Sustainable Environment Research 26 (2016) 51–54

Contents lists available at ScienceDirect

Sustainable Environment Research

journal homepage: www.journals.elsevier.com/sustainable-environment-research/

Original research article

Characterization of Singapore RDF resources and analysis of their heating value

Lei Zhao [a], Apostolos Giannis [a], Wan-Yee Lam [b], Sheng-Xuan Lin [a], Ke Yin [a], Guo-An Yuan [a], Jing-Yuan Wang [a, b, *]

[a] Residues and Resource Reclamation Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, Singapore, 637141, Singapore
[b] School of Civil and Environmental Engineering, Nanyang Technological University, Singapore, 639798, Singapore

ARTICLE INFO

Article history:
Received 1 May 2015
Received in revised form 26 August 2015
Accepted 18 September 2015
Available online 5 April 2016

Keywords:
RDF
Landfill mining material
Chicken manure
Calorific value

ABSTRACT

Refuse Derived Fuel (RDF) was formulated from several municipal waste components in Singapore in order to maximize energy efficiency and minimize the environmental impacts. At first, the physicochemical properties (proximate and ultimate analysis, chloro, heavy metals) and the heating values of waste components were analyzed to assess their thermal behaviour. Three RDF prototypes were formulated by combining individual waste type in various fractions with respect to their properties and heating values. Landfill mining material and chicken manure were also involved in the RDF formation as alternative fuel sources. Optimum RDF was formulated consisting of 42% plastics, 41% paper/cardboard, 7% textile and 10% horticultural waste, based on the existing Singapore waste composition. This RDF had a lower heating value of 23.7 MJ kg^{-1}, which was less than mineral fuel but it could meet the fuel requirements given in the European standards. The addition of chicken manure and landfill mining material in RDF lowered the heating value and increased heavy metal concentration, but they are considered good alternative fuel. It is believed that power plants or dedicated incinerators could be potential end-users of RDF in Singapore.

1. Introduction

Municipal solid waste (MSW) management is one of the most eminent environmental problems arising from rapid industrialization, increasing population and economic development. 130 Mt of MSW are incinerated each year in the 600 Waste-to-Energy (WTE) plants worldwide [1]. The WTE plants provide a good alternative to relieve the environmental burdens coming from landfilling. For land-scarce Singapore, incineration is an effective approach to extend the service life span of the one and only landfill [2].

Energy recovery through WTE plants is a beneficial solution in face of the rising energy prices. The high calorific value fuel, which is produced after the removal of non-combustible materials such as ferrous materials, glass, grit etc., is termed refuse-derived fuel (RDF). RDF typically consists of paper, plastic, textiles and other combustible materials. It presents several advantages as a fuel compared to raw MSW such as higher heating value, more homogeneous physicochemical composition, ease of storage, handling and transportation, lower pollutant emissions and reduced excess air requirement during combustion. For example, the raw MSW has a typical calorific value of 9.1 MJ kg^{-1} while the processed RDF pellets have a typical calorific value of 18 MJ kg^{-1} [3].

Current regulations set high quality standards for RDF so that it can be readily accepted as a substitute fuel in most combustion systems without major modifications. However, the production of high calorific value RDF requires complex production lines with a greater number of separation steps, leading to a higher production costs which reduce the market prospect of the product [4–6]. In order to obtain relatively stable RDF production, the waste streams need to be dried, sorted and homogenous [3]. Dried feedstock reduces the amount of required start-up energy. Homogenous waste produces stable calorific value. Using these approaches, the quality of RDF is regulated for maximizing the effectiveness of WTE plants.

* Corresponding author.
E-mail address: jywang@ntu.edu.sg (J.-Y. Wang).
Peer review under responsibility of Chinese Institute of Environmental Engineering.

http://dx.doi.org/10.1016/j.serj.2015.09.003

The aim of this paper was to produce a high quality RDF by sorting materials from several waste streams in Singapore. It was analyzed the physiochemical properties and energy content of several components of MSW to determine their suitability for RDF production. It was further identified the components with high heavy metals and Cl concentration, and eliminated from the waste stream. Considering these factors, three different RDF mixtures were formulated to determine the optimal quality in terms of high calorific value and low environmental impacts.

2. Materials and methods

2.1. Materials

Several waste components were collected for this study such as plastics, paper/cardboard, textile, horticulture and food waste. Landfill mining materials and chicken manure from poultry farm were also included in RDF mixture. Landfill mining provides the opportunity to recover combustible materials that could otherwise be used to generate electricity in WTE plants. The feasibility of using landfill mining materials and chicken manure in RDF production was evaluated in the present study, thereby reducing the volume occupied by these materials and extending the service time of existing disposal and landfill sites. Fig. 1 presents the amount of MSW disposed in Singapore in 2014.

2.2. Proximate and elemental analysis

Before proximate and elemental analysis, the waste components materials were shredded in a cutting mill using a 0.5 mm sieve. Proximate analysis was conducted according to ASTM Standard D5142 [7]. Several parameters were determined including moisture, ash and volatile matter content. Elemental analysis (CHNOS) was conducted using Elemental analyser (Germany).

2.3. Calorific value determination

The calorific value was tested using a bomb calorimeter (IKA, Germany). The analysis was duplicated. The bomb calorimeter provided Higher Heating Value (HHV). The Lower Heating Value (LHV) was determined by using the HHV obtained from the bomb calorimeter including the hydrogen content and moisture of the waste components [8]. Equations (1) and (2) were used to determine the LHV of the waste samples:

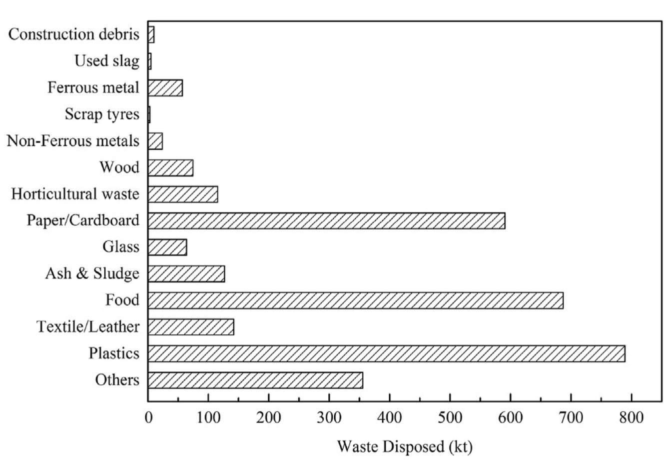

Fig. 1. Amount of waste disposed in Singapore (2014).

$$LHV_{dry} = HHV_{dry} - 2441.8 \times \frac{9H_{dry}}{100} \quad (1)$$

$$LHV_{wet} = LHV_{dry} \times \frac{100 - W}{100} - 24.42W \quad (2)$$

where: HHV_{dry} is the HHV of a dry sample (kJ kg^{-1}), LHV_{dry} is the LHV of a dry sample (kJ kg^{-1}), H_{dry} is the weight percentage of hydrogen, LHV_{wet} is the LHV of a wet sample and W is the percentage of moisture in sample. Heat energy for vaporisation of water is 2442 kJ kg^{-1}.

2.4. Cl determination

Chloro content in waste component was analysed using a combination of High Pressure Decomposition Device (HPDD) Method with Ion Chromatography (IC) according to ASTM Standard D808 [9]. This method uses a Bomb Calorimeter to perform HPDD Method. 0.8 g of sample was used, while 5 mL of sodium carbonate (50 g L^{-1}) solution was added to absorb chlorine gas produced during combustion. The solution in the bomb was collected in a beaker by rinsing the interior of the bomb, the sample cup and the lid with deionised water. The collected solution was filtrated through a 0.45 μm filter paper, then brought up to 50 mL with deionized water and tested for chloride content using an IC analyser (Dionex ICS-1100, USA).

2.5. Heavy metals analysis

The metal concentrations in the samples were measured through by microwave digestion. The microwave digestion was carried out by dissolving 0.1 g of sample in concentrated nitric acid. The samples were subjected to controlled pressure and temperature for 3 h. Triplicates were carried out for each waste type. Afterwards, the samples were diluted to 25 mL and analyzed in Inductively Coupled Plasma spectrometry.

3. Results and discussion

3.1. Waste characterisation

3.1.1. Proximate analysis

Table 1 shows the results of the proximate analysis for the individual waste component. Moisture, ash content and volatile matter (wt%) could provide a good indication of the combustibility of the MSW [10]. The LHV values were calculated on wet basis. Results shows that plastics (i.e., Polypropylene/polyethylene (PP/PE), polyethylene terephthalate (PET) and polystyrene (PS)) contained higher percentage of volatile matter and higher LHV_{wet}

Table 1
Proximate analysis of waste components.

Sample	Moisture (%)	Ash content (%)	Volatile matter (%)	LHV (MJ kg^{-1})
PP/PE	0.06	0.03	99.4	43.2
PS	0.12	0.02	99.8	39.9
PET	0.5	0.1	94.6	21.9
Textile	5.4	0.9	93.6	16.6
Landfill mining materials	21.2	8.1	63.3	14.1
Paper	7.1	17.1	75.6	12.1
Horticulture	45.3	2.7	46.5	8.9
Chicken manure	16.3	34.3	51.4	7.8
Biomass waste	73.8	1.1	21.4	4.1