Investigation on the Interaction of Lignocellulose and Starch-Based Wastes in Wet Torrefaction Process

Budi Triyono[1,*] Pandji Prawisudha[2] Mardiyati[2] Ari Darmawan Pasek[2]

[1]*Mechanical Engineering Department, Politeknik Negeri Bandung, Indonesia*
[2]*Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Indonesia*
[*]*Corresponding author. Email: budi.triyono@polban.ac.id*

ABSTRACT
Indonesia, with a population of about 250 million people, not only produces large amounts of municipal solid waste (MSW) but also requires large amounts of energy. The conversion of MSW into solid fuel can be the solution to solve the problems. Indonesian MSW is dominated by high moisture-organic wastes such as leaf litter, food waste, vegetable waste, and fruit waste. The wet torrefaction is a thermal decomposition process that uses high temperature and high-pressure liquid to decompose biomass or MSW, which effectively increases the fuel properties of high moisture MSW. The purpose of this study was to determine the interaction of waste components consisting of lignocellulose and starch-based waste during the wet torrefaction process. After sample preparation, the wet torrefaction experiments were performed for two types of samples: individual samples and dual waste. The wet torrefied products were then dried and prepared for thermogravimetric analysis. These results provide the thermogravimetric analysis (TGA) of individual and dual samples to investigate the significance of interactions between waste components. Analysis of the significance of interactions was done by comparing the average curve of data from two individual samples (non-interaction) with the experimental data of dual samples (with interaction). The results showed that the interaction between leaf litter, vegetable waste, and fruit waste (lignocellulosic-based wastes) was relatively small and negligible during the wet torrefaction process. Meanwhile, food waste (starch-based) interacted with leaf litter, vegetable, and fruit waste during the wet torrefaction process. In formulating equations to predict the fuel properties of the wet torrefied products, it does not only consider the composition of waste and operating temperatures but also needs to consider the interaction between the components of waste, especially food (starch-based) waste.

Keywords: *Municipal Solid Waste, Lignocellulosic-based Waste, Starch-based Waste, Wet Torrefaction, Interaction.*

1. INTRODUCTION

Indonesia, with a population of more than 250 million people, generates garbage or municipal solid waste (MSW) at about 0.7 kg/capita per day or about 175,342 tons per day or 64 million tons per year [1] [2]. In Indonesia, up to 68.64% of the total MSW was only collected and transported to temporary landfills and then transported by trucks to the final landfills. The rest is stored in the soil at about 9.47%, composted at 7.10%, burned at 4.73%, dumped into rivers of 3.55%, and others around 6.51% [3].

A high population of Indonesian people produces large amounts of MSW and needs large amounts of energy. The conversion of MSW into solid fuel is a strategic step that can be one of the solutions to solve both problems at once. The wet torrefaction process (WT), also known as hydrothermal carbonization (HTC), is an innovative technology that has been developed since the 2010s to convert high moisture content biomass, including MSW, into solid fuel. Previous literature studies show that the product of the wet torrefaction process of Japanese MSW samples had a calorific value similar to sub-bituminous coal with lower chlorine content. Hence, it was recommended to be blended with coal in the co-firing application at a ratio of 20% [4]. The wet torrefaction is also proven to produce a uniform shape and size pulp product with a fourfold increase in density or 75% reduction of waste volume [5].

In wet torrefaction or hydrothermal carbonization (HTC), high temperatures and pressurized liquids are used as a medium to decompose MSW or biomass in order to increase its fuel properties such as physical properties, calorific value, and grindability. The reactor for wet torrefaction is a pressure vessel designed to operate at high pressure and temperatures. Temperature, residence time, and solid load are the main parameters of the wet torrefaction process.

The field survey results show that most of the organic waste samples are lignocellulosic-based biomass. During the wet torrefaction process, the amorphous cellulose oligomers break at temperatures higher than 150 ºC, and hemicelluloses are easily solubilized and hydrolyzed in water at a temperature above 180 °C [6]. The wet torrefaction temperatures below 230 ºC with a relatively short reaction time are enough to hydrolyze hemicellulose. Lignin mostly to be undecomposed under wet torrefaction conditions [7].

The source of MSW in major cities in Indonesia such as Bandung city is dominated by residential waste (66.02 %), market waste (8.25 %), commercial area (4.04 %), Road waste (6.20 %), industrial waste (10.65 %) and garbages from public facilities (4.85 %) [3]. The field surveys to some residential TPS in Bandung city showed that leaf litter, food waste, vegetable waste, and fruit waste were the four main types of organic waste with a percentage of 41.50%, 27.97%, 17.32%, and 13.21%, respectively [8].

The wet torrefaction process can effectively reduce the inherent moisture content, thereby increasing the calorific value. In addition, wet torrefaction is proven to effectively reduce ash content, especially for fruit and vegetable waste samples. The experimental results that have been carried out show that a higher operating temperature of the wet torrefaction process will increase the calorific value but accompanied by a decrease in mass yield; it was a consequence of the severity of the process. Meanwhile, a different result was found in the food waste experiments: in high temperatures (more than 175 °C), the increase of the calorific value was accompanied by an increase in mass yield [9].

The previous research has produced a model equation to predict several fuel properties of hydrochar, which was formulated and compiled from individual data from each waste component, assuming no interaction occurs during the process. The equations resulting from this stage are predicted to have large deviations because interactions between the waste components have not been considered. To reduce the deviation from the calculation results, a correction factor that can represent the level of interaction quantitatively is needed. This level of interaction should be influenced by operating temperature and waste composition. Therefore it is necessary to conduct further studies to investigate the interactions between waste components and formulate them in empirical equations.

This study aims to determine the interaction of waste components consisting of lignocellulose and starch-based waste during the wet torrefaction process. Through this investigation of interaction, it is expected to know which components of the waste interact or do not interact with other waste. The waste component that shows significant interactions will focus on developing the experimental design for the next experiments.

2. METHODOLOGY

The reactor used in this experiment was a 2.5 liters stainless steel laboratory scale reactor and equipped with a stirrer. The heat source was an electric heater and was controlled by automatic temperature control. Four types of investigated wastes were leaf litter (TW), food waste (FdW), vegetable waste (VW), and fruit waste (FW). Because four types of samples need to be investigated, the dual sample variations analyzed were: leaf litter and vegetable waste (TW-VW), leaf litter and fruit waste (TW-FW), vegetable waste and fruit waste (VW-FW), leaf litter and food waste (TW-FdW), vegetable waste and food waste (VW-FdW), as well as fruit waste and food waste (FW-FdW). The experimental design is shown in Table 1.

Table 1. The experimental design of investigation on the interaction of waste components

No	Parameter			
	Component of Waste		Temperature (°C)	Sample ID
1	Leaf litter (TW)	Vegetable waste (VW)	150	15030 TW-VW
2			175	17530 TW-VW
3			200	20030 TW-VW
4	Leaf litter (TW)	Food waste (FdW)	150	15030 TW-FdW
5			175	17530 TW-FdW
6			200	20030 TW-FdW
7	Leaf litter (TW)	Fruit waste (FW)	150	15030 TW-FW
8			175	17530 TW-FW
9			200	20030 TW-FW

No	Parameter			
	Component of Waste		Temperature (°C)	Sample ID
10	Vegetable waste (VW	Food waste (FdW)	150	15030 VW-FdW
11			175	17530 VW-FdW
12			200	20030 VW-FdW
13	Vegetable waste (VW	Fruit waste (FW)	150	15030 VW-FW
14			175	17530 VW-FW
15			200	20030 VW-FW
16	Food waste (FdW)	Fruit waste (FW)	150	15030 FW-FdW
17			175	17530 FW-FdW
18			200	20030 FW-FdW

The temperature of 200 °C and holding time of 30 minutes was proven to be the optimum condition of wet torrefaction to convert Indonesian mixed MSW into a coal-like solid fuel with an HHV of 33.01 MJ/kg (dry based) and with a more uniform shape and particle size [10]. In this research, the temperature was varied at 150, 175, and 200 °C. The workflow of research is shown in Figure 1. After sample preparation, the wet torrefaction experiments were performed for two types of samples: individual samples and dual waste. The purpose of the experiment and testing of individual samples is to determine the effect of wet torrefaction on the physical characteristics of each waste. At the same time, the experiment and testing of the dual sample (with interaction) aim to see the significance of the interaction between the two waste components by comparing with individual data (non-interaction).

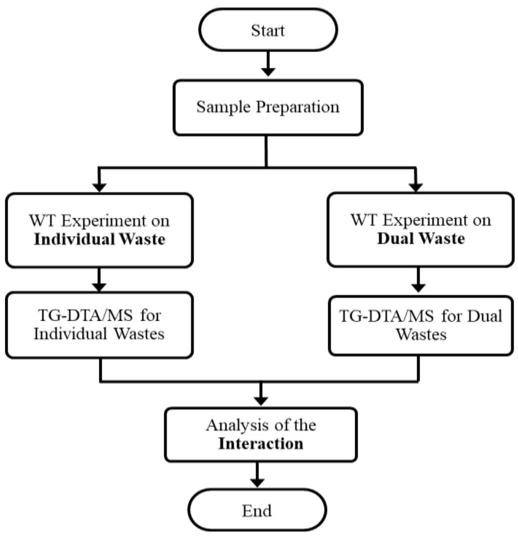

Figure 1 The workflow to investigate the interaction between waste components.

The wet torrefied products were then dried and prepared for thermogravimetric analysis. This result provides the thermogravimetric analysis (TGA) of individual and dual samples to investigate the significance of interactions between waste components. The significance of interactions was analyzed by comparing the average curve of data from two individual samples (non-interaction) with the experimental data of dual samples (with interaction).

3. RESULTS AND DISCUSSION

Figure 2 shows the calculated TGA curve (average) of two individual data of leaf litter (TW) and vegetable waste (VW) shown by the dashed-line and the TGA curve of the product from the dual sample (experimental product) shown by the solid-line. The calculation curves (non-interaction) coincide and have similar pattern with the curve of the experimental results at all temperatures. This similar pattern of curves and low of errors indicated that the interaction between leaf litter (TW) and vegetable waste (VW) during the wet torrefaction process was relatively small and could be negligible. Similar results also were shown by analysis for dual sample of leaf litter-fruit waste (TW-FW) and vegetable waste-fruit waste (VW-FW).

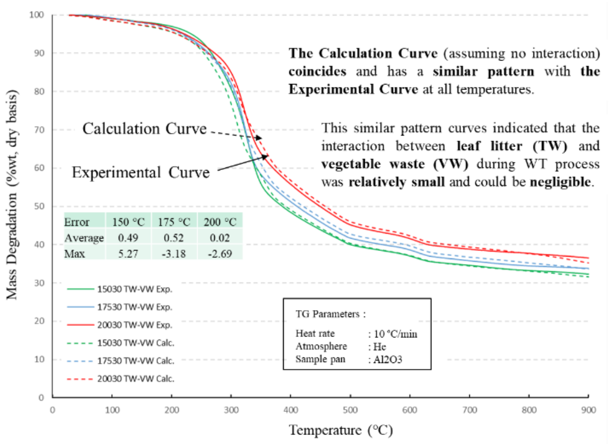

Figure 2 Investigation of interaction between leaf litter (TW) and vegetable waste (VW).

Figure 3 shows the investigation of the interaction between leaf litter (TW) and food waste (FdW). The calculation curves (non-interaction) do not coincide and have a different pattern with the experimental results curve at all temperatures. The errors are also significant for all temperatures. These indicated that food waste (FdW) interacted with leaf litter during the wet torrefaction process and should be considered on equations formulation. Similar results also were shown by analysis for dual samples of food waste-vegetable waste (FdW-VW) and Food waste-fruit waste (FdW-FW).

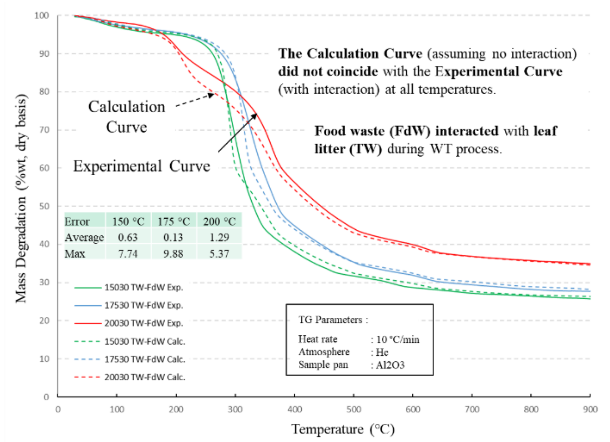

Figure 3 Investigation of interaction between leaf litter (TW) and food waste (FdW).

The curves resulting from the investigation of interactions between food (starch-based) waste and the three lignocellulosic wastes show a tendency for the experimental (with interaction) curve to be on the top and right of the calculation curve. During the wet torrefaction process on mixed lignocellulosic and starch-based biomass at the temperature of about 180°C, food waste turns into dextrin that is soluble in water and at a higher temperature decompose into intermediate products and then carbonized as carbon [11]. The products from food waste coat the undecomposed lignocellulosic-based biomass. In the thermogravimetric analysis (TGA), this "coating" will inhibit the lignocellulosic biomass decomposition process indicated by the delay in decomposition time.

The mechanism of starch-based material decomposition during the wet torrefaction process at a temperature of 200 °C and higher has not been widely discussed by other papers, so that the anomaly found in previous experiments: the increasing of mass yield and energy yield at wet torrefaction temperatures of 200 °C and higher [9], could not be explained with certainty yet. In order to explore this phenomenon, further research related to the stach-based waste decomposition mechanism still needs to be done, especially at relatively high temperatures of wet torrefaction.

4. CONCLUSION

During the wet torrefaction process, the interaction between leaf litter, vegetable waste, and fruit waste (lignocellulosic-based wastes) was relatively small and negligible. Meanwhile, Food waste (starch-based waste) interacted with leaf litter, vegetable waste, and fruit waste during the wet torrefaction process. In formulating equations to predict the fuel properties of the wet torrefied products, it not only considers the composition of waste and operating temperatures but also the interaction between the components of waste, especially food (starch-based) waste.

REFERENCES

[1] Badan Pusat Statistik Indonesia (2013): *Indonesia population projection 2010-2035*, 978–979. https://doi.org/2101018

[2] UNEP (2017): *Summary report: Waste management in ASEAN countries* (U. N. E. Programme, Ed.), United Nations Environment Programme, Thailand.

[3] KNLH Republik Indonesia (2008): *Statistik persampahan domestik Indonesia*.

[4] Yoshikawa, K. (2009): Hydrothermal treatment of municipal solid waste to produce solid fuel, *7th International Energy Conversion Engineering Conference, 2-5 August 2009, Denver, Colorado.*, (August), 1–12. https://doi.org/10.1007/978-3-642-54458-3_14

[5] Prawisudha, P., and Novianti, S. (2011): Municipal solid waste treatment using hydrothermal process to produce a renewable energy source, *Inovasi*, **19**, 15–22

[6] Toor, S. S., Rosendahl, L. A., Hoffmann, J., Pedersen, T. H., Nielsen, R. P., and Søgaard, E. G. (2014): Hydrothermal liquefaction of biomass,

189–217 *in Application of hydrothermal Reaction to Biomass Conversion*

[7] Coronella, C. J., Lynam, J. G., Reza, M. T., and Uddin, and M. H. (2014): Hydrothermal carbonization of lignocellulosic biomass, 275–311 *in Application of Hydrothermal Reactions to Biomass Conversion*, Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-54458-3

[8] Triyono, B., Prawisudha, P., Pasek, A. D., and Mardiyati (2017): Study on utilization of Indonesian non-recycled municipal solid waste as renewable solid fuel, *International Conference on Thermal Science and Technology (ICTST)*, 020004. https://doi.org/10.1063/1.5046588

[9] Triyono, B., Prawisudha, P., Mardiyati, and Pasek, A. D. (2018): Experimental study on utilization of Indonesian non-recycled organic waste as renewable solid fuel using wet torrefaction process, *Engineering Journal*, Volume 22 Issue 6, DOI:10.4186/ej.2018.22.6.81

[10] Triyono, B., Prawisudha, P., Aziz, M., Mardiyati, Pasek, A. D., and Yoshikawa, K. (2019): Utilization of mixed organic-plastic municipal solid waste as renewable solid fuel employing wet torrefaction, *Waste Management*, Volume 95, 1-9. https://doi.org/10.1016/j.wasman.2019.05.055.

[11] Qi, Y., Zhang, M., Qi, L., and Qi, Y. (2016): Mechanism for the formation and growth of carbonaceous spheres from sucrose by hydrothermal carbonization, *RSC Advances*, **6**(25), 20814–20823. https://doi.org/10.1039/c5ra26725k