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Characterization of Municipal Solid Waste in Malaysia for Energy Recovery

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Abstract. Municipal solid waste (MSW) generation that grows continuously without proper management become worrying phenomenon. Currently, Malaysia is dependent on landfills with almost 85% of waste collected ending up in dumpsites. In order to propose an alternative for solid waste management plan instead of landfill, and to develop a waste-to-energy (WtE) system, the details study of municipal solid waste (MSW) generated is crucial. This paper presents a proposal for energy recovery to produce RDF by studying the characterization of MSW generated in Malaysia; the physical and chemical properties (proximate and ultimate analysis, calorific value or energy content, and thermal analysis) of the waste components to produce a high-quality RDF. The raw MSW sample consisted of 45% organics and food waste, 13% plastics, 9% papers, and 12% diapers. For raw MSW sample, total moisture content, ash content, volatile matter, and fixed carbon were 14.60%, 7.05%, 69.35% and 9% respectively. Gross calorific value is 4538 kcal/kg and carbon content are 45%. The optimum produced RDF sample was found at operating temperature 400 ℃ with total moisture content, ash content, volatile matter, and fixed carbon were 0.75%, 21.65%, 48.35% and 29.22% respectively. Gross calorific value is 6600.15 kcal/kg and carbon content are 64%.

1. Introduction

Malaysians last year discarded up to about 33,000 metric tons of rubbish on a daily basis, resulting in the government spending about RM1.2 billion in rubbish collection [1]. The country is currently dependent on landfills with almost 85% of waste collected ending up in landfills. About 49,670 metric tons per day of waste is expected to be generated by Malaysians in the year of 2020 [2].

Malaysia currently has 170 waste disposal sites, but only 14 with the status of sanitary landfill. MSW disposal and treatment essentially pose problems in many countries due to their voluminous characteristic. The customary means of MSW management is via landfill disposal but its dependency is gradually being limited by developed countries due to environmental concerns. Even though not apparent as it seems, Malaysia is gradually experiencing scarcity of available land for development [3]. Rapid economic growth by industrialization of the developing countries in Asia has created serious problems of waste disposal due to uncontrolled and unmonitored urbanization [4]. The problem is further aggravated by the lack of financial as well as human resources trained in waste management practices in the sphere of collection, transportation, processing and final disposal.

Whereas aspects like recovery, reuse and recycle of the solid waste is grossly demand and supply driven or disorganized in most cases [5]. Despite rising up in recycling activities, only 17.5% of Malaysians recycled their waste [6]. Added to the problem is that the waste segregation programme is still in poor condition and need quite some time to be fully implemented by the citizen. Many countries especially the developing countries still using landfill for their waste management. Some developed countries employing incineration in order to destroy their waste and consumed energy that produced from the process. Almost 85% of MSW management is via landfilling while incinerators have been used only on a small-scale basis in Malaysia [3]. Besides, the existing incinerator technology is considered ineffective to handle domestic MSW due to economic reasons, the waste contains high moisture content and mixed waste was sent to the incinerator without separation. Not only no added-value product from incinerating the waste, the process also releases pollution.

There is an increasing demand for replacing primary resources in manufacturing and fossil fuels in energy production with competitive and renewable alternatives. At the same time, many countries especially developing countries, still landfill the majority of their MSW, causing significant environmental challenges and wasting a valuable resource. By converting MSW into value-added product, a municipality can reduce the environmental impact of waste and increase its revenues from recycling and energy sales. Refuse-derived fuel (RDF) is a fuel produced from various types of wastes such as MSW, industrial wastes or commercial wastes. Waste is no longer a sickening problem but can be the source of valuable raw materials and competitive alternative to fossil fuels. Also, energy-intensive industries are looking at using RDF to replace fossil fuels. The technologies offered many benefits such as; it is the combination of high fuel flexibility, high power production efficiency and good environmental performance. This provides plant operators with more options when sourcing fuels and more electricity production, where both improving the plant profitability. MSW has a very good calorific value like paper, plastics and textile [7] which makes it a good source of energy. It presents several advantages as a fuel compared to raw MSW such as higher heating value, more homogeneous physical-chemical composition, ease of storage, handling and transportation, lower pollution emission and reduce excess air requirement during combustion [8]. The waste gasification concept turns RDF into clean gas for combustion and provides the highest power production efficiency for energy from waste. The conversion of MSW into RDF may eliminate the non-combustible fraction, reducing its size and moisture content, homogenization of the waste, and in some cases its transformation into pellets [9].

MSW is one of the sources of biomass that can be treated to produce RDF for efficient energy recovery. Therefore, details study of MSW generated is required in order to design an alternative for solid waste management plan, and to develop a waste-to-energy (WtE) system. This paper aimed to produce a high-quality RDF by using the MSW material streams in Malaysia. To determine whether the MSW are suitable for the RDF production, sample characterization is needed by analyzing the physical and chemical properties (proximate and ultimate analysis, calorific value or energy content, and thermal degradation analysis) of the waste components.

2. Material and methods

2.1 Material

The raw MSW material sample consisted of 45% organics and food waste, 13% plastics, 9% papers, 12% diapers, which accounted about 79% by weight was used as the main reference for the type of raw MSW used in this study [10]. The rest disposed of materials in the chart was considered as the waste that was recovered by recycling processes such as rigid plastics, glass, metals or other incombustible materials. The percentage of composition for organic and food, and plastic fraction has been used as reference for the amount of MSW to be converted to RDF (produced RDF). The composition for organic and food waste was 77.6% while for plastics waste was 22.4% for every prepared sample of produced RDF. Thus, the weight ratios of organics to plastics waste of produced RDF were about 7 to 3.

For this experiment, all the materials were pre-compressed and shredded to ~0.5mm. The sample preparation was divided into two categories. First, the sample characterization of pre-compressed raw MSW and second, the thermal treatment processing to convert pre-compressed raw MSW into produced RDF. Proximate and ultimate analysis, calorific value determination, and thermal degradation analysis test was done for the sample characterization.

2.2 Proximate analysis

The proximate analysis process separates the samples products into four groups; moisture, volatile, ash, and fixed carbon [11]. The test methods were done to determine the composition of both type of samples for pre-compressed raw MSW and produced RDF in terms of its gross components [12]. Moisture content was determined according to ASTME1756-01 standard [12]. The experimental test started by weighing 1 gram (w_i) of both type material sample into a pre-weight dish and was dried into an oven at 105°C for 2 hours' time. Then, immediately placed into a desiccator for cooling. Reweight (w_o) the sample and the weight difference represent the moisture content (MC), MC (%) = ((w_i - w_o) / w_i) x 100. Volatile matter of a material is vapor released when the sample is heated. ASTM standard E-827 determination of volatile matter was used to determine the volatile matter [13]. The same MSW material sample that was used in determining the moisture content was reheated at 950°C for 2 hours' time and again immediately placed into a desiccator for cooling. The process was done in a vacuum condition, where the crucible container used should be covered during heating to avoid any contact with air during the combustion. Reweight the sample once it cooled down, and the weight difference represents the volatile matter (VM). Ash is an inorganic solid residue left after the sample is completely burned [12], which represents the natural substances after carbon, oxygen, sulphur and water [14]. The ash content was determined according to ASTMD1102 standard [13]. In the process, remaining material sample from volatile matter was reheated at 575 ℃ for 1-hour time. Reweight the sample after cooled down, and it represents the ash content (AC). Fixed carbon (FC) is the solid carbon in the material that remains in the sample after devolatilization process (a process where the vapor is released when the sample is heated). The fixed carbon defined by carbon found in the material which left after the volatile test. It determined by removing the mass of volatile from the original mass of the sample [14], FC (%) = 100 - MC - VM – AC.

2.3 Ultimate analysis

The ultimate analysis or elemental analysis involves the determination of weight percent of carbon, as well as sulphur, nitrogen, and oxygen. Trace elements that occur in the material sample are typically included as a part of the ultimate analysis.

2.4 Calorific value

The calorific value represents the amount of chemical energy in the material components, which depends on its carbon, moisture, and hydrogen contents of the sample. The calorific value analysis of the samples was done using bomb calorimeter and was calculated according to ASTM D240 [15].

2.5 TG-DTA

Thermogravimetry (TG) is a technique measuring the variation in mass of a sample when it undergoes temperature scanning in a controlled atmosphere. This variation in mass can be either a loss of mass (vapour emission) or a gain of mass (gas fixation). Differential thermal analysis (DTA) is a technique measuring the difference in temperature between a sample and a reference (a thermally inert material) as a function of the time or the temperature, when they undergo temperature scanning in a controlled atmosphere. The DTA method enables any transformation to be detected for all the categories of materials [16]. The TG-DTA characteristics of all the samples were run under Nitrogen condition. About 25mg sample with an average 1mm particle size was loaded into an aluminium crucible and heated in the furnace from 25 to 650 ℃ temperature with 10 ℃ /minute heating rate.

2.6 Converting MSW into RDF

The produced RDF was referred to the Malaysia waste composition [10] through developed thermal treatment processing. The preparation to convert MSW into RDF involved in two main processes which are first is the pre-treatment of raw MSW and second is the thermal treatment processing itself. Pre-compressed raw MSW was shredded and dried in the oven at 105 ℃ for 24 hours to reduce the moisture content, then compacted it into pallet form in the mold with dimension of 2.5 cm diameter and 8 cm height. Three different operating temperature; 400 ℃, 500 ℃ and 600 ℃ was used to conduct the thermal treatment processing, with constant 30 minutes of holding time and proceed with characterization.

3. Results and discussion

3.1 Proximate and ultimate analysis

Table 1 shows the proximate and ultimate analysis result for pre-compressed raw MSW composition in Malaysia. Moisture, ash, and volatile matter content (wt%) could provide a good indication of the combustibility of the MSW. For pre-compressed raw MSW sample in Table 1, total moisture content, ash content, volatile matter, and fixed carbon were 14.60%, 7.05%, 69.35% and 9% respectively. Gross calorific value is 4538 kcal/kg and carbon content are 45%.

Table 2 shows the result for produced RDF sample at three different operating temperature; 400 ℃, 500 ℃ and 600 ℃. The result shows the moisture, ash, and volatile matter content was increased by increasing the temperature, whilst the fixed carbon, carbon content and calorific value were decreased by increasing the temperature. As the temperature increase, volatile matter also increases, but carbon content is decreasing. These might be because of the hydrocarbon chain that produced when the temperature is risen up. The highest fixed carbon, carbon content and calorific value were found at the minimum operating temperature of 400 ℃. Moisture content for produced RDF seem has been reduced due to pre-treatment and the thermal treatment processes which also causing lower value for volatile matter. Ash content and fixed carbon content shows higher value in produced RDF compared to the raw MSW. The presence of inorganic materials like plastics often contribute to high ash contents of produced RDF, while other easily carbonized organic materials other than plastics and cellulose would be responsible for the much higher fixed carbon contents [17].

Table 1. Proximate and ultimate analysis, and calorific value result for MSW generated in Malaysia

Sample	Proximate and ultimate analysis (%):					Calorific value (kcal/kg):
	Moisture content	Volatile matter	Ash content	Fixed carbon	Carbon content	
Raw MSW	14.6	69.35	7.05	9.00	45.00	4538.00

Table 2. Proximate and ultimate analysis, and calorific value result for produced RDF

Sample	Proximate and ultimate analysis (%):					Calorific value (kcal/kg):
	Moisture content	Volatile matter	Ash content	Fixed carbon	Carbon content	
400 ℃	0.75	48.35	21.65	29.22	64.00	6600.15
500 ℃	0.96	55.11	34.36	9.57	44.00	4372.91
600 ℃	1.06	61.69	35.08	2.17	38.00	4149.71

3.2 Calorific value

Calorific value is one of the important tested parameters for MSW characterization to determine the available heating value in it. The calorific value is the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions. As in Table 2, produced RDF for Sample A at temperature of 400 ℃ has the highest gross calorific value with 6600.16 kcal/kg. Pre-compressed raw MSW has only 4538 kcal/kg calorific value. High reading of calorific value for produced RDF relates with the lower volatile matter and high fixed carbon content. The result indicates that the produced RDF under the 400 ℃ has high potential to be used for waste-to-energy applications.

3.3 TG-DTA

The results show the trend of weight loss (TG) and the changed of weight loss (DTA) for both pre-compressed raw MSW and produced RDF. The thermal analysis for pre-compressed raw MSW has three main parts in Figure 1. For TG pattern, the first part shows, as the sample particles were exposed to 100 ℃, evaporation of moisture and volatile materials took place, and the weight loss was accompanied by an endothermic peak in the DTA pattern. High amount of moisture and volatile materials which is about 60%. Second part is subsequent reaction occurred between 150-350 ℃ was weight loss due to the lignocellulose decomposition, and it was accompanied by endothermic peak in the DTA pattern. Lignocellulose materials are about 35-45%. Third part is reaction happen between 350-600 ℃ was the weight loss because of plastic and hemicellulose decomposition, with endothermic peak. Plastic materials are about 10% and residue is about 10%.

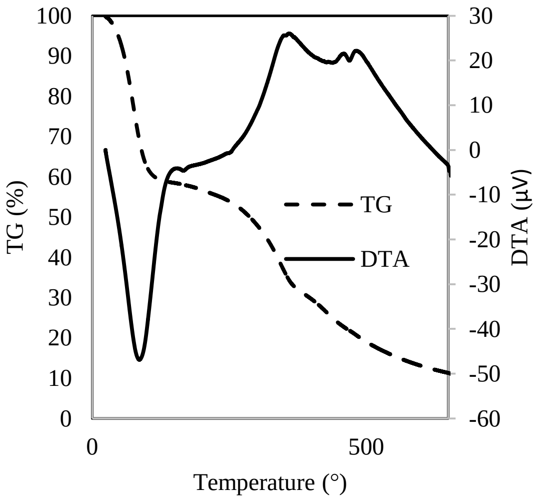

Figure 1. Thermal analysis of Raw MSW performed on wet basis

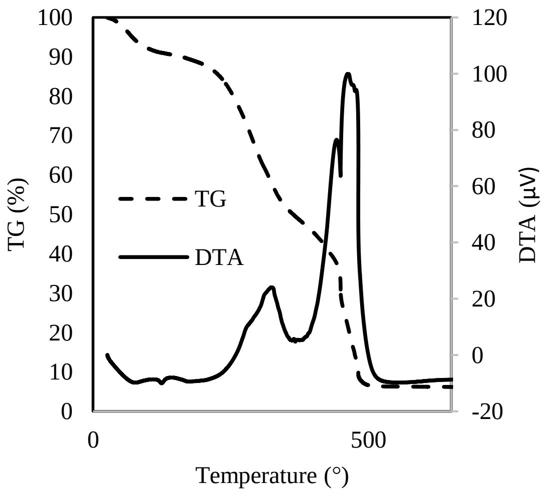

Figure 2. Thermal analysis of produced performed on wet basis

The thermal analysis for produced RDF also has three main parts in Figure 2. The first part at 100 ℃, there is evaporation of moisture and volatile materials released about 10% in TG pattern, with corresponding to endothermic peak in DTA pattern. Second part is the reaction occurred between 250-400 ℃ was weight loss due to the lignocellulose decomposition, and it was accompanied by exothermic peak in the DTA pattern. Lignocellulose materials are about 40-60%. Third part is reaction happen between 400-600 ℃ was the weight loss because of plastic and hemicellulose decomposition, with exothermic peak. Plastic materials are about 10-30% and residue are about 5%.

4. Conclusion

- The raw MSW consists of 45% organics and food waste, 13% plastics, 9% papers, and 12% diapers. The rest disposed materials were considered as the waste that was recovered by recycling processes such as rigid plastics, glass, metals or other incombustible materials.
- The produced RDF was burned in three different operating temperature; 400 ℃, 500 ℃ and 600 ℃, that consist of 77.6% food waste, and 22.4% plastics waste.

- For pre-compressed raw MSW sample, total moisture content, ash content, volatile matter, and fixed carbon were 14.60%, 7.05%, 69.35% and 9% respectively. Gross calorific value is 4538 kcal/kg and carbon content are 45%.
- For produced RDF, the optimum result was found at the minimum operating temperature 400 ℃ with total moisture content, ash content, volatile matter, and fixed carbon were 0.75%, 21.65%, 48.35% and 29.22% respectively. Gross calorific value is 6600.15 kcal/kg and carbon content are 64%.

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