Journal of Environmental Sciences Vol.17, No.6, pp.1004—1007, 2005

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2005)06-1004-04 **CLC number**: X713 **Document code**: A

Ambient air temperature effects on the temperature of sewage sludge composting process

HUANG Qi-fei[1,*], CHEN Tong-bin[2], GAO Ding[2], HUANG Ze-chun[2]

(1. Chinese Research Academy of Environmental Sciences, Beijing 100012, China. E-mail: huangqf@craes.org.cn; 2. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China)

Abstract: Using data obtained with a full-scale sewage sludge composting facility, this paper studied the effects of ambient air temperature on the composting temperature with varying volume ratios of sewage sludge and recycled compost to bulking agent. Two volume ratios were examined experimentally, 1:0:1 and 3:1:2. The results show that composting temperature was influenced by ambient air temperature and the influence was more significant when composting was in the temperature rising process: composting temperature changed 2.4—6.5℃ when ambient air temperature changed 13℃. On the other hand, the influence was not significant when composting was in the high-temperature and/or temperature falling process: composting temperature changed 0.75—1.3℃ when ambient air temperature changed 8—15℃. Hysteresis effect was observed in composting temperature's responses to ambient air temperature. When the ventilation capability of pile was excellent(at a volume ratio of 1:0:1), the hysteresis time was short and ranging 1.1—1.2 h. On the contrary, when the proportion of added bulking agent was low, therefore less porosity in the substrate(at a volume ratio of 3:1:2), the hysteresis time was long and ranging 1.9—3.1 h.

Keywords: sewage sludge; composting; ambient air temperature; hysteresis

Introduction

Temperature is the most important ecological factor within composting material (Finstein, 1975; Atlas, 1981). Many studies have been undertaken on composting systems focusing on the effects to temperature such as its increase and maxima during processing, limits on resident microbes, heat losses from the mass, process control and the ecological nature of the process, including microbial succession(Regan, 1971; Poincelot, 1974; Suler, 1977; Sikora, 1985; Miller, 1988; Campbell, 1990a; 1990b).

The temperature between the center and the surface of the composting mass differs greatly in static piles because of ambient airflow(Poincelot, 1974; Finstein, 1986a; 1986b). Turning of stacks or forced aeration, as in environmentally controlled composting, can control temperature effectively (Miller, 1990; Harper, 1992). Termination of such practices results in the temperature soon returning to the range of 70℃ to 80℃(Poincelot, 1974).

There are three mechanisms in the heat-exchanging process between composting pile and surroundings: conduction, convection, and radiation(Haug, 1993). Small quantity of heat in the composting pile is dispersed through radiation and conduction, and large quantity of heat is lost due to convection (Fogiel, 1999), and ambient air temperature relates to these mechanisms(Lomax, 1984; Das, 1997). The composting substrate temperature depends largely on ambient airflow(Finstein, 1986a), so the heat-exchanging process is important for composting temperature. Ambient air temperature near the freezing point can significantly influence the composting temperature (Liao, 1995). Microorganisms need sufficient oxygen to decompose substrate during initial stage(Tiquia, 1996), but when supplying oxygen through forced aeration and the ambient air temperature is too low, composting substrate temperature probably can not reach the lowest point that is necessary to start composting process (Seki, 1999). Composting process has been significantly slowed down or even stopped when composting substrate temperature is below 20℃ (Mosher, 1977; Haug, 1993). These studies show that ambient air temperature is an overriding factor for accomplishing the composting process.

The goal of this study was to investigate the effects of ambient air temperature and find out how it impacts the composting temperature of aerated static pile systems, and the magnitude of the impact.

1 Materials and methods

An outline of one of these piles along with the associated controlling systems is shown schematically in Fig.1.

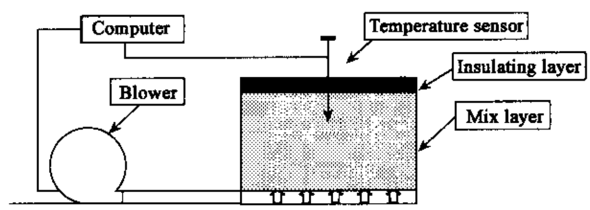

Fig.1 Schematic sketch of the composting system

Two aerated static piles were prepared in a building with two 1.6 m (length) × 1.0 m(width) bays, with cement floors and walls, and aeration boards were laid on the bottom of the bays. The piles contained sewage sludge(dry matter = 15.0%, VOC = 51%), recycled compost (dry matter = 60.9%, VOC = 38.3%) and inorganic bulking agent (moisture content = 2.7%, saturation moisture content = 65.7%) with two proportions: 3:1:2(Treatment 1) and 1:0:1(Treatment 2) by volume. A 10-cm-depth bulking agent layer on the aeration boards dispersed ambient air through the 1.5 m high mix layer. Both piles were covered with a 20 cm insulating layer of recycled compost.

Each bay had a 0.25 kW blower to supply and control ambient air. The aeration capacity of blower is 6.5 m^3/min and the wind pressure is 680 Pa. Sensors were inserted into the geometrical center of piles to detect the pile temperature, and the readings are gathered by the computerized control system. Three sensors were used in ambient air to detect the ambient air temperature. A three-stage control algorithm controlled the damper duty cycle of blowers(Leton, 1990).

Foundation item: The Hi-Tech Research and Development Program(863) of China(No. 2001AA644010); * Corresponding author

Control software logged temperatures every 15 min and generated reports.

Experiments were carried out during the autumn (Treatment 1) and spring (Treatment 2). The primary composting processes took 16 d.

2 Results and discussion

2.1 Simulation influence model of ambient air temperature on composting temperature

A complete composting process was composed of four parts: temperature increasing period, high-temperature period, temperature decreasing period and maturing period (Gray, 1971). Composting process was divided according to the temperature variation.

There is no heat exchange between composting pile and ambient air when there is no temperature difference. But usually the temperature difference exists because ambient air temperature frequently varies and this variation influences the heat exchanging process: (1) When air temperature is higher than the composting temperature, larger quantities of heat would be transferred to the composting pile through the heat exchanging process as ambient air temperature rises; (2) when air temperature is lower than the composting temperature, smaller quantity of heat would be lost from composting pile when ambient air temperature rises. Under both conditions, the composing temperature increases, but this increase is so small that it is overwhelmed by the macro trend of composting temperature and not noticeable. For the same reason, composting temperature would decrease when ambient air temperature declines. Ambient air temperature affects composting temperature within a 24 h period because its varying cycle is 24 h. Fig.2 is a hypothesis model of this influence.

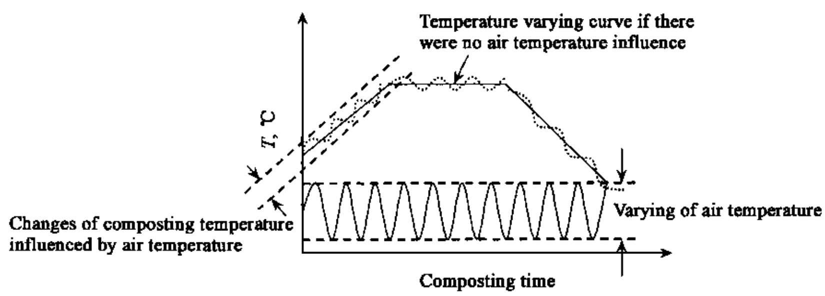

Fig.2 Hypothesis model of ambient air temperature influence

The varying curve of ambient air temperature is never an ideal sinusoidal or cosine curve because there are always other variations during the day and night time. However, the temperature daily fluctuation trend always exists and under its influence, the composting temperature also appears to have small cyclic fluctuations.

2.2 Effect of ambient air temperature on composting temperature

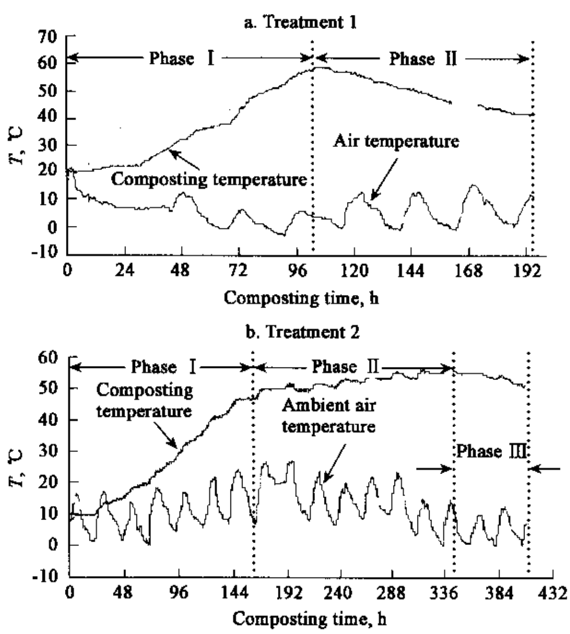

Fig.3 Temperature curve and partition of periods

Fig.3 is the composting temperature variation curve, and the composting process could be divided into several periods according to temperature developing trend. Every period was regression analyzed using linear model and the results are shown in Table 1. T and t were the representatives of pile temperature and composting time, respectively.

The results of significance test show that it fits the temperature simulation performed with a linear model. A regressed value was obtained when parameter of time was introduced into the regression equations of Table 1. Detected value subtracts the regressed value, and the residual value was the response of composting temperature to ambient air temperature (Fig.4).

Table 1 Results of regression analysis

Volume ratio	Periods of composting	Regression equations	R^{2*}	F
3:1:2	Phase Ⅰ	$T = 0.43t + 13.64$	0.97	11820^{**}
	Phase Ⅱ	$T = -0.21t + 80.91$	0.99	33851^{**}
1:0:1	Phase Ⅰ	$T = 0.22t - 5.11$	0.95	51429^{**}
	Phase Ⅱ	$T = 0.04t + 39.92$	0.88	14439^{**}
	Phase Ⅲ	$T = -0.07t + 83.66$	0.82	3243^{**}

Notes: * Correlation coefficient; ** $p < 0.01$

The ascending or descending trend of composting temperature variation curve was homologous with ambient air temperature variation in rough as shown in Fig. 4. The phenomenon proved that ambient air temperature clearly impacts the pile temperature.

Fig. 3a shows that ambient air temperature changed greatly when composting process was in the temperature increasing process. Not only was there periodical variation

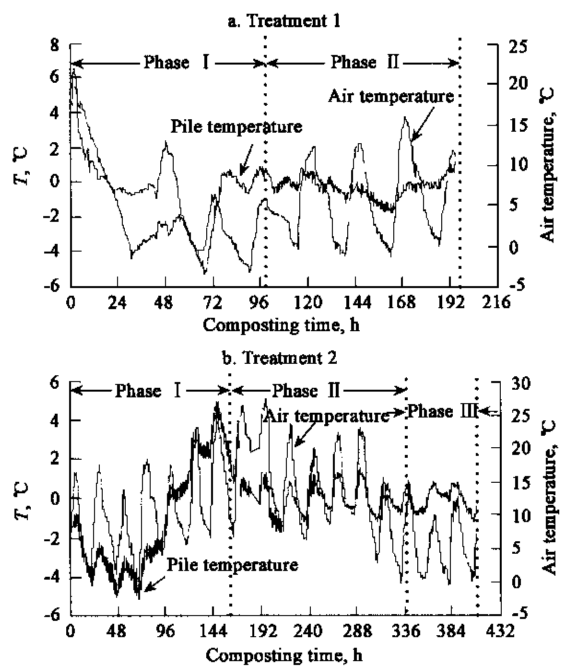

Fig.4 Influence of ambient air temperature on composting temperature

between day and night, but also the big daily change due to a climate temperature falling period, the influence of ambient air temperature on pile temperature is very significant (Fig. 4a). According to the variation degree of ambient air temperature in phase I, the period could be divided into 2 periods: ambient air temperature changed 13℃ during 0—72 h when pile temperature would change 6.5℃; during 72—103.5 h (Fig.3a), pile temperature would change 1.2℃ responding to 8℃ variation of ambient air temperature.

The influence was more obvious during initial stage of composting process, which may be induced by influencing mechanism of ambient air temperature and microorganism activities.

The insulation characteristics (preserving heat) of the experimental aerobic static pile are excellent, but the composting pile was not completely enclosed. There was temperature difference between pile and ambient, and pile would exchange heat with ambient air with three modes: conduction, convection, and radiation. On the other hand, oxygen needed during composting was applied by ambient air, and ambient air temperature would influence pile temperature when applying oxygen.

Many studies showed that, the best temperature range is 30—40℃ for mesophilic microorganism to proliferate, and thermophilic microorganism proliferated rapidly in 50—60℃.

Microorganism was cultivated and domesticated in the initial stage of composting process, so heat is not yet produced in large amount. Ambient air temperature not only influences pile temperature with 3 physical modes directly, it also impacts the microorganism activity evidently. And with pile temperature increasing from 20℃ to 40℃ during 0—72 h (Fig. 3a), it falls in the best temperature range for the proliferation of mesophilic microorganisms. These two factors appear to explain the significant impact from the ambient air temperature fluctuation.

Pile temperature changed from 40 to 60℃ during 70—103.5 h (Fig. 3a), which was comfortable to thermophilic microorganism. Pile temperature would change about 1.2℃ when ambient air temperature varied 8℃. The result indicated that the influence of ambient air temperature was not significant when pile is in higher temperature. The influence of ambient air temperature on microorganism activity appears to be muffled by the pile's self-generated heat when pile temperature is high.

As shown in Fig.3a, when composting process goes into the temperature decreasing period (103.5—195 h), and the daily fluctuation of ambient air temperature is for about 14℃ between day and night, the pile temperature varies about 0.75℃.

The maximum point of producing heat had passed and mesophilic microorganism activities started to dominate again when pile temperature decreased gradually; however, since easily degradable organic material has almost been exhausted at this point, main part of the microorganisms during this period are those capable of decomposing complicated organic materials. Pile temperature kept above 40℃ at the moment (Fig.3a), and the influence of ambient air temperature on microorganism is small. Actually, the influence of ambient air temperature on pile temperature is decided mainly by the insulation property of pile (Finstein, 1986a; 1986b).

Pile temperature changes only after ambient air temperature varied for some time, indicating that there was a hysteresis in pile temperature's response to ambient air temperature (Fig. 3a). The hysteresis time were 1.9, 3.1 and 2.9 h respectively during 3 period: 0—72 h, 72—103.5 h and 103.5—195 h. The hysteresis time was the shortest during initial stage of composting, which shows that the "cushion" capacity of pile temperature was the weakest during initial stages. As explained above, the interactions between the ambient air temperature and the microorganism activities appear to be the reason for this.

For the treatment 2, there is noticeable influence of ambient air temperature on the pile temperature during the first period (0—165 h): pile temperature changed 2.4℃ when ambient air temperature changed 13℃ (Fig.4b).

Although pile temperature continues to rise during the second period (165—340 h), the speed was slow ($k = 0.04$, Table 1). Pile temperature would change 1.3℃ when ambient air temperature changed 15℃.

The influence of ambient air temperature was the smallest during the third period (340—407 h) when pile temperature descended, which would change 12℃ and pile temperature changed 1.0℃.

Ambient air temperature would influence pile temperature notably during initial stage, but the influence is very small during high-temperature period and the temperature decreasing period, which was similar to the phenomenon of treatment 1. Compared with the influence of treatment 1, the influence to treatment 2 is even smaller. Substrate moisture content of treatment 2 was higher than that of treatment 1, so the "buffering" effect is greater because the specific heat of water was large. On the other hand, the daily difference of ambient air temperature was small during initial stage (Fig. 3b), so the influence of ambient air temperature is not easily noticeable as that of treatment 1.

The hysteresis times were 1.2, 1.1 and 1.2 h respectively during 3 period, which were shorter than that of treatment 1. The ventilation characteristic of pile is better because the porosity of substrate was more when more bulking agent was added, which maybe the main reason for the higher sensitivity of the response of pile temperature.

3 Conclusions

This paper experimentally studied and explained the interactions among ambient air temperature, microorganism activities and pile material as dominant factors in a composting process. It has been found that the ambient air temperature impacts the composting temperature but the magnitude of such impact varies at different stages of composting. The impact is significant when the composting process is in the temperature increasing stage. Our experiment showed a composting temperature change of 2.4—6.5℃ for an ambient air temperature variation of 13℃. The magnitude of impact is smaller when composting process is in the high-temperature or temperature descending stage. It is observed that the composting temperature changes for only 0.75—1.3℃ while the ambient air temperature changes for 8—15℃.

There is a hysteresis in composting temperature's responses to ambient air temperature. When the volume ratio is 1:0:1 and the ventilation is excellent, the hysteresis time is shorter and about 1.1—1.2 h. While when the proportion of added bulking agent is low for a pile of volume ratio 3:1:2, the hysteresis time is longer and about 1.9—2.1 h.

Acknowledgement: The authors thank Dr. Qiuyang Wu and Dr. Peter Ringele for their assistance with analytical approaches, documentation, and manuscript reviews.

References:

Atlas R M, Bartha R, 1981. Microbial ecology: fundamentals and applications [M]. Massachusetts, USA: Addiso-Wesley Publishing.

Campbell C D, Darbyshire J F, 1990a. The composting of tree bark in small reactors self-heating experiments[J]. Biological Wastes, 31: 145—161.

Campbell C D, Darbyshire J F, 1990b. The composting of tree-bark in small reactors adiabatic and fixed temperature experiments[J]. Biological Wastes, 31: 175—185.

Das K, Keener H M, 1997. Numerical model for the dynamic simulation of a large scale composting system[J]. Trans-ASAE, 40(4): 1179—1189.

Finstein M S, Miller F C, Strom P F, 1986a. Monitoring and evaluating composting process performance[J]. Journal of the Water Pollution Control Federation, 58: 272—278.

Finstein M S, Miller F C, Strom P F, 1986b. Waste treatment composting as a controlled system[J]. Biotechnology, 8: 396—443.

Finstein M S, Morris M L, 1975. Microbiology of municipality solid waste composting[J]. Advances in Applied Microbiology, 19: 113—151.

Fogiel A C, Bernuth R D, Michel F C *et al.*, 1999. Experimental verification of the natural convective transfer of ambient air through an ambient airy manure compost media [C]. ASAE-CSAE-SCGR Annual International Meeting, Toronto, Ontario, Canada, 18—21 July, 1999. ASAE Paper, No. 99-4053.

Gray K R, Sherman K, Biddlestone A J, 1971. A review of composting[J]. Soil Assoc J, 17(1): 33—47.

Harper E, Miller F C, Macauley B J, 1992. Physical management and interpretation of an environmentally controlled composting ecosystem[J]. Australian Journal of Experimental Agriculture, 32: 657—667.

Haug R T, 1993. The practical handbook of compost engineering[M]. Florida USA: Lewis Publishers, Boca Raton.

Leton T G, Stentiford E I, 1990. Control of aeration in static pile composing[J]. Waste Management and Research, 8: 299—306.

Liao P H, Vizcarra A T, Chen A *et al.*, 1995. A comparison of different bulking agents for the composting of fish offal[J]. Compost Science and Utilization, 3(2): 80—86.

Lomax K M, Collins N E, Denneny C M, 1984. Simulating mushroom compost heat production[J]. Biocycle, 25(3): 38—40.

Miller F C, Harper E R, Macauley B J, 1990. Composting based on moderately thermophilic and aerobic conditions for the production of commercial mushroom growing compost [J]. Australian Journal of Experimental Agriculture, 30: 289—296.

Miller F C, 1988. Temperature in mushroom compost[J]. Biocycle, 30(1): 42—47.

Mosher D, Anderson R K, 1997. Composting sewage sludge by high-rate suction aeration techniques—the process as conducted at Bangor, ME, and some guides of general applicability[Z]. United States of America Government Printing Office, Washington, District of Columbia.

Poincelot R P, 1974. A scientific examination of the principles and practice of composting[J]. Compost Science, 16: 24—31.

Regan R W, Jeris J S, 1971. A review of the decomposition of cellulose and refuse[J]. Compost Science, 11: 17—20.

Seki H, 1999. Analysis of optimum control problem for composting process based on the variational principle[J]. Environment Control in Biology, 37: 13—19.

Sikora L J, Sowers M A. 1985. Effect of temperature control on the composting process[J]. Journal of Environmental Quality, 14: 434—439.

Suler K J, Finstein M S. 1977. Effect of temperature, aeration and moisture on carbon dioxide formation in bench-scale, continuous thermophilic composting of solid waste[J]. Applied and Environmental Microbiology, 33: 345—350.

Tiquia S M, Tam N F, Hodgkiss I J, 1996. Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents [J]. Bioresour Technol, 55(3): 201—206.

(Received for review March 4, 2005. Accepted June 10, 2005)