

Influence of aeration rate on nitrogen during blackwater composting

Joonkyu Kim, Insang Song, Jisun Jong, Sangjoon Lee, Pyoungsan Kim,
Euna Jeong, Joonhong Park, Younkyoo Choung*

*School of Civil and Environmental Engineering, College of Engineering,
Yonsei University, Seoul (120-749), Korea*

Tel. +82 2 2123 2801; Fax +82 2 365 1965; email: choung@yonsei.ac.kr

Received 31 January 2008; revised accepted 15 May 2008

Abstract

The paper aimed to study the influence of the aeration rate on nitrogen dynamics during the composting of Blackwater sludge with sawdust. The increased aeration was responsible for an increase in ammonia emissions and for the decrease in nitrogen losses through leaching. At high aeration rates, losses of nitrogen in leachates and as ammonia in exhaust gas accounted for 90.99% of the nitrogen removed from the material. At low aeration rates, those accounted for 47.85% of the nitrogen removed from the material. The nitrification rate was found to be proportional to the mean content of $\text{NH}_4^+/\text{NH}_3$ in the material, i.e., initial $\text{NH}_4^+/\text{NH}_3$ plus $\text{NH}_4^+/\text{NH}_3$ released by ammonification minus the losses in leachates and in exhaust gas. The aeration rate was shown to be a main parameter affecting nitrogen dynamics during composting, since it controlled the ammonification, the ammonia emission and the nitrification processes.

Keywords: Composting; Aeration rate; Biodegradation; Nitrogen; $\text{NH}_4^+/\text{NH}_3$; Ammonification

1. Introduction

Nitrogen is closely related to carbon in biodegradation, and microorganisms use 15–30 carbons per a nitrogen unit. Through theoretical calculations, the optimum C/N rate for fast composting ranges between 15 and 30. A high C/N rate is a factor that restricts the growth of microorganisms. On the other hand, a low C/N rate results in excessive nitrogen, while the

increased ammonia in fuel gas produced during composting accounts for nitrogen source losses. Therefore, a carbon source may be added to increase C/N rate or nitrogen-fixing, and this process plays a role in decreasing ammonia emissions. Regarding this, Kayhanian and Tchobanoglous emphasized that accurate decision regarding the actual amount of carbon and nitrogen used should be fundamental, considering the microbial metabolism [1]. In the related literature, Paillat et al. reported that nitrogen-fixing was dependent on the biodegradation of carbon during the

* Corresponding author.

composting of livestock manure [2], while Liang et al. reported that addition of carbon source (10% dry weight) decreased the nitrogen emissions produced by the generation of heat [3,4].

An important parameter in the biodegradation process is also related to important factors for deformation and reduction in nitrogen. Ammonification (the action whereby organic nitrogen is decomposed to create ammonia-based nitrogen) causes the deformation of organic nitrogen within $\text{NH}_4^+/\text{NH}_3$, occurring simultaneously with organic biodegradation. Bhoyar et al. reported that maximum ammonification occurred in the temperature range of 60–70°C [5], and the ammonification enabled the decrease of ammonia in fuel gas to be related to the control of temperature and aeration rate. In addition, Liang et al. reported that the addition of shock-absorbing decreased the ammonia emissions by a small amount [3,4], but Pagans et al. reported that it was difficult to adjust pH during the composting processes [6]. As mentioned above, it is considered to be very difficult to decrease the ammonia emission through pH control. With respect to the amount of aeration, Elwell et al. explained and reported through their demonstration that intermittent aeration effectively reduced ammonia emissions [7]. However, Pagans et al. reported that limiting oxygen decreased biodegradability [6], while Liang et al. revealed that there is a close relationship between the aeration amount and the volatility of ammonia [3,4]. Namely, the presentation of an unclear aeration amount may not clearly explain the relationship with a decreased ammonia emission.

Nitrification is influenced by the environmental state of the composting material. After a composting period of about 30–50 days, the nitrate in the composting material usually increases [8, 9]. In other words, the oxygen is used to nitrification even when the temperature is reduced to less than 50°C and when biodegradation is gradually decreased, because the density of $\text{NH}_4^+/\text{NH}_3$ becomes low enough to prevent degradation of nitrification. Cronje et al. reported that forced convection increased nitrification [10]. However, nitrate usually exists in small amounts within compost. Nitrogen oxide emissions occur in a small portion of the initial nitrogen. Elwell et al. reported that an increased aeration amount and dried material (DM) decreased nitrogen oxide emissions [7]. On the other hand, Hao

et al. reported that nitrogen oxide emissions increased when the convection amount increased [11]. Cronje et al. conducted monitoring to explain low levels of nitrate with compost [10], and if the mass balance of nitrogen is found to be unbalanced even when oxygen is greater than 15%, the reason may be usually attributed to denitrification, as biodegradable carbon is still available. It was explained that nitrogen losses through denitrification are caused by the fact that 13–33% of nitrogen was eliminated from the initial material. Janzen et al. reported that they could not explain the loss of 10.1% through measuring the mass balance of nitrogen during the composting processes [12].

This study aimed at studying the dynamic influence of the aeration rate on nitrogen during organic composting. It was thought that the previous literature had not adequately clarified the relationship between aeration rate and ammonification, ammonia emission, nitrification and denitrification process, with respect to composting processes. In this regard, the study aimed at establishing a clearer understanding and knowledge on the subject.

2. Materials and method

2.1. Composting reactor and monitoring method

The basic shape and structure of the reactor was designed with reference to previous studies and literature on lab-scaled composting experiments. In order to protect thermal generation reaction from conductivity loss, the reactor was made of acrylic resin with a relatively low thermal conductivity, and the exterior side was covered with polyurethane insulation materials, to minimize thermal loss. Fig. 1 shows the outlines of the reactor and the monitoring method applied to this experiment. The entire appearance is a circular shape, using acrylic resin, whose total efficient volume is about 0.1 L. (Height = 350 mm, diameter = 300 mm). To analyze leachate during the composting reaction, a leachate sampling port was installed in the bottom of the reactor, and the unit to collect emission gas in the upper side of reactor, and the gas sampling port was connected to the measuring unit in order to minimize measured loss and to measure the load amount on a daily basis. In addition, to collect the produced condensed water, the collecting pipe for condensed

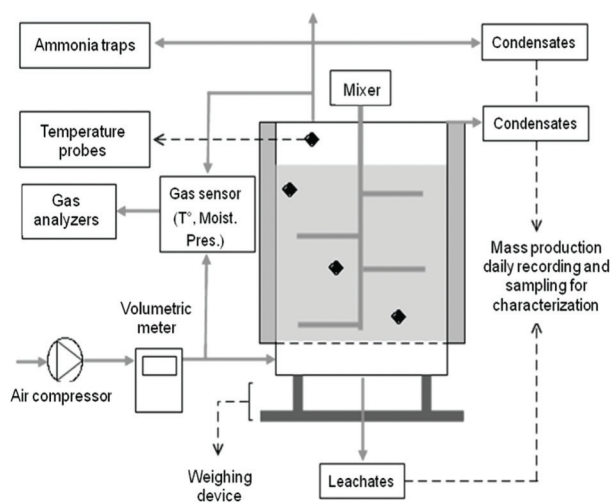


Fig. 1. Composting reactor and monitoring diagram.

water was installed before the gas-measuring unit. While the installed pulsator-type agitator continues to agitate at about 10 rpm, aerobic conditions were continuously maintained in the reactor, and the mixtures within the reactor were also maintained in a uniform status. The aeration was supplied from the downside to the upward stream of the reactor. Fig. 1 showed the aeration rate in the individual experiment. The inflow air was measured by the gas volume measurer, and the volume of dried gas was measured daily during the composting system. Pressure, moisture, and temperature were measured based on the inflow of dried air, and the density of oxygen and methane (CH_4) in the air inflow and outflow were measured, respectively. The oxygen density was measured using the parametric measurer, and methane density was analyzed using the IR spectrometric analyzer. The temperature of the composting material and that of the gaseous material within the reactor were serially measured with the temperature measuring ports in four positions in total. As the composting progressed, the according changes in mass were serially measured when the weighing system installed at the bottom of reactor measured the entire weight of the reactor. The ammonia was measured by collecting its inflow and outflow into sulfuric acid (H_2SO_4 , 1 N). In addition, the measurements were made for total carbon (TC), total organic carbon, organic nitrogen, nitrate and nitrogen oxide.



2.2. Characteristics of material and pre-treatment

This composting experiment was conducted using mixtures of sawdust and sludge produced in the blackwater treatment process. The blackwater sludge was brought from Seoul City Jungryang sewage disposal plant, and the dried sludge cake with a moisture content of 60–70% was applied to this experiment. For the purpose of the experiment, the sludge was mixed with sawdust within 24 h of its extraction from the sewage disposal plant. The sawdust was produced during the process of pallet (supportive tool made of wood, used at warehouses or plants to carry and store the cargo; Carried by a forklift) manufacture, and only oak sawdust without foreign materials was selected. Sawdust was collected only once during the experiment period, and dried at room temperature after first being cleansed with distilled water. In order to see the physical and chemical properties, we screened the sawdust with a sieve, and selected pieces with a 0.1–0.5 cm granular size. Aqueous extraction was conducted on the sawdust, to eliminate water-soluble chemicals. After aqueous extraction was conducted three times, it was found that the density of total phosphorous (TP), Chemical Oxygen Demand (COD), organic nitrogen (N_{org}), ammonia-based nitrogen ($\text{NH}_4^+/\text{NH}_3$), nitrate (NO_3^-) and nitrogen oxide (NO_2^-) was maintained at less than the measuring

Table 1
Characteristics of raw material.

| Component | Sample | Sludge | Sawdust |
|----------------------|---------------|--------|---------|
| pH | | 7.02 | 6.58 |
| Moisture content (%) | | 75.53 | 6.98 |
| Total solid (%) | | 24.47 | 93.10 |
| Ash content (%) | | 10.30 | 2.00 |
| Porosity* | | 40.00 | 98.00 |
| Volatile solid (%) | | 18.98 | 87.79 |
| T-C** | Dry basis (%) | 39.51 | 54.90 |
| T-N | | 2.46 | 1.67 |
| C/N ratio | | 16.02 | 32.84 |
| Conductivity (ms/m) | | 42.80 | 3.50 |
| Salinity | | 0.25 | 0.32 |

All data are mean value.

* Porosity: sketchy.

** T-C = $(100 - \% \text{Ash})/1.89$.

range. The sawdust was applied to the experiment after being dried and kept at room temperature. Table 1 shows Characteristics of raw materials.

Sludge and sawdust were mixed at a ratio of 1.24:1 (kg/kg), which is the mix rate widely used based on mass standards in the actual process. After sufficiently mixing the sludge and sawdust, we applied about 0.1 L per experiment. The weight of the entire mixture was kept in the range of 12–13.5 kg (coefficient of variance (CV): less than 2.5%), and the moisture content at 55–65% (CV: less than 4.5 %), all of which were specimens with constant density.

2.3. Pre-treatment of materials and analysis method

All dry specimens and organic materials (OMs) were cleansed three times and then dried for the purpose of measurement of their contents. After selecting 100 g from each sludge and mixture after composting per individual experiment, we conducted aqueous extractions, in order to separate the water-soluble portion from the insoluble portion.

In the aqueous extractions, 1 kg of distilled water was added to and analyzed per 100 g of specimen. After 30 min of centrifugal separation followed by solid–liquid separation, the extraction was repeated four times, respectively. The mixtures were filtered through micro filter (MF), through which the soluble

fraction (SF) was separated and the remaining solid material was deemed to be the non-soluble fraction (NSF) after being dried. Throughout the pre-treatment, we ignored the carbon and nitrogen in the SF within the sawdust, because they were in very small portion, compared to the carbon and nitrogen in the SF within the sludge. After the completion of composting experiment, the composting fraction became homogenized again, and we extracted the specimen and then measured the contents of dry material and OM. Using sieve screening and aqueous extractions, the SF within the sawdust granule was successfully separated from the NSF and sawdust granule. Aqueous extraction was performed by adding 200 mL of water to the 100 g specimen and mixing for about 20 min, after which the mixture was filtered through an eight-mesh sieve. This process was repeated four times. The contents of sawdust, sludge and DM of the composted compounds were measured after being dried at 80°C and becoming in the constant state. As these specimens were potentially combustible, we did not use high temperature for the drying process, but used the Standard Method NF U 44–160 instead in order to measure the contents of OM, and then dried specimens at 550°C three times in total, and extracted 500 mL again to analyze.

Our measurements of every parameter were repeated three times, to increase the reliability of the experiment. This means that pre-treatment was conducted 9 times on average in measuring all the soluble solid materials. The analysis was performed when the CV was less than 5%. The following describes our analysis according to the analysis parameter, on the sludge, composting material, and the SF in lactates and condensed water.

- TC: The specimen was oxidized with CO₂, in order to detect carbon, and the oxidized CO₂ was measured by an infrared ray spectrophotometer according to the Standard Method (NF-EN-13137). Also, COD was measured according to Standard Method.
- Total nitrogen oxide-based nitrogen (NH₄⁺/NH₃): Total nitrogen oxide was analyzed using the steam method, using manganese oxide (MgO). Boracic acid (H₃BO₃, 40 g/L) was used as the distilled material, and the distillation of H₃BO₃ was analyzed with the reverse method, using sulfuric acid (H₂SO₄, 0.2 N).
- Organic nitrogen (N_{org}: organic nitrogen content): Kjeldahl nitrogen method quantified with dilute

sulfuric acid, after photochemically using the distilled water. At this time, quantification is made according to the appropriate method of $\text{NH}_4^+/\text{NH}_3$ as indicated as Standard Method (ISO 11261). The OM can be acquired by extracting $\text{NH}_4^+/\text{NH}_3$, using the Kjeldahl nitrogen method.

- Nitrate and nitrogen oxide (NO_2^- , NO_3^-): Nitrate and nitrogen oxide were quantified, according to the distilled water method using MgO.

Other solid types of total carbon and organic nitrogen were analyzed based on the Standard Methods.

2.4. Characteristics of composting material and experiment method

Each experiment was conducted by increasing the aeration rate, respectively, and the aeration rate was kept at a constant rate without changes during the experiment period. There have been many previous studies and literature on the subject of the optimum aeration rate for sludge composting, which has been mainly reported as about 200 L/h and 500 L/h [13, 14]. This study also defines 200 and 500 L/h as its standard, and set aeration of 100 and 200 L/h to assess a low aeration rate, and an aeration rate of 500, 750, 1100 L/h to assess a high aeration rate. Furthermore, in order to observe changes in the same aeration rate, we conducted one more experiments at an aeration rate of 200 L/h. Namely, we gave the changes of aeration rate to 100, 200, 500, 750 and 1100 L/h, respectively, and then named the conducted experiments as F100, F200(1), F200(2), F500, F750 and F1100, respectively. The composting experiment was conducted for 35–50 days, respectively.

Table 2
Composting experiment status.

| Parameter | F100 | F200(1) | F200(2) | F500 | F750 | F1100 | Mean | CV (%) |
|---|------|---------|---------|------|-------|-------|------|--------|
| Fresh masses ratio (kg/kg) ^a | 1.24 | 1.22 | 1.24 | 1.24 | 1.25 | 1.25 | 1.24 | 0.9 |
| Total mass (kg) | 1.93 | 1.92 | 1.94 | 1.92 | 1.93 | 1.95 | 1.93 | 0.6 |
| Initial mixture moisture (%) | 69.4 | 71.3 | 68.3 | 69.4 | 67.6 | 66.2 | 68.7 | 2.3 |
| Aeration flow (L/h) | 100 | 200 | 200 | 500 | 750 | 1100 | | |
| Aeration rate (L/h/kgDM) | 1.69 | 3.62 | 3.25 | 8.48 | 11.98 | 16.63 | | |

^a Sludge/sawdust (kg/kg).

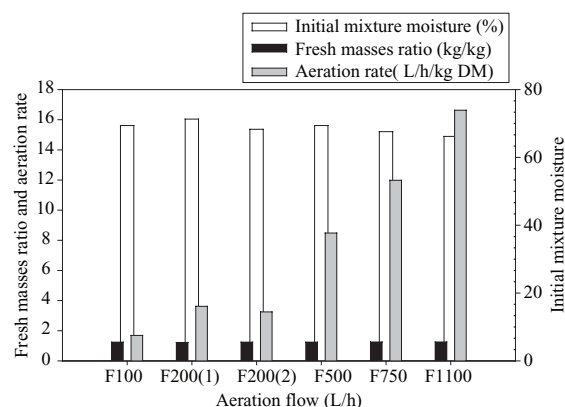


Fig. 2. Composting experiment status.

The sludge and sawdust was applied at 1.24:1 of mass rate, in all experiments. Table 2 and Figure 2 shows the experiment material data breaking down by the sludge and sawdust mixture, including the mass rate, total mass, moisture content, aeration quantity and aeration rate before and after the composting.

3. Results and discussion

3.1. Influence of aeration rate on nitrogen transformation

To compare the nitrogen loss-related leachates, emissions and nitrification, we expressed these losses by using $\text{NH}_4^+/\text{NH}_3$ produced by the ammonification and $\text{NH}_4^+/\text{NH}_3$ existed in the initial stage (Table 3). In this case, we regarded the differences between the total nitrogen eliminated from the initial material, and the nitrogen eliminated in the form of leachates and gas, as matching to $\text{NH}_4^+/\text{NH}_3$ transformed by

Table 3

$\text{NH}_4^+/\text{NH}_3$ contents and nitrification rate in the initial and final stage in the leaches.

| Trial | Initial content ^a (Mass in kgN) | Org. N removal | Available $\text{NH}_4^+/\text{NH}_3$ | |
|---------|---|----------------|---------------------------------------|----------------------------|
| F100 | 0.166 | 0.534 | 0.700 | |
| F200(1) | 0.685 | 0.440 | 1.125 | |
| F200(2) | 0.116 | 1.450 | 1.566 | |
| F500 | 0.237 | 0.885 | 1.122 | |
| F750 | 0.184 | 0.623 | 0.807 | |
| F1100 | 0.355 | 0.446 | 0.801 | |
| Trial | Leaching rate (%) | Emission rate | Nitrification rate | Final content ^a |
| F100 | 41.0 | 13.7 | 10.1 | 0.246 |
| F200(1) | 15.0 | 20.4 | 39.7 | 0.28 |
| F200(2) | 22.6 | 38.1 | 21.4 | 0.28 |
| F500 | 9.8 | 68.9 | 8.1 | 0.149 |
| F750 | 4.0 | 82.4 | 5.2 | 0.068 |
| F1100 | 6.7 | 80.0 | 1.0 | 0.098 |

^a N as $\text{NH}_4^+/\text{NH}_3$.

nitrification. The leaching rate, emission rate and nitrification rate are shown in Table 3, and those are expressed in the form of changes according to the aeration rate, as shown in Fig. 3. As the aeration rate was changed from 100 to 1100 L/h, the leaching rate was decreased by about 35% while the emission rate increased by 70%, accordingly. However, at a rate of 200 L/h, the initial contents of $\text{NH}_4^+/\text{NH}_3$ were five times higher in F200(1) than in F200(2), but the emission rate was almost two times lower in F200(1).

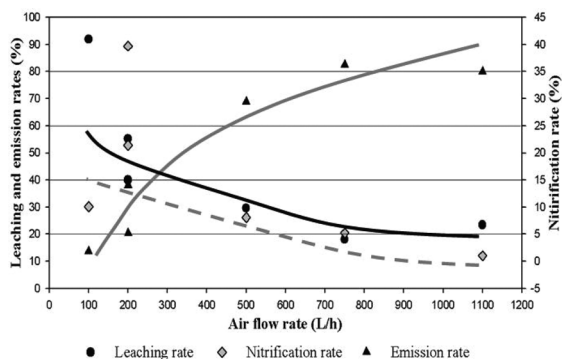


Fig. 3. Leaching rate, emission rate and nitrification rate.

addition, with respect to aeration rates that were greater than 200 L/h, the nitrification generally tended to decrease when the aeration rate went up. At a rate of 200 L/h, compared to the emission rate, the nitrification rate showed much higher value in F200(1) than in F200(2). Accordingly, it was found that emission and nitrification rates were not changed simply by aeration rate, but that the same would apply to oxygen available for nitrification.

In the six versions of the experiment, the moisture content ranged from 59% to 67%, which means that the moisture content is not related to emission and nitrification. At low aeration rates, compared to experiments with aeration rates higher than 100 L/h, the oxygen density of fuel gas is higher in F200(1) than in F200(2), which may explain the differences between the aeration and nitrification rate (Fig. 4). With respect to F500, F750 and F1100, a high aeration rate is considered to be the reason of the low density of $\text{NH}_4^+/\text{NH}_3$ in the composting material, as the result of the low nitrification rate.

If the high density of $\text{NH}_4^+/\text{NH}_3$ is maintained and oxygen is not limited in the composting system, the nitrification rate is expected to be high. Compared the results of this study with the previous literature, it can

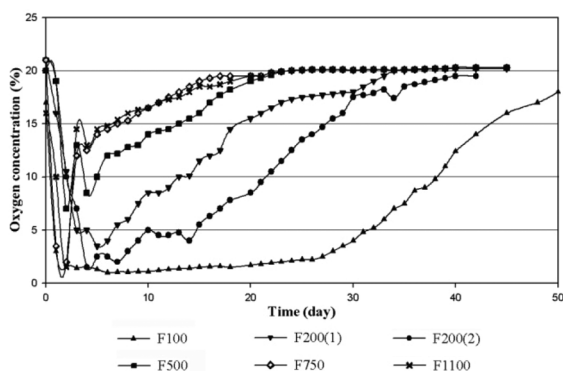


Fig. 4. Oxygen density of fuel gas.

be considered that ammonification occurs at the same rate as the oxygen consumption rate through biodegradation. Therefore, considering that the elimination of organic nitrogen is proportionate to the oxygen consumption, an emission amount of $\text{NH}_4^+/\text{NH}_3$ can be calculated. The losses caused by leachate and emission may be calculated by deducting from the emission caused by ammonification. It was not possible to calculate this by expressing the $\text{NH}_4^+/\text{NH}_3$ density in the time function, and the loss caused by the nitrification was ignored because of its fairly low value.

Fig. 5 shows the correlation between the reduction of density and the accumulation of $\text{NH}_4^+/\text{NH}_3$ in 500 L/h, which was applied as the standard aeration rate in this study. At the initial stage of reaction, $\text{NH}_4^+/\text{NH}_3$ by the leaching and fuel gas emission was accumulated, while the emission by the ammonia increased, maintaining the correlation. About 25 days

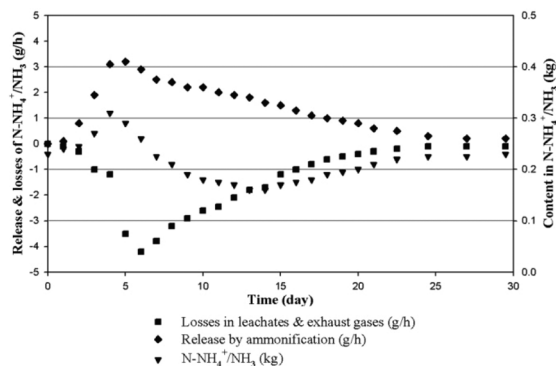


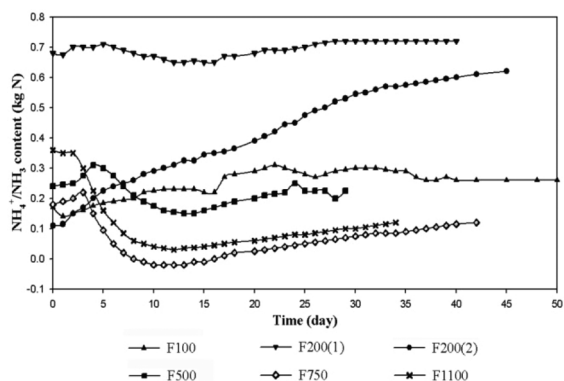
Fig. 5. Decrease and accumulation of $\text{NH}_4^+/\text{NH}_3$ density.

from the reaction, constant density was maintained without increase/decrease. Accordingly, the density of $\text{NH}_4^+/\text{NH}_3$ that had been maintained at about 1.2 g/h around the 50 days from the reaction started to gradually decrease, and then remained at constant degree again afterwards. The density of $\text{NH}_4^+/\text{NH}_3$ works in correlation with the loss in the leachates and fuel gas and the elimination of ammonification, which means that the density of $\text{NH}_4^+/\text{NH}_3$ is closely related to ammonification, fuel gas and condensed water.

As loss by nitrification is ignored in all experiment calculations, $\text{NH}_4^+/\text{NH}_3$ was lower than the calculated value. The final contents in the respective F100, F500, F750 and F1100 (Table 3) were slightly lower than the calculated value, showing 0.313, 0.230, 0.109 and 0.101 kg of $\text{NH}_4^+/\text{NH}_3$ in each experiment (Fig. 5). With respect to F100, F500, F750 and F1100, the density through composting over $\text{NH}_4^+/\text{NH}_3$ was considerably close to the calculated density. Fig. 5 assures the lower density of $\text{NH}_4^+/\text{NH}_3$ in 750 and 1100 L/h, which is considered as the cause of the nitrification rate being measured as a low value for F750 and F1100. On the other hand, since the nitrification rate for F200(1) and F200(2) is higher, the final contents of $\text{NH}_4^+/\text{NH}_3$ were much lower than calculated, showing 0.701 and 0.605 kg of $\text{NH}_4^+/\text{NH}_3$, respectively. However, as for F200(1)–F200(2), $\text{NH}_4^+/\text{NH}_3$ was found to be generally higher than in F100, F500, F750 and F1100.

Using Fig. 5, it was possible to determine the average maximum value of $\text{NH}_4^+/\text{NH}_3$ through the entire composting process. These values were 0.28, 0.69, 0.41, 0.22, 0.06 and 0.11 kg, respectively, for F100, F200(1), F200(2), F500, F750 and F1100. The dynamic properties for nitrification were not clearly known. This means that nitrification may continuously occur at the initial or final stage of composting, or throughout the entire experiment. The actual density of $\text{NH}_4^+/\text{NH}_3$ ranges between the average maximum value and the loss created by nitrification. Accordingly, it is possible to estimate the average contents of $\text{NH}_4^+/\text{NH}_3$ over all experiments, considering the fact that it is the average between the average maximum value and the loss created by nitrification. F200(1) and F200(2) showed a high nitrification rate, but it was lower accuracy of the corresponding estimated value.

However, Fig. 6 and Fig. 7 showed the increase of the average value of $\text{NH}_4^+/\text{NH}_3$ available to

Fig. 6. Changes of $\text{NH}_4^+/\text{NH}_3$ over time.

nitrification, which brought the increase of the nitrification rate. The differences in the nitrification rate for F100 and F200(2) are explainable because of the lower oxygen amount (within fuel gas) in F100 than in F200(2). The nitrification was found to be controlled by the oxygen available to $\text{NH}_4^+/\text{NH}_3$ and the nitrification. Accordingly, the ammonification and nitrification are dependent on aeration such as the aeration rate. The aeration rate is the main parameter of nitrogen loss, through leaching and ammonia emission. The aeration rate provides sufficient oxygen necessary for both biodegradation and nitrification, without excessive aeration, which is the cause of ammonia emission.

3.2. Temperature and oxygen consumption ratio of composting

Fig. 8 showed temperature was increased and decreased fast when aeration rate was high. Maximum

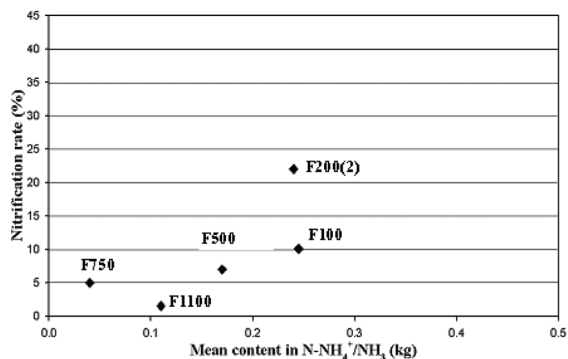
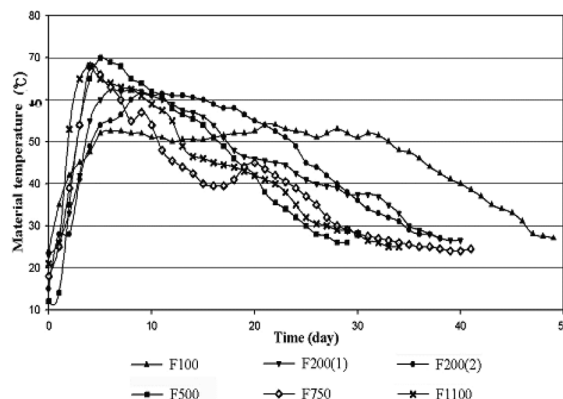
Fig. 7. Changes of $\text{NH}_4^+/\text{NH}_3$ within composting system.

Fig. 8. Temperature change of composting.

temperature was average 67°C when aeration rate was above 500 L/h (500, 750, 1100 L/h). When aeration rate was 100 L/h, temperature was increased at maximum 50°C and was maintained for 25 days. When aeration rate was 200 L/h, temperature was increased at 62°C and was maintained for 5 days. When aeration ratio was above 500 L/h, oxygen consumption ratio of effluent gas was above 10%. When aeration ratio was 200 L/h, oxygen consumption ratio was maintained below 5% for 30 days. When aeration ratio was 100 L/h, oxygen consumption ratio was maintained below 5% for 6–12 days. At Fig. 9, concentration of oxygen in influent and effluent gas was expressed as $r\text{O}_2(t)$ and relationship between oxygen consumption and $r\text{O}_2(t)$ was showed. When aeration ratio was 750 and 1100 L/h, oxygen consumption was increased fast until maximum and decreased slow and stopped finally. When

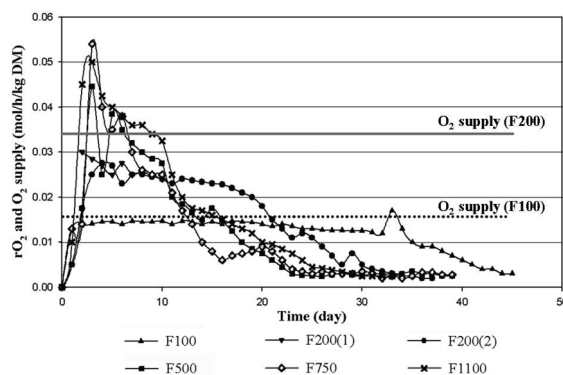


Fig. 9. Oxygen consumption ratio during composting.

aeration ratio was F100, F200(2) and F200(1), each oxygen consumption was increased for 25 days, 4 days and 10 days and decreased. It means that oxygen could limit biodegradation and slow velocity of decomposition. When aeration ratio was low, maximum ratio of oxygen consumption was lower than initial oxygen ratio. It means oxygen was limited. In case of F500, limiting of oxygen was maintained under 1 day.

Methane at 500, 750 and 1100 L/h was shown as low value while methane at 100 L/h was shown above 3000 ppm for 29 days. At 200 L/h, methane was increased until 2400 ppm for 2 days and decreased fast. At 6th day, methane became zero. Temperature, oxygen consumption and methane could delay composting at 100 and 200 L/h. While, at 750 and 1100 L/h, oxygen did not limit composting.

4. Conclusion

At high aeration, most nitrogen removed from the raw materials was emitted in the form of ammonia, where 79–94% of nitrogen was eliminated, and the addition of nitrogen loss to ammonia emission of leachates accounted for 90–99% of the removed nitrogen. At low aeration, the ammonia emission and loss of leachates only accounted for 47–85% of the eliminated nitrogen. At a low aeration rate, the density of $\text{NH}_4^+/\text{NH}_3$ of the final composting showed a higher value than at a high aeration rate. The loss not included in the range of 15–53% of the eliminated nitrogen is considered to have been caused by nitrogen emission followed by nitrification and denitrification.

These show that when oxygen is not restricted, the contents of $\text{NH}_4^+/\text{NH}_3$ available for nitrification, i.e., $[(\text{Initial } \text{NH}_4^+/\text{NH}_3) + (\text{NH}_4^+/\text{NH}_3 \text{ emitted by ammonification}) - (\text{loss within the leachates and ammonia within the emission gas})]$ would lead to the increased nitrification. As for the similar density of $\text{NH}_4^+/\text{NH}_3$, a lower density than that of the oxygen in fuel gas causes lower nitrification.

Considering the biodegradation from that perspective, we can see that ammonification and nitrification depend on aeration, and the aeration rate becomes the main parameter of nitrogen oxide emission. Furthermore, as the function of oxygen density of fuel gas, control of aeration can be considered to be a method of reducing nitrogen oxide emissions.

Acknowledgments

This work has been supported by Yonsei University, Center for Future Infrastructure System, a Brain Korea 21 Program, Korea.

This research was supported by a grant (06ConstructionCoreB02) from High-tech Urban Development Program (HUDP) funded by Ministry of Land, Transport, Maritime Affairs of Korea Government.

References

- [1] M. Kayhanian and G. Tchobanoglous, Composting of C/N ratios for various organic fractions, *Biocycle*, 33(5) (1992) 58–60.
- [2] J.M. Paillat, P. Robin, M. Hassouna, et al., Prediction ammonia and carbon dioxide emissions from carbon and nitrogen biodegradability during animal waste composting, *Atmos. Environ.*, 39 (2005) 833–842.
- [3] C. Liang, K.C. Das and R.W. McClendon, The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend, *Bioresour. Technol.*, 86 (2006) 131–137.
- [4] Y. Liang, J.J. Leonard, J.J.R. Feddes, et al., Influence of carbon and buffer amendment on ammonia volatilization in composting, *Bioresour. Technol.*, 97 (2003) 748–761.
- [5] R. Bhoyar, M. Olaniya and A. Bhide, Effect of temperature on mineralization of nitrogen during aerobic composting, *Indian J. Environ. Health*, 21 (1979) 23–24.
- [6] E. Pagans, R. Barrena, X. Font, et al., Ammonia emissions from the temperature, *Chemosphere*, 62 (2006) 1534–1542.
- [7] D.L. Elwell, J.H. Hong and H.M. Keener, Composting hog manure/sawdust mixtures using intermittent and continuous aeration: ammonia emissions, *Compost Sci. Util.*, 10 (2002) 142–149.
- [8] Choung, Y. K., Park, J. H., Go, K. B. (1994) “A mathematical model for the behavior of nitrogen and phosphorus during the aerobic digestion”, *KSCE Journal of Civil Eng.*, vol.14, No. 3, 635–674.
- [9] Jung, O. J., An, J. H. (2001) “The influence of air feed rate on the composting process of food wastes”, *Environmental Engineering Research*, 23, 1013–1018.
- [10] Cronje, A.L., Barker, A.J., Guy, S., et al. (2002) Ammonia emissions and pathogen inactivation during composting. In: Michel, F.C., Rynk, R.F., Hoitink, H.A.J.

- (Eds.), *Composting and Compost Utilization*. The J.G Press. Inc., Emmaus, PA, 845-856.
- [11] Hao, X., Chang, C., Larney, F.J., et al. (2001) "Greenhouse gas emissions during cattle feedlot manure composting", *J. Environ. Qual.* 30, 376-386.
- [12] Janzen, R.A., Feddes, J.J.R., Leonard, J.J., et al. (1997) "Composting for resource recovery-strategies to retain nitrogen" In: McGill, W.B. (Ed.), *Sustainability of Manure Management*.
- [13] Keener, H. M., Elwell, D. L., Ekinci, K., Hoitink, H. A. J. (2001) "Composting and value-added utilization of manure from a highrise swine finishing facility", *Compost Science and Utilization*, 9(4), 312-321.
- [14] Miyatake, F., and Iwabuchi, K. (2000) "Effect of high compost temperature on enzymatic activity and species diversity of culturable bacteria in cattle manure compost", *Bioresource Technology*, 96(16), 1821-1825.