Study of Hyrothermally RDF Samples for Energy Applications: Thermogravimetric Analysis

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Abstract - It has become the need of our society to use municipal solid waste (MSW) under the vision of waste-to-energy (WTE) strategy in order to utilise MSW and to address the energy issues over the world. With respect to the energy, refused derived fuel (RDF) is the energy source of MSW, whose reliability and quality is analysed in this work. The energy content and combustion characteristics of RDFs in oxygen-enriched environment are explored. Three different RDFs (RDF-A, RDF-B and RDF-C) had been adopted from three different waste materials. Plastics, wood and cloth are the major constituents in the recipe of taken RDFs. Proximate and ultimate analysis, thermogravimetric analysis and calorific value tests had been performed for all RDF samples. The results showed that the RDF-A contains high amount of carbon (52.44%) and hydrogen (4.184%) content and good calorific value (5278 k.cal/kg), which leads to a better fuel quality. TGA analysis revealed that with the increase in the volatile matter fraction of RDFs, the retention time under combustion atmosphere has also been increased accordingly. By analysing of all results, RDF-A was suggested to be the best for energy applications and can be used as fuel for various combustion reactions.

1. Introduction

Municipal solid waste (MSW) is a composite material of different wastes, generated by our society. A huge amount of MSW is generated continuously in different ways from daily activities (Haydar & Masood, 2011). Various kinds of wastes such as plastics, wood, glass, metals, cloth, and paper, are dumped into landfill sites every day. Proper solid waste management (SWM) is very important in order to minimize harmful effects of hazardous solid waste on the environment (Šuhaj, Haydary, Husár, Steltenpohl, & Šupa, 2019; Haydar & Masood, 2011). SWM is a serious problem in Pakistan, as landfill sites are depleting with the passage of time. In addition to that due to environmental pollution some sustainable solutions should be implemented to mitigate this serious issue. The uncontrolled open dumping sites are a serious threat for the environment and surroundings in the densely populated areas, hence, affecting the public health adversely (Khalid Farooq & Kumar, 2013). Waste to energy (WTE) strategies, is a sustainable approach to manage the municipal solid and in current electricity scenario. MSW can become opportunity to mitigate this issue by converting the waste into useful energy and electricity.

For the last few decades, to solve both energy and waste issues simultaneously, manufacturing of refused derived fuel (RDF) has become the area of interest for the researchers as one of the WTE
strategies (Rada & Andreottola, 2012). It is more convenient and efficient to store, transport and handle RDF than its parent MSW form (Garg, Smith, Hill, Simms, & Pollard, 2007). In addition, a well segregated RDF has higher calorific value and good combustion behavior for its application as fuel (DmitryPorshnov, Ozols, Ansome-Bertina, Burlakovs, & Klavins, 2018). The use of RDF in ‘mass burn’ technologies (incineration) and in ‘conversion’ technologies (gasification, pyrolysis) is gaining wide attention in the world (Özge, Mutlu, Yaman, & Acma, 2016). Some of previous studies described the thermal behavior of various RDFs on the basis of ultimate and proximate analysis and the results from these studies revealed that the RDF samples consists of higher amount of volatile matter and lower fixed carbon content (Gug, Cacciola, & J.Sobkowicz, 2015; Zhou, Zhang, Arnold, Yang, & Blasiak, 2013; Akdağ, Atımtay, & Sanin, 2016).

Being a segregated form of MSW, RDF emits lower amount of harmful matters during decomposition process than raw MSW (Jun-lin, Liang, & Chang-ming, 2008). Qinching et al. (Cheng, Wendong, & Yun-han, 2004) investigated the gases surrounding the production line of RDF and detected no poisonous gas such as HCl and SO2 in the production site. Lui et al. (HU, 2004) has reported that the concentration of polluting emissions in RDF combustion were lower than that for rural waste. These results encouraged us to investigate the thermal behavior and combustion characteristics of the RDFs manufactured from the solid waste streams from different areas of Lahore, to determine their possible energy applications.

The aim of this study is to determine the quality of various RDFs on the basis of composition, thermal and ignition behavior. Moreover, energy content was determined by the calorific values of the RDFs. Three types of RDFs were selected on the basis of observed availability trends at the waste buster’s plant.

2. Material And Methods

Three RDF samples were selected from the Waste Buster’s Material Recovery Facility, Lahore, Pakistan. The samples are denoted as RDF-A, RDF-B and RDF-C. The collected MSW is separated on the basis of organic and inorganic fractions by passing through trommel. The organic waste is used for composting, while the inorganic waste is sent to the recovery unit for the segregation of recyclables and non-recyclables. Non-recyclable waste is further processed to RDF. Finally, pellets of RDFs are formed by adding the molasses to achieve the strong binding of the pellets. Materials selection was made on the basis of their surplus availability and potential to be used for making RDFs by using plastics, textile and wood. Three samples, RDF-A, RDF-B and RDF-C were received from Waste Busters in the form of pellets of 38 mm dia.

The moisture of the RDF samples is 1 grams each, was determined through oven, EYELA NDO 450-ND (Tokyo) according to ASTM standard E790-08. After that, samples were oxidized in muffle furnace, Lenton (South Korea) at 550 and 750 °C for 2 h, that determine the volatile and ash content respectively. Finally, the fixed carbon was calculated by subtracting the percentages of moisture, ash content and volatile from total amount of samples.

The calorific values were detected by bomb calorimeter, LECO AC 500 (Germany). The procedure adopted in this analysis follows ASTM E711-87 standard. Sample after placing inside steel bath was adjusted in adiabatically insulated combustion chamber. Before conducting the experiment, the calorimeter was calibrated using benzoic acid pellets method.

The contents of C, N, O, S and H were determined by the LECO 628 CHN-X analyzer (Germany) according to ASTM D-3176. The samples were dropped in combustion chamber at a temperature of about 950 °C.

| Sample | Moisture (%) | Volatile Matter (%) | Fixed Carbon (%) | Ash Contents (%) |
|--------|--------------|---------------------|------------------|------------------|
| RDF-A  | 8.8          | 78.3                | 9.5              | 8.3              |
| RDF-B  | 9.5          | 67.5                | 9.1              | 18.9             |
| RDF-C  | 14.3         | 66.8                | 8.4              | 20.5             |
Thermo gravimetric analysis (TGA) was carried out according to ISO 11358-1 method by using SDT q600 TGA instrument (America). Samples weighing about 15 mg were placed in a pottery crucible. Initially, temperature was raised and maintained at 25°C for 1 min. Subsequently, sample was heated up to 950 °C with heating rate of 10 °C / min and dry air flow of 40 ml/ min.

3. Result and Discussion
Thermal and energy efficiency of different RDFs was evaluated by the proximate, ultimate, thermo gravimetric and calorific value analysis. The proximate analysis of RDFs showed that volatile matter (VM) and ash were the major constituents of all samples. The amount of volatile matter in RDF-A, RDF-B and RDF-C was found to be 77.3, 64.5 and 69.8 %, while ash content was estimated as 10.3, 18.9 and 20.5% respectively (Table 1). The high volatile matter, fixed and low ash in RDF-A than other RDFs; might be due to the presence of high content of plastics than other ingredients (Idris, et al., 2010). RDF-A demonstrated the lowest amount of moisture and suggested that there was no or small quantity of water absorbing component (e.g. cloth) in its composition. Since, RDF-A contains high concentration of volatile matter and small moisture content, that results in low ignition temperature and combustion can be initiated at relatively lower temperature than RDF-B and RDF-C (Mortari, Avila, Santos, & Crnkovic, 2010). Table 1 demonstrates that all RDF samples investigated in the current study have appreciable amount of volatile matters and fixed carbon contents. Hence, reported RDFs may be used as an alternative combustion fuel. Ash content of any fuel determines its calorific value and leftover residues after combustion. Proximate analysis of the samples used in current study demonstrated least amount of ash in RDF-A, that showed its ability and potential to be used as a waste derivative for energy purpose in terms of calorific value (Zhao, et al., 2016).

In addition, RDF-A, RDF-B and RDF-C pre-dominantly contained carbon and oxygen (Table 2), indicating that all components used for the manufacturing of RDF samples have good energy prospective (Zhao, et al., 2016). During combustion of RDF-A hydrocarbons will react with oxygen and liberate more heat of combustion. The hydrogen content in all RDF samples used in the current study was comparatively lower (Table 2), however, slightly higher amount of hydrogen was present in RDF-A. Nitrogen oxide (NOX) is major cause of smog, acid rain and formation of fine particulate matter (PM) in the atmosphere. Therefore, its concentration in RDFs should be as low as much possible for health friendly environment. However, RDF-A has the lowest amount of nitrogen and less potential of producing NOX during combustion than other RDFs. Sulfur is a critical component of RDFs and responsible for the scaling and fouling of the boiler parts. The controlling measures are taken to eliminate the sulfur emissions during pre/post combustion of fuels. Sulfur was found in minor composition 0.24 and 0.22% for RDF-B and RDF-C, respectively and was not detected in RDF-A (Grammelis, Basinas, Malliopoulou, & Sakellaropoulos, 2009).

Calorific values for RDF-A, RDF-B & RDF-C are 5278, 4845 and 4598 Kcal/kg, respectively. Since, plastics have higher heat of combustion due to their stable structure of chemical bonding and lower oxygen content (Valverde Salamanca, 2013), the enhanced calorific value of RDF-A is probably due to presence of plastics (Valverde Salamanca, 2013). The highest calorific value of RDF-A supports the complete combustion of RDF-A will result in more useful heat production. Hence, proved to be more energy efficient as compared to RDF-B and RDF-C.

The Fig. 1 displays the TG & DTG curves of three different RDF samples. DTG curves of RDFs comprise of peaks for the mass loss in different regions. From 0 °C to 150 °C, is the drying stage
Fig. 1: TG & DTG profiles of RDF-A, RDF-B and RDF-C respectively

which all the moisture and lighter volatile matters were removed. After the evaporation of the moisture content, the second region begins in which the devolatization of all the RDFs took place up to 500 °C. From the TGA curve it was analyzed that RDF-A has the lowest moisture content, due to which the steepness of the curve in the moisture region is less than that of RDF-B and RDF-C. These results reinforce the results obtained by the proximate analysis of the RDFs.

During combustion, the major decomposition of RDF samples takes place between 200 °C to 600 °C. Initially, the components of RDFs having lower melting points like cellulose were burnt followed by the complex organics like lignin (LI, ZHAO, QIN, & WU, 2016; Li, Wang, Li, & Chi, 2015). From DTG analysis of RDF samples it can be observed that the peak of the DTG curve and its duration increases due to possible increase of plastic content in the RDFs. It can be seen that RDF-A has more pronounced DTG curve than other RDFs, probably due to the complete removal of hemicellulose
In addition, RDF-B & RDF-C have shown sharp peaks at particular temperatures while RDF-A was continuously activated. In addition to that it was observed that the formation of peaks and shoulders are lesser in number as compared to previously reported RDFs (Akdağ, Atımtay, & Sanin, 2016; LI, ZHAO, QIN, & WU, 2016; Li, Wang, Li, & Chi, 2015). Table 1 and Figure 1 showed the proximate analysis result obtained from laboratory method and Thermo-gravimetric analysis. In both cases combustion analysis was completed about 700 °C and the values obtained in both cases showed close agreement. Higher amount of mass loss was recorded for RDF-A against temperature. Which means that under similar conditions for combustion, RDF-A will have more thermal degradation than RDF-B and RDF-C. Thermal degradation defines the energy content of the burning fuel, as higher the thermal degradation period, more heat will be produced during combustion. During TGA analysis lowest ash content of RDF-A was observed due to its maximum weight loss under given combustion conditions. Ash is unwanted & un-avoidable by-product and its lower amount might increase the heat transfer efficiency of the boiler.

4. Conclusion
Three RDF samples having different composition are used in this research work. For all RDFs decomposition occurred in the initial stages (gas phase) due to high amount of volatile matter as compared to the fixed carbon content. However, RDF-A had the highest volatile fraction and lowest ash content than others. The potential of RDF-A to be used for energy application was better due to the presence of higher amount of carbon and hydrogen. In addition, no sulfur was detected in RDF-A and make it favorable for environment. However, calorific values of all RDFs investigated in current study has sufficient calorific value for combustion process. RDF-A had the highest retention time under similar pre-determined condition for the purpose of combustion and mass loss respectively. Therefore, RDF-A was found best of all samples for the purpose of energy applications.

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