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Characteristics of municipal solid waste and sewage sludge co-composting

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A R T I C L E I N F O

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A B S T R A C T

The purpose of this work is to study the characteristics of the co-composting of municipal solid waste (MSW) and sewage sludge (SS). Four main influencing factors (aeration pattern, proportion of MSW and SS, aeration rate and mature compost (MC) recycling) were systematically investigated through changes of temperature, oxygen consumption rate, organic matters, moisture content, carbon, nitrogen, carbon-to-nitrogen ratio, nitrogen loss, sulphur and hydrogen. We found that a continuous aeration pattern during composting was superior to an intermittent aeration pattern, since the latter delayed the composting process. A 3:1 (v:v) mixture of MSW and SS was most beneficial to composting. It maintained the highest temperature for the longest duration and achieved the fastest organic matter degradation and highest N content in the final composting product. A 0.5 L/min kgVS aeration rate best ensured rapid initiation and maintained moderate moisture content for microorganisms. After the mature MC was recycled to the fresh materials as a bulking agent, the structure and moisture of the initial materials were improved. A higher proportion of MC resulted in quicker decrease of the temperature, oxygen consumption rate and moisture. Therefore a 3:1:1 (v:v:v) proportion of MSW: SS: MC is recommended.

1. Introduction

Due to rapid increases in urban population, municipal solid waste (MSW) and sewage sludge (SS) have increased dramatically in the past 20 years. Environmental pollution caused by MSW and SS has become a serious social problem which hinders urban development, especially for large cities in developing countries, such as Shanghai. It is critical that we find ways to effectively reuse such wastes and reduce their impact on the environment.

The organic content of waste is generally higher in developing countries; therefore, composting is an appropriate alternative for waste management (Kanat et al., 2006). On average, over 50% of MSW in a developing country can be readily composted (Hoornweg et al., 1999). Composting not only helps to solve the problem of waste disposal, but also produces a useful bioamendment agent (compost) (Banegas et al., 2007). MSW usually has the characteristics of an incompact structure and a relatively high carbon-to-nitrogen ratio (C/N), whereas SS usually has the characteristics of a dense structure due to its high moisture content and low C/N. Therefore, SS requires a larger amount of bulking agent (such as sawdust, vegetal remains, or straw) to absorb moisture, provide the composting mass with an appropriate degree of sponginess and aeration, and increase the C/N (Chen et al., 1996; Marek et al., 2003; Banegas et al., 2007; Guardia et al., 2008). MSW could act as a bulking agent for sludge due to its loose structure and relative high C/N. Mixing MSW and SS can thus improve the structure and C/N of sewage, increase the nitrogen content of MSW for the compost product, and meet the goal of fast sanitization and stabilization.

Composting is a popular way to treat organic solid waste (Bari and Koenig, 2001), but there are many factors that affect the composting process, such as the proportions of the mixture, the aeration rate, oxygen consumption rates, compost recycling, moisture content, pH and C/N, and so on (Golueke and Diaz, 1996; Smith and Hughes, 2004; Meunchang et al., 2005). For different materials, the composting parameters are different. For example, Banegas et al. (2007) studied the composting of sludge with sawdust as the bulking agent and found that a 1:1 proportion was most suitable for aerobic sludge. Meunchang et al. (2005) conducted composting experiments with a 2:1 ratio of filter cake and bagasse to reduce the C:N ratio in order to reduce N loss during composting. An optimal composting mixture of 50% food waste, 40% manure, and 10% bulking agent was found in a previous in-vessel composting study by Cekmecelioglu et al. (2005). Marek et al. (2003) suggested that only a small part of the SS could be utilized for composting because of limitations on the volumetric ratio between other organic wastes and SS, given the required properties of the raw mixture (moisture, porosity and the ratio C/N).

Kulcu and Yaldiz (2004) found that the highest organic matter degradation and temperature values were obtained at an aeration rate of 0.4 L air $min^{-1} kg_{om}^{-1}$ in a study of the composting of agricul-

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tural wastes. In a study of the composting of dairy manure with rice straw, Li et al. (2008) reported that an aeration rate of 0.25 L/min kg VS was capable of achieving the highest composting temperature.

Despite many previous studies on MSW or SS composting, information on the characteristics of the co-composting of MSW and SS is not available. The purpose of this study is to investigate the effects of aeration pattern, the proportion of MSW and SS, aeration rate, and mature compost (MC) recycling on the characteristics of the co-composting of MSW and SS, through changes in temperature, oxygen consumption, organic matter, moisture content, carbon (C), nitrogen (N), C/N, and N loss. This study may provide a guide for application on an industrial scale.

2. Materials and methods

2.1. Composting materials

MSW and SS from an urban waste solid composting plant and an urban wastewater treatment plant in Shanghai were used in this study. The MSW contained many oversized materials (diameter > 100 mm), such as plastic bags and clothing, due to the limits of economic conditions and source separation; these would affect aeration and retard composting periods. In addition, the moisture content of the waste could be as high as 80% during the rainy season. The raw MSW with large-sized materials and high moisture content was first deposited for 20 days to remove excessive water, in order to aid in the subsequent separation. The wastes were then screened through a rotary drum sieve to retain contents sized smaller than 60 mm. After these pretreatments, the MSW was uniform and its structure was incompact. SS was taken from the sludge dewatering workroom in the municipal wastewater treatment plant. The main characteristics of MSW and SS are shown in Table 1.

2.2. Composting methods

Homogenization of the mixture is critical for aeration, but the structure of dewatered SS is viscous and not easy to spread. If the ratio of SS is high, the mixture will not mix uniformly. Therefore, the ratio of MSW and SS was chosen to achieve optimal homogenization and an incompact structure. The MSW was mixed with SS at three different ratios (9:1, 5:1, and 3:1, MSW:SS, v:v) during the experiments. The mixtures then underwent the process of aerobic composting. Additional composting experiments were conducted with mixtures of MSW, SS and MC.

A positively pressurized aeration system was used in the experiments. Approximately 150 kg of the materials were composted in columnar vessels 60 cm in diameter and 80 cm in depth. A perforated plastic plate was installed in the reactor, elevated 0.10 m from the bottom, for ventilation and to support the composting materials. A perforated plastic pipe was laid under the perforated plastic plate to supply air. Glass thermometers were mounted 0.3 m below the surface of the materials for temperature monitoring. Additionally, rubber pipes (5 mm in diameter) were placed at the same position to measure the oxygen concentration in the interstitial air of the pile.

The composting experiments included four groups (Table 2), with each experiment lasting 28 days. The mixture of MSW and SS was composted in the first three experiments; in Experiment 4, the MC (a 3:1 mixture of MSW and SS after 28 days of composting) was recycled into the raw 3:1 mixture of MSW and SS to shorten the start-up time and accelerate the composting process.

In Experiment 1, continuous aeration (CA) and intermittent aeration (IA) were compared to investigate the effect of aeration manner on the composting of a 9:1 mixture of MSW:SS under a 0.5 L/min kg VS aeration rate. In Experiment 2, three ratios of MSW and SS (9:1, 5:1 and 3:1, v:v) were tested to find appropriate proportions of the mixture under continuous aeration at 0.5 L/min kg VS. In Experiment 3, three aeration rates (0.2, 0.5 and 0.8 L/min kg VS) were applied to study the influence of the aeration rate on the composting process of a 3:1 mixture of MSW:SS under continuous aeration. In Experiment 4, different ratios of MC (MSW:SS:MC, 3:1:1, 3:1:2, 3:1:3, v:v:v) were used to investigate the optimum recycling ratio for the composting process under continuous aeration.

Each treatment was repeated three times.

2.3. Sampling and analyses

Samples were taken every 3 days. Each sample consisted of eight subsamples taken from different locations in the pile (Banegas et al., 2007). One portion of each sample was air-dried and crushed into powder using a high speed muller, then sieved through a 2 mm sieve and stored for elemental analysis. Another portion was used for the NH_4^+-N and pH analysis, and the rest of the sample was used for the analysis of moisture content and organic matter content.

The oxygen consumption was determined by measuring changes in oxygen concentration (vol.%) over time in the interstitial air of the pile two times per day. An oxygen meter (CYS-1, Shanghai, China) was used to measure the oxygen concentration. The maximum oxygen concentration C_0 (O_2, %) was first measured under aeration. The air blower was then turned off and the oxygen concentration C_t (O_2, %) was measured every 4 min until it dropped below 5%. The maximum oxygen consumption rate (rO_2, %/min) was obtained by calculating the negative slope of the linear portion of the C_0 and C_t curves.

The compost temperature and ambient temperature were monitored using glass thermometers twice a day until the termination of the composting trial. Bulk density was measured according to

Table 1
Characteristics of the composted materials

Parameter	Municipal solid waste	Sewage sludge
Organic matter (%)	49.1 ± 0.5	45.5 ± 0.6
Moisture content (%)	61.2 ± 1.2	77.8 ± 2.4
pH	6.28 ± 0.12	6.68 ± 0.08
Organic carbon (g kg^{-1})	296.6 ± 3.3	264.8 ± 3.5
Total nitrogen (g kg^{-1})	12.33 ± 0.41	25.05 ± 0.23
Ratio of carbon and nitrogen (C/N)	25 ± 1	10 ± 1
NH_4^+-N (g kg^{-1})	11.41 ± 0.61	3.162 ± 0.145
P(g kg^{-1})	4.941 ± 0.526	10.25 ± 0.35
K(g kg^{-1})	29.44 ± 2.87	3.849 ± 0.231

Note: the reported values are mean±STDEV of the three repeats.

Table 2
Designs of the composting experiments

	MSW:SS :MC (v: v: v)	Aeration pattern	Aeration rate (L/min kg VS)
Experiment 1	9 : 1 : 0	Continuous	0.5
	9 : 1 : 0	Intermittent[a]	0.5
	9 : 1 : 0	Continuous	0.5
Experiment 2	5 : 1 : 0	Continuous	0.5
	3 : 1 : 0	Continuous	0.5
	3 : 1 : 0	Continuous	0.2
Experiment 3	3 : 1 : 0	Continuous	0.5
	3 : 1 : 0	Continuous	0.8
	3 : 1 : 1	Continuous	0.5
Experiment 4	3 : 1 : 2	Continuous	0.5
	3 : 1 : 3	Continuous	0.5

[a] Intermittent aeration mode 2 h aeration and 1 h pause.