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Effects of hydrothermal treatment on characteristics and combustion behaviors of municipal solid wastes

Liang Lu [a,*], Tomoaki Namioka [a], Kunio Yoshikawa [b]

[a] Department of Environmental Science and Technology, G5-8, 4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan
[b] Frontier Research Center Tokyo Institute of Technology, G5-8, 4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan

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ABSTRACT

The conversion of municipal solid wastes (MSW) to energy for co-combustion with coal may be a viable MSW disposal solution from the view point of suppression of the environmental pollution as well as reduction of coal consumption. This paper describes the application of innovative hydrothermal technology on different kinds of MSW to produce powder-like solid products appropriate for co-combustion with coal. In this work, three kinds of surrogated MSW (Japanese MSW, Indian MSW and Chinese MSW) different in composition and characteristics were subjected to the hydrothermal treatment (HT) at 220 °C and 2.4 MPa for 30 min. After the HT, the combustion behaviors of the samples were determined by investigating the sample weight loss (TG) and the rate of weight loss (DTG) through the thermogravimetric analysis (TGA). In addition, the effects of the HT on the characteristics and the combustion behaviors of the MSW were explored by comparing with three standard samples such as rice, cellulose and polypropylene (PP) both before and after the HT. The results obtained in this study can be drawn as the following: The HT is capable for converting MSW into uniform powder samples with low moisture content, regular shapes and high bulk density. During the HT, the hydrolysis reaction leads to the loss in volatile matter and the carbonization results in the gain in fixed carbon. The higher heating values of the three kinds of MSW after the HT are enhanced by 1.01–1.41 times (energy content per weight) and 6.39–9.00 times (energy content per volume). The combustion behaviors of the MSW in this study before the HT were dominated by the substance major in weight whereas for the ones after the HT, the intrinsic characteristics of the MSW can play an important role in determining the combustion behaviors.

1. Introduction

In recent years, many countries are facing with problems associated with municipal solid wastes (MSW) disposal especially in developing countries like China and India. In China, it is reported that at present, the per-capita generation of MSW has reached about 1 kg/day, and the annual total generation is approximately 150 million tons. About 90% of the total amount of MSW produced in China is disposed by landfilling. Most of the landfill sites in major cities were built in the early 1990s and now have reached the designed service life [1]. Moreover, the adverse environmental effects on soil, water and air drawn by the unsanitary and unstable landfills are demonstrated [2,3]. Like China, India is also confronting the same situation. Therefore traditional treatment is not only 'misappropriating' the land for human activity at a rapid speed but also threatening our planet and human health [4,5]. On the other hand, countries all over the world urge to promote the utilization of wastes for energy recovery especially for Japan which is known as a country short of energy resources.

In general, the compositional characteristics of MSW vary considerably from countries to cities, towns and regions. This is strongly influenced by the custom, living style, degree of development as well as regulation on MSW disposal, etc. On the other hand, MSW contains a lot of biomass such as wood, paper which could be useful resources through suitable waste-to-energy (WTE) treatments. So targets have to be established for further effective MSW utilization in which the thermal treatment especially combustion enjoys advantages that are not found in other methods [6]: outstanding reduction in waste volume, thermal destruction of toxic organic constituents, etc. Nevertheless, high moisture content of MSW makes it difficult to recover enough energy from the combustion process [7].

On the other hand, due to relatively large reserves and low price, countries worldwide rely heavily on coal for electricity generation and coal will continue to be the predominant fuel for the foreseeable future [8,9]. Consequently, greenhouse gas emissions from coal-fired power plants (CO_2, CH_4, etc.) have become a global concern. Nowadays a number of techniques have been proposed

* Corresponding author. Tel.: +81 80 4197 1027; fax: +81 45 924 5518.
E-mail address: lu.l.ae@m.titech.ac.jp (L. Lu).

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for reducing the greenhouse emissions from coal combustion among which the co-combustion of coal with biomass has earned the popularity because biomass is carbon neutral [10,11]. Studies and researches have confirmed that the co-combustion of coal with woody biomass has a positive effect both on environment and resource saving [12–14]. Furthermore, hydrothermally treated MSW is also proved to be able to co-combust with coal at a low blend ratio in our previous research [14], whereas little has been done related to the effects of hydrothermal treatment (HT) on the changes of characteristics and combustion behaviors of MSW.

Nowadays, the most crucial technical barriers in introducing MSW into existent combustion systems are (1) high moisture content of MSW accompanied with low bulk density and low heating value leading to low combustion performance; (2) heterogeneous compositions and properties resulting in unpredictable combustion behaviors.

In this research, three kinds of surrogated MSW (Japanese MSW, Indian MSW and Chinese MSW) which are different in compositions and characteristics were subjected to HT in a small-scale autoclave facility to find out the feasibility of the HT on converting MSW with high moisture content, irregular shapes and low bulk density into powder products with stable characteristics. The combustion behaviors were determined by investigating the sample weight loss (TG) and the rate of weight loss (DTG) with the help of thermogravimetric analysis (TGA) [14–22]. Moreover, in order to ensure the effective utilization of hydrothermally treated MSW, the effects of the HT on sample characteristics and the combustion behaviors were discussed by comparing the proximate analysis as well as the DTG profiles of the three kinds MSW and the three standard samples such as rice, cellulose and polypropylene (PP) which are the dominant components in the MSW before and after the HT. In addition, heating values of the MSW before and after the HT were also discussed. The objective of this work is to affirm the feasibility of the HT for treating different kinds of MSW aiming at enhancing the combustion performance and to clarify the effect of the HT on the characteristics and combustion behaviors of different MSW.

2. Experimental

2.1. Sources of material

In this research, three kinds of MSW produced in Japan, India and China were selected. Due to the difficulty in acquiring large amount of MSW to confirm the uniformity of their composition, the three kinds of MSW employed in this research were surrogated ones prepared according to Table 1 [23–25]. The Japanese MSW consists of huge amount of paper and food while the Indian MSW contains a lot of food with dominant inert substances. The Chinese MSW is abundant in food and plastics. The surrogated MSW were manually prepared by blending the representative substances together after being cut into small sizes with scissors. The selected representative wastes were such as papers composed of newspaper and tissue (paper is produced from pulp derived from wood and wood is mainly composed of cellulose), plastics composed of plastic bags and rubber glove (PP plastic bags for packing were chosen), woods composed of sticks and leaves, textiles composed of clothes, food residue obtained from a cafeteria (most of the food residue obtained were rice) and inerts composed of sands and soils.

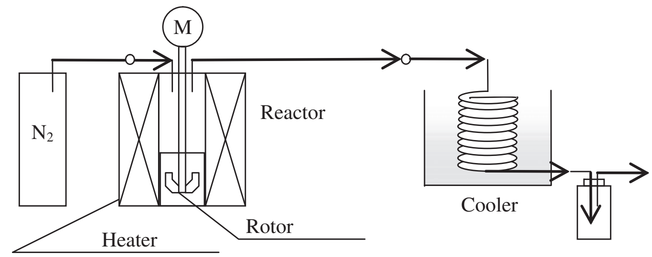

Fig. 1. Small-scale autoclave facility.

Considering that MSW is mainly composed of food, paper, plastics, wood (Table 1) and the sources of the surrogated MSW, three standard samples such as rice, cellulose and polypropylene (PP) standing for food, paper + wood and plastics were chosen as references.

With regard to sample size, both in the cases of fuel analysis and TGA, for hydrothermally treated samples, they were ground and sieved to the size in the range of 100–180 μm and so were the standard samples as rice and cellulose before the HT. For MSW samples before the HT, their sizes were as large as 1–2 mm. Especially, due to the difficulty in obtaining PP with small size, the size of PP granule in this research was about 2 mm.

2.2. Hydrothermal treatment

The three kinds of MSW were subjected to the HT using a small-scale autoclave facility shown in Fig. 1. The small-scale autoclave facility consists of a reactor, a heater and a cooler (steam condenser). Because the size distribution of the samples is not important for HT, samples with large size were directly used in the experiments. The MSW pre-blended with the same weight of water (20 g sample and 20 g water which is considered to be the most proper proportion according to the experiment attempts) was put into the reaction tube with the volume of 500 ml. Before experiment, nitrogen was introduced through a nitrogen cylinder in order to create an oxygen free environment in the reactor and then the reactor was sealed. As the temperature rose, the water added as well as the moisture in the MSW vaporized to form steam and the target pressure and temperature were 220 °C and 2.4 MPa. The holding time was 30 min. The rotor was kept stirring during the experiment ensuring the uniformity of the samples. After finishing the reaction, the heater was switched off and the residual steam was discharged to let the pressure and the temperature fall down to the atmospheric and room temperature. Then the products were taken out of the reactor.

In the case of standard samples, rice, cellulose and PP were treated in the same condition as MSW. Specially, PP was mixed with cellulose at the weight ratio of 1:1 in order to avoid its melting and sticking onto the rotor blade in the reactor.

2.3. Fuel analysis

Proximate analysis and the higher heating value (HHV) of the samples were measured before and after the HT for comparison.

Table 1
Composition of typical Japanese, Indian and Chinese MSW.

	Paper (wt.%)	Plastics (wt.%)	Wood (wt.%)	Food (wt.%)	Textiles (wt.%)	Inert (wt.%)	Total (wt.%)
Japanese MSW	42.9	6.8	9.0	35.9	4.4	1.0	100
Indian MSW	27.2	4.0	40.8		5.7	22.3	100
Chinese MSW	12.8	13.0	9.1	58.8	4.4	1.9	100