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Optimization of Binder Percentage in Organic Waste-Based Briquettes: Impact on Calorific Value and Combustion Rate

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Abstract

This research focuses on optimizing the binder percentage in organic waste-based briquettes to improve their calorific value and combustion rate. Conducted through experimental methods, organic waste such as sawdust, dry leaves, and branches were processed into briquettes using varying concentrations of tapioca starch as a binder (10%, 12.5%, 15%, and 17.5%). The experiment evaluated key performance metrics, including calorific value, combustion rate, moisture content, ash content, and briquette density. Results showed that the optimal calorific value (9,234 cal/g) was achieved with 10% binder, while the highest combustion rate (0.586 g/min) occurred at 15% binder concentration. These findings suggest that lower binder percentages result in higher energy efficiency, while higher binder content prolongs combustion. However, increased binder content also led to higher ash production, with the highest ash content recorded at 17.5% binder. The research highlights that balancing the binder ratio is essential for creating briquettes that are both energy-efficient and environmentally sustainable, offering a viable alternative to traditional fuels in Indonesia's pursuit of renewable energy solutions.

Keywords: Organic waste; Briquettes; Binder optimization; Calorific value; Combustion rate.

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INTRODUCTION

Indonesia faces a significant challenge in managing its large volume of organic waste, which includes materials like sawdust, dry leaves, and onion skins. With the global shift towards renewable energy and the growing recognition of the limitations of conventional fossil fuels, there has been increasing interest in finding sustainable alternatives for energy generation (Saptadi et al., 2023). Organic waste offers a unique opportunity due to its high availability and potential energy content, making it suitable for developing biofuel solutions, such as briquettes. These briquettes, made from compressed organic waste, present a promising solution to addressing both the rising demand for renewable energy and the persistent issue of waste management. A major focus of current research is to optimize the binder percentage in briquettes to improve their calorific value and combustion efficiency, thereby increasing their viability as an energy source. This research aims to investigate how varying binder levels affect the performance of briquettes and to determine the optimal binder composition for better fuel efficiency and usability.

The production of organic waste-based briquettes holds great promise for Indonesia, where the growing demand for renewable energy aligns with the need for better waste management. Utami & Ningsih (2021) highlighted that organic waste briquettes offer solid fuel quality comparable to coal, reinforcing their potential as a viable alternative in regions where coal remains dominant. However, moisture content in the organic material presents a significant challenge in briquette production. Moisture directly affects combustion efficiency and calorific value, meaning that the production process must be carefully managed to ensure optimal energy output while minimizing emissions. In this way, briquettes serve a dual purpose: they not only contribute to renewable energy generation but also provide a solution for reducing environmental waste. This research aims to address these production challenges by investigating the moisture content's role and proposing solutions to improve the briquette-making process.

The importance of renewable energy in Indonesia cannot be overstated, particularly as the country's fossil fuel resources, such as oil, are becoming increasingly limited. Organic waste briquettes offer a sustainable solution to this issue by providing a renewable energy source that can replace fossil fuels in various applications (Aljarwi et al., 2020). Several types of organic waste, including rice husks, corn cobs, and peanut shells, have been identified as potential feedstocks for briquette production (Jannah et al., 2022; Wijaya et al., 2023). These materials are widely available in rural areas, and their conversion into briquettes not only reduces waste but also provides a reliable energy source for communities. By utilizing local organic waste, briquette production supports both environmental sustainability and energy independence. This research seeks to explore the potential of these local resources in briquette production and to contribute to a circular economy by reducing waste and creating renewable energy.

Despite the potential benefits, one of the main challenges in producing organic briquettes is determining the optimal binder percentage. Binders are essential in improving the structural integrity of briquettes, ensuring that they hold together during combustion. Aljarwi et al. (2020) demonstrated that the calorific value of organic briquettes can range from 2509.50 cal to 5771.85 cal, while the combustion rate varies between 1.80 g/min and 2.62 g/min. Although these figures are promising, there is still room for improvement, particularly in optimizing the binder levels to achieve the highest possible fuel efficiency. Finding the right balance between binder percentage, calorific value, and combustion rate is key to enhancing the performance and scalability of organic briquettes as a fuel source. This study aims to contribute to this area by determining the best binder ratio to enhance both the durability and energy output of briquettes.

In rural regions like Pringgarata Village, organic waste is the most common form of refuse, often accumulating in large piles of untreated material. Priyadi et al. (2021) pointed out the potential for this waste, predominantly from trees and plants, to be repurposed as a biofuel, particularly in the form of briquettes. While this waste is usually left to decompose, it holds significant energy potential, especially when processed into briquettes that can be used for heating and cooking. Wood and branch waste, in particular, have high moisture content, around 13.75%, which necessitates careful drying and binder optimization to ensure efficient combustion (Santosa & Soemarno, 2014). By converting this organic material into briquettes, rural households and communities can gain access to a renewable and locally sourced energy supply, while also addressing the problem of unmanaged waste. This research will focus on optimizing the moisture and binder content to improve the combustion properties of briquettes, aiming to enhance their applicability in rural energy use.

This study focuses on investigating the impact of different binder percentages on the calorific value and combustion rate of organic waste-based briquettes.

Previous research suggests that current binder ratios are not yet fully optimized for achieving the best possible fuel efficiency. Therefore, the primary objective is to determine the optimal binder percentage that can reduce the combustion rate while increasing the calorific value. The focus will be on types of organic waste commonly found in Indonesia, with an emphasis on using locally sourced materials to ensure that the production process is economically viable and environmentally sustainable. This research aims to enhance the usability of briquettes for both household and industrial applications, contributing to Indonesia's renewable energy strategy. By fine-tuning the binder composition, the research intends to develop more efficient briquettes that can help meet the country's growing energy needs.

The composition of organic waste plays a crucial role in briquette production, particularly due to its high cellulose and lignin content. Maimunawaro et al. (2021) noted that organic waste contains approximately 50-60% cellulose and 5% lignin, both of which are essential for forming a solid briquette. Lignin acts as a natural binder during the production process, while cellulose contributes to the energy content of the briquettes. These components make organic waste an ideal material for biofuel production, as they enhance both the structural integrity and the calorific value of the briquettes. The key challenge lies in optimizing the binder percentage to further improve the efficiency of the briquettes. The study's contribution will involve analyzing the interaction between lignin content, cellulose, and binder, aiming to maximize both the mechanical strength and energy output of the briquettes.

Given Indonesia's significant production of organic waste and the rising demand for renewable energy, the development of organic waste-based briquettes is particularly timely. By optimizing the binder percentage in the production process, this research seeks to improve the calorific value and combustion efficiency of the briquettes, making them more viable for widespread use. Through detailed analysis of organic waste composition, moisture content, and binder optimization, the study aims to develop a briquette that can serve as a reliable and environmentally friendly fuel alternative. In doing so, it supports Indonesia's broader goal of transitioning to a more sustainable energy future, while addressing the environmental challenges posed by unmanaged organic waste. The research will contribute to the understanding of how to improve organic waste management and energy production at the local level, supporting both environmental sustainability and energy security.

The global reliance on fossil fuels remains a pressing issue, despite the growing urgency for renewable alternatives. In rural areas, the development of alternative energy sources like biomass is particularly crucial for addressing energy poverty and promoting sustainability. Biomass, especially organic waste, offers a renewable and sustainable source of fuel, which can be transformed into briquettes through processes like carbonization and compression. The production of briquettes not only provides an effective means of managing waste but also represents a step toward creating a cleaner, more sustainable energy future for communities (Surabaya, 2016). This dual benefit makes briquette production a key focus for renewable energy development in Indonesia. This research's contribution lies in demonstrating how organic waste briquettes can simultaneously address local waste issues and provide a sustainable energy source.

Energy generation, in its simplest form, relies on the combustion process, where fuel is burned to release heat energy. This process, known as the fire triangle, involves the interaction of fuel, oxygen, and heat (Sarifuddin et al., 2017). Briquettes are no exception to this principle, and their energy efficiency depends on the optimization of fuel composition. Binder optimization is particularly important because it directly affects how efficiently the briquettes burn. By fine-tuning the binder percentage, the calorific value and combustion rate of briquettes can be improved, making them a more viable and efficient renewable energy source for both domestic and industrial use. This research aims to contribute by proposing practical binder ratios that enhance briquette performance while ensuring minimal environmental impact.

Biomass, including organic waste, plays a vital role in the production of renewable fuels. As a renewable resource, biomass can be converted into energy through various processes, including combustion. Biomass briquettes, produced from agricultural residues and organic waste, offer a low-sulfur, low-emission fuel alternative, making them an environmentally friendly option (Samsinar et al., 2016). While biomass combustion does release carbon dioxide, it is part of the natural carbon cycle, making it a more sustainable energy source compared to fossil fuels. The production of biomass briquettes from organic waste not only reduces waste but also provides a renewable energy source for rural areas, contributing to energy security and sustainability. This research contributes by exploring how Indonesia can make better use of organic waste through energy-efficient briquette production, promoting a shift toward renewable energy.

In conclusion, Indonesia's dependence on fossil fuels has long driven its energy sector, but the limitations of these resources, coupled with the global demand for renewable energy, highlight the need for sustainable alternatives. Organic waste-based briquettes offer a promising solution by transforming waste materials into a renewable energy source. The challenge lies in optimizing the binder percentage in the briquette production process to enhance both calorific value and combustion efficiency, making the briquettes more suitable for widespread use. By addressing this challenge, this research contributes to Indonesia's efforts to develop efficient and sustainable energy solutions for the future. Through the utilization of organic waste and improved production methods, briquettes have the potential to become an important component of Indonesia's renewable energy landscape, supporting both waste management and energy generation initiatives. The research objectives include determining the optimal binder composition for improving briquette efficiency and contributing to Indonesia's transition towards renewable energy sources while addressing critical environmental and energy challenges.

Study objectives, hypothesis, and novelty

The main objective of this research is to optimize the binder percentage in briquettes made from organic waste to achieve both an improved calorific value and a suitable combustion rate. Organic waste, which is widely available in Indonesia, presents a sustainable resource for biofuel production. However, achieving an efficient energy output from these briquettes depends heavily on the appropriate combination of raw materials and binders. As such, this research focuses on adjusting the binder ratio to enhance the energy characteristics of the briquettes, specifically targeting an optimal calorific value and a slower, more controlled combustion rate.

The hypothesis underlying this study is that a precise binder percentage can significantly improve the quality of organic waste-based briquettes by enhancing their calorific value and controlling their combustion rate. It is expected that adjusting the binder ratio will not only improve the structural integrity of the briquettes but also reduce their combustion speed, leading to increased energy efficiency. This adjustment aims to offer a practical solution for both households and industries that require longer-lasting, more efficient biofuel alternatives. The novelty of the study lies in its focus on optimizing binder levels to specifically address the challenge of high combustion rates, a problem that has not been extensively explored in previous research.

To achieve the primary goal of the study, the specific objectives include investigating the effects of varying binder percentages on the calorific value of organic waste briquettes, analyzing how different binder ratios impact the combustion rate, and determining the optimal binder percentage that balances both calorific value and combustion rate to achieve the most efficient energy output. These objectives aim to enhance the practicality and efficiency of organic waste briquettes as a renewable energy source.

The expected outcomes of this study include the identification of an ideal binder-to-waste ratio that maximizes calorific value while minimizing the combustion rate. The optimization of this ratio is crucial in developing a biofuel product that not only reduces waste but also meets the energy demands of households and small-scale industries in an environmentally sustainable manner.

METHOD

Type of research

The research utilized an experimental design, conducted in a controlled laboratory setting at Universitas Pendidikan Mandalika (Undikma), specifically in the Physics Laboratory. This experimental approach was chosen to precisely evaluate how different binder percentages affect the performance of organic waste-based briquettes. The study focused on varying the concentration of tapioca starch, used as a binder, to observe its influence on the calorific value and combustion rate of the briquettes. Initially, organic waste such as dry leaves, sawdust, and small branches were collected locally, sun-dried for moisture reduction, and carbonized into charcoal by heating them over a high flame. The carbonized material was then ground into fine particles to ensure uniformity in the briquette properties.

In the next stage, the carbonized waste was combined with different proportions of tapioca starch binder (10%, 12.5%, 15%, and 17.5% of the total volume). The starch was mixed with water and heated until it formed a homogeneous paste, which was then blended with the carbonized material. The mixture was pressed into 3x3 cm cube molds using a manual briquette press and left to sun-dry for several days to achieve the required hardness. Following this, performance tests were conducted, including calorific value measurement with a calorimeter, combustion rate analysis, and assessments of moisture content, ash content, and briquette density. The data were analyzed to compare the effects of different binder concentrations on the briquettes, helping to determine the optimal composition for efficient combustion and high energy output. This research design enabled a detailed evaluation of binder concentration on biofuel production from organic waste.

Research location and duration

The research will be conducted from October 2023 to April 2024 at the Physics Laboratory of FSTT UNDIKMA.

Research instrumen

The research instruments used in this study were carefully selected to support the production, testing, and analysis of organic waste-based briquettes. These instruments played a critical role in measuring the physical and combustion properties of the briquettes, ensuring that data collection throughout the experiment was precise and reliable. To produce the briquettes, a manual briquette press was used to compress the mixture of carbonized organic waste and tapioca binder into uniformly shaped cubes, each with dimensions of 3x3 cm. This standardized shape ensured consistency in the burning properties of the briquettes. The calorific value of the briquettes was measured using a calorimeter, which provided accurate data on the heat energy released during combustion, helping to assess the fuel efficiency of different briquette compositions. Additional tools like thermometers and stopwatches were used to measure temperature changes and combustion rates, respectively, while a scale ensured accurate weighing of materials.

Other supporting instruments included an ayakan (sieve) for obtaining uniform particle sizes, a measuring cup for precise water measurement in binder preparation, and mortar and pestle for grinding carbonized materials into finer particles. For material handling during preparation and carbonization, buckets and pans were utilized. A digital balance ensured high-accuracy measurements, particularly for post-combustion residues and ash. Together, these instruments enabled a controlled and precise experimental process, yielding reliable data on the optimal binder percentage for producing efficient, high-calorific briquettes.

Data collection techniques

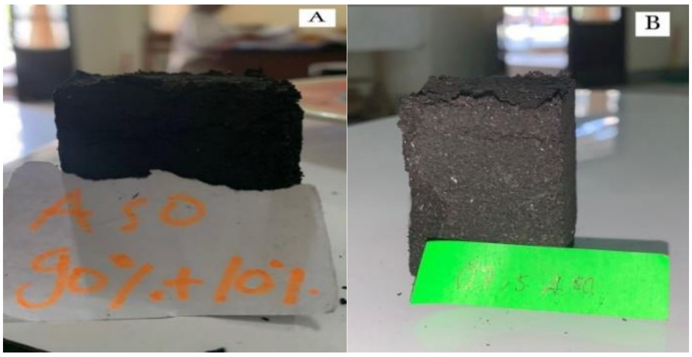
The data collection for this research focused on evaluating the physical and thermal properties of organic waste-based briquettes produced with varying binder percentages. The primary data collected were related to calorific value, combustion rate, moisture content, ash content, and briquette density. To measure the calorific value, a calorimeter was used to record the heat energy released when each briquette was burned. The combustion rate was observed by timing how long it took for the briquettes to burn completely from ignition until the fire extinguished. Additionally, moisture content was measured by weighing the briquettes before and after drying them under sunlight to assess the water retained within the briquettes. Ash content was evaluated by burning the briquettes fully and then weighing the residual ash. Finally, the density of each briquette was determined by measuring the mass and volume of the briquettes to assess the compactness, which influences both calorific value and combustion efficiency. Data were recorded systematically for all variations of binder percentages to allow for comparative analysis.

Data analysis techniques

The analysis of the collected data was centered on understanding how the binder percentage influenced the performance of the briquettes in terms of their energy output, burning efficiency, and physical stability. Calorific value data were analyzed by comparing the heat energy generated by each briquette variant to identify the most energy-efficient formulation. Combustion rate data were assessed to determine how quickly each briquette burned, with lower combustion rates indicating better fuel efficiency. Moisture content was analyzed to evaluate its impact on the ease of ignition and combustion quality, while ash content was reviewed to understand the non-combustible residue, which affects the fuel's cleanliness and efficiency. Lastly, density measurements were analyzed to correlate the compactness of the briquettes with their burning performance. The results from each set of tests were compared across the different binder concentrations to identify the optimal binder ratio that produced the best balance of calorific value, combustion rate, and overall fuel efficiency.

RESULTS AND DISCUSSION

Organic waste is one of the biomass materials that can be used to produce bio-briquettes. The process of making organic waste bio-briquettes involves several stages. Stage I is the preparation of materials, which includes the collection and drying of organic waste. The drying process is carried out for one day to reduce the moisture content in the waste. Stage II involves the carbonization process, where the dried organic waste is roasted until it turns black and becomes charcoal. After that, the charcoal is crushed into fine particles. Stage III is the production of a binder made from tapioca flour (starch). In this stage, tapioca starch is mixed with water until it becomes a homogeneous mixture, then heated over medium heat until it thickens and forms a glue-like substance. Stage IV is the molding of bio-briquettes. The mixed materials are pressed into block-shaped molds using a manual press. Afterward, the briquettes are sun-dried. The results of the organic waste bio-briquettes production can be seen in Figure 1.



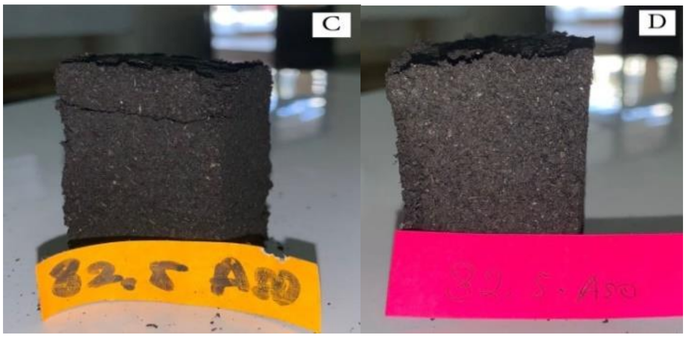


Figure 1. Briquettes made from ASO materials with compositions: A. 90%+10%, B. 87.5%+12.5%, C. 85%+15%, D. 82.5%+17.5%.

Briquette density analysis

Density (P) refers to the compactness or density of a bio-briquette, expressed in mass per unit volume. The results of the density analysis of the bio-briquettes are presented in Table 1 and Figure 2.

Table 1. ASO Briquette Density Values

Samples	Composition percentages	Density (g/cm³)
A	90%ASO+10%PTT	0,437
B	87,5%ASO+12,5%PTT	0,461
C	85%ASO+15%PTT	0,500
D	82,5%ASO+17,5%PTT	0,381

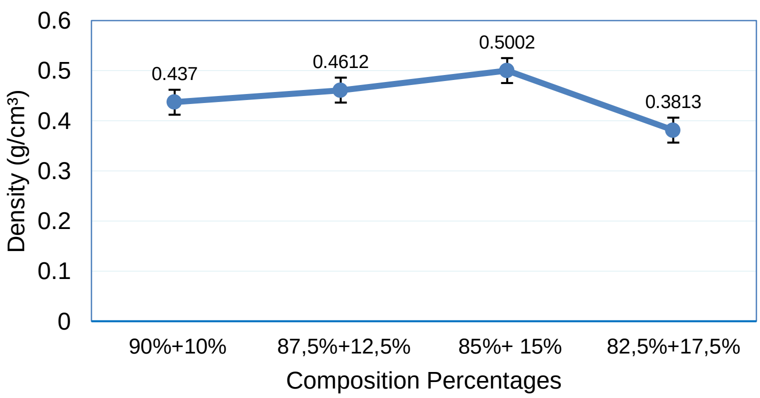


Figure 2. ASO Briquette Density Graph: A (90+10), B (87.5+12.5), C (85+15), D (82.5+17.5)

Based on Table 1 and Figure 2, it can be observed that the composition percentages have different effects on the briquette density. The density values range from 0.381 g/cm³ to 0.500 g/cm³. The highest density is achieved with sample C (85% organic waste and 15% binder) at 0.500 g/cm³, while the lowest density is with sample D at 0.381 g/cm³. Although there is no established standard for assessing briquette quality based on density, this study shows that the composition of the organic waste affects the density inconsistently. According to research by Naim et al. (2013), denser briquettes tend to have longer combustion times, meaning density plays a significant role in determining the combustion rate.

Moisture content analysis

Moisture content significantly influences the quality of briquettes. It is preferable for the moisture content to be as low as possible to increase the calorific value. There is an inverse relationship between moisture content and calorific value: the higher the moisture content, the lower the calorific value and the harder it is to ignite the briquette. This is because some of the heat generated during combustion is used to evaporate the water in the briquette. The drying process of bio-briquettes aims to reduce moisture content. The results of the moisture content analysis are presented in Table 2 and Figure 3.

Table 2. ASO Briquette Moisture Content Test

Samples	Composition percentages	Moisture Content (%)
A	90%ASO+10%PTT	4,647
B	87,5%ASO+12,5%PTT	4,259
C	85%ASO+15%PTT	4,211
D	82,5%ASO+17,5%PTT	4,922

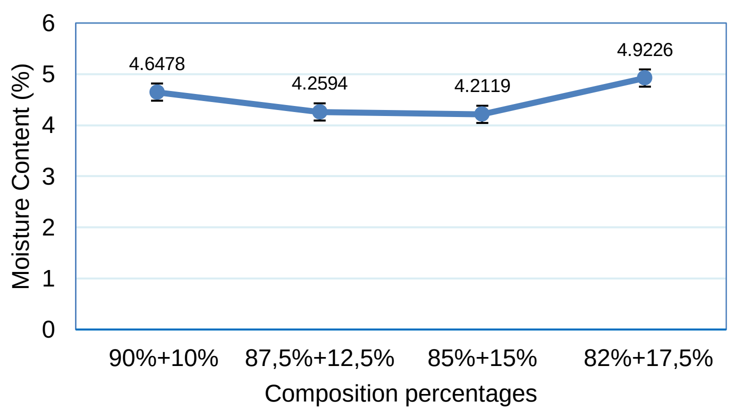


Figure 3. ASO Briquette Moisture Content Graph: A (90+10), B (87.5+12.5), C (85+15), D (82.5+17.5)

As shown in Table 2 and Figure 3, the highest moisture content is found in sample D, with 82.5% organic waste and 17.5% tapioca binder, at 4.922%. The lowest moisture content is in sample C, with 85% organic waste and 15% binder, at 4.211%. The differences in moisture content between the samples can be attributed to the amount of water retained in the briquettes during the drying process. According to Widodo (2016), briquettes with moisture content below the standard of ≤8%, as set by the Indonesian National Standard (SNI 01-6235-2000), are acceptable. The research aligns with Triasmoro et al. (2020), who found that tapioca starch as a binder results in moisture content ranging from 9.399% to 10.634%, which exceeds the SNI standard. Therefore, achieving low moisture content is crucial to improving the calorific value of briquettes.

Ash content analysis

High ash content in briquettes can reduce their quality, as it leads to lower calorific value and can form clinkers that make ignition difficult. The results of the ash content analysis are shown in Table 3 and Figure 4.

Table 3. ASO Briquette Ash Content

Samples	Composition percentages	Ash content (%)
A	90%ASO+10%PTT	7,774
B	87,5%ASO+12,5%PTT	7,185
C	85%ASO+15%PTT	8,362
D	82,5%ASO+17,5PTT	10,741

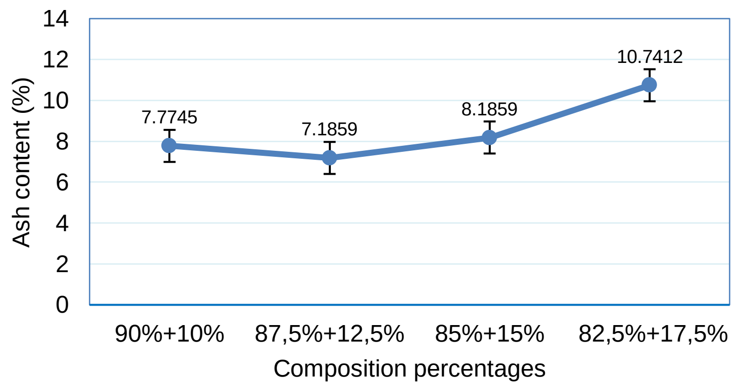


Figure 4. ASO Briquette Ash Content Graph: A (90+10), B (87.5+12.5), C (85+15), D (82.5+17.5)

As depicted in Table 3 and Figure 4, the highest ash content is found in sample D, while the lowest is in sample B. According to Mulyanto (2023), high ash content can be detrimental to briquette quality, as it reduces calorific value and creates clinkers during combustion. The results from this study show that the ash content of the briquettes generally exceeds the maximum SNI standard of 8%, indicating the need for further optimization.

Calorific value analysis

Calorific value represents the maximum heat energy released by a fuel during combustion and is a key parameter in assessing briquette quality. The results of the calorific value analysis are presented in Table 4 and Figure 5.

Table 4. ASO Briquette Calorific Value

Samples	Composition percentages	Calorific value (cal)
A	90%ASO+10%PTT	9.234
B	87,5%ASO+12,5%PTT	7.829
C	85%ASO + 15%PTT	5.420
D	82,5%ASO+17,5%PTT	7.428

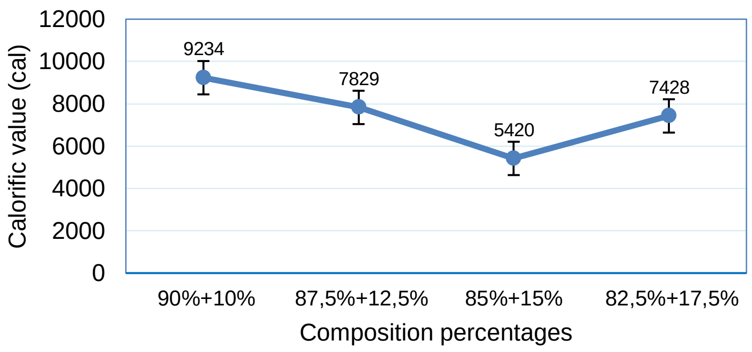


Figure 5. ASO Briquette Calorific Value Graph: A (90+10), B (87.5+12.5), C (85+15), D (82.5+17.5)

The highest calorific value was found in sample A (90% organic waste and 10% binder), at 9,234 calories, indicating that this composition is the most efficient for energy production. As the binder percentage increases, the calorific value decreases, suggesting that higher binder content reduces the overall energy output. These findings are in line with Sulistyaningkarti & Utami (2017), who concluded that lower binder percentages tend to result in higher calorific values, making the briquettes more energy-efficient. The study by Mahendra & Praswanto (2022) also confirms that the combination of organic waste and wood powder affects calorific values, where lower moisture and binder content improve fuel efficiency.

Combustion rate analysis

The combustion rate measures how quickly a briquette burns. A higher combustion rate means the briquette burns more rapidly. The results of the combustion rate analysis are shown in Table 5 and Figure 6.

Table 5. ASO Briquette Combustion Rate

Samples	Composition percentages	Combustion rate (gr/min)
A	90%AS0+10%PTT	0,542
B	87,5%ASO+12,5%PTT	0,566
C	85%ASO + 15%PTT	0,586
D	82,5%ASO+17,5%PTT	0,525

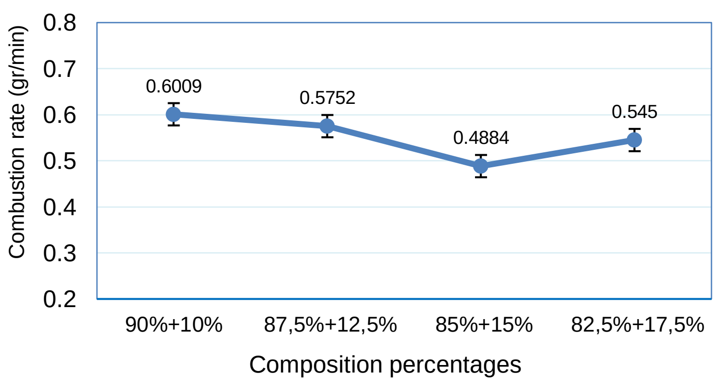


Figure 6. ASO Briquette Combustion Rate Graph: A (90+10), B (87.5+12.5), C (85+15), D (82.5+17.5)

According to the results, sample C (85% organic waste and 15% binder) exhibited the highest combustion rate, while sample D had the lowest. This indicates that a higher binder percentage tends to slow down the combustion rate, resulting in a longer burn time, which is beneficial for applications that require sustained heat (Irbah et al., 2022). An ideal briquette has a slow combustion rate with high calorific value, ensuring it burns efficiently while producing significant energy.

CONCLUSION

The findings of this research highlight the potential of organic waste-based briquettes as a renewable and sustainable energy source, particularly in regions like Indonesia where organic waste is abundant. The study demonstrated that the binder percentage plays a critical role in determining the performance of the briquettes, especially regarding calorific value and combustion rate. Among the tested formulations, a binder percentage of 10% resulted in the highest calorific value, making it the most energy-efficient option. Meanwhile, higher binder percentages contributed to slower combustion rates, which could extend the burn time of the briquettes, but they also reduced the calorific value. These results suggest that a balanced binder-to-organic waste ratio is necessary to optimize the fuel efficiency of the briquettes for both household and industrial use. Additionally, the research underscores the importance of controlling moisture content and ash production in the briquette-making process. While the moisture content remained within acceptable limits, the ash content for most samples exceeded the maximum standards set by the Indonesian National Standard (SNI). This indicates that further refinements in the drying and binder processes are needed to enhance briquette quality. Overall, the study contributes valuable insights into how organic waste can be effectively transformed into bio-briquettes, offering a practical solution for both waste management and renewable energy generation. Through optimizing the binder percentage, this research helps pave the way for more efficient, sustainable energy solutions that could alleviate Indonesia's dependence on fossil fuels.

RECOMMENDATION

This research recommends using a 10% tapioca starch binder in organic waste briquettes to achieve the highest calorific value and energy efficiency, as lower binder content maintains energy output without compromising structural integrity. Future studies should explore alternative binder materials that could enhance performance and reduce costs, while improving moisture control during production is essential to optimize both calorific value and combustion efficiency. The production of organic waste briquettes should be promoted in rural areas as a sustainable fuel alternative, with local governments supporting the establishment of briquette production facilities using available organic waste. Additionally, efforts should be made to reduce ash content and emissions during combustion to minimize environmental impact and comply with regulatory standards.

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