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Optimal turning method of composting regarding hygienic safety

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Abstract: The new turning method was proposed and verified its effectiveness to pathogens by laboratory scale experiments. Considering the results obtained from the previous studies, it could be said that turning of a composting pile was essential in terms of hygienic aspects but the number of turning should be minimized. Effectiveness of inactivation was estimated for each composting run. From this estimation, turning by layers, which is different from conventional turning that mixes compost pile entirely, was proposed and investigated its performance by experiments. Composting operations with static pile method, complete mix(conventional) turning method, and proposed turning(layer turning) method were done and their effectiveness on inactivation of indicator microorganism was evaluated and compared. As results, the conventional turning method was not a proper method in terms of pathogen inactivation, whereas, the proposed turning method showed an excellent performance and should be employed in a composting operation.

Keywords: composting; turning; inactivation; hygienic safety

Introduction

Composting is a well developed and promised technology for treatment of organic waste. It is also a technology of resource recovery and convert the waste into valuable materials such as fertilizer and soil amendment. Composting, however, has not been fully understood yet and hygienic aspect of composting, especially, has a room for doubt. Many researchers have conducted the studies related to hygienic safety of composting (Deportes, 1998; Hassen, 2001; Hay, 1996; Shaban, 1999).

For hygienically safe operation of composting, the series of studies were performed. Firstly, temperature distribution in compost piles was studied and uneven distribution vertically and horizontally in the piles was observed(Tateda, 2002). It was found that the top and middle layers were effective zones whereas the bottom layer did not show any effectiveness. Secondly, effects of composting heating pattern on fate of bacterial indicator microorganisms were observed in terms of hygienic safety of composting (Tateda, 2003). Inactivation and regrowth of the microorganisms were investigated under the different composting operation modes. It was concluded that temperature in a compost pile should not be controlled and turning of a pile should be minimized. From results of the two previous studies, it can be concluded that turning of a compost pile is necessary but should be minimized and done effectively, otherwise, low inactivation and regrowth of pathogenic microorganisms are expected.

The purpose of this study is to propose a new turning method and evaluate its effectiveness in terms of hygienic aspect. Effective areas of the composting were estimated using the data obtained in Tateda *et al*. (Tateda, 2002). Considering the effective areas and the results from Tateda *et al*. (Tateda, 2003), turning by layers was proposed as a new turning method. This was the third study in series and was verifying effectiveness of the proposed turning method using a laboratory scale compost reactor.

1 Materials and methods

1.1 Reactors

Three of 35 litter fishing cool boxes available at any DIY shops were modified into reactors(Fig.1) and the system of the reactors imitated the one of the reactor in Tateda *et al*. (Tateda, 2002). The two PVC pipes were placed on the bottom of the reactor and air was supplied through the pipes by an air compressor(BABECOM, Hitachi). The air went out through a pipe placed at the high position of a wall of the reactor and moisture in the air was trapped in a container installed at the end of the pipe. Finally, dry air went out from the container.

1.2 Composting substrate

Dog food(Aijou Monogatari Beef taste, Yeaster, Japan) was used as substrate of composting in order to provide the same quality of substrate for each operation. Dog food was grinded by a commercial juicer mixer before use.

1.3 Inoculation of indicator

Escherichia coli K-12(*E. coli* K-12) was used as the indicator microorganism. *E. coli* was cultured in a 2 L sterile LB broth for one day on an incubator shaker(RKc, REX-C900, Japan) at 120 r/min and 28℃. After incubation, the cells were harvested by centrifugation at 10000 × g at 4℃ for 10 min and re-suspended in 500 mg/L sterile sodium tripolyphosphate buffer(pH 7.0). Inoculation was carried out by adding suspension of *E. coli* into compost material before experiments and gave approximately 107 cfu/g (dry base) of the material. The number of *E. coli* in the mixed materials at $t = 0$ was assessed by taking 10 samples from the mixed material randomly and then the number was

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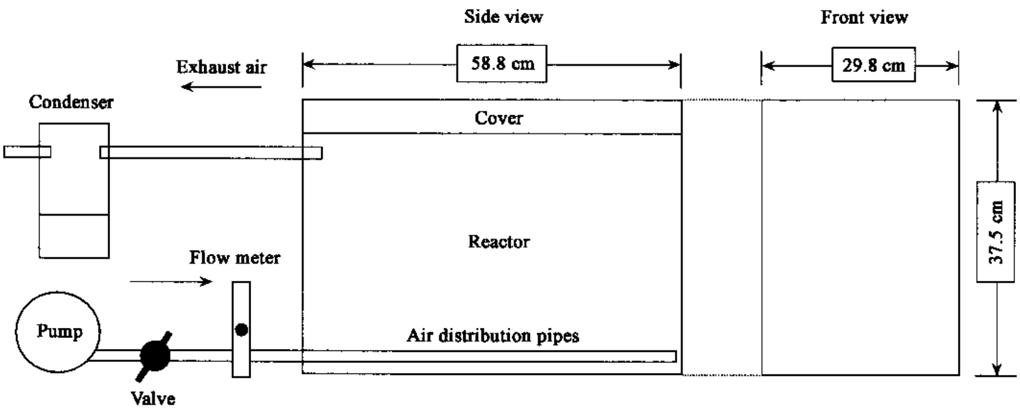


Fig.1 Compost reactor

averaged.

1.4 Temperature measurement

Following the proposal of representative temperature measuring points discussed in Tateda *et al*. (Tateda, 2002), temperatures of the bottom and the top layers were measured using thermocouples and a data logger (HOBO H8 Onset, Technical Support). Ambient temperature was also measured simultaneously. Collected data were analyzed by Microsoft Excel software.

1.5 Analytical methods

Moisture content was measured by drying samples at 110℃. Survival of *E. coli* was assessed by the plate counting method. After 9 d, compost piles were completely mixed. Three of a 1 g of the mixed compost material was placed in a glass tube with 9 ml of sterile sodium tripolyphosphate buffer solution (5 mg/L) and vortexed for 1 min at maximum speed in order to obtain a 10^{-1} suspension. The suspension was stayed for 5 min and then a 1 ml of aliquot of supernatant was transferred into sterile sodium tripolyphosphate buffer solution (5 mg/L) to make 1:10 serial dilution. A 0.1 ml of aliquot was taken for plate counting on Desoxycholate agar. The counting was done in triplicate.

1.6 Food/seed (F/S) ratio

From the results of Tateda *et al*. (Tateda, 2002), the T_{65} was faster with the small F/S ratio when ambient temperature was above 20℃. 6 kg of dog food and 7 kg of seed compost were mixed, therefore, 0.86 of F/S ratio was used for this study. Seed compost was obtained from a composting company (NESCO, Japan).

1.7 Heating pattern

The single impact heating pattern was used for all composting operations unless the compost pile was turned because the pattern showed the highest performance regarding hygienic aspect in the result of Tateda *et al*. (Tateda, 2003).

1.8 Estimation of effectiveness of inactivation

Effectiveness of inactivation of the nineteen composting operations performed in Tateda *et al*. (Tateda, 2002) was estimated. For the estimation, the compost piles were divided into blocks and each block was 20 cm in length × 20 cm in width × 15 cm in height (Fig.2). Each composting operation had different temperature measuring points and the block whose temperature recorded at more than 55℃ and lasted for more than 72 h (American standard) was considered as an effective block. The American standard of composting for disinfection was applied for this estimation because Japanese one (more than 65℃ and more than 48 h) could not fit to the temperature profiles and effectiveness of each operation became extremely low. Several assumptions were made for helping the estimation more ideal and were as follows.

Assumption (1): A block sandwiched horizontally and vertically by the blocks which showed effectiveness was counted as an effective block.

Assumption (2): Temperature of center and intermediate areas was always higher than corner and wall areas within the same layer.

Assumption (3): Temperature of upper layer was always higher than that of lower layer.

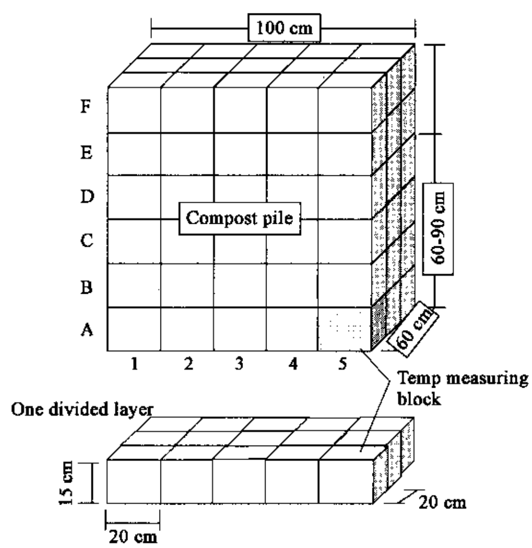


Fig.2 Division of a compost pile for estimation of effectiveness

1.9 Turning methods

The three turning methods were employed in this study. One was no turning composting or static pile method. The second one was complete mix composting or conventional turning method. The final one was the proposed turning method. The proposed turning method was the turning by layers. Dividing a compost pile into three layers, the bottom layer, the lowest temperature zone, will be turned to the top and the top layer, the highest temperature zone, will be turned to the bottom. The proposed turning method was, therefore, the turning of layers whereas the conventional turning method is turning by complete mix of the entire pile.

1.10 Experimental procedure

Each run of composting was operated for 9 d and counting the number of *E. coli* was done at $t = 0$ and $t = 9$ (d) for all the runs. For the static pile method, the compost material was placed into a reactor and run for 9 d without turning. For the conventional turning method, the compost material was placed into a reactor and the turning was done twice during 9 d. The whole compost pile was completely mixed during turning. For the proposed turning method, the compost material was placed into a reactor and the turning was done twice for 9 d. Whole compost pile was taken out from the reactor and divided into the three layers. Each layer was mixed completely, and then the compost material of the top layer was placed in the bottom layer and the compost material of the bottom layer was placed in the top. The compost material in the middle layer stayed in the middle.

2 Results

2.1 Estimation of effectiveness of inactivation

Effectiveness of inactivation for each composting run conducted in Tateda *et al*. (Tateda, 2002) was estimated. The results of the estimation are shown in Fig. 3 and the estimation processes for each operation were explained in Appendix. According to the results, eleven operations showed some effectiveness in their piles, on the other hand, eight operations were no show of effectiveness in their piles. Effectiveness showed in the top layer and sometimes in the middle layer, but it never showed in bottom layer. Conventional turning of composting is a method of mixing an entire pile of composting, which means that effective layer will be mixed with no effective layer. The results implied that the method was not reasonable and effective because it spread the risk of pathogens by mixing effective layers with non-effective layers. Turning by layers, therefore, was proposed and verified its effectiveness by experiments. To avoid non-effectiveness of composting piles, Fig. 4 helped the operations. This was the relationship between the effectiveness and airflow/amb. temp. The figure indicated that composting pile showed some effectiveness of inactivation when airflow/(amb. temp) was below approximately 30 (1/min/m³ 1/℃) and the pile did not showed any effectiveness of inactivation when airflow/amb. temp was over 30. Considering this relationship, the value of airflow/amb. temp should be below 30(1/min/m³ 1/℃).

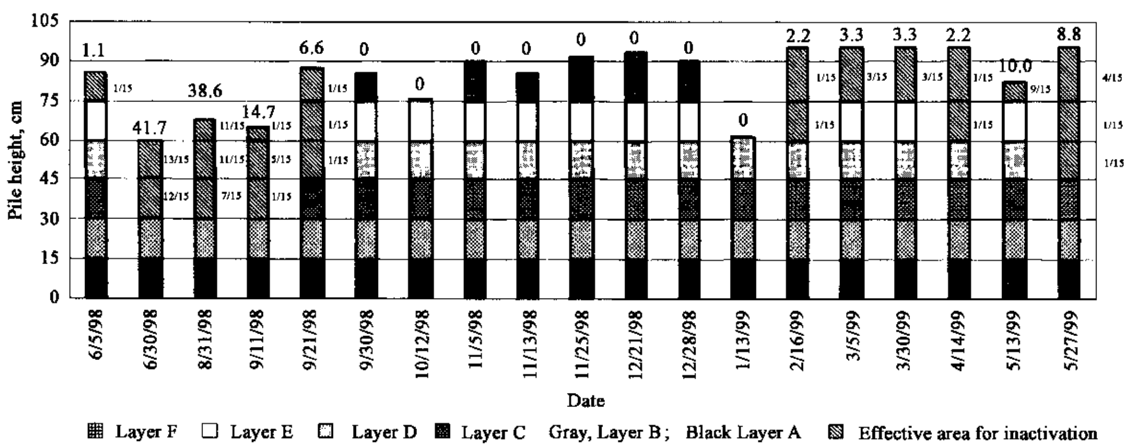


Fig.3 Effectiveness after assumptions

A number above each column indicates effectiveness of the run(% of the pile); fractions beside each column indicate effectiveness of each layer(a ratio of effective and non-effective blocks)

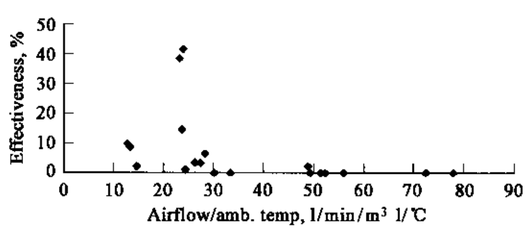


Fig.4 Relationship between effectiveness and airflow/ambient temperature

2.2 Composting operation

Operational parameters and survival of *E. coli* for the three operations are summarized in Tables 1 and Table 2, respectively. Following the experimental procedures in Tateda *et al*. (Tateda, 2002), a compost pile was simply divided by three layers and temperature was measured at the top and bottom representative areas. Five runs were conducted for each method. Temperature profiles of the methods were the typical ones.

Table 1 Operational parameters for the three operations

Composting operation methods	Ambient temp., ℃	Airflow rate, $l/min/m^3$	Airflow/amb. temp. ratio, $l/min/m^3$ l/℃	F/S
Static pile	25.5	244	9.57	0.86
Conventional turning	23.6	244	10.3	0.86
Proposed turning	17.1	183	10.7	0.86

Table 2 Survival of *E. coli* under three composting operations

Composting methods	Operation duration, d	Moisture contents, % w/w	Survival number of *E. coli*, cfu/g dw
Static pile	0	49	4.9×10^7
	9	43	5.6×10^4
Conventional turning	0	47	5.1×10^7
	0	35	1.3×10^5
Proposed turning	0	48	5.3×10^7
	9	31	ND

2.4 Static pile method

Temperature profile is shown in Fig.5. The temperature of compost pile was uniform up to approximately 100 h and after 100 h the temperature of the bottom layer decreased faster than that of the top layer. Viable populations of 5.6×10^4 cfu/g dw of *E. coli* were remained after 9 d.

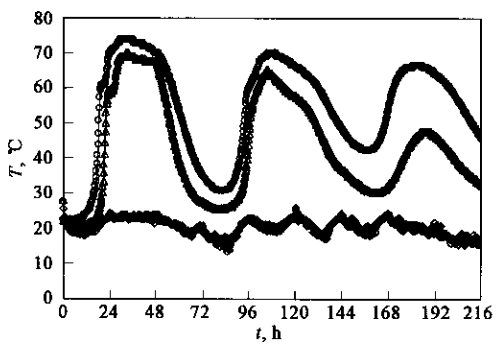


Fig.5 Temperature profiles of static pile composting
Circles, top layer; triangles, bottom layer; diamonds, ambient temperature

2.5 Conventional turning method

Temperature profile is shown in Fig.6. The temperature of the compost pile was not uniform and the temperature of the bottom layer was lower than that of the top. Complete pile mixing was conducted twice after 72 and 144 h during turning. The temperature in the bottom layer increased quickly after the first turning as high as the temperature before turning, however, increase of the temperature of the bottom layer stopped around 45℃ after the second turning. Viable populations of 1.3×10^5 cfu/g dw of *E. coli* were observed after 9 d.

2.6 Proposed turning method

Temperature profile is shown in Fig.7. The temperature of the bottom layer was clearly lower than that of the top layer. Turning was conducted twice after 72 and 144 h, and the temperature of the bottom layer decreased more turning by turning. Considering the top layer as a highly effective layer

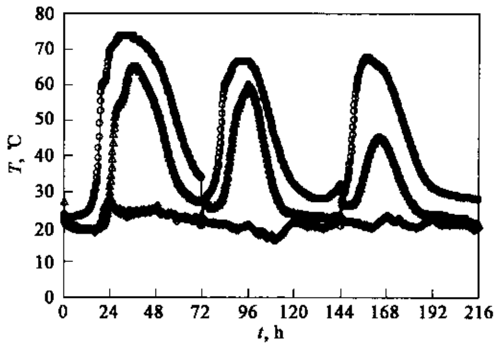


Fig.6 Temperature profiles of conventional turning composting
Circles, top layer; triangles, bottom layer; diamonds, ambient temperature

and the middle layer as an effective layer, the bottom layer was replaces by the top layer during turning and the middle layer stayed in middle after turning. No viable cells of *E. coli* was found after 9 d.

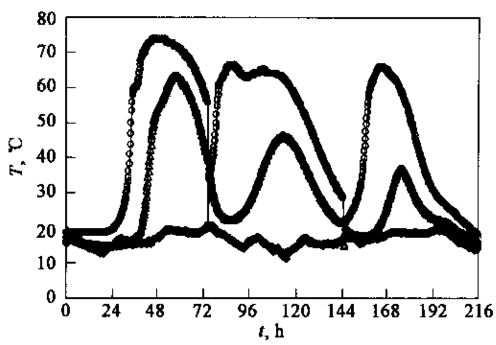


Fig.7 Temperature profiles of proposed turning composting
Circles, top layer; triangles, bottom layer; diamonds, ambient temperature

3 Discussion

Composting was operated by the three turning methods, no turning or static turning method, complete mix method or conventional turning method, and proposed turning method, and survival numbers of *E. coli* from the three methods were investigated in terms of hygienic safety. T_{65} of static pile and conventional turning methods were faster than that of proposed turning method because of high ambient temperature (> 20℃) while ambient temperature of proposed turning method was below 20℃ (17.1℃). Temperature of the compost pile operated by static pile method maintained higher comparing with the other two methods because heat loss was minimum due to no turning. However, it can be thought that survival of *E. coli* at lower temperature areas such as the bottom layer and the area along the reactor walls contributed to 5.6×10^4 cfu/g dw of *E. coli* remained after 9 d. Heat maintenance in the compost pile operated by conventional turning method was poorest among the three methods, and its survival of *E. coli* showed the highest among the three methods and was 1.3×10^5 cfu/g dw. Static pile method was operated here under the single-impact heating composting, then the result of *E. coli* survival between static pile method and conventional turning method was correspond to the result between the single-impact heating composting and intermittent heating composting described in Tateda *et al*. (Tateda, 2003). *E. coli* was not detected after 9 d in the compost pile operated by proposed turning method. After 72 h, the compost material of the top layer was mixed completely and then placed in a reactor as the bottom layer, and the material of the bottom layer was place as the top layer after complete mixing. After 144 h, the same procedure was performed. The compost material in the top later was placed in the reactor as the bottom layer and vice versa. From the result of this study, turning by layers and placing the layer under appropriate temperature condition are critical important regarding hygienic aspect.

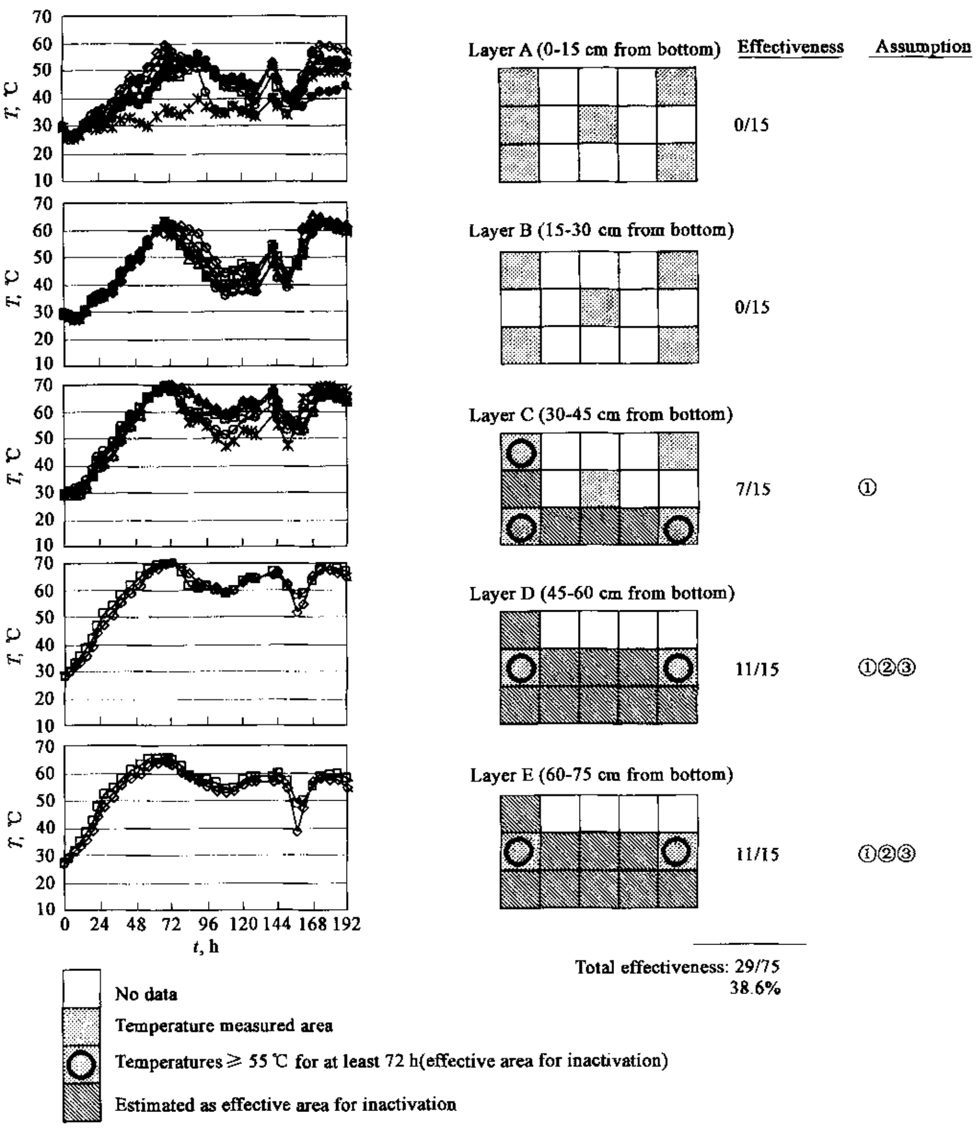
4 Conclusions

Hygienic aspect of composting is one of great concerns for using composting technology. As a conclusion, conventional turning method which mixes compost material completely throughout compost pile is not a proper method in terms of hygiene. The proposed turning method showed an excellent performance and should be employed in a composting operation.

Appendix:

The estimation of effectiveness was shown by the two typical examples. The graphs shown on the left side were temperature profiles of layers of a compost pile, and the figures of divided compost pile and its effective areas were shown on the center. On the right side, calculation of effectiveness and assumption for the calculation were described.

The operation on August 31, 2004



Layers A and B: There were no effective temperature measuring points.

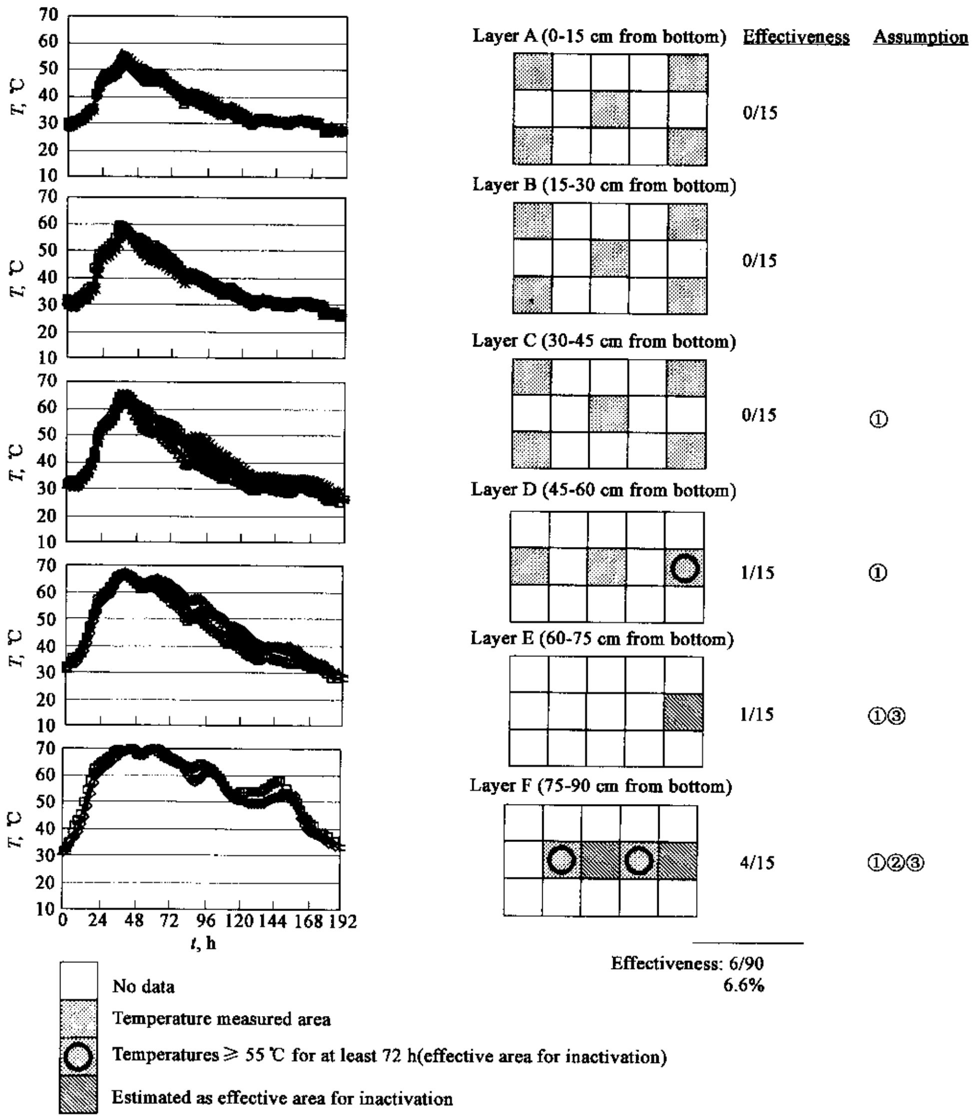
Layer C: Three temperature measuring points out five showed effectiveness and the areas sandwiched between effective temperature measuring points were estimated as effective areas(Assumption 1).

Layer D: There were two temperature-measuring points and both areas showed effectiveness. The areas sandwiched between the both areas were counted as effective areas (Assumption 1). The areas were also located inside from the measuring points, therefore, the areas were counted as effective areas(Assumption 2). The areas located upper of the effective areas of Layer C counted as effective areas (Assumption 3).

Layer E: There were two temperature-measuring points and both areas showed effectiveness. The same assumptions were applied.

The total effective areas were 29 out of 75 and effectiveness of the compost became 38.6%.

The operation on September 21, 2004



Layers A, B, and C: There was no effective temperature measuring points.

Layer D: There were three temperature measuring points and one of the three showed effectiveness.

Layer E: The area located upper of the effective areas of Layer D counted as effective area (Assumption 3).

Layer F: There were two temperature-measuring points and both areas showed effectiveness. The area sandwiched between the both areas was counted as effective areas (Assumption 1). The areas were also located inside from the measuring points, therefore, the areas were counted as effective areas (Assumption 2). The area located upper of the effective areas of Layer E counted as effective area (Assumption 3).

The total effective areas were 6 out of 90 and effectiveness of the compost became 6.6%.

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