Ammonia Emissions from Composting Hog Manure Amended with Sawdust under Continuous and Intermittent Aeration

돈분과 톱밥혼합물의 연속 및 간헐 통기 퇴비화에서 암모니아 휘산

Hong, Ji Hyung
홍 지 형

Abstract

Ammonia emissions during composting of hog manure mixed with sawdust were studied in four runs comprising a total of 22 pilot-scale reactor vessels. These four runs extended previous work and both verified and extended the previous conclusions. The pilot-scale vessels were 205 L, insulated, stainless steel drums that were aerated either continuously (high/low thermostatically controlled fans) or intermittently (5 min high fan, 55 min off). Temperature, ammonia emissions, air flow rates, carbon dioxide production and oxygen utilization, moisture and dry matter reduction, initial and final chemical compositions were measured. Ammonia emissions from the intermittently aerated vessels were only about 50% as great as those from the continuously aerated ones, but this was found to be a result more related to total air flow than to aeration technique. All of the data for total ammonia emissions versus total air flow were fitted with a linear regression line, $y = 0.1309x + 29.835$ where y is ammonia expressed as g of N and x is air flow in kg with $R^2 = 0.6808$. This general trend indicates that about 50% reduction in ammonia emissions can be achieved with 75% reduction in air flow. For the aeration techniques used, the minimum oxygen level in the exhaust gas from the vessels was 5% and this is probably a resonable lower limit constraining air flow reduction. However, within this constraint, lower air flow now appears to be a technique that can reduce odorous ammonia emissions.

I. Introduction

Composting is one approach to dealing with animal manures. This can have several benefits. In particular, moisture reduction can improve the economics of transportation and allow for wider area application of nutrients. However, significant emissions of odorous compounds can occur during composting and the development of procedures that reducing such emissions is important. Ekinci *et*

College of Agriculture and Life Sciences,
Sunchon National University

Keywords : composting, air flow, ammonia emission, hog manure, odor.

al.(1999) have recently shown that pH and carbon to nitrogen ratio (C/N) play an important, interactive role in determining ammonia emissions from composting paper production waste. Michel and Reddy (1998) have also shown that oxygenation level plays an important role in determining odorous emissions.

Emissions from swine and other manures have been studied by Tanaka *et al.* (1991), Burton *et al.* (1993), Osada *et al.* (1994), Kuroda *et al.* (1996), and Hong *et al.* (1998). In particular, this last paper discussed the previous work and indicated that intermittent aeration compared to continuous aeration might be a practical way to reduce nitrogen loss and ammonia emissions during composting of swine manure. The results presented here verify this previous work (Hong *et al.*, 1998) and allow for a more general interpretation of the effect of aeration technique on ammonia emission.

Ⅱ. Materials and Procedures

This research study examined the effects of aeration on hog manure composting during the high rate phase using both continuous aeration and intermittent aeration.

Four experimental runs were conducted that form the database for the results reported here. These runs were begun on 3/26/98 (run 085-98) that lasted 28.9 days, 4/30/98 (run 120-98) that lasted 28.9 days, 12/1/98 (run 335-98) that lasted 20.9 days and 6/22/99 (run 173-99) that lasted 16.9 days.

Due to data collection limitations and procedural matters that made some vessels inapplicable to this study, only data from 4 to 7 vessels per run for a total 22 vessels are presented. Hog and sow manure were collected from a nearby agricultural teaching facility and mixed by hand in single vessel lot of 74.4 kg (ww) manure to 22.2 kg of sawdust. Material samples were collected at the start and end of each run and analyzed for various chemical and physical properties. Vessel contents were not remixed during the runs. For each vessel of each run, two initial and two final samples were oven dried at 100℃ for two days to determine moisture content. Other samples were analyzed in duplicate for pH, ash content, carbon and nitrogen contents, and C/N ratio by the Research, Extension and Analytical Laboratory at the Ohio Agricultural Research and Development Center using standard laboratory techniques.

The experiments were conducted in eight, 205 L pilot-scale vessels (Fig. 1A) with 5.0 cm of polystyrene insulation on all sides. A perforated galvanized steel grate formed a plenum at the

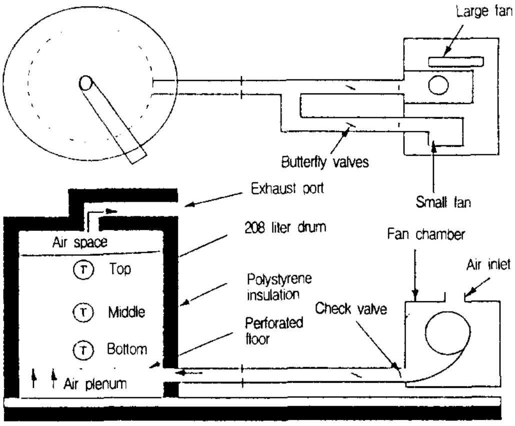

Fig. 1A Schematic illustration of a reactor vessel

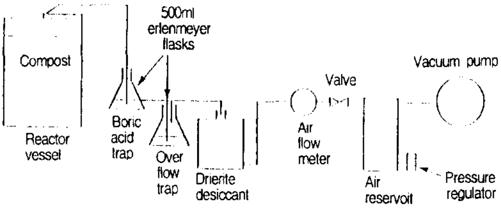

Fig. 1B Schematic illustration of an ammonia sampling system barrel's base to distribute air uniformly through the compost. Two fans were connected to provide air to each barrel through a 4.76 cm (ID) PVC pipe that was equipped with an orifice plate.

Air was blown through a plenum and up through the composting material to a header where exhaust gases could be sampled. The fans that supplied this air were either run in a high/low (approximately 0.9 or 0.3 L/min · kgDM), thermostatically controlled, continuous mode, or in an on/off (nominal 5 min on high out of each hour), timer controlled, intermittent mode. Various properties, including temperature readings, fan operating times, and pressure drops across orifice plates to supply air flow data were recorded every 10 minutes with a Kaye Digi III Data Logger and a MFE tape recorder.

Ammonia produced during composting was collected in a 200 mL acid trap as shown in Fig. 1B. Small portions of the exhaust gas streams were bubbled through 0.67 M boric acid solution traps for either 12 or 24-hour periods. The solutions were then titrated with 0.7 N HCL to determine ammonia concentration in the exit gas. Combined with total air flow information this yielded values for total ammonia production.

Ammonia concentration was calculated as:

$$NH_3(\mathrm{ppm}) = \frac{\mathrm{HCL(mL)} \times 9.29\mathrm{mg}(NH_3\text{-}N)/\mathrm{mL}}{\mathrm{Sampling\ \ flow\ rate(L/min)} \times \mathrm{time(min)}} \times \frac{\mathrm{mole}}{17\mathrm{g} \cdot \mathrm{N}}\ \frac{22.4\mathrm{L}}{\mathrm{mole}} \times 1000$$

Ⅲ. Results and Discussion

The initial and final values for total mass, density, moisture content, C and N content, C/N, ash content and pH for the materials of each of the applicable runs are given in Tables 1 and 2, respectively. Data for the vessels receiving intermittent aeration are distinguished by bold type in these tables.

The initial mixtures of manure and sawdust were similar across the four runs reported but did have enough variation, particularly in pH, to influence the composting activity. Initial moisture contents were all in the range 60.1±3.1% (wb) with no discernable pattern, while carbon to nitrogen ratios (C/N) ranged from 19 to 28 with run 335-98 having the lowest values and run No. 4 having the highest ones. The pH values of runs 085-98 and 120-98 and two of the applicable vessels of run 335-98 were low, ranging from 5.25 to 5.90 and with a majority being between 5.4 and 5.6. The other two applicable vessels of run 335-98 were slightly higher, at 6.0 and all of the run 173-99 vessels varied between pH 7.4 and 8.2.

Fig. 2 shows the average ammonia emissions per kg of initial compost for the each of continuous (black symbol) and intermittent (white symbol) groups of vessels for the four runs (run 335-98 int. is missing data). The effect of pH on start of high bacterial activity is apparent. The higher pH vessels have early, rapid temperature rise and carbon dioxide production (data not presented here due to space constraints) and show ammonia release within the first three days or less. The low pH vessels take significantly longer to reach high temperatures and only begin ammonia release around day eight. The averaged data for the run 335-98 vessels shows a combination of these effects. For this run, the two pH 6.0 vessels start out slightly delayed, this apparently being right at a critical boundary value for the bacteria and then, after significant ammonia release, their production begins to taper off around day eight. The two lower pH 335-98 vessels start significant produc-

Table 1 Initial physical and chemical properties of the mixes

	total mass	density	moisture	carbon	nitrogen		ash	
	(kg, ww)	(kg/m^3)	(%, wb)	(%, db)	(%, db)	C/N	(%, db)	pH
Run 085-98								
Vessel 1	96.0	579	58.1	45.5	1.94	23.5	7.01	5.60
Vessel 2	96.5	582	62.0	45.5	1.94	23.5	7.01	5.60
Vessel 3	**95.6**	**585**	**60.8**	**46.3**	**2.02**	**22.9**	**8.10**	**5.35**
Vessel 4	**96.0**	**570**	**60.6**	**46.3**	**2.02**	**22.9**	**8.10**	**5.35**
Vessel 5	**95.7**	**577**	**62.5**	**45.3**	**2.12**	**21.4**	**9.55**	**5.90**
Vessel 6	**96.2**	**571**	**58.6**	**45.3**	**2.12**	**21.4**	**9.55**	**5.90**
Vessel 7	92.2	556	57.1	46.7	1.94	24.1	5.84	5.25
Run 120-98								
Vessel 1	103.5	615	63.1	45.5	1.97	23.1	7.85	5.50
Vessel 3	**95.8**	**544**	**61.1**	**44.7**	**2.06**	**20.2**	**7.60**	**5.55**
Vessel 5	**94.8**	**539**	**59.8**	**44.0**	**2.18**	**20.2**	**7.94**	**5.50**
Vessel 7	97.6	546	60.2	44.8	2.14	20.9	8.46	5.50
Run 335-98								
Vessel 1	96.0	545	60.2	44.7	1.99	22.5	9.00	5.95
Vessel 3	96.7	519	61.4	46.6	2.34	19.9	8.00	5.55
Vessel 4	101.5	545	59.8	45.4	2.38	19.1	9.00	5.45
Vessel 5	95.6	521	63.2	45.1	1.94	23.3	7.50	6.00
Run 173-99								
Vessel 1	81.1	442	61.0	41.6	1.70	24.6	13.7	8.03
Vessel 2	85.2	464	62.8	42.9	1.51	28.4	12.5	7.98
Vessel 3	**84.6**	**460**	**61.7**	**41.1**	**1.67**	**25.5**	**14.8**	**8.23**
Vessel 4	**89.5**	**487**	**63.2**	**41.3**	**1.78**	**23.1**	**13.9**	**7.66**
Vessel 5	**80.3**	**431**	**62.7**	**39.4**	**1.74**	**22.7**	**16.5**	**8.03**
Vessel 6	**85.8**	**460**	**62.8**	**41.7**	**1.61**	**26.1**	**11.9**	**7.56**
Vessel 7	80.8	452	60.4	38.9	1.57	24.5	13.7	7.46

For run 085-98, the C, N, C/N, ash and pH values for vessel pairs 1&2, 3&r and 5&y are based on single samples per pair.
Vessels and values for intermittent aeration treatment are shown in bold type.
ww is wet weight, wb is wet basis, and db is dry basis.

Table 2 Final physical and chemical properties of the mixes

	total mass	density	moisture	carbon	nitrogen		ash	
	(kg, ww)	(kg/m^3)	(%, wb)	(%, db)	(%, db)	C/N	(%, db)	pH
Run 085-98								
Vessel 1	54.2	393	43.7	40.6	2.41	16.8	10.77	7.40
Vessel 2	56.5	396	43.3	39.2	2.51	15.6	10.45	7.60
Vessel 3	**69.0**	**500**	**56.3**	**42.1**	**2.43**	**17.3**	**10.75**	**7.65**
Vessel 4	**72.8**	**519**	**56.8**	**42.1**	**2.36**	**17.8**	**11.11**	**7.90**
Vessel 5	**71.4**	**528**	**56.7**	**41.6**	**2.34**	**17.8**	**9.42**	**7.80**
Vessel 6	**71.7**	**502**	**54.5**	**41.5**	**2.66**	**15.6**	**12.46**	**7.90**
Vessel 7	49.6	347	42.0	39.8	2.34	17.0	12.60	7.65
Run 120-98								
Vessel 1	48.4	345	35.6	39.7	2.44	16.3	11.11	8.00
Vessel 3	**72.1**	**504**	**57.8**	**42.7**	**2.20**	**19.4**	**10.30**	**7.85**
Vessel 5	**78.8**	**561**	**54.2**	**41.3**	**2.43**	**17.0**	**10.57**	**7.40**
Vessel 7	**54.4**	**380**	**44.3**	**39.9**	**2.32**	**17.2**	**11.02**	**7.85**
Run 335-98								
Vessel 1	57.6	396	59.1	42.5	2.42	17.5	12.00	6.90
Vessel 3	67.9	451	55.3	43.3	2.55	17.0	10.00	7.80
Vessel 4	63.1	405	41.3	43.7	2.50	17.5	11.50	7.90
Vessel 5	49.2	316	39.7	42.2	2.22	19.0	11.50	7.45
Run 173-99								
Vessel 1	47.6	296	48.7	40.4	2.84	14.1	14.61	7.02
Vessel 2	48.6	302	48.1	40.3	2.23	18.1	15.93	6.97
Vessel 3	**64.6**	**408**	**59.6**	**40.4**	**1.99**	**20.3**	**14.58**	**7.15**
Vessel 4	**69.7**	**434**	**60.9**	**41.9**	**2.06**	**19.6**	**14.23**	**7.68**
Vessel 5	**60.1**	**386**	**60.9**	**40.6**	**1.87**	**20.5**	**15.16**	**7.15**
Vessel 6	**67.3**	**426**	**59.6**	**39.8**	**1.97**	**21.6**	**14.20**	**7.08**
Vessel 7	47.1	288	43.3	39.5	1.90	20.9	16.29	7.20

Vessels and values for intermittent aeration treatment are shown in bold type.
ww is wet weight, wb is wet basis, and db is dry basis.

tion around this latter time to raise the average ammonia production for these four vessels to values consistent with those of the other continuous air reactor results.

The results shown in Fig. 1 emphasize the difference in ammonia emission between the continuous and intermittent aeration cases. Just based on appearance, the intermittent values are only about half as great as those for the continuous cases. When strict numerical comparisons are made between average final values for the two situations within each of the three runs where both cases were measured and then these three averages are in turn averaged, then there is a measured ammonia reduction of 49.8±17.4 % with a corresponding air flow reduction of 74.3 ±2.1 %. These results are in good general agreement with the earlier Hong *et al.* (1998) values and, at this level, support their conclusion that intermittent aeration appears to be a method of reducing ammonia emissions.

Fig. 2 shows final ammonia emissions as a function of air flow values for each of the 22 vessels [Note that run 335-98 pH pairings do not correspond to the apparent pairs of triangles in the figure: the higher pH runs are the triangles to the right in each pair.]. These values have not been put on a per unit mass basis and so there are some small relative shifts in vertical position. Of greater significance, there is also some arbitrariness in the horizontal position of the points shown. As can be seen in Fig. 2, ammonia production had either gone to zero or been considerably reduced before the end of most of the runs. Thus there were periods of increase in total air flow value that had nothing to do with ammonia emissions, and other choices for run time could have shifted the points either left or right. Nevertheless, there is clearly a trend toward greater ammonia emission with greater air flow. The linear fit to the specific values shown accounts for 68% of the variation in the data and higher order fits did not improve this significancy (Note that the consistent trend across the data for the two aeration techniques further supports the validity of the modified calculational techniques noted above.). The fit line gives a 58% ammonia reduction for 75% air flow decrease, reinforcing the above calculation with numbers that apply to all four runs. Thus it appears that total air flow, rather than aeration procedure, is the important variable

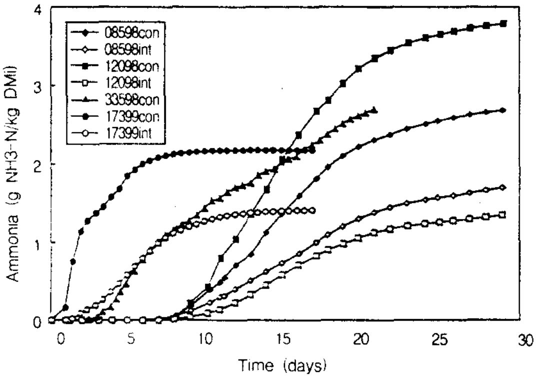

Fig. 2 Cumulative average ammonia emissions

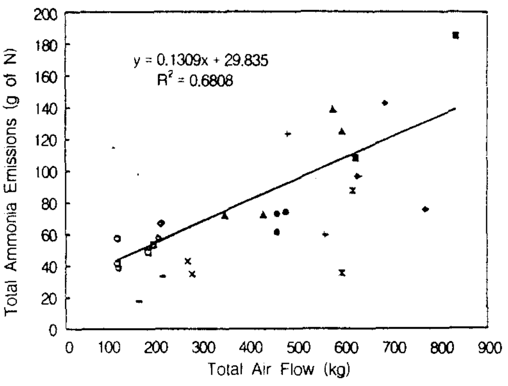

Fig. 3 Total ammonia emissions as a function of total airflow

Black symbols are the same as In Fig. 2
Gray symbols represent the earlier Hong *et al.* (1998) results, see test for discussion.
The trend line applies to the black points only.

relative to ammonia production (Note that for these runs oxygen levels in the exhaust gas did drop as low as 5% in some cases and this is undoubtedly an important factor limiting how far air flow should be reduced.). It is not known what the mechanism for this effect is. Potential possibilities include simple diffusion inhibition as ammonia concentration in the open spaces of the compost mass increases, biological inhibition resulting from ammonia concentration increase, and/or shifts in bacterial populations at lower oxygen concentrations (and larger pockets of micro-oxygenic or anaerobic conditions) that could provide alternative nitrogen loss pathways. More research will be needed to pin down the mechanism.

These relationships between emissions and air flow offers opportunities for creative engineering of manure composting systems. For instance, single fans might be used for several compost units in sequence and gaseous outputs might only need to be cleaned (i.e. biofiltration) for short portions of the composting period. In such ways, it ought to be possible to use less equipment at greater efficiency while reducing unwanted environmental impacts.

The data were examined for initial C/N and pH influences on ammonia emissions such as have been observed by Ekinci *et al.* (1999). While some pairs of points did seem to show ammonia reductions with decreased pH and/or increased C/N, there was too much overall noise to consistently support such a conclusion. Additionally, while a thorough analysis has not yet been made, it does not appear that greater retention of N with reduced ammonia emissions, as had been suggested by Hong *et al.* (1998), can be supported by the present data due at least in part to high variability.

One similar run has been made on composting of dewatered cow manure. While more analysis still must be performed on this data, it appears that a lesser but similar ammonia reduction can be seen in this data.

Ⅳ. Conclusions

Initial pH influenced rate of onset of bacterial activity in the hog manure/sawdust mixes studied, and pH=6.0 appears to be a critical boundary below which self heating or CO_2 evolution is retarded.

Ammonia release from composting hog manure is reduced by controlling air flow at low levels. This presumably has a lower limit based on air needed to maintain aerobic conditions. This may apply to other manures as well. It provides opportunities for engineering manure composting systems to utilize aeration more efficiently.

This research was supported by the Korea Science & Engineering Foundation under the KOSEF/NSF Scientist Exchange Program Agreement. Author is grateful to Dr. H. M. Keener, The Ohio State University for his contribution to publish this paper.

References

1. Burton, C. H., R. W. Sneath and J. W. Farrent. 1993. Emissions of nitrogen oxide gases during aerobic treatment of animal slurries. Bioresource Technology 45:233-235.
2. Ekinci, K., H. M. Keener and D. L. Elwell. 1999. Composting short paper fiber with broiler litter and additives-effects of initial pH and carbon/nitrogen ratio on ammonia emission. Compost Science & Utilization, accepted for publication.
3. Elwell, D. L., H. M. Keener, H. A. J. Hoitink, R. C. Hansen and J. Hoff. 1994. Pilot and full scale

evaluations of leaves as an amendment in sewage sludge composting. Compost Science & Utilization 2(2):55-74.

4. Hong, J. H., H. M. Keener and D. L. Elwell. 1998. Preliminary study of the effect of continuous and intermittent aeration on composting hog manure amended with sawdust. Compost Science & Utilization 6(4):74-88.
5. Hong, J. H., B. M. Choi and K .J. Park. 2000. A comparative study on the aerobic biodegradation of the continuous and intermittent aeration in bin composting system. Jour. of the Korean Soc. of Agricultural Engineers 42:61-67.
6. Kuroda, K., T. Osada, M. Yonaga, A. Kanematu, T. Nitta, S. Mouri and T. Kojima. 1996. Emissions of malodorous compounds and greenhouse gases from omposting swine feces. Bioresource Technology 56:265-271.
7. Michel, F. C. and C.A. Reddy. 1998. Effect of oxygenation level on yard trimmings composting rate, odor production and compost quality in bench-scale reactors. Compost Science & Utilization 6(4):6-14.
8. Osada, T., K. Kuroda and M. Yonaga. 1994. Reducing nitrous oxide gas emission from fill and draw type activated sludge process. Water Resource 29:1607-1608.
9. Tanaka, H., K. Kuroda, T. Osada, M. Yonaga, M. Suzuki and M. Inba. 1991. Aerial VFA in livestock houses and animal waste treatment facilities. Animal Science Technology(Japanese) 62(10):955-965.