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Original Research Paper

Effect of a New Bulking Agent on Sewage Sludge Composting

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ABSTRACT

To improve bulking agent (BA) reusability and reduce bulking agent costs, a new bulking agent was developed using straw and methylene diphenyl diisocyanate. The objective of this study was to investigate the effect of the new bulking agent on sewage sludge composting. The results showed that the new bulking agent has high recovery ratio when used in sewage sludge composting, and can improve the composting process. Decreasing the mass ratio of sewage sludge to bulking agent from 3:1 to 2.5:1 in compost pile improved the rate of temperature increase, increased the maximum temperature, shortened the thermophilic stage of the composting process, and achieved an even temperature distribution during the initial heating phase. The recovery ratios for the bulking agent with mass ratios of 3:1 and 2.5:1 were 94.7% and 92.2%, respectively. The recovery and reuse of this new bulking agent could significantly reduce the cost of bulking agents in the composting of sewage sludge, and the appropriate mass ratio of sewage sludge to bulking agent is 2.5:1.

INTRODUCTION

Owing to the rapid increase in urban population and advances in sewage treatment, the volume of sewage sludge produced worldwide has increased dramatically in the past 20 years. By 2010, China had more than 2800 municipal sewage treatment plants, producing about 30 million tons of wet sewage sludge (moisture content 80%) per year (Ma et al. 2012). Composting is a major method of sewage sludge treatment (Zhou et al. 2013), which a biological process that reduces the volume and mass of sewage sludge, while producing a safe, stable and nutrient rich soil amendment (Haug 1993, Mato et al. 1994), but sewage sludge cannot be composted alone due to its high moisture content and poor air permeability. Bulking agent (BA) can adjust moisture content (MC) and free air space (FAS) of composting materials (Mason et al. 2004), provide the optimal FAS and regulates the water content of the sewage sludge being composted (Iqbal et al. 2010). Of the factors which influence composting, the selection of an appropriate BA plays an essential role in improving composting efficiency.

Numerous researchers have reported the effectiveness of adding a BA to improve the composting process (Larsen & McCartney 2000, Rynk et al. 2000). Traditional BAs are agricultural wastes, including sawdust, wheat straw, rice husks, wood chips, rice bran, chopped hay and peanut shells (Kim et al. 2008, Gea et al. 2007, Adhikari et al. 2009, Iqbal et al. 2010), but traditional BAs have some drawbacks, such as weak resistance to compaction, easily damaged and lost during composting (Blanco & almendros 1995), purchase and handling (transportation and storage) of BAs is costly (Gupta & Garg 2008). So, a new BA was developed using straw and methylene diphenyl diisocyanate (MDI), which has high water absorption ability, high compression strength, no inhibitory effect on microbial activity and can be recycled (Ma et al. 2012). This study was to: (i) determine the effect of the new BA in sewage sludge composting, and the optimal BA to sewage sludge ratio; and (ii) test the degradation rate, break down ratio and cost during compost of the new BA.

MATERIALS AND METHODS

Sewage sludge and new bulking agent: Dewatered sewage sludge was collected from the Qinghe Wastewater Treatment Plant, Beijing. Wheat straw was acquired from farmland near Beijing. The new BA was formed into a cube (2 × 2 × 1.8 cm) with a bulk density of 721.39 kg/m^3. Sewage sludge and the new BA were mixed together at two different weight ratios, 2.5:1 (T1) and 3:1 (T2), and then placed into two identical composting bioreactors (Zhou et al. 2013.). The height of the two compost matrix was 750 mm, and the volume of the compost mixture was 0.21m^3.

The bioreactor was maintained in an aerobic condition using an air pump that was controlled by computer. The aeration parameters were adjusted for the different composting stages based on temperature (T). During the increasing temperature phase ($T < 60°C$), the aeration cycle was 15 min (aerated for 2 min and unaerated for 13 min). During the early thermophilic phase ($T > 60°C$, $RO_2 > 6×103\ \varepsilon L\ L^{-1}$

min^{-1}), the 15 min cycle involved aeration for 3 min and 12 min unaerated, while during the late thermophilic phase (T > 60°C), the 15 min cycle was aerated for 5 min and unaerated for 10 min.

Sample analysis: The initial composting materials were analyzed to determine the following parameters: moisture content (105°C for 24h), volatile solids (550°C for 6h) (APHA 1995); and FAS (Barrington et al. 2002, Iqbal et al. 2010). Each parameter was determined as the mean of three replicates.

FAS: The FAS was determined from the bulk density and the wet particle density. The wet particle density was determined by placing 5g material in a graduated cylinder and submerged it in kerosene. The particle density was calculated after confirming the density of kerosene (0.79 kg/m^3) and determining the mass of kerosene added (Barrington et al. 2002). This wet particle density was used to calculate the FAS using the equation below (Iqbal et al. 2010).

$$FAS(\%) = 100 \times (1 - \frac{BD}{PD})$$

Where FAS is the free air space (%), BD is the bulk density (kg/m^3) and PD is the wet particle density (kg/m^3).

The breakdown ratio of the BA: The breakdown ratio of the BA was measured gravimetrically. After composting, the BA was screened out of the compost mixture using a sieve, and weighed. The moisture was measured, and the dry weight was calculated. The breakdown ratio was calculated by the following formula:

$$BR = \frac{A-R}{(1-C)\cdot A}, \quad C = \frac{(D-F)}{D}$$

Where BR is the breakdown ratio of the BA, A is the original dry weight of the BA, R is the dry weight of the recovered BA, C is the degradation rate of the BA during composting, D is the average mass of the BA before composting, and F is the average mass of the recycled BA.

RESULTS AND DISCUSSION

Changes in physical and chemical characteristics of the mixture before and after composting: The FAS is an important factor in determining the quantity and movement of air through the composting matrix, and ideally, the FAS should be higher than 30% (Haug 1993). Table 2 gives the physical and chemical characteristics of the T1 and T2 mixtures before and after composting. Mixtures at both ratios can improve the structure of the compost piles, so that the initial FAS was 37.88% and 47.32%, in T1 and T2, respectively.

The composting process in T1 and T2 lasted 16 and 21 days, respectively. After composting, the volume and mass of the composted material within the reactors has decreased significantly. This decrease was mainly due to the decrease in the moisture and organic matter contents of the composting mixture. After composting, the total volume of the mixture in T1 reduced from 0.21m^3 to 0.17m^3, a reduction of 19.1%, while for T2, the total volume reduced from 0.21m^3 to 0.16m^3, a reduction of 23.2%. Concurrently, the total mass of T1 reduced from 136.1 kg to 100.7 kg, a reduction of 26.5%; while the moisture content reduced from 61.56% to 54.02%, a reduction of 12.1%; and the VS of the sewage sludge reduced from 76.77% to 58.78%. For T2, the total mass reduced from 156.6 kg to 109.4 kg, a reduction of 30.1%; while the moisture content reduced from 64.15% to 57.04%, a reduction of 11.0%; and the VS of the sewage sludge reduced from 76.77% to 63.67%.

Temperature changes during composting: Composting is a self-heating process, and temperature is one of the most important indicators of the efficiency of the composting process (Imbeah 1998) and its influence on the activity and di-

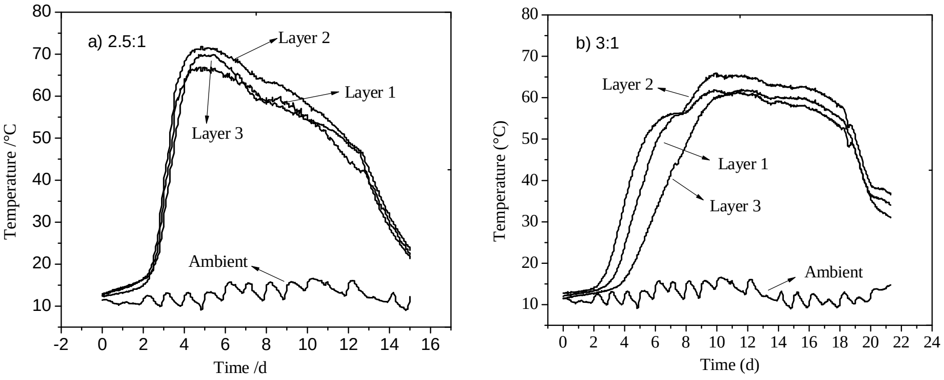

Fig. 1: Temperature changes during composting process.

Table 1: Physicochemical characteristics of the composted materials.

Treatment	Material	Mass (kg)	Volume (m^3)	BD (kg m^{-3})	FAS (%)	MC (%)	VS (%)
T1	Sewage sludge	97.2	-	1010.20	-	83.32	76.77
	Bulking agent	38.8	-	721. 39	-	7.16	-
	Mixture	136.1	0.21	627.19	47.32	61.56	76.77
T2	Sewage sludge	118.6	-	1010.20	-	83.32	76.77
	Bulking agent	39.1	-	721. 39	-	7.16	-
	Mixture	156.6	0.21	730.89	37.88	64.15	76.77

Table 2: Physicochemical characteristics of the T1 and T2 mixtures before and after composting.

Treatment	Material	Mass (kg)	Volume (m^3)	BD (kg m^{-3})	FAS (%)	MC (%)	VS (%)
T1	Mixture	136.1	0.21	627.19	47.32	61.56	76.77
	Compost	100.7	-	-	-	54.02	58.78
T2	Mixture	156.6	0.21	730.89	37.88	64.15	76.77
	Compost	109.4	-	-	-	57.04	63.67

versity of microorganisms (Finstein et al. 1986). The composting process in T1 and T2 lasted 16 and 21days, respectively, with daily ambient temperatures varying from 7°C to 15°C (Fig. 1). The initial temperature of the matrix was 10°C, which is not very suitable for microbial activity during the composting process. All trials experienced temperature changes specific to three distinct phases: a mesophilic phase, a thermophilic phase and a cooling phase (Fig. 1).

The variation in sewage sludge to BA mass ratios led to different temperature profiles of the different mixtures. The temperature in T1 increased slowly during the first 2 days of composting (Fig. 1a). The temperature in all three layers began a fast upward trend after the first 2.1, 2.0 and 2.0 days, with heating rates of 21.5, 22.7 and 21.1°C/day, respectively. The peak temperature values of 69.9, 71.8 and 66.7°C from the first to third layers were reached after 4.5, 4.5 and 4.6 days, respectively. The times that the temperature remained above 55°C from layers 1 to 3 were 8.6, 9.0 and 7.5 days, respectively.

For trial T2, the temperature increased slowly during the first few days (Fig. 1b), and increasing temperature phase took longer to start for T2 compared with T1. The rapid temperature increasing phase in layers 1-3 began after 2.8, 2.2 and 4.0 days, and the heating rates were 7.8, 7.7 and 6.2°C/day, respectively. The peak temperature values of 61.5, 67.5 and 58.6°C in layers 1-3 occurred after 8.8, 9.0, and 11.0 days, respectively. The temperature remained above 55°C in layers 1-3 for 12.1, 13.0 and 9.7 days, respectively. Rule 503 specified by the US Environmental Protection Agency states that for aerated static pile composting, the temperature should remain above 55°C for more than 3 days to meet the hazard minimization criteria. All trials meet the sanitation criteria specified in this rule.

The results showed that decreasing the mass ratios of BA to sewage sludge in the compost pile improved the rate of temperature increase, increased the maximum temperature, reduced the thermophilic temperature stage and composting cycles, and achieved an even temperature distribution during the initial heating phase.

Bulking agent recovery ratio and cost: After composting, some of the BA was degraded by microorganisms, and some of the BA was broken down owing to mixing, compaction and screening. These loses will affect the recovery ratio of the BA. After composting, the average mass of each piece of BA from the T1 trial (dry weight) was reduced from 4.82 g to 4.69 g, while the average mass of each piece of BA from the T2 trial was reduced from 4.82 g to 4.68 g, equating to degradation rates for T1 and T2 of 2.72% and 2.91%, respectively. The total mass of the BA (dry weight) added to T1 was reduced from 36.05 kg to 34.20 kg (a loss of 5.26%), and in T2 reduced from 36.23 kg to 33.50 kg (a loss of 7.76%). Consequently, the recovery ratios for two treatments were 94.7% and 92.2%, respectively.

A basic cost estimate was conducted (Table 3), and the total costs of the new BA were separated into three groups: the purchase costs of wheat straw and binder (MDI), and production costs. Based on local prices in China, the total cost of production of the new BA is 1360 RMB/t, of which the costs of purchasing straw and binder (MDI) were 360 RMB and 800 RMB, respectively, and the cost of manufacture was 200 RMB. The handling costs for the new BA in T1 and T2 were 28.6 RMB and 34.8 RMB, respectively, per ton. In comparison, if composting occurred using the same mass ratios with straw as the BA, its recovery ratio was assumed to be 50%, owing to the difficulty isolating it from the sludge, so the handling costs per ton for straw at the same ratios were calculated as 71.9 RMB and 59.3 RMB, respectively.

Thus, when compared with traditional BA (straw), the new BA was able to be recovered and reused for subsequent composting trials, thereby reducing the cost of BA significantly.

CONCLUTIONS

This work evaluates the effect of using different mass ratios (sewage sludge to BA) during sewage sludge composting. Decreasing the mass ratio of BA to sewage sludge from 3:1 to 2.5:1 in the mixture improved the rate of temperature increase, increased the maximum temperature and reduced the length of the thermophilic temperature stage and the composting time. After composting, the degradation rate of the new BA was between 2.72 and 2.91%, and its recovery ratios were 92.2% to 94.7%. The new BA also significantly reduced the cost associated with BAs during sewage sludge composting. Considering both composting efficiency and cost, a ratio of sewage sludge to BA mass of 2.5:1 should be used during composting.

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