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Influence of aeration on volatile sulfur compounds (VSCs) and NH_3 emissions during aerobic composting of kitchen waste

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ABSTRACT

This study investigates the influence of aeration on volatile sulfur compounds (VSCs) and ammonia (NH_3) emissions during kitchen waste composting. Aerobic composting of kitchen waste and cornstalks was conducted at a ratio of 85:15 (wet weight basis) in 60 L reactors for 30 days. The gas emissions were analyzed with force aeration at rates of 0.1 (A1), 0.2 (A2) and 0.3 (A3) L (kg DM min)$^{-1}$, respectively. Results showed that VSCs emission at the low aeration rate (A1) was more significant than that at other two rates (i.e., A2 and A3 treatment), where no considerable emission difference was observed. On the other hand, NH_3 emission reduced as the aeration rate decreased. It is noteworthy that the aeration rate did not significantly affect the compost quality. These results suggest that the aeration rate of 0.2 L (kg DM min)$^{-1}$ may be applied to control VSCs and NH_3 emissions during kitchen waste composting.

1. Introduction

With gradual changes in the structure of energy consumption and improvements of living standards in China, the proportion of kitchen waste to municipal solid waste (MSW), is increasing distinctly (Xu et al., 2011). There were 490 million tones of MSW generated in China in 2014, and more than 40% was kitchen waste (Sheng, 2015; Dong and Qu, 2001). In some areas, kitchen waste accounts for more than 60% due to the high percentage of fruit, vegetable, and food waste (Lin et al., 2011; Wang and Nie, 2001; Wang, 2009). Kitchen waste contains a high proportion of biodegradable organic compounds, and can therefore serve as a renewable resource in MSW. Owing to the characteristics of high moisture content, high content of organic components and salt, and low calorific value (Li et al., 2009; Zhao et al., 2009), it is sustainable to handle kitchen waste as organic waste.

Composting is a biological process that can reduce the volume and mass of kitchen waste. Over the last decades, composting has been widely used for converting organic wastes into relatively stable products for use as fertilizer or for soil amendment (Lin et al., 2008; Nair and Okamitsu, 2010). However, the imbalanced nutrients, such as carbon and nitrogen, high moisture content, and compact structure may discharge by-products, such as malodor and leachate, which can cause secondary environmental pollution, especially in countries with high population density. These factors limit the usage of kitchen waste as mono-substrate in the composting process (Pagans et al., 2006; Domingo and Nadal, 2009).

Odor pollution caused by volatile trace compounds, such as volatile sulfur compounds (VSCs) released from kitchen waste, is a critical public concern, although the potential negative effects of these odors on human health remains debatable (Capelli et al., 2011; Li et al., 2013). Zhang et al. (2012) reported that 43 gaseous compounds were detected during kitchen waste composting, including 6 VSCs, 22 hydrocarbons, 11 aromatic hydrocarbons, and 5 other odorous substances. In their study, the odor intensity was significantly correlated with the concentrations of VSCs emitted during kitchen waste composting ($p < 0.01$), and approximately 55% of the initial total sulfur was lost in the forms of VSCs. VSCs are volatile organic compounds (VOCs) that contain sulfur and reduced sulfur compounds (RSCs), such as hydrogen sulfide (H_2S), methyl mercaptan (MM), dimethyl sulfide (DMS), dimethyl disulfide (DMDS), carbonyl sulfide (OCS), and carbon disulfide (CS_2) (Panetta et al., 2005). The VSCs compounds are characterized by a low detection threshold and strong odor activities, and therefore contribute to odorous pollution even at very low emission concentrations (Yu et al., 2007). Volatile sulfur compounds (VSCs) have been identified as the predominant odorants emitted during organic waste composting (Komilis et al., 2004; Wu et al., 2010). Leachate is an indirect emission source of odor substances and its production rate is between 20 and 40% (based on the wet

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weight of compost material) (Schlegelmilch et al., 2005; Eitzer, 1995; Zhang et al., 2012). Ammonia emission is the largest part in all odor substances. Previous studies showed that 9.6–46% of the initial total nitrogen (TN) is lost in the form of NH_3 during composting (Fukumoto et al., 2003; Morand et al., 2005; Jiang et al., 2013; Zhang, 2012).

The aerobic condition during the composting process is a critical factor determining the discharge of unwanted emissions (Haug, 1993; Smet et al., 1999). It is widely accepted that VSCs are released from organic materials during anaerobic and exothermic or incomplete aerobic fermentation processes (Leach et al., 1999; Statheropoulos et al., 2005; Higgins et al., 2006). Komilis et al. (2004) reported that substantial emission of VSCs could occur, even under aerobic conditions. Poor O_2 transfer caused by insufficient aeration is always considered the main reason for odor gas production during MSW composting (Scaglia et al., 2011). Some studies indicated that increased aeration rates can helps to reduce VSC emission during organic waste composting. Rajamäeki et al. (2005) reported that the concentrations of DMDS and H_2S were higher in the composter bin with low aeration (~0.5 L/min) than in that with high aeration (~9 L/min) during kitchen waste composting. Chen et al. (2011) found that maintaining the O_2 concentration higher than 14% in the pile could reduce H_2S production during large-scale sewage sludge composting. However, some studies show that an increased aeration rate was responsible for an increase in NH_3 emission (Guardia et al., 2008; Elwell et al., 2002; Kim et al., 2009; Osada et al., 2000). Li et al. (2008) observed that NH_3 emission at an aeration rate of 0.50 L/min kg VS was higher than that at other aerations such as 0.125, 0.25 and 0.75 L/min kg initial VS, and the aeration rate of 0.25 L $(\text{kg VS min})^{-1}$ VS was considered to be the best for NH_3, H_2S, and MM control during dairy manure composting with rice straw. Shen et al. (2011) found that NH_3 emission at an aeration rate of 0.2 $m^3\ min^{-1}\ m^{-3}$ was higher than that at other aeration rates, such as 0.01 and 0.1 $m^3\ min^{-1}\ m^{-3}$ during aerobic composting of chicken manure and high C/N waste mixture.

Composting aeration rate seems to be a main parameter influencing gaseous emissions (Scaglia et al., 2011; Pagans et al., 2006; Shen et al., 2011; Turan et al., 2007; Gao et al., 2010; Delgado-Rodriguez et al., 2011). However, little research is currently published on combined VSCs and NH_3 control strategies based on aeration rate during kitchen waste composting.

This study aims to investigate the influence of aeration supply on the emission of VSCs and NH_3 during kitchen waste composting. Corn stalks were used as bulking agents to improve the composting conditions and reduce the leachate production. Gaseous emissions and composting temperature, as well as maturity were systematically compared at different aeration rates. Results reported here may provide a unique insight into the methods to control odorous gaseous emissions during kitchen waste composting.

2. Materials and methods

2.1. Raw composting materials

Kitchen waste was collected from a separate collection system in south Beijing. The kitchen waste consisted of, by wet weight, 54% uneaten vegetables, 23% fruit peels, 14% uneaten portions of meals, and 9% leaves. Chopped cornstalk (with a length of 2–3 cm) was used as the bulking agent. Key physicochemical properties of the raw materials are presented in Table 1. A mixture of kitchen waste and cornstalks at a ratio of 85:15 (wet weight basis) were composted. This mixture ratio can effectively avoid leachate production during composting (Zhang et al., 2012).

Table 1
Characteristics of raw materials (average values ± standard deviations from three replicates).

Materials	TOC (%)[a]	TKN (%)[a]	TS (%)[a]	Moisture content (%)	C/N
Kitchen waste	35.1 ± 3.4	2.5 ± 0.5	0.4 ± 0.0	69.6 ± 5.2	16.2
Cornstalks	43.4 ± 2.9	0.8 ± 0.2	0.3 ± 0.0	9.1 ± 0.3	52.9

TOC: total organic carbon; TKN: total Kjeldahl nitrogen; TS: total sulfur.
[a] Based on dry matter (DM).

2.2. Experimental design and methods

VSC and NH_3 emissions during kitchen waste composting were investigated at three different aeration rates (i.e., 0.1, 0.2 and 0.3 L $(\text{kg DM min})^{-1}$, denoted as A1, A2 and A3 treatment, respectively). All treatments were performed in 60 L heat-insulated composting reactors with forced aeration systems for 30 days. Detailed descriptions of these reactors are also available elsewhere (Yang et al., 2013). In brief, these composting reactors were identical with an inner diameter of 0.36 m and a height of 0.6 m. A C-LGX program was used to control the aeration intervals and record the composting pile temperature. Composting piles were manually turned over once a week. Solid samples were collected from three sampling ports and then mixed thoroughly on day 0, 3, 7, 14, 21, and 30 of composting. A certain amount of the solid samples were air-dried and subsequently grounded to pass through a 1 mm sieve.

2.3. Analytic method

Gas samples were collected ten times from a sampling port on top of the reactors throughout the experiment (i.e., on day 0, 3, 5, 7, 11, 15, 20, 25, and 30). An SOC-01 sampling device (Tianjin Dylan Auto Environmental Protection Sci-tech Company, Ltd., China) was used for VSC collection. VSCs were analyzed based on the method previously reported by Zhang et al. (2013) using a Gas Chromatography-Mass Selective Detector (Model 5975N, Agilent Technologies, USA) coupled with an Entech 7890 Preconcentrator (Entech Instruments Inc., CA, USA). NH_3 was trapped by boric acid (2%) and then titrated against 0.5 M H_2SO_4 for quantification. The O_2 and H_2S were analyzed daily using a portable biogas analyzer (Biogas Check, Geotech, UK). The biogas analyzer has two built-in sensors that were used to determine O_2 and H_2S, with a measurement range of 0–25% (±1% volume) and 0–500 ppm (±2.0% full-scale), respectively.

Ground and sieved samples were used to assess the TN, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and total sulfur (TS). TKN and TOC were determined according to Chinese National Standard (NY 525-2002). TS and TN were determined using an Elementary analyzer (Elementar Analysensysteme Vario MACRO cube, Germany).

Fresh samples were processed for moisture measurement based on a method reported by Thompson et al. (2002). In addition, the fresh compost samples (n = 3) were also mixed with distilled water (1:10 w/w) and then shaken for 0.5 h. The mixture was centrifuged and the supernatant was filtered through a 0.45 mL filter membrane to determine the germination index (GI). It is well established that GI can be used to assess the phytotoxicity of the compost (Sellami et al., 2008). In this study, twenty pakchoi seeds were distributed on filter papers in Petri dishes (10 cm in diameter) and moistened with 10 mL filtered compost supernatant. Three replicate dishes for each sample were incubated at 20 °C for three days. The number of germinating seeds and root lengths

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