Improvement of Combustion Quality of Biomass Briquette from Water Hyacinth (*Eichhornia crassipes*) for Alternative Energy

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Abstract: Water hyacinth (*Eichhornia crassipes*) is a floating plant species, which spreads rapidly in fresh water area. This plant has found to cause environmental problems, such as clogging drainage, water intakes, and ditches, shading out other aquatic vegetation and interfering with fishing, shipping as well as recreational activities. In contrast to its drawbacks, water hyacinth is considered as one of the potential agricultural wastes in Indonesia that can be processed into an alternative solid fuel. Carbonization followed by briquetting is one of the methods that can be applied to process biomass into solid fuels. This work investigated the effect of carbonization temperature and two different types of binders on combustion characteristic of water hyacinth biomass. In this work, carbonization was carried out at three different temperatures, i.e. 350ºC, 400ºC and 450ºC, while comparing the application of two types of binders, which were tapioca gel and polyvinyl acetate (PVAc) adhesive. The results showed that carbonization process of water hyacinth increased the fixed carbon content and the calorific value, and the best result was obtained at 450oC with tapioca gel as the binder. With this condition, the fixed carbon content in the biomass briquette could be increased up to 34.14% with a calorific value of 3,837 kcal/kg. Although the combustion efficiency was only 4.89%. The application of water hyacinth as biomass briquette has shown a promising alternative to reduce CO emission and the above-mentioned environment problems.

Keywords: Water hyacinth, biomass, briquette, alternative energy

1. Introduction

Water hyacinth (*Eichhornia crassipes*) is a floating plant species that lives in water. The ability to rapidly cover whole waterways makes water hyacinth as the world's worst aquatic weed. In fact, the growth of water hyacinth within 6 months can reach 125 tons wet weight in the area of 1 ha (Istirokhatun et al., 2015). The existence of water hyacinth causes the difficulty of sunlight entering the water system and the reduction of oxygen content in water. For several years, water hyacinth has been a serious problem in Indonesia. In fact, the population of water hyacinth in Indonesia is very abundant across the country's water system, including lakes, swamps, etc. Moreover, this aquatic plant has some negative effects, such as blocking irrigation channels, eliminating native aquatic plants, and restricting livestock access to water to name a few (Istirokhatun et al., 2015). Since the availability of water hyacinth is very abundant in Indonesia because of its rapid growth, so it has great potential in terms of raw materials. In fact, water hyacinth has a high content of cellulose, hemicellulose, and lignin so it has a great potential to be utilized as a source for the production of biomass briquette. Biomass briquette is one of the most promising solid fuel to mitigate greenhouse gas emission during production and utilization. One of the methods for processing water hyacinth into biomass is by carbonization and briquetting process. By doing carbonization, the space need for storage can be smaller, and more importantly the combustion quality can also be improved (Surono, 2010). Although several studies have been done to produce biomass briquette from water hyacinth, no research has really compared the combustion quality of non-carbonized and carbonized water hyacinth at various temperature, which is important for combustion quality improvement. An improvement of the combustion quality through the application of carbonization and modified briquetting process through different types of binder needs to be further studied. Such study can be a solution to an emerging environmental problem and to energy deficiency.

2. Research Method

2.1. Materials and Equipment

The main materials used in this research were water hyacinths which were collected directly from Lake Cipondoh in Tangerang, Banten. In connection with the binders, tapioca flour and polyvinyl acetate (PVAc) adhesive (LEM FOX) were prepared to hold the biomass briquettes fine particle all together.

The equipment used for this research were oven for drying process, chopping machine for chopping the water hyacinth, furnace for carbonization, grinder for grinding the sample, sieve (40-mesh) for obtaining the needed particle size of a sample, and briquette press for forming biomass briquettes. Figure 1 shows several equipment used in the research.

Figure 1. Furnace (Left) and Briquette Press (Right)

2.2. Experimental Procedure

First of all, water hyacinths were wholly collected from Lake Cipondoh in Tangerang, Banten. Furthermore, the water hyacinths were roughly chopped by using chopper. Due to the different treatment for preparing non-carbonized and carbonized water hyacinths, the processes were done separately. Non-carbonization process was done by sun drying and grinding the water hyacinths into fine particles. As for the carbonization process, the water hyacinths were carbonized for 1 hour at several temperatures (350ºC, 400ºC, and 450ºC) in the furnace and ground using grinder as well. Both non-carbonized and carbonized samples were sieved with a 40-mesh sieve.

After that, two different types of binders (tapioca gel and polyvinyl acetate (PVAc) adhesive) were prepared to be mixed with either non-carbonized or carbonized (350ºC, 400ºC, and 450ºC samples. Prior to its mixing process with the sieved samples, tapioca flour and tap water were mixed in proportion of 1:5, whereas PVAc adhesive and tap water were mixed in proportion of 5:3. For each set of briquette sample, 5% tapioca gel or PVAc adhesive mixture on the entire mass of the sample was used. After mixing with the binders, the non-carbonized and carbonized samples were molded and compressed in a briquette press. The briquettes were immediately dried in an oven for 24 hours at 60ºC. Figure 2 shows the biomass briquettes made from different treatments.

Figure 2. Water Hyacinth Biomass Briquettes with Different Treatments

2.3. Experimental Procedure

Once the water hyacinth biomass briquettes were successfully made, the analytical procedure could be performed. The analyses were to determine proximate analysis (moisture content, ash content, volatile matter content, and fixed carbon content), ultimate analysis (nitrogen content, sulphur content, and chlorine content), and calorific value.

3. Results and Discussions

3.1. Proximate and Ultimate Analysis

The proximate analysis in this research was to determine the moisture, ash, volatile matter, and fixed carbon content of the water hyacinth biomass briquette, whereas the ultimate analysis was to determine nitrogen (N), sulphur (S), and chlorine content of the water hyacinth biomass briquette biomass briquette

Table 1: Proximate and Ultimate Analysis Results

Sample	**Moisture Content (%-w)**	**Moisture Content (%-w)**	**Ash Content (%-w)**	**Volatile Matter Content (%-w)**	**Fixed Carbon Content (%-w)**	**N (g/100g)**	**S (g/100g)**	**Cl (g/100g)**
Binder Type	**Sample**							
5% Tapioca Gel	Non-Carbonized	2.055	22.395	61.845	15.760	1.325	0.210	3.390
	350ºC	1.275	37.080	26.585	26.335	1.825	0.200	5.700
	400ºC	0.695	38.010	32.535	29.455	1.915	0.300	5.700
	450ºC	0.505	40.615	25.275	34.110	2.185	0.320	5.730
5% PVAc Adhesive	Non-Carbonized	1.875	20.885	61.690	17.425	1.595	0.200	3.690
	350ºC	0.895	36.360	37.345	26.295	1.870	0.170	5.700
	400ºC	0.605	37.890	33.165	28.945	1.970	0.280	5.730
	450ºC	0.515	40.615	25.250	34.140	1.970	0.310	5.700

3.1.1. Effect of Binder Types and Carbonization Treatment on Moisture, Ash, Volatile Matter, and Fixed Carbon Content of Water Hyacinth Biomass Briquette

Moisture content is the ratio of water in a material that lost during the drying process. The lower the moisture content the better the quality of the biomass briquette. According to the Table 1, the moisture content of biomass briquette using PVAc adhesive is lower than tapioca gel in the first three treatments. Compared to tapioca gel, PVAc adhesive is more able to make the biomass briquettes less porous, which make the water in the surrounding not easily absorbed the by the biomass briquettes (Karim, Ariyanto, & Firmansyah, 2014). In contrast, Faujiah (2016) adds that adhesive such as tapioca gel which contains starch, may possibly absorb water from the air. Consequently, the non-carbonized and carbonized biomass briquette with 5% tapioca gel has more moisture content than using 5% PVAc adhesive. In terms of carbonization treatment, the lowest moisture content is 0.505%, which occurs in carbonized biomass briquettes at 450°C with 5% tapioca gel. This has almost the same value as carbonized biomass briquettes at 450°C with 5% PVAc adhesive, which is 0.515%. While the highest moisture content is 2.055%, which occurs in non-carbonized biomass briquettes with 5% tapioca gel. The moisture contents of the water hyacinth biomass briquettes are lower along with the increase in carbonization temperature. That means, the water in the sample will be driven off as vapour during the carbonization process, resulting in lower moisture content in the final product.

As for the ash content, since it is incombustible and may cause corrosion, so it is actually unwanted. The ash content of biomass briquette using tapioca gel is higher than PVAc adhesive in the first three treatments. The high amount of ash content found in the biomass briquette with 5% tapioca gel also affected by the high content of inorganic substances found in tapioca gel such as SiO_2, MgO, Fe_2O_3, AlF_3, MgF_2, and Fe (Maryono, Sudding, & Rahmawati, 2013). However, the ash content of carbonized biomass 450°C with either tapioca gel or PVAc adhesive achieves an even result. Although the use of binder contributes amount of ash into the water hyacinth biomass briquettes, but the binder should still be applied. Otherwise, the biomass briquettes will be easily crumbled and difficult to be utilized as a fuel. In terms of carbonization treatment, the lowest ash content is 20.885%, which occurs in non-carbonized biomass briquettes with 5% PVAc adhesive. While the highest ash content is 40.615% reached by carbonized biomass at 450°C, where two binders (tapioca gel and PVAc adhesive) achieve an even result. That means, the ash contents of the water hyacinth biomass briquettes are higher along with the increase in carbonization temperature. The higher the carbonization temperature, will cause decomposition in the water hyacinth, while the remaining composition turns into ash. This was also occurred in the research by Wahyusi et al. (2012), where the ash content of peanut skin biomass briquette was increased along with the increase in carbonization temperature

In addition, volatile matter content is a parameter to measure amount of smoke produced during the combustion process. According to Table 1, the lowest volatile matter content is 25.25%, which occurs in carbonized biomass briquettes at with 5% PVAc adhesive. This has almost the same value as carbonized biomass briquettes at 450°C with 5% tapioca gel, which is 25.275%. While the highest volatile matter content is 61.845%, which occurs in non-carbonized biomass briquettes with 5% tapioca gel. This has almost the same value as non-carbonized biomass briquettes with 5% PVAc adhesive, which is 61.69%. The similarities of volatile matter content between two binder types in the biomass briquettes indicate no correlation with the composition of binder.

Lastly, fixed carbon is one of the parameters used to determine the quality of the briquettes, where the higher the fixed carbon content, the better the quality of the briquettes in which less smoke will be produced during the combustion process. According to Table 1, the highest fixed carbon content is 34.14%, which occurs in carbonized biomass briquettes with 5% PVAc adhesive. At 350°C, 400°C and 450°C, the carbonized biomass briquettes with either 5% tapioca gel or 5% PVAc adhesive have almost the same fixed carbon contents. The similarities of fixed carbon content between two binder types in the carbonized biomass briquettes indicate no correlation with the composition of binder. In terms of carbonization treatment, the increasing carbonization temperature causes volatile matters is released and more carbon is formed due to decomposition of organic polymers at higher temperature.

3.1.2. Effect of Binder Types and Carbonization Treatment on Nitrogen, Sulphur, and Chlorine Content of Water Hyacinth Biomass Briquette

The presence of nitrogen (N), sulphur (S), and chlorine (Cl) may involve the formation of ash content and toxic compound may cause human health complications (Pilusa, Huberts, & Muzenda, 2013). According to Table 1, the lowest nitrogen content is 1.325%, which occurs in non-carbonized biomass briquettes with 5% tapioca gel. While the highest nitrogen content is 2.185% reached by carbonized biomass at 450°C with 5% tapioca gel as well. The nitrogen contents of the water hyacinth biomass briquettes are higher along with the increase in carbonization temperature. However, there is similarity of nitrogen content between two binder types in the carbonized biomass briquettes. That indicates no correlation with the composition of the binders. In fact, at 350°C, 400°C and 450°C, the carbonized biomass briquettes with either 5% tapioca gel or 5% PVAc adhesive have almost the same nitrogen content. In terms of carbonization treatment, it indicates the increase in nitrogen content is subjected to the increase in carbonization temperature. That is actually in line with the increase in ash content as well, where the higher the carbonization temperature, the higher the ash content. That means, a certain amount of ash comprises nitrogen as its chemical constituent.

As for the sulphur content, the lowest sulphur content is 0.17%, which occurs in carbonized biomass briquettes at 350°C with 5% PVAc adhesive. While the highest sulphur content is 0.32% reached by carbonized biomass at 450°C with 5% tapioca gel. Both non-carbonized and carbonized biomass briquettes with either 5% tapioca gel or 5% PVAc adhesive have almost the same sulphur contents, although the carbonized biomass briquettes shows a quite small increase in sulphur concentration. In fact, water hyacinth actually releases small amount of sulphur, nitrogen, and chlorides. The increase in sulphur content is probably due to the enrichment of sulphur in the solid phase during the biomass carbonization process (Cheah, Malone, & Feik, 2014).

Lastly, according to Table 1, the lowest chlorine content is 3.39%, which occurs in non-carbonized biomass briquettes with 5% tapioca gel. While the highest chlorine content is 5.73% reached by carbonized biomass at 450°C with 5% tapioca gel as well. However, there is similarity of chlorine content between two binder types in the carbonized biomass briquettes. That indicates no correlation with the main composition of the binders. In fact, at 350°C, 400°C and 450°C, the carbonized biomass briquettes with either 5% tapioca gel or 5% PVAc adhesive have almost the same chlorine content. The difference is due to the additional of tap water in binder preparation. The presence of chlorine in the tap water is used as disinfectant and bacteria controller. Consequently, the chlorine content in both binders was unavoidable. In terms carbonization treatment, it has been discussed before, that nitrogen, sulphur and chlorine are significant have an effect on reactions forming ash. The higher the temperature, the higher the ash content which makes the amount of chlorine as its constituent increases.

3.2. Calorific Value

Calorific value is the most important parameter that explains the energy amount in the biomass briquette. In other words, the higher calorific value, the better the combustion quality. The result of the calorific value of the water hyacinth biomass briquette is shown below in Figure 4.

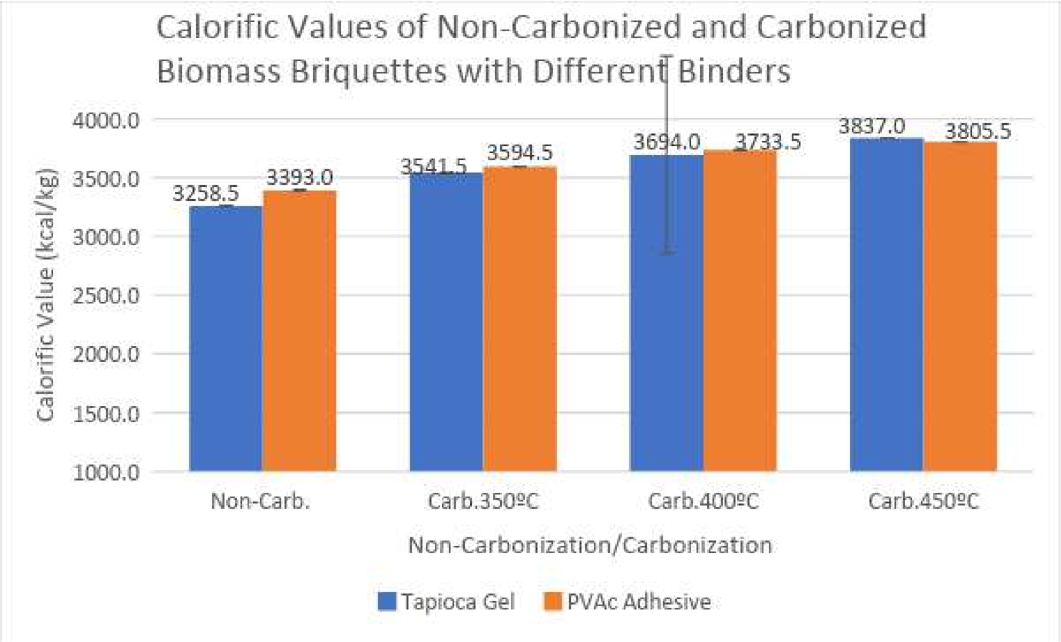

Figure 3. Histogram of Calorific Value of Non-Carbonized and Carbonized Biomass Briquette in Various Temperatures from Water Hyacinth with Different Binder Types

3.2.1. Effect of Binder Types on Calorific Value of Water Hyacinth Biomass Briquette

According to the Figure 3, in the first three treatments the calorific value of biomass briquette using PVAc adhesive is higher than tapioca gel. PVAc adhesive contains not too much water, thus the amount of fixed carbon in the biomass briquette is larger compare to tapioca gel. In contrast, the non-carbonized and carbonized biomass briquette with 5% tapioca gel has more moisture content than using 5% PVAc adhesive as discussed previously and shown in Table 1. With low moisture content, no heat will be wasted away just to evaporate the water. Instead, the energy of the remaining calories in the biomass briquette will be greater.

As for the carbonized biomass briquette at 450°C, the use of tapioca gel (3837 kcal/kg) can surpass the use of PVAc adhesive (3805.5 kcal/kg), in terms of the calorific value. However, the difference between them is only 0.82%, which is extremely small. This is probably due to the impurities in the briquette during the briquetting process, which consequently slows down the increase in calorific value. Overall, the carbonized biomass briquette at 450°C with either tapioca gel or PVAc adhesive shows no significant difference in terms of the calorific value.

3.2.2. *Effect of Carbonization Treatment on Calorific Value of Water Hyacinth Biomass Briquette*

According to the Figure 3 above, the calorific value of the non-carbonized and carbonized biomass briquettes using 5% tapioca gel ranged from 3258.5 to 3837 kcal/kg. Whereas the calorific value of the non-carbonized and carbonized biomass briquettes using 5% polyvinyl acetate (PVAc) adhesive ranged from 3933 to 3805.5 kcal/kg. The highest calorific value is 3837 kcal/kg, which occurs in carbonized biomass briquettes at 450°C with 5% tapioca gel. This has almost the same value as carbonized biomass briquettes at 450°C with 5% PVAc adhesive, which is 3805.5 kcal/kg. While the lowest moisture content is 3258.5 kcal/kg which occurs in non-carbonized biomass briquettes with 5% tapioca gel. That means, the calorific value of the water hyacinth biomass briquettes increases along with the increase in carbonization temperature. The same condition also occurs in the result of fixed carbon content. This is because calorific value is inseparable with the influence of moisture content, ash content, volatile matter content, and fixed carbon content.

The carbonization process undergoes several stages (Fachry, Sari, Dipura, & Najamudin, 2010; Maryono et al., 2013), where the first stage is the release of water vapor from the water hyacinth, along with the decomposition of cellulose into distillates which mostly contain acids and methanol. The second stage is the release of volatile substances which is the result of intensive cellulose decomposition as well as gradually burning the carbon, which is characterized by the emission of CO. The next stage is the decomposition of lignin compounds, which produces more tar (fixed carbon) as the temperature increases. The reaction is expressed below.

$$(C_6H_{10}O_5)_n \rightarrow CH_3COOH + 3CO_2 + 2H_2O + CH_3OH + 5H_2 + 3CO \tag{1}$$

$$[(C_9H_{10}O_3)(CH_3O)]_n \rightarrow C_{18}H_{11}CH_3\,(_{tar}) + C_6H_5OH + CO + CO_2 + CH_4 + H_2 \tag{2}$$

$$(C_xH_yO_z)_n + O_2 \rightarrow C(_{graphite}) + CO(_g) + H_2O(_g) \tag{3}$$

These processed were also occurred in the research by Surono (2010), where the calorific value of corn cobs biomass briquette increased along with the increase in carbonization temperature. This is due to the higher the carbonization temperature, the lower the moisture content and the volatile matter content in the carbonized biomass briquette. As a result, the amount of fixed carbon of the carbonized biomass becomes higher as can be seen in Table 1. In contrast, without involving carbonization process, the non-carbonized biomass briquette produces the smallest calorific value among others.

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