Effects of aeration method, aeration rate and turning frequency on bio-drying performance of municipal solid waste

Jing Yuan[1], Difang Zhang[1], Yun Li[1], Wenhai Luo[1], Hongyu Zhang[2], Ji Li [1], Guoying Wang[1], Guoxue Li[1,*]

[1] Beijing Key Laboratory of Farmland Soil Pollution Prevention and Remediation, College of Resources and Environmental Science, China Agricultural University, Beijing 100193, China
[2] Beijing Building Materirals Academy of Science Research/State Key Laboratory of Solid Waste Reuse for Building Material, Beijing 100041, China
Keywords: Municipal solid waste, Bio-drying, Aeration rate, Turning frequency, Water removal, Energy utilization
Presenting author email: jingyuan@cau.edu.cn

1. Introduction

In recent years, the generation of municipal solid waste (MSW) has increased considerably with accelerating urbanization in China. MSW in many developing countries (such as China) is typically characterized by high water content (as high as 75%) because of the relatively high proportion of food waste (>60%) (Norbu et al., 2005; Münnich et al., 2006). In most cases, MSW is incinerated in incinerators without pre-treatment in China because the calorific value of MSW is not suitable for a direct combustion because of its high humidity. A large amount of petroleum and coal are typically added to support combustion.

Bio-drying technology, aimed towards removing water by microbial activity, is regarded as a good solution for reducing the water content of wet organic wastes (He et al., 2010; Rada et al., 2015; Tom et al., 2016). How to effectively and economically utilize the bio-generated energy to remove more water in less time under optimal operations is a crucial problem of bio-drying (Choi et al., 2001; Velis et al., 2009). Aeration and turning are two important operations which simultaneously exert both positive (vapor emission) and negative (heat loss) effects on bio-drying. Aeration is necessary to remove water from the matrix, whose temperature affects temperature of air-flow and subsequently its water holding capacity (NavaeeArdeh et al., 2006). Turning could be particularly profitable for homogenization of pasty sludge with poor mechanical strength (Le´onard et al., 2008).

This paper focuses on investigating the interactive influence of aeration method, aeration rate and turning frequency on water removal, sorting efficiency and biomass energy utilization of MSW as a biomass resource. As a result of the mass and heat balance calculation, the water holding capacity of aeration and heat loss via different approaches were clarified.

2. Materials and methods

The MSW feedstock was collected from a sorting collection system at the Majialou MSW transfer station in Beijing, China. Cornstalks were obtained from a research station at the China Agricultural University. The properties of the raw materials are shown in Table 1.

Table 1. Physical and chemical characteristics of 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·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
Higher heat value (HHV) (kJ·kg^{-1})[a]	15543±124	17894±79	16899±201
Lower heat value (LHV) (kJ·kg^{-1})[b]	-366±17	14664±77	2422±36

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

In this study, the MSW and cornstalks were combined at a ratio of 9:1 (wet weight) for bio-drying. After mixing adequately, all materials were loaded in a series of bio-drying reactors (60 L). The details of this reactor system can be found elsewhere (Yuan et al., 2017). In this study, we investigated ten treatments, each treatment was performed in triplicate. Intermittent aeration treatment I1 with an instantaneous and average aeration rate of 0.35 and 0.3 L kg^{-1} DMmin^{-1}, respectively. Intermittent aeration treatment I2 with an instantaneous and average aeration rate of 0.6 and 0.3 L kg^{-1} DMmin^{-1}, respectively. Continuous aeration rates were set at 0.2 (CI), 0.3 (C2), 0.4 (C3), 0.5 (C4) and 0.6 (C5) L kg^{-1} DMmin^{-1}. Turning frequency were set at no turn (T0), per 2 days (T2), per 3 days (C2) and per 6 days (T6). The I1, I2, C2, T0 and T2 treatments had a same total aeration volume theoretically with an average aeration rate of 0.3 L kg^{-1} $DMmin^{-1}$. Each bio-drying trial operated for 18 days and a forced-draft aeration system was used.

The temperature was recorded. Condensate water were collected and weighed every day. A sample of the solid material was taken from each vessel. Each sample was divided into two parts. One part was stored at 4°C and the other was air-dried and ground to pass through a 1 mm sieve. The wet samples were analyzed for moisture content. The dried and ground samples were analyzed for total nitrogen (TN), total carbon (TC), volatile solids (VS) contents and higher heat value (HHV) and lower heat value (LHV). Theoretical calculation of heat balance in the bio-drying system was calculated based on the equations described in the references (Yuan et al., 2017).

3. Results and discussion

The temperature determines the amount of water gasification, and aeration determines the carried amount of water vapor during bio-drying. Changing aeration method, aeration rate and turning frequency could not affect the $\sum FP$ index significantly under the same total aeration volume. For the continuous aeration treatments (from C1 to C5), the water losses increased gradually with the increasing aeration rates, C4 treatment got the peak value of water losses, and than water losses decreased with the increasing aeration rates (C5). It is indicated that when the continuous aeration rate was higher than 0.5 $L\cdot kg^{-1}DM\cdot min^{-1}$, the effect of increasing aeration rate on water losses reduced gradually. There was a significant positive correlation between the ratio and the index (R = 0.941, $p <$ 0.001). The I value increased gradually with the increasing aeration rate, the C4 treatment gave the highest I value (4.12), corresponding to a higher ratio (4.23). This result indicated that the best bio-drying performance had a maximum limit on the ventilation volume, when it exceeded the limit, the increase of the ratio will not lead to the increase of I value. Therefore, the air-flow rate was suggested to be optimized according to the temperature changes, to make full use of the evaporative conditions created by temperature and provide an adequate capacity for carrying vapor. The heat used for evaporation accounted for 42.3%–68.3% of total energy consumption, it was the main source of heat consumption (He et al., 2013).

Table 2. Temperature integration (TI), $\sum FP$ values, water loss rate, VS loss rate, bio-drying index (I), the utilization rate of evaporation heat and final LHV of bio-drying.

Treatment	TI[a] (°C)	$\sum FP$[b] (m^3 kPa)	Water removal rate (%)	VS loss rate (%)	Ratio[c]	I[d]	QER[e] (%)	Final LHV ($kJ\cdot kg^{-1}$)
I1	756	1945	51.53	39.02	2.57	2.86	50.6	4435
I2	733	1862	49.74	39.69	2.54	2.72	52.0	4569
C1	737	1164	31.23	36.51	1.58	1.7	42.3	3717
C2	759	1901	48.87	40.39	2.51	2.45	53.3	4499
C3	695	2284	56.76	38.8	3.29	3.17	59.8	7177
C4	681	2663	66.01	34.72	4.23	4.12	68.3	9440
C5	701	3456	62.39	34.47	4.93	3.81	65.8	8678
T0	761	1671	41.91	35.31	2.24	2.32	43.8	3165
T2	688	1676	49.87	41.45	2.44	2.49	51.2	4348
T6	644	2976	59.44	35.38	4.62	3.63	60.1	5333

[a] TI: The temperature integration (TI) index was defined as the accumulated daily differences between the waste and ambient temperatures.
[b] $\sum FP$ indicates the product of the accumulation of airflow rate and saturated vapor pressure of the ventilated air.
[c] Ratio of $\sum FP$ to temperature integration.
[d] The bio-drying index (I), defined as the ratio of water losses to organics losses.
[e] QER: The biologically generated heat during bio-drying used for water evaporation.

4. Conclusions

Under the certain conditions (total aeration volume was relatively low and remained the same), changing the aeration method and turning frequency had no significant effect on bio-drying performance. The main factor affecting the performance of bio-drying was the total aeration volume. There was a peak value for aeration rate during bio-drying, the aeration rate of 0.5 $L\cdot kg^{-1}DM\cdot min^{-1}$ achieved the highest water-removal rate (0.5$kg\cdot kg^{-1}$), bio-drying index (4.12), lower heat value (9440 $kJ\cdot kg^{-1}$) and 68.3% heat consumption used for evaporation. It had a negative effect on bio-drying performance when the aeration rate was above 0.5 $L\cdot kg^{-1}DM\cdot min^{-1}$.

There was a significant positive correlation between the ratio and the bio-drying index, and a ratio of around 4.23 indicated that a bio-drying process has proper ventilation. The function of turning could be achieved through increasing aeration, allowed to reduce the energy consuming of turning. The recommended parameters for bio-drying are a continuous aeration rate of 0.5 $L\cdot kg^{-1}DM\cdot min^{-1}$ and a turning frequency of per three days.

Acknowledgements

This work was financially supported by the project of “State Key Laboratory of Solid Waste Reuse for Building Materials” [grant number SWR-2014-005].