Production of Briquettes to Utilize Woody Cutting Waste at Universitas Internasional Semen Indonesia (UISI)

Q A M O Arifianti, A Rahmat, U Anggarini, E F Nugrahani, and K K Ummatin

1,4,5 Engineering Management Universitas Internasional Semen Indonesia Gresik, Indonesia
2,3 Chemical Engineering, Universitas Internasional Semen Indonesia, Gresik, Indonesia

Email: qurrotin.arifianti@uisi.ac.id, anni.rahmat@uisi.ac.id, ufafa.anggarini@uisi.ac.id, elita.nugrahani@uisi.ac.id, kuntum.ummatin@uisi.ac.id

Abstract. Universitas Internasional Semen Indonesia (UISI) disposes abundant amount of woody waste, such as leaves, twigs, and branches from the pruning of woody plants. The aim of this research is to convert this waste into combustible biomass briquettes by varying the particle size and binder ratio. A hydraulic press with 2 tons power and a cylindrical iron mold with diameter of 3.5 cm and height of 3 cm were used for the briquetting process. The physical characteristics of woody waste briquette, such as moisture content, ash content, volatile matter and carbon fix were evaluated using proximate analysis. The caloric value of briquetted fuel was measured by bomb calorimeter. The combustion test was conducted to determine the combustion characteristic of briquettes. The general result shows that the caloric value of developed briquettes was between 3402 and 3630 kcal/kg. The moisture content of briquette ranged from 1.080-1.16%. Volatile matter was found in the range of 22.2 to 39.4%. Ash content was 31.2-35.9%, and carbon fix was 23.54-45.52%. The shortest ignition time was 229 s. The longest burning time was 78 minutes. Based on TG/DTA results, woody waste briquette decomposition occurred from 49°C to 801°C.

1. Introduction

Energy is a major component supporting all activities of humans. Mostly, energy sources are derived from fossils which could not be renewed. Energy needs in the world are increasing along with population growth, for example Indonesia has experienced an energy crisis in 2005 which caused rising fuel price. To overcome these problems Indonesian government made a policy by reducing the amount of petroleum production in 2014 by 818 thousand billion barrels per day to 700 thousand billion barrels per day in 2019, then the addition of power plants in 2014 amounted to 50.7 GW to 86.6 GW in 2019, and the addition of alternative energy utilization by 10-16% in 2015-2019.

Alternative energy has several types including biofuel, biomass, geothermal, water, wind, sun and ocean waves. They might be converted into various forms including liquid and solid fuels as needed. Universitas Internasional Semen Indonesia is located in an ex-cement industry area where many vegetation planted in those location. Every day, abundant amount of woody waste is disposed without any additional treatment to increase the value. Based on numerous literature, agriculture and forestry waste could be utilized as energy source. Supriyatno and M Krishna [1] utilized organic waste from POLBAN Bandung campus area including flameboyant wood twigs (Delonix Regia), angasna leaves (Pterocarpus Indicus) and pine flowers (Pine Forest). The results showed that the best calorific value
was pine flower charcoal briquette of 4731.77 cal / gr (19873.434 kJ / kg), while leaf briquettes had a low heating value of 3475.86 cal / gr (14598.612 kJ / kg).

M Y Thoha and D E Fajrin [2] created charcoal briquettes from teak leaves with palm sugar sago binder. The results of this research indicate that the higher the binder substitution, the higher the water content, the higher the ash content, the higher the volatile matter level, the lower carbon fixed and the lower heating value. I Suryani et al. [3] used biochar briquettes from bintaro fruit and coconut shell by varying the carbonization temperature and the composition of raw materials. The results showed that composition of raw materials of bintaro fruit and coconut shell 40%: 60% produced optimum charcoal briquettes.

The present research aims to investigate the potential of woody waste in UISI campus area as biochar briquettes and also its characteristic. In this experiment, two variations were constructed, namely variations of binder and particle size. The woody waste briquettes were created with three different percentage of binder, i.e. 5%, 10%, and 15%. The crushed samples were sieved into three particle size, i.e. 16-30 mesh, 30-50 mesh, and 50-100 mesh. Several test were conducted to evaluate the briquettes performance, for example proximate analysis including the detection of moisture content, ash content, volatile matter, and fixed carbon, calorimetry test (to measure the heating value of briquettes), and combustion test. Thermogravimetry/ Differential Thermal Analysis (TG/DTA) was also performed to indicate various thermal properties of briquettes, monitor the change of mass, temperature and heat flow against time, and determine whether decomposition reactions are exothermic or endothermic. S R Teixeira et al. [4] used thermogravimetric (TGA) analysis to characterize charcoal briquettes from fly ash sugarcane bagasse. TGA briquette data showed organic concentration increased to 53% and ash concentration dropped to 35%. Z O K Atakli et al. [5] used a thermogravimetric analysis to determine the combustion characteristics of a mixture of Turkish and coal nut shells.

Although similar research works could be found [6] [7] [8], but the current experiment is important as an initial step to utilize the woody waste in campus area, especially in UISI and also to determine its characteristic which may differ from another previous works. Moreover, research on the thermochemical and pyrolytic properties of woody waste briquettes have not been yet completely reported in the literature.

2. Methodology

2.1. Briquette Production

The collection of woody waste from UISI were dried under direct sunlight for three consecutive days started from 8.00 to 16.00. Subsequently, the waste was carbonized to produce biochar at temperature ±286 °C. The experiment consists of two major parts. First part is to determine the best binder composition. The binder percentages were 5%, 10%, and 15% (dry basis) of tapioca starch with heterogenous particle size. The composition percentage of water, biochar, and tapioca flour can be seen in table 1.

| Percentage Mass (gram) | Biochar | Binder | Biochar | Tapioca Flour | Water |
|-----------------------|---------|--------|---------|---------------|-------|
| 95% 5%                | 47.5    | 2.5    | 60      |                |       |
| 90% 10%               | 45      | 5      | 60      |                |       |
| 85% 15%               | 42.5    | 7.5    | 60      |                |       |

As seen on Table 1, 60 grams of water used in the experiment since briquettes were easily created and molded. The composition that has the highest caloric value would be used as a reference to complete the second part. The second part is to find the best particle size. To reduce the particle size of woody biomass, the grinding process was performed using a pulverizer mill (as shown in Figure 1). The sample was crushed into three size fractions of 16-30, 30-50, and 50-100 mesh. The briquettes were formed in a briquetting hydraulic press – BHP, with two tons power. The press machine could be seen...
in Figure 1. Afterwards, the briquettes were dried in an oven at 75°C for ± 3 hours to remove the water.

Figure 1. Pulverizer

2.2. Briquette Performance Test
Several test were conducted to analyze the characteristic and performance of briquettes. Proximate test was executed to detect the percentage of moisture content, ash, volatile matter and fix carbon. To test the moisture content, the briquette sample was weighed 5 grams and put into a porcelain cup. Later, the sample was heated in an oven which had a temperature of 105°C in 3 hours (according to SNI standard). After 3 hours, the samples were then allowed to cool down to room temperature and removed from the oven then the sample were weighed again. To determine ash content, the briquette sample was heated in the furnace at 850 °C for 4 hours. Meanwhile, to analyze volatile matter, sample heating process was performed in a furnace at 900°C for ± 7 minutes. In order to maintain the furnace condition, the pick-up was carried out the next day. Then the samples were weighed again.

A bomb calorimeter was used to obtain the caloric value of briquettes. A combustion test was performed to predict the ignition time, burning time, and combustion rate. Combustion test was carried out by burning briquettes in each variation with heating (as a trigger for briquetting ignition). Figure 2 shows the installation scheme for combustion characteristics testing. Observations were made using an infrared thermometer and camcorder to see changes in briquettes in detail. The measured data were initial and final mass, initial ignition time, briquette temperature and burning time. The test was repeated 3 times to get more accurate results on each variation. The first step to conduct combustion test is burning the zinc plate placed on the stove and heated for ± 5 minutes or until the burner surface reaches a temperature of ± 300-400 °C. After temperature condition was achieved, the briquettes were placed on the surface of the burner. The ignition time was measured after the briquette was placed and the briquette started to produce flame. If the flame started appearing, the stove would be turned off.

Figure 2. Installation Scheme for Combustion Test
(1: digital balance; 2: portable gas stove; 3: iron sheet; 4: briquette; 5: infrared thermometer; 6: gas hose; 7: regulator; 8: gas holder)
Subsequently, to detect thermochemical and pyrolytic properties, a 2.39 mg of briquette powder was tested using DT-TGA. The sample was heated at a rate of 10°C/min from 20°C to 801°C in nitrogen-oxygen flowing at the rate of 50 mL/min.

3. Result

3.1. Preliminary Test

Table 2. Calorimetry Test Result

| Binder Percentage | Calorific Value | Unit  |
|-------------------|----------------|-------|
| 5%                | 2973           | Cal/gram |
| 10%               | 3630           | Cal/gram |
| 15%               | 3601           |       |

Table 2 shows the calorific value of briquettes with different binder composition. The value was measured by using bomb calorimeter operated at 21.2 °C and 58% humidity. Based on the table, the calorific value of briquette lies in a range 2973 Cal/gram to 3630 Cal/gram, where the variation that contained 10% binder has the highest calorific value. The best binder percentage then used as a reference to create briquettes with different particle size.

3.2. Secondary Test Proximate Analysis

Table 3 compares the proximate analysis result consisting of moisture content, volatile matter, ash, and fixed carbon for each variation. For moisture content parameter, briquette with 50-100 mesh has the lowest moisture content. At the smallest particle size (50-100 mesh), constituent particles are tighter, thus a fewer cavities would be formed. The existence of cavity could store water which means the greater the particle size of the material of briquette, the greater the amount of water in briquettes. Each variation has a water content that meet the requirement of briquettes in Indonesian national standards (SNI), which the maximum limit is 8%. Based on Table 3, the smaller particle size, the lower volatile matter is obtained. It occurs since less denser briquettes would store more moisture, thus volatile matter was detected in a larger amount. Volatile matter for all variations meet the specification in SNI standard.

Ash is defined as the residual mass obtained after combustion process, under controlled conditions (time and temperature). As the ash content is higher, the briquette has more unburn inorganic substances. Thus, the briquettes would have low quality. Based on Table 3, the greater the particle size of briquettes, the higher the value of ash content. The ash value exceeds SNI standard, which the maximum permitted value is 8%. Improvements are needed to reach the expected standard.

Fixed carbon determines the amount of carbon contained in the material. Fixed carbon contents used to measure solid material that can be burned during combustion process. Fixed carbon is calculated by add the percentage of moisture content, volatile matter, ash content together and this sum is subtracted from 100%. Fix carbon would be higher if moisture content, ash, and volatile matter
have lower value. The percentage value of fixed carbon based on the calculation results do not satisfy SNI standard.

3.3. Bomb Calorimeter Test

Table 4. Calorimetry Test Result

| Particle Size (mesh) | Calorific Value | Unit      |
|----------------------|-----------------|-----------|
| 16-30                | 3402            | Cal/gram  |
| 30-50                | 3485            | Cal/gram  |
| 50-100               | 3630            | Cal/gram  |

Calorific value is a number that states the amount of heat energy released by the complete combustion of a fuel. The calorific value can determine the quality of briquettes. Based on the test result, the smaller the particle size of the briquette, the greater the heat value will be obtained. These findings are consistent with fix carbon trendline for each variation as aforementioned in proximate analysis. The variation of 50-100 mesh particle size has the highest heat value but it still falls behind SNI standards.

Figure 3. Combustion Process of Biochar Briquettes
Table 5. Combustion Test Result

| Particle Size (mesh) | Initial Ignition Time (s) | Combustion Rate (gram/min) | Burning Time (min) |
|----------------------|----------------------------|---------------------------|-------------------|
| 16-30                | 293                        | 0.171                     | 78                |
| 30-50                | 282                        | 0.181                     | 72.7              |
| 50-100               | 229                        | 0.190                     | 68.7              |

Figure 3 shows the combustion process on woody waste briquette. The photos were taken every 10 minutes. Flames started to appear from the lowest surface of briquettes. As it propagated to all part of the briquette, ash was formed from the outer layer. Table 5 compares ignition time, combustion rate, and burning time of each particle size. As shown in Table 5, 16-30 mesh briquettes require 4 minutes 53 seconds, 30-50 mesh Briquettes need 4 minutes 42 seconds, and 50-100 mesh briquettes take 3 minutes 49 seconds for initial ignition. Subsequently, for the burning time, the smaller the particle, the shorter the burning time. It reveals that as the briquette particles get smaller, the distance between constituent particles would be closer, thus the flames propagate quickly. Therefore, the smallest particle size has the highest combustion rate.

Figure 4 shows the distribution of briquette temperature change during burning process. The measurement was conducted by pointing the infrared thermometer on the top-center of briquette. Based on the Figure 4, 50-100 mesh briquettes reach the highest combustion temperature. The main reason of this phenomenon is due to a higher calorific value on 50-100 mesh briquettes.

3.4. Thermal-pyrolytic analysis

Briquettes decomposition usually occurs in 4 stages, specifically drying (~100 °C), heating (100-300 °C), devolatilization and char aggregations (200-600 °C) [10]. Figure 5 shows the TG/DTA curves of woody waste briquette. It presents three important parameters against time, namely weight, temperature, and heat flow under pyrolysis conditions. Generally, woody waste briquette performs multiple peak describing the particular stage of decompositions. To figure out the characteristics of whole process, temperatures should be identified, especially the peak temperature of reactions. Table 6 compares the initial, peak, and final temperature of briquette decomposition. These basic findings show the consistency with another previous works [10] [11].

The first stage shows a mass reduction of 6.66% (0.158 mg) at a temperature around 49°C to 221°C which the process denotes the evaporation of moisture from the inside outward. Although the woody waste was carbonized which means the moisture content could be reduced significantly, but the addition of water on binder composition to form briquettes may increase the moisture content.
Based on Figure 4, a peak could be found as an indication of endothermic reaction. The second stage is the stage of initial heating briquettes that occur between 221°C -354°C, with a mass reduction of 16.9% (0.4 mg). The devolatilization stage or degradation of briquettes take place with a single endothermic peak at temperatures of 354°C -462°C. As shown in Figure 5, at this stage there is a gradual mass reduction of 30% (0.73 mg), accompanied by the loss of some volatile components.

![Figure 5. TG-DTA Curves](image)

The fourth stage is the step of char carbon aggregation that occurs at a temperature of 462°C - 801°C. At this stage, there is no significant reduction of briquette mass since it has the lowest mass reduction percentage among all where the value is around 3%. However, char would be formed during the carbon pyrolysis process.

| Decomposition Stage | Temperature (°C) |
|---------------------|------------------|
|                     | Initial | Peak | Final |
| Drying              | 49      | 154  | 221   |
| Heating             | 221     | 302  | 354   |
| Devolatilization    | 354     | 437  | 462   |
| Char Aggregation    | 462     | -    | 801   |

### Table 6. Briquette Decomposition Temperature

4. Conclusion

It can be concluded from the experiment that woody waste in UISI area could be utilized as bio briquettes in terms of increasing the value of the waste. The highest calorific value is obtained in 50-100 mesh briquettes with 10% binder percentage. The only parameter that satisfy the criteria of good quality briquette in SNI standard is moisture content. Therefore, it is necessary to add another raw material in order to improve the quality of the briquette.

5. References

[1] Merry, Supriyantodan, "Studi Kasus Energi Alternatif Briket Sampah Lingkungan Kampus Polban Bandung," in Seminar Nasional Teknik Kimia, Yogyakarta, 2010.

[2] Thoha, M Yusuf and Fajrin, Diana Ekawati, "Pembuatan briket arang dari daun jati dengan sagu aren sebagai pengikat," Jurnal Teknik Kimia, vol. 17, no. 1, 2010.
[3] Suryani, Indah and Dahlan, M Hatta and others, "Pembuatan Briket Arang Dari Campuran Buah Bintaro dan Tempurung Kelapa Menggunakan Perekat Amilum," Jurnal Teknik Kimia, vol. 18, no. 1, 2012.

[4] Teixeira, SR and Pena, AFV and Miguel, AG, "Briquetting of charcoal from sugar-cane bagasse fly ash (scbfa) as an alternative fuel," Waste management, vol. 30, no. 5, pp. 804-807, 2010.

[5] Kocabas-Atakli, Zuleyha Ozlem and Okyay-Oner, Firuze and Yurum, Yuda, "Combustion characteristics of Turkish hazelnutshell biomass, lignite coal, and their respective blends via thermogravimetric analysis," Journal of Thermal Analysis and Calorimetry, vol. 119, no. 3, pp. 1723--1729, 2015.

[6] Bhattarai, Pushkar and Sapkota, Ramchandra and Ghimire, Rudra Mani, "Effects of Binder and Charcoal Particle Size on the Physical and Thermal Properties of Beehive Briquettes," in IOE Graduate Conference, 2016..

[7] Waluyo, Joko and Pratiwi, Yuli and Sukmawati, Paramita D, "Biochar Briquette from Jackfruit Crust, Production, Mechanical and Proximate Properties," International Journal of Scientific Engineering and Science (IJSES), vol. 1, no. 11, pp. 42-44, 2017.

[8] Rusdianto, Andrew Setiawan and Choiron, Miftahul, "Analysis of Bio Pellet Process based on Mass Balance," Agriculture and Agricultural Science Procedia, vol. 3, pp. 262-265, 2015.

[9] Standar Mutu Briket Arang Kayu (No.1/6235/2000), 2000.

[10] Nyakuma, Bemgba Bevan and Johari, Anwar and Ahmad, Arshad and Abdullah, Tuan Amran Tuan, "Comparative analysis of the calorific fuel properties of Empty Fruit Bunch Fiber and Briquette," Energy Procedia, vol. 52, pp. 466-473, 2014.

[11] B. B. Nyakuma, "Thermogravimetric and kinetic analysis of melon (Citrullus colocynthis L.) seed husk using the distributed activation energy model," Environmental and Climate Technologies, vol. 15, no. 1, pp. 77-89, 2015.

Acknowledgments
This work was funded by Universitas Internasional Semen Indonesia through the scheme of Hibah Riset Bersaing 2018. The title of the research is Proses Pembuatan dan Karakterisasi Bahan Bakar Briket dari Sampah Organik UISI.