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Upgrading Quality of Biobriquette Coconut Shell (*Cocos nucifera*) and Coal with Microwave Drying Treatment

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ABSTRACT: Subbituminous coal is found abundantly in Indonesia, especially in Sumatra, has significant potential for use as a raw material for briquettes and bio-briquettes. Subbituminous coal is a type of medium-rank coal with low calorific value about 4500-5000 cal/g. Therefore, the combination of coal with coconut shell biomass can increase the calorific value and briquettes quality. This study aims to improve the quality of biobriquettes through variations in carbonization temperature, the ratio of coconut shells to sub-bituminous coal, and the microwave drying. The briquette production conducted with carbonization process in 2 hours with variation temperature used were 300°C and 400°C, and raw material ratios consisted of 0:100, 25:75, 50:50, and 75:25 with the addition of tapioca adhesive of 15%. Low temperature carbonization (300-400°C) improves fuel quality by removing moisture and volatile matter, resulting in bio-briquettes with high calorific values. The optimal raw material ratio helps reduce combustion exhaust emissions. The charcoal crushed, mixed, casted and dried with microwave drying at 800 Watt. Microwave treatment contributed significantly to the reduction of moisture and ash content. The product briquettes were analyzed based on proximate parameters. The best conditions were achieved at a 75% coconut shell: 25% coal and a carbonization temperature of 300°C, characterized by the highest calorific value (5655 cal/g), the lowest ash content (0.65%), and the lowest inherent moisture (7.74%) that meets briquette quality standards of PERMEN ESDM No. 47/2006, while the lowest volatile matter (42.93%) and the highest carbon (48.77%) was also achieved in 75% coconut shell: 25% coal.

Keywords: Briquettes; Coconut Shell; Carbonization; Microwave; Proximate Analysis; Sub-bituminous Coal

1. INTRODUCTION

Energy is a fundamental need in human life, spanning households, industry, and transportation. In line with population growth and economic development, global energy demand continues to show significant

increases. The International Energy Agency (IEA) World Energy Outlook 2023 report notes that global energy demand will increase by 2.2% by 2024, driven primarily by developing countries like Indonesia. In South Sumatera, PT. Bukit Asam, Tbk, obtained the

resource content of the hanging coal seam of 25,570,170 tons and the main coal seam of 1,275,631,640 tons. The coal quality rating in the hanging coal seam is Subbituminous B coal, and the A1 coal seam is Subbituminous A Coal while the coal seam ratings A2, B, B1, B2, and C are High volatile C Bituminous. The increase demand with depleted source urges the search for alternative, renewable, and environmentally friendly energy sources to ensure sustainable energy availability (Jiang et al, 2020).

The abundant and underutilized energy source is biomass, particularly from agricultural waste and byproducts from the coconut industry (Kusman et al, 2024). Biomass has a complex lignocellulosic structure mainly composed of cellulose, lignin, hemicellulose, and other extractive components, making it suitable for thermochemical conversion processes such as carbonization or pyrolysis that transform organic constituents into solid carbon-rich materials (Hanifah et al., 2025; Aini et al., 2022). Coconuts (*Cocos nucifera*) are an important commodity in Indonesia, both for consumption and industry. South Sumatra Province, as one of the largest coconut producers, produced 61,564 tons of coconuts in 2023, according to data from the Central Statistics Agency (BPS). Despite abundant coconut production, the use of coconut shell waste as an energy source remains limited. Coconut shells (CS), generally considered waste, have significant potential for use as an environmentally friendly alternative fuel. Coconut shell could be an alternative biomass to combine with coal as material briquette. The high carbon content of coconut shells can increase calorific value of briquette products because coal subbituminous has low calorific fuel, about 4500-5000 cal/g (Arisandy dan Uzaimi, 2017). Coconut shells contain 49.62% carbon (C). The carbon content increases to 64.87% after carbonization (Suryadi et al., 2022). Briquettes, a form of alternative energy, can be developed from a mixture of coconut shells and coal. The characteristics of subbituminous coal with relatively moderate to low water and ash content, high volatile levels, and quite good calorific value (4500-5000

cal/g), subbituminous coal is very suitable as the main raw material for briquettes. Meanwhile, coconut shells have a relatively high fixed carbon content, around 18.28%, resulting in high calorific value, around 6900 to 7300 calories per gram. This calorific value far exceeds the minimum standard set by the Indonesian National Standard (SNI) (5000 cal/g), making coconut shell briquettes highly efficient and effective as an alternative fuel for both domestic and small-scale industries. However, the quality of these briquettes is significantly influenced by several factors, including the carbonization temperature and the raw material mixture ratio. The appropriate carbonization temperature can increase the calorific value and mechanical strength of the briquettes, while an optimal mixture ratio can help reduce exhaust emissions during combustion. The carbonization temperature range of 300–400°C was selected because it represents the effective devolatilization zone of coconut shell. During carbonization, hemicellulose decomposes below 200°C, cellulose within 200–400°C, and lignin at temperatures above 400°C, allowing effective volatile release and enhanced fixed carbon formation without excessive structural degradation (Olatunji et al., 2024). Furthermore, the ash content of the coal also influences the quality of the resulting briquettes. It must be decreased to achieve the standard quality of briquette. The microwave drying is believed can be reduce ash content. The use of a microwave oven at 800 Watt for 5 minutes during the coal agglomeration process can reduce ash content to 9.98% and moisture content to 1.51% (Sahari & Hardjono, 2023).

By utilizing coconut shell waste and optimizing the briquette coal manufacturing process, this work reduce waste generated from the coconut industry and also contribute to the provision of a more sustainable and environmentally friendly energy source. This study aims to evaluate the effects of carbonization temperature and the coconut shell–coal ratio on briquette quality and combustion performance, as well as to assess the impact of microwave treatment on reducing ash content in the resulting briquettes.

Therefore, further research is urgently needed to explore the full potential of coconut shell and coal briquettes and to find solutions that can meet Indonesia's growing energy needs.

2. MATERIAL AND METHODS

This study used coconut shells and sub-bituminous coal as the main ingredients, which were then processed into biobriquettes with the addition of tapioca adhesive at 15% of the total mass of the mixture. The tools used were a 40-mesh sieve, a beaker, a hot plate, an aluminum mold, a mortar, an analytical balance, an oven, a microwave, a spatula, a stirring rod, a furnace, and an aluminum pan.

2.1. Briquette Manufacturing Process

The process of producing coconut shell-coal biobriquettes was divided into four steps: pretreatment, carbonization, mixing and casting, and drying with microwave. During the pretreatment process, the coconut shells were cleaned to remove dirt and then sun-dried for approximately three days until a constant weight was achieved. The carbonization process was conducted at two different temperatures, 300°C and 400°C, for 2 hours. The coconut shell charcoal was ground using a mortar and sieved through a 40-mesh sieve. In the mixing process, the mixture of coconut shell charcoal and sub-bituminous coal was prepared in advance according to the ratio variations of 0:100, 25:75, 50:50, and 75:25 then mixed with 15% tapioca binder. The addition of tapioca binder aims to form a compact and dense briquette texture (Santosa et al, 2023). All components were stirred until homogeneous. The mixture was molded and weighed to determine their initial weight. The molded briquettes were then dried using an 800-watt microwave for 5 minutes until reached a dry state. After the drying process was complete, the briquettes were briefly cooled and then weighed to determine their final weight, which served as a basis for evaluating mass changes during the drying process. The briquette products were then analyzed for their characteristics through proximate tests, including moisture content, ash content, volatile matter content, fixed carbon content, and calorific value.

2.2. Briquette Quality Analysis

Proximate analysis is a fuel property testing method that aims to determine the water content, ash content, volatile matter, and fixed carbon in a sample (Suwankamnoed et al., 2025). The determination of these parameters is carried out based on standard methods established by the American Society for Testing and Materials (ASTM) D3172–D3175.

Inherent Moisture

Moisture content is a measurement of the water content in a sample that has been dried and ground into a powder. High moisture content will reduce the quality of the briquettes because most of the heat energy is used to evaporate the excess water, resulting in more smoke from combustion (Dewi et al., 2022). Moisture content can be determined using Equation 1.

$$IM = \frac{(m_2 - m_3)}{(m_2 - m_1)} \times 100\% \quad (1)$$

Where, m_1 represents the weight of the empty weighing bottle and cap (g), m_2 represents the weight of the weighing bottle, cap, and sample before heating (g), and m_3 represents the weight of the weighing bottle, cap, and sample after heating (g).

Ash Content

Ash content is an indicator used to determine the amount of ash produced after combustion (Indrawati et al., 2024). Ash content is the remaining inorganic matter contained in biobriquettes. This ash content results from impurities that adhere to the biobriquette formation process. Ash content can be determined by Equation 2.

$$AC = \frac{(m_3 - m_1)}{(m_2 - m_1)} \times 100\% \quad (2)$$

Where, m_1 represents the weight of the empty cup (g), m_2 represents the weight of the empty cup and sample before the washing process (g), and m_3 represents the weight of the empty cup and sample after the sample was converted to ash (g).

Volatile Matter

Volatile matter content is a substance that can evaporate as a result of the decomposition of compounds still present in the briquette other

than water. Volatile matter content can be determined using Equation 3.

$$VM = \frac{(m2-m3)}{(m2-m1)} \times 100\% \quad (3)$$

Where, m1 represents the weight of the weighing bottle and cap (g), m2 represents the weight of the weighing bottle, cap, and sample before heating (g), and m3 represents the weight of the weighing bottle, cap, and sample after heating (g).

Fixed Carbon

Fixed carbon content is the amount of pure carbon contained in a briquette. Determining carbon content aims to determine the value or amount of pure carbon contained in the briquette. The fixed carbon content in a sample is determined indirectly through calculations based on proximate analysis results (Djonny et al., 2025). The fixed carbon content can be determined using the Equation 4.

$$FC = 100\% - (IM + AC + VM) \quad (4)$$

Where, IM represents the inherent moisture content (%), AC represents the ash content (%), and VM represents the volatile matter content (%).

Calorific Value

Calorific value is one of the determinants of briquette quality. If the calorific value of the briquette produced is less than 5000 (cal/g), then the briquette is of poor quality. If the calorific value of the briquette is greater than 5000 (cal/g), then the briquette quality is better. Calorific value can be determined using the bomb calorimeter equipment (Inegbedion, 2022).

3. Result and Discussion

The results of proximate analysis on biobriquettes with varying ratios of coconut shells (CS) and coal (C) are presented in Table 1. It shows significant variations in several parameters, such as inherent moisture (IM), ash content, volatile matter (VM), fixed carbon (FC), and calorific value (cal/g). Overall, the calorific value of the resulting briquettes ranged from 4934 to 6075 cal/g, which meets the standards set by PERMEN ESDM No. 47 of 2006 (minimum calorific value of 4400 cal/g).

Table 1. Proximate Analysis of Coconut Shell and Coal Biobriquettes

No	Sample	Poximat Analysis (%)				Calorific Value (cal/g)
		IM	Ash	VM	FC	
1	1A	14.59	2.73	46.66	36.02	5058
2	2A	9.24	2.10	26.55	42.11	5343
3	3A	7.74	0.56	42.93	48.77	5655
4	1B	8.87	2.85	43.67	44.61	5460
5	2B	9.31	1.95	43.25	45.49	5501
6	3B	7.94	1.77	43.67	46.62	5554
7	C	12.95	2.28	51.39	33.38	4934

The sample codes used in this study were described as follows: C represents coal briquettes with a composition of 0% coconut shell (CS) and 100% coal (C). Samples 1A, 2A, and 3A represent briquettes carbonized at 300°C with coconut shell-to-coal ratios of 25:75, 50:50, and 75:25, respectively. Meanwhile, samples 1B, 2B, and 3B represent briquettes carbonized at 400°C with coconut shell-to-coal ratios of 25:75, 50:50, and 75:25, respectively.

3.1. The Effect of Feed Ratio and Carbonization Temperature on Inherent Moisture (IM)

Briquettes with a high water content tend to be more difficult to ignite, produce a lot of smoke, have a low calorific value, are heavier, and require a longer drying time.

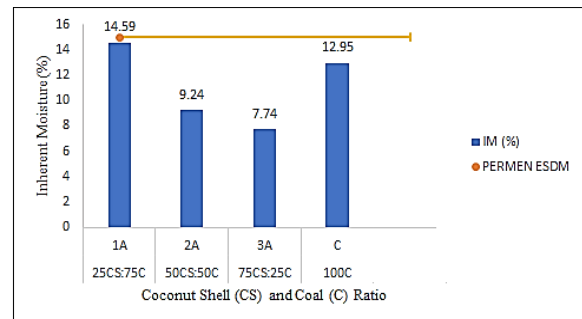


Figure 1. Inherent Moisture (%) in 300°C carbonization temperature

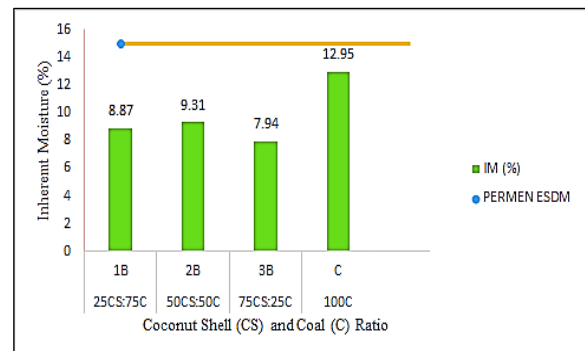


Figure 2. Inherent Moisture (%) in 400°C carbonization temperature

Figure 1 and Figure 2 shows the inherent moisture (IM) content of the briquettes shows that the higher the coconut shell ratio, the lower the briquette's moisture content. Briquettes with 75% coconut shell (samples 3A and 3B) have the lowest moisture content, namely 7.74% at 300°C and 7.94% at 400°C. This indicates that coconut shells have a more open pore structure and more easily release water vapor during the carbonization process, while coal (sample C) has the highest moisture content (12.95%) that indicates the compact structure (Liu et al, 2021) and tend to absorb water (Xu et al, 2022). From Figure 1, in 300°C carbonization temperature, the increase of coconut shell content leads the lowest inherent moisture. It occurs due to the coconut shells naturally have drier physical and chemical characteristics than coal (especially lignite and sub-bituminous as low rank coal). Furthermore, the water easily evaporates because coconut shell charcoal has more pores and (Paradise et al, 2021).

3.2. The Effect of Feed Ratio and Carbonization Temperature on Ash Content

The ash content variation from the research results was influenced by the composition of the raw materials and the carbonization temperature. In the carbonization process of briquettes containing coconut shells, the main organic compounds such as hemicellulose, cellulose, and lignin gradually decompose with increasing temperature.

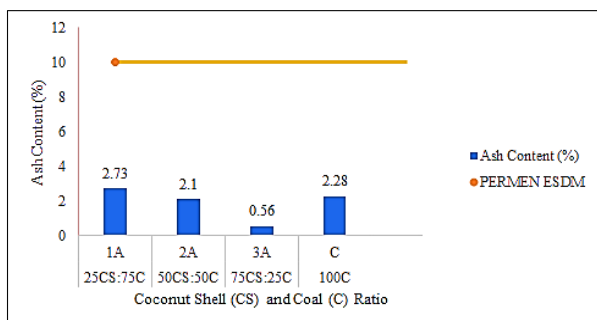


Figure 3. Ash Content (%) in 300°C Carbonization Temperature

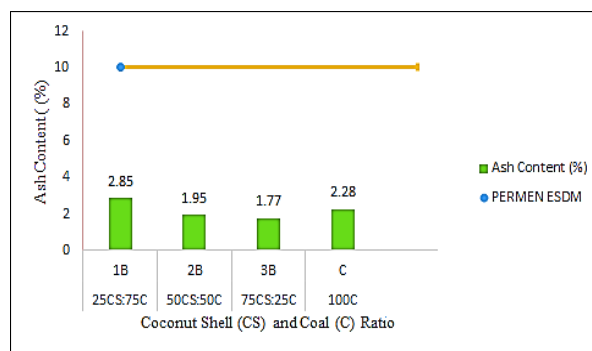


Figure 4. Ash Content in 400°C Carbonization Temperature

From Figure 3 and Figure 4, the ash content of the resulting briquettes varied from 0.56% to 2.85%. The higher the coconut shell ratio, the lower the ash content. Figure 3 shows that at a carbonization temperature of 300°C, sample 3A (75% coconut shell) produced the lowest ash content, at 0.56%, while sample 1B (25% coconut shell, 75% coal) produced the highest ash content, at 2.85%. This indicates that coal, which has a higher mineral content, contributes more to ash formation than coconut shell. The coal sample C has high ash about 2.25%. The highest content of coconut shell in raw material ratio leads the lowest ash content, it is because the coconut shell contain less ash content (Paradise et al, 2021). Meanwhile, At higher coal ratios, ash content increases because sub-bituminous coal contains inorganic minerals such as silica (SiO₂), alumina (Al₂O₃), iron oxide (Fe₂O₃), and calcium oxide (CaO) (Monika & Sulistyohadi, 2019). When organic components decompose and are released as volatile gases, the mineral fraction becomes more concentrated, thereby increasing the ash content. The carbonization temperature is also increase the ash because the combustion process in high temperature lead the lignin decomposition (Li et al, 2020).

3.3. The Effect of Feed and Carbonization Temperature Ratio on Volatile matter

Briquettes with high volatile matter (VM) tend to produce more smoke during the combustion process, because these volatile compounds turn into gas when exposed to heat (Murni et al., 2021; Syarif et al., 2019).

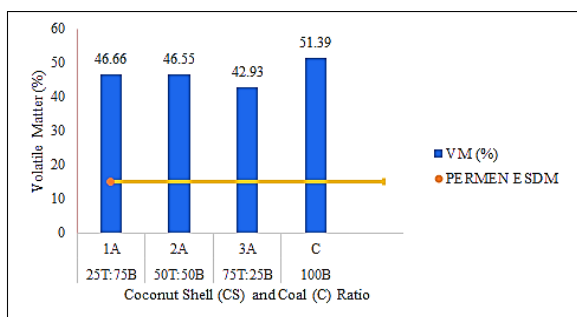


Figure 5. Volatile Matter (%) in 300°C Carbonization Temperature

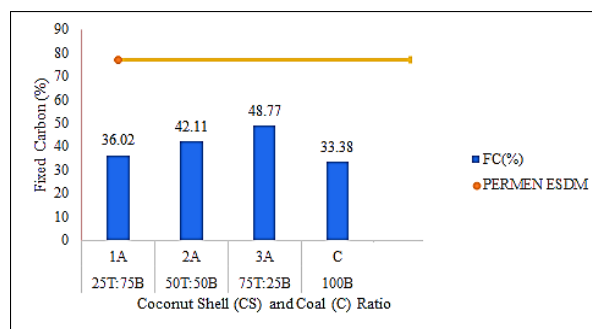


Figure 7 Fixed carbon (%) 300°C Carbonization Temperature

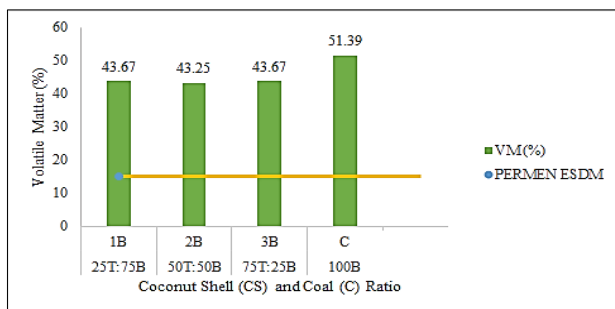


Figure 6. Volatile Matter 400°C Carbonization Temperature

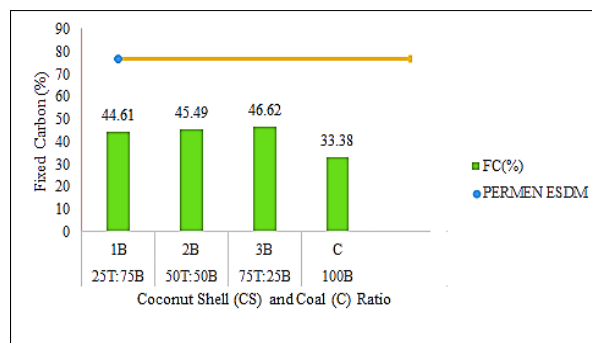


Figure 8 Fixed carbon (%) 400°C Carbonization Temperature

Figure 5 shows the volatile matter at 300°C while Figure 6 shows the volatile matter at 400°C. Volatile matter (VM) content indicates that briquettes with higher coal content have higher volatile matter levels. Sample 1A (25% coconut shell, 75% coal) had the highest VM (46.66%), while sample 3A (75% coconut shell) had the lowest VM (42,93%). Increasing the carbonization temperature rise VM levels, because most volatile compounds decompose at higher temperatures (Wang et al, 2023).

3.4. The Effect of Feed Ratio and Carbonization Temperature on Fixed Carbon

According to ESDM Regulation No. 47 of 2006, the fixed carbon content of briquettes that meets the standard is > 77%. The higher the carbonization temperature in the biobriquette mixture, the higher the fixed carbon content and calorific value of the briquettes (Nurhayati 2019). This is caused by the higher carbonization temperature, more volatile substances will be released from the briquettes, so that the fixed carbon content increases.

From Figure 7 and Figure 8, the fixed carbon (FC) of briquettes increases with increasing carbonization temperature and increasing coconut shell ratio in the mixture. Figure 8 describes that sample 3B, with 75% coconut shell at 400°C, produced the highest FC (48.77%). In contrast, coal has a lower FC (33.38 %) because it is the low rank coal which contains volatile compounds and water that have not yet fully decomposed.

3.5. The Effect of Feed Ratio and Carbonization Temperature on Calorific Value

Calorific value is one of the main indicators that determines the quality of briquettes. The higher the calorific value, the better the quality of the briquettes. The calorific value is greatly influenced by the ash and moisture content of the briquettes. (Ardiansyah et al, 2022)

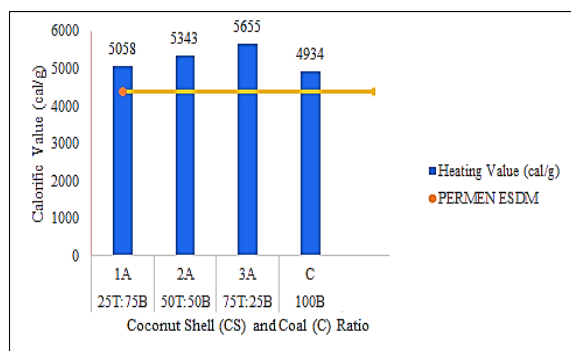


Figure 9. Calorific Value in 300°C Carbonization Temperature

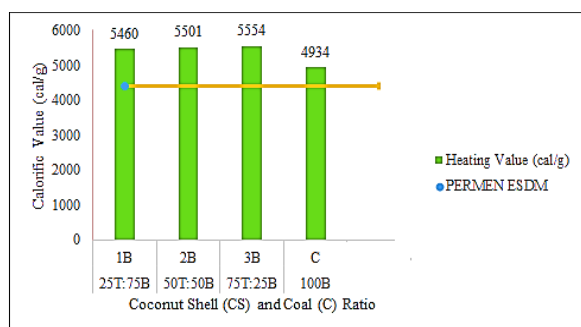


Figure 10. Calorific Value in 400°C Carbonization Temperature

Figure 9 and Figure 10 presents The calorific value of briquettes increases with increasing carbonization temperature and increasing coconut shell ratio. Figure 10 shows that sample C (100% Coal) has the lowest calorific value (4934 cal/g) which does not meet SNI standards (>5000 cal/g), the addition of coconut shells to briquettes can increase the quality of the calorific value of briquettes to a range (5058-5655 cal/g). From Figure 9 shows sample 3A (75% coconut shells at a temperature of 300°C) has the highest calorific value (5655 cal/g). While at a higher carbonization temperature of 400°C the calorific value obtained is 5554 cal/g. This is because the higher carbonization temperature causes higher ash and volatile matter content that influence the fixed carbon, so it can reduce the calorific value because the energy formed is converted into ash residue and volatile matter. Putri (2024) states that the amount of carbon bonded in briquettes depends on the results of the moisture content, ash content and volatile matter content.

4. CONCLUSIONS

Based on the research results, increasing the percentage of coconut shell and CARBONIZATION

temperature produces briquettes with better quality, indicated by a decrease in ash content, an increase in fixed carbon, and an increase in calorific value. The higher coconut shell composition also provides superior combustion performance, including faster ignition time, longer burning duration, and more effective water boiling ability. In addition, the use of microwave as a drying method has been proven to provide even volumetric heating, thereby accelerating water evaporation and reducing ash components, which overall contributes to improving the final quality of the briquettes in terms of moisture content, ash, and calorific value that meet standard SNI and PERMEN ESDM No 47 of 2006.

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