

## Experimental Studies on Hydrothermal Processes of Municipal Solid Waste to Produce Solid Fuel

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**Abstract:** Global warming and energy crisis (increasing of energy demands, depletion of fossil fuel, and increasing of fuel price) are hot issues in the world. The Municipal Solid Waste (MSW) production in big cities such as Bandung (Indonesia), which causes Environmental problem such as Green House Gases (GHG) comprised of CH<sub>4</sub> and CO<sub>2</sub>, increases significantly with economic and populations growth. It becomes hard to handle the problem of MSW because the only method available is open dumping, and finding open land near Bandung for this method becomes more difficult. Moreover the availability of fossil fuel such as Coal cannot last long; so the other alternative fuel is needed. Using the Hydrothermal process to reduce the volume of the MSW which is mostly organic component and to utilize the solid powder resulted as solid fuel for co-firing with coal in Power Plant will benefit not only in solving the MSW problem but also reducing the coal consumption in the power plant. In this study, the hydrothermal processes were done by using a laboratory scale apparatus with MSW components as the samples. The experiments were done at various temperatures, 180 °C, 200 °C, and 220 °C inside an experimental autoclave. After hydrothermal process, the processed sample was dried in an oven for 24 hours and then was crushed. The final product is like powder which is concludes as solid fuel. The final step is properties analyses. The results of the experiments show that the process time, the water amount and the temperature which are applied in hydrothermal process, affect the proximate compositions. The moisture and fixed carbon content decrease and the volatile matter increases, so that the MSW's calorific value increases. Based on the experiments, it can be concluded that hydrothermal process can be applied to produce solid fuel from MSW.

**Keywords:** municipal solid waste (MSW), hydrothermal process, solid fuel

### 1. INTRODUCTION

Due to increasing of economic and population growth, energy demand also increases. Thus power plants have to be built to meet the demand of energy. Many industries are now using coal for their power generation. This has resulted in a significant increase in the demand of coal. For the years 2009-2010, Indonesian coal consumption increases 13.7% (www.bp.com (British Petroleum)). It will lead to fast depletion of coal resources and also environmental issue due to the CO<sub>2</sub> emission.

At the same time, there has been a problem of municipal solid waste (MSW) disposal in developing countries like Indonesia especially in big cities. The present practice of MSW disposal is open dumping and

landfills which will create environmental, land limitation and social problems. Moreover, the adverse environment effects on soil, water and air drawn by the unsanitary and unstable landfills are demonstrated (Assmuth, 1992; Lander, Fellner, & Brunner, 2009) and threatening human health (Durmusoglu, Taspinar, & Karademir, 2010; Hung, Wu, Chen, Shin, Yu, & Ma, 2009). The traditional incineration is facing with the problems of its pollution as well as the public opposition. Thermal process such as combustion, pyrolysis, and gasification offers great benefits over traditional methods of disposing MSW. These thermal methods not only recover useful energy values from MSW but also reduce the quantity of waste being ultimately sent to the landfill. Currently, countries all over the world urge to promote the utilization of waste to energy recovery.

In general, the compositional characteristics of MSW vary considerably from countries to cities, towns, and regions. This is strongly influenced by the custom, living style, degree of development as well as regulation on MSW disposal, etc. Furthermore, MSW contains

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biomass such as wood, paper, food residues, and plastics which could be useful resources. Nevertheless moisture content of MSW makes it difficult to recover energy from the thermal processes(Liang, et al., 2008).

There are researches about hydrothermal treatment to produce useful organic matter or to recover energy from organic wastes, or sludge, or real biomass, or industrial waste (Jomaa, Shanableh, Khalil, & Trebilco, 2003; Shanableh, 2000; He, Li, Kong, Wang, & Xu, 2008; Goto, Obuchi, Hirose, Sakaki, & Shibata, 2004);however only few are designed to produce solid fuel.

In this present study, the authors investigated the effect of hydrothermal process with various conditions of temperature, holding time, and water amount; which were applied to MSW components as the sample to produce solid fuel. The proximate, ultimate, and calorific value analyses of samples were also investigated. The results then analyze to obtain the optimum process parameters.

## 2. EXPERIMENTS

### 2.1. The samples

In this research, mixture of MSW components which are organics such as banana peel and water spinach and plastics such as styrofoam and polypropylene were tested as the sample. The percentage of organic and plastic in Bandung city, Indonesia is 45.36% and 4.64% by weight respectively. It consists of 22.68% banana peel, 22.68% water spinach, 2.32% styrofoam, and 2.32% polypropylene. The samples were manually prepared by blending them after being cut into small sizes.

### 2.2. Experimental apparatus and procedure

Experiments of hydrothermal process were carried out in a 500 ml laboratory scale autoclave. The autoclave can be operated at a maximum temperature of 400 °C and maximum pressure of 20 MPa. The autoclave was heated by electrical heater. The temperature was controlled within  $\pm 2$  °C. For each test, 40 g of sample

and a certain amount of deionized water were put inside a glass container as shown in Fig.1. Then the glass was placed inside the autoclave and then the autoclave was sealed.



Fig.1. Glass container and sample

The amount of water used in the experiment was 40 ml and 80 ml.

Before experiment, nitrogen from a nitrogen cylinder was introduced in order to create an oxygen free environment inside the autoclave. Then, the experimental setup was heated. The experiments were done for autoclave temperature, 180, 200, and 220 °C. The holding times were varied from 30, 60 and 90 min. Those three main processing parameters, i.e., (1) the amount of water, (2) the temperature, and (3) the holding times, were varied as shown in Table 1.

The stirrer was kept stirring during the experiment ensuring the uniformity of the samples. After finishing the reaction, the heater was switched off and the release valve was opened suddenly to release steam inside the reactor. The pressure inside the reactor reduced quickly but the temperature of the reactor was still high. After the temperature reached the room temperature, then the products were taken out of the reactor. The schematic diagram of experimental setup is shown in Figure 2.

All processed samples were then dried in a constant-temperature oven at 105 °C for 24 hours and crushed to become powder for analyzing.

Table 1. Variation of experimental operating conditions

Exp ID	A11/B11	A12/B12	A13/B13	A21/B21	A22/B22	A23/B23	A31/B31	A32/B32	A33/B33
T (°C)	180	180	180	200	200	200	220	220	220
HT (min)	30	60	90	30	60	90	30	60	90
W (ml)	40/80	40/80	40/80	40/80	40/80	40/80	40/80	40/80	40/80

Exp – Experimental

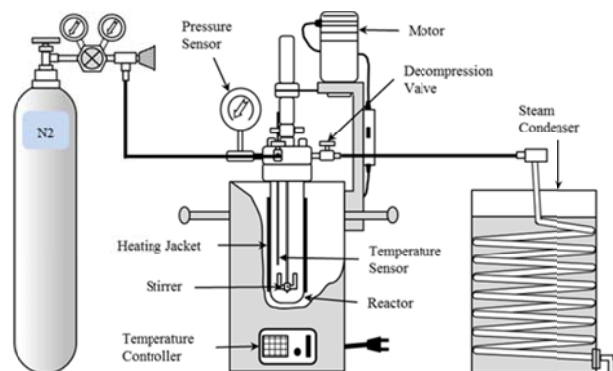


Fig.2.Schematic diagram of experimental setup

### 2.3. Sample analysis

Each dried original component was tested in TekMIRA (Research and Development Center for Mineral and Coal Technology) in Bandung for determination of moisture content (M, based on ASTM D.3173), ash (Ash, based on ASTM D.3174), and volatile matter content (VM, based on ASTM D.3175). Then the fixed carbon was estimated by the mass balance ( $FC=100\%-M-VM-Ash$ ). The ultimate analysis was performed for determination of carbon (C) and hydrogen (H), based on ASTM D.3178, nitrogen (N), based on ASTM D.3179, sulphur (S), based on ASTM D.4239, and the oxygen was determined by the mass balance ( $O=100\%-C-H-N-S-Ash$ ). The calorific value (HHV) was determined by ASTM D.5865 method.

Dried processed samples were tested in TekMIRA for calorific value analysis. But proximate analysis was carried out by SHIMADZU D 50 simultaneous TGA/DTA analyzer. Non-isothermal combustion was performed for all samples in the furnace of the TGA at atmospheric pressure. The samples weight loss (TG) and the rate of weight loss (DTG) were recorded continuously under dynamic conditions as a function of time and temperature in the range of room temperature to 650 °C at the heating rate of 10°C/min. Air at 150 ml/min flow rate was used as a reactive gas. These dynamic runs were carried out by placing around 10 mg of dried samples on a pan. Each sample was tested for twice and the results showed a good repeatability.

C, H, N contents were measured with an elemental analyzer (Perkin Elmer 2400 Series II CHN). S was not detected during analyzing. O was determined by mass balance ( $O=100\%-C-H-N-Ash$ ).

The proximate, ultimate, and calorific value analyses of each original component are presented in Table 2. Properties of plastic and organic are quite different. Moisture, fixed carbon, and ash content of plastics are much lower compared to the organics. Further, the volatile content of plastics is very high, which is the key element to initiate ignition. But the organics contain high oxygen, due to the content of cellulose, hemicellulose and lignin in the organic,

compared to plastics. The calorific value of plastics is much higher compared to organics. On the other hand, from Table 2 it can be found that sample which contains of high volatile matter content, it can provide high calorific value. Decreasing of volatile matter led to decreasing of calorific values as well such as PP (VM=99.8% with 45.44 MJ/kg), SF (VM=99.14% with 39.33 MJ/kg), BS (VM=68.47% with 20.93 MJ/kg), WS (VM=63.96% with 14.93 MJ/kg). Anyway fixed carbon content affects the calorific value of sample too.

Table 2. Original component analyses

	PP	SF	BP	WS
Proximate <sup>adb</sup>				
Moisture (%)	0.04	0.11	3.31	12.39
Ash (%)	-	0.36	8.97	8.26
VM (%)	99.8	99.14	68.47	63.96
FC (%)	0.16	0.39	19.25	15.39
CV <sup>adb</sup>				
HHV (MJ/kg)	45.44	39.33	20.93	14.93

CV – calorific value, HHV – high heating value

adb – air dry basis

PP – polypropylene

SF – styrofoam

BP – banana peel

WS – water spinach

### 3. RESULTS AND DISCUSSION

The dried processed sample after grinding is shown in Figure 3. It can be seen that the thermal decomposition and carbonization occurs in the process, and the MSW component volume reduces significantly.



Fig.3. Sample after hydrothermal process

Properties of organics component were used in comparison of properties of original component and processed sample due to high percentage of organics in original component.

Figure 4 to 7 show typical results of hydrothermal process applied to MSW component. Figure 4 shows the change of moisture content of original component after hydrothermal process. It can be seen that the moisture content decreases after process. This is because the effect of hydrothermal process on cellulose, hemicellulose and lignin of organic component. The

drying process on processed samples after hydrothermal process was so efficient.

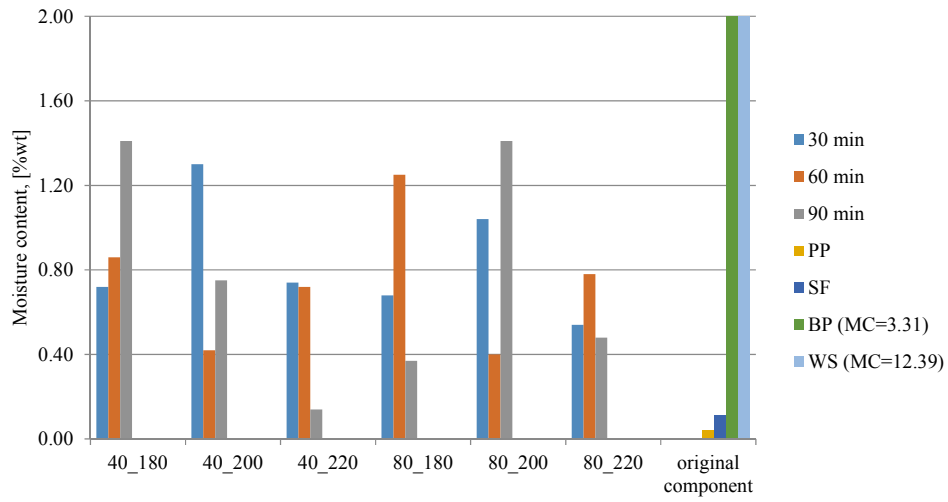


Fig.4.Effect of hydrothermal process on moisture content in various conditions

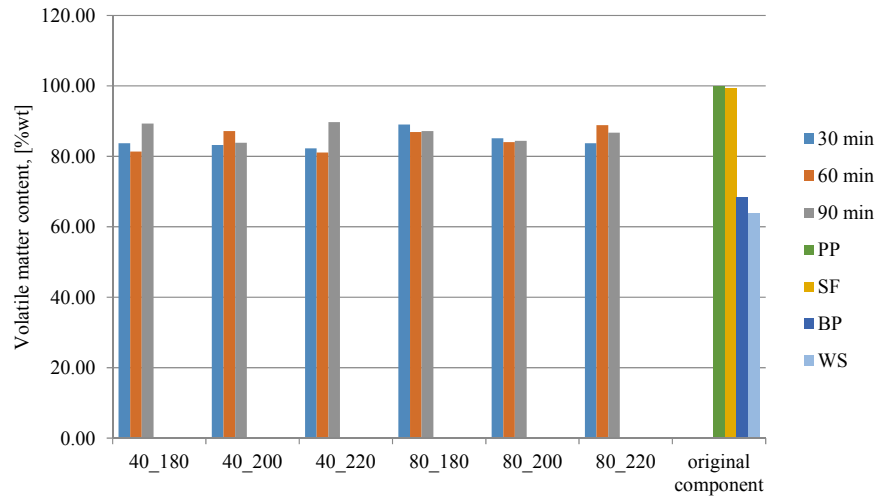


Fig.5. Effect of hydrothermal process on volatile matter content in various conditions

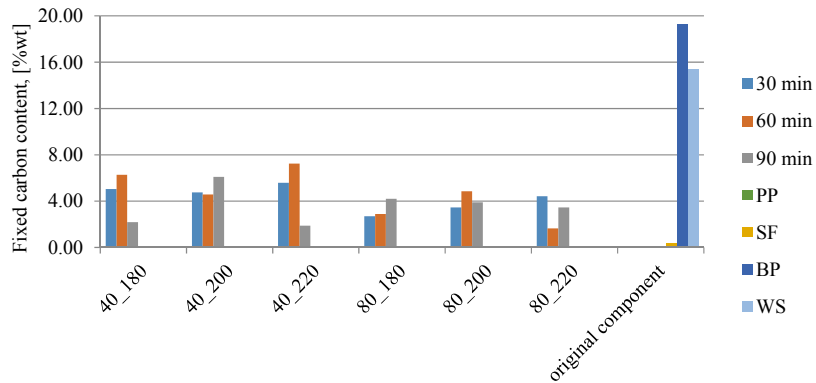


Fig.6. Effect of hydrothermal process on fixed carbon in various conditions

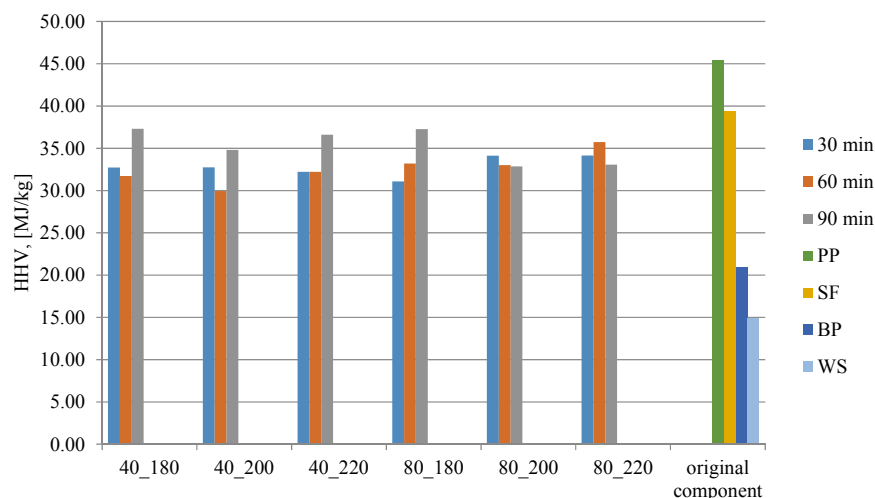


Fig.7. Effect of hydrothermal process on HHV in various conditions

In addition it can be seen that higher process temperature, processed samples have lower moisture content.

Figure 5 shows the variation of volatile matter content in the sample after hydrothermal process. It can be seen that the volatile matter increases after the process. The high temperature might produce more volatile matter content resulting more easy to initiate combustion of the fuel. Moreover, using more process water causes higher volatile matter content, while the influence of holding time is not clear in this result.

The variation of fixed carbon of sample by hydrothermal process is shown in Figure 6. It can be seen that the fixed carbon content of sample decreases after process due to increasing of volatile matter content. In the condition A13 and A23, sample has lower fixed carbon content but higher volatile matter content. The calorific value (HHV) will have the same tendency with that.

The calorific value (HHV) of the processed sample is shown in Figure 7. It can be seen that HHV increase after the process. Moreover, Figure 7 shown that long holding time (90 min) leads higher HHV like in conditions A13, A23, A33, and B13 except conditions B23 and B33 which lead lower HHV compared to 30 min and 60 min of holding time. In addition it can be seen that amount of process water does not influence HHV. It can be conclude that less amount of process water is better for hydrothermal process. Figure 7 shown that the condition A13 is the best condition in this research, which processed sample has the highest HHV (37.31 MJ/kg) compared to processed sample of other conditions.

#### 4. CONCLUSIONS

The analyses (proximate and calorific value) of processed samples proved that the process time, the water amount, and the temperature which were used in hydro-thermal process affect the properties of sample. Process produced samples with low moisture content and high VM which led to have high HHV. The highest HHV is 37.31 MJ/kg which was analyzed from sample operated under 180 °C of temperature, 40 ml of water, and the holding time for 90 min.

It can be conclude that the hydrothermal process can be applied to produce solid fuel from MSW.

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