



# Reduction of ammonia inhibition of organic matter degradation by turning during a laboratory-scale swine manure composting

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**Abstract** — Inhibitory effect of ammonia on the organic matter degradation at the outer region was simulated using a composting system consisted of two miniature-scale reactors with different constant temperature connected in series. The lower and upper reactors were incubated at 70 and 40 °C, respectively. Composting runs were conducted with or without turning. The ammonia inhibition of organic matter degradation in the upper reactor was more severe during the earlier stages of composting without turning, i.e., 24–60 h, when the ammonia concentration supplied from the lower reactor exceeded 500 ppm, than that in composting with daily turning. Furthermore, the different degradation rate of organic matter between composting with and without turning corresponded to the difference in the growth of mesophilic bacteria that was considered to be affected by the ammonia. It was elucidated that turning reduced the ammonia inhibition of degradation of organic material during composting.

**Keywords** — composting; microbial cell density; organic matter degradation; simple numerical model; swine manure; turning operation

## I. INTRODUCTION

In large-scale composting with forced aeration, air supplied from the bottom of the pile passes through the inner core of pile where high concentration of ammonia is produced as results of protein degradation; the ammonia gas contained in air is then, exposed to the outer regions of composting pile which has a relatively low temperature. So far, although extensive research have been conducted with relation to the various aspects of the inhibitory effect of ammonia, including on the growth of animal cells [1], bacteria such as *Corynebacterium glutamicum*, *Escherichia coli*, and *Bacillus subtilis* [2], and on the performance of anaerobic biodegradation [3], the detailed knowledge about ammonia inhibition of the degradation of organic materials during composting is yet to be attained. The aim of this study was to elucidate the inhibitory effect of ammonia on organic matter degradation and to investigate the effect of turning on the ammonia inhibition of degradation of organic material during composting. Moreover, an attempt was made to predict the degradation pattern of organic material during composting with the use of a simple numerical model.

## II. MATERIALS AND METHODS

Composting materials was the mixture of swine manure, compost product preliminary produced in our laboratory from swine manure, sawdust as bulking agent, and a commercial seeding material (Alles G; Matsumoto Laboratory of Microorganisms Co., Ltd., Matsumoto, Japan) [4] with a ratio of 10:10:10:1 on dry weight basis. Some characteristics of the raw composting materials are shown in Table 1. Prior to the start of composting, the pH of the raw mixture was adjusted to 8.0 by the addition of slaked lime, and to 60% moisture content by the addition of distilled water. Miniature-scale composting system [4] was used and four types of composting runs (A, B, C, and D) were carried out for 10 days. In each run, fifteen gram of the raw material was placed inside each reactor, and two reactors were connected in series. In Run A, both upper and lower reactors were maintained at 40 °C while those of Run B were at 70 °C. In the case of Run C which corresponded to the composting without turning, composting in lower reactor was kept at 70 °C whereas that in upper reactor was maintained at 40 °C. Compostings in lower and upper reactors of Run D which

corresponded to the composting with turning were the same as those of Run C, and the material from reactors of Run D was mixed and returned to each reactor once daily.

To ensure the homogeneity, the composting material inside each reactor was agitated using a sterilized spatula daily. The composting temperature was kept constant using an incubator (Model IS 800; Yamato Scientific Co., Ltd., Tokyo, Japan) while a 5-L plastic bag (Tedlar Bag; Omi Odoair Service Co., Ltd., Omihachiman, Japan) was used to capture the exhaust gas. At each 12-h interval, the plastic bag was changed, and the volume of the exhaust gas captured was measured and subjected to CO<sub>2</sub> and NH<sub>3</sub> concentration analysis using Kitagawa gas detector (Komyo Rikagaku Kogyo K.K., Tokyo, Japan). For simplicity, the upper and lower reactors were indicated by (U) and (L) together with the run names.

Compost at day-0 and day-10 were withdrawn and analysed for the cell densities of mesophilic and thermophilic bacteria using a dilution plating method with the use of a trypticase soy agar medium [4]. The degradation patterns in Runs A, B, and C were numerically predicted using the first-order kinetics [5] which was integrated and simplified as shown in Eq. (1):

$$Q = C_c[1 - \exp(-\alpha(t - t_L))] \dots\dots\dots (1)$$

where  $Q$  is the quantity of carbon corresponding to the CO<sub>2</sub> evolved at a certain time (mol),  $C_c$  is the maximum amount of carbon that can be degraded during composting (mol),  $\alpha$  is the degradability coefficient based on the quantity of carbon in the swine manure (h<sup>-1</sup>),  $t$  is the time during which organic material decomposes (h), and  $t_L$  is the lag time before the organic materials begin to decompose (h).

Table 1. Main characteristics of composting matrices. Values are average  $\pm$  95% confidence intervals for the averaged values (n=3).

	Swine manure	Compost product	Sawdust	Seeding material
Moisture content (%)	70.7 $\pm$ 0.14	52.1 $\pm$ 2.46	8.0 $\pm$ 0.27	4.9 $\pm$ 0.74
Ash content (%)	11.5 $\pm$ 1.65	14.5 $\pm$ 0.87	0.7 $\pm$ 0.25	91.1 $\pm$ 0.63
C content (%)	44.1 $\pm$ 1.27	40.5 $\pm$ 0.34	49.6 $\pm$ 0.02	0.5 $\pm$ 0.30
N content (%)	2.9 $\pm$ 0.17	2.6 $\pm$ 0.16	0.1 $\pm$ 0.00	ND <sup>a</sup>
H content (%)	5.9 $\pm$ 0.01	4.5 $\pm$ 0.12	5.8 $\pm$ 0.24	0.6 $\pm$ 0.42
C/N ratio	15.2 $\pm$ 0.97	15.8 $\pm$ 1.09	551.2 $\pm$ 0.28	-

<sup>a</sup> ND: not detected.

### III. RESULTS AND DISCUSSION

The courses of the evolution rate and cumulative emission of CO<sub>2</sub> for all runs are shown in Fig. 1. The organic material was degraded vigorously at the start of composting, and the CO<sub>2</sub> evolution for all runs peaked at 24 h.

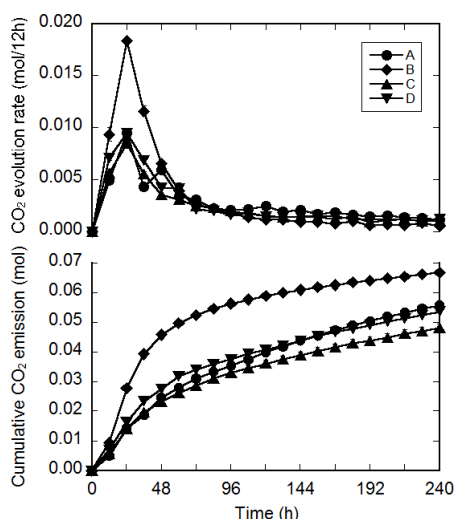


Fig. 1 The courses of evolution and cumulative emission of CO<sub>2</sub> during Runs A, B, C, and D. Error bars showed 95% confidence intervals for the average values (n=3), but are not detectable on the figure.

The degradation of organic matter was highest in Run B, followed by Runs A, D, and C, respectively. As composting continued, it could be thought that the cumulative CO<sub>2</sub> emission in Run C would be half of the sum of those generated in Runs A and B; on the other hand, the results show that there was least degradation of organic

matter in Run C. The low cumulative CO<sub>2</sub> emission in Run C relative to Run A indicates that the exhaust gas from Run C(L) greatly inhibited the degradation of organic matter in Run C(U).

Despite the same composting temperatures between Runs C and D, the ammonia inhibition was more severe in Run C(U) than that in Run D(U) as indicated by less amount of CO<sub>2</sub> evolution in Run C compared to that in Run D. This seems to suggest that turning the material once daily during composting reduced the ammonia inhibition of organic matter degradation by transferring the active microorganisms from the lower reactor to upper reactor where the ammonia inhibition occurred, during which these active organisms may contribute to the degradation of organic material.

The courses of the evolution rate and cumulative emission of NH<sub>3</sub> for all runs are shown in Fig. 2. With the progress of composting, the cumulative NH<sub>3</sub> emission was largest in Run B while only small amount of NH<sub>3</sub> evolved in Runs A, C, and D.

Although compostings in Runs C(L) and D(L) were set at 70 °C, the NH<sub>3</sub> emission from Runs C and D was far less than half of that of Run B, suggesting that NH<sub>3</sub> supplied from the lower reactor could be trapped and accumulated in Runs C(U) and D(U). Similar values of cumulative CO<sub>2</sub> emission were observed when comparing that in Run B with twice of that in the composting run conducted in our previous study with the use of a single reactor at 70 °C [4], indicating that the organic matter degradation was similar in both upper and lower reactors of Run B, and that the inhibition caused by the introduction of NH<sub>3</sub> gas from Runs B(L) to B(U) was negligible, although the ammonia concentration was extremely high, and far higher than that of Run A (see Fig. 3).

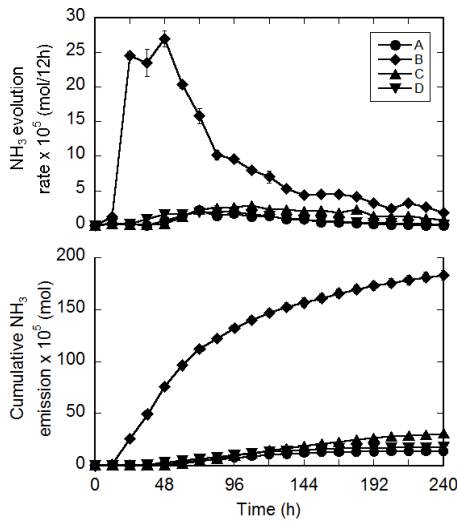


Fig. 2 The courses of evolution and cumulative emission of NH<sub>3</sub> during Runs A, B, C, and D. Error bars showed 95% confidence intervals for the average values (n=3), but are not detectable on the figure.

Therefore, it can be deduced that the amounts of CO<sub>2</sub> and NH<sub>3</sub> produced in the upper reactor were equal to those produced in the lower reactor when composting was conducted at the same temperature in both reactors. Thus, the amounts of CO<sub>2</sub> and NH<sub>3</sub> evolved either from the upper or lower reactor for Runs A and B each represented half of the overall totals under the conditions of Runs A and B.

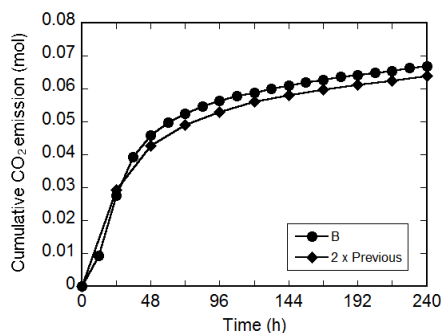


Fig. 3 Comparison of the courses of cumulative CO<sub>2</sub> emission in Run B with twice that of our previous study [4].

The amount of CO<sub>2</sub> or NH<sub>3</sub> generated in Run C(U) was calculated by subtracting half of those generated in Run B from that of Run C, since the lower reactor was maintained at 70 °C during Run C (Fig. 4).

Less NH<sub>3</sub> was supplied from the lower to upper reactor during Run A than Run C. Moreover, the total NH<sub>3</sub> evolution in Run C (see Fig. 2) was far smaller than that in Run C(L), confirming that the large amount of NH<sub>3</sub> accumulated in Run C(U). A significant difference of CO<sub>2</sub> evolution rate between A(U) and C(U) was observed, especially during the first 60 h of composting; however, these rates later converged (see Fig. 4). This may be because the rate of ammonia evolution was high during the early stages of composting except for the initial 12 h. It can be considered that microbial activity within Run C(U) was suppressed due to the high concentration of NH<sub>3</sub>, resulting in significant inhibition of organic degradation,

especially during 24—60 h of composting. As determined by fitting a curve to the experimental data with  $t_L = 0$ , the parameters set for the prediction of degradation patterns in Runs A, B, and C, are shown in Table 2.

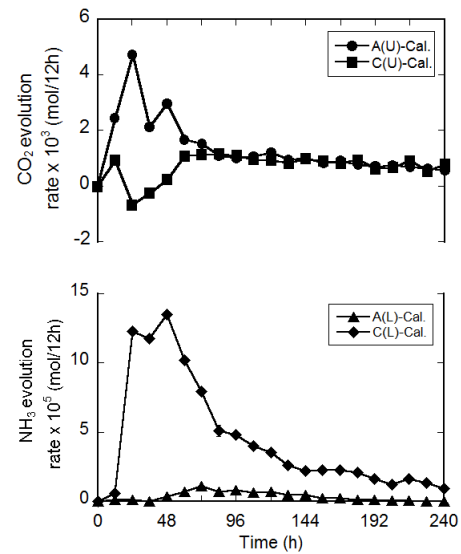


Fig. 4 The calculated evolution of CO<sub>2</sub> and NH<sub>3</sub> for upper and lower reactors (Runs A and C), respectively.

As composting progressed, the measured and predicted values of the cumulative CO<sub>2</sub> emission coincided well for the cases of Run A ( $R^2 = 0.99$ ) and Run B ( $R^2 = 0.98$ ), whereas there was a large discrepancy between the measured and predicted values in Run C ( $R^2 = 0.94$ ) which was the sum of the predicted values from Runs C(L) and C(U) (Fig. 5). Further study is necessary in order to incorporate the ammonia inhibition into the numerical model for Run C.

Table 2. Prediction parameters used in the numerical model in Runs A, B, and C.

	A-Pre.	B-Pre.	C-Pre.	
			C(U)	C(L)
$C_c$ (mol)	0.066	0.066	0.033	0.033
$\alpha$ (h <sup>-1</sup> )	0.0083	0.021	0.003	0.021

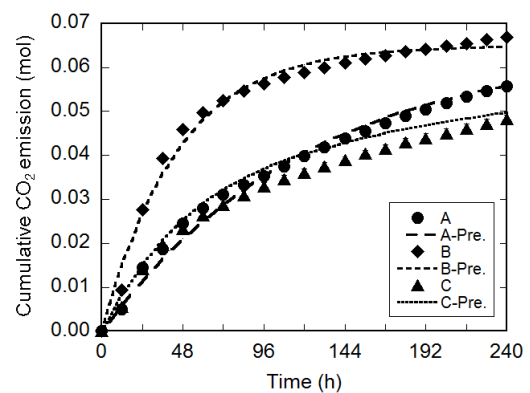


Fig. 5 Measured and predicted cumulative CO<sub>2</sub> emission during Runs A, B, and C.

Fig. 6 shows the cell densities of bacteria during composting on day-0 and day-10 in the upper reactors of Runs A, C, and D. Despite the same composting

temperature of 40 °C, microbial population of mesophilic bacteria in Run C(U) was approximately one order of magnitude less than that in Run A(U) (Fig. 6). These results seem to confirm that ammonia inhibited the activity of mesophile in Run C(U). At the final day of composting, the cell density of mesophile in Run C(U) was one order of magnitude lower than that in Run D(U), although composting temperatures of both reactors of Runs C and D were maintained at the same level suggesting that the ammonia inhibition of organic matter degradation became less severe during composting with daily turning. This could be attributed to the fact that microorganisms were subsequently supplied from lower to upper reactors for Run D.

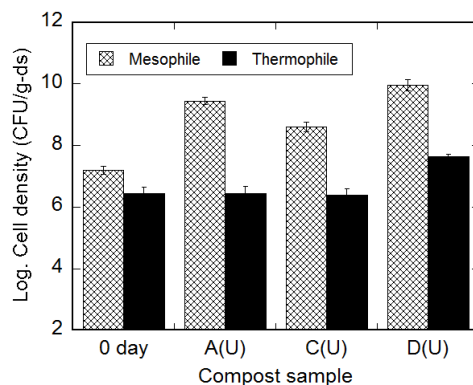


Fig. 6 The cell densities of bacteria during composting on day-0 and day-10 in the upper reactors of Runs A, C, and D. Error bars show 95% confidence intervals for the average values (n=3).

Similarly, cell density of thermophilic bacteria in Run D(U) was increased by one order of magnitude compared to those in Runs A(U) and C(U) which remained similar to

the initial value of  $2.5 \times 10^6$  CFU/g-ds (Fig. 6); these suggested that the activity of thermophilic bacteria were not inhibited by the  $\text{NH}_3$  while turning increased the microbial population of thermophile which contributed to organic matter degradation during low temperature composting.

#### IV. CONCLUSIONS

The inhibitory effect of ammonia on organic matter degradation was elucidated by using laboratory-scale composting system. Turning compost over once-daily reduced the inhibitory effect of ammonia on organic matter degradation during composting. It was confirmed that the degradation pattern of organic material during composting at constant temperature could be expressed by a simple numerical model.

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