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Production of bio-briquette from biochar derived from pyrolysis of cashew nut waste

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ABSTRACT

Bio-briquette has been successfully made from biochar by-products of the liquid smoke production from cashew nut wastes. The cashew nut wastes were first converted into biomass biochar using a pyrolysis method. This biomass has a lower calorific value than the produced bio-briquettes thus the biomass calorific value can be increased by converting it to bio-briquettes. The purpose of this study was to assess the effect of particle size and adhesive concentration on the quality of bio-briquettes produced. The bio-briquette production was initiated by grinding and sieving the biomass biochar by using sieves of 70, 140 and 200 mesh. Proximate analysis (moisture content, ash content, volatile substance, fixed carbon), and calorific value were then carried out. After the optimum particle size was obtained, bio-briquettes were then produced using a tapioca flour adhesive at concentrations of 8%, 10% and 12% with the addition of hot water until homogeneity of the mixture was attained. The obtained bio-briquettes were then pressed at a pressure of 300 kg/cm^2 and oven-dried for 4-6 h. The results showed that the best particle size for bio-briquettes production was obtained by using a 200 mesh, and the best adhesive concentration was 12% resulting in a bio-briquette compressive strength of 7.60 kg/cm^2.

Key words : *Bio-briquette, Biochar, Cashew nut waste, Pyrolysis*

Introduction

Some researchers have made efforts to reduce dependence on petroleum and its derivatives as sources of raw materials. Raw materials that can substitute petroleum as a source of fuel are biomass and biofuel (Sirajudin *et al.*, 2013). One of the ways of obtaining biofuel is by biomass briquetting (Cahyono *et al.*, 2017). Biomass is a very abundant, renewable raw material that is environmentally friendly and can first be processed into biochar by using pyrolysis. Pyrolysis is thermal destruction of biomass in the absence of air/oxygen (Ozbay and Ayrilmis, 2017). Solid pyrolysis products contain char, ash and unchanged biomass. Conditions under which pyrolysis is carried out determine chemical composition of the solid products. Char can be used for preparation of active carbon provided that pore structure and surface area are appropriate (Faizal, 2017). During pyrolysis, large molecular hydrocarbons in biomass break down into relatively small molecules in the form of liquids, solids (generally biochar) and gases (Basu, 2013). Biomass has a lower calorific value than bio-briquettes (Tamilvanan, 2013). Thus the calorific value of char from biomass can be increased by converting it into

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bio-briquettes, which can be an alternative to fossil fuels. A bio-briquette is biochar in a particular shape, made by using pressing techniques and adhesives (Fikri and Sartika, 2018).

Some of the sources of biomass that can be converted into bio-briquettes are: wood, coconut shell, palm shell biochar, empty palm fruit bunches, banana peels, rice husk, peanut shell, jatropha, durian skin, cocoa shells, corn cobs (Faizal, 2017) and banana leaves (Maia *et al.*, 2014). Biobriquettes made from these biomass sources exhibit many advantages over other solid fuels such as:

(a) lower price than that of coal,
(b) bio-briquettes are a renewable source in contrast to oil, coal or lignite, which deposits once used, cannot be replaced (non-renewable),
(c) bio-briquettes do not contain sulphur, so that pollution of the environment is avoided,
(d) practically, bio-briquettes have a higher calorific value than other solid fuel sources,
(e) ash content in bio-briquettes is much lower than that in coal (about 2-10% vs. 20-40%, respectively),
(f) compared to coal, combustion of bio-briquettes is more uniform,
(g) bio-briquettes can be produced near the consumers; therefore, supplies are not dependent on erratic transportation over long distances, and
(h) due to the low moisture content and higher density, bio-briquettes provide much higher boiling efficiency as compared to fire wood or loose biomass (Sharma *et al*., 2015).

Based on data from the Central Bureau of Statistics of Southeast, the production of cashew nut from 2011 to 2013 was on the increase, with an area of 117,414 Ha. Cashew nut waste is a by-product from the cashew nut processing and if burnt, can cause environmental pollution.

To make bio-briquettes, adhesive materials are needed merge components and to obtain hardness and compactenss. Some of the commonly used adhesive materials are soil mud, starch and molasses. The type of adhesive used affects the quality of bio-briquette produced and high-quality adhesive will result in high-quality bio-briquettes.

The aim of this study was to make bio-briquettes from biochar, a by-product from the liquid smoke production from cashew nut waste, using tapioca starch as the adhesive. Variables that affect the bio-briquette quality such as the effect of particle size and adhesive concentration were studied.

Materials and Methods

Materials

The main ingredients used in this study were the biochar as a by-product from the liquid smoke production from cashew nut waste obtained from obtained from Muna Regency, South East Sulawesi. Pyrolysis experiments were performed by using 2 kg of cashew nut wastes placed in a pyrolysis reactor. The pyrolysis temperatures was 350 ^{o}C. Biochar was collected in the reactor at the end of the experiment after 1 h and weighed. The adhesive material used was tapioca flour obtained from around the city of Makassar. Bio-briquettes were produced by using bio-briquettes press machines (Krisbow hydraulic press floor type 10T obtained from Johnson Store Makassar, Figure 1).

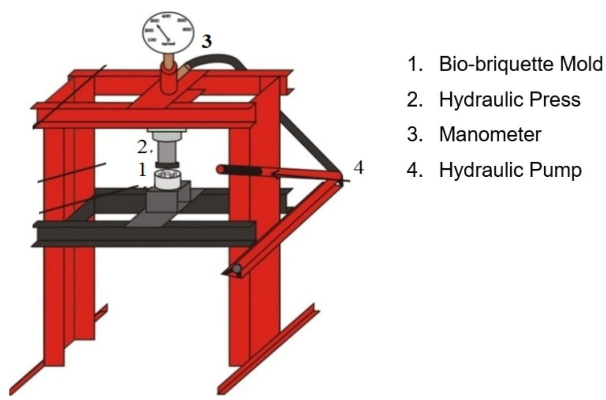

Fig. 1. Schematic presentation of the apparatus for production of bio-briquettes

Production of bio-briquettes

In this research, bio-briquettes were produced by pyrolysis of cashew nut waste. Three products were obtained as a result of pyrolysis at the temperature of 350 °C: liquid smoke, tar, and biochar.The obtained biochar was milled manually using both traditional tools and a blender until the particles attained a tiny size and became homogeneous. Then, it was passed through sieves of 70, 140 and 200 mesh. Particles of biochar that could not pass through the sieves were milled again. Then the biochar was characterized by proximate (moisture content, ash content, volatile matter, and fixed carbon) and calorific value analyses. Proximate analyses performed in the Laboratory Superintending

Company of Indonesia (Sucofindo) Makassar Indonesia. For the elemental analysis, the following standard procedures were used: ASTM D3173, ASTM D3174 and ASTM D3175 procedures for moisture, ash and volatile matter respectively. Fixed carbon was determinate using the data previously obtained in the proximate analysis using the formula FC (%) = 100 - (percentage of moisture + percentage of ash + percentage of VM). The calorific value were determined using a PARR- bomb calorimeter, according to ASTM D5865. This method follows the standard procedure of the American Society for Testing and Materials (ASTM, 2013). From the test results, the size of raw materials, which met requirements for bio-briquettes manufacture was 200 mesh.

To make a slurry or a dough, biochar was mixed with tapioca flour and added ethanol and warm water (ratio 50% ethanol: 50% water). The mixture was then stirred until it became. Afterward, adhesive was then added at a ratio of 8%, 10% and 12% respectively of the total slurry. Then the mixture was inserted into a mold in the press and compression proceeded for 5 min until the pressure reached 29.4 MPa (300 kgf/cm^2). The bio-briquttes were molded into a shape of a hollow cylinder. After removal from the mold the obtained bio-briquettes were weighed to get the initial weight and then dried in the oven at temperature 50 ^{o}C for 4-6 hours until completely dry. During drying, the bio-briquettes were flipped so that they would dry evenly distributed.

Results and Discussion

The effect of particle size on the quality of bio-briquettes

The obtained biochar was characterized by proximate analysis (moisture content, ash content, volatile matter, and fixed carbon) and calorific value. Table 1. There are several factors that affect the bio-briquettes quality including the moisture content, ash content, volatile matter, fixed carbon, calorific value. High moisture content will result in a low calorific value (Carnaje *et al*., 2018; Ollett *et al*., 1993; Onukak *et al*., 2017). High moisture levels cause lower thermal efficiency and burning rate so that it is preferred that the bio-briquettes has a lower moisture level (Onukak *et al*., 2017). Table 1 shows that smaller particle sizes lead to higher moisture contents. This is of a very large surface area of small particles, causing higher water absorption as the char particles are also highly hygroscopic. The process of water absorption by biochar begins after the pyrolysis process is completed. Water is trapped within the pores of small biochar particles becoming difficult to evaporate. Moisture contents determined in the present research were lower than those reported in and below the limit of 8 wt% set by the standard for biochar bio-briquettes (SNI 016235-2000).

In addition to the moisture content, ash content also affects the quality of the bio-briquettes produced. Ash is the waste material from the burning processes. The main component present in ash is a non-combustible mineral known as silica, which is left behind after the combustion process has ended (Glushankova *et al*., 2018). Presence of ash decreases the heating value (Akowuah *et al*., 2012; Onchieku *et al*., 2012; Onukak *et al*., 2017) so that the quality bio-briwuettes with high ash contents is low (Carnaje *et al*., 2018). From Table 1, it can be seen that the larger the particle size, the smaller the ash content. Ash content of the shells of cashew nuts could be due to many chemical elements present in the shells. Ash generally contains calcium, potassium, magnesium, sodium, manganese, iron, aluminum, zinc, silica, copper and chromium, depending on the type of biomass (Olanders and Steenari, 1995; Zhu *et al*., 2011). Minerals that cannot be oxidized by oxygen such as SiO_2, Al_2O_3, Fe_2O_3, CaO, and alkali will remain in the solid form as ash after burning, The ash content obtained in this study was 4.3 wt%, lower

Table 1. Proximate test results and ultimate analysis for different bio-briquettes particle sizes

Size (mesh)	Moisture (wt%)	Ash (wt%)	Volatile matter (wt%)	Fixed carbon (wt%)	Calorific value (MJ/kg)
70	4.95	4.30	19.56	71.19	29.48
140	5.30	5.08	18.40	71.27	29.51
200	5.30	4.96	17.16	72.62	29.49

than that reported (Tamilvanan, 2013; Ujjinappa and Krishnamurthy, 2018) The tolerance level for the ash content in a fuel is below 4 wt% (Oyelaran *et al*., 2017) while it is 8 wt% biochar bio-briquettes (SNI 016235-2000) so that the biochar produced in this study meets this standard.

Volatile substances also affect the quality of bio-briquettes and as the particle size decreased, the concentration of volatile substances is lower (Karunanithy *et al*., 2012). Table 1 shows that the highest content of volatile matter was 19.56 wt% in particles from a 70 mesh sieve, while the lowest content of 17.16 wt% was in particles from a 200 mesh.

In terms of particle size this is made possible by the difference in density between particles at 70 mesh sieve having lower density, the biobriquette pores become larger. This condition resulted at the time of testing process of volatile matter level require faster time so that the substance of flying not yet evaporated maximal compared with biobriquette which with higher density that is sieve 200 mesh. The content of high volatile matter has a weakness that is low levels of carbon bound. Levels of high volatile matter the results of this study is lower than research. This is in accordance with the findings of Suvunnapob *et al*., (2015) (Suvunnapob *et al*., 2015) that wood with high density will produce bio-briquette with more volatile matter.

The content of volatile matter is inversely proportional to the level of the fixed carbon. Levels of volatile matter from the results of this study are lower than those reported in literature (Tamilvanan, 2013; Ujjinappa and Krishnamurthy, 2018). Table 1 shows that larger particle size tends to decrease carbon content. Low carbon levels indicate poor fuel quality. The bonded carbon content meets the Japanese (60% - 80%) and the UK (75.3%) bio-briquette standards.

Particle size greatly affects the heat that will be produced by briquettes, hence determining the quality of bio-briquettes produced (Sutrisno *et al*., 2017). Table 1 shows that the highest calorific value of 29.51 MJ/kg had the particles of 140 mesh The high heating value can generate greater heat energy and can be utilized for a wider range of purposes (Abimbola and Yekin, 2017). The lowest calorific value of 29.48 MJ/kg was recorded for particles of 70 mesh. From the particle size of bio-briquettes, it can be deduced that the smaller the particle size, the higher the calorific value. The calorific value recorded in this study is higher than the values reported in literature (Tamilvanan, 2013; Ujjinappa and Krishnamurthy, 2018) Coals from Odagbo (Kogi State) and Ezimo (Enugu State), both in Nigeria, were reported to have calorific values of 22.60 MJ/kg (5398 cal/g) and 19.10 MJ/kg (4562 cal/g), respectively (Chukwu *et al.*, 2016). Results obtained in the present study show that bio-briquettes from cashew nut waste can compete favorably with those coal providing a source of renewable energy.

The effect of adhesive concentration on the bio-briquette strength

The effect of adhesive concentration on bio-briquettes compressive strength is presented in Table 2. It can be seen that the compressive strength increased as the adhesive concentration increased so that the best results were obtained at the adhesive concentration of 12 wt%. A compressive strength test is performed to determine the strength of a product when subjected to a load with a certain pressure (Borowski *et al*., 2017). The level of strength is determined when the product is no longer able to withstand the load. Highest compressive strength value at 12% adhesive concentration was 7.45 Pa, while the lowest compressive strength value at 8% adhesive concentration was 7.42 Pa. In general, an increase in the adhesive concentration causes a corresponding increase in compressive strength. The increase in adhesive concentration will cause the bonding between the briquette biochar particles and the adhesive to become stronger, thereby increasing resistance to impact (Rahman *et al*., 2003). This is due to the bonding power of the adhesive so that when the bio-briquette is dropped, the particles will be released in small bits. The strength of bio-briquette from this research appears to be higher than those from studies by (Onukak *et al*., 2017). This shows that an increase in adhesive concentration strengthens the bond between the adhesive and the material of the bio-briquette.

Table 2. The effect of adhesive concentration on the bio-briquette compressive strength (particle size for briquette production from cashew nut waste was 200 mesh)

No	Adhesive content (%)	Bio-briquette strength (Pa)
1	8	7.42
2	10	7.43
3	12	7.45

Table 3. Proximate analysis and heating value of biomasses of various materials

Material	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Calorie value (MJ/kg)	Reference
Cashew nut waste	5.30	4.96	17.16	72.62	29.49	This work
Cashew shell	9.72	3.05	77.81	19.14	20.77	(Sawadogo *et al.*, 2018)
Cotton stalk	10.70	2.90	75.10	11.30	17.50	(Wu *et al.*, 2018)
Wood sawdust	8.90	3.10	78.60	9.40	17.60	
Rice husk	12.00	12.65	56.46	18.88	14.76	(Department of Alternative Energy Development and Efficiency, 2012)
Rice straw	10.00	10.39	60.70	18.90	13.66	
Bagasse	50.73	1.43	41.98	5.86	9.24	
Cane trash	9.20	6.10	67.80	16.90	16.80	
Palm fiber	38.50	4.42	42.68	14.39	13.14	
Corncob	40.00	0.90	45.42	13.68	11.29	
Tapioca rhizome	59.40	1.50	31.00	8.10	7.46	
Eucalyptus bark	60.00	2.44	28.00	9.56	6.82	
Coconut shell	12.56	5.85	62.96	18.63	16.88	

Comparison of bio-briquettes produced from various materials

Calorific properties of bio-briquettes produced in this study showed that cashew nut waste is very suitable for the briquette production as shown in Table 3. The calorific value of bio-briquettes produced from cashew nut waste (29.49 MJ/kg) in this work is higher than those bio-briquettes reported in literature (Department of Alternative Energy Development and Efficiency, 2012). A high calorific value will make combustion more efficient thereby reducing the amount of bio-briquettes used (Shekhar, 2011).

In addition, other factors that influence the quality of briquettes are the moisture content and volatile substances. The moisture content affects the ignition process as well as the low water content speeds up the combustion rate of briquettes (Obi and Okongwu, 2016). The moisture content of cashew nut waste material for making bio-briquettes has lower moisture content than the other raw materials (Table 3). The moisture content in bio-briquettes from cashew nut waste is 5.3 wt%, therefore, making the bio-briquette from cashew nut waste is better because the combustion process that takes place will be faster. In addition, the low moisture content will also produce a low volatile matter. In Table 3, the volatile matter for bio-briquettes from cashew nut waste was 17.16%. At a low content of volatile substances, the smoke from the bio-briquettes combustion will be low. This makes bio-briquettes from cashew nut waste an environmentally friendly briquette because it can reduce the global warming effect and serve as a potential source of renewable solid fuels.

Conclusion

From the result of this research, it can be concluded that particle size and adhesive concentration affect the moisture content, ash content, fixed carbon content and bio-briquette volatility of cashew nut wastes. Optimum particle size for making bio-briquettes from cashew nut wastes was that from 200 mesh with calorific value of 29.49 MJ/kg, moisture content of 5.3%, ash content of 4.3%, volatile substances content of 17.16% and carbon content of 72.62%, meets the standardization of biochar bio-briquette (SNI 016235-2000) and also the Japanese bio-briquette standards. The best concentration of tapioca starch adhesive is 12% with a compressive strength of 7.45 Pa.

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