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RESEARCH ARTICLE

Briquetting of charcoal from residue of pyrolyzed palm kernel shells

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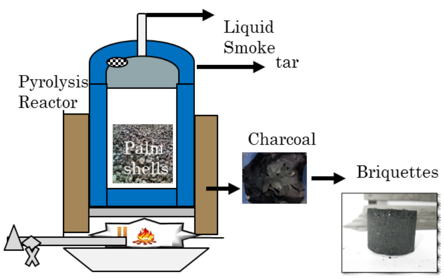
Graphical abstract



Abstract

Pyrolysis of palm kernel shells results a by-product of charcoal, which can then be used as raw material to make briquettes. This research aimed to identify the influence of binder varieties and pyrolysis temperature on the quality of the resulting briquettes. The binders used were tapioca starch and poly(vinyl alcohol) at ratios of 5%, 6%, 7%, 8%, 9% and 10%. The parameters tested to identify the quality of the resulting briquettes were compressive strength, water resistance and calorific value. The results showed that with poly(vinyl alcohol) binder, the highest compressive strength obtained was 106 kgf/cm^2 at 9%, whereas the highest compressive strength value for tapioca starch binder was 91 kgf/cm^2 at 10%. The highest water resistance was obtained at 10% for both binders: 70 seconds for poly(vinyl alcohol) and 288 seconds for tapioca starch. The highest calorific value was obtained at 10% for both types of binders: 5541.47 cal/g with poly(vinyl alcohol) and 5494.76 cal/g with tapioca starch.

Keywords: Pyrolysis, charcoal, briquettes, calorific value, compressive strength, water resistant

INTRODUCTION

Liquid Petroleum Gas (LPG) is currently considered to be a solution to oil fuel price increase. However, in the future, LPG will meet the same fate as oil fuel and its price will increase too. Therefore, there is a need to develop bioenergy as an alternative source of energy. In addition, the world has increased concern about the environment while bioenergy's main advantage is that it is renewable and environmentally friendly. One comprehensive approach to strengthen energy security is by diversifying energy from various sources. The use of other sources including biomass is expected to increase every year. The development of biomass as a source of renewable energy depends on national energy policies and green energy policies.

Indonesia is the largest producer of palm oil, with a plantation area of up to 10.9 million hectares, producing 23.9 million tons of crude palm oil (Ditjen perkebunan Indonesia, 2014). This industry generates abundant biomass waste, such as palm kernel shell, empty fruit bunches, mesocarp fibre, palm fronds and trunks (Loh, 2017), which can be readily used as a source of renewable energy as well as valuable organic materials via different conversion processes, such as thermochemical (Awalluudin *et al.*, 2015; Chang, 2014) hydrothermal process fluids (Chan *et al.*, 2014; Faisal *et al.*, 2007; Faisal *et al.*, 2016), biological or their combination.

It has been reported that one hectare of palm oil plantation produces about 50–70 tons of biomass residues (Shuit *et al.*, 2009) and about 90% biomass residue is discarded as waste (Awalludin *et al.*, 2015). Hence, the availability of palm kernel shells as raw materials for a downstream industry is promising. Palm kernel shells are usually used to fuel power plants because of their low moisture content (Aljuboori, 2013; Sulaiman *et al.*, 2010). In addition, palm kernel shells can also be utilized for various needs, such as boiler fuel, a source of cellulose and road fills. Current development sees palm oil kernel shells to be used to produce liquid smoke to replace formalin as food preservatives, rubber coagulant and biopesticide. Three products resulted from liquid smoke pyrolysis are liquid smoke, tar and charcoal residue (Faisal *et al.*, 2013; Faisal *et al.*, 2016; Kong *et al.*, 2014).

The process of making liquid smoke will result in around half as much as charcoal residue that used as the raw materials, which is still largely unutilized. One way to use this residue is to turn it into charcoal briquettes, a form of renewable energy. After such a process, the resulting charcoal briquettes will have better properties, such as higher energy density, no smoke, no smell and ease of use. To our knowledge, there is no information about briquettes preparation from charcoal residue of liquid smoke pyrolysis that has been reported.

Several types of research on biobriquette making have been conducted by using biomasses such as palm fibre and shells (Husain *et al.*, 2002), sugarcane bagasse fly ash (Teixeira *et al.*, 2010), corn stover and switchgrass (Kaliyan and Morey, 2010), sawdust (Antwi-Boasiako and Acheampong, 2016), wheat-straw (Wamukonya and Jenkins, 1995) and rice milling by-product (Ndindeng *et al.*, 2015). The characterization of briquettes produced from palm kernel shells from the residue of gasification has been studied and it shown that the tensile strength, impact resistance and water resistance of the briquettes with starch binder are imperative for suitable briquette quality (Bazargan *et al.*, 2014). Husain *et al.* (2002) studied the basic characteristics of briquettes prepared from palm fibre and shell from the processing of palm nuts to palm oil. The use of sawdust and empty fruit bunch (in powder and fibre forms) as raw materials for briquettes at high temperature and pressure using screw extrusion technology has also been investigated (Nasrin *et al*., 2008).

This research aimed in utilizing charcoal residue produced from pyrolysis of palm kernel shells to make briquettes. The resulting briquettes were expected to have calorific, compressive strength and water resistance values according to standards.

EXPERIMENTAL

Materials

The raw material used was charcoal from palm kernel shell pyrolysis residue. The charcoal was crushed with a crusher/ball mill and sifted with a sieve vibrator until its particles reached the size of 60 mesh according to Indonesian National Standard (SNI) 01-6235-2000. All samples were in the same size. Milling was required because particle size might determine the strength of the briquettes.

Making briquettes

The sifted charcoal particles were subsequently mixed with one of the binders: organic (tapioca starch) or synthetic (poly(vinyl alcohol)) at ratios of 5%, 6%, 7%, 8%, 9% and 10%. Tapioca starch was cooked in water to make glue (Muazzu and Julia, 2015) with a ratio of 1:3 at a temperature of 70°C. This binder and the fine raw materials were mixed to make a homogeneous mixture, poured into a mould and exposed to a pre-determined pressure. The pressing machine in which the sample mixture was poured into a mould would exert 8 tonnes of pressure. The mould itself consisted of three parts: base, cylinder and stamp. The mould construction consisted of two parts: a cylindrical tube 20 mm in diameter and a solid cylinder that functioned as a piston to put pressure on the raw materials in the cylindrical tube. After the briquettes taken up shape, they were dried in an oven at 60°C for 24 hours. This drying was aimed in reducing the water content that might increase during the moulding process because high water content in briquettes would encourage fungal growth (Maryono, 2013). Calorific value (by bomb calorimeter in accordance with ASTM International, ASTM Standard E711-87), compressive strength (by Computer Type Universal Testing Machines, China) and water resistance assessments (based on method developed by Richards (Richards, 1990)) were performed to measure the quality of the resulting briquettes.

RESULTS AND DISCUSSION

Briquettes shape and stability

This research examined the briquettes' physical shape and stability by assessing the visual appearance after pressing and drying. The shape of the resulting briquettes using different binders (poly(vinyl alcohol) and tapioca starch) can be seen in Fig. 1.

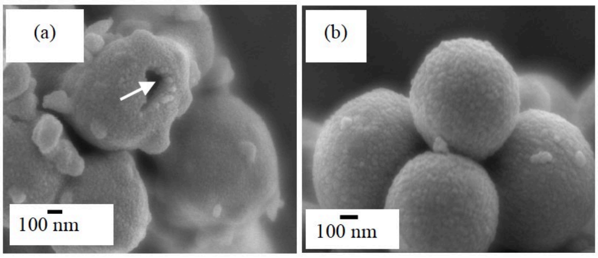


Fig. 1 (a) Briquettes with poly(vinyl alcohol) binder at 10%. (b) Briquettes with tapioca starch binder at 10%.

Fig. 1 shows that different binders gave different quality in the resulting briquettes: poly(vinyl alcohol) gave a solid visual without cracks while organic binder (tapioca starch) resulted in small cracks on the top. The poly(vinyl alcohol) liquid form enabled it to be distributed evenly over the briquette binder during pressing. After the binder was mixed and pressure was exerted during pressing, the liquid binder would spread easily, reaching all the charcoal particles, making the particles bond and giving it a solid shape. On the other hand, tapioca starch has more sticky consistency, meaning that it was distributed less evenly, giving it a weaker bond. Therefore, the use of poly(vinyl alcohol) binder in briquettes resulted in better physical quality.

This research also showed that briquettes with poly(vinyl alcohol) binder that left in humid conditions for one month would have fungal growth, as seen in Fig. 2. This was due to the binder's liquid properties that made the charcoal hygroscopic and therefore, it able to absorb water easily from the air when being left in the open. In turn, the briquettes turned brittle as the fungal growth occured (Maryono, 2013). In addition, high water content in briquettes would reduce their quality due to microbes and the amount of smoke that resulted during burning. To anticipate these drawbacks, the dried briquettes were immediately bagged to keep them dry.

Fig. 2 Briquettes using poly(vinyl alcohol) binder with fungus growth.

Binder influence on briquettes compressive strength

The compressive strength of briquettes influences in their stable physical quality so that they do not disintegrate easily during packing and transporting. Higher compressive strength guarantees the briquettes' better durability (Demirbas, 1999). The durability depends on the particle size of the raw materials, type and percentage of binder and the pressure during the pressing process (Jittabut, 2015; Kaliyan and Morey, 2009). Higher uniformity in particle size will result in higher density and solidity. Binder percentage imposed influence on briquette compressive strength, as can be seen in Fig. 3.

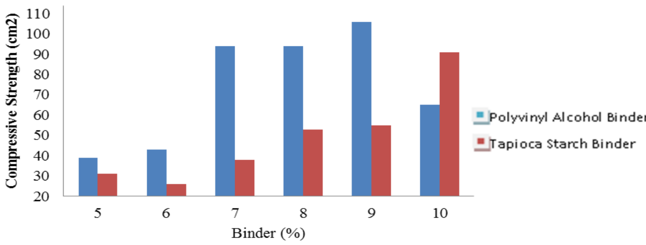


Fig. 3 The effect of tapioca starch and poly(vinyl alcohol) binders at different percentages on compressive strength.

Fig. 3 shows that higher poly(vinyl alcohol) percentage would produce higher compressive strength, despite a slight anomaly at 10%. The testing found that the lowest compressive strength was 39 kgf/cm^2 at 5% while the highest was 106 kgf/cm^2 at 9%. The value was higher than that of briquettes from rice straw and sugarcane leaves (Jittabut, 2015). For tapioca starch binder, the lowest compressive strength was 31 kgf/cm^2 at 6% while the highest was 91 kgf/cm^2 at 10%. The compressive strength usually also depends on briquetting pressure and particle size (Demirbas, 1999). A small percentage of binder resulted in a weaker bond between charcoal particles, so the resulting briquettes have low durability, whereas at 9%, the particle density was higher and it increased the compressive strength within a certain limit. The current results agreed with previous findings, where the optimum moisture content in densification and briquetting of biomass might range from 8% to 20% (Kaliyan and Morey, 2009). In addition, Fig. 3 shows the effects of organic and synthetic binders on charcoal briquettes. Poly(vinyl alcohol) binder gave higher compressive strength values compared with tapioca starch because the synthetic commercial binder has better bonding properties that comply with relevant standards, whereas tapioca starch is natural and possesses certain drawbacks. The standard of compressive strength value might differ in many countries. The Japan compressive strength standard value of charcoal briquette is 60 kgf/cm^2 (Mangkau, 2011). This study showed that a compressive strength that could meet Japan's standards was achieved at 7%, 8%, 9% and 10% with poly(vinyl alcohol) and 10% with tapioca starch.

Fig. 3 shows that the compressive strength values at 10% poly(vinyl alcohol) were lower than for tapioca starch binder because an increase in poly(vinyl alcohol) also increased the water content, so that the briquettes became softer and their compressive strength was declined. At high water content, the combination of water and binder can create a surface cover that is too thick and therefore, loosening the bond between particles and resulting in weaker briquettes (Yildirim and Ozbayoglu, 2013).

Binder influence on the water resistance of briquettes

Testing the water resistance of briquettes was aimed to identify their resistance to water in the air during storage. The influence of poly(vinyl alcohol) and tapioca starch percentage on water resistance can be seen in Fig. 4. Binder composition influenced water resistance, where a higher percentage of binder resulted in longer briquette resistance to water. The lowest water resistance in both binders was found at 5%: 37 seconds for poly(vinyl alcohol) and 103 seconds for tapioca starch. The highest water resistance in both binders was found at 10%: 50 seconds for poly(vinyl alcohol) and 288 seconds for tapioca starch. These results explained that water resistance was influenced by briquette density so that its pores could not absorb water and hence, binder percentage was directly influenced in density: higher binder percentage exhibited higher briquette density, probably because water contained in the binder could be locked within the charcoal pores, therefore giving the briquettes higher density.

Fig. 4 shows that during soaking, briquettes with tapioca starch binder required a longer time to absorb water compared with briquettes with poly(vinyl alcohol) binder. Poly(vinyl alcohol) is water soluble, so when the briquettes were soaked in water, the poly(vinyl alcohol) in the briquettes will be dissolved and the briquettes disintegrated rather quickly. Tapioca starch binder, on the other hand, is not water soluble, so when the sample was soaked in water, it required a longer time to crack. Briquettes with 5% poly(vinyl alcohol) binder took 48.06 seconds to crack in water and completely disintegrated within five minutes, while briquettes with 5% tapioca starch binder took 103 seconds to crack and were still whole three hours later.

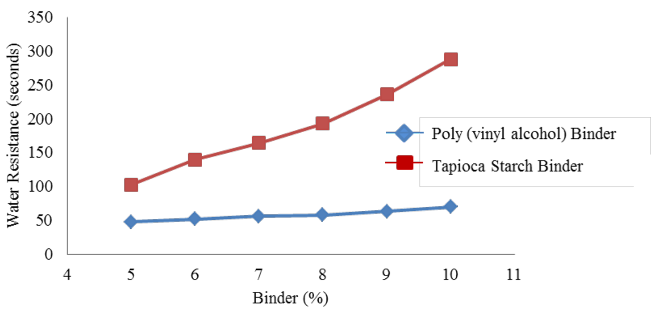


Fig. 4 The influence of poly(vinyl alcohol) and tapioca starch binders with different percentages on water resistance.

Binder influence on caloric value

Calorific value is the measurement of heat and energy produced. This value is crucial in determining briquettes' ability to be used as fuel. During pyrolysis, the organic matters contained in oil palm kernel shell will be disintegrated: water evaporates at 100–120°C, cellulose disintegrates into liquid smoke and a small amount of tar at 270–310°C and at 310–500°C, lignin disintegrates to produce more tar (Maryono, 2013).

Fig. 5 shows that the higher binder percentage resulted in the higher calorific value due to the additional carbon elements contained in the binder. Data on poly(vinyl alcohol) binder showed that the lowest calorific value was 5234.57 cal/g at 5% binder while the highest calorific value was 5541.47 cal/g at 10% binder because poly(vinyl alcohol) contains alcohol, which is another flammable compound. With tapioca starch, the lowest calorific value was 5294.57 cal/g at 5% and the highest calorific value was 5494.76 cal/g at 10% because tapioca starch possesses high carbon content that can increase the calorific value in briquettes.

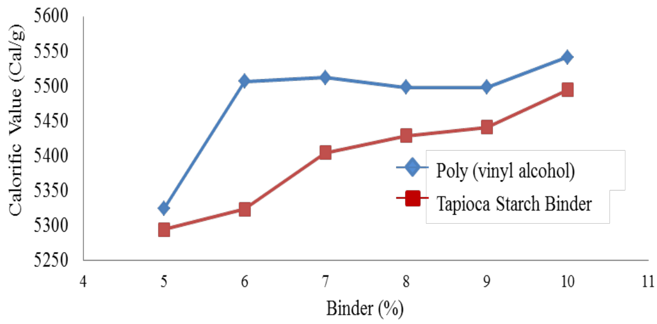


Fig. 5 The relations between poly(vinyl alcohol) and tapioca starch percentage and calorific value.

Briquettes using poly(vinyl alcohol) binder possessed higher calorific value compared with those using tapioca starch binder. Poly(vinyl alcohol) contains the functional group O–H, which can trigger combustion and 1674 cal/g energy whereas tapioca starch only contains 306 cal/g. All the produced briquettes fulfilled the SNI criterion of producing more than 5000 cal/g energy.

The influence on briquettes quality of charcoal produced at different pyrolisis temperatures

Good quality fuel contains high carbon and high calorific value. The pyrolysis process is an incomplete combustion with limited oxygen, which produces volatile matter that released in the form of gas or smoke and residue in the form of a gas of carbon charcoal. It was found that the best formation of carbon during pyrolysis occurred at 300–500°C and it produced smoke due to the release of volatile matter that could evaporate easily (Nuriana *et al.*, 2014). The quality of briquettes was based on the pyrolysis temperature used to produce charcoal, as can be seen in Table 1.

Table 1 The influence of temperature on briquettes quality with 5% poly(vinyl alcohol) binder used in pyrolysis to produce charcoal.

Pyrolysis Temperature Used to Produce Charcoal (°C)	Calorific value (cal/g)	Compressive strength (kgf/cm2)	Water Resistance (seconds)
300	5324.57	39	48.05
340	5494.76	79	52.43
380	5294.55	84	57.33

The highest calorific value in charcoal briquettes was 5494.76 cal/g at 340°C pyrolysis temperature and the lowest calorific value was 5294.55 cal/g at 380°C pyrolysis temperature. Theoretically, the calorific value should increase in parallel to the increase in pyrolysis temperature due to the higher resulting carbon value (Ronsse *et al.*, 2015). However, this research found that the calorific value was decreased at 380°C. The same tendency was also found in previous research (Fuwape, 1996), where the calorific value increased at 300–350°C but decreased at 400°C.

In terms of compressive strength, the higher pyrolysis temperature gave the higher compressive strength with the highest compressive strength of 16.95 kgf/cm^2 was obtained at 380°C. Higher pyrolysis temperature would result in bigger charcoal pores, in which the binder could enter the pores easily during the mixing and therefore, increasing the compressive strength. In addition, the higher pyrolysis temperature indicated that the lesser water was bound to charcoal, resulting in the stronger briquettes formed.

Similarly, the water resistance was increased as the higher temperature was applied during pyrolysis, hence increasing the water resistance. The highest water resistance was 57.33 seconds, obtained at 380°C pyrolysis temperature. The compressive strength was also increased along with the longer water resistance.

The influence of combustion on poly(vinyl alcohol) and tapioca starch binders

Good combustion characteristics are parts of briquette quality, in which the briquettes are easy to light, burn longer, produce little smoke that disappears quickly and have high calorific value. The length of the fire will influence combustion quality and efficiency: the longer the fire is lit with constant speed, the better the quality of combustion. Below are the involved reactions:

$$C + \tfrac{1}{2}\, O_2 \longrightarrow CO \quad (1)$$

$$CO + \tfrac{1}{2}\, O_2 \longrightarrow CO_2 \quad (2)$$

$$C + CO2 \longrightarrow 2CO \quad (3)$$

$$C + H_2O \longrightarrow CO + H_2 \quad (4)$$

(a) (b)

Fig. 6 (a) Combustion from briquettes with poly(vinyl alcohol). (b) Combustion from briquettes with tapioca starch.

The observation performed on the combustion of briquettes was made from pyrolysis residue charcoal. The different binders showed that combustion required the same time to start, five seconds, but the resulting fire was different. As seen in Fig. 6, a briquette with poly(vinyl alcohol) binder produced a blue-red flame whereas a briquette with tapioca starch binder produced red flame only. This was due to the poly(vinyl alcohol) binder that possesses hydroxyl groups of alcohol, which will burn blue. Research by Jamilatun (2008) showed that several types of briquettes made from different raw materials needed different amounts of time to start combusting until they produced fire: coconut shells 53 seconds, rice hull 15 seconds, sawdust 10 seconds, corn cob 8 seconds, coal 6 seconds and wood charcoal 5 seconds. The speed was achieved due to the low water content in briquettes.

CONCLUSION

This study showed that the quality of briquettes made from pyrolysis residue charcoal could meet the standard of quality applicable to briquettes (Indonesian National Standard). The type of binders used would affect the quality of the resulting briquettes. The binder could also increase the calorific value due to its carbon content; however, excessive use of binder could decrease the calorific value. The highest calorific value was obtained at 10% for both binders: 5541.47 cal/g for poly(vinyl alcohol) and 5494.76 cal/g for tapioca. It took five seconds to start the fire in briquettes with both poly(vinyl alcohol) binder and tapioca starch binder. Based on their calorific value and combustion characteristics, briquettes made using charcoal produced from palm oil kernel shell residue in liquid smoke pyrolysis are a good source of alternative fuel.

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