Journal of Environmental Management 218 (2018) 416–424

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Effects of the aeration pattern, aeration rate, and turning frequency on municipal solid waste biodrying performance

Jing Yuan [a], Difang Zhang [a], Yun Li [a], Ji Li [a], Wenhai Luo [a], Hongyu Zhang [b], Guoying Wang [a], Guoxue Li [a, *]

[a] Beijing Key Laboratory of Farmland Soil Pollution Prevention and Remediation, College of Resources and Environmental Science, China Agricultural University, Beijing 100193, China
[b] Beijing Building Materials Academy of Science Research/State Key Laboratory of Solid Waste Reuse for Building Material, Beijing 100041, China

ARTICLE INFO

Article history:
Received 24 January 2018
Received in revised form
9 April 2018
Accepted 20 April 2018

Keywords:
Biodrying
Municipal solid waste
Aeration volume
Turning frequency
Water evaporation
Energy use

ABSTRACT

Interactive influences of the aeration pattern, aeration rate, and turning frequency on municipal solid waste biodrying performance were investigated. Energy and water mass balances were used to identify the main water-removal routes and determine the amount of energy used and efficiency. Changing the aeration pattern and turning frequency did not significantly affect biodrying performance when the other conditions and total aeration volume were constant. The total aeration volume controlled the pile temperature and evaporation, making it the main factor affecting water loss during biodrying. A continuous aeration rate of 0.5 L kg^{-1} dry matter·min^{-1} gave the best biodrying performance (the highest water-removal rate, biodrying index, and sorting efficiency, 0.5 kg kg^{-1}, 4.12, and 86.87%, respectively, and the highest lower heat value (LHV) and heat utilization rate, 9440 kJ kg^{-1} and 68.3%, respectively). There was an optimum aeration rate, water loss reaching a maximum at an aeration rate of 0.5 L kg^{-1} DM·min^{-1} and not increasing further as the aeration rate increased further. Lower aeration rates gave higher volatile solid degradation rates. The effects of turning could be achieved by increasing the aeration rate. The recommended biodrying parameters are continuous aeration at an aeration rate of 0.5 L kg^{-1} dry matter min^{-1} and one turn every 3 d.

1. Introduction

The amount of municipal solid waste (MSW) produced in China has increased considerably in recent years because of accelerating urbanization. Combustion is an effective MSW treatment method that stabilizes the waste, decreases the waste volume as much as possible, benefits sanitation, and allows energy to be recovered (Liu and Liu, 2005). However, in many developing countries, such as China, MSW typically has a high water content (up to 75%) because it contains a relatively high proportion (>60%) of food waste (He et al., 2005; Münnich et al., 2006). The high water content decreases the amount of energy that is actually recovered through combustion and increases the operating costs. MSW must be dried before it can be used to produce energy. Biodrying, in which water is removed through microbial activity, is a good way of decreasing the water content of wet organic waste. As well as giving a high water-removal rate, biodrying is expected to prevent the degradation of organic matter, preserving energy for subsequent use, e.g., as fuel (Adani et al., 2002).

It is necessary to determine optimal biodrying operating conditions to allow bio-generated energy to be effectively and economically used, to remove as much water as possible in as little time as possible (Velis et al., 2009). Aeration (using a defined aeration pattern and aeration rate) and turning are two important operations that both positively affect (removing vapor emissions) and negatively affect (removing heat) biodrying (Zhao et al., 2010; Cai et al., 2013, 2015). It has been found in previous studies that lower air flow rates give higher matrix temperatures (Huilinir and Villegas, 2015; Sen and Annachhatre, 2015). However, decreasing the air flow rate will mean less evaporated water will be removed and the moisture content will decrease less (Adani et al., 2002; Yuan et al., 2017).

A high aeration rate is required to quickly and effectively dry organic matter (Adani et al., 2002; Cai et al., 2013). Zhao et al. (2010) studied the effect of changing the air flow rate on dewatered sludge

* Corresponding author.
E-mail address: ligx@cau.edu.cn (G. Li).

https://doi.org/10.1016/j.jenvman.2018.04.089
0301-4797/

biodrying and found that a higher percentage of the heat was used for evaporation at higher air flow rates than at lower air flow rates. Sharara et al. (2012) found that better drying energies and drying times were achieved at higher aeration rates than at lower aeration rates. Sen and Annachhatre (2015) found a higher airflow rates ($0.03\ m^3\ kg^{-1}\ h^{-1}$) had a lower final moisture content (24.0%) on the biodrying of cassava peel mixed with activated sludge waste. However, there is experimental evidence that lower pile temperatures caused by excessive aeration will delay fermentation and decrease the amount of water lost (Finstein et al., 1986; Zhang et al., 2010; Shen et al., 2011). Colomer-Mendoza et al. (2013) found that high air flow rates ($>2\ L\ kg^{-1}$ DM min^{-1}) affected the gardening waste biodrying process because the thermophilic phase did not occur, meaning the waste was dried physically rather than through biodrying. Huilinir and Villegas (2014) found that higher airflow rates caused the temperature in the matrix to be lower, and the volatile solid (VS) content to decrease less. Convective drying but no biodrying occurred at an air flow rate of $5.26\ L\ kg^{-1}$ VS min^{-1}. There is therefore an optimum aeration rate for the biodrying process.

The aeration pattern, aeration time, and air volume also affect biodrying performance. Zhang et al. (2008) attempted to improve the water-removal rate by adding a hydrolytic stage (0–4 d) prior to aerobic degradation. Jalil et al. (2016) found an optimum ventilation rate of 10 min every 3 h decreased the moisture content by 81.84%. Zhou et al. (2014) found that, using the same aeration rate, a longer aeration time decreased the water content of biodrying sewage sludge. The key factor affecting biodrying was the aeration time rather than the temporary aeration rate when the same total aeration volume was used. Different temporary and average aeration rates were not used in the studies mentioned above, so the effects of both parameters on biodrying performance need to be evaluated.

Turning is critical to the biodrying process because turning the material at an appropriate time can prevent excessive heat loss and cause the material to ferment homogeneously (Léonard et al., 2008; Cukjati et al., 2012; Awasthi et al., 2014); Shao et al. (2015) found that the turning frequency affects the rate at which moisture is removed because turning affects both self-heating during the biodrying process and the retention of heat in the pile of material. Cai et al. (2013) studied the drying effects of mechanical turning and found that turning in the temperature-increasing phase was less effective than turning at other times. Zhao et al. (2010) found more water was removed using a higher turning frequency for 2 d than using a lower turning frequency for 4 d, but that a high air flow rate did not improve water removal at a high turning frequency.

The effects of aeration and turning on biodrying have been studied separately, but the simultaneous effects of the aeration pattern, aeration rate, and turning frequency have not been studied. The study presented here was focused on assessing the interactive influences of the aeration method, aeration rate, and turning frequency on water removal, the sorting efficiency, and biomass energy utilization achieved during the biodrying of MSW. In addition, the mass and heat balance calculation, the water holding capacity of aeration and heat loss via different approaches were calculated and clarified.

2. Materials and methods

2.1. Materials and experimental setup

The MSW feedstock was collected from a sorting collection system at the Majialou MSW transfer station in Beijing, China. The MSW consisted of, by wet mass, 62.75% kitchen waste, 21.67% paper, 8.74% plastics, and 6.84% other materials. Cornstalks were obtained from a research station at the China Agricultural University. The cornstalks were passed through a cutting mill to produce pieces with sizes of 1–5 cm. The properties of the raw materials are shown in Table 1. The MSW and cornstalks were combined at a wet weight ratio of 9:1 before the mixture was biodried. This ratio was used because 10% cornstalks has been found to be the optimum for adjusting the moisture contents and C/N ratios of materials to be biodried (Zhang et al., 2013; Yuan et al., 2017). The initial wet weight of the MSW and cornstalk mixture to be biodried was 30 kg.

Table 1
Physical and chemical characteristics of the raw materials.

Materials	MSW	Cornstalks	Mixes of MSW and cornstalks
Moisture (%)[a]	71.47 ± 1.57	4.67 ± 0.45	60.39 ± 2.40
Bulk density ($kg\cdot m^{-3}$)[a]	694.97 ± 25.46	168.14 ± 8.73	513.13 ± 14.62
Free air space (FAS) (%)[b]	30.85	84.23	51.01
Total carbon (TC) (%)[b]	35.97 ± 0.54	42.72 ± 0.47	39.48 ± 0.56
Total nitrogen (TN) (%)[b]	1.82 ± 0.02	1.11 ± 0.00	1.47 ± 0.02
C/N	19.76	38.49	26.86
Volatile solids (VS) (%)[b]	72.64 ± 0.45	89.3 ± 0.26	80.91 ± 0.09
Lower heat value (LHV) ($kJ\cdot kg^{-1}$)[a]	−366 ± 17	14664 ± 77	2422 ± 36

[a] Wet weight basis.
[b] Dry weight basis.

Each biodrying test was performed in a 60 L laboratory-scale stainless steel column reactor 0.6 m high and with a 0.36 m inner diameter (Fig. 1). Each reactor had two layers of stainless steel to minimize heat loss. A stainless steel cap was fitted to the top of each reactor to allow the reactor to be filled and emptied. A 3 mm stainless steel grid was placed at the bottom of each reactor to support the composting bed and ensure that the gases added were uniformly distributed. There were two holes in the bottom of each reactor, one to allow the reactor to be aerated (the aeration gas was added using a controllable aquarium pump) and the other to allow leachate to drain away. The lid of each reactor had two holes, one to allow a temperature sensor to be inserted and the other to allow gas within the vessel to be sampled. An exhaust port (50 mm inner diameter) in the lid of each reactor was connected to a condenser using plastic piping. A jar at the bottom of the condenser allowed the condensed water to be collected. This experimental setup was used in a previous study (Yuan et al., 2017).

We performed 10 treatments with the aim of determining the effects of different aeration methods, aeration rates, and turning frequencies on the biodrying performance. The conditions used in the treatments are shown in Table 2. Each treatment was performed in triplicate. The intermittent aeration treatment I1 had instantaneous and average aeration rates of 0.35 and $0.3\ L\ kg^{-1}$ DM min^{-1}, respectively. The intermittent aeration treatment I2 had instantaneous and average aeration rates of 0.6 and $0.3\ L\ kg^{-1}$ DM min^{-1}, respectively. The continuous aeration treatments C1, C2, C3, C4, and C5 had continuous aeration rates of 0.2, 0.3, 0.4, 0.5, and $0.6\ L\ kg^{-1}$ DM min^{-1}, respectively. These aeration rates were selected based on the results of previous studies (Yuan et al., 2016, 2017). The turning frequencies in treatments T0, T2, C2, and T6 were zero, once each 2 d, once each 3 d, and once each 6 d, respectively. The biodrying material was mixed and turned manually outside the reactor and mixed completely for about 30 min until the matrix was uniform. The aeration rates were selected based on the results of a study performed by Yuan et al. (2017), and the turning frequencies were selected based on the results of studies performed by Zhao et al. (2010) and Cai et al. (2013).

Treatments I1, I2, C2, T0, and T2 all had the same theoretical total aeration volume and an average aeration rate of $0.3\ L\ kg^{-1}$ DM min^{-1}. Treatments C5 and I2 had the same instantaneous aeration