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PREPARATION AND CHARACTERIZATION OF BIO-COAL BRIQUETTES FROM PYROLYZED BIOMASS-COAL BLENDS

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Abstract

In this paper, the characteristics of bio-coal briquettes produced from a blend of pyrolyzed biomass and coal were investigated. Prior to being molded into the briquettes, biomass (in the form of oil palm shell and canarium nutshell) and coal were firstly pyrolyzed at 400 and 500 °C. The briquette was prepared by blending the pyrolyzed biomass and coal at various compositions (in the range of 12.5-87.5% of biomass) and then mixed thoroughly with a starch solution. A blend of 40 g of material was formed in a cylindrical shape (diameter of 5 cm, length of 3 cm) and was pressed at 10 tons using a hydraulic press. The bio-coal briquettes were measured its calorific value, equilibrium moisture content (EMC), burning characteristics (ignition time, burn out time, overall burning rate), and CO-CO_2 emission from their burning. The measurement results showed that the briquette had a calorific value of 20.81-27.16 MJ/kg and EMC of 5.90-8.00%. The presence of biomass slightly lowered the calorific value and raised the EMC. On the contrary, the ignition time and burn out time were getting shorter and the overall burning rate became faster. The biomass in the briquettes also contributed significantly to decreasing CO and CO_2 emission.

Keywords: Bio-coal briquettes, Biomass, Characteristics, Pyrolysis.

1. Introduction

The world's need for energy increases very rapidly in recent years. On the other hand, the reserve of fossil fuel, as the primary energy source, has been depleted steadily. Therefore, a global search for alternative energy resources has been done intensively within the last few years. Biomass has attracted much attention since it can be used as a chemical feedstock and or a renewable energy source. Due to its sustainability and environmentally friendly characteristics, biomass is considered to be a promising alternative. Various types of biomass sources can be found almost all over the world in large quantities, less expensive, and they have the potential for further utilization.

One potential biomass resource that is abundant and not expensive is residue from the agricultural crops, such as oil palm shell and canarium nutshell. Oil palm shell (OPS) is a residue from the oil milling process. These materials are found in large quantities in Indonesia, particularly in Sumatra Island. Meanwhile, canarium nutshell (CNS) is a by-product of its oil nut extraction process. The oil is conventional for food and medicinal uses. Canarium is a species widely found in eastern Indonesia, such as in Sulawesi and Moluccas Islands.

There are several methods to utilize these residues as an energy source. The oldest and conventional one is by direct combustion. However, owing to their high oxygen and moisture content, the energy generated is relatively low. Moreover, the bulky volume of these residues caused several difficulties in storage and transportation. To solve this problem, people have attempted to make a denser product by briquetting. Several works have reported the briquetting of these residues [1, 2] and as well as other biomasses [3-7].

In order to raise the energy content of the briquette, several researchers blended the biomass with coal [8, 9]. However, a briquette with a high percentage of biomass still has a relatively low calorific value. Hence, a pyrolysis pre-treatment prior to briquetting becomes one option to lift up the calorific value of the briquette.

It was known that the use of coal, particularly for household fuel, often creates a negative impact on indoor environment quality, as well as to human health. Indoor air pollution, increasing the risk of chronic obstructive pulmonary disease, lung cancer, and acute respiratory infections in childhood were common problems found elsewhere, such as in China [10-12], Korea [13], Vietnam [14], Indonesia [15], and other developing countries [16]. To reduce the risks generated from the coal briquette burning, several researchers have attempted using biomass as a coal substitute of the briquettes [17-19]. The presence of biomass in the biomass-coal briquette has a positive impact. However, a briquette with a high percentage of biomass still has a relatively low calorific value. In this work, the pyrolysis pre-treatment method has been attempted prior to briquetting as an alternative to lifting up the calorific value of the briquette. The main objective of this work is to investigate the characteristics of the briquette of pyrolyzed biomass-coal blends.

2. Experiments

2.1. Materials

OPS and CNS were collected from the plantation in Sumatra and Sulawesi, while the coal was obtained from a coal mining in Kalimantan. Prior to use, each material was pulverized to form a powder. Material with a particle size of -30 mesh was used in the experiments. The proximate and ultimate analyses of a raw sample (coal, OPS, and CNS) were presented in Tables 1 and 2 respectively.

Table 1. Proximate analysis and calorific value of the raw sample.

Material	Moisture, wt.% adb	Ash, wt.% adb	Volatile, wt.% adb	Fixed carbon, wt.% adb	Calorific value, MJ/kg
Coal	12.11	4.08	38.89	44.92	23.80
CNS	7.87	0.94	74.70	16.49	18.39
OPS	5.80	1.80	74.00	18.40	19.64

*adb = air-dried basis

Table 2. Ultimate analysis of the raw sample.

Material	C, wt.% db	H, wt.% db	O*), wt.% db	N, wt.% db	S, wt.% db
Coal	60.85	5.39	28.28	1.23	0.17
CNS	46.74	6.25	45.97	0.08	0.02
OPS	49.50	5.70	44.40	0.80	0.0

*) by difference; db = dry basis

2.2. Apparatus and experimental methods

Each material (coal, OPS, and CNS) was firstly pyrolyzed using the same method that has been published elsewhere [20]. Briefly, pyrolysis was conducted in a pyrolysis reactor, schematically drawn in Fig. 1. A sample of 400 g of material was put into the pyrolysis reactor and the reactor was then gradually heated up to the target temperature (400 and 500 °C). At the target temperature, the reaction was held for 150 min and then the reactor was cooled down. After cooling, the solid was recovered and was oven-dried at 105 °C for 4 hours. Approximately 30% of the feed was obtained as a pyrolyzed solid product. A bio-coal briquette was produced by blending pyrolyzed coal and biomass at various compositions (e.g., percent of biomass ranges from 12.5 to 87.5%). A coal-biomass mixture was then mixed thoroughly with a starch solution (1.5 g of starch in 5 ml of water) as a binder. A 40 g of the mixture was then molded in a cylindrical shape (diameter of 5 cm and length of 3 cm) and it was pressed at 10 tons using a hydraulic press to form a briquette. The briquette was further dried at 105 °C in an oven for 8 hours to obtain the final product.

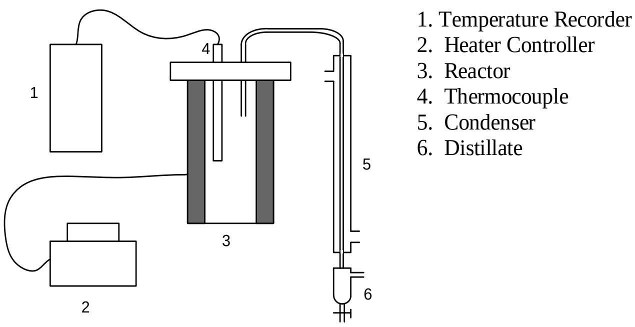

Fig. 1. Schematic diagram of the pyrolysis apparatus.

2.3. Analysis

The briquettes were analyzed using several methods. The gross calorific value (GCV) of briquettes was determined based on ASTM D 201 procedure. The equilibrium moisture content (EMC) of the product was measured according to Japanese Industrial Standards JIS M 8811.

Briefly, the sample was placed inside a desiccator that contains saturated salt (NaCl) solution for several hours until the equilibrium was reached. Then, the moisture content of the solid was quickly measured using a Sartorius MA 150 analyzer.

The burning characteristics of the briquettes (comprises ignition time, burn out time, and overall burning rate) were also evaluated. Ignition time was defined as the time required for a flame to raise the temperature of the briquette to its ignition point. Burn out time is the time taken for a briquette to be completely burnt out; starting from a constant flame is hold. These two characteristics were determined using a procedure developed by Onuegbu et al. [8]. Meanwhile, the overall burning rate (formulated in Eq. (1)) is defined as the speed of burning of the briquette in a whole period of burning. This is evaluated based on a procedure done by Davies and Abolude [21]. In addition, gas emission from the burning was evaluated using a gas analyzer.

$$BR = \frac{W_1 - W_2}{TB} \tag{1}$$

3. Results and Discussion

3.1. Calorific value

Under pyrolysis, the feed material was thermally cracked, resulting in changes in physical and chemical bonds. Hence, cellulose, hemicellulose, lignin and other large molecular compounds were broken down into simpler and smaller molecules. The remaining feed material was recovered as a solid residue, which yielded material for briquette after dried.

During pyrolysis, carbonization occurred, wherein most of the volatile matter of the material was degraded and converted into the unrecovered product (tar and gas). On the contrary, most of the carbon remained in the solid leading to an increase in calorific value.

As shown in Table 3, the energy content of the briquette decreased, along with the increase in the percent of the biomass. It was due to the lower energy content of biomass than coal; therefore, the contribution of energy from biomass to the total energy of the briquette became less significant. Compared to CNS, the briquette of OPS had slightly higher energy content (5313-6488 kcal/kg versus 4971-6113 kcal/kg).

All of these indicated that the calorific value of the briquette strongly depends on the calorific value of its constituent materials. It is interesting to note that all the briquettes pass the minimum requirement of calorific value for commercial purpose as stated by DIN 51731 (>17.5 MJ/kg).

The effect of temperature of pyrolysis on the calorific value of the briquette can also be observed from Table 3. The briquette obtained from a higher temperature of pyrolysis had higher calorific value. This is because carbonization reactions occurred more progressively at 500 °C than at 400 °C. Hence, the devolatilization of biomass took place more completely at higher temperature leading to a decrease in oxygen and hydrogen content. As a result, the calorific value of briquette increased. As shown in Table 3, the highest calorific value of the briquette produced was 27.16 and 25.59 MJ/kg, for OPS-coal and CNS-coal respectively.

The calorific value of the OPS-coal briquette in this study was comparable with that was explored by other researchers. Ma et al. [22] reported that pyrolyzed OPS at 250-750 °C has a calorific value ranging from 20.47 to 31.55 MJ/kg. Meanwhile, Faizal et al. [23] and Sabil et al. [24] mentioned in their report that briquette prepared from torrefied OPS (300 °C) has a calorific value of 24.91 and 22.86 MJ/kg respectively.

On the other hand, this OPS-coal briquette has a higher calorific value than briquette made from OPS-coal-oil palm mesocarp fiber without prior pyrolysis treatment (20.53-22.66 MJ/kg) [25].

Table 3. The calorific value of briquettes from pyrolyzed biomass-coal blends.

Percent biomass	Calorific value, MJ/kg			
	OPS-coal		CNS-coal	
	400 °C	500 °C	400 °C	500 °C
12.5	26.67	27.16	24.56	25.59
20.0	24.50	25.55	23.09	24.46
50.0	23.97	23.15	21.52	22.99
80.0	22.99	23.71	21.34	21.65
87.5	22.24	22.85	20.81	21.87

3.2. Equilibrium moisture content

To evaluate the product's characteristics in adsorbing humid or moisture from the air during storage, the equilibrium moisture content (EMC) of the briquettes was measured. The measurement results were illustrated in Figs. 2 and 3.

As shown in Figs. 2 and 3, the EMC of the briquette increased along with the percentage of biomass. This is due to the characteristic of the surface of biomass material was naturally more hydrophilic than that of coal.

Compared to biomass, coal has more aromatic compounds, which have a hydrophobic surface characteristic, resist humidity and water adsorption from the air. Therefore, a briquette with a lower percentage of biomass had lower EMC.

The EMC measured for briquettes was in the range of 5.90-8.00%. Both the bio-coal briquettes from OPS and CNS had EMC value close to each other for the same composition and degree of treatment. The EMC as low as 5.90% was obtained from the OPS-coal briquette of 500 °C, while the highest EMC of 8.00% was measured for CNS-coal briquette of 400 °C.

The temperature of pyrolysis had a considerable effect on the EMC. Carbonization at higher temperature produced more aromatic compounds caused the surface characteristics of the briquette becomes more hydrophobic.

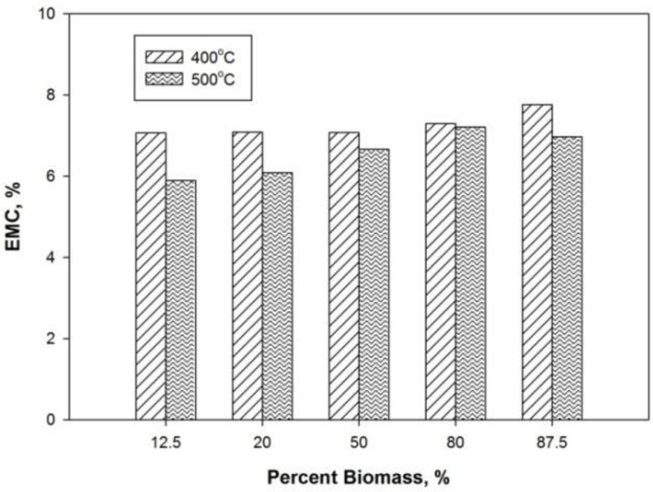

Fig. 2. EMC of briquettes of pyrolyzed OPS-coal.

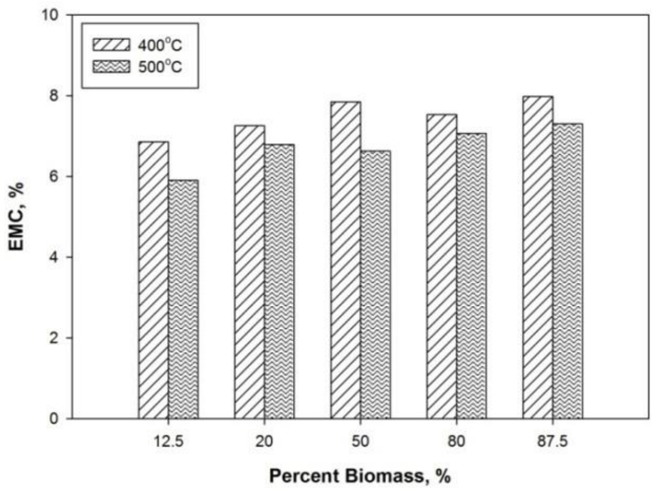

Fig. 3. EMC of briquettes of pyrolyzed CNS-coal.

3.3. Burning characteristics

The results of ignition time, burn out time and the overall burning rate is shown in Figs. 4 to 9.

According to Figs. 4 and 5, it is observed that the presence of biomass reduced the ignition time of the briquettes. As the percentage of biomass increased, the ignition time of the briquettes became shorter. It indicated that the biomass was more reactive and more easily to be burnt.

Therefore, the briquette with more biomass content ignited earlier than others, which can be correlated with the volatile matter content.

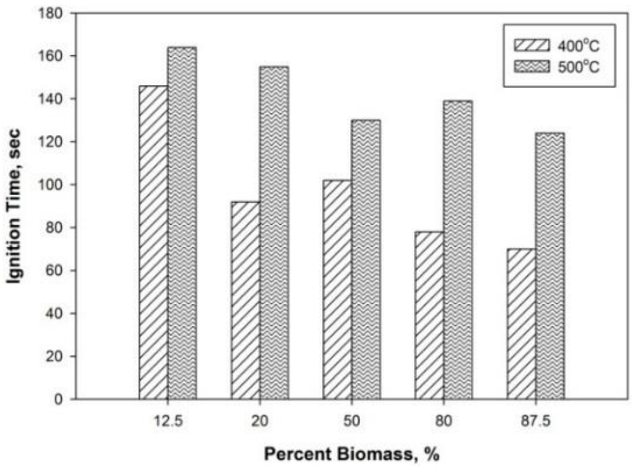

Fig. 4. Ignition time of briquettes of pyrolyzed OPS-coal.

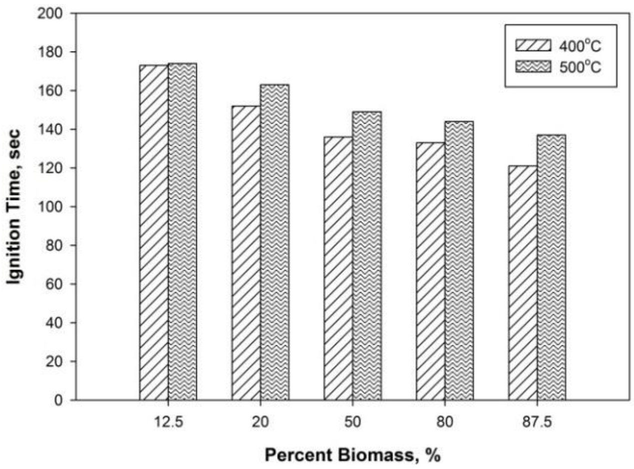

Fig. 5. Ignition time of briquettes of pyrolyzed CNS-coal.

This result is in agreement with other previous works [26-28]. On the other hand, coal contained a few amounts of mineral constituents that took time for its ignition. For the briquette that has been produced, part of the coal was substituted by biomass; therefore, a shorter time was required to ignite it.

It was also seen that an increase in pyrolysis temperature caused the ignition time of the briquettes were getting longer. This probably due to the less volatile matter contained in the briquette since devolatilization of biomass and coal accomplished more completely at a higher temperature. In fact, the volatile matter was burnt first at the initial step of the burning of a material. From these figures, it can be said that both OPS-coal and CNS-coal prepared at 400 °C were ignited more easily. Figures 4 and 5 also pointed out that the briquette of OPS-coal had an earlier ignition time range than that of CNS-coal (70-164 seconds vs. 121-174 seconds).

The effect of the biomass on the burn out time of the briquette was relatively similar. As illustrated in Figs. 6 and 7, the presence of biomass also reduced the burn out time of the briquettes. Therefore, it can be said that the briquette contained more biomass had a shorter ignition time and burn out time. Meanwhile, it was also seen that the briquettes of OPS-coal demonstrated significant differences compared to the briquette of CNS-coal, particularly for a high percentage of biomass. The burn out time of OPS-coal was much shorter than that of CNS-coal. The burn out time range of OPS-coal was 185-242 min, while that of CNS-coal was 180-290 min.

The effect of pyrolysis temperature on burn out time can be observed more clearly on Fig. 7. Hence, burn out the time of briquette prepared at 500 °C was shorter for all composition variation (180-290 min vs. 255-300 min). This is in line with Jenkin et al. [29] who reported nearly 75% of the volatile loss during the initial step of pyrolysis. Figure 7 also showed that variation of burn out time for 80.0 and 87.5% biomass briquette was almost negligible.

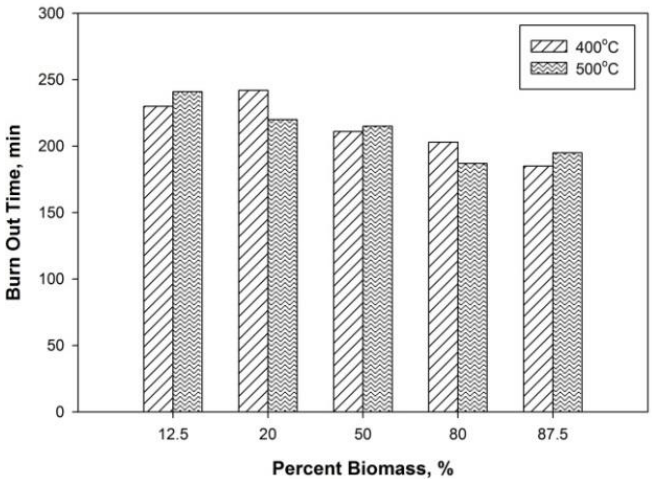

Fig. 6. Burn out time of briquettes of pyrolyzed OPS-coal.

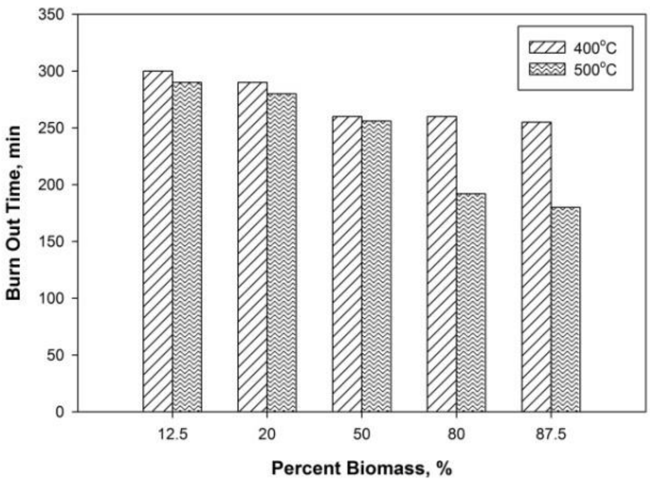

Fig. 7. Burn out time of briquettes of pyrolyzed CNS-coal.

Figures 8 and 9 show the overall burning rate of the briquette. Since the burn out time for the biomass was shorter than that for coal, therefore, it can be understood that for the relatively same weight of biomass-coal blends, a briquette with a higher percentage of biomass showed a faster overall burning rate. However, the effect of the biomass on the overall burning rate of the OPS-coal briquette was less sensitive than that on the CNS-coal briquette. Figure 8 shows that the overall burning rate of the OPS-coal briquette was nearly constant. From Figs. 8 and 9, it can also be said that the effect of the temperature of pyrolysis on the overall burning rate was less significant.

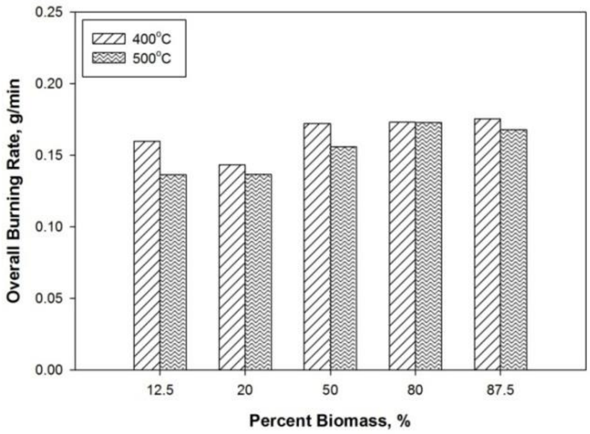

Fig. 8. Overall burning rate of briquettes of pyrolyzed OPS-coal.

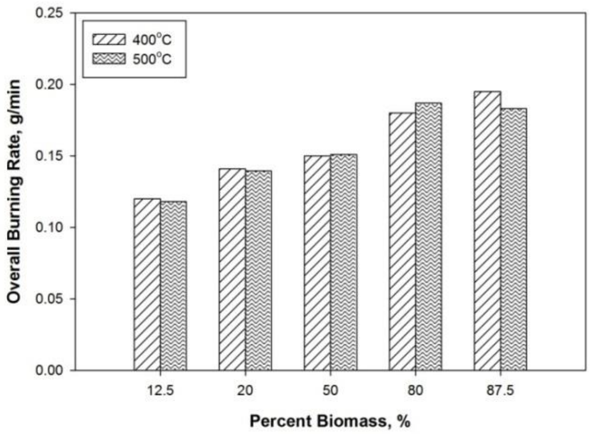

Fig. 9. Overall burning rate of briquettes of pyrolyzed CNS-coal.

3.4. Gas emission

The CO and CO_2 emission measurement results were presented in Tables 4 and 5. It was shown that the effect of biomass on the reduction of CO and CO_2 emission was very attractive. The biomass made significant contribution to decreasing emission both CO and CO_2. In case of the briquette of OPS-coal, the CO emission decreased gradually from 0.35 to 0.11% (400 °C) and from 0.28 to 0.01% (500 °C), while, simultaneously, the CO_2 emission declined from 1.2 to 0.3% (400 °C) and from 1.4 to 0.5% (500 °C). On the other hand, the CO emission from the briquette of CNS-coal decreased from 0.17 to 0.06% (400 °C) and from 0.28 to 0.11% (500 °C), while the CO_2 emission was reduced from 1.3 to 0.7% (400 °C) and 1.2 to 0.6% (400 °C).

This was probably due to the fixed carbon content in the biomass, which was further converted into CO and CO_2 gas, which was less than that in the coal. Thus, during its burning, a briquette with a higher percentage of coal-generated more CO and CO_2 gas. Hence, it can be said that the presence of the biomass in the briquette gave a better impact on the quality of air emission.

Table 4. CO emission of briquettes of pyrolyzed biomass-coal blends.

Percent Biomass	CO emission, % vol			
	OPS-Coal		CNS-Coal	
	400 °C	500 °C	400 °C	500 °C
12.5	0.35	0.28	0.17	0.28
20.0	0.23	0.16	0.16	0.24
50.0	0.26	0.17	0.14	0.27
80.0	0.14	0.04	0.1	0.2
87.5	0.11	0.01	0.06	0.11

Table 5. CO_2 emission of briquettes of pyrolyzed biomass-coal blends.

Percent Biomass	CO_2 emission, % vol			
	OPS-Coal		CNS-Coal	
	400 °C	500 °C	400 °C	500 °C
12.5	1.20	1.40	1.30	1.20
20.0	0.80	1.20	1.10	1.10
50.0	0.70	1.00	1.00	1.00
80.0	0.50	0.70	0.90	0.80
87.5	0.30	0.50	0.70	0.60

4. Conclusions

Despite the fact that presence of the biomass in the briquettes lowered the calorific value, it gave a significant contribution to improving the burning characteristics. The briquette with a higher percentage of biomass was relatively easier to ignite. Moreover, the burn out time of the briquette was shorter and the overall burning rate became faster. In addition, the quality of air emission (CO and CO_2) was much improved. The temperature of pyrolysis had a significant impact on the calorific value of the briquettes. Higher temperature pyrolysis produced a briquette with higher calorific value.

However, the pyrolysis temperature had less influence on the overall burning rate. The overall burning rate for the OPS-coal briquettes was relatively constant for all composition evaluated. Compared to the OPS-coal briquettes, the CNS-coal briquettes had a lower calorific value, a longer ignition time and burn out time, and a slower overall burning rate.

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Nomenclatures

BR	Burning rate, g/min
TB	Burn out time, min
W_1	Initial weight of the briquette (prior to burning), g
W_2	Final weight of the briquette (after burning), g

Abbreviations

CNS	Canarium Nutshell
EMC	Equilibrium Moisture Content
GCV	Gross Calorific Value
OPS	Oil Palm Shell

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