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New insights into the interactions between carbon dioxide and ammonia emissions during sewage sludge composting

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HIGHLIGHTS

- Readily degradable carbon source increases CO_2 emission and decreases NH_3 emission.
- CO_2 emission rate is related to the intensity of ammonia assimilation.
- Readily degradable carbon source can stimulate ammonia assimilation.
- Stimulation of ammonia assimilation can reduce ammonia emission effectively.
- Addition of 70% sucrose/30% straw powder at 108 h gave the least NH_3 emission.

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ABSTRACT

This study aimed to investigate the role of carbon dioxide in reducing ammonia emissions. Three variations of a composting experiment were conducted in a laboratory-scale reactor, all of which exhibited the three typical composting phases. Approximately 70% of the ammonia emissions occurred within 96–144 h of the thermophilic stage. The maximum rate of change for the carbon dioxide emissions occurred at different times for different carbon source types, mixing rates, and addition times. The rate of change and total concentration of emitted carbon dioxide played a crucial role in ammonia emission due to their relationship to the intensity of ammonia assimilation. The addition of a carbon source that could be utilized by thermophilic microorganisms stimulated ammonia assimilation and thus reduced ammonia emissions. These findings suggested that the addition of a 7:3 mixture of sucrose and straw powder at 108 h is suitable for reducing ammonia emissions.

1. Introduction

Composting is one of several disposal methods for biosolids that allows their reuse as soil conditioners and fertilizers in gardens, for food and feed crops, and in rangelands (Shammas and Wang, 2009). Sewage sludge composting provides an effective and economic method for sludge disposal in developing countries, including China, which tend to be characterized by rapid increases in sludge production and abundant agricultural resources (Tai et al., 2011; Wang et al., 2011; Zhu, 2007). An unfortunate occurrence during composting is the loss of nitrogen through ammonia emission (Ogunwande et al., 2008; Witter and Lopez-Real, 1988), which reduces the agricultural value of the product and contributes to air pollution, such as the formation of atmospheric particles and odor (Hafner et al., 2013).

Carbon dioxide and ammonia are two major byproducts of composting due to the oxidation of organic matter. Sewage sludge normally has a high moisture content and low C/N ratio, which are favorable conditions for ammonia emission (Jiang et al., 2011; Ogunwande et al., 2008). Theoretically, the emission of ammonia is greater if the C/N ratio is <15. Different types of carbon compounds have been used to increase the C/N ratio, such as rice straw, sawdust, glucose, molasses and triacylglycerol (Matsumura et al., 2010; Nakasaki et al., 1992; Zhu, 2007). When carbon-rich compounds were added, they were converted to carbon dioxide by microbes and utilized for nitrogen immobilization, which is important for reducing ammonia loss. According to a previous study, ammonia emission strongly depends on the biodegradation of organic carbon. Additionally, carbon dioxide emission is a commonly used parameter for estimating organic carbon decomposition (Nakasaki et al., 2009). The rate of carbon dioxide production is directly correlated with the availability of organic

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Table 1
Physicochemical parameters of the raw materials.

	Sewage sludge	Sawdust	Straw powder
Moisture content (%)	84.6 ± 0.6	9.1 ± 0.05	6.7 ± 0.03
Organic matter (% ds)	61.6 ± 1.5	94.8 ± 2.1	86.4 ± 2.5
TOC (% ds)	23.1 ± 1.7	48.8 ± 1.2	44.3 ± 2.3
Kjeldahl-N (% ds)	3.13 ± 0.1	0.12 ± 0.004	0.24 ± 0.005
pH	6.9 ± 0.4	7.1 ± 0.5	7.2 ± 0.04
C/N	7.38	406.7	184.6

Note: Values are mean ± standard deviation based on three times replication.

carbon and depends on the oxidation degree of the organic carbon. Thus, it could be useful to consider ammonia and carbon dioxide emissions as a single entity and to investigate the interactions between carbon dioxide and ammonia emissions.

A series of studies of carbon dioxide and ammonia emissions during composting have been carried out in recent years. Komilis and Ham (2006) provided a method for predicting carbon dioxide and ammonia yields during the composting of municipal solid wastes. Paillat et al. (2005) proposed a predictive model for ammonia and carbon dioxide emissions during the thermophilic phase of composting. Ni et al. (2000) found that the carbon dioxide emissions influenced the pH, and thus changed the behavior, of the ammonia emissions.

However, although several studies involving the evolutions of ammonia and carbon dioxide release during composting have been reported, most laboratory studies have focused on quantitative measurements or the creation of a mathematical model for predicting carbon dioxide and ammonia emissions (Hafner et al., 2013). Ammonia and carbon dioxide emissions result from the biological decomposition of organic matter during composting, which is affected by both the environmental conditions (e.g., temperature, pH, and moisture content) and the chemical composition of the substrate (e.g., C/N ratio, ammonium concentration, and biodegradation of organic matter) (Ogunwande et al., 2008). Thus, using a model-based simulation alone is insufficient for understanding the interaction between carbon dioxide and ammonia emissions. Based on previous results, these complicated interactions play a significant role in controlling nitrogen losses (Komilis and Ham, 2006). Therefore, further studies are needed to expand the understanding of the co-reaction of carbon dioxide and ammonia emissions, especially from the perspective of microbial metabolism.

Therefore, three composting experiments were conducted in which the types, mixing ratio, and addition time of carbon-rich compounds were varied. The objectives of this study were (1) to study the behavior of carbon dioxide and ammonia emissions during the composting of sewage sludge under different composting conditions and (2) to explain the role of carbon dioxide in ammonia emissions and develop an effective method to reduce ammonia emissions.

2. Methods

2.1. Composting materials and equipment

Dewatered sewage sludge generated during municipal wastewater treatment was used as the composting material. Because of its high moisture content (up to 85%) and poor aerobic conditions, the sludge cannot be composted alone. Sawdust with a particle size of less than 5 mm, which was collected from a wood manufactory, was used as the bulking agent. To ensure homogeneity, the sludge and sawdust were mixed sufficiently before composting. The mixing ratio of sludge:sawdust was 6:1 (wet weight). Next, this mixture was divided into several parts, each with similar compositions. Compared with the sewage sludge and the carbon-rich compounds used, the available carbon sources in the sawdust were negligible. Thus, the sawdust was considered an inert substance used to adjust the moisture content and provide an adequate porosity for composting. The characteristics of the raw materials are shown in Table 1.

A schematic diagram of the experimental-scale composting equipment is shown in Fig. 1. The airflow was first passed through a trap containing distilled water to humidify the air and then passed through a trap containing NaOH solution to eliminate carbon dioxide. Carbon dioxide-free air was supplied from the bottom of the reactor and passed through the composting material. The

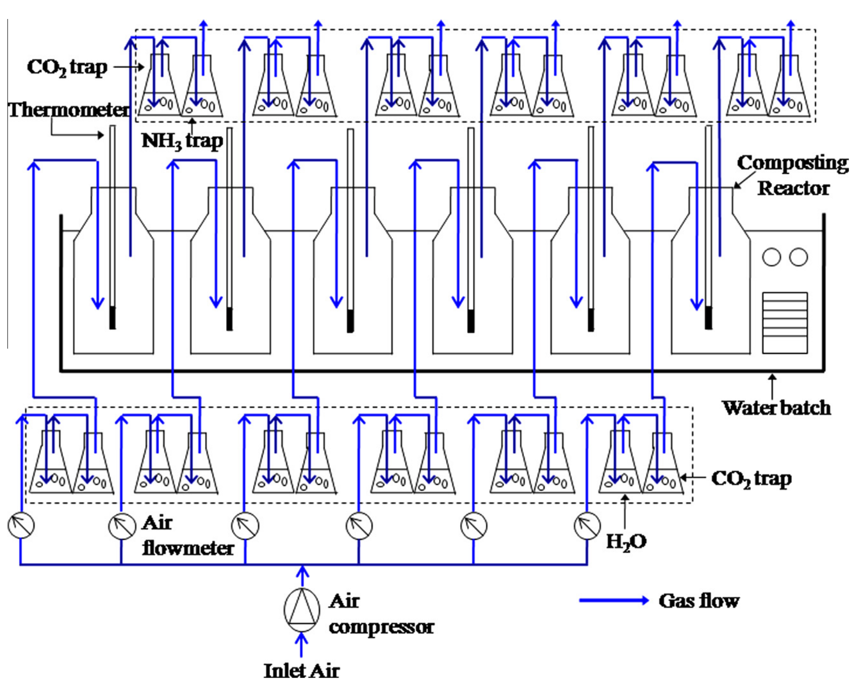

Fig. 1. Schematic diagram of the composting system.