Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Spatial and temporal distribution of pore gas concentrations during mainstream large-scale trough composting in China

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ARTICLE INFO

Article history:
Received 11 October 2017
Revised 28 January 2018
Accepted 29 January 2018
Available online xxxx

Keywords:
Spatial distribution
Temporal distribution
Pore gas concentration
Large-scale composting
Correlation

ABSTRACT

With the advantages of high treatment capacity and low operational cost, large-scale trough composting has become one of the mainstream composting patterns in composting plants in China. This study measured concentrations of O_2, CO_2, CH_4 and NH_3 on-site to investigate the spatial and temporal distribution of pore gas concentrations during mainstream large-scale trough composting in China. The results showed that the temperature in the center of the pile was obviously higher than that in the side of the pile. Pore O_2 concentration rapidly decreased and maintained <5% (in volume) for 38 days or more in both the center and side of the pile and effective O_2 diffusion occurred at most in every two contiguous layers. Pore CO_2 and CH_4 concentrations at each measurement point were positively correlated ($0.436 \le r \le 0.570$, $P < 0.01$) and the concentrations in the side of the pile were obviously lower than those in the center. The top layer exhibited highest pore O_2 concentration and lowest CO_2 and CH_4 concentrations, and the bottom layer was on the contrary. No significant differences in pore NH_3 concentrations between different layers or between different measurement points in the same layer were found. Therefore, mixing the center and the side of the pile when mechanical turning and adjusting the height of the pile according to the physical properties of bulking agents are suggested to optimize the oxygen distribution and promote the composting process during large-scale trough composting when the pile was naturally aerated, which will contribute to improving the current undesirable atmosphere environment in China.

1. Introduction

With the increasing production of animal manure, aerobic composting has been widely used in the recovery, stabilization and volume reduction of this solid waste (Bari and Koenig, 2001). Because of the high treatment capacity and low operational cost, large-scale trough composting under regular mechanical turning without forced aeration has become one of the mainstream composting patterns in composting plants in China. Under this pattern, the mechanical turning event mixes the raw materials and is the sole active source of oxygen (O_2) during aerobic composting. However, the turning frequency in previous studies rarely exceed once every 2 days during large-scale composting (Cook et al., 2015; Michel et al., 1996; Ogunwande et al., 2008), which means that the piles are practically under naturally aerated conditions for the majority of the composting period.

During the natural aeration period of composting, microorganisms consume O_2 and produce and release various gases including carbon dioxide (CO_2), methane (CH_4) and ammonia (NH_3) due to the partially anaerobic condition; these gases are substantial threats to both human activities and environmental protection. On a macro-scale, considering that a composting pile is composed of compost materials and internal pores (Zeng et al., 2016), the gases in the pores are heated by microbial activity, which reduces air density and increases partial pressure, and creates an air flux from the bottom layer to the top layer in naturally aerated piles (Oudart et al., 2015; Poulsen, 2010, 2011). However, the gas production rate differs with spatial gradients because of inhomogeneous mixing and compaction effects, the generated concentration differences are the driving force for air diffusion and transfer inside the pores (Ni, 1999). Hence, monitoring the spatial and temporal distribution of pore gas concentrations is an important method to evaluate and optimize the aeration strategy and expound the air movement (Poulsen, 2011). On a particle-scale, composting mixtures are divided into large substrate particle group, small substrate particle group and the pores between them. Oxygen in the pores enters the substrate particles by dissolving and diffusing, meanwhile, gases generated during microbial degradation diffuse into the pores (Ge et al., 2016a,b, 2015a; Wang and

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https://doi.org/10.1016/j.wasman.2018.01.044
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Ai, 2016). The pores are the gas exchange interface between the microorganisms and the ambient environment, and the spatial and temporal distribution of pore gas concentrations effectively reflects the composting process (Richard et al., 2004).

Wang et al. (2011) studied the residual oxygen content in the upper, middle and bottom regions of a reactor and found a higher oxygen content in the upper region throughout the entire composting process and a lowest residual oxygen level in the middle region during the first 5 days although the fresh air was blown from the bottom of the reactor. Kasinski et al. (2016) measured the O_2 and CO_2 concentrations in three different depths when testing the efficacy of an integrated passive and active aeration system in a full-scale composting reactor and the results showed no problems with the oxygen diffusion, which was confirmed by the extremely low CO_2 concentration. Poulsen (2011) measured the distribution of O_2 and CO_2 concentrations across a triangular cross section of a full-scale composting from Day 16 to Day 26 and exhibited high O_2 concentrations near the surface and high CO_2 concentrations near the center of the pile. Cabanas-Vargas and Stentiford (2006) compared the O_2, CO_2 and CH_4 concentrations in different depths at bench-scale with that on-site during the maturation phase of composting and found that O_2 concentration decreased but CO_2 and CH_4 concentrations increased from the surface to the deepest point both at bench-scale and on-site. However, a systematic study on the spatial differences and temporal changes of the main gases (O_2, CO_2, CH_4, NH_3, H_2S, and N_2O) produced during large-scale aerobic composting remains absent from the current literature.

The aim of this study was to investigate the spatial and temporal distribution of pore gas (O_2, CO_2, CH_4 and NH_3) concentrations and correlations among them to provide data support to expound the gas movement, optimize the aeration strategy and promote the composting process during mainstream large-scale trough composting in China.

2. Materials and methods

2.1. Experiment design

To achieve the appropriate moisture content (about 67%) and free air space (>30%) of the initial mixture (Haug, 1993; Kulcu et al., 2008), fresh chicken manure, mushroom residue and tapioca flour collected from a foreign trade corporation in Zhucheng (Shandong Province, China) were mixed at a ratio of 2:2:1 (wet weight). Because of the lack of raw materials, a total of about 35 tons of the mixture was finally loaded into one side of a concrete trough (length × width × height = 60 × 6 × 1.2 m^3), and the pile was actually about 10 m in length as shown in Fig. 1. The mixture was mechanically turned twice a day (8:30 and 16:30) during the 45-day composting. Each mechanical turning process lasted for about 30 min, after which the pile became thinner in height and larger in surface area because the shifting and spreading occurred together, leading to an intense heat loss to the environment. Therefore a bulldozer was used every 7–10 days to reconstruct the pile to maintain the initial cross sectional dimension. No leachate was obtained during the whole composting process. The basic physicochemical properties of the raw materials, initial mixture and final composts were listed in Table 1.

2.2. Measurement methods

Three fresh samples were respectively collected from the top (A2), middle (A3) and bottom (A4) layer in the center of the pile every 2 days in the first 15 days and every 3 days in the next 30 days. Each sampling was about 1.5 kg and obtained by mixing five subsamples collected from five randomly chosen points within an area of 1.5 m in diameter. One part of each fresh sample was air-dried, ground, passed through a 40 mesh sieve and used to measure the moisture content (MC), organic matter (OM) according to standard method (TMECC, 2000), and total nitrogen (TN), total carbon (TC) using an element analyzer (Elementar Vario MACRO, Germany). While another part (about 10 g of each fresh sample) was immediately mixed with deionized water, shaken, centrifuged and filtered for the measurement of the germination index (GI) according to Guo et al. (2012). Moreover, free air space was theoretically calculated based on easily measured parameters, which was described in details in our previous study (Zeng et al., 2016).

Considering the symmetry of the pile, all measurements of temperature and gas concentration were conducted on one half of the cross section (Fig. 1). Between the two turning events every day (9:00 to 16:30), a monitoring system for large-scale aerobic composting introduced in our previous work (Zeng et al., 2016, 2015) was used to collect the continuous temperature data in the air above the pile (A1), the center of the pile (A2, A3 and A4), the side of the pile (A5, A6 and A7) and the ambient (A8) as shown in Fig. 1. The top layer (A2 and A5), the middle layer (A3 and A6) and the bottom layer (A4 and A7) were 15 cm, 55 cm and 95 cm in depth, respectively.

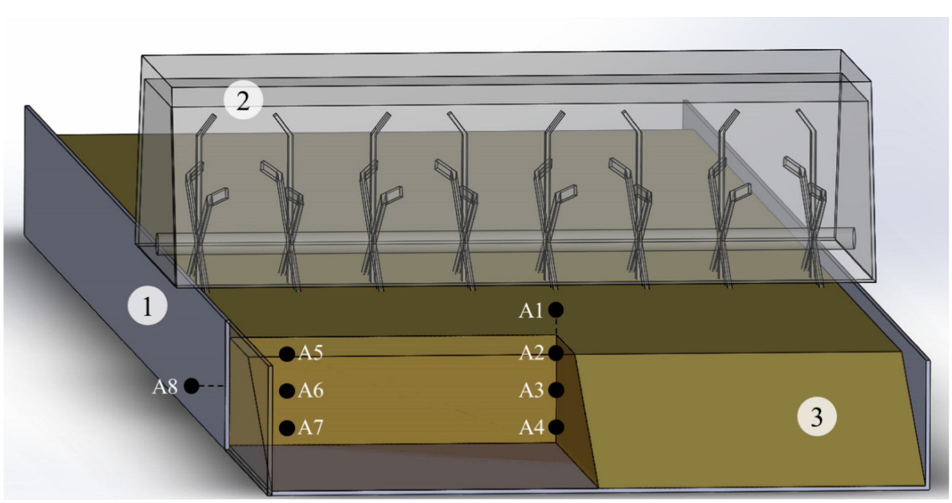

Fig. 1. Schematic of the composting system: 1. The concrete trough, 2. The compost turner, 3. The composting pile, (A1) the air above the pile, (A2) the top layer in the center of the pile, (A3) the middle layer in the center of the pile, (A4) the bottom layer in the center of the pile, (A5) the top layer in the side of the pile, (A6) the middle layer in the side of the pile, (A7) the bottom layer in the side of the pile and (A8) the ambient.

Please cite this article in press as: Zeng, J., et al. Spatial and temporal distribution of pore gas concentrations during mainstream large-scale trough composting in China. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.01.044