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The Effect of Pyrolysis Temperature and Raw Materials Mass Comparison on the Characteristics of Briquettes from a Mixture of Rice Husk (*Oryza sativa* L.) and Jengkol Peel (*Pithecellobium jiringa*) Using Starch Adhesives

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ABSTRACT

Briquettes offer a sustainable alternative energy source and support waste recycling, though the challenge of low calorific value remains. Therefore, this study aimed to determine the effect of pyrolysis temperature and the ratio of rice husk (*Oryza sativa* L.) to jengkol peel (*Pithecellobium jiringa*) on briquettes quality. During the procedures, carbonization was carried out at temperatures between 400 °C and 550 °C using starch as an adhesive. The mass ratio of rice husks and jengkol peel used was 1:1, 2:1, 3:1, and 3:2. Subsequently, several tests were carried out, including water content, ash content, bound carbon content, and heating value. The results showed that as the pyrolysis temperature increased during carbonization, the water and ash content decreased, while the bound carbon content and heating value increased. In addition, the water, ash, and bound carbon content of briquettes produced in this study was 2%-7%, 2%-7%, and 87%-96%, respectively. The results also showed that higher temperatures as well as a 1:1 ratio yielded products with optimal characteristics, namely a calorific value of 5576.34 cal/g. Hence, the combination of rice husks and a jengkol peel produced high-quality briquettes with optimal heating value.

***Keywords*:** Briquettes, Rice husk, Jengkol peel, Pyrolysis temperature, Calorific value

Introduction

Briquettes are solid fuels produced by mixing organic materials with adhesives and other substances. These briquettes convert biomass particles into high-density forms, leading to high combustion efficiency and low pollution emissions. In addition, their size typically ranges from 25-85 mm, with a density of 700 kg.m^{-3} to 1200 kg.m^{-3} depending on the material used and compression conditions.[1]
Briquettes are primarily produced from agricultural waste, including charcoal briquettes. The use of agricultural waste as raw materials can increase economic value and profits for society. One of the key advantages of using briquettes is their accessibility and ability to provide an easier way to obtain energy supplies.[2] In addition, some biomass that can serve as raw materials includes wheat stalks, coconut fiber flakes, rice husks, coal ash,[3] maize cob, sugarcane bagasse, and discarded polyethylene composite.[4]
In line with these findings, rice is one of the main foods in Indonesia, which generates a significant amount of husks as waste. Rice husks (*Oryza sativa* L.) typically contain large amounts of methane gas and cause environmental pollution, but can be processed as charcoal briquettes.[5] Similarly, jengkol (*Pithecellobium jiringa*), a common fruit in Indonesia, produces waste in the form of peel, which is rarely used and offers low economic value.

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Several studies have explored the use of agricultural waste in the production of briquettes. For example, Suvunnapob et al., [7] investigated the use of cotton dust mixed with sawdust through a direct pressing, which had the highest calorific value of 3960 kcal/kg.[6] In addition, Suryaningsih et al.,[8] used rice husks with a furnace and produced the best calorific value of 3126 cal/g.[7] Based on previous findings, this current study explored the combination of rice husk and jengkol peel to enhance fuel efficiency. Jengkol peel is known to possess high calorific value, which can affect fuel efficiency or savings. This research used briquettes made from a mixture of rice husks and jengkol peel. Briquettes from rice husks and jengkol peel have already been made, but no one has done it by mixing these two raw materials.
Previous studies have produced briquettes from rice husks using a furnace to obtain products rich in carbon. Despite the potential, the use of a furnace with varying temperatures can lead to inconsistent burn efficiency and increased emissions. Meanwhile, pyrolysis comprises the complete thermal decomposition of biomass, which aids in carbon sequestration by converting it into stable components.[8] Hence, in this research, making charcoal is done by a pyrolysis process. Pyrolysis is a carbonization method that destroys or decomposes organic materials into physically different materials using high temperatures without oxygen. The products obtained from the process are solids, oil, and gas, with the resulting solids typically having a pure carbon content.[9] Several studies have shown that the quality of briquettes is influenced by various factors, including the type of biomass, carbonization conditions (temperature and time), briquetting conditions (pressure and type of press), and the type of binger or binding material.[10] Therefore, this study aimed to determine the effect of pyrolysis temperature and raw materials mass ratio on the characteristics of briquettes. The results are compared with Indonesian National Standards (SNI) 016235-2000, followed by The British Standards (BS) Institution BS 1016: Part 5: 1977.

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Materials and Methods

Equipment

The equipment used were a pyrolyzer (pyrolysis tool), furnace (Muffle F6010, thermo scientific thermolyne, USA), sieve tray (40 and 60 Mesh, RLS Test Sieve Analysis Mart'l S/Steel, Indonesia), desiccator (glass 400 mm, Dianrui, Indonesia), analytical balance (AS220 R2, Radwag, Poland), and blender (BL152GF, Miyako, Indonesia). The analysis of the characteristics of briquettes included water and ash content conducted in an oven (UN 55 53L, Memmert, Germany), bound carbon content, and calorific value using a bomb calorimeter (C2000 with Dynamic Method 25 ºC, IKA, Germany).

Plant Collection and Identification

The raw materials used in this study were rice husks obtained from rice mills in Batubara Regency, Sumatera Utara, Indonesia (3°07'52.4"N 99°35'07.5"E), jengkol peel obtained from the local market in Medan, Sumatera Utara, Indonesia (3°33'55.1"N 98°39'44.1"E). In addition, packaging tapioca flour (starch) adhesive, which was sold on the market in Medan, Sumatera Utara, Indonesia (3°34'00.1"N 98°39'36.9"E) was collected in July 2023. The samples collected were authenticated at the Medanese Herbarium, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan, Sumatera Utara, Indonesia (3°33'34.6"N 98°39'16.8"E). The voucher number of authentication of the samples were 2695/MEDA/2024 for rice husk and 2694/MEDA/2024 for jengkol peel.

Raw Material Preparation

The raw materials were rice husks and jengkol peel, which were collected and cleaned. The jengkol peel was cut into small pieces. Subsequently, the rice husks and jengkol peel were dried under sunlight for 2 days.[11]

Pyrolysis Process

The raw materials for rice husks and jengkol peel, each 2 kg, were put into the pyrolyzer and then closed tightly. The pyrolysis tool was turned on, and its temperature and time were set according to specific variations, namely 400 ºC, 450 ºC, 500 ºC, and 550 ºC for 2 hours in atmospheric condition.[12]

Adhesive Application

The adhesive used was tapioca flour (starch), which was weighed and mixed with water in a ratio of 3:1 in 30 g. This mixture was then heated for about 15 minutes at 70 ºC to ensure that the colour changed from cloudy white to clear.[13]

The procedure of Making Briquettes

The charcoal from the pyrolysis results was ground using a blender and filtered using a 40/60 mesh sieve. Subsequently, 20 g of briquettes were put into the briquettes press with variations in the mass ratio of the raw materials, and 5 g of adhesive was given, then pressed with a pressure of 100 kg/cm^2. The resulting briquettes had a diameter of 5 cm and a thickness of 2 cm as many as 16 products. Subsequently, the results were dried using an oven at 105 ºC for 2 hours. The briquettes from the oven were placed into a desiccator until the temperature was close to room temperature.[14] The briquettes formed were then subjected to a proximate test to obtain water, ash, and bound carbon content and heating values following SNI 016235-2000 standards. The briquettes's final product appearance was shown in Figure 1.

Figure 1: The final product appearance of the briquettes made from waste

Statistical analysis

The data collected was further analyzed through Statistical Package Software for Social Sciences (SPSS) IBM Corp., version 29.0.2.0, released 2023 for analysis of variance (ANOVA) followed posthoc by Tukey's test to express the data distribution by significant value (p of 0.05).

Results and Discussion

Briquettes Water Content Test

According to Figure 2, briquettes with a raw material mass ratio of 1:1 had water content decreasing from 4% to 2% as the pyrolysis temperature increased from 400 ^{O}C to 550 ^{O}C. Meanwhile, for briquettes with a raw material mass ratio of 2:1, 3:1, and 3:2, the water content increased to a pyrolysis temperature of 500 ºC, and it decreased to 550 ºC. Theoretically, charcoal briquettes with high water content required high heat to evaporate the water to ensure that it could reduce the thermal efficiency of combustion,[15] and produced less heat, while when burning biocharcoal briquettes could produce less heat.[16]

Based on these results, the lowest water content was found in charcoal briquettes with a pyrolysis temperature variation of 400 ºC with a raw material mass ratio of 2:1 and charcoal briquettes with a pyrolysis temperature variation of 550 ºC with a raw material mass ratio of 1:1, namely 2% each. The highest water content was found in charcoal briquettes with a pyrolysis temperature of 500 ºC and a raw material mass ratio of 3:1, namely 7%. The water content tolerance level for briquettes was between 8% to 12%,[17] and complied with the SNI 016235-2000 standard, implying that the water content was less than 8%. Statistical analysis using ANOVA on temperature variables and raw material mass on briquettes water content was conducted in Table 1. According to the results of the analysis, the p value of more than 0.05 was obtained, which suggested that the data was normally distributed and therefore insignificant.

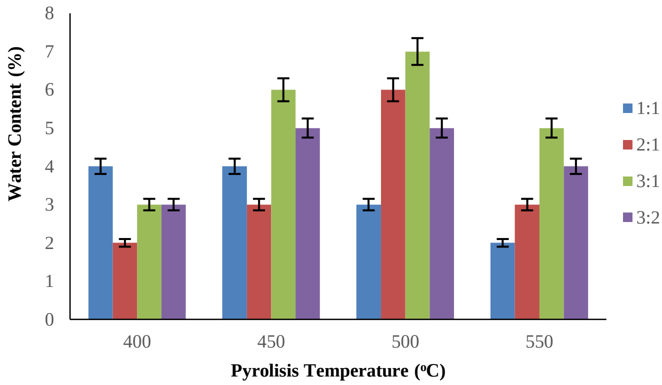

Figure 2: Effect of Pyrolysis Temperature and Comparison of Rice Husk and Jengkol Peel Mixtures on the Water Content of Briquettes

Briquettes Ash Content Test

Based on Figure 3, with a raw material mass ratio of 1:1, the ash content in the briquettes decreased from 6% to 2% as the pyrolysis temperature increased from 400 ^{O}C to 550 ^{O}C. Meanwhile, for briquettes with a raw material mass ratio of 2:1, 3:1, and 3:2, the ash content fluctuated with increasing pyrolysis temperature from 400 ^{O}C - 550 ^{O}C. The high ash content was related to the pyrolysis process, which left components that were difficult to burn in the raw materials used.[18] Furthermore, high ash content could reduce the heating value, which reduced the quality of the briquettes.[19] The impurities influenced the high ash content in the raw material, therefore, the mineral content in charcoal was relatively high, affecting the combustion process. External impurities from the environment could also cause high ash content during the briquettes-making process.[18]

Based on the results of the analysis, it was be observed that the highest ash content was found at a pyrolysis temperature of 500 ºC and a raw

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material mass ratio of 3:2, namely 7%. Meanwhile, the lowest ash content was found at a pyrolysis temperature of 550 ºC and a raw material mass ratio of 1:1, namely 2%. The water content of the briquettes obtained complied with SNI 01-6235-2000 standards (≤ 8%). Statistical analysis using ANOVA on temperature variables and raw material mass on briquettes ash content was analyzed in Table 1. Based on the results of the analysis, the p value of more than 0.05 was obtained, which suggested that the data was normally distributed and therefore insignificant.

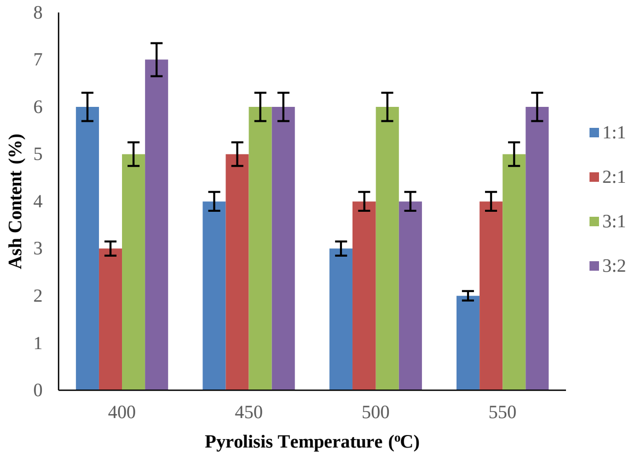

Figure 3: Effect of Pyrolysis Temperature and Comparison of Rice Husk and Jengkol Peel Mixtures on the Ash Content of Briquettes

Bound Carbon Content Test of Briquettes

Based on Figure 4, briquettes with a raw material mass ratio of 1:1 had bound carbon content increasing from 90% to 96% as the pyrolysis temperature increased from 400 ^{O}C to 550 ^{O}C. Meanwhile, the bound carbon content fluctuated as the pyrolysis temperature increased from 400 ^{O}C to 550 ^{O}C for briquettes with raw material mass ratios of 2:1, 3:1, and 3:2. Briquettes that used high levels of additional materials such as adhesives could increase the ash content and volatile matter content of the briquettes, therefore reducing the bound carbon content.[20] Bound carbon was the carbon content that did not evaporate at the combustion temperature to determine the volatile matter content, while carbon in the ultimate analysis was all the carbon contained in the fuel, including that which evaporated at the combustion temperature for the volatile matter content.[21] The amount of bound carbon content was one of the main contributors to the calorific value of charcoal. In addition, the bound carbon content was directly proportional to the calorific value of the charcoal briquettes. The higher the bound carbon content, the higher the calorific value.[15]

According to the proximate analysis results, the higher the bound carbon content produced in the briquettes, the higher the calorific value. The bound carbon content of the briquettes produced at several variations in the mass ratio of raw materials and pyrolysis temperature ranged between 87% to 96%. The lowest bound carbon content was found in briquettes with a pyrolysis temperature of 500 ºC and a raw material mass ratio of 3:1, namely 87%. In comparison, the highest bound carbon content was found in briquettes with a pyrolysis temperature of 550 ºC and a mass ratio of 1:1 of 96%. The carbon content of the briquettes obtained was following SNI 01-6235-2000 standards (≥ 77%). Statistical analysis using ANOVA on temperature variables and raw material mass on briquettes-bound carbon content was presented in Table 1. Based on the results of the analysis, the p value of more than 0.05 was obtained, which indicated that the data was normally distributed and therefore insignificant.

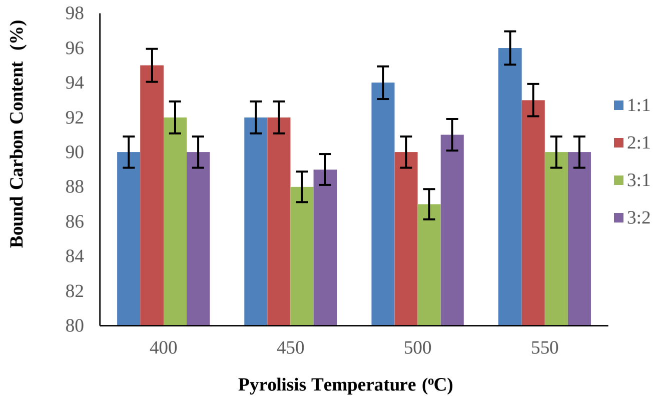

Figure 4: Effect of Pyrolysis Temperature and Comparison of Rice Husk and Jengkol Peel Mixtures on the Bound Carbon Content

Briquettes Calorific Value Test

Based on Figure 5, the calorific value of briquettes with a raw material mass ratio of 1:1 increased from 5266.79 cal/g to 5576.34 cal/g as the pyrolysis temperature increased from 400 ^{O}C to 550 ^{O}C. Meanwhile, briquettes with a raw material mass ratio of 2:1, 3:1, and 3:2 calorific values fluctuated with increasing pyrolysis temperature from 400 ^{O}C to 550 ^{O}C. The calorific value of briquettes carbonized with a pyrolysis temperature of 550 ºC was high compared to that of briquettes carbonized at 400 ºC, 450 ºC, and 500 ºC. The higher the combustion temperature of the raw material in the briquettes-making process, the higher the calorific value of the briquettes.[22] Based on the mass ratio, briquettes had a high calorific value at a ratio of 1:1. Furthermore, variations in the mass ratio of raw materials used when making briquettes affected the briquettes' water content and calorific value.

The calorific value of briquettes depended on the calorific value of the biomass used as raw material and also the density of the briquettes produced.[23] The primary components of biomass were carbon, oxygen, hydrogen, nitrogen, and hydrogen. However, the composition of the biomass affected the combustion characteristics. The calorific value of fuel decreased during combustion due to volatile materials during the combustion phase.[22] The lower the water content of the briquettes, the higher the calorific value. High water content could reduce thermal efficiency and calorific value because high heat was required to evaporate the water in the briquettes. Furthermore, fuel that had high humidity could cause excessive smoke emissions and risk of explosion, as well as cause the growth of mold and other microorganisms.[24] The increase in calorific value at higher temperatures was consistent with findings by Suryaningsih et al., [8] that linked high-temperature pyrolysis to improved fuel characteristics.[7]

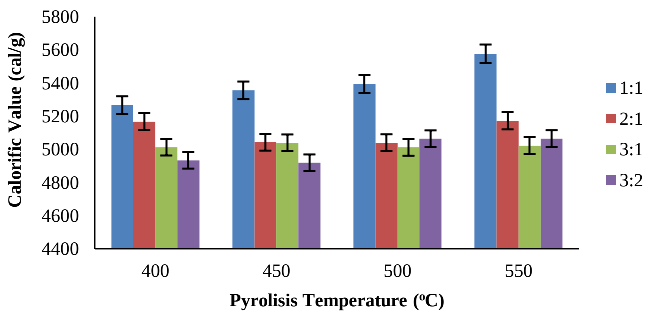

Figure 5: Effect of Pyrolysis Temperature and Comparison of Rice Husk and Jengkol Peel Mixtures on the Calorific Value

In this study, it was found that the lowest calorific value was found in the sample at 450 ºC and a raw material mass ratio of 3:2 temperature, namely 4919.74 cal/g. The highest calorific value was found in the sample at 550 ºC and a raw material mass ratio of 1:1, namely 5576.34

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cal/g. In addition, the calorific value of these briquettes was following with the SNI 01-6235-2000 standard (≥ 5000 cal/g). Only 1 out of 16 briquettes did not reach the value of 5,000 cal/g. The results suggested that optimizing the pyrolysis temperature and material ratio could significantly enhance briquettes quality, offering a sustainable energy source. Statistical analysis using ANOVA on temperature variables and raw material mass on briquettes-bound carbon content was presented in Table 1. Based on the results of the analysis, the p value of more than 0.05 was obtained, which indicated that the data was normally distributed and therefore insignificant.

The summary of the briquettes results produced at 550 ºC and a raw material ratio of 1:1 compared to other studies and the SNI 01-6235-2000 standards was shown in Table 2.

The application of high pyrolysis temperatures accelerated the decomposition of raw materials,[25] with 550 °C identified as the suitable temperature for achieving the best results. This study achieved the highest quality briquettes using a 1:1 ratio of rice husk to jengkol peel, which was consistent with the findings of Obi and Okongwu [27], who produced briquettes of the best quality using a 1:1 blend of rice husk and palm oil mill sludge.[26]

Table 1: ANOVA analysis of temperature variables and raw material mass on briquette water, ash, bound carbon content and calorific value

Variables	Description	Sum of Squares	df	Mean Square	F	Sig.
Temperature on water content	Between groups	12.188	3	4.063	2.349	0.124
	Within groups	20.750	12	1.729		
Raw material mass on water content	Between groups	9.688	3	3.229	1.667	0.227
	Within groups	23.250	12	1.938		
Temperature on ash content	Between groups	4.000	3	1.333	0.640	0.604
	Within groups	25.000	12	2.083		
Temperature on ash content	Between groups	12.500	3	4.167	3.030	0.071
	Within groups	16.500	12	1.375		
Temperature on bound carbon content	Between groups	11.188	3	3.729	0.565	0.649
	Within groups	79.250	12	6.604		
Temperature on bound carbon content	Between groups	40.688	3	13.563	3.271	0.059
	Within groups	49.750	12	4.146		
Temperature on calorific value	Between groups	36123.806	3	12041.269	0.315	0.815
	Within groups	459247.890	12	38270.658		
Temperature on calorific value	Between groups	408428.883	3	136142.961	3.791	0.068
	Within groups	86942.814	12	7245.234		

Table 2: Summary of the briqquets results produced with a pyrolysis temperature of 550 ºC and a raw material ratio of 1:1 compared to the SNI 01-6235-2000 standards

References	Water content (%)	Ash content (%)	Bound carbon content (%)	Calorific value (cal/g)
[6]	10.84	5.30	89.74	3960
[7]	5.65	46.10	12.37	3126
This study	2	2	96	5576.34
SNI 01-6235-2000 standards	≤8	≤8	≥77	≥5000

Conclusion

In conclusion, the characteristics of briquettes were greatly influenced by production temperature. The higher the pyrolysis temperature during carbonization, the lower the water content, therefore the ash content, bound carbon content, and heating value could increase. This study demonstrated that a 1:1 ratio of rice husk to jengkol peel at 550°C produced briquettes with a superior calorific value of 5576.34 cal/g aligning with SNI 01-6235-2000 standards. The prospects of the study could greatly improve briquettes quality, providing a sustainable energy source. Future studies could explore the economic viability of large-scale production and the environmental impact of widespread briquettes use.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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