Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Characterization, thermochemical conversion studies, and heating value modeling of municipal solid waste

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ARTICLE INFO

Article history:
Received 8 May 2015
Revised 22 September 2015
Accepted 25 September 2015
Available online xxxx

Keywords:
Municipal solid waste characterization
High heating value
Multiple regression analysis

ABSTRACT

A study was carried out to examine the characteristics of municipal solid waste (MSW) from the City of Red Deer, Alberta, Canada. Experiments were performed for determining the moisture content, proximate and ultimate compositions, heating value of fourteen wastes in different categories. Their thermal weight loss behaviors under pyrolysis/torrefaction conditions were also investigated in a thermogravimetric analyzer (TGA). An empirical model was developed for the high heating value (HHV) estimation of MSW. A total of 193 experimental data were collected from this study and those in the literature, of which 161 data were used for model derivation; and, 32 additional data were used for model validation. The model was developed using multiple regression analysis and a stepwise regression method: HHV (MJ/kg) = 0.350 C + 1.01 H − 0.0826 O, which is expressed in terms of weight percentages on a dry basis of carbon (C), hydrogen (H) and oxygen (O). The validation results suggest that this model was effective in producing accurate outputs that were close to the experimental values. In addition, it had the lowest error level in comparison with seven other models from the literature.

1. Introduction

Waste-to-energy (WTE) processes generate energy or chemical products using municipal solid waste (MSW). Not only are they great alternatives to other MSW disposal methods, these methods also provide promising options to produce alternative fuels/chemicals by biochemical or thermochemical processes.

In biochemical conversion, MSW is broken down into smaller molecules by microorganisms under aerobic or anaerobic conditions with minimal energy input. However, this process is much slower compared to the thermochemical conversion and only suitable to the biodegradable wastes. In addition, separation of large amounts of non-beneficial water from the products causes additional problems.

Although thermochemical conversion is considered as a destructive process that consumes lots of energy, it still has a few advantages compared to biochemical conversion such as reduced water use, short production cycle and easier continuous operation. Thermochemical conversion technologies fall into three broad categories: incineration (also known as controlled combustion), pyrolysis (if conducted at a low temperature, pyrolysis can also be called torrefaction), and gasification.

Incineration is the most broadly used WTE technology. However, new WTE commercial projects are hard to get launched, due to environmental concerns and political pressure (Psomopoulos et al., 2009). On the other hand, pyrolysis and gasification technologies of MSW are still in laboratory scale research or commercial demonstration stages, due to the lack of adequate MSW characterization data for feasibility studies and facility design.

MSW is often quantified and characterized by the source of generation or the type of material that provides its physical composition. However, in the design of a WTE facility, it is also important to consider other factors, such as the moisture content, the volatile and fixed carbon contents, the proportion of non-combustibles, and the sulfur content. These characteristics are crucial for the selection of the technology, the capacity determination of the furnace/boiler, and the design of auxiliary facilities, such as flue gas cleanup equipment.

The heating or calorific value is one of the most important characteristics of MSW in determining the fuel's energy content. It is approximately inversely proportional to the capacity of a WTE furnace/boiler (Reddy, 2011) and is either measured by a bomb calorimeter or calculated by an empirical model. It is critical to have accurate and reliable heating value data for the design,

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http://dx.doi.org/10.1016/j.wasman.2015.09.036
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operation and maintenance of a WTE plant. However, not all MSW management facilities are equipped with bomb calorimeters in order to determine the heating values. Moreover, the experimental measurement of the heating value is tedious and requires advanced technical skills in the handling of equipment (Kathiravale et al., 2003).

The most common calculation method currently being used is the equation derived by Dulong (Kathiravale et al., 2003). However, the Dulong model was originally derived for coal and may not be suitable for the heating value estimation of MSW, due to the physical and chemical differences between coal and MSW. Other advanced models derived for coal or biomass are also not favorable choices.

The objectives of this study were, therefore, the collection of MSW characterization data and the development of an empirical model to accurately predict the heating values of MSW. In order to meet these objectives, various characterization tests were conducted, including the experimental heating value measurements of 14 different categories of MSW. A thermogravimetric analyzer (TGA) was used to simulate two thermochemical processes, namely pyrolysis and torrefaction, to study the thermal weight loss behavior of MSW. Solid products (chars) were collected, quantified and analyzed, with an emphasis on their elemental compositions. In addition, different statistical analysis methods were employed to build an empirical model that can calculate the high heating values (HHVs) of MSW.

2. Material and methods

2.1. Sampling

The sampling of 14 different landfill wastes was conducted at the City of Red Deer's Waste Treatment Facility in Alberta, Canada. The physical composition of the landfill waste from the City of Red Deer is shown in Fig. 1. Around 0.5–2.0 kg materials were sampled for each category; and their dimension size range from 100 to 5000 mm. The samples were in their original conditions that did not experience any washing or cleaning process. All samples were dried immediately after sampling to obtain their true moisture contents. After drying, these samples were separately sealed and contained within plastic bags or bottles with a desiccant agent based on the relevant category.

According to the material properties, the samples were divided into 7 categories: wood waste, rubber/leather/multiple/composite organic material, non-recyclable paper (food packaging/newspaper/paper towel/paper cups, no cardboard), carpet waste, rigid plastic, textile waste, and film/styrofoam waste. Each category contained two samples from different sources: residential; and ICI (industrial, commercial and institutional). The ICI wastes can come from construction industry, commercial facilities, and institutions such as university or hospital.

This sampling range covered almost all types of organic landfill MSW, except waste water sludge, food wastes, human fecal matter, hospital wastes, manures and animal wastes. These organic wastes were not considered in this work due to their possible biohazardous properties, since the sampling, storage, pretreatment and experimental handling of these wastes require special disinfection or bio-protection instruments. Inorganic components or recyclable wastes, such as glass or metal, were not considered in our sampling range.

2.2. Basic characterization

Basic characterization in this study refers to four types of measurements: moisture content determination, proximate analysis, ultimate analysis and heating value determination. Every sample was tested three times for each type of the measurement; then, an average value was calculated and used to represent the sample's characteristic result.

The moisture content was measured using an oven drying procedure, with the specimen weighed outside of oven, according to ASTM D1348-94(2008). The samples were dried in an oven at 70 °C to a constant weight.

After the determination of their moisture contents, the dried samples were ground by grinders (Blendtec Professional 750 blender and Black & Decker coffee bean grinder) at room temperature. Combination use of two different grinders help break different samples (rigid or ductile) more thoroughly into homogeneous particles. The grinding process was occasionally stopped if obvious over-heat was observed, in order to not result in changes of materials' characteristics and also not exceed the grinder's operation

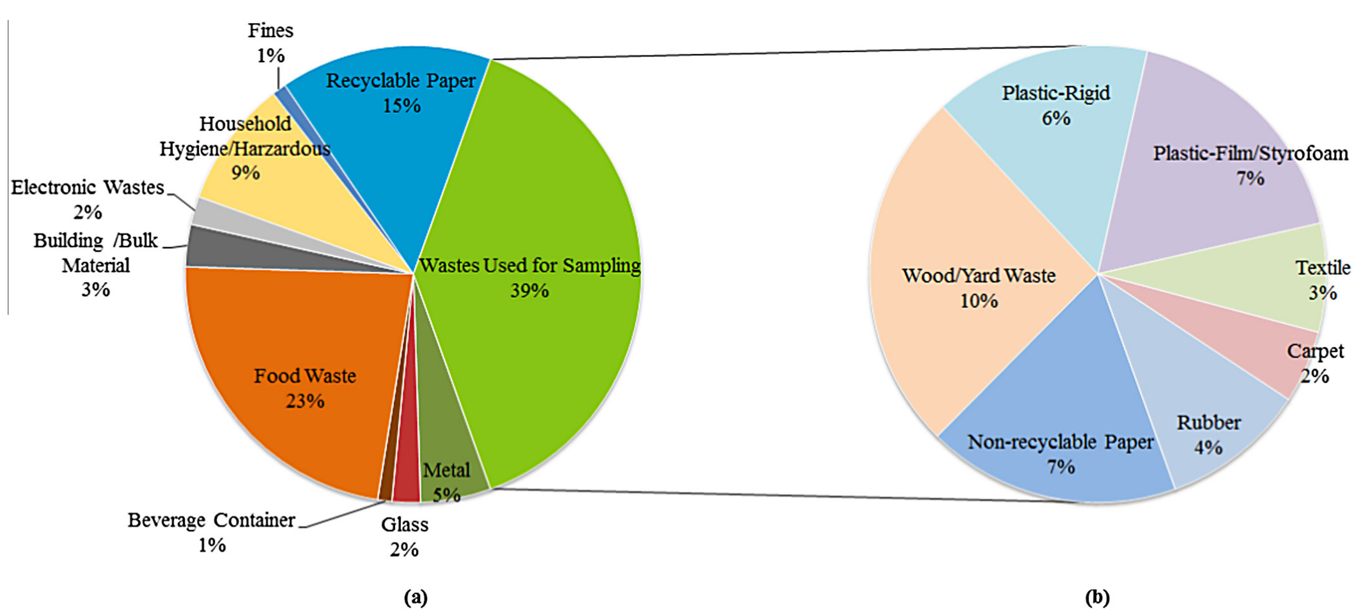

Fig. 1. Physical composition of: (a) MSW from the City of Red Deer (as-received basis), and (b) wastes used for sampling.

Please cite this article in press as: Shi, H., et al. Characterization, thermochemical conversion studies, and heating value modeling of municipal solid waste. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.09.036