Odor Emission Control and Nitrogen Recycling by Using Adsorption Treatment at the Pilot Scale Composting Facility

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Abstract

The odors emitted during the first two weeks of composting were conveyed into replicated adsorption reactors (3.8m x 7.2m), loaded with finished compost, to remove odors at a pilot scale composting facility. The initial composting material (50 m³) consisted of dairy cattle manure and sawdust. Finished compost of the same volume filled the adsorption reactors. The ammonia concentrations of the exhaust air from the adsorption reactors averaged 17.2 ppm for the first reactor and 7.8 ppm for the second reactor, and the reduction rates were 91.6% and 96.4%, respectively. Adsorption treatment using finished compost is effective in eliminating sulfur compounds, and the reduction rates were ranged from 72.8% to 100%. The reduction rates for i-valeric acid showed positive values (56-64%), although the rates for the other volatile fatty acids showed negative values. After the treatment, the adsorbent contained great number of ammonium nitrogen, and was nitrified 81-88% within three day by keeping the adsorbent in aerobic conditions. Total ammonia emission during the thermophilic stage was measured at 787g/t, and 768g/t of ammonia was trapped by the finished compost in winter. Therefore, the ammonia emission during the thermophilic stage was reduced 97.6% by using the adsorption system.

Key words: Adsorption, Ammonia, Composting, Odor, Nitrogen, Recycling

1. Introduction

Annual animal excretion in Japan was estimated as 65 million tons of feces and 29 million tons of urine (Chino *et al.*, 1999), and an approximately 20% of the total (18 million tons) was excreted in Kyushu. Composting reduces odor and thereby, creates a more desirable product for land application and when applied to the land, less nutrients are susceptible to run off while providing a similar amount of nutrients to liquid manure (Adler, 1998). Offensive odor emission associated with the livestock industry is a major problem, and ammonia emissions during the composting are highly concentrated. Japanese offensive odor control law regulates 22 substances of which ammonia, sulfur compounds, volatile fatty acids and trimethyl amine are associated with livestock husbandry. Ammonia emission, one of the largest compounds in typical emissions, is caused by the degradation of nitrogenous components into ammonia. Nitrogen loss through volatilization of ammonia from animal waste enhances nutrient loss, contributes to acid rain deposition (ApSimon *et al.*, 1987), and increases the nitrogen load for the natural ecosystems (Roelfs *et al.*, 1985; Hartung, 1990). McConnell (1978) reported that the estimated emission rate of ammonia is 174 million ton/year or 39×10^4 mol/sec (20% of this is as ammonium ion) to the atmosphere. With composting, ammonia emission during the first two weeks represents approximately

90% of total emissions, and its emission during the first three days is about 80% of total emissions (data from two composting reactors, first and second weeks). Biofiltration to remove odor compounds has been used for waste treatment for years. Smith *et al.* (1973) reported that soil adsorbs many odor compounds, although the biofiltration using soil required a large area. O'Neill *et al.* (1992) stated that biofilters require the lowest cost, and the odor removal efficiencies of biofilters ranged from 50 to 90%.

This research targeted the reduction of odor emitted during composting from the composting reactors first and second weeks (represents approximately 90% of total emission) by adsorption treatment using finished composts as an adsorbent.

2. Methods and Materials

2.1 Pilot Plant Facility

The composting facility was built to manage the manure from 100 head of dairy cattle (manure: 29.4t/week, composting material: 35t/week). The composting materials were homogenized every week and supplied with forced aeration (Table 1) in order to complete the thermophilic stage of composting within four weeks. After the thermophilic stage, the composting material was kept for an additional three months under mesophilic conditions of composting (materials to below 45°C), during which time the

materials were homogenized approximately once per month. The construction costs were ¥16.8 million for the composting facility and ¥4.3 million for the deodorization system.

Table 1. Aeration during weeks 1-4 of the thermophilic stage of composting dairy cattle manure and sawdust, mass ratio 5:1

Composting week	1st	2nd	3rd	4th
Aeration ¹ , L min ⁻¹	56	33	29	28

¹Aeration rate based on initial volume

Fig. 1 Schematic of Composting Facility

2.2 Deodorization Method

Ammonia emission occurred during the thermophilic stage, with 90% of the total ammonia emitted during the first two weeks of composting. The gaseous emissions from the first two weeks of composting at the pilot scale composting facility were passed through adsorption reactors (3.8m x 7.2m) to remove odor. This exhaust air was pulled by turbo blowers with approximately 4.9 (first week) and 6.5 (second week) times greater rates than the composting aeration rates and were 17.2 (first week) and 14.3 (second week) m³(air)•m⁻³(compost)•h⁻¹. The properties of absorbent and the schematic of the system are shown in Table 2 and Figure 2. The initial volume of the composting material, consisting of dairy cattle manure and sawdust was 50 m³. A similar volume of finished compost was used for the adsorption reactors. Portions of the inlet and exhaust air were passed into a 1.6 mM sulfuric acid solution every 6 hour. Volumes of the passed air were measured by using gas flow meters (Shinagawa,

DC-1C) with an accuracy of ±0.7%. The ammonia concentrations of the gas-trapped solutions were measured by ion chromatography (Towa, ICA-5000 system), and the ammonia concentrations of the air were calculated based on the sampling air volumes and solution concentrations. Concentrations of sulfur compounds and volatile fatty acids were measured every 6 hour by gas chromatography (Shimazu, GC-14B).

Table 2 Properties of adsorbent

Composting reactor	Repetition	Absorption reactor				
		Inlet air (°C)	Absorbent (°C)	Aeration (m ³ /min)	Volume (m ³)	W.C.* (%)
1st week	1	32.3	33.5	13.8	51.3	45.0
	2	25.1	27.5	13.7	45.0	42.0
2nd week	1	23.0	23.9	10.7	45.0	38.8
	2	21.9	23.6	10.8	45.0	N/A

* : Water content

2.3 Ammonia stabilization

The compost, aged approximately one year after the thermophilic stage of composting that consisted of dairy cattle manure and sawdust. Ammonia solution was added into the compost, and the water content was adjusted to about 60%. Additives, finished compost (FCA) and activated sludge (ASA), were mixed with the ammonia-added compost on a 10% of wet weight basis. Each sample was put into a 300 ml beaker and incubated at constant temperature. The water contents of the samples were adjusted every three or four days. Each treatment was replicated three times. Total nitrogen (T-N) was measured as the total of ammonium nitrogen (NH₄⁺-N), organic nitrogen, nitrite nitrogen (NO₂⁻-N), and nitrate nitrogen (NO₃⁻-N). Total ammonium nitrogen and organic nitrogen was measured by the Kjeldahl method (Kjeltec auto sampler system). Ammonium, nitrite, and nitrate nitrogen were measured by HPLC (ICA-5000 system, TOA Electronics Co., Tokyo, Japan). Statistical analysis was performed by using SAS (Carry, SAS Institute), and the values were compared at P<0.05.

3. Results and Discussion

3.1 Ammonia Emission

The ammonia concentrations in the inlet and exhaust air of the adsorption reactors are plotted in Figure 3 (first week) and Figure 4 (second week). The maximum concentrations of the inlet air for the adsorption reactors were 689 ppm for the first week reactor and 569 ppm for the second week reactor. The biological deodorization system is often unstable at concentrations greater than 200 ppm ammonia. Therefore, it was necessary to mix fresh air to reduce the inlet ammonia concentration. The advantage of the adsorption system is that the system handles highly contaminated (>200 ppm NH₃) air. The ammonia concentrations of the exhaust air from the

Fig. 2 Schematic of the deodorization and N recycling system

adsorption reactors averaged 17.2 ppm for the first reactor and 7.8 ppm for the second reactor when the corresponding concentrations in the inlet air averaged 205.6 and 224.8 ppm, respectively. Thus, the ammonia reduction rates were 91.6% and 96.4%, respectively. The ammonia concentration of air leaving the adsorption reactor increased with decrease of inlet concentration (Figure 3). Total ammonia loading of 22.3 kg/week (first week reactor) and 19.6 kg/week (second week reactor) were added to the adsorption reactors, which were reduced to 1.7 kg/week and 0.7 kg/week, respectively. Condensation water occurred in the piping from the fermentation and adsorption reactors, and the amount of the condensation was measured to be 159 L/week with 808 ppm ammonium nitrogen concentration. The amount of condensation water was reduced to approximately 40L/week/reactor by covering the piping with heat insulator.

Fig. 3 Ammonia concentrations of inlet and exhaust air of the first week adsorption reactor.

Fig. 4 Ammonia concentrations of inlet and exhaust air of the second week adsorption reactor.

3.2 Sulfur compound and VFA emissions

The concentrations and reduction rates of the sulfur compounds and volatile fatty acids are summarized in Table 3. Hydrogen sulfide was detected only during the first day after the start of

composting or re-mixing, and was removed by 82%. Methyl mercaptan was significantly ($P<0.05$) removed by the adsorption treatment. Dimethyl sulfide were decreased 83%, and dimethyl disulfide was reduced 91%. Therefore, the adsorption treatment using finished compost is effective in eliminating sulfur compounds. The reduction rates for *i*-valeric acid showed positive values (56-64%), although significant differences ($P>0.05$) were not detected. The reduction rates for the other volatile fatty acids showed negative values. In particular, *n*-valeric acid concentrations in the exhaust air were 1.5-7.9 times greater than that in the inlet air, and were significantly increased ($P<0.05$).

3.3 Stabilization of absorbed ammonia in compost

Most of the ammonium nitrogen (81.4% to 87.5%) was decreased within three days, by using the well stabilized finished compost (Figure 5). The sum of nitrite nitrogen and nitrate nitrogen concentrations for the activated sludge and finished compost treatments were significantly increased within seven days, compared to twenty-first days for the no-additive stabilized compost and a much longer duration for the just-finished thermophilic stage compost (Figure 6).

Fig. 6 Nitrite and nitrate-N concentration in compost

Fig. 5 Ammonium-N concentration in compost

Table 3 Summary of average emissions of sulfur compound and volatile fatty acids

Reactor	Unit	Hydrogen sulfide	Methyl Mercaptan	Dimethyl sulfide	Dimethyl disulfide	Propionic acid	<i>n</i> -Butyric acid	<i>i</i> -Valeric acid	<i>n</i> -Valeric acid
1st week	Inlet (mol)	0.045	0.623	0.267	0.040	0.046	0.040	0.079	0.069
	Exhaust (mol)	0.008	0.000	0.021	0.004	0.068	0.059	0.032	0.007
	Reduction (%)	82.5	100.0	92.3	91.0	-49.1	-50.3	59.7	89.3
2nd week	Inlet (mol)	0.023	1.607	0.060	0.000	0.022	0.221	0.146	0.025
	Exhaust (mol)	0.003	0.000	0.016	0.001	0.040	0.064	0.061	0.045
	Reduction (%)	88.3	100.0	72.8	-	-84.3	71.1	58.4	-77.1

The sum of nitrite nitrogen and nitrate nitrogen of the finished compost treatments (FCA) were decreased after the twenty-first days, and thus converted to organic nitrogen. Pollution of underground water through leaching of nitrogen can be minimized by converting ammonium nitrogen to organic nitrogen.

3.4 Total ammonia emission

The total ammonia emission during the thermophilic stage was evaluated in winter. The emission rates are shown in Table 4. From the table, total ammonia emission during the thermophilic stage was measured at 787g/t. The decomposing rate during the winter was approximately 60% compared to the rate during the summer. During the evaluation, the ammonia removal efficiencies were 99.5% for the first week adsorption reactor and 96.7% for the second week reactor. A total of 778.9 g/t ammonia was conducted into the deodorization system, and was reduced to 10.8g/t. Thus, 768.1g/t of ammonia was trapped by the finished compost in the two adsorption reactors. The ammonia emission during the thermophilic stage reactors was reduced 97.6% and the rate was 2.4% to the atmosphere by using the adsorption system.

3.5 Nutrients of NH₃ adsorbed compost

Table 5 shows the nutrient contents of composts. The initial total nitrogen was 19 mg-N/g_{DM}, and was increased to 61 mg-N/g_{DM} at WK1 reactor after 9-week continuous treatments. The nitrogen was increased 4.7 mg-N/g_{DM}/week. The organic nitrogen was increased 9 mg-N/g_{DM} and the in-organic nitrogen was increased 33 mg-N/g_{DM}. Thus, the most of adsorbed nitrogen was remained in either ammonia nitrogen or nitrate nitrogen.

For the cattle manure in Japan, the relative efficiencies of fertilizer for nitrogen, phosphorus and potassium are 30, 60 and 90%, respectively. Thus, the efficiency of potassium is the greatest among the three. The amount of compost that can be fertilized should be calculated based on each component, and the minimum number is the applicable compost amount for the farm lands. For most of the cattle compost, the amount based on potassium is employed, and the shortages of other components such as

nitrogen and phosphorus are provided by the chemical fertilizer. Ammonia adsorbed composts contents a large amount of nitrogen, and can reduce the use of chemical fertilizer. However, the application methods should be well-considered since the nitrate nitrogen is easily run-off by rain. The composts are therefore suitable for protected cultivation from rain.

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Table 4 Ammonia emission from the composting facility during winter

Variable	Thermophilic stage					Adsorption reactor				Emission to atmosphere
	1st week	2nd week	3rd week	4th week	Total	1st week		2nd week		
						In	Out	In	Out	
Emission ⁺ (g/t)	616.8	162.1	6.9	0.8	786.6	616.8	3.2	162.1	7.6	18.5
Ratio ⁺⁺ (%)	78.4	20.6	0.9	0.1	100.0	3.4	4.4	5.4	6.4	2.4

+: Emission rate based on initial composting material weight

++: Ratio to the total ammonia emission during the thermophilic stage

Table 5 Nutrients of ammonia adsorbed compost

	Total-N mg-N/g _{DM}	NH ₄ -N mg-N/g _{DM}	NO ₃ -N mg-N/g _{DM}	Organic-N mg-N/g _{DM}	Phosphorus %	Potassium %	MC (%)	pH	EC
Initial	19.2	0.1	0.6	18.6	2.1	4.6	55.1	8.6	6.8
9WK Treat.	61.0	12.5	20.9	27.7	1.9	4.3	45.0	6.7	18.7