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# The Role of Compost Pile Turning for Improving Performance of Composting

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**Abstract**

**Experiments were performed with sewage sludge using a 600 *l* in-vessel aerated static pile composting system during a two-year period. Fifteen batch runs were operated to determine the distributions of temperature throughout the composting pile in order to assess the proportion of the pile that were exposed to effective and ineffective temperature conditions during composting. Effects and interactions of several main factors such as aeration and moisture content on the evolutions of the process temperature were investigated. Aeration and heat evaporation led to high rates of moisture removal from the composting pile. Rapid reduction of moisture seemed to result in a significant reduction in biodegradation rate, thereby causing low temperature zones in the composting pile. This study proved that aeration rate and initial moisture content had a great influence on composting performance.**

**Keywords:** composting, temperature distribution, pile turning, aeration rate, moisture content

## INTRODUCTION

Composting is a perfect recycling method to convert organic waste to valuable materials because its recycling pattern draws a circle not one like drawing cascade recycle pattern and finally going to final disposal sites. Compost, a final treated state of organic waste, is returned to soil and becomes nutrients for vegetables, and the vegetables are consumed by farm animals and people. After consumption, organic waste and night-soil were composted and again follows the same route as described above. Although composting is a perfect method for recycling of waste, it has several severe drawbacks in terms of operation. Odor and un-uniform quality of compost material are the most considerable negative possessions in composting.

In recent years, due to successful odor control and other cost effective measures, many of composting systems have been developed as in-vessel systems with forced aeration[1-4]. The efficiency of these composting processes, however, is not always good due to problems caused by improper operation[4-8]. It was reported that the in-vessel static-pile composting systems with air recycle could not ensure temperature uniformity throughout the composting pile[4,6,7,9]. Wide variation in temperature is a result of non-turning and

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contributed significantly to lower the efficiency of the composting process, resulting in premature compost product with incomplete disinfection[4,5,10,11]. Previous studies have suggested that improvement for this problem relies on careful control of three key factors, namely temperature, aeration, and moisture content[7,10,12]. The interdependences between these factors in composting, however, have not been completely elucidated[3,8]. A better understanding of the interactions among aeration, moisture content, and temperature accompanying microbial inactivation, leads to better control of the composting process.

The purpose of this study was to assess the relationships between these factors and their effects on composting performance and to perceive the role of turning of composting pile in order to optimize the effectiveness of composting operation. Quality of compost can be assessed by physico-chemically and biologically. Compost degraded well without phytotoxity is essential for ecosystem of soil and plant growth and is assessed by physico-chemical parameters. Compost should be free from pathogens because compost is often handled by people's hands. So, hygienic aspect of compost is extremely important, which is assessed by biological parameters. Heterogeneous characteristics of compost can be achieved to as homogeneous as possible by only pile turning.

## MATERIALS AND METHODS

**Reactor description** A 600 *l* pilot-scale reactor was used to investigate the behavior of an in-vessel static bed composting process with air recycle, (Fig. 1). The reactor was constructed with 1 cm thick polystyrene sheet and insulated with 1.5 cm wooden sheet to further to minimize heat loss to the outside, a 4 cm free air space between the polystyrene and wooden sheets was provided. The internal dimensions were 100 cm high, 100 cm long, and 60 cm wide. The inside of the reactor was lined with non-corrosive and high temperature resistant stainless steel plates with a thickness of 0.05 cm. The top of the reactor was covered by a plastic roof. Air was forced into the reactor by a blower and internally distributed through two perforated PVC pipes installed at the bottom of the reactor. Aeration rates were regulated using valve-flow meters. Exhaust air was collected from the top of the reactor, and then sent back to the reactor with addition of fresh air after for trapping the moisture in the water condensate tank.

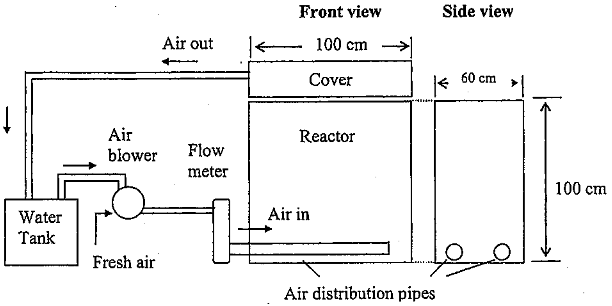


Fig. 1 Diagram of composting reactor

**Substrate preparation** Sewage sludge was obtained from a sewage treatment plant in Osaka Prefecture, Japan during a two-year period (1998 and 1999). The moisture content of the sludge was about 65–70% (w/w). The characteristics of raw sludge were shown in Table 1. The sludge sample was chopped and was size-reduced through a 1 cm sieve, and mixed with compost seed (previously produced compost). The mixture with moisture content of about 45–57% (w/w) was loaded into the reactor to a height approximately 90 cm from the bottom. Bulking agents were not added to the mixture.

**Temperature measurement** Composting pile in the reactor was divided into six layers according to the different depths of the composting pile, i.e., 15, 30, 45, 60, 75, and 90 cm from the bottom of the reactor and was shown in Fig. 2–(a). Temperature each layer was measured using thermocouples (Platinum, constantan (A type), 100Ω 2mA, Chino, Tokyo) and automatically recorded

Table 1 Characteristics of sewage sludge

| | |
|---|---|
| pH | 4.5 – 5.6 |
| Moisture content (% wet weight) | 65 – 70 |
| Volatile solids (% wet weight) | 24.5 – 26.8 |
| Total Kjeldahl Nitrogen (% dry weight) | 1.54 – 2.15 |
| Total organic carbon (% dry weight) | 46.3 – 54.5 |
| Electrical conductivity (mS/cm) | 0.22 – 0.50 |

with a Chino LE 100 Datalogger. The temperature measuring points at each layer was shown in Fig. 2-(b). Representative temperature of each pile layer was a mean of all measured values of the entire layer at a time during composting. Thermal conditions in the pile were vertically divided into two zones: above and below 60℃. Sixty degree (℃) was selected in this study as the target temperature for optimal biodegradation of organic waste and effective pathogen inactivation[6, 9, 13, 14]. Fifteen composting runs were done under the conditions of different initial moisture content and different aeration rate. A constant aeration rate was operated throughout each composting operation.

**Physico-chemical analysis** Moisture content (%ww) was determined by drying the sample in a convection oven at 110℃ for 24 h. Electrical conductivity (EC) and pH were measured by EC meter (PK-5, DKK., Ltd) and pH meter (TPX-90i, Toko., Ltd). Total organic carbon and total Kjeldahl nitrogen were determined according to Hue and Lin (1995). Detail of the procedure for measuring total organic carbon was as follow. A 30mg compost sample was oxidized with 10 m*l* 0.167*M* $K_2Cr_2O_7$ + 10 m*l* concentrated $H_2SO_4$ at 180 ℃ for 15 minutes. The suspension was cooled to room temperature and diluted with approximately 100 m*l* water, then titrated with 0.25*M* $FeSO_4$ solution, using ferroin as an indicator. Detail of the procedure for measuring Total Kjeldahl nitrogen was as follow. A 0.30g compost sample was digested at 350 ℃ in 5 m*l* concentrated of $H_2SO_4$ + 1.0g catalyst ($K_2SO_4$:$CuSO_4$ $5H_2O$: Se in 100:10:1 proportion). Distillation of $NH_3$ took place after the digest was cooled, diluted with 20 m*l* $H_2O$, and neutralized with 10M NaOH.

**Biological analysis** To investigate the effectiveness of pathogen inactivation in composting, *Salmonella* and faecal streptococcus (FS) were selected as indicators. A three gram fresh sample was suspended in 300 m*l* of sterile water by sonicating for 2.5 min, and serially diluted to $10^{-7}$. The diluents, thereafter, was used for determination of *Salmonella* and FS by plate counting method. *Salmonella* were enumerated on Brilliant Green (BG) medium after 24 h incubation at 37℃. Faecal streptococcus was assayed by using KF streptococcus medium after 24 h incubation at 37℃.

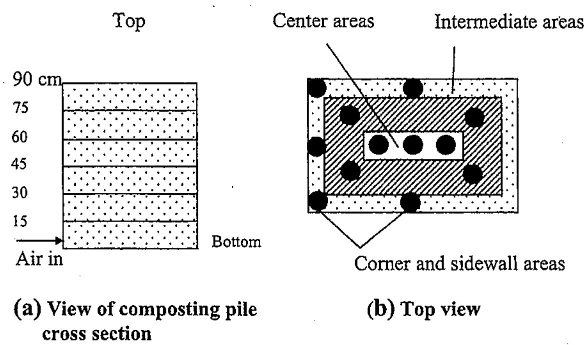


Fig. 2 (a) Six pile layers, (b) temperature measuring point of each layer

## RESULTS AND DISCUSSION

**Influence of aeration** Fig. 3 shows a representative temperature profile of six pile layers. The temperatures were lowest in the bottom layer, and increased with increasing pile heights in the order. Around the top surface of the composting pile showed the highest temperature. The bottom layer was located closest to the air distribution pipes, and therefore was strongly influenced by the temperature of inflow air, which temperature in turn strongly depended on the ambient

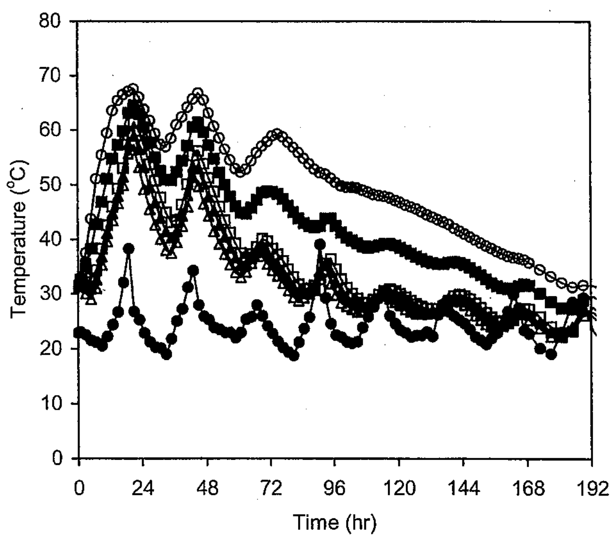


Fig. 3 Temperature profiles at different pile heights during composting.
△, 15 cm from the bottom; ▲, 30 cm; □, 45 cm; ■, 60-75 cm; ○, 90 cm; ●, ambient temperature

temperatures ($T_{amb}$). The results indicated that the increases and decreases of the temperatures in this layer almost coincided with the fluctuation of the ambient temperatures, and about six hours lag time was observed in the temperature curves. Hence, it could be said that the temperatures of this layer were significantly influenced by aeration rate and ambient temperature. Whereas in the higher layers, the temperature initially increased promptly and reached the first maximum peaks without a lag period. Especially, the top layer, where the cooling effect of the inflow air was almost negligible, and heat accumulated from the lower layers due to up-flow aeration and heat evaporation, gave the highest temperature of the composting pile.

Table 2 summarizes the results obtained from fifteen batch operations. The maximum temperature differences ($\Delta T_{max}$) obtained from the difference between temperatures at 15 cm (the bottom layer) and 90 cm (the top layer) pile heights regarding below and above 20 ℃ of $T_{amb}$ was shown in Table 2. $\Delta T_{max}$ values were employed because they would reflect the extent of temperature variation in the pile. Since $T_{amb}$ of 20 ℃ is the critical value for compost operation, performance of composting would be different upon below and above of 20 ℃[4], so that operation data should be analyzed separately based on below and above the temperature. The decrease of $\Delta T_{max}$ values could reflect a more uniform temperature distribution, and vice versa. When $T_{amb}$ < 20 ℃, up to aeration rate of 1 *l*/min/kg, $\Delta T_{max}$ values increased as aeration rate increase, but $\Delta T_{max}$ values became small after aeration rate exceeded 1 *l*/min/kg (Table 2 and Fig. 4-(a)). When $T_{amb}$ > 20 ℃, $\Delta T_{max}$ values increased as aeration rate increased and then $\Delta T_{max}$ values became constant after aeration rate exceeded around 1 *l*/min/kg (Table 2 and Fig. 4-(b)). Results indicated that $\Delta T_{max}$ values were significantly influenced by aeration rate.

**Influence of moisture content** It was suggested that in composting, water be necessary to support microbial activity and maintenance of 50-70 % moisture content in the entire the pile the during active phase be key for successful composting[3,7,10,12,14,15]. Moisture removal from the composting material was the result of heat vaporization and aeration. This moisture reduction can cause a significant reduction in the rate of metabolism, and thereby reduces heat generation. Fig. 5-(a) shows the curves of moisture content obtained from one typical composting operation. The temperatures of

Table 2 Data from 15 runs regarding ambient temperature below and above 20 ℃

| $T_{amb}$ (℃) | Initial moisture (% ww) | Aeration rate (*l*/min/kg) | $\Delta T_{max}$ (15–90 cm) (℃) | Low temp zone ($f_1$) (% pile volume) | Ideal numbers of pile turning (turns) |
|---|---|---|---|---|---|
| <20 | 55 | 0.84 | 31 | 50 | 20 |
| | 55 | 0.85 | 23 | 33 | 12 |
| | 57 | 0.69 | 24 | 33 | 12 |
| | 57 | 0.83 | 20 | 33 | 12 |
| | 45 | 1.33 | 14 | 50 | 20 |
| | 49 | 0.51 | 13 | 33 | 12 |
| | 49 | 1.38 | 13 | 100 | impossible |
| | 50 | 0.52 | 12 | 16 | 8 |
| | 50 | 0.63 | 10 | 33 | 12 |
| >20 | 50 | 0.88 | 18 | 33 | 12 |
| | 50 | 1.5 | 18 | 33 | 12 |
| | 55 | 0.46 | 4 | 0 | 0 |
| | 55 | 1.38 | 16 | 50 | 20 |
| | 57 | 1.3 | 17 | 33 | 12 |
| | 45 | 0.55 | 11 | 33 | 12 |

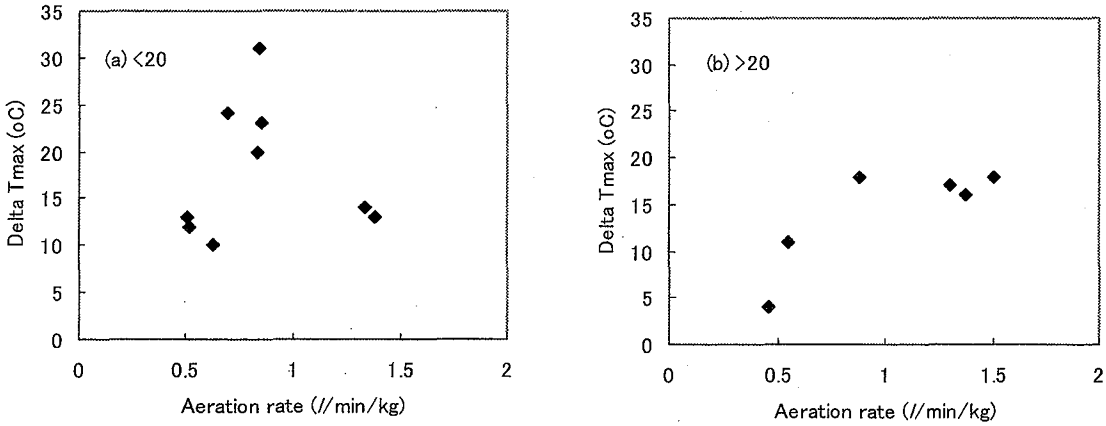


Fig. 4 Aeration rate vs. $\Delta T_{max}$ regarding ambient temperature below (a) and above (b) 20 ℃

the bottom and middle layers decreased and reached ambient at the eighth day (Fig. 5-(b)), corresponding to the reductions of moisture content to 35 and 37%. Whereas, in the top layer at that time the moisture content was still above 60%, and the temperature was higher than 50℃. These results correspond to the conclusions of the previous studies[10]. It was indicated that temperature in the pile was significantly influenced by moisture content. The differences of moisture content at different pile heights could be attributed to the non-uniformity of temperature distribution in the pile. Moisture control is essential for maximum microbial activity and thus for maintaining sufficiently high temperature required for pathogen inactivation.

The results indicated that $\Delta T_{max}$ values were significantly influenced by initial moisture content (Fig. 6). When $T_{amb}$ < 20 ℃, $\Delta T_{max}$ values increased as initial moisture content increased (Table 2 and Fig. 6-(a)), which meant that temperature distribution in composting piles became more unevenly at high initial moisture contents in cool weather. When $T_{amb}$ > 20 ℃, $\Delta T_{max}$ values did not show any trends regarding change of initial moisture content (Table 2 and Fig. 6-(b)). It was confirmed that initial moisture content was an important operational factor and should be properly controlled along with aeration rate during the composting operation, especially, when $T_{amb}$ was below 20℃.

**Temperature distribution and composting performance** As can be seen in Table 2, approximately 67% of the pile was usually composted in the high temperature (higher than 60℃) zone, and about 33% was in the low temperature zone (below 60℃). Temperatures higher than 60℃ in the entire pile were observed when ambient temperatures were higher than 20℃ with 55% initial moisture and 0.46 $l$/min/kg aeration rate. In

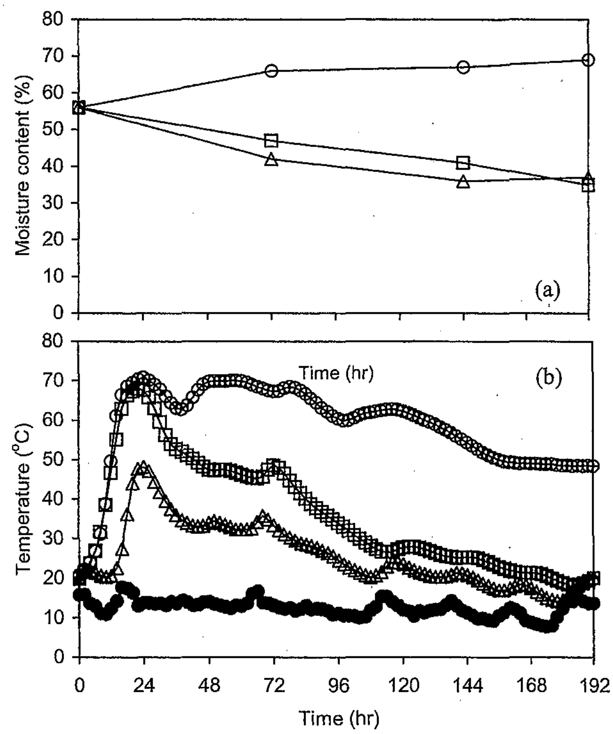


Fig. 5 (a) Changes of moisture contents, (b) temperature changes at different pile heights during composting.
○, 90 cm from the bottom; □, 45 cm; △, 15 cm; ●, ambient temperature

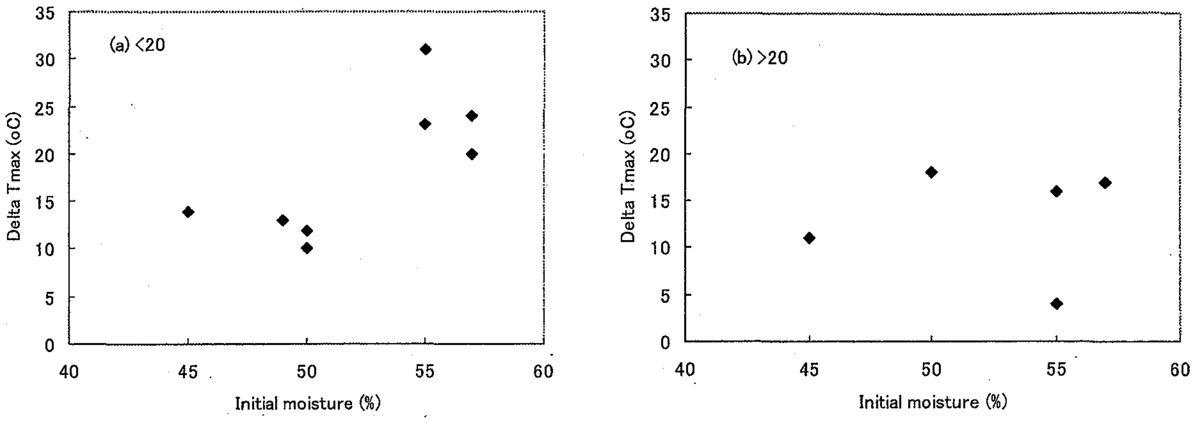


Fig. 6 Initial moisture vs. $\Delta T_{max}$ regarding ambient temperature below (a) and above (b) 20 ℃

the ambient temperatures below 20℃, non high temperature zone (above 60℃) in the entire pile was observed with 49% initial moisture and a 1.38 $l$/min/kg aeration rate. The influences of the pile thermal condition on the composting performance of pathogen inactivation and change of C/N ratio were in Figs. 7 and 8. Almost no pathogens destruction (Fig. 7) and nor a decrease in C/N (Fig. 8) in the bottom layer was observed, which may suggest that the unexpected low temperatures in this layer could cause such low composting efficiency. These facts indicated that to achieve effective composting and hygienically safe compost, all the amount of the composting material must undergo appropriate high temperature conditions in the process. The compost processes were always operated in a period of 12 days. The quality of the final compost after 15 experiments was shown in Table 3. It was indicated that the better compost quality was always achieved when ambient temperatures were higher than 20℃.

**Turning regulation** Pile turning has been offerred as the solution to overcome the problem of non-uniform temperature distribution[6,7]. By complete turning all the material can be composted under appropriate conditions of aeration, moisture content and temperature that favor maximum microbial activity and effective pathogen inactivation. On the other hand, this method itself has some disadvantages such as release of odor, and rising cost of labor[7]. It was also indicated that turning led to less effective inactivation

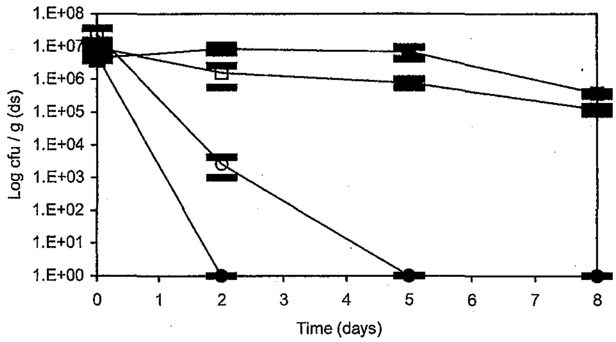


Fig. 7 Population changes of *Salmonella* and faecal streptococcus (FS) as a function of time for the samples collected at the center area of pile layers.
■, *Salmonella* at 15 cm from the bottom (bottom layer); ○, *Salmonella* at 90 cm (top layer); □, FS at 15 cm (bottom layer); ●, FS at 90 cm (top layer)

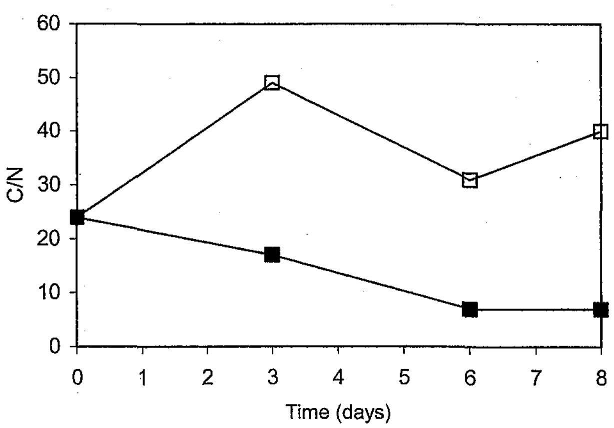


Fig. 8 C/N changes with time for the samples collected at the center area of pile layers.
■, 90 cm from the bottom (top layer);
□, 15 cm (bottom layer)

Table 3 Compost quality before and after 12 days composting operations

| Parameters | $T_{amb}$ > 20℃ | | | $T_{amb}$ < 20℃ | | |
|---|---|---|---|---|---|---|
| | Aver | Min | Max | Aver | Min | Max |
| Moisture content (%) | | | | | | |
| Before | 51 | 45 | 57 | 53 | 49 | 57 |
| After | 27.5 | 20 | 35 | 38.5 | 28 | 49 |
| Electrical conductivity (mS/cm) | | | | | | |
| Before | 1.5 | 1.2 | 1.8 | 1.4 | 1.0 | 1.9 |
| After | 3.5 | 2.2 | 4.8 | 2.5 | 1.9 | 3.4 |
| pH | | | | | | |
| Before | 6.7 | 6.0 | 7.6 | 7.3 | 6.5 | 8.2 |
| After | 7.9 | 7.3 | 8.5 | 8.2 | 8.0 | 8.5 |
| C/N (dry weight basis) | | | | | | |
| Before | 25 | 24 | 27 | 26 | 24 | 31 |
| After | 15 | 12 | 18 | 20 | 15 | 25 |

and should be minimized[14,16,17].

In the static pile, temperatures below 60℃ (the low temperature zone) can be theoretically considered as sublethal, causing no organism destruction. Lethal effect of temperatures occurs in the high temperature zone (higher 60℃). The efficiency of thermal inactivation was discribed by Haug (1993) as

$$N_t = N_o[f_l + f_h e^{(-k_d \Delta_t)}]^n \quad (1)$$

and $f_l + f_h = 1$ (2)

Where $N_t$ is surviving number of organisms, $N_o$ is initial number of organisms, $f_l$ is amount of composting pile in the sublethal temperature zone, $f_h$ is fraction of compostiing pile in the lethal temperature zone, $\Delta_t$ is time interval between turning (usually, days), $k_d$ is thermal death coefficient, and n is number of turnings. Between each turning period, if the time interval of high temperature zone is appropriatelly maintained to achieve complete destruction of undesired organisms (≥ 60℃ for at least 2 h)[14], the value of $k_d\Delta_t$ will be infinity. Under these conditions Eq. (1) reduces to

$$N_t = N_o(f_l)^n \quad \text{or} \quad N_t / N_o = (f_l)^n \quad (3)$$

For this model, it must be assured that all the composting pile was redistributed completely after each turning period. Eq. (3) suggests that, turnings can be minimized by minimizing the amount of the material in the low temperature zone ($f_l$). The results obtained from this study indicated that $f_l$ could be minimized by controlling aeration and moisture content. Based on the results from this study, $f_l$ was observed to be 0.33, to achieve a 6 $\log_{10}$ reduction of undesirable microbes ($N_t$ / $N_o$ is $10^{-6}$) in the high temperature zone number of pile turnings (n) is determined from Eq. (3) as

$$(0.33)^n = 10^{-6}$$

Logarithmic transformation and rearranging

$$n = -6 / \log_{10} 0.33$$

Thus, composting should be operated with at least 12 pile turnings in order to achieve the above desired inactivation when $f_l$ was 33%. Ideal numbers of turning were shown in Table 2. According the table, throughout a year, 20 pile turnings maximum were required for achieving complete inactivation of pathogen in terms of hygienic safety for this study. According to Table 2, the ideal number of pile turning was zero at 0.46 *l*/min/kg of aeration rate. The number of pile turning seemed increased if aeration rate exceeded 1 *l*/min/kg. Employment of much smaller rate than 0.46 *l*/min/kg would show a better performance of composting. More studies need to clarify the effect when aeration rate was small.

## CONCLUSIONS

The results of this study show that aeration and initial moisture content have a great influence on temperature distribution in the composting pile, and were very important limiting factors for sewage sludge composting.

Consequently, appropriate management of aeration and moisture content by proper turning during composting may improve the efficiency of the composting process. By complete turning, all the amount of the composting material can be exposed to controlled conditions of temperature and moisture content that favor maximum microbial activity and effective pathogen inactivation. The model of periodical turning was proposed to optimize the composting performance. From this study, we hope that the most essential limitations of this composting process were pointed out and the obtained data can be applied for practical composting.

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