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# Research and demonstration results for a new “Double-Solution” technology for municipal solid waste treatment

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ABSTRACT

In this paper, the pyrolysis characteristics of six typical components in municipal solid waste (MSW) were investigated through a TG-FTIR combined technique and it was concluded that the main pyrolysis process of the biomass components (including food residues, sawdust and paper) occurred at 150–600 °C. The main volatiles were multi-component gas including $H_2O$, $CO_2$, and CO. The main pyrolysis temperatures of three artificial products (PP, PVC and leather) was ranged from 200 to 500 °C. The wavelength of small molecule gases ($CH_4$, $CO_2$ and CO) and the the chemical bonds (C=O and C=C) were observed in the infrared spectrum Based on the pyrolysis temperature interval and volatile constituent, a new “double-solution” process of pyrolysis and oxygen-enrichment decomposition MSW was designed. To achieve this process, a double-solution project was built for the direct treatment of MSW (10 t/d). The complete setup of equipment and analysis of the byproducts has been reported in this paper to indicate the performance of this process. Energy balance and economic benefits were analysed for the process supporting. It was successfully demonstrated that the double-solution process was the environmentally friendly alternative method for MSW treatment in Chinese rural areas.

## 1. Introduction

In China, municipal solid waste (MSW) had not been subjected to collection and transportation by classified waste types which has resulted in higher moisture content, more complex composition, and lower average calorific value (Zhang et al., 2010). Therefore, the management and disposition of MSW in China is difficult. In Chinese cities, landfill disposal and incineration for power generation had been the most popular techniques applied to securely dispose of MSW (Hargreaves et al., 2008). However, MSW produced in rural areas (accounting for 40% in China) was not included in the MSW collection and transportation system. Townships in China with developed economies and facilitation transport utilized the mode of village-collection, town-transfer, and county-centralized treatment to dispose of MSW. Simple-incineration and simple-landfill have been widely applied in Chinese rural areas without convenient transport, or when too far from a centralized disposal centre (Mastellone et al., 2009). However, simple-incineration and simple-landfill come with a high risk of environmental pollution. In this context, developing new technologies for MSW disposition is of great significance.

In recent years, a typical MSW treatment technology called pyrolysis technology has gradually been applied. It has the significant advantage of effective control of pollution, small footprint, simplicity of operation and so on, however, current pyrolysis technology is still inadequate. For example, with unsorted MSW, most of the pyrolysis technologies require a storage site for separation which resulted in higher investment and more complex processes in the operation (Koehler et al., 2011). Moreover, pyrolysis gas produced by the process has not been fully utilized, and the pyrolysis process required external energy, leading to low thermal efficiency. In addition, pyrolysis technology often fails to treat inorganic components at sufficiently with high temperature (Kim et al., 2004).

The most important part of the pyrolysis technology is the reactors. The reported reactors for MSW pyrolysis include fixed-bed reactors, rotary kilns, fluidised bed reactors and some innovative reactors (Chen et al., 2014). The fixed-bed reactor is characterized by a low heating rate (HR) due to its low heat transfer efficient. Therefore, when a greater sample mass is fed in, the temperature inside the sample is not uniform and the feedstock is decomposed at different temperatures. Thus, fixed-bed reactors have seldom been adopted in scale-up facilities due to their inefficiency. In comparison, rotary kilns are more efficient than fixed-bed reactors in heating up the feedstock. However, the small wall surface over

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which the unit mass of the feedstock and the coarse size of the resulting particles, results in a low HR. Fluidised-bed reactors are characterized by a high HR and good blending of the feedstock. Therefore, fluidised-bed reactors are more frequently used to describe the influence of temperature and residence time on pyrolysis behavior and products. Although fluidised-bed reactors have been extensively adopted in laboratory studies, their industrial application is not common for MSW pyrolysis. Tubular reactors are generally heated externally, and it is easy to design and run a tubular reactor if the heat transfer coefficient is known because of its simplicity and safety. As a typical tubular reactor, the screw tube, with low construction and operation costs, appear to have great prospects. However, tubular reactors have the same rigid requirements for MSW pretreatment as the fluidised-bed reactors due to the small channel for passage of MSW. In addition, erosion caused by sand and other hard solids contained in the MSW could be a risk for this reactor, and heat transfer coefficients are not well defined for different waste types (Chen et al., 2015a,b).

In summary, pyrolysis reaction devices are usually not adequate for MSW treatment. The pyrolysis processes that have been commercialized also need to be improved in terms of their thermal efficiency, secondary pollution control, and process simplification. Therefore, for the work reported in this paper, the thermogravimetry-Fourier transform infrared spectroscopy TGA-FTIR system was employed to investigate the pyrolysis characteristics of municipal solid waste and to realize reasonable design and precise control of pyrolysis reactions. Based on the TGA-FTIR results, a complete setup of pyrolysis technology and equipment for MSW treatment was developed. Based on this technology, a double-solution process was developed for the direct treatment of MSW (10 t/d) and results on this technology was reported herein. To evaluate the environmental performance of the process, the characteristics of the by-products were analysed.

## 2. Analysis of MSW pyrolysis characteristics

### 2.1. Experimental section

#### 2.1.1. Materials

According to the types of MSW components, we chose six main components of MSW for pyrolysis characterization, including food residues, paper, sawdust, plastics (PP and PVC), and textiles (leather). Food residues, paper and sawdust were dried at 105 °C for 8 h and ground to a particle size of less than 0.25 mm. PP, PVC and leather with a particle size of about 75 μm were purchased from Shanghai Electrical and Mechanical Technology Co, Ltd. Table 1 shows the elements of the samples and the results of industrial analysis. Food residues, paper and sawdust are biomass materials with carbon content and oxygen content close to 30% and 50%, respectively. Leather, PVC and PP are synthetic materials, with higher contents of carbon and volatiles, and a relatively low content of fixed carbon.

#### 2.1.2. Experimental method

Thermogravimetry-Fourier transform infrared spectroscopy (TG-FTIR) not only can determine the relationship between the weightlessness and temperature of thermal decomposition, but also can detect the composition of the pyrolysis products. In this experiment, the TG-FTIR technique was used to carry out atmospheric pyrolysis with a non-isothermal thermogravimetric method. The experimental atmosphere was 99.99% high purity nitrogen with a flow rate of 50 mL/min. The experiment was carried out at a heating rate of 10 °C/min, rising to 1000 °C from the ambient temperature. Thermogravimetric analyser was connected with an infrared analyser using pipe insulation so that the pyrolysis gas all entered the infrared spectrometer and the composition of the pyrolysis gas was determined in real time. The thermogravimetric analyser was a Thermax500 thermogravimetric analyzer manufactured by ThermoCahn, USA. The thermal balance accuracy was 1 μg. Fourier transform infrared spectroscopy was Vector22 produced by Bruker company, wavenumber ranged from 4000 to 450 $\text{cm}^{-1}$ with a resolution of 1 $\text{cm}^{-1}$, cycle scan 8 times.

### 2.2. Results and discussion

#### 2.2.1. TG/DTG analysis

TG and DTG curves of all samples are presented in Fig. 1. As shown, the pyrolysis process of combustible components could be divided into three regions, region I (preheating), region II (organic decomposition), region III (secondary decomposition).

The main pyrolysis temperature intervals, the weight loss during each pyrolysis stage, and the temperature for maximum weight loss of the six components during each pyrolysis stage are given in Table S1. As shown in Fig. 1(a–c), The thermal decomposition of food residues, paper and sawdust was similar, which could be regarded as the hydrolysis of cellulose, hemicellulose and lignin (Gunasee et al., 2016). The preheating temperature was below 200 °C and the mass fraction curves of the three samples showed a decrease of 4.39%, 8.0% and 6.03%, respectively, this was caused by the evaporation of the free water and chemically combined water with increasing temperature. From Fig. 1(d–f), the preheating temperature range for PP, PVC and leather ranged from room temperature to 250 °C, there was only a slight loss of mass at this temperature range because the free water and chemically combined water content of leather, PP and PET were extremely low.

When the temperature rose from 200 to 500 °C, the six samples showed a significant change in the mass curve, corresponding to the second stage in the pyrolysis process. The temperature of fastest mass loss for each of the six components was 302, 310, 308, 479, 310 and 490 °C, respectively, which was quite close to the peak temperature for gas production. Over 50% of the mass loss for PP, PVC and leather occurred in this temperature range, mainly because the organic components in the samples were decomposed into tar, $CH_4$, CO, $CO_2$ and other substances.

When the temperature exceeded 600 °C, the third stage of pyrolysis was entered. It could be seen in the TG curves that the mass losses in this temperature range was not obvious. The mass

**Table 1**
Proximate and ultimate analysis of MSW.

| Samples | Proximate analysis | | | Ultimate analysis | | | | |
|---|---|---|---|---|---|---|---|---|
| | $A_d$% | $V_d$ | $FC_d$ | $S_{t,daf}$% | $C_{daf}$% | $O_{daf}$% | $H_{daf}$% | $N_{daf}$% |
| Food Residue | 2.91 | 76.49 | 20.60 | 1.199 | 31.267 | 52.06 | 8.73 | 6.67 |
| Paper | 2.11 | 79.33 | 18.56 | 0.12 | 33.99 | 46.35 | 5.31 | 14.07 |
| Wood | 1.86 | 67.60 | 30.54 | 1.1646 | 31.063 | 52.05 | 7.14 | 8.51 |
| Leather | 0.46 | 88.60 | 10.94 | 0.09 | 42.49 | 37.23 | 3.46 | 16.03 |
| PVC | 0.11 | 94.93 | 4.96 | 0.18 | 53.13 | 31.79 | 3.94 | 10.11 |
| PP | 0.08 | 89.99 | 9.93 | 0.895 | 52.47 | 20.03 | 4.57 | 0.794 |

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