International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:7, No:12, 2013

Use of Biomass as Co-Fuel in Briquetting of Low-Rank Coal: Strengthen the Energy Supply and Save the Environment

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Abstract**—**In order to fulfill world energy demand, several efforts have been done to look for new and renewable energy candidates to substitute oil and gas. Biomass is one of new and renewable energy sources, which is abundant in Indonesia. Palm kernel shell is a kind of biomass discharge from palm oil industries as a waste. On the other hand, *Jatropha curcas* that is easy to grow in Indonesia is also a typical energy source either for bio-diesel or biomass. In this study, biomass was used as co-fuel in briquetting of low-rank coal to suppress the release of emission (such as CO, NO_x and SO_x) during coal combustion. Desulfurizer, CaO-base, was also added to ensure the SO_x capture is effectively occurred. Ratio of coal to palm kernel shell (w/w) in the bio-briquette were 50:50, 60:40, 70:30, 80:20 and 90:10, while ratio of calcium to sulfur (Ca/S) in mole/mole were 1:1; 1.25:1; 1.5:1; 1.75:1 and 2:1. The bio-briquette then subjected to physical characterization and combustion test. The results show that the maximum weight loss in the durability measurement was ±6%. In addition, the highest stove efficiency for each desulfurizer was observed at the coal/PKS ratio of 90:10 and Ca/S ratio of 1:1 (except for the scallop shell desulfurizer that appeared at two Ca/S ratios; 1.25:1 and 1.5:1, respectively), i.e. 13.8% for the lime; 15.86% for the oyster shell; 14.54% for the scallop shell and 15.84% for the green mussel shell desulfurizers.

Keywords**—**Biomass, low-rank coal, bio-briquette, new and renewable energy, palm kernel shell.

I. INTRODUCTION

INDONESIA has a potency of biomass in abundant, equivalent to 49.81 MW, especially from agriculture, plantation and forestry sectors. Among them are palm kernel shell (PKS), palm empty fruit bunch, palm midrib, rice husk, rice straw, corncob, candlenut shell, coconut fiber, coconut shell, sawdust, etc. Nowadays, those energy sources do not maximally utilized yet.

On the other hand, Indonesian coal reserve is predicted as much as 38.9 billion tons. However, utilization of coal particularly low-rank coal (LRC) is not optimal yet. The used of coal should be encouraged even though coal is not renewable energy source. Coal consumption could be made long-life through diversification such as blending of coal with biomass. Beside produce the energy, coal firing also contributes to air pollution due to particulate and gas emission release. Sometime, low combustion efficiency is also faced in single coal burning. This is not good from economic point of view.

Bulk coal-biomass blend is not convenient to apply for house hold/home industry stove. Densification/briquetting is one of the available technologies to convert bulk coal-biomass into briquettes form in order to improve the effectiveness for transport, storage, feeding into the stove and burning of coal-biomass blend [1].

It was found that mixing a feed biomass having high natural binding capacity with the base feed (in this case is coal) can improve the strength and durability of the densified products [2]. Biomass may behave as a binder during briquetting [3].

Other advantages, bio-briquette has low ignition temperature and short burnout time compare to coal briquette. It is well known that biomass has generally high volatile matter. Therefore, addition of biomass in coal briquette might improve burning rate of briquette [4].

Impact on the environment could also be achieved, in addition to the emissions reduction, by avoiding green house gases (GHGs) release (particularly methane) from biomass dumping. In this case, biomass does not need to dump because it is directly used as fuel when it is discharged from mill or harvesting area. The number of GHGs from avoiding biomass dumping and from substitution of fossil fuel with biomass has been accounted in the previous publication [5].

This research is addressed to investigate the influence of coal/PKS ratios, types of desulfurizers and Ca/S ratios (Ca in desulfurizer; S in coal and biomass) on the physical characteristics of bio-briquettes and stove efficiency in bio-briquettes application. Discussion on the desulfurization and its kinetic evaluation is dealt in a different article [6].

II. MATERIALS AND METHODS

A. Materials

Materials used in the research were LCR taken from West Aceh District and PKS taken from palm oil mill (POM) in Aceh Tamiang District, Aceh Province. Lime**,** oyster shell, scallop shell and green mussel shell were collected in Banda Aceh City and Aceh Besar District. Starch (tapioca-based) and *Jatropha curcas* seeds (JCS) that used as binder were also found in Banda Aceh. All the mentioned districts and city are

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located in Aceh Province, Indonesia. Starch is commercially available in the market.

Why JCS used as a binder is supported by the fact that JCS contains a gum that is possible to act as the binder, besides, the jatropha itself is also renewable energy source. JCS shells and crude jatropha oil has been investigated as the fuel in direct combustion [7], [8]. Crude jatropha oil is produced from jatropha seed. In this study, jatropha used consists of seed and shell.

B. Experimental Conditions

Study was performed at the following conditions. Product bio-briquettes have a cylindrical form with diameter 1.6cm and height 20mm, briquetting pressure was 6 ton/cm^2, hold pressing time was 5 minutes, the content of starch and jatropha seeds mixture as a binding agent in the bio-briquette was 10% (w/w); according to the previous studies, the amount of binder which produce good performance bio-briquette was in the range of 10-15% (w/w) [9]-[11]. Ratios of the coal/PKS was 90:10 (w/w) and ratios of the Ca/S were 1:1, 1.25:1, 1.5:1, 1.75:1 and 2:1 (mole/mole). Particle size of LRC, PKS, JCS and adsorbents was -60/+pan mesh. Proximate and calorific analysis on LRC, PKS and JCS result the data as presented in Table I. Lime, oyster shell, scallop shell and green mussel shell contain Ca as much as 29.3, 29.1, 27.8 and 27.6% (w/w), respectively.

C. Experimental Procedure

In the raw material preparation step, LCR, PKS, JCS and desulfurizers were crushed, dried (air dried), sieved and mixed to produce homogenous mixture (starch was also added to the mixture here). After stirred the mixture then put into the mold to be pressed to produce the bio-briquettes. Fig. 1 presents the steps of the bio-briquettes preparation.

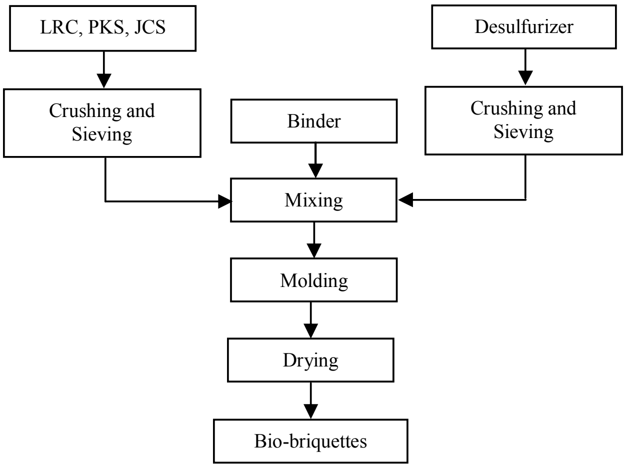

Fig. 1 Steps of bio-briquettes preparation

D. Characterization and Burning Test

Product of the bio-briquettes then subjected for the physical characterization (such as durability and water resistance) and burning test in the modified stove to observe the stove efficiency. Detail discussion on the modified stove design and performance was written down elsewhere [12].

TABLE I
PROXIMATE, TOTAL SULFUR AND CALORIC DATA

Parameter ^{a}	LRC	PKS	JCS
Moisture (%)	5.83	4.30	5.98
Ash (%)	5.40	2.63	4.16
Volatile Matter (%)	46.00	73.65	75.62
Fixed Carbon (%)	42.77	19.42	14.24
Total Sulfur (%)	0.38	0.13	0.21
Calorific Value (cal/g)	5,904	4,865	5,864

^{a}air dried base.

At first, the bio-briquettes durability was determined based on the mass loss by tumbling can method. Test was performed at 60 rpm for 3min according to ASABE Standards of S269.4 with small modification. The durability was predicted using the equation mentioned below [2]:

$$B_d = \frac{m_f}{m_i} x100\% \tag{1}$$

where B_d is bio-briquettes durability (%), m_i is initial mass of bio-briquettes (g), and m_f is final mass of bio-briquettes (g).

Afterwards, water resistance was measured by submersion the bio-briquettes into the water medium at room temperature. In this observation, the bio-briquettes was immersed in the 500ml water and waited until the bio-briquettes were completely destroyed and dispersed in the water. The time required for the bio-briquettes destruction and dispersion was recorded [3].

Finally, stove efficiency was investigated by heating and boiling or evaporating the water in a vessel on the modified stove. The stove efficiency was calculated by the following equation [13]:

$$\eta = \frac{m_{wi} C_{pw} (T_e - T_i) + m_{we} H_l}{m_b H_b} \tag{2}$$

where:
m_{wi} = initial mass of water in vessel (g),
C_{pw} = specific heat of water (J/g ^{o}C),
m_{we} = mass of evaporated water (g),
m_b = mass of bio-briquettes (g),
T_e = temperature of evaporation (^{o}C),
T_i = temperature of water in vessel (^{o}C),
H_l = vaporization heat of water at 100 ^{o}C and 10^5 Pa (J/g),
H_b = calorific value of bio-briquettes (J/g).

III. RESULTS AND DISCUSSION

A. Durability

Durability of bio-briquettes was strongly related to physical forces that bond coal and biomass particles together [2]. In this study, the durability test was done to investigate the effect of shock on bio-briquette due to packaging and transportation.

Figs. 2-5 presented the bio-briquette durability examination for all desulfurizers. From the figures, it can be seen that putting in the desulfurizers give no significant effect on the durability.

Fig. 3 showed the durability of the bio-briquette with the addition of the oyster shell as desulfurizer. As illustrated in Fig. 2, the durability tends to decrease as the PKS in the bio-briquette increase. The phenomena in Fig. 3 were similar to Fig. 2

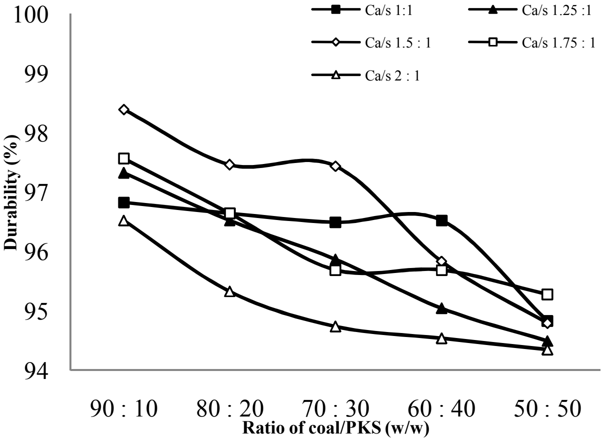

Fig. 2 Durability of bio-briquettes using lime desulfurizer

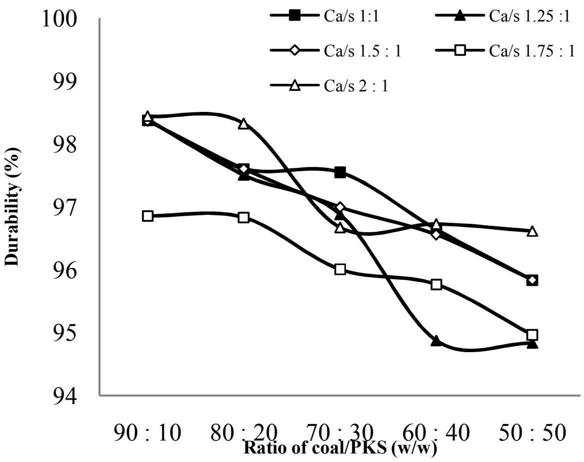

Fig. 3 Durability of bio-briquettes using oyster shell desulfurizer

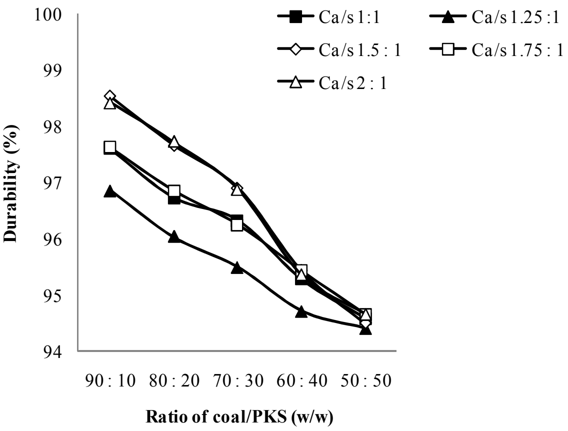

Fig. 4 Durability of bio-briquettes using scallop shell desulfurizer

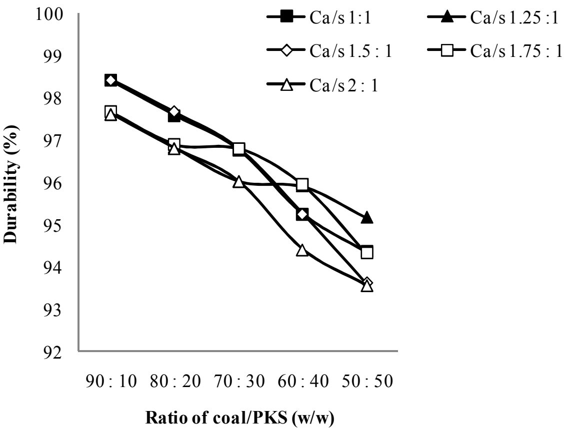

Fig. 5 Durability of bio-briquettes using green mussel shell desulfurizer

Then, Fig. 4 presented the durability of bio-briquette using the scallop shell as desulfurizer. This figure described the same trend as Figs. 2 and 3. From this research, it can be concluded that the higher the biomass (PKS) content in the bio-briquettes provided the lower durability. It was caused by the fact that PKS was not fully bound with the coal.

At last, Fig. 5 illustrated the durability of bio-briquette with the green mussel shell desulfurizer. The result has no quite different with results in Figs. 2-4; the increase in the PKS causes the decrease in the durability of bio-briquette. The data informed also the bio-briquettes produced in this study can stand at the continuous shake or vibration for 3min. From all the data of durability test, it can be proved that the bio-briquette was strong enough, because the weight loss during the test was small; the maximum amount was 6.5%.

It can be concluded that the bio-briquettes produced were strong enough, with the durability more than 93%. In over all, the data showed that increase the PKS content in the bio-briquettes will decrease the durability. It was probably caused by the bond between coal and PKS was not as strong as the inter particles bond of coal itself. Indeed, the inter particles bond of PKS is lower than that of the coal.

B. Water Resistance

The water resistance defined as the time required for bio-briquettes destruction and dispersion in the water medium. The bio-briquettes, which are needed long time for destroying and dispersing, have strong structure. The effect of coal/PKS ratio was clearly provided; the water resistance decreased when the PKS content in the bio-briquettes increased. This phenomenon might be explained as follow; the PKS structure was more hydrophilic compare to the coal structure and/or the coal structure was more hydrophobic than the PKS structure. It should be noted that this is only presumes statement. It requires a more deep investigation on the structure of coal and PKS in order to prove the statement.

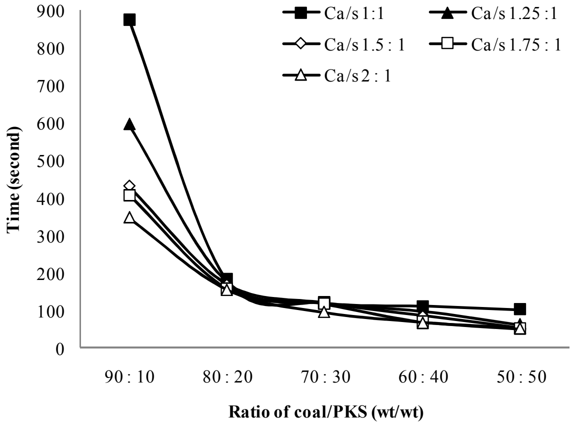

Fig. 6 Water resistance of bio-briquettes using lime desulfurizer

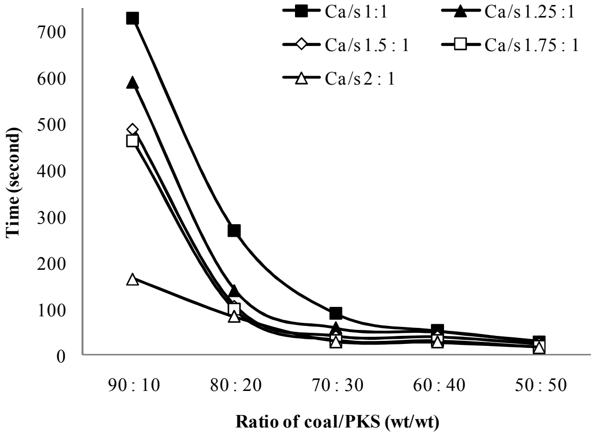

Fig. 7 Water resistance of bio-briquettes using oyster shell desulfurizer

The important results that the water resistance data found here supported the fact obtained in the durability measurement; the highest coal/PKS ratio provided the strongest bio-briquettes. And, the effect of Ca/S became evident; the lowest Ca/S ratio provided the strongest bio-briquette.

In this study, it is found that the best bio-briquettes that can be used in small industries/household are exhibited by the bio-briquettes molded using the 90% coal and the Ca/S ratio 1:1 as shown in Figs. 6 and 7. The bio-briquettes with 90% of coal are more feasible to produce in terms of the water resistance since sometimes the briquettes exposure to moist air when it is stored or transported. Generally, the bio-briquettes have the higher Ca/S are easy to destroyed and dispersed or in other word have the weak structure. The data presented here agreed well to the data reported by Yaman et al. [3] for the biomass-lignite coal briquettes at the various compositions.

As reflected in the durability pattern, where the durability tendencies for all investigation conditions were similar; the water resistance profiles are also exhibited the same phenomena. Hence, to avoid too many similar figures, the data for the scallop and green mussel shells desulfurizers were not included any more here.

C. Stove Efficiency

The result of burning test of the bio-briquette showed the coal/PKS ratio has a significant effect on the stove efficiency.

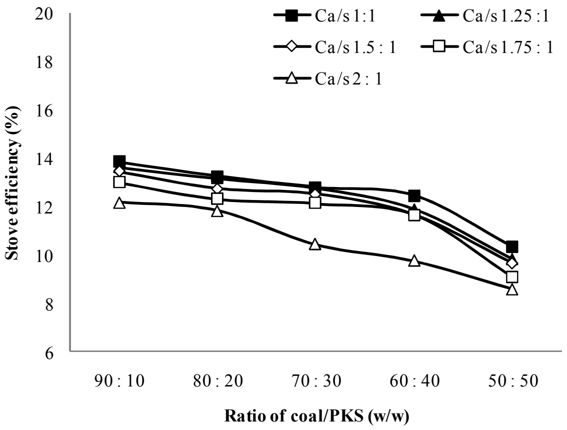

Fig. 8 Stove efficiency for bio-briquettes using lime desulfurizer

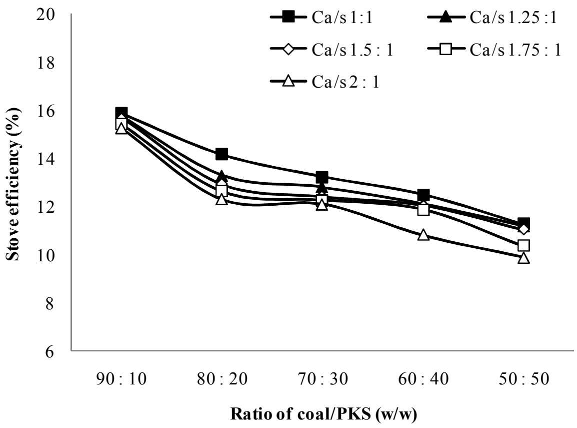

Fig. 9 Stove efficiency for bio-briquettes using oyster shell desulfurizer

Fig. 8 illustrated that the higher coal content in the bio-briquette, the higher stove efficiency. The highest efficiency was resulted from the bio-briquette at the coal/PKS ratio of 90:10 and the Ca/S ratio of 1:1, i.e. 13.8%, and the lowest efficiency was served by the bio-briquette with the coal/PKS ratio of 50:50 and the Ca/S ratio of 2:1, i.e. 8.57%.

Thereafter, Fig. 9 showed that the higher ratio of the Ca/S in the bio-briquette the lower stove efficiency. It can be seen that the bio-briquettes with the coal/PKS ratio of 90:10 and the Ca/S ratios of 1:1, 1.25:1, 1.5:1, 1.75:1, and 2:1 have the stove efficiencies of 15.86, 15.73, 15.65, 15.40, and 15.23%, respectively. The 15.86% was the highest efficiency.

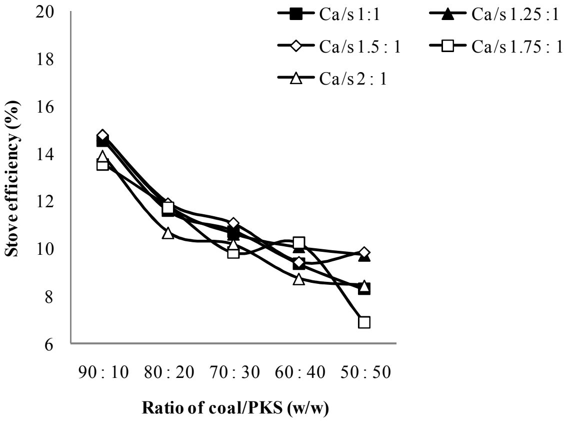

Fig. 10 Stove efficiency for bio-briquettes using scallop shell desulfurizer

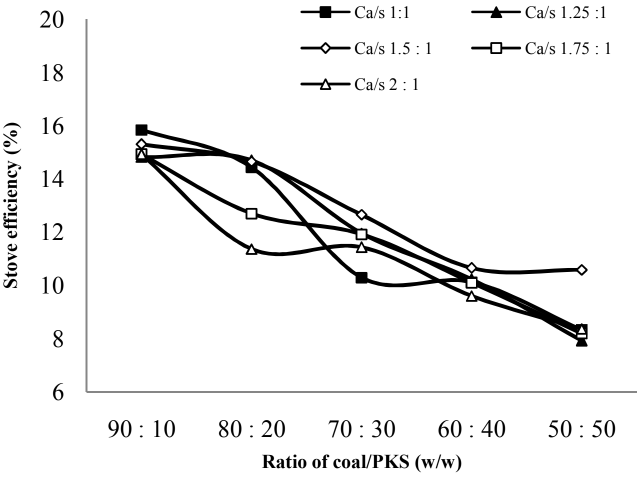

Fig. 11 Stove efficiency for bio-briquettes green mussel shell desulfurizer

Fig. 10 described that the increase of coal in bio-briquette will increase the stove efficiency. The highest efficiency reflected from the bio-briquette with the coal/PKS ratio of 90:10 and the Ca/S ratio of 1:1 was 14.54%.

After all, applying the green mussel shell as the desulfurizer might led to the increase in the stove efficiency. The greatest efficiency was also yielded from the bio-briquette at the coal/PKS ratio of 90:10 and ratio of Ca/S of 1:1, was 15.84% as can be seen in Fig. 11. It is clear that the increase of the desulfurizer content in the bio-briquette could reduce the stove efficiency, however, this condition has a benefit in lowering the SO_2 emission release during the bio-briquettes firing [6].

IV. CONCLUSION

The durability tends to decrease as the biomass (PKS) content in the bio-briquette increase. The maximum mass loss from the bio-briquette with the addition of lime, oyster shell, scallop shell and green mussel shell desulfurizers was about 6.5%. The highest stove efficiency was 15.86% for the oyster shell desulfurizer and 15.84% for the green mussel shell desulfurizer; both appeared at the coal/PKS ratio of 90:10 and the Ca/S ratio of 1:1.

ACKNOWLEDGMENT

This study was funded by Directorate General of Higher Education, Ministry of National Education through The Hibah Penelitian Strategis Nasional with the contract number 516/SP2H/PP/DP2M/VII/2010.

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