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Research article

Optimization of Starch Adhesive in Bagasse Charcoal Briquettes

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A B S T R A C T

The limitations of fossil energy are driving the development of the SDGs as the population and energy needs grow. Briquettes made from agricultural waste, especially bagasse, are a potential renewable, environmentally friendly alternative energy source that can reduce dependence on fossil fuels while utilizing abundant sugar industry waste. This study aims to analyze the quality of bagasse waste briquettes with varying starch flour additions (0%, 5%, 10%, and 15%) as an adhesive. The manufacturing process includes a press method using a pressurized hydraulic machine to produce briquettes with SNI (01-6235-2000) quality standards. The quality parameters tested include density, moisture content, combustion rate, and drop test. The test results showed significant variation in characteristics between treatments. The SU3 treatment showed the highest density (0.7389 g/cm³) with the highest residual combustion ash (12.47%). The SU4 treatment showed the best physical characteristics with a drop test value of 99.11% and the lowest moisture content (20.98%). In addition, the SU4 treatment has the second-lowest combustion rate (0.084 g/min) and the lowest combustion residue (1.7 g). These findings indicate that the SU4 formulation produces briquettes with the best combination of physical characteristics and combustion efficiency.

1. INTRODUCTION

Sugarcane bagasse from the Indonesian sugar industry produces around 8-9 million tons per year, especially in Lampung. [1] Briquettes produced from bagasse have a mechanical durability (drop test) of 99.29%, a compressive strength of up to 150.82 N·mm-1, and a calorific value of 17.06 MJ.kg [2] The chemical composition of bagasse is composed of 31-54%% cellulose, and 13-39% lignin, which offers high potential as an alternative fuel with a low combustion rate. [3] The raw form of bagasse has a low energy density due to a low-density structure and high moisture content (>50%) [4] The characteristics of this bagasse pose challenges for storage, as it is susceptible to microbial growth and can cause environmental pollution if not processed properly. To overcome this problem, compaction into briquettes using adhesives such as starch flour, with comparisons of starch-starch mixture formulations, can increase energy density and combustion rate. [5] The briquettes from sugarcane bagasse can then be integrated as an alternative fuel to environmentally friendly fossil energy sources. [6].

The waste generated by the sugarcane industry can be converted into bio-briquettes, which comprise 35.45% of the total mass of the waste used. The potential of sugarcane bagasse waste biomass has the potential to develop renewable energy sources with a higher selling value compared to
to other types of biomass waste on the market [7]. The densification process involves compressing biomass with the addition of binding agents under high-pressure, high-temperature conditions.

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Table 1. Compound Content of Sugarcane Bagasse

Senyawa	Quantity (%)
SiO_2	70.97
Al_2O_3	0.33
Fe_2O_3	0.36
Na_2O	4.82
K_2O	4.82
MgO	0.82
$C_5H_{10}O_5$	22.27

increase the ratio of energy content per unit volume of biomass. This densification treatment can increase bulk density, simplify handling and logistics processes, and improve the thermal properties of biomass. Based on previous research, the comparison of tapioca adhesives has a significant effect on the mechanical properties of briquettes. The 10% adhesive concentration produces briquettes with better mechanical properties by increasing particle bonding and the structure's density. The briquettes produce a density of 0.36–0.44 g/cm3, a moisture content of 4.04-6.42%, and a combustion rate of 1,818–3,125 g/min. [8]. Therefore, this study was conducted to determine the effect of variations in the addition of starch flour as an adhesive on the physical characteristics and combustion performance of bagasse charcoal briquettes.

2. MATERIAL AND METHOD

2.1 Materials

The materials used in the formulation of briquettes include bagasse from sugarcane ice traders as the main raw material, tapioca flour purchased from the Korpri Sukarame Regional Store as an adhesive, and water as a solvent and adhesive activator.

2.2 Method

The study used 4 treatments to determine the characteristics of the briquettes.

Table 1. Sugarcane Bagasse Briquette Formulation

Treatment	Charcoal (gr)	Flour (%)
SU1	50	0%
SU2	50	5%
SU3	50	10%
SU4	50	15%

This research was conducted at the Biosystems Laboratory, Faculty of Industrial Technology, and includes a series of research processes shown in Figure 1.

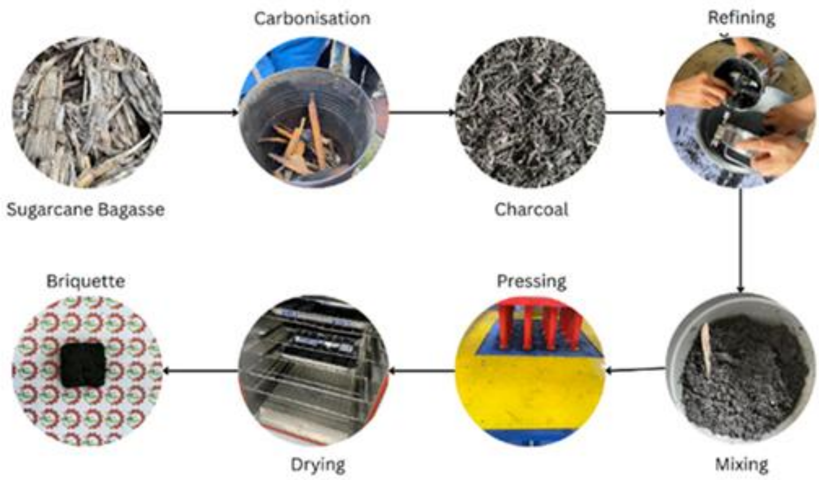

Figure 1. Research Schematic Diagram

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2.2.1 Carbonization

The process of making briquettes begins with the carbonization of sugarcane bagasse. The material is placed in a carbonization furnace or drum and heated to about 400–500 °C under limited-oxygen conditions for 1 hour, until charcoal forms. [9]. Once the carbonization process is complete, the charcoal is allowed to cool naturally without direct contact with outside air to prevent complete combustion. The cooled charcoal is then removed from the furnace and is ready for the next stage. The higher the temperature and the longer the carbonization time, the greater the amount of evaporation that is released, so that the rate of remaining flying substances becomes lower [10].

2.2.2 Refinement

The carbonized charcoal is then crushed using the Milling Crusher Machine (Fomac) tool until it becomes a fine powder. The coarse charcoal is returned to the refining process until it reaches the desired size, as a smooth, uniform particle size increases the strength and density of the briquettes. Fine particles facilitate mixing with adhesives, resulting in denser, more durable briquettes. [11].

2.2.3 Mixing

The adhesive used is tapioca flour, with a concentration of about 5-15% by weight of the charcoal powder. Tapioca flour is dissolved in water, then gradually mixed into charcoal powder while stirring until a homogeneous, plastic dough is obtained. [12]. Water is added just enough so the dough is easy to mold, but not too soft. The resulting samples totaled 16, with 4 treatments and 4 iterations.

2.2.4 Densification

The briquette dough is then placed in the mold, and the densification process is carried out using a briquette press machine (PT. Multi Indah Lestari Teknik). Pressing is done at 500 psi using a hydraulic press, ensuring the briquettes have good density and mechanical strength. [6]. After molding, the briquettes are carefully removed from the mold to prevent damage to the shape.

2.2.5 Drying

Molded briquettes are dried in an oven (constant Type FCH-9006) at about 105 °C for 7 hours, until the moisture content is low, generally below 8%. After the drying process is complete, the briquettes are ready for use or further tested to determine their physical and energy properties, such as density, compressive strength, and calorific value.

2.3 Characterization of Briquettes

The characterization of briquettes includes several parameters, namely density, moisture content, drop test, and combustion rate.

2.3.1 Density

The density test is carried out by measuring the mass and volume of briquettes to determine the density level of the densification process, which affects storage efficiency and combustion characteristics [13].

$$\text{Density}=\frac{\text{Lots of Briquette}}{\text{Volume}} \quad \text{.................................. (1)}$$

2.3.2 Moisture Content

Moisture content was determined by the oven method at 105 °C to constant weight to assess the water content in the briquettes, as moisture content greatly affects the calorific value, mechanical strength, and combustion rate stability. [14].

$$\text{Moisture content} = \frac{mass\ before - mass\ after}{mass\ before}\ x\ 100\% \quad \text{...... (2)}$$

2.3.3 Drop test

The drop test is carried out by repeatedly dropping briquettes from a height of 80 cm to assess mechanical durability and durability during transportation and storage of the resulting briquettes. [15].

$$\text{Durability index (\%)} = 100 - \text{weight loss (\%)} \quad \text{................(3)}$$

2.3.4 Burn Rate

The combustion rate test was conducted by measuring the decrease in briquette mass over time during combustion to determine the flame's efficiency and stability. [16].

$$\text{Combustion Rate} = \frac{Mass\ of\ Briquettes\ burned\ time}{Time} \quad \text{..........(4)}$$

3. RESULT AND DISCUSSION

3.1 Density

The highest density value among the four treatments was in SU3, at 0.7389 gr/cm3, and the lowest was in SU1, at 0.4606 gr/cm3, as shown in Figure 2. The average of the four treatments was 0.1055 g/cm3, indicating variation among the treatments. This variation in the data is due to manufacturing process factors, such as the composition of the adhesive mixture (tapioca flour) and the printing pressure (500 psi). [2].

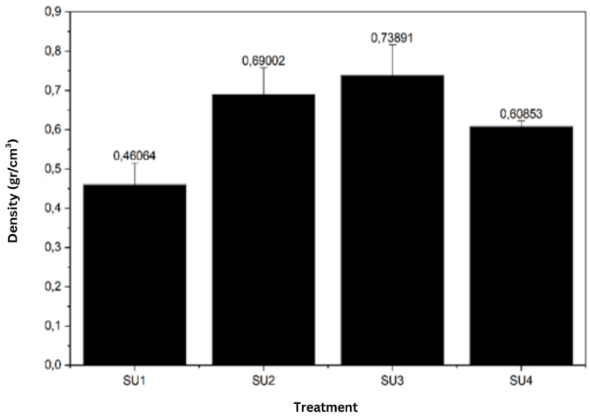

Figure 2. Graph of the results of the briquette treatment density analysis

The high-density values in SU3 show a positive correlation with low ash content and moderate combustion rates. This shows efficient combustion with a slow rate and stable heat. The high density of SU3 shows a negative correlation with drop tests that indicate low impact resistance at suboptimal porosity. [17]. SU3 shows the highest potential for use in industrial applications (coal substitutes) with densities close to 0.8 gr/cm3, with high combustion efficiency and low emissions [18]. The decrease in density seen in SU4 indicates an excess adhesive or a suboptimal particle size (too large), resulting in briquettes with high porosity and the potential for unstable combustion rates. [19].

3.2 Moisture Content

The moisture content across the four treatments was generally high, averaging 32.51%, as shown in Figure 3. The graph shows a fairly high variation in the difference due to less-than-optimal adhesives and carbonization processes [20]. The moisture content obtained correlates with mechanical quality and combustion rate. The results from SU2 showed a negative correlation with high density and drop test parameters, which reduced mechanical strength due to the release of water vapor during printing. [21].

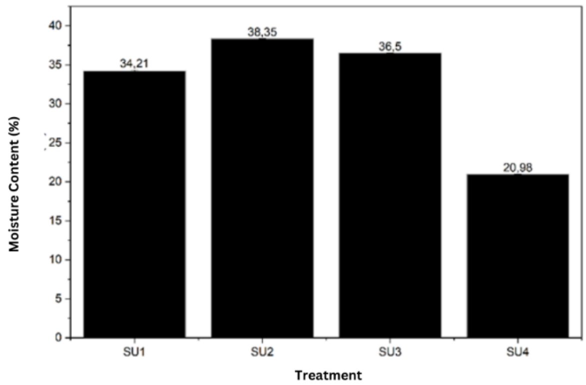

Figure 3. Graph of the results of the analysis of the moisture content of the treatment of briquettes

The line trend obtained from the briquette treatment data shows the highest moisture content in SU2 and the lowest in SU4, at 20.98%. The moisture content in the treatment is obtained from the composition of the water added during the manufacturing process, which is higher than in other treatments. SU4 showed the highest effectiveness in drying and higher moisture output in the pressing process [22].

3.3 Drop Test

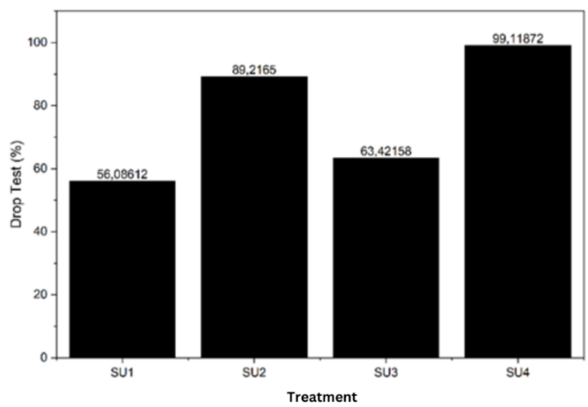

Figure 4. Graph of the results of the *briquette treatment* drop test analysis

The drop test conducted on the briquette treatment showed varying values, with an average of 76.97% (Figure 4). The values obtained indicate the need for production optimization to manufacture bagasse briquettes at>90% to increase durability and reduce combustion emissions by up to 20% [23]. The drop test value obtained was positively correlated with density and moisture content, with higher values indicating higher humidity in the treatment, thereby affecting the mechanical strength and the expansion power of water vapor in the treatment [11].

3.4 Burn Rate

Based on the results of the combustion rate test shown in Figure 5. The average overall combustion rate in the treatment was 0.091 g/min, with substantial variation and a standard deviation of 0.042 g/min. The highest combustion rate is observed in SU3, indicating inefficient combustion with a short combustion duration. SU1 has a low, stable combustion rate, making combustion more efficient and meeting production standards. Factors that can affect the combustion rate value, such as the composition of the adhesive used in SU2 and 4, can reduce the combustion rate more efficiently, because a low amount of adhesive can increase the burning duration of the treatment. [24].

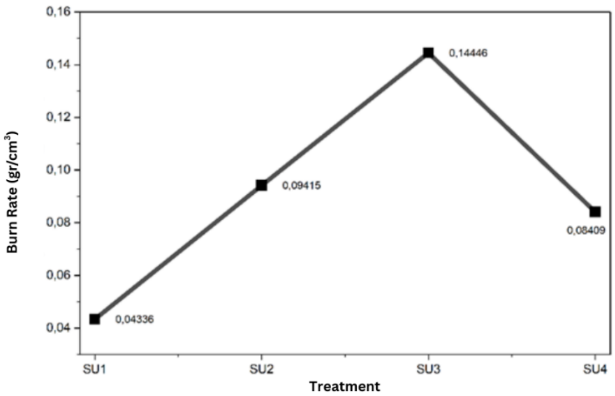

Figure 5. Graph of the results of the combustion rate analysis of briquette treatment

The high combustion rate in SU3 is due to the adhesive composition factor, which is used in higher quantities to increase the combustion rate. Starch adhesives used in greater quantities will accelerate oxidation and combustion, thereby reducing the treatment's combustion efficiency. [25]. The ratio of charcoal to adhesive in the briquette composition needs to be adjusted to better support efficient combustion, resulting in briquettes with a higher combustion rate. [26].

Overall, SU4 is the best, as it offers an optimal balance across all parameters, with advantages in low moisture content and high drop tests, which are crucial for long-term stability and handling during transport and distribution. [22]. SU4 is close to the ideal criteria for biomass briquettes from bagasse, where low moisture content prevents microbiological degradation and increases volumetric calorific values by 15-18 MJ/m³. At the same time, the >95% drop test ensures transport durability without significant material loss (>5%). Despite the moderate density, this value is still above the minimum threshold (0.6 g/cm³) for efficient densification, and the moderate combustion rate supports stable combustion with low emissions. A moderate ash content (13.17%) is still feasible for domestic applications. [27].

4. CONCLUSION

Based on the results of the density, moisture content, combustion rate, and fall resistance tests, it can be concluded that the type of adhesive significantly affects the briquettes' physical characteristics and combustion performance. The treatment with 15% adhesive (SU4) shows the best quality, with adequate density, the lowest moisture content, the highest mechanical resistance, and a stable combustion rate. The SU4 treatment produced the lowest moisture content (20.98%), a density of 0.80653 g/cm3, and the highest drop test value (99.11872%). These results show that the right adhesive formulation can improve the quality of bagasse briquettes, making them a potential sustainable alternative fuel.

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