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# Energy Potential and Impact of Briquettes Produced from Soy Sauce Industry Soybean Waste and Sugarcane Bagasse

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**Abstract**
Indonesia's energy demand continues to increase, but energy fulfillment still relies on coal, which has a negative impact on the environment. Seeing the potential of biomass as fuel, this study is intended to analyze the potential use of soybean dregs from soy sauce factories and sugarcane bagasse as fuel and to evaluate the characteristics of biomass briquettes according to the composition and particle size of the materials. Sugarcane bagasse and soy sauce bagasse were varied with a ratio of 63%:27%, 45%:45%, and 27%:63%, respectively with a mixture of 10% adhesive from cassava flour and molasses. The mesh size was chosen at 80 (177 µm) and 150 (99 µm) to compare the effect of particles <100 µm and >100 µm. Briquettes with characteristics that meet almost all aspect standards are briquettes with a composition of 27% soy sauce dregs and 63% sugarcane dregs with a mesh size of 150. The results of the water content are 4.20%, ash content 7.46%, volatile matter content 23.73%, and calorific value 5948 calories/gram. However, the results of the CO emission test in the early minutes of combustion (1287 ppm) did not meet the quality standard. This study proves that soy sauce dregs and sugarcane dregs waste can be an environmentally friendly alternative fuel with further emission control.
**Keywords:** *biomass briquette ;soybean dregs; sugarcane bagasse; calorific value; co emissions*

**Abstrak**
Kebutuhan energi di Indonesia terus meningkat, tetapi pemenuhan energi masih mengandalkan batubara yang memberikan dampak negatif ke lingkungan. Melihat adanya potensi biomassa sebagai bahan bakar, penelitian ini dimaksudkan untuk menganalisis potensi pemanfaatan ampas kedelai pabrik kecap dan ampas tebu sebagai bahan bakar dan melakukan evaluasi karakteristik hasil briket biomassa sesuai dengan komposisi dan ukuran partikel bahan. Ampas tebu dan ampas kecap divariasikan dengan perbandingan masing-masing 63%:27%, 45%:45%, dan 27%:63% dengan campuran 10% perekat dari tepung singkong dan molase. Ukuran mesh dipilih 80 (177 µm) dan 150 (99 µm) untuk membandingkan pengaruh partikel < 100 µm dan >100 µm. Briket dengan karakteristik yang memenuhi hampir semua standar aspek adalah briket dengan komposisi ampas kecap 27% dan ampas tebu 63% dengan ukuran mesh 150. Hasil kadar air sebesar 4,20%, kadar abu 7,46%, kadar zat terbang 23,73%, nilai kalori 5948 kalori/gram Namun, hasil uji emisi CO pada menit awal pembakaran (1287 ppm) tidak memenuhi standar baku mutu. Penelitian ini membuktikan bahwa limbah ampas kecap dan ampas tebu dapat menjadi bahan bakar alternatif ramah lingkungan dengan pengendalian emisi lebih lanjut.
**Kata Kunci:** *briket biomassa; ampas kecap; ampas tebu; nilai kalor; emisi co*

## 1. Introduction

The use of coal as an energy source is still massive in Indonesia. In 2022, approximately 165 million tons of coal were utilized as fuel. It is projected that by 2025, coal demand will increase to 208.5 million tons [1]. However, the growing population will continue to drive up energy demands, making coal an unsustainable solution. According to [2], coal is a non-renewable energy source that is not sustainable; in fact, the closure of coal mines in Western Europe has led to significantly cleaner air. Moreover, coal mining contributes up to 90% to climate change. Therefore, alternative renewable energy sources are urgently needed [3].

Indonesia has fertile land rich in biomass potential. Soybean residue and sugarcane bagasse are common and underutilized waste materials. Sugarcane bagasse is a by-product of sugar production, while soybean residue is a fermentation by-product from soy sauce factories. These residues are often discarded in large amounts, leading to potential decomposition and disruption of surrounding ecosystems [4]. Biomass refers to organic material derived from living organisms, either plants or animals, that can be used as an energy source. Studies by [5] and [6] have shown that briquettes made from sugarcane bagasse and soybean residue have relatively high calorific values, making them a promising alternative to reduce coal dependency. This energy is generated from the carbon content in the biomass. Although briquettes have been developed for a long time, their production, particularly regarding energy and emissions, has been further optimized following concerns over a potential energy crisis due to excessive exploitation. According to the International Energy Agency's *World Energy Outlook* (2021) in [7], biomass energy is one of the renewable solutions to address dependence on fossil fuels.

There are various types of briquettes based on their raw material. According to [8], briquettes can be made from agricultural waste such as rice husks, corn cobs, and fruit or vegetable peels. Additionally, briquettes can be produced from organic solid waste (such as animal manure and kitchen waste) or wood industry waste. In Indonesia, the feasibility of briquettes is regulated by the National Standardization Agency (BSN) under the Indonesian National Standard (SNI) No. 4931 of 2010. This regulation sets minimum calorific values and maximum allowable moisture content, ash content, and volatile matter for both coal and biomass briquettes. These characteristics are crucial as they are interrelated and affect the energy and emissions produced. Energy optimization of briquettes can be achieved through proper processing and technology. Before the raw material is converted into briquettes, a carbonization process is needed to increase the carbon content, thereby enhancing the calorific value. According to [9], several carbonization technologies, such as pyrolysis, torrefaction, and hydrothermal carbonization, can be employed to enhance energy yield.

Furthermore, [10] states that briquettes produced using torrefaction technology can reach energy values comparable to coal briquettes, though they still fall short of high-grade coal. Additionally, [11] notes that preprocessing methods like sieving and the addition of binders can reduce ash content and smoke generation. Initial testing is essential to determine the characteristics of sugarcane bagasse and soybean residue, as these directly influence the properties of the resulting briquettes, even after processing [12]. Therefore, this study aims to analyze the potential and determine the optimal composition for biomass briquettes using soybean and sugarcane residues. Mesh sizes of 80 (177 μm) and 150 (99 μm) were chosen based on [13], which found that mesh sizes <100 μm result in better briquette characteristics compared to those >100 μm.

## 2. Material and Methods

### *2.1 Raw Material Preparation*

The soybean residue used in this study is a by-product of the soy sauce fermentation process, obtained from the Jeruk Pecel Tulen Soy Sauce Factory, while the sugarcane bagasse is derived from the leftover fiber after sugarcane juice extraction. Both of these materials are readily available and abundant. Raw material preparation includes collection and cleaning to remove small waste contaminants such as plastic and sand. The binders used in the briquette production are cassava starch and molasses, mixed in equal proportions, making up a total of 10% of the briquette's weight. To assess the potential of these two types of residue, an initial characterization test was conducted.

**Table 1**. Characteristics of soybean dregs

| Parameter | | Unit |
|---|---|---|
| Fixed Carbon | 26,9 | % |
| Calorific Value | 3105,5 | cal/gr |
| Moisture Content | 10,303 | % |
| Ash Content | 17,009 | % |
| Volatile Matter | 28,277 | % |

Source : Analysis results (2025)

**Table 2**. Characteristics of sugarcane bagasse

| Parameter | | Unit |
|---|---|---|
| Fixed Carbon | 29,88 | % |
| Calorific Value | 3880,8 | cal/gr |
| Moisture Content | 3,333 | % |
| Ash Content | 5,062 | % |
| Volatile Matter | 32,336 | % |

Source : Analysis results (2025)

*2.2 Carbonization*

The initial raw material characteristics still did not meet many requirements, such as having a low calorific value. As stated by [9], the carbonization technology used in this study was the pyrolysis technique. Soybean residue and sugarcane bagasse were burned at a temperature of 500°C for 60 minutes in a pyrolysis reactor. This combustion process aimed to increase the carbon content as the raw material undergoes charring. It also helps to evaporate moisture and volatile matter, resulting in lower levels of both, while burning residual minerals or organic substances that leave behind ash residue.

*2.3 Briquetting*

After carbonization, the raw materials were crushed into granules to facilitate the sieving process. Once sufficiently fine, the materials were sieved using mesh sizes 80 and 150 to ensure uniform particle size, which improves the resulting briquette characteristics. All materials were then mixed according to the following compositions: soybean residue 63% : sugarcane bagasse 27%, soybean residue 45% : sugarcane bagasse 45%, and soybean residue 27% : sugarcane bagasse 63%, with cassava starch binder (5%) and molasses (5%) added based on the total weight of the briquette. The next stage was molding. Molding was carried out manually using a hydraulic press with mold dimensions of 5 cm in diameter and 5 cm in height, followed by oven drying for 2 hours at 105°C.

*2.3 Analysis*

The analyses conducted included moisture content, ash content, volatile matter, calorific value, and CO concentration during combustion. **Table 3** shows the testing methods used to evaluate the characteristics of the biomass briquettes.

**Table 3**. Testing Methods for Biomass Briquette Characteristics

| Parameter | Metode Uji | Unit |
|---|---|---|
| Calorific Value | *Bomb Calorimeter* | cal/gr |
| Moisture Content | SNI 13-3478-1994 | % |
| Ash Content | SNI 13-3481- 1994 | % |
| Volatile Matter | SNI 13-3999-1995 | % |
| CO Concentration | *Gas Analyzer* Testo 350 | ppm |

Source : Analysis results (2025)

## 3. Results and Discussion

*3.1 Moisture Content*

Moisture content was tested to determine the amount of water contained in the briquette samples, using the SNI 13-3478-1994 method [14], which involves heating in an oven at 105°C for 1 hour. One of the factors contributing to high moisture content is the hydrophilic nature of the raw materials (which absorb moisture from the surroundings, thus increasing moisture levels), leading to a reduction in calorific value [7]. The calorific value decreases because the heat energy produced by the briquette is first used to evaporate the moisture [8]. The analysis results, shown in **Table 4**, indicate that the moisture content in the briquette samples ranges from 4% to 7%.

**Table 4**. Results of moisture content analysis

| Parameter | | Unit |
|---|---|---|
| AK63% : AT27% 80 mesh | 7.39 | % |
| AK45% : AT45% 80 mesh | 6,77 | % |
| AK27% : AT63% 80 mesh | 6,21 | % |
| AK63% : AT27% 150 mesh | 6,10 | % |
| AK45% : AT45% 150 mesh | 5,00 | % |
| AK27% : AT63% 150 mesh | 4,20 | % |

Source : Analysis results (2025)

This moisture content is still below the maximum limit set by the National Standardization Agency in SNI 4931:2010, which is a maximum of 12%. The lowest moisture content was found in the briquette sample with 27% soybean residue and 63% sugarcane bagasse at mesh size 150, which was 4.20%. Meanwhile, the highest moisture content was found in the briquette sample with 63% sugarcane bagasse and 27% soybean residue at mesh size 80, which was 7.39%. Smaller mesh sizes facilitate easier evaporation of water because the particles are smaller and the density increases, leaving no space for water within the briquette [15].

**Figure 1** shows the moisture content graph results, indicating that the higher the proportion of soybean residue used, the higher the moisture content, even with different mesh sizes. This corresponds with the initial characteristic test of soybean residue, which contains a high sugar content. The sugar content affects the hydrophilic properties of the material, thus increasing its moisture retention [16].

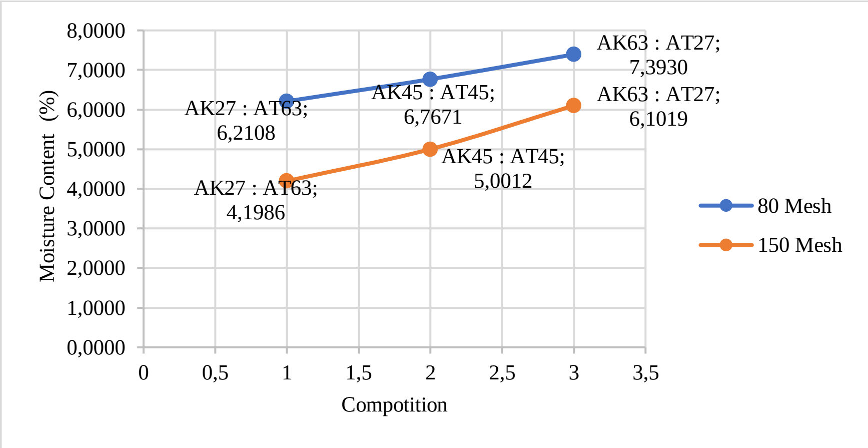


**Figure 1**. Graph of Moisture Content (%)
Source : Analysis results, (2025)

*3.2 Ash Content*

The ash content of the briquettes was tested using a furnace according to SNI 13-3481-1994. The ash content test must be conducted after the moisture content test to ensure accuracy, so that the weighed ash is not mixed with moisture. The samples were initially heated at 500°C for 30 minutes, followed by heating at 815°C for 1 hour to ensure complete combustion of the briquettes, leaving only ash or incomplete combustion residues. Ash content indicates the effectiveness of combustion; the higher the ash content, the more inorganic substances or unburned organic residues remain from the carbonization process [17]. However, ash content can also originate from binders that do not burn optimally during oven drying. The National Standardization Agency sets the maximum ash content limit at 15%. The analysis results show that the ash content of the briquette samples ranges from 7% to 13%, which meets the standards set in SNI 4931:2010.

**Table 5**. Results of ash content analysis

| Parameter | | Unit |
|---|---|---|
| AK63% : AT27% 80 mesh | 13,29 | % |
| AK45% : AT45% 80 mesh | 9,47 | % |
| AK27% : AT63% 80 mesh | 8,16 | % |
| AK63% : AT27% 150 mesh | 11,52 | % |
| AK45% : AT45% 150 mesh | 8,44 | % |
| AK27% : AT63% 150 mesh | 7,46 | % |

Source : Analysis results, (2025)

The highest ash content was found in the briquette sample with 63% sugarcane bagasse and 27% soybean residue at mesh size 80, which was 13.29%, while the lowest ash content was from the briquette sample with 27% soybean residue and 63% sugarcane bagasse at mesh size 150, which was 7.46%. Smaller particle sizes consistently result in lower ash content because smaller particles enable more complete combustion and have a larger surface area due to tighter compaction between particles, which enhances oxygen interaction and allows residues to burn thoroughly [15].

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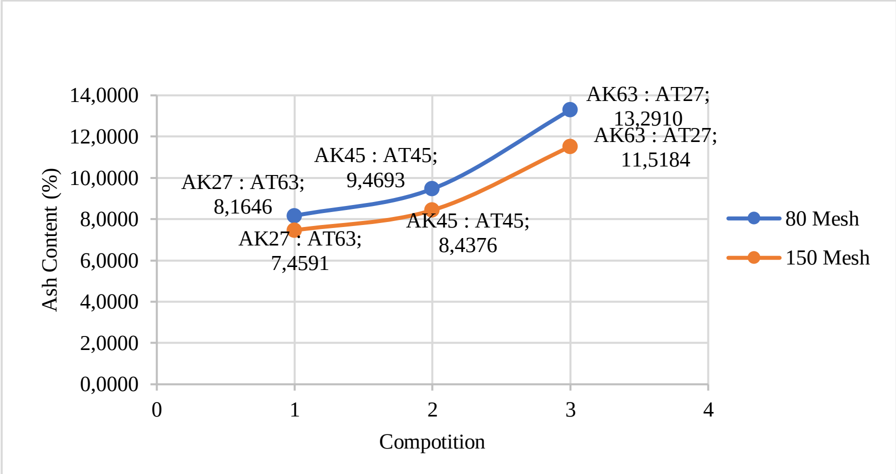


**Figure 2**. Graph of Ash Content (%)
Source : Analysis results, (2025)

Composition also affects ash content; briquettes with higher soybean residue content have higher ash content, consistent with the initial characteristics of soybean residue, which has a higher ash content compared to sugarcane bagasse. This means soybean residue contains more organic and inorganic residues. This issue can be addressed by applying high pressure during molding so that the ash is bound within the briquette structure and burns completely during combustion [18].

*3.3 Volatile Matter*

Another important characteristic tested is the volatile matter content. Volatile matter indicates the amount of substances that easily evaporate during briquette combustion. These volatile substances result from the decomposition of organic compounds remaining in the briquette after production. The volatile matter test must be conducted after the moisture content test to ensure accurate results. The volatile matter analysis was performed according to SNI 13-3999-1995 by heating the sample in a furnace at 950°C for 7 minutes, then weighing it to determine the mass ratio of the sample. High volatile matter content will result in higher smoke emissions during combustion. According to [11], carbonization of the material can reduce volatile matter because it evaporates during the carbonization process. The analysis results show that the volatile matter content of the briquette samples nearly meets the maximum standard of 22% set by SNI 4931:2010, except for the briquette sample with 63% soybean residue and 27% sugarcane bagasse at mesh size 150, which has the highest volatile matter content of 23.73%, as shown in **Table 6**.

**Table 6**. Results of volatile matter analysis

| Parameter | | Unit |
|---|---|---|
| AK63% : AT27% 80 mesh | 12,82 | % |
| AK45% : AT45% 80 mesh | 15,55 | % |
| AK27% : AT63% 80 mesh | 17,19 | % |
| AK63% : AT27% 150 mesh | 15,52 | % |
| AK45% : AT45% 150 mesh | 19,58 | % |
| AK27% : AT63% 150 mesh | 23,73 | % |

Source : Analysis results, (2025)

The lowest volatile matter content was found in the briquette with 63% soybean residue and 27% sugarcane bagasse at mesh size 80, measuring 12.82%. From this study, it can be concluded that the higher the sugarcane bagasse content, the higher the volatile matter content. This corresponds to the initial analysis, where sugarcane bagasse has a higher volatile matter content than soybean residue. Previous research by [19], showed volatile matter content reaching 30% with 100% sugarcane bagasse composition. Additionally, smaller mesh sizes result in higher volatile matter content, as illustrated in **Figure 3**. Mesh size 150 consistently produces higher volatile matter content compared to mesh size 80. According to [20], smaller particle sizes make it difficult for organic compounds to decompose due to the tight bonding between briquette particles.

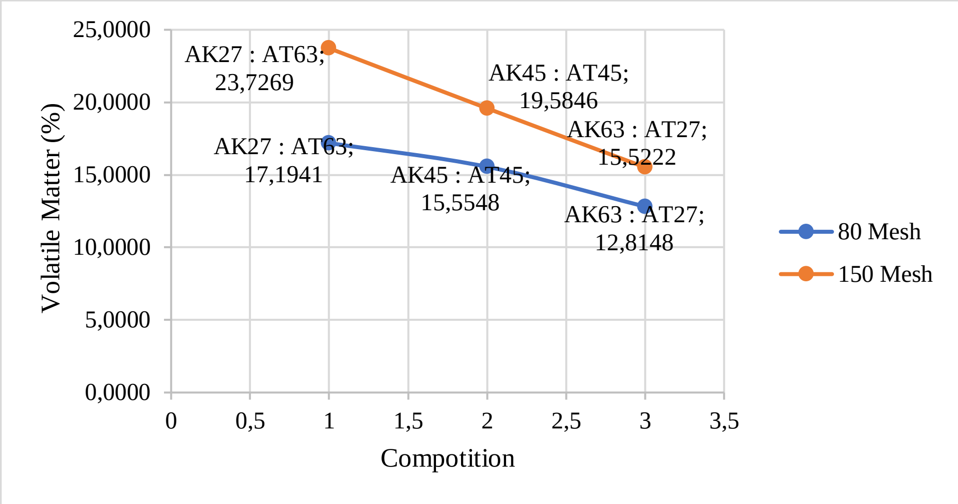


**Figure 3**. Graph of Volatile Matter (%)
Source : Analysis results, 2025

*3.4 Calorific Value*

Calorific value is the amount of energy contained in the briquette and serves as the main parameter for energy procurement from biomass. The calorific value represents the amount of heat energy produced only during complete combustion. Incomplete combustion reduces the calorific value and results in high ash content and volatile matter. The calorific value measurement is conducted using a bomb calorimeter, which calculates the value based on the temperature increase in the calorimeter medium. The calorific value is greatly influenced by moisture content, ash content, and volatile matter content. According to [21], the carbon content, which is the source of combustion energy, decreases if moisture, ash, and volatile matter contents are high.

**Table 7**. Results of calorific value analysis

| Parameter | | Unit |
|---|---|---|
| AK63% : AT27% 80 mesh | 5538,2956 | Kal/gr |
| AK45% : AT45% 80 mesh | 5691,4518 | Kal/gr |
| AK27% : AT63% 80 mesh | 5839,2130 | Kal/gr |
| AK63% : AT27% 150 mesh | 5591,0440 | Kal/gr |
| AK45% : AT45% 150 mesh | 5809,0393 | Kal/gr |
| AK27% : AT63% 150 mesh | 5948,3372 | Kal/gr |

Source : Analysis results, (2025)

In this study, the calorific value of the briquettes ranged from 5500 to 5900 cal/g, meeting the SNI 4931:2010 standard for bio-coal briquettes classified as Class A, the highest grade, which requires a calorific value between 5000 and 6000 cal/g. The lowest calorific value was produced by the briquette sample with 63% soybean residue and 27% sugarcane bagasse at mesh size 80, which was 5538.30 cal/g. The highest calorific value was produced by the briquette composition of 27% soybean residue and 63% sugarcane bagasse at a mesh size of 150. According to [22], proximate analysis is important to determine the characteristics of materials such as soybean residue, which has higher moisture, ash, and volatile matter contents compared to sugarcane bagasse, resulting in a lower calorific value. Meanwhile, smaller particle sizes, such as mesh 150, increase briquette density, allowing more optimal and uniform combustion, thereby producing higher energy output [23].

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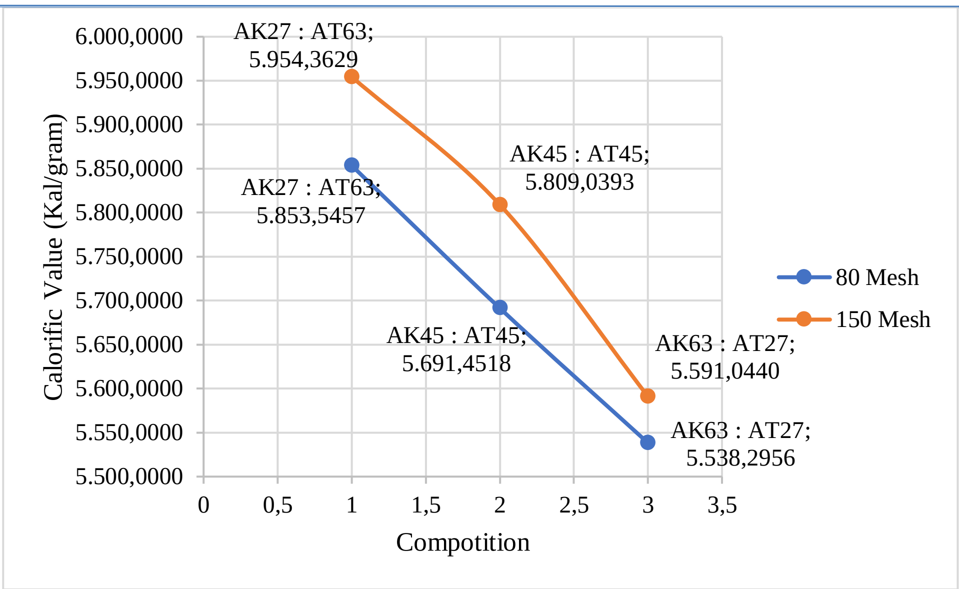


**Figure 4.** Graph of Calorific Value (%)
Source : Analysis results, (2025)

*3.5 CO Concentration*

Although the briquettes have a high calorific value, the combustion process has the potential to be incomplete. Therefore, an analysis of CO concentration produced during briquette combustion over 60 minutes was conducted. The analysis was carried out using a furnace equipped with a testo 350 gas analyzer sensor at the sampling port. The test was performed on briquettes with a composition of 27% soybean residue and 63% sugarcane bagasse at mesh size 150, as this composition yielded the best results in almost all tests except for volatile matter content, which exceeded the standard. The maximum allowable CO concentration in briquette combustion is regulated by the Ministry of Energy and Mineral Resources Regulation No. 47 of 2006 at 726 mg/Nm³, or equivalent to 633.67 ppm.

The analysis results showed that CO emissions during the first 40 minutes of combustion did not meet the established quality standards. However, as combustion progressed and the fuel amount decreased, the CO concentration dropped and complied with the standards. According to [24], high CO levels can be caused by uneven air distribution during combustion or insufficient oxygen supply in the combustion chamber. This is supported by research indicating that ash content can block briquette pores, making it difficult for released carbon to fully bond with oxygen [25]. Compared to the study conducted by [26], CO concentrations from class 1-4 wood briquettes were higher at the beginning of combustion, ranging from 2100 to 4200 ppm.

**Table 8**. Results of CO concentration analysis

| Parameter | | Unit |
|---|---|---|
| 10 minutes | 1287 | ppm |
| 20 minutes | 1018 | ppm |
| 30 minutes | 815 | ppm |
| 40 minutes | 651 | ppm |
| 50 minutes | 512 | ppm |
| 60 minutes | 396 | ppm |

Source : Analysis results, (2025)

## 4. Conclusion

The analysis results showed that the briquette composition with 27% soybean residue and 63% sugarcane bagasse at mesh size 150 produced briquettes with the following characteristics: moisture content of 4.1986%, ash content of 7.4591%, volatile matter content of 23.4873%, calorific value of 5954.3629 cal/g, and CO concentration ranging from 396 to 1218 ppm, which decreased over the combustion period. The volatile matter content parameter did not meet the SNI 4931:2010 standard, and the CO concentration exceeded the limit set by the Ministry of Energy and Mineral Resources Regulation No. 047 of 2006, with a maximum allowable CO level of 633.67 ppm. The briquette characteristics correspond to the initial characteristics of the raw materials, emphasizing the importance of raw material selection in improving biomass briquette energy quality.

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## 6. Abbreviations

| | |
|---|---|
| *ESDM* | Ministry of Energy and Mineral Resources of the Republic of Indonesia |
| *%* | Percentage |
| *CO* | reduce, reuse, and recycle |
| *AK* | Soybean dregs |
| *AT* | Sugarcane bagasse |

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