A Study on Indonesian Municipal Solid Waste Potential for High Calorific Solid Fuel by Torrefaction Process

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Abstract

Municipal Solid Waste (MSW) production in some capital cities of Indonesia is numerously increase every year beyond dthe capability of the conventional treatment. For example the production of MSW in Jakarta is 27.966 m³/day, Surabaya is 8.700 m³/day, Bandung is 7.500 m³/day and Medan is 3.973 m³/day. The analysis results of MSW in Bandung city show that main composition of waste component is biomass (84.63%, weight) which consist of twigs, leaves, food residues and papers. The average volumetric density of this MSW is 223 kg/m³ and its calorific value is ranging from 2,500 to 4,000 kcal/kg. This paper deal with a study on the improvement of Indonesian MSW combustion characteristic by torrefaction process, so that the processed MSW can be used as a solid fuel. The torrefaction process applied to the MSW show that the process can improve the solid material energy density. This improvement caused by decreasing of oxygen to carbon ratio during decomposition processes of its fractions. The result also shows that torrefaction process increases the MSW's energy density producing higher calorific value and which can be used as solid fuel for a furnace.

Keywords*: Torrefaction, municipal solid waste (MSW), energy density, solid fuel.*

1 INTRODUCTION

National primary energy source is still based on fossil fuels, namely oil, natural gas and coal. National primary energy consumption in 2007 reached 114.6 million tons equivalent of oil, with the details of 54.4 million tonnes (47.48%) derived from petroleum, 30.4 million tons (26.55%) of natural gas, 27.8 million tons (24.27%) of coal and the remaining 2 million tons (1.7%) comes from hydroelectric power. With population and per capita energy consumption is likely to increase, the necessary efforts to seek intensive alternative energy sources.

Municipal solid waste (MSW) is known as a source of problems, especially in big cities in Indonesia, actually has the potential to be processed into alternative energy resources are environmentally friendly. MSW production in several major cities in Indonesia is quite large, ranging from the highest of Jakarta for 27966 m³/day, Surabaya 8700 m³/day, Bandung 7500 m³/day and Medan 3973 m³/day. For example, for the city of Bandung with MSW production for 7500 m³/day and the value of the density weighted average volume of 223 kg/m³, if taken to the lowest calorific value of solid waste samples is the city of Bandung, namely 2500 kcal/kg, the production of MSW is equivalent to 200 MW of heat power.

But in application, utilization of waste directly as a fuel has many obstacles, both technical and non-technical. Technical constraints include the high water content, low energy density and the components that a heterogeneous and diverse forms. While non-technical constraints are a bad smell and the potential source of germs. Various constraints caused improper waste used as fuel. Conversely, if the waste management applied the right technology it will get two benefits at once, i.e., reduced significantly the amount of MSW and alternative fuel produced from garbage.

One of the MSW processing technologies that promises that can produce solid fuel is torrefaction. Torrefaction is a heat treatment process at a given temperature (for biomass is usually between 200-300ºC), which performed at atmospheric pressure in absence of oxygen. On biomass torrefaction managed to increase its energy density and improve its characteristics as a fuel. Wood biomass torrefaction successful in raising the value of energy density and leaving up to 90% [1]. In addition, the combustion properties of wood smoke produced results torrefaction fewer than wood that is not torrefied [2]. Hariadi et al. tried to conduct torrefaction on non-biomass materials, namely peat. Torrefaction of peat successfully raise heating value *(HHV)* to the equivalent of coal subbituminus C to *high volatile* C bituminus classification ASTM D 388 [3].

Meanwhile, the MSW torrefaction process has not been done. In this research study will be conducted on the MSW torrefaction process that can produce solid fuel high in calories. Types of MSW that will be examined are that components can be used as fuel and not taken by scavengers. Analysis of waste torrefaction done only at the solid product, which is determines its calorific value. The specifically objectives of this study to get the kind of waste components which can be improved fuel quality through the process and get torrefaction temperature and residence time to produce maximum heating value.

2 CHARACTERISTICS OF MUNICIPAL SOLID WASTE

Study on solid waste in the city of Bandung, Indonesia conducted by Pasek et al., 2007 [4]. This study aims to get the MSW characteristics, among them the number, composition, density and combustion properties. The amount of waste handled by local government city of Bandung reach 7500 m^3/day. The largest MSW composition derived from organic components (leaves, twigs, food residues and paper), which reached 84.63% (% weight). The average density of MSW is 223 kg/m³. Calorific values of solid waste components of city of Bandung are vary between the in 2500 to 11000 kcal/kg. Content of solid waste components of Bandung city is dominated by volatile matter. Fixed carbon content and the *inherent* water less than 20%, while the ash content of less than 15%. Content of carbon element found in most (more than 80%) in styrofoam components and various types of plastic. Meanwhile, the waste component of the paper contains more oxygen elements. Some components of waste chlorine element is detected, the rubber sandals, plastic packaging, PVC pipes and food residues.

3 WASTE TORREFACTION

3.1 Formulation of the Sample

Based on the type of material, municipal solid waste in general can be grouped into two main components, namely organic and inorganic components. In terms of fuel, the waste components can be divided into two groups, namely the components that can be utilized as a fuel and components that cannot be utilized as fuel. In addition, in practice in the field, waste components can also be separated into two groups, the components taken by scavengers and the abandoned.

In the waste torrefaction, testing samples were chosen based on consideration of the above grouping criteria, i.e., components that can be utilized as a fuel and not taken by scavengers. From the organic component, the sample is selected as the test specimen is garbage yard (leaves) and food residues (rice), while the inorganic component is selected from plastic non-recycled, the plastic packaging of food and beverages as well as synthetic rubber.

The sampled leaves taken from the yard collected on the day when the test performed. Samples from the food residues had previously been dried for several days so that the water content is not too high.

In preparation, leaves and food residues first crushed using the *blender*. Plastics and rubber samples collected from discarded trash. The first type of plastic (plastic-1) is the plastic packaging of food (instant noodles) and the second type of plastic (plastic-2) is the plastic packaging of instant beverages that contain layers of aluminum foil. Both types of plastics are most commonly found in landfill waste because they cannot be recycled and not worthy of scavengers. Rubber chosen for the sample is synthetic rubber, the rubber tires of a motorcycle. Tires that have been damaged in normally cannot be used anymore because they cannot be patched. This rubber types can actually be used for other purposes if it is large enough. Rubber tires are not used in a rubber usually torn or relatively small size. Because the plastic and rubber samples could not crush using be a *blender*, then the plastic and rubber small cut to the size of approximately 1 $cm^{2.}$

3.2 Torrefaction Experiment

Waste torrefaction experiment was conducted in Thermodynamics Laboratory ITB PPAU-IR using a bench-scale torrefaction reactor using superheated steam media. Schematic diagram of test equipment is shown in Figure 1. Steam enter the reactor after pass the pressure regulator and the regulator mass flow rate. The outside of the reactor equipped with electric heaters that can be arranged so that the temperature of the reactor can be in accordance with the desired value. Specimen is placed in waste containers that placed particular in the reactors. Gas is out of the reactor are steam with volatile matters from torrefaction process. The temperature and mass of the remaining specimens in the form of solids was measured each time using data acquisition devices are available to see the profile of the rate of mass loss.

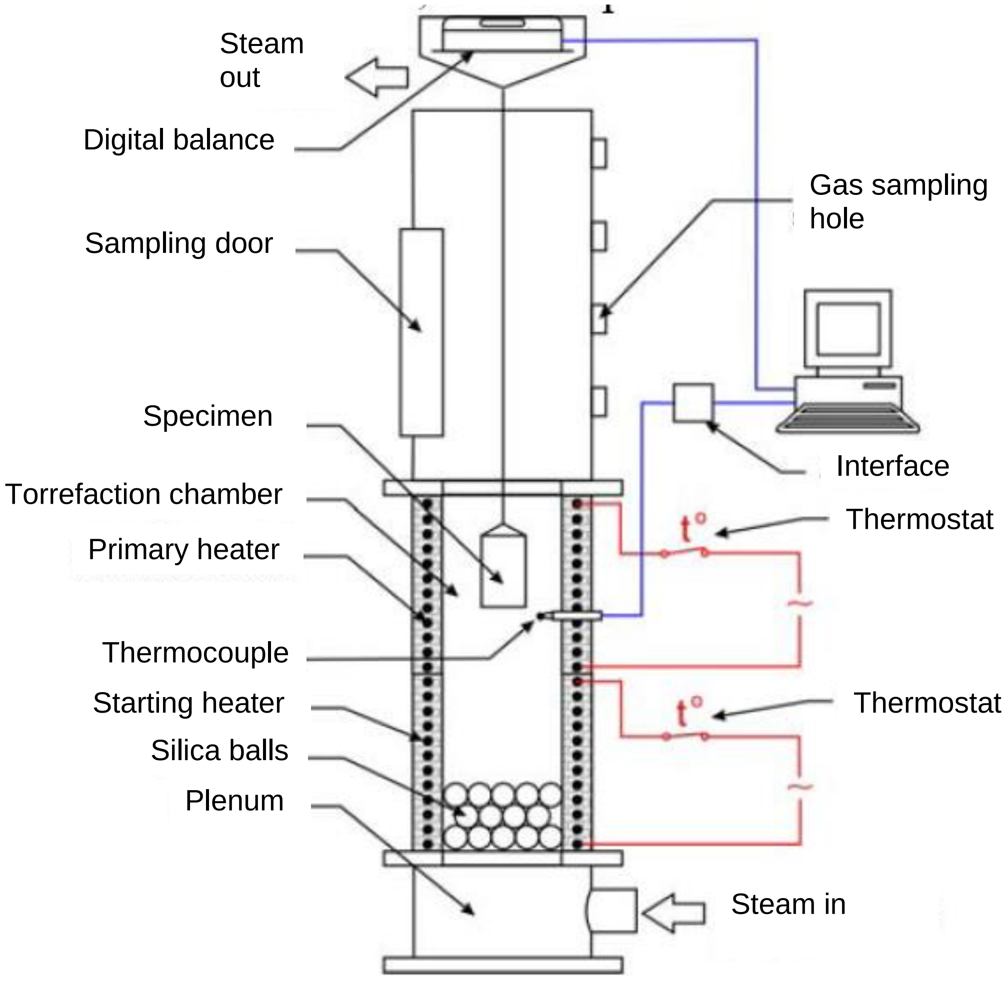


Figure 1 Schematic of bench scale torrefaction equipment [3].

Initial mass and size of the specimens are not the same for each sample, depending on the type and density. Each sample tested separately with two variations of temperature and resident time of torrefaction. Temperature variation is same for all specimens, i.e. 250 and 300°C. While residence time, the first variation is the same for all specimens, which is 60 minutes, and the second variation is the length of time required to start the asymptotic mass loss. Variations of torrefaction temperature and residence time for the various samples can be seen in Table 1.

Table 1 Variation of torrefaction temperature and residence time for the various samples.

Sample	**Torrefaction Temperature (°C)**	**Resident Time (min)**
Leaves	300	60
		20
	250	60
		25
Food residues	300	60
		25
	250	60
		35
Plastic-1	250	25
Plastic-2	300	60
Rubbers	300	60

4 RESULTS AND DISCUSSION

Solid product of waste torrefaction results are physically similar to products of biomass torrefaction, namely black-gray in color and are fragile. Torrefaction products from all components of the waste like this character, except for the first type of plastic (plastic-1), gray color mixed with white. Solid material results in plastic and rubber torrefaction harder than torrefaction results of leaves and food residues.

When the plastic and rubber-1 torrefied they melt and form a crust that cling tightly to the specimen container. That solid material causes sweat pores in the container made of wire netting covered. With the closing of the pores of this vessel, steam is used as media of torrefaction cannot evenly heated specimen. For that, torrefaction process on both types of samples was discontinued for other parameter variations.

4.1 Mass Loss

In this experiment mass loss of torrefied waste specimen can be observed at any time. Figure 2 shows the relative mass of specimens from different samples, namely the mass of the specimens measured at any time divided by the mass of initial sample obtained from the experiment.

Profiles of solids mass loss of the various components of the waste samples showed the same pattern, namely the rate of mass loss is relatively rapid at the beginning of the process, then slowed down and eventually tend to be asymptotic. For the same sample components with the temperature varying process, as visible on the leaves and food residues, the time taken until a constant mass of solid value more quickly to higher temperatures of torrefaction. The time needed to tend to a solid mass at a constant value of leaves torrefaction process is about 20 and 25 minutes for the torrefaction temperature 300°C and 250°C respectively. As for the food residue, the time required is approximately 25 and 35 minutes for the torrefaction temperature 300°C and 250°C respectively. These results agreed with experimental results of biomass torrefaction, where the process temperature is higher, rate of mass loss more rapidly.

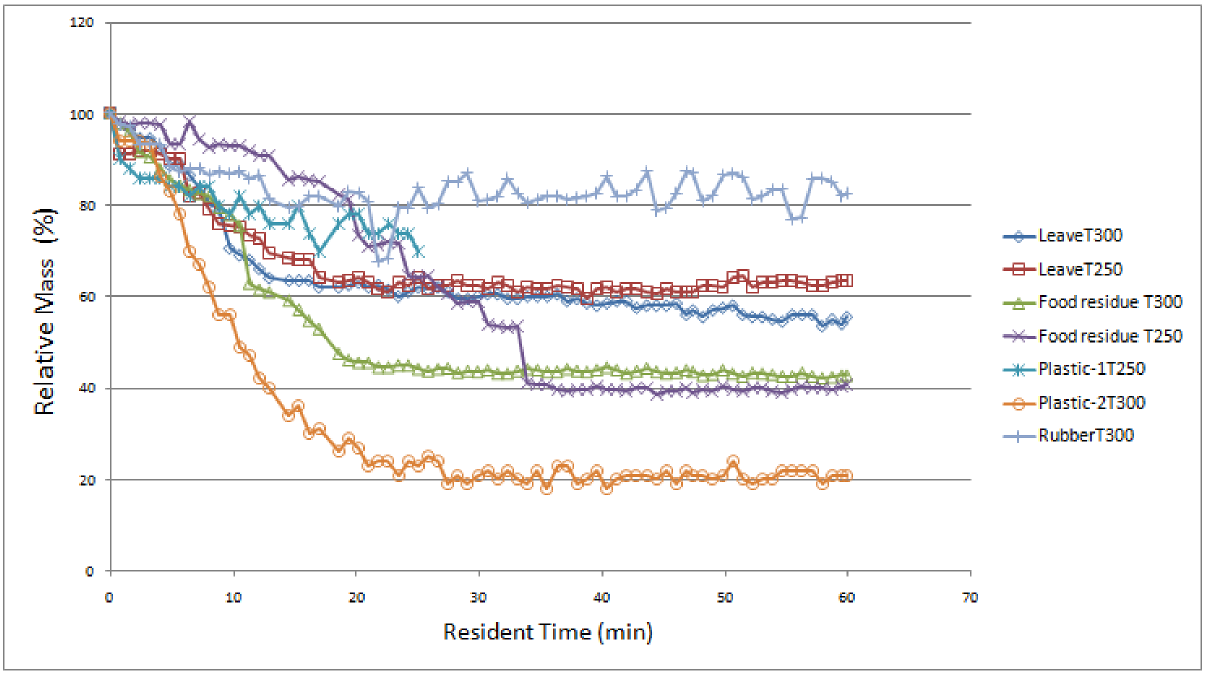


Figure 2 Graph of mass loss on various samples of waste components.

In leaf torrefaction, the relative mass loss of solids remaining when its value tend to constant is about 60%, the same for both torrefaction temperature variations. While the food residue sample, the relative mass loss of solids remaining are approximately 43% and 40% for torrefaction temperature 300°C and 250°C respectively. The mass of solids remaining in the leaf is greater than the rest of the food. This is because the carbon content remained at leaves larger than the food residues [4].

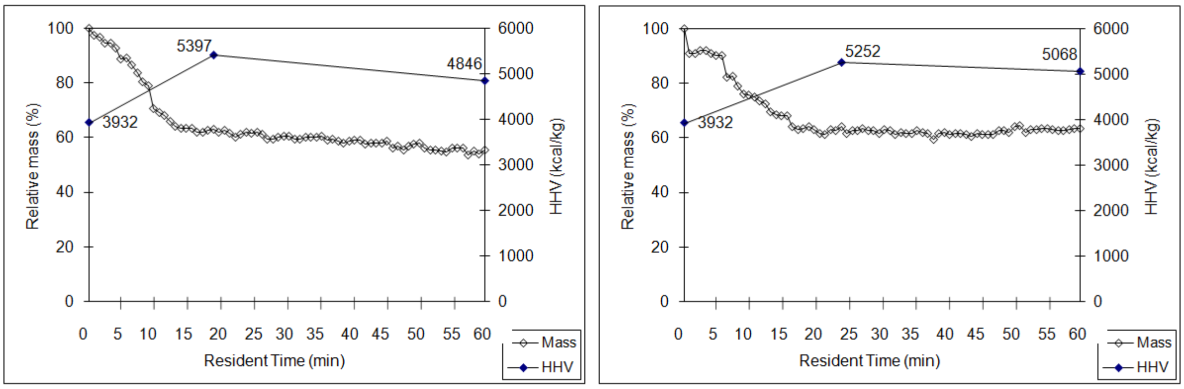
In the second type of plastic, the remaining solid material is aluminum foil, namely approximately 20%. This is probably because the plastic material on a plastic sample-2 is dominated by light volatile matters that evaporate when they torrefied. Aluminum foil is not combustible so that torrefaction products from plastic type-2 cannot be used as fuel.

As already mentioned above, the torrefaction process of plastic-1 and the rubber causing it to melt and cling to the specimen container. The closed pores of the container caused the flow of steam pressure on the lower surface of the container (base) to be large and it affects the results of specimen mass loss measurements. This can be seen from the graph that fluctuation of mass loss is relatively large, as shown in Figure 2. In addition, the inaccuracy of the mass loss measurement is also caused by the possibility of mass that falls or drips when melted. With this condition, the torrefaction test of plastic-1 and rubber was discontinued for a variety of other parameters.

4.2 Heating Value of Products

Heating value measured in this experiment is higher heating value (HHV) at air-dry base (adb) conditions. The waste component that will be determined its heating value is organic components, namely the leaves and food residues. Torrefaction products from plastic-2 cannot be burned, while the product of plastic-1 and rubber doubt the accuracy of mass loss measurements. In addition, the test results of both types of the samples indicate that they not fit for torrefaction process.

Heating value of leaves and food residues is measured at three condition, that are at raw material, at point of start the asymptotic mass loss and at the end of the process (resident time 60 minutes). HHV of torrefied leaves for the various parameter shown in Figure 3.



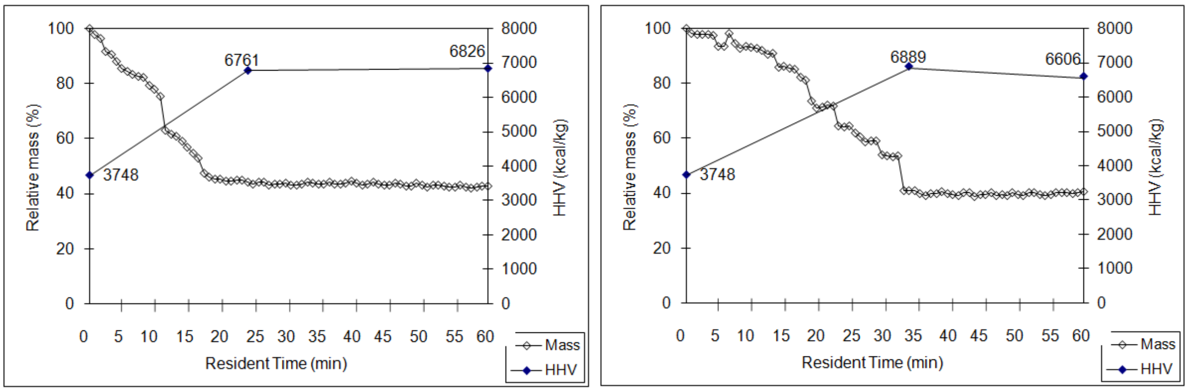
a) T = 300°C b) T = 250°C

Figure 3 HHV of torrefied leaves at various residence time and temperature processes.

Measurement results show that the calorific value of torrefaction products increased compared to raw material of leaf. Calorific value at the point starts the asymptotic mass loss slightly higher than the calorific value at the end of the process. The maximum heating value obtained at the temperature 300°C and resident time 20 minutes, namely 5397 kcal/kg. Compared with initial calorific value, calorific value of this torrefaction product is increase of 27%.

The results of these measurements agreed with the results of research on biomass torrefaction, where for the higher process temperatures, the resulting heating value is also higher. Test results also showed that the resident time is longer (60 minutes) does not always produce the product that have higher heating value. The results of this test is slightly different from the results of previous torrefaction experiment, in which heating value is usually proportional to the time lived.

Similar results were also obtained from the test results of calorific value of food residue, as shown in Figure 4. Calorific value at point the start asymptotic mass loss is relatively equal to the calorific value at the end of the process. In food residues torrefaction, an increase in calorific value of products reaches 46% compared to the raw material, namely from 3748 kcal/kg to 6889 kcal/kg. Figure 4 also shows that the maximum calorific value obtained at the temperature 250°C is relative equal to the maximum calorific value at a temperature of 300°C.



a) T = 300°C b) T = 250°C

Figure 4 HHV of torrefied food residues at various residence time and temperature processes.

The interesting thing about this MSW torrefaction is that the variation of torrefaction temperature and resident time result the relatively same of calorific value. Difference of the maximum heating value and the any point heating value of torrefaction products is very small, i.e. among 0,03-01 and 0,01-0,04 for leaves and food residues respectively. The results of this study identified that torrefaction process for municipal solid waste components can be more economical, i.e. at relatively low temperature and relatively short time.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

1. From several types of municipal solid waste components that are selected to be sampled in this study, only two components that can be torrefied, namely the leaves and food residue. Torrefaction on instant food packaging plastic (plastic-1) and synthetic rubber could not be done because this component materials to melt and cling to the specimen container so that the measurement of the mass during the process is not accurate. Whereas in the torrefaction on plastic packaging instant drinks (plastic-2) leaving only a dense material that cannot be burned (aluminum foil).
2. The maximum heating value of the product of leaves torrefaction obtained at a process temperature 300°C and resident time 20 minutes, namely 5397 kcal/kg, or an increase of 27% compared to the calorific value of raw material.
3. The maximum heating value of the product of food residues torrefaction obtained at a process temperature 250°C and resident time 30 minutes, namely 6889 kcal/kg, or an increase of 46% compared to the calorific value of raw material.
4. From the variations of process temperature and resident time, calorific value produced no significant difference from the maximum heating value for each sample, which is at variance among 0,03-01 and 0,01-0,04 for leaves and food residues respectively.

5.2 Recommendations

1. Torrefaction experiment should be performed on various components of other municipal solid waste for each component and either a combination of all components so that the results obtained are more representative of the overall MSW.
2. Taking into account the economic value, torrefaction on organic waste components should be done at relatively low temperatures, e.g. 250°C and resident time less than 30 minutes.

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