

Effect of bio-drying on sorting and combustion performances of municipal solid waste

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Abstract

The aerobic and combined hydrolytic–aerobic bio-drying processes were separately set up to investigate sorting and combustion performances of MSW by bio-drying. Results showed that the sorting efficiency was found to be correlated with water content negatively (correlation coefficient, $R=-0.89$) and organics degradation positively ($R=0.92$). The high heating values were correlated with organics degradation positively ($R=0.90$), whereas the low heating values were negatively correlated with water content ($R=-0.96$). The potential emissions of combustion gases were correlated with organics degradation (correlation coefficient, $R=0.67$ for HCl, $R=0.96$ for SO_2 , $R=0.91$ for PCDD/Fs and $R=-0.60$ for NO_x). Interestingly, the bio-drying could significantly improve the ratio of gas emissions to low heating values, although it resulted in the increase of the emissions per kg of combustion wastes.

Keywords

Municipal solid waste; bio-drying; sorting efficiency; combustion; HCl; SO_2 ; NO_x ; PCDD/Fs

1 Introduction

The municipal solid waste (MSW) is comprised of food waste and recyclable materials, such as wasted plastics, paper, glasses and metals, etc. The latter can be utilized as resources after mechanical or manual sorting. On the other hand, combustion is one of the most effective options for disposing MSW due to minimizing the amounts of wastes and recovering energy (LIU AND LIU, 2005; ZHANG ET AL., 2008). Nevertheless, the MSW in China is typically characterized by high water content (HE ET AL., 2005), which may reduce the feasibility of sorting for beneficial utilization and the efficiency of energy recovery. The bio-drying can remove water in MSW and favor both resources recovery and combustion (ADANI ET AL., 2002; CHOI ET AL., 2001; RADA ET AL., 2005). The bio-drying could be performed by both aerobic and combined hydrolytic–aerobic processes (SUGNI ET AL., 2005; ZHANG ET AL., 2008a). The later was characterized by supplementing a hydrolytic stage prior to the aerobic degradation.

The bio-drying has showed an improvement both in sorting efficiency and in heating values for MSW (ADANI ET AL., 2002; NORBU ET AL., 2005; RADA ET AL., 2007). Nevertheless, it is still unclear the quantitative correlations of the sorting efficiency and heating values with organics degradation and water removal during bio-drying. The

combustion of MSW will release the harmful emissions of acidic gases (HCl, SO₂ and NO_x, etc.) and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs). These emissions originate from the combustion of the compounds containing chlorines, sulfurs and nitrogen which will be transformed, transferred or degradation during bio-drying. Until now, the influence of bio-drying on the gas emissions in the combustion of MSW is still unknown.

2 Materials and methods

2.1 Characteristics of the MSW feedstock

The MSW was sampled from a residential area in Shanghai, China. The sampled wastes used in this study comprised of 64% (w w⁻¹, in wet weight, the same below) kitchen waste, 20% (w w⁻¹) paper, 7.5% (w w⁻¹) plastics and 8.5% (w w⁻¹) others. The initial water content was 68% (w w⁻¹).

2.2 Experimental equipment

The trials were performed in the column reactors, as previously reported by ZHANG ET AL. (2008b). Briefly, each column (400 mm i.d. and 1200 mm height) was wrapped by 100-mm-thick hollow cotton for thermal insulation. At the bottom, a 100-mm-high layer filled with crockery balls (diameter about 5 mm) was placed for leachate drainage. Above the balls, there was a perforated baffle (2-mm mesh) to support the waste and to facilitate aeration. In order to avoid heat loss and vapor condensation, two layers of straw and cotton were placed above the waste. For aeration, a whirlpool pump (XGB-8, Penghu Co, Shanghai, China) and a gas-flow meter (LZB-10, Shanghai Instrument Co, Shanghai, China) were used.

2.3 Experimental setup and operation

Three batches, i.e. one aerobic and two combined processes, were performed for bio-drying. The aerobic process (marked as "Aerobic") was operated with a ventilation interval of 7 min run / 23 min stop and the fed wastes were manually turned every 2 days. The combined hydrolytic-aerobic processes contained both hydrolytic and aerobic stages. During the hydrolytic stage (0–4 days), the combined processes were separately operated by natural aeration (marked as "Combined 1") and by insufficient aeration of a ventilation interval of 10 min run / 230 min stop (marked as "Combined 2"). During the aerobic stage (5–16 days), the operation was the same as that for the Aerobic. As described previously (ZHANG ET AL., 2008a), the air-inflow rate was fixed at 0.056 m³ per kg wet wastes per hour during the whole experiment. After mixing adequately,

28 kg of the above-mentioned raw MSW was loaded into each column and each experiment was conducted for 16 days.

2.4 Sampling and analytical methods

To assess the sorting efficiency, approximately 4 kg of MSW was sampled every 4 days when the fed materials were turned and the detailed operation for sorting was described as NORBU ET AL. (2005). After sorting, these samples were re-mixed with wastes and loaded into the column. At the same time, each sample of about 200 g was collected from the top, middle and bottom of the column and then mixed for analysis. After determining water contents, these drying samples were reduced into size $\Phi < 0.5$ mm for further analysis. Carbon, hydrogen, nitrogen and sulfur contents were measured by an elemental analyzer (Vario EL III, Elementar, Germany). The heating values were calculated according to ultimate analysis as suggested by HE ET AL. (2004), MARZI ET AL. (2007) and RADA ET AL. (2007). The above indices were analyzed in triplicate for all samples with standard deviations less than 10%.

2.5 Combustion experiment

The combustion experiment was performed in a combustion reactor tube (40 mm i.d. and 710 mm length). Before combustion, the reactor tube was preheated to 850°C and then the drying material was put into by a ceramic boat. During the combustion, the flue gas was sampled by the sampling train and the impingers were submerged in ice bathes. The aqueous solutions of $\text{Na}_2\text{CO}_3/\text{NaHCO}_3$, ammonium sulfamate and dilute sulfuric acid/peroxide were respectively used to absorb HCl, SO_2 and NO_x in combustion gases. The sampled HCl and SO_2 were then analyzed by an Ion Chromatography (ICS-1500, Dionex, USA), and NO_x was determined using ultraviolet spectrophotometric method (EPA OF CHINA, 2001).

2.6 Statistical analysis

All statistical analysis was performed using SPSS 16.0 (SPSS, Inc., Chicago, USA). Pearson's correlation coefficient was used to evaluate the linear correlation between two parameters. The correlations presented were confirmed at a 95% confidence level.

3 Results and discussions

3.1 Organics degradation and water content during bio-drying

Figure 1 presents organics degradation rate and water content during bio-drying. The calculation equations are listed in the appendix. In the first 4 days, the Aerobic had a higher organics degradation rate than the Combined 1 and Combined 2, due to more oxygen supplied. Also, from day 5 to day 8, more organics were degraded for the Aerobic. From day 9 on, both Combined 1 and Combined 2 had higher organics degradation rates than the Aerobic, due to more organics available for the combined processes. As for the total rates of organics degradation, the Aerobic had the highest rate, followed by the Combined 2 and Combined 1. The water contents for Combined 1, Combined 2 and Aerobic were mitigated during bio-drying. After bio-drying, the Combined 2 had the lowest final water content, followed by the Aerobic and Combined 1 (**Figure 1b**).

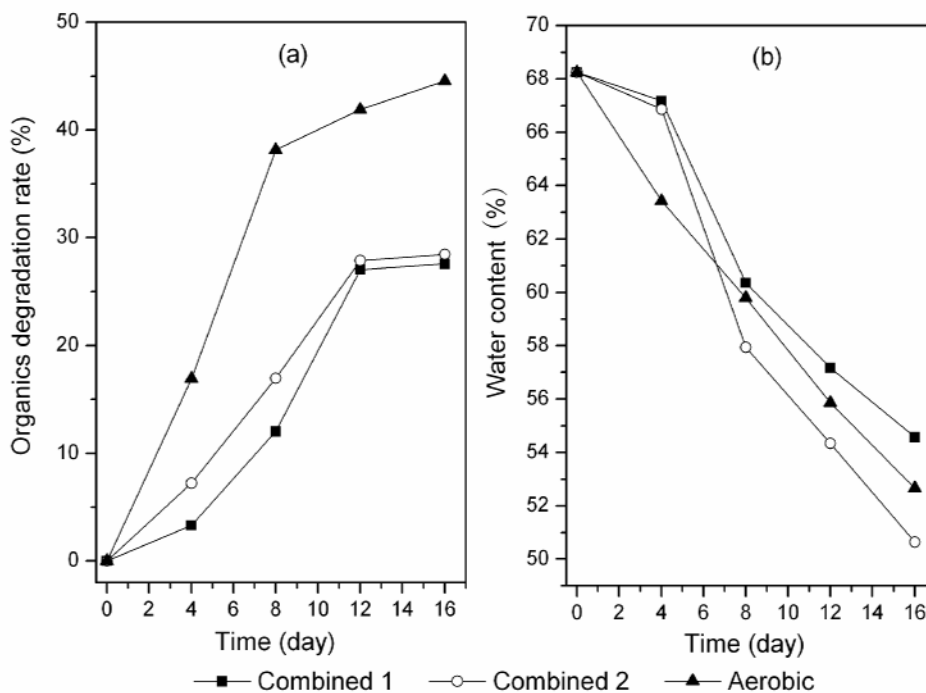


Figure 1 Organics degradation rate and water content during bio-drying

(a) Organics degradation rate; (b) Water content

3.2 Sorting efficiency during bio-drying

The sorting efficiency could be evaluated by the criterion as **eq.(1)** (NORBU ET AL., 2005).

$$SE = \frac{P_{<60}}{W} \times 100\% \quad (1)$$

where, SE (%) was the sorting efficiency, $P_{<60}$ (kg) was the amount of underflow fractions (under 60-mm screens) and W (kg) was the total waste.

Figure 2 indicates the evolution of the sorting efficiency of MSW during bio-drying. Obviously, the bio-drying could effectively improve the sorting efficiency for all of the three batches. After bio-drying, the sorting efficiencies for the Combined 1, Combined 2 and Aerobic were 62%, 71% and 68%, significantly enhanced from the initial of 34%. In the first 12 days, the sorting efficiency followed a decreasing order of the Aerobic > Combined 2 > Combined 1, resulting from different granule sizes reduced by organics degradation. At the last period of bio-drying, however, the Combined 2 had the highest sorting efficiency, attributed to the lowest final water content of MSW. As a whole, the sorting efficiency was correlated with the water content of MSW negatively (correlation coefficient, $R=-0.89$) and the organics degradation rates positively (correlation coefficient, $R=0.92$).

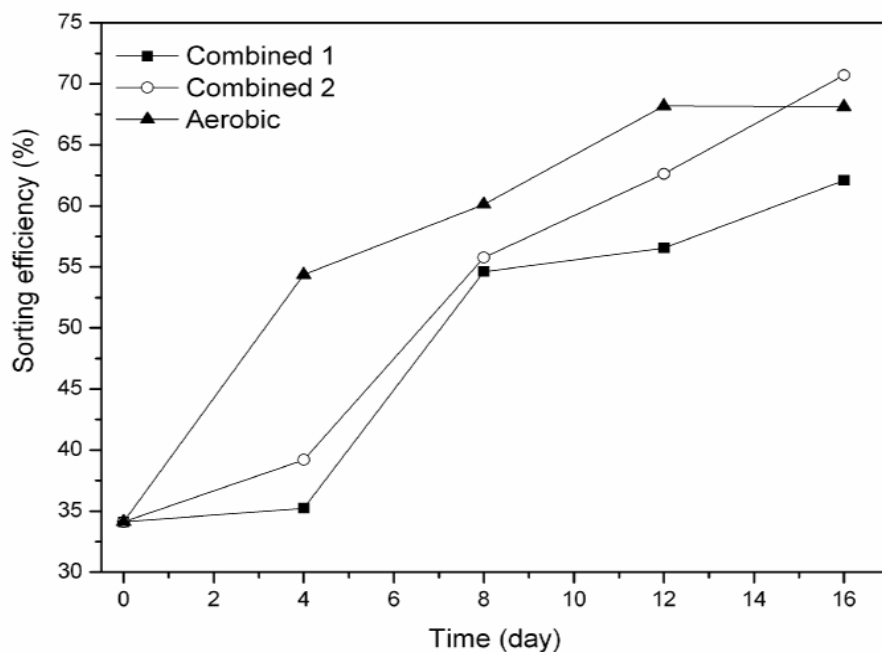


Figure 2 Evolution of the sorting efficiency of MSW during bio-drying

3.3 Heating values during bio-drying

The high heating value (HHV) indicated the quantity of heat generated from the complete combustion of the dry material, while the low heating value (LHV) reflected the

heating value of wet material. The bio-drying played an important role in the improvement of both HHVs and LHVs of MSW. After bio-drying, the HHVs were enhanced from 15400 kJ/kg to 19600 (Combined 1), 20100 (Combined 2) and 19900 kJ/kg (Aerobic). Furthermore, for Combined 1, Combined 2 and Aerobic, the LHVs were respectively improved to 7540, 8590 and 8260 kJ/kg from the initial of 3557.9 kJ/kg. **Figure 3** indicates the correlation between the heating values with organics degradation rates and water contents during bio-drying. The HHVs were positively correlated with organics degradation rates (correlation coefficient, $R=0.90$). This could be explained that the ratio of plastics fraction was enhanced as a result of organics degradation while the plastics had a high HHV. The LHVs were negatively correlated with water content ($R=-0.96$).

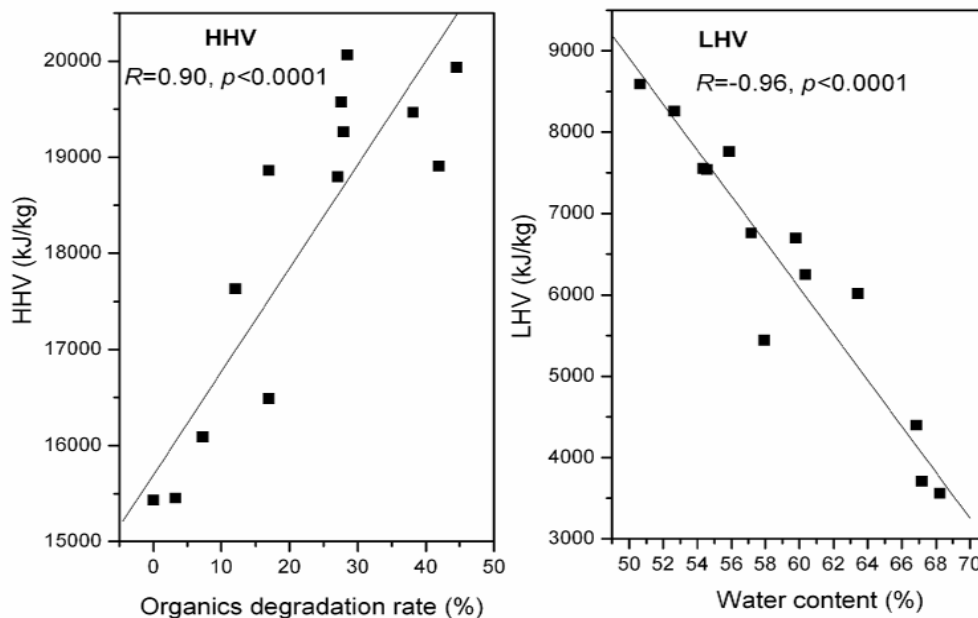


Figure 3 Correlation between the heating values with organics degradation rates and water contents during bio-drying

3.4 Emissions of HCl, SO₂ and NO_x and Potential for PCDD/Fs formation in the combustion during bio-drying

The emissions of HCl, SO₂ and NO_x in MSW combustion during bio-drying are shown in **Figure 4**. The HCl emissions of combustion increased during bio-drying with a decreasing order of the Aerobic > Combined 2 > Combined 1. After bio-drying, the HCl emissions in the combustion of MSW increased by 74.8%, 35.2% and 38.1% for the Aerobic, Combined 1 and Combined 2, respectively. Moreover, there was a positive correlation

between the HCl emissions and organics degradation during bio-drying, with a correlation coefficient of 0.67.

There was a peak for SO₂ emissions in the combustion on day 4 or 8. This was a result of the increase of sulfurs concentration in organics fraction of MSW and the increase of plastics fraction containing much less sulfurs during bio-drying. Nevertheless, the bio-drying would still result in the increase of SO₂ emissions. On day 16, the SO₂ emissions for the Aerobic, Combined 1 and Combined 2 increased by 29.3%, 7.6% and 10.2% respectively, when compared with the initial.

Interestingly, the NO_x emissions could be mitigated by bio-drying especially. In the first 8 days, the combined processes released more NO_x than the Aerobic, attributed to the lower organics degradation rates (**Figure 1**). From then on, similar emissions of NO_x were observed for the Aerobic, Combined 1 and Combined 2. At the end of bio-drying, the NO_x emissions in the combustion of MSW were minimized by approximately 25%. The NO_x emissions were negatively correlated with organics degradation, with a correlation coefficient of -0.60.

The formation of dioxins during combustion could be attributed to either inorganic chlorides or organic chlorines with insignificant differences (HATANAKA ET AL., 2000; HATANAKA ET AL., 2005; YASUHARA ET AL., 2001; WIKSTRÖM ET AL., 1999; WIKSTRÖM AND MARKLUND, 2001). The PCDD/Fs formation was mainly influenced by the combustion conditions (WIKSTRÖM AND MARKLUND, 2001). Under a certain combustion condition, for the samples consist of the same ingredients, the dioxin formation or toxic equivalent (TEQ) was quantitatively correlated with chlorine contents (WIKSTRÖM AND MARKLUND, 2001; YASUHARA ET AL., 2001; YASUHARA ET AL., 2002). Therefore, under the same combustion conditions described by YASUHARA ET AL. (2002), a regression equation for TEQ (Y) and chlorines content (X) of "Y = 0.738X + 0.115" could be used to predict the potential for PCDD/Fs formation. The TEQ in the combustion during bio-drying is presented in **Table 1**. The bio-drying could cause the increase of TEQ and the Aerobic had the highest values, followed by Combined 2 and combined 1. Compared with the initial, the potential for PCDD/Fs formation after bio-drying increased by 58.2%, 30.4% and 30.3% for the Aerobic, Combined 1 and combined 2, respectively. There was a positive correlation between the potential for PCDD/Fs formation and organics degradation with a correlation coefficient of 0.91.

Assumed that 1 kg of raw MSW and bio-drying products was combusted, the combustion emissions were showed in **Table 2**. Unfortunately, the bio-drying caused the increase of the emissions of combustion gases. However, besides the combustion emissions, the heating value was also considered for a better combustion performance. Thereby, the index (*I*), defined as the ratio of gas emissions to LHV, was introduced to

evaluate the combustion performance. I values for HCl, SO₂, NO_x and PCDD/Fs before and after bio-drying are also listed in **Table 2**. Interestingly, the potential emissions of combustion gases per LHV were significantly mitigated after bio-drying, as indicated by I values. Furthermore, the Combined 2 was proposed for bio-drying due to the lowest I value. Therefore, the bio-drying was favorable for the improvement of combustion performances when considering LHVs.

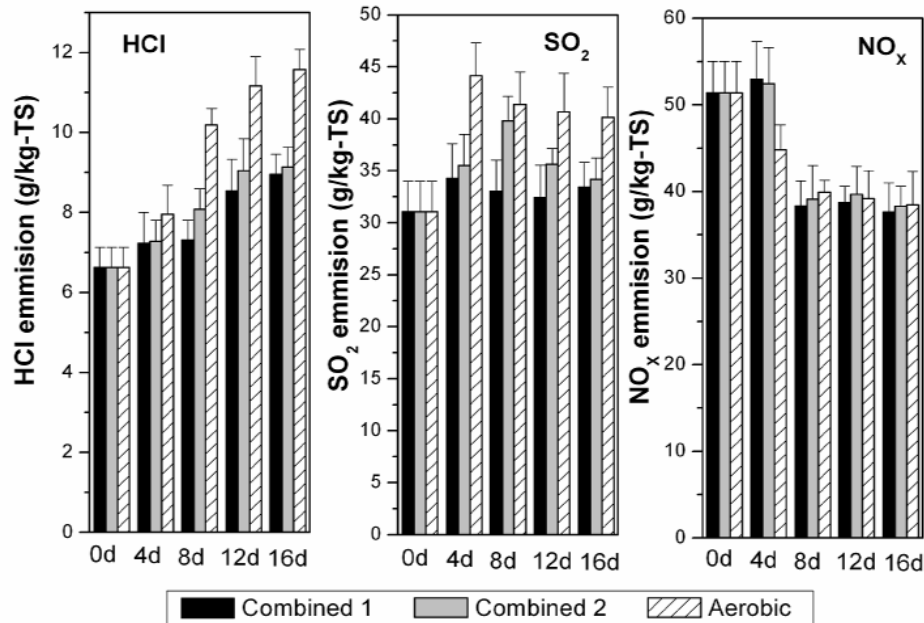


Figure 4 Combustion emissions of HCl, SO₂ and NO_x during bio-drying

Table 1 Potential of TEQ formation in the combustion of MSW during bio-drying

Time	Inorganic chlorine (g/kg-TS)			Organic chlorine (g/kg-TS)			Potential of TEQ ^a for- formation (mg/kg-TS ^b)		
	A	B	C	A	B	C	A	B	C
Day 0	9.793	9.793	9.793	2.182	2.182	2.182	0.999	0.999	0.999
Day 4	10.652	10.681	11.659	2.424	2.473	2.595	1.080	1.086	1.167
Day 8	11.421	11.539	15.032	2.617	2.680	3.387	1.151	1.164	1.474
Day 12	12.395	12.934	16.045	2.809	3.013	3.630	1.237	1.292	1.567
Day 16	13.106	13.026	16.178	2.990	3.048	3.680	1.303	1.301	1.581

^a TEQ: toxic equivalent; ^b TS: total solid; A: Combined 1; B: Combined 2; C: Aerobic.

Table 2 Combustion emissions *a* and *I* *b* for HCl, SO₂, NO_x and PCDD/Fs before and after bio-drying

Samples	HCl (g)	<i>I</i> _{HCl} (mg/kJ)	SO ₂ (g)	<i>I</i> _{SO2} (mg/kJ)	NO _x (g)	<i>I</i> _{NOx} (mg/kJ)	PCDD/Fs (mg TEQ)	<i>I</i> _{PCDD/Fs} (ng TEQ/kJ)	
Raw MSW	2.1	5.9	9.9	27.5	16.3	45.5	0.32	0.9	
Bio-drying products	A	4.1	2.6	15.2	9.8	17.1	11.0	0.59	0.4
	B	4.5	2.1	16.9	8.1	18.9	9.0	0.64	0.3
	C	5.5	3.0	19.0	10.3	18.2	9.8	0.75	0.4

^a Combustion emissions were calculated based on 1 kg materials; ^b *I*: ratio of gas emissions to LHV; A: Combined 1; B: Combined 2; C: Aerobic.

4 Conclusions

During bio-drying, the sorting efficiency was found to be correlated with water content negatively and organics degradation positively. The high heating values and low heating values were negatively correlated with organics degradation and water content, respectively.

The bio-drying would result in the increase of HCl and SO₂ emissions and the potential for PCDD/Fs formation in the combustion of MSW. Nevertheless, the NO_x emissions could be reduced by bio-drying. Interestingly, the bio-drying could improve the ratio of gas emissions to LHV significantly, although it resulted in the increase of the emissions per kg of combustion wastes.

As a whole, the bio-drying was not only favorable for the sorting and energy recovery, but also could improve the ratio of gas emissions to low heating values. Therefore, the bio-drying could be proposed as an effective strategy before resource recovery or combustion of municipal solid wastes with high water content.

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