. It should be noted the influent COD, except P1, included relatively higher NBD organic portions (see Table 1).

NO_2N formation

Figure 3 shows NO_2N accumulation with nitrogen loads based on the oxic volume. It was believed that NO_2N nitrification occurred due to free ammonia inhibition with higher nitrogen load and higher pH (Eum and Choi, 2001). It seemed the minimum nitrogen loads for NO_2N nitrification would be around 0.3 kgTKN/oxic m^3/d without pH adjustment for piggery waste treatment. The required minimum pH for NO_2N formation at this load seemed to be 8 at the end of oxic stage. However, NO_2N nitrification seemed to be possible at lower nitrogen loads with the addition of alkalinity or increased pH.

Applicability of piggery waste to nightsoil plant towards sustainable development

The septage portion has been increased to 80% in smaller cities due to the use of flush toilets and the influent concentrations of existing nightsoil plants were significantly reduced at about 60% as shown in N1 and N2 plants (see Table 1). The flow rate was also reduced at about 30% and the overall reduction in terms of load would be about 70%. This would provide rooms for piggery waste application to the existing nightsoil plants towards

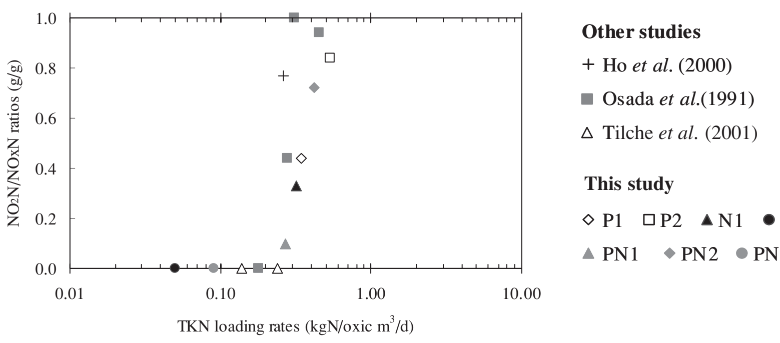


Figure 3 NO_2N fractions at various nitrogen loads

sustainable development. If this is possible without large changes in the existing plants, there would be a great benefit in terms of construction cost and reducing the effort for site selections for new plants. New construction is difficult, since no resident wants to have any waste treatment plant nearby. At present, there are about 140 aerobic nightsoil plants with an average capacity of 50 m^3/d in Korea.

For model design, two types of waste strengths were considered; 42 g/L TCOD for scraper separation (like P2), and 12 and 4 g/L TCOD (like P1) for clean operations. Nitrogen strengths were assumed to vary accordingly (see Table 1). The nightsoil strength was assumed to be the same as that of N2. Biological phosphorus removal was not considered because it could be removed easily by the follow-up process along with solid separation and color removal.

The critical factor to be considered for the estimation of applicable piggery waste was the nitrogen load, but the organic load was also important because of reactor temperature during summer particularly with the higher strength. It was assumed the heat produced from the microbial reaction was 14,700 kJ/kgO_2 consumed for carbon removal (Lapara *et al.*, 1999) and the ambient temperatures were 25°C for summer and 10°C for winter, respectively. The critical P/N ratio not to exceed 35°C inhibiting nitrification was 0.2/1 (see Figure 4), of which organic load was 0.7 kgCOD/m^3/d equivalent to 0.2 kgTKN/oxic m^3/d with higher strength during summer.

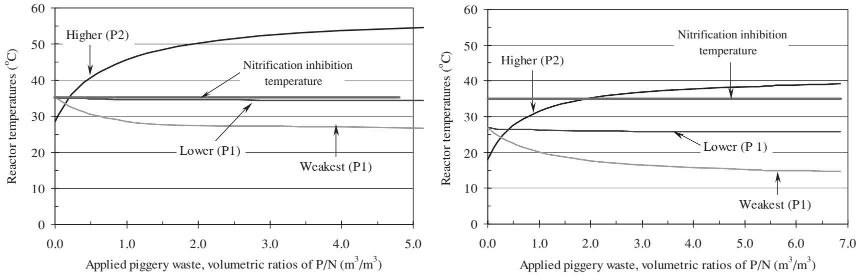
Using the measured AURs (NH_4N uptake rate) of 8 (with a range of 6.4 to 11.5) for nightsoil and 13 (7.1 to 23.3) mgNH_4N/L/hr for piggery waste, the computed HRT for the higher strength was 15 d equivalent to 0.5 kgTKN/oxic m^3/d. In addition, the computed HRT for denitrification with NURs (NOxN uptake rate) of 8 (7.4 to 9.5) for nightsoil and 13 (8.0 to 16.3) mgNOxN/L/hr for piggery waste was 15 d.

The estimated applicable ratios of P/N were 0.2/1 to 6.5/1 depending on the influent strength and season as shown in Table 4. With lower strength, additional alkalinity was required for a complete nitrification (with a minimum requirement: Alk/TKN = 3), and additional carbon was also required for higher denitrification (with a minimum requirement: TCOD/TKN = 6 and BOD/TKN = 3). NO_2N accumulation seemed to be possible except those summer months (about 4 months) with the higher strength.

As indicated earlier, the solids developed in the bioreactors were not settled easily, but the bioreactor with the weakest strength might increase the settleability and the operating SRT could be longer than HRT. It could be seen from Table 4 that the combined influent strength not to require additional alkalinity and carbon as well as not to increase the reactor

Table 4 Estimated amount of applicable piggery waste to the existing nightsoil plants

Design conditions	**Higher strength (TCOD 42 g/L)**		**Lower strength (TCOD 12 g/L)**	**Weakest strength (TCOD 4 g/L)**
Applicable loads	Summer	Winter	All year	All year
kgCOD/m^3/d	0.7	1.7	1.2	1.2
kgTKN/oxic m^3/d	0.2	0.5	0.5	0.5
Reactor temperature (°C)	35	32	27~35	15~28
P/N ratios	0.2/1	1/1	2.5/1	6.5/1
Oxic HRTs (days)	15	9.5	7.5	2.6
Total HRTs (days)	30	20	15	5
Influent				
TCOD (g/L)	21.0	32.5	13.6	6.2
BOD (g/L)	8.8	15.5	5.6	2.6
TKN (g/L)	2.4	4.3	2.5	1.2
TCOD/TKN	8.8	7.6	5.4	5.2
BOD/TKN	3.6	3.6	2.3	2.1
Alk/TKN	3.3	3.2	1.8	1.9



(a) Summer **(b) Winter**

Figure 4 Predicted reactor temperatures with applied piggery wastes of 3 different strength: higher, lower and weakest

temperature inhibiting nitrification during summer was 21 g/L COD, 8.8 g/L BOD and 2.4 g/L TKN with 30 dHRT. With this concentration, the existing nightsoil plants could increase their flow rates at about 40% more than designed for the application of piggery waste. Also, these plants could be operated at SBR modes with on and off aeration with small modifications (Choi *et al.*, 1997).

Summary and conclusions

Lab and full-scale plants were evaluated for the combined treatment with piggery waste and nightsoil during the course of this study and the following conclusions were drawn for sustainable development.

- Both alkalinity and carbon to nitrogen ratios were the most important parameters for nitrification and denitrification. The minimum Alk/TKN and TCOD/TKN ratios were respectively 3 and 6 at which more than 90% nitrogen removal could be achieved.
- Nightsoil showed higher ratios of alkalinity and carbon to nitrogen helped nitrification and denitrification for those combined plants PN1 and PN2 with weak piggery waste and strong nightsoil consisting of 10% septage. However, alkalinity and carbon addition was necessary with the weak nightsoil consisting of 80% septage when the combined COD is less than 21 g/L.
- NO_2N accumulation occurred at a load exceeding 0.3 kgTKN/oxic m^3/d (0.15 kgTKN/m^3/d) with a minimum pH of 8 at the end of oxic stage.
- The computed maximum nitrogen load for the combined treatment was 0.5 kgTKN/oxic m^3/d. If the applied strength exceeds 21 g/L COD, the maximum applicable organic load should be limited to 0.7 kgCOD/m^3/d during summer in order not to exceed the inhibiting temperature of 35°C.

Acknowledgements

This study was conducted with the financial supports from the Korean Ministry of Education (BK21) and the Ministry of Environment (Eco-technopia 21). The authors also would like to extend their sincere thanks to those plant operators who provided useful information.

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