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Combustion Behavior of Fuel Briquettes Made from Ulin Wood and Gelam Wood Residues

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ABSTRACT

Solid fuel from the briquetting of ulin wood and gelam wood residue was investigated in this work. The effect of compaction pressure (10, 12, and 15 MPa), and briquette formulation were investigated. The ulin wood and gelam wood were blended in the mixing ratios of 100:0, 70:30, 50:50, 30:70, and 0:100, respectively. The size of the particle was fixed of 50 μm. The ulin wood and gelam wood were carbonized under fixed temperature (500°C), and time (120 min). The gelatinized binder (cassava starch) was 20% of the total briquettes weight. The densification was carried out using the briquetting machine (piston-press type) laboratory scale. The compaction pressure briquette had a significant effect on some characteristics of briquette (ash content, moisture content, volatile matter, bulk density, and combustion rate). An increasing in compaction pressure briquettes resulted in low ash content, moisture content, and volatile matter but the reverse is the case for bulk density. However, the mixing ratio slightly affected. High combustion rate (3.18 g/min) achieved at low compaction pressure (10 MPa).

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1. INTRODUCTION

The depletion of fossil-fuel reserves and increasing environmental pollution caused by the large-scale application of fossil fuel, the energy obtained from biomass and biomass waste has received much attention in recent years. This problem has driven researchers to develop possible methods of innovating new fuel resources. To handle the waste material, educating the citizen is contributive to careful strategies. Indonesia's biomass energy resources are abundant. 52% of the land was covered by forest, 13% of arable land, 12% of permanent crops, meadows, and pastures is about 6% and 17% of other lands [1]. Indonesia has huge biomass energy potential, not only an energy challenge but also potentially suitable bioenergy and can be distinguished between municipal [2], industrial waste [3], forest waste [4], and agriculture wastes [5,6]. However, only a small portion has been utilized. The biomass from forestry and agriculture wastes is a plentiful feedstock for the production of solid fuels such as briquette. In the future, bioenergy conversion of biomass is also regarded to keep increasing. However, the characteristics of biomass such as moisture content, low energy density have required high cost for processing on direct combustion use [7]. There are several technologies for converting biomass into energy i.e., thermochemical conversion, biochemical conversion, and mechanical conversion. Among various thermochemical conversion technology carbonization is simple and promising. The biomass carbonization technique has benefits such as low raw material is needed, operational with the simple way, and low energy consumption [8–10].

In this context, Monedero et al. [11] examined the effect of hydrothermal carbonization on the properties, devolatilization, and combustion kinetics of Chilean biomass residues. They reported that carbon and heating value increased afetr HTC. Furthermore, Sun et al. [12] reported that the carbonization on raw biomass materials

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could impact the natures of fuel and emmision of PM_{22} significantly.

The briquetting technology is relatively well known. Many researchers studied the production of solid fuels briquette from rice husk and sawdust [13], coffee-pine [14], cow dung [14], corn cob [15], these and more studies remain few given the number of wastes generated from forestry and processing. Differences in hydro-geological conditions in different regions imply that the physical properties of forest wastes must be geo-specific [14,15]. Due to biomass variability, a continuous effort must be applied to the development and characterization of biomass briquettes for sustainable energy development.

Ulin wood and gelam wood are a key group of hardwood trees. A categorization that encompasses a wide range of species across varying ecological habitats [18]. The Borneo ulin wood, locally known as Belian, is a canopy tree found in the lowland dipterocarp rain forests of eastern, southern Kalimantan, and southern Sumatra (Indonesia). The residual of ulin wood and gelam wood can be converted into bioenergy resources. The carbon content of this wood is about 50%. According to reported data by Tumuluru et al. [19] biomass with high lignin, protein, or starch content possess better compaction that those with high cellulose content. As reported by Harahap et al. [20] the characteristics of nanocrystal from corncorb showed the atomic structure of cellulose nanocrystal quite regular so obtained a high crystallinity index. High crystallinity indext indcated that the intact structure resulted in a porous and amorphous [21].

Recently, ulin wood materials have been introduced as building construction, bridge construction, and shipping or almost for the architecture field. Ulin wood and gelam wood in view decade decreased due to over-exploitation and this matter is causing some environmental problems. Therefore, briquetting technology is one of the promising technology to overcome this problem. To handling characteristics of feedstock and enhancing the volumetric calorific value of biomass, the densification process is a solution [22]. To make ulin wood and gelam wood treatment energetically efficient, not only the densification process is needed but also carbonization of the biomass before briquette production is another method to enhancing the properties of briquette such as removal volatile materials from the feedstock.

Because the different charatersitics of the materials (ulin wood and gelam wood) in the context of volatile materials, studies into the combustion behavior of briquette fuels mixed ulin wood and gelam wood would be interest. Studies concerning the phisical and combustion properties of agriculture residue bio-briquette were reported earlier [23]. However, to the best of author knowledge, no report into the effect of compaction pressure and briquette mixed composition on the combustion behavior as well as combustion rate of forest residue (ulin wood and gelam wood) mixture have been published. Thus, we here aim to investigate the effect of compaction pressure and briquette mixed composition on the combustion behavior as well as combustion rate of fuel-briquettes made from ulin wood and gelam wood residues (a typical wood in South Kalimantan, Indonesia). This information must be important for the bioenergy sector to improve economic aspects and alternative uses for these natural materials.

2. MATERIALS AND METHODS

2.1. Preparation of raw materials The feedstock (ulin wood and gelam wood) used in this work was obtained from milling sites in Borneo, Southern Kalimantan. The whole feedstock was manually drying (sun dried) until achieving the lower moisture content (< 15 % dry basis). The characteristic of raw materials was obtained in our research group [19,20] as given in Table 1.

2. 2. Carbonization and Preparation of Mixtures

The dried feedstock obtained was carbonized in the furnace at 500°C. The three factors considered are compaction pressure (10, 12, and 15 MPa), mixing ratio (0:100, 70:30, 50:50, 30:70, and 100:0). The particle was fixed of 50 μm. Binder concentration fixed of 20% (cassava starch) was the usual proportions for briquette production [26]. The cassava starch binder was prepared by mixing with the water and boiling them to obtain the good binder. 20% of the binder was mixed for each mixing ratio and was prepared for the compaction process.

2. 3. Briquette Production The compaction pressure of the briquette and mixing ratio were investigated. A manual hand briquetting press machine was used to compress the biomass in this study. The machine equipped with the cylinder briquetting die (id: 40 mm and length: 50 mm). The compaction pressure machine using the hydraulic press machine used in this study shown in Figure 1. To produced briquette, at first, the powdered raw materials mixed with the binder were placed in the die and pressed with the plunger by

TABEL 1. Characteristics of the raw materials

Raw Materials	Proximate analysis [wt%]			Ultimate analysis [wt%]			
	FC	VM	Ash	C	H	N	O
Ulin wood	22.8	74.3	2.8	49.2	5.6	0.3	44.7
Gelam wood	76.4	13.6	3.1	81.3	1.9	0.4	15.4

Figure 1. The compaction pressure machine using the hydraulic press machine

applying the pressure of 10, 12, and 15 MPa to get the briquettes at the desired shape. The holding time of each briquette was 100 s and the sample was produced in duplicate. Mass and weight were taken using a digital weighing immediately. Then sun-dried for 2-3 days to remove the moisture content and keep at room temperature.

3. ANALITICAL METHODS

3. 1. Moisture Content, Volatile Matter, and Ash Content The calculation of moisture content, ash content and volatile matter in this study was conducted. The moisture content of the sample briquette is as follows:

$$MC(wt\%) = \frac{W_i - W_f}{W_i} x100\% \tag{1}$$

where W_i is the initial weight of the sample and W_f is the final weight of the sample after drying. The volatile matter (VM) for each sample was calculated based on the weight of the sample after drying in an oven and heated in the furnace, as indicated in Equation (2):

$$VM(wt\%) = \frac{W_{od} - W_{fd}}{W_{od}} x\,100\% \tag{2}$$

where W_{od} is the weight of the oven-dried sample and W_{fd} is the weight of the furnace-dried sample.

The ash content was calculated based on the procedure given in ASTMD-317. The ash content (AC) determination method semblable with volatile matter (VM). However, the heating temperature was 550 °C for 5h and weight after cooling. The AC was determined using Equation (3) state as follows:

$$AC(wt\%) = \frac{SW_{(od)} - SW_{(fd)}}{SW_{(od)}} x\,100\% \tag{3}$$

where $SW_{(od)}$ is sample weight after drying in the oven and $SW_{(fd)}$ is sample weight after heated in the furnace and cooling in the desiccator.

3. 2. Bulk Density The density of the briquette was calculated after the pressing process was done. The density of the briquette initially as the ratio of mass to the volume of the briquette. This method agreed well with the previous study [27]. The bulk density was determined as:

$$\rho\left(g / cm^3\right) = \frac{M}{V} \tag{4}$$

where ρ is the density of the briquette sample, the mass of the briquette sample (M), and volume of the briquette sample (V). the mass of briquette sample was weighed by using a digital weighing balance (KI-124-precision digital scale).

3. 3. Combustion Rate The combustion rate basically indicates the burning capability of the briquette. One of the briquette samples was weight before combustion, then the briquette sample was ignited and burned. The combustion time and the briquette sample weight were collected to determine the combustion ratio (Equation (5)).

$$\text{Combustion rate}\left(g / \min\right) = \frac{W_{bb}}{\text{Combustion time}} \tag{5}$$

where Wbb is the weight of burned briquette sample (g) and combustion time (min).

4. RESULTS AND DISCUSSION

4. 1. Moisture Content, Ash Content, and Volatile Matter Figures 2(a), 2(b), and 2(c) show the moisture content, ash content, and volatile matter of the briquette samples. The moisture content was decreased with higher compaction pressure. The briquette made from 0:100 mixing ratio of the ulin wood to gelam wood, 15 MPa compaction pressure exhibited the lower moisture content and higher moisture content of 3.0 (wt%) was observed for the briquette made from 100:0 (ulin wood and gelam wood) under compaction pressure of 10 MPa, it might be the hygroscopic character with the high porosity of the carbonized ulin wood and gelam wood materials. The results obtained good agreement with Mandra [28], who obtained the higher moisture content (6 - 8%) on high compacting pressure in case of the charcoal briquette from agricultural waste. Generally, low moisture content indicated high calorific value, and high moisture content represents the high energy consumption.

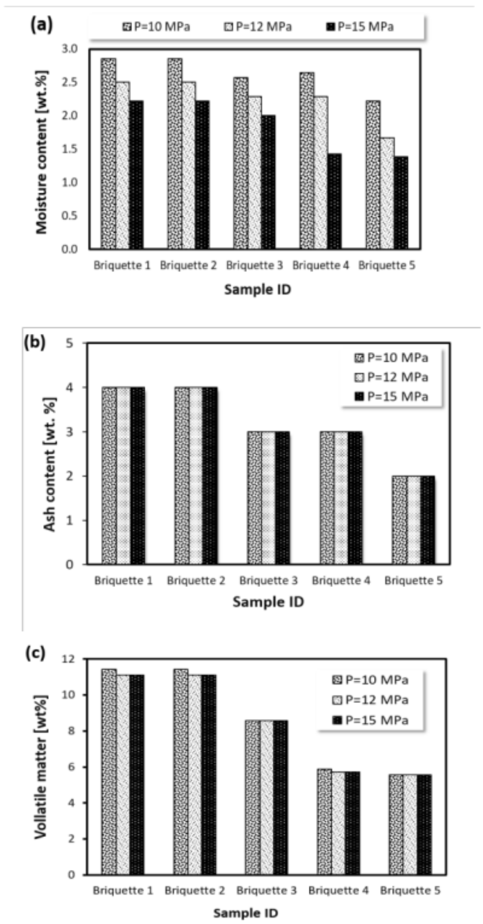

Figure 2. Effect of compaction pressure and mixing ratios on (a) moisture content, (b) ash content, and (c) volatile matter

From Figure 2, it is shown that the ash content, moisture content, and volatile matter were decreased with compaction pressure. It might be the high density of the briquette sample and some binder effect causes a reduction in ash, moisture content, and volatile matter. This result agrees well with a previous study [29] where ash content, moisture content, and volatile matter decreased when the resin was added into the briquettes.

4. 2. The Bulk Density of the Briquette Samples and it Comparison The density of the briquette samples in this study ranged from 600-880 kg/m^3 depending on the compaction pressure and mixing ratio of the briquettes. Figure 3(a) showed the density of the briquette sample at different compaction die pressure. The same trend was observed for all briquette samples. Briquette density increased considerably as the compaction pressure. The value obtained was higher than the previous study, the comparison studies were demonstrated in Figure 3(b) in cased of briquette made from corn stover [30], soda weed, and sawdust [31]. In case of corn stover the bulk density was obtained around 700 kg/m^3, soda weed mixed sawdush was exedeed 700 kg/m^3. The observations also consistent with the previous work conducted by Gong et al. [32] who observed that the briquette density decreased as moisture content increased in cased of briquette made from mixture corn stover and peanut shells.

Adapa et al. [33] reported that the compact density could possibly be attributed to the moisture content for all raw materials (barley, canola, oat, and wheat straw). In contrast, Widyan et al. [34] showed that the briquette density increased with the moisture content for olive cake. Therefore, an optimal moisture content exists for each feedstock to produce briquettes with high density and strength. This study obtained that ulin wood and gelam wood mixed can be compacted into high-density briquettes (600-880 kg/m^3) at a low moisture content range of 2-3%. The maximum density exceeded 880

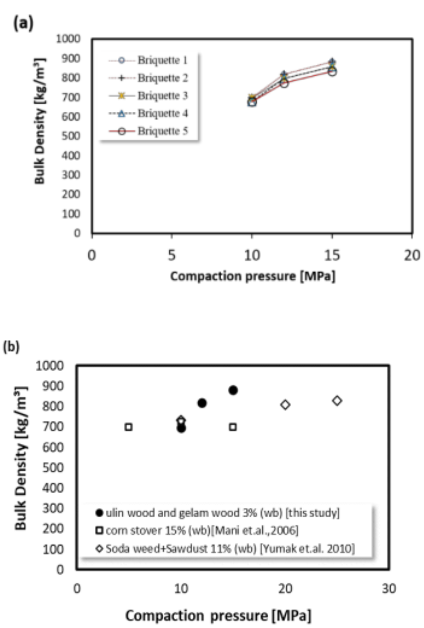

Figure 3. (a) Bulk density of the briquette sample in the different compaction die pressure (b) Bulk density comparison with other studies

kg/m^3. These results agreed with previous study [35], who obtained the strong and crack-free briquette made from corn stover with lower moisture content.

4. 3. Determination of Combustion Behavior In this study combustion characteristics (ash content, moisture content, and volatile matter), ignition time, and combustion rate were analyzed. Figure 4 present the combustion rate for all the briquettes sample with different mixing ratio and compaction pressure. The combustion rate of the briquette was in the range of 2-3 g/min. This result was agreed well with the previous results by Thabout et al. [36] who obtained 2-3 g/min of burning rate for the briquettes made from corn cob mixed with palm fiber. The results showed the combustion rate decreased with the increase of compaction pressure of the briquettes sample. This might be the increase of density for the higher compaction pressure briquette reduces the air within the product, this low porosity will restrict the mass and heat transfer during combustion. The same relationship was also reported by Pandey et al. [37] for pine needle briquettes and Chuangcharoen [38] for agriculture waste briquettes. They mentioned that different combustion rate has been caused by the distinct fixed carbon in the feedstock, briquette can be burn easily and quickly at lower fixed carbon and led to increasing the combustion rate.

The percentage of the initial mass per minute for the combustion rate can be expressed as the Normalized Burning Rate (NBR) as shown in Figure 5.

As shown in Figure 5, the steady-state flaming combustion phase or referred to as Normalized Burning Rate (NBR) expressed in percent of initial mass per minute. The briquette can sustain expressed by ignition phase. The combustion rate of the beriquettes are associated with their morphological charateristics. The combustion temperature profile in the burning zone of the brqieutte are shown in Figures 6(a), 6(b), and 6(c). In

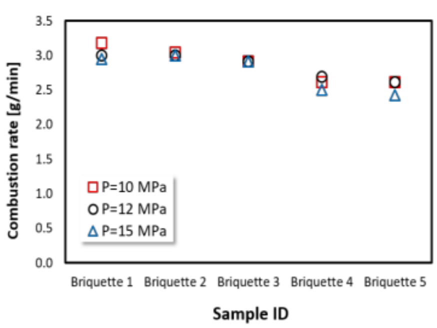

Figure 4. Combustion rate for all the briquettes sample with different mixing ratio and compaction pressure

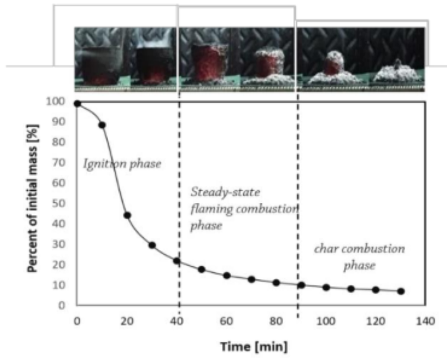

Figure 5. Normalized burning rate (NBR)

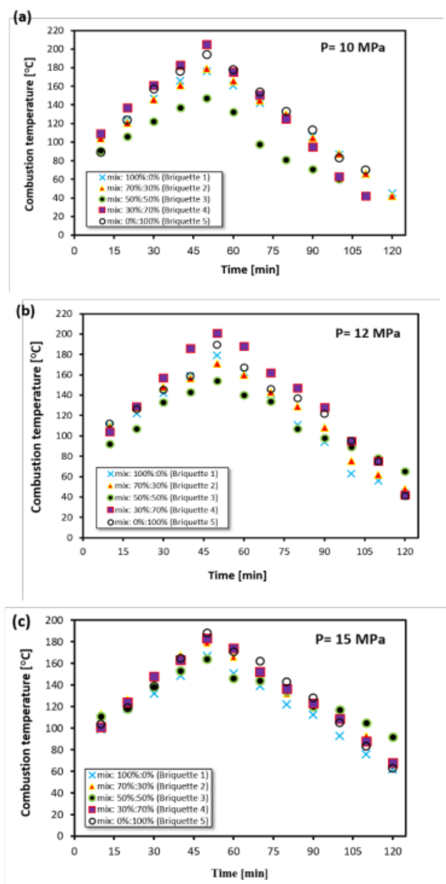

Figure 6. Combustion temperature profile at the different compaction pressure of (a) 10 MPa, (b) 12 MPa, and (c) 15 MPa

all curves of T (°C) versus t (min), typical temperatures and various of compection pressure and mixing ratio of briquette were measured. All figures show the same trend wich is some losses of mass appeared near 45°C, corresponding to the realese of the moisture content and the rapid losses of mass reaching 10%/min.

5. CONCLUSION

We herein inverstigated and confirmed the effect varying compaction pressure and mixing ratios on the combustion behavior as well as the combustion rate of fuel-briquettes made from ulin wood and gelam wood repsetively. Our results show the following:

1. The operating parameters (compaction pressure and mixing ratio) slightly affected the Ash content, MC, and VM.
2. Bulk density of all briquette samples increased with an increase in compaction pressure of up to 10 MPa.
3. Highest bulk density (880 kg/m^3) can obtained from the blend of carbonized ulin wood and gelam wood (70:30) mixing ratio and the lowers from briquette with the mixing ratio of 0:100 (exceeded 600 kg/m^3).
4. The combustion rate decreased with an increase in compaction pressure. The slowest combustion rate obtained of 2.43 g/min briquette made from 0:100 of ulin wood and gelam wood and 15 MPa.

6. ACKNOWLEDGEMENT

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Persian Abstract

چکیده

در این کار سوخت جامد حاصل از قالبگیری چوب اولین و باقی مانده چوب گلام مورد بررسی قرار گرفت. تأثیر فشار تراکم (۱۰ ، ۱۲ و ۱۵ مگاپاسکال) و فرمولاسیون بریکت مورد بررسی قرار گرفت. IW و GW به ترتیب در نسبتهای ۱۰۰: ۰ ، ۷۰:۳۰، ۵۰:۵۰ ، ۳۰:۷۰ و ۰: ۱۰۰ با هم مخلوط شدند. اندازه ذرات ۵۰ میکرومتر ثابت شد. IW و GW در دمای ثابت (۵۰۰ درجه سانتیگراد) و زمان (۱۲۰ دقیقه) کربن دارشدند. چسب ژلاتینیزه شده (نشاسته کاساوا) ۲۰٪ از کل وزن قالبها بود. تراکم با استفاده از مقیاس آزمایشگاهی دستگاه بریکتینگ (نوع پیستون – پرس) انجام شد. بریکت فشار تراکم بر برخی خصوصیات بریکت (میزان خاکستر ، رطوبت ، ماده فرار ، چگالی فله و میزان احتراق) تأثیر معنی داری داشت. افزایش بریکتهای فشار تراکم منجر به پایین آمدن خاکستر ، میزان رطوبت و مواد فرار شد اما برعکس آن برای چگالی فله است. با این حال ، نسبت اختلاط کمی تحت تأثیر قرار گرفته است. سرعت احتراق بالاتر (۳/۱۸ گرم در دقیقه) در فشار تراکم کمتر (۱۰ مگاپاسکال) حاصل شد.

Combustion Behavior of Fuel Briquettes Made from Ulin Wood and Gelam Wood Residues

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