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Characterization of Gelam Wood Pellets: Effects of Compaction Pressure and Binder Type As Engine Fuel

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***Abstract*—** Wood pellets are a renewable energy source produced through biomass densification to enhance energy efficiency and handling properties. This study aims to evaluate the effect of binder type and compaction pressure on the physical and combustion characteristics of Gelam wood pellets. An experimental method was applied using Gelam wood with binder variations of molasses (C1), palm sugar (C2), and without binder (C3), under compaction pressures of 40, 60, and 80 kg/cm². The pellets were tested for moisture content, ash content, volatile matter, calorific value, ignition time, combustion temperature, and burning rate. The results show that C3 exhibits the lowest moisture content (11.61%) and low ash content (1.24%), while C1 shows the lowest ash content (0.06%). The highest calorific value was obtained in C2 (3999.65 cal/g), followed by C1 (3996.17 cal/g), whereas C3 showed a lower value (3912.56 cal/g). Volatile matter increased from 84.41% (C1) to 90.94% (C3), indicating improved ignition reactivity. Ignition time increased with compaction pressure, reaching up to 34 s (C3, 80 kg/cm²). Combustion temperature was highest in C1 at 180 °C, while the burning rate decreased from 0.02273 g/s to 0.01433 g/s with increasing pressure. Overall, molasses binder provides the best combustion performance. These findings confirm that binder type and compaction pressure significantly influence pellet quality and energy performance.

Keywords— Gelam wood pellets, Binder type, Compaction pressures, Physical characteristics, Combustion characteristics.

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I. INTRODUCTION

Wood pellets are a mechanical densification technology that increases biomass density, thereby improving energy efficiency and handling characteristics [1]. Their production involves pre-treatment, drying, size reduction, pelletizing, cooling, and final drying stages [2]. Wood pellets are widely used for residential and industrial energy applications, including power generation systems, due to their relatively high calorific value and potential to substitute fossil fuels [3–5]. The renewable nature of biomass further strengthens its role as a sustainable energy source [6].

Gelam wood, which grows abundantly in the peat swamp forests of South Kalimantan, represents a promising local biomass resource due to its relatively high density and rapid growth rate (1–1.5 cm/year) [7,8]. Despite this potential, its utilization as a feedstock for pellet production remains underexplored compared to conventional biomass materials.

Previous studies have demonstrated that binder type, particle size, and processing conditions significantly influence pellet properties, including calorific value, moisture content, and combustion behavior [9–16]. However, most studies focus on commonly used binders (e.g., starch-based adhesives) and do not consider locally available natural binders such as molasses and palm sugar. Moreover, existing research typically evaluates individual parameters rather than systematically analyzing the combined effects of binder type and compaction pressure on both physical and combustion characteristics.

As a result, a critical research gap remains in understanding how the interaction between binder composition and compaction pressure governs the overall performance of gelam wood pellets. This limitation contributes to the inability of current gelam-based pellets to achieve energy characteristics comparable to coal.

Therefore, this study aims to investigate the combined effect of binder type (molasses and palm sugar) and compaction pressure on the physical and combustion properties of gelam wood pellets. The novelty of this work lies in the integrated evaluation of local biomass with natural binders under controlled processing conditions, providing new insights into optimizing pellet quality and enhancing its potential as a renewable energy source.

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Figure 1. Gelam Wood

II. METHOD

To produce gelam wood pellets, the following steps must be carried out.

A. Material Preparation

The preparation of materials to be used in this research is as follows:

1. Gelam wood was obtained from Banjarbaru City.
2. The wood was chopped using a chopper into fine particles.
3. The gelam wood powder was subsequently oven-dried at 100–120 °C for 1 hour to further reduce its moisture content.
4. After drying, the powder was sieved using an MBT sieve shaker with a 40-mesh sieve to obtain a uniform particle size distribution.

B. Preparation of Palm Sugar and Molasses Binder

Palm sugar was heated with water at a ratio of 20 g of palm sugar to 20 mL of water and stirred for 5 minutes until a homogeneous solution was obtained. The prepared solution was then used as a binder. Molasses, being in liquid form, was used directly without further preparation. In this study, 5 g of binder was added to every 100 g of wood pellet mixture.

C. *Mixing of Wood Pellet Components*

1. Gelam wood powder and binder were weighed using a digital balance according to the binder variations.
2. The mixture was then blended to ensure homogeneity. The binder variations used in this study included no binder, palm sugar binder, and molasses binder.

D. *Pelletizing Process*

The mixture of gelam wood powder and binder was molded using a cylindrical die. The pelletizing process was carried out under compaction pressures of 40, 60, and 80 kg/cm², with a pressing time of 1 minute for each variation.

E. *Pellet Drying*

The molded pellets were oven-dried at 100–120 °C for 1 hour to reduce moisture content, particularly that originating from the palm sugar and molasses binders.

Figure 2. Gelam Wood *Pellets*

F. *Pellet Testing*

The dried pellets were subjected to physical and combustion property tests. The physical properties included moisture content, ash content, volatile matter, and calorific value. The combustion characteristics included ignition time, flash point, ignition delay time, burning rate, flame height, and flame temperature.

Physical property tests were conducted at the Balai Standardisasi dan Pelayanan Jasa Industri (BSPJI) Banjarbaru Laboratory, while combustion tests were performed at the Internal Combustion Engine Laboratory, Department of Mechanical Engineering, Universitas Lambung Mangkurat.

III. RESULTS AND DISCUSSION

The data obtained from the physical and combustion characteristic tests of gelam wood pellets were processed into graphical form and subsequently analyzed. For clarity and consistency throughout this study, the samples are designated as follows: C1 (95% gelam wood + 5% molasses), C2 (95% gelam wood + 5% palm sugar), and C3 (100% gelam wood without adhesive).

A. Moisture Content

The moisture content of the gelam wood pellets in this study is as shown in Figure 3.

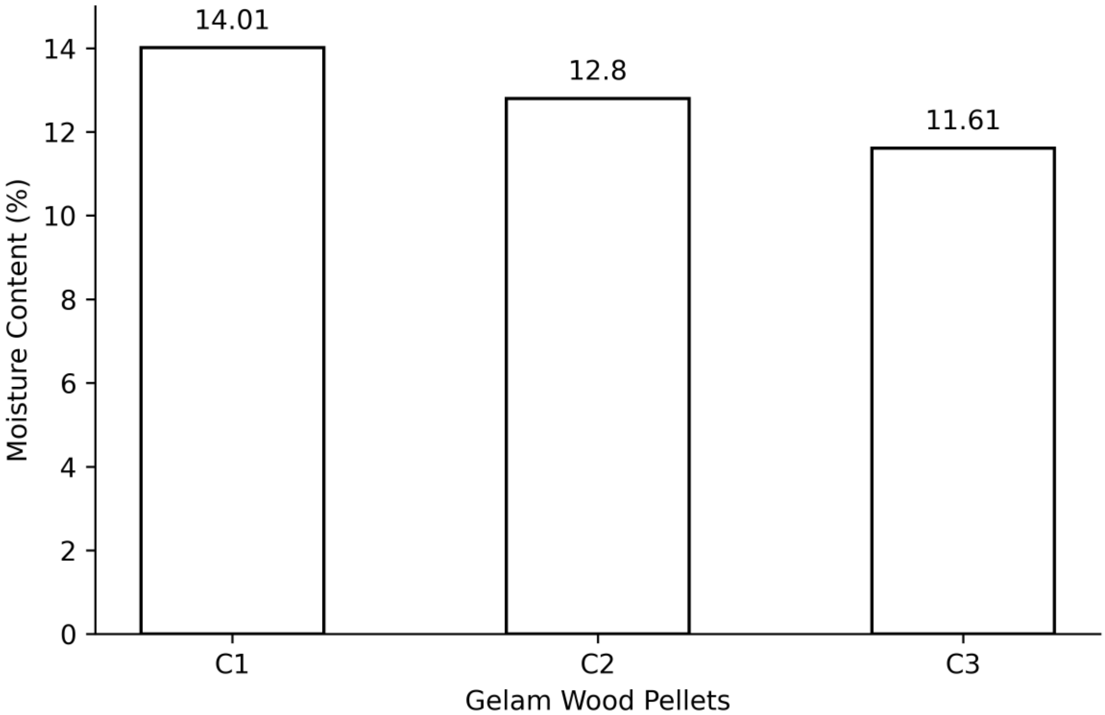

Figure 3. Moisture Content Of Gelam Wood Pellets.

The results of the moisture content analysis of gelam wood pellets are presented in Figure 3. It can be observed that the moisture content decreases with the variation of binders in samples C1, C2, and C3. The moisture content of C1 was recorded at 14.2%, which decreased to 12.8% in C2 and reached the lowest value of 11.7% in C3. This reduction indicates that the binder variation has a significant influence on the moisture content of gelam wood pellets.

Moisture content is a critical parameter in determining the quality of wood pellets. High moisture content reduces combustion efficiency, as a considerable portion of the energy is consumed to evaporate water before combustion can occur [17]. In contrast, low moisture content enhances the calorific value, accelerates ignition, and promotes cleaner combustion [18]. According to international standards such as ENplus A1, the acceptable moisture content for high-quality wood pellets is a maximum of 10–12% [19]. Therefore, the results of this study indicate that the gelam wood pellets in sample C3 are close to meeting international quality standards, while C1 and C2 remain slightly above the optimal range.

The decrease in moisture content from C1 to C3 may be attributed to improved processing conditions, such as higher drying temperatures, more optimal compaction pressure, and a more uniform particle size distribution [20]. These factors facilitate the removal of both free and bound water from the biomass, resulting in pellets with improved stability. Low moisture content also contributes significantly to higher energy density and better storage stability of the pellets [21].

Overall, the observed decreasing trend in moisture content highlights the importance of process optimization in producing gelam wood pellets that meet renewable energy quality standards and support their application as an environmentally friendly alternative fuel.

B. Ash Content

The ash content of the gelam wood pellets in this study is shown in Figure 4.

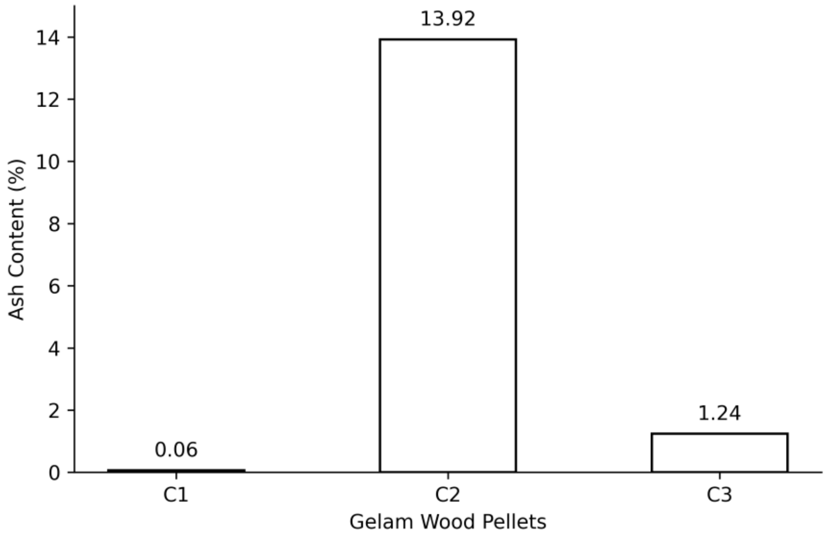

Figure 4. Ash Content Of Gelam Wood Pellets.

The results of the ash content analysis of gelam wood pellets are presented in Figure 4. The ash content exhibits significant fluctuations across the different treatments. In sample C1, the ash content is very low at approximately 0.06%, followed by a sharp increase in C2 to 13.92%, and then a substantial decrease in C3 to around 1.24%.

Ash content is an important parameter in evaluating pellet quality, as it represents the amount of inorganic residue remaining after combustion [22]. The high ash content observed in C2 may be attributed to the influence of processing conditions, particularly drying and compaction, which can affect the distribution and retention of inorganic compounds within the pellets [21].

From a technical perspective, high ash content negatively impacts combustion performance. Pellets with high ash content tend to produce more solid residues, which can lead to slagging and fouling in combustion systems, reduce thermal efficiency, and accelerate equipment degradation [23]. In contrast, low ash content, as observed in C1 and C3, is more desirable because it results in cleaner combustion and higher calorific value. When compared to the ENplus A1 standard, which specifies a maximum ash content of 1.5% for high-quality pellets [19], only samples C1 and C3 meet the required criteria, whereas C2 significantly exceeds the permissible limit.

C. *Volatile Matter Content*

The volatile matter content of the gelam wood pellets in this study is shown in Figure 5.

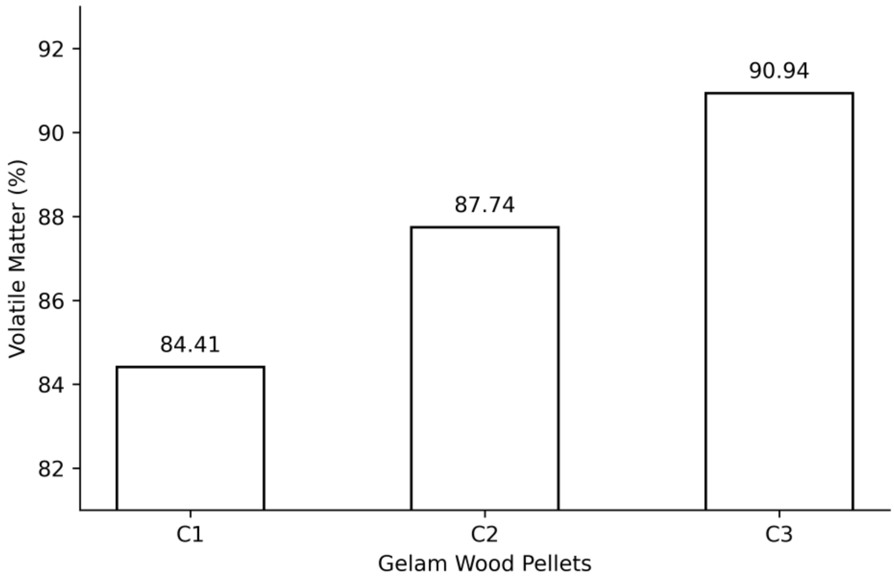

Figure 5. Volatile Matter Content Of Gelam Wood Pellets.

Figure 5 presents the volatile matter content of gelam wood pellets for samples C1, C2, and C3. The results indicate a gradual increase, with C1 recorded at 84.41%, rising to 87.74% in C2, and reaching the highest value of 91.94% in C3.

Volatile matter represents the fraction of organic compounds that readily vaporize during combustion, and it plays a crucial role in determining the thermal behavior of pellets [24]. A high volatile matter content generally indicates a greater proportion of easily combustible organic components, such as cellulose, hemicellulose, and lignin, resulting in faster ignition and enhanced combustibility [25]. This is evident in sample C3, which exhibits the highest volatile matter content and is therefore expected to ignite more rapidly and exhibit more reactive combustion behavior.

However, excessively high volatile matter content may lead to a rapid combustion rate, resulting in a shorter burning duration [26]. In certain applications, such as industrial furnaces, this can reduce combustion stability. Therefore, maintaining a balance between volatile matter, moisture content, ash content, and calorific value is essential for evaluating the overall quality of gelam wood pellets.

Compared to typical biomass materials, the volatile matter content of gelam wood pellets is relatively high, as most biomass generally contains volatile matter in the range of 70–85%. This elevated volatile content indicates strong energy potential, although proper control of the combustion rate remains necessary to ensure suitability for specific applications.

D. Calorific Value

The calorific value of gelam wood pellets in this study is shown in Figure 6.

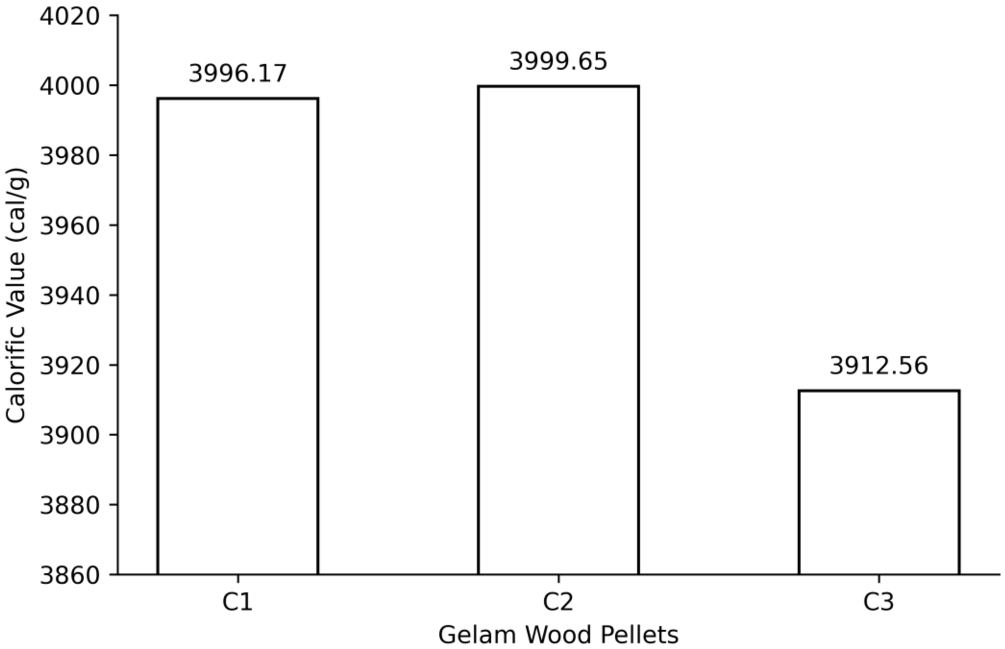

Figure 6. Calorific Value of Gelam Wood Pellets.

Figure 6 presents the calorific value (cal/g) of gelam wood pellets for samples C1, C2, and C3. The results indicate that the calorific value of C1 is approximately 3996.17 cal/g, slightly increases in C2 to about 3999.65 cal/g, and then decreases significantly in C3 to around 3912.56 cal/g.

Calorific value is a key parameter in determining the quality of pellets as a solid fuel, as it directly reflects the amount of heat energy released during combustion [24]. A higher calorific value generally indicates a greater proportion of combustible organic matter, along with relatively low moisture and ash contents [27]. This condition is observed in samples C1 and C2, which maintain calorific values close to 4000 cal/g. In contrast, the decrease observed in C3 may be associated with changes in ash content (see Figure 10) as well as a reduction in energy density due to the absence of binder in the composition.

According to the Indonesian National Standard (SNI 8021-2014) for biomass briquettes, the recommended minimum calorific value for solid biomass fuels is 4000 cal/g [28]. Therefore, the calorific values of gelam wood pellets in samples C1, C2, and C3 are slightly below the recommended threshold. This finding suggests that production conditions play a significant role in determining the resulting energy quality. Optimization of drying processes, careful selection of raw materials, and control of ash content are essential factors in achieving higher calorific values.

Overall, these results indicate that gelam wood pellets have considerable potential as a renewable energy source; however, further process optimization is required to ensure consistent quality in accordance with established biomass energy standards.

E. Ignition Time

The ignition time of gelam wood pellets in this study is presented in Figure 7.

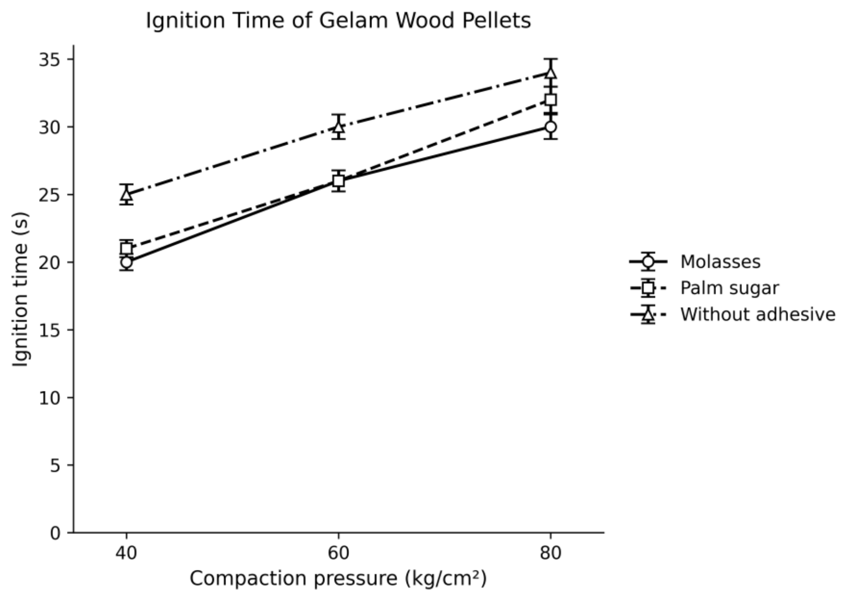

Figure 7. Ignition Time Of Gelam Wood Pellets.

Pellets without adhesive exhibited longer ignition times at all compaction pressures. At 40 kg/cm², the ignition time was 25 s, increasing to 34 s at 80 kg/cm². This longer ignition time can be attributed to the absence of components that facilitate the initiation of combustion, resulting in a delayed attainment of the ignition point.

Pellets with palm sugar as a binder showed shorter ignition times compared to those without adhesive. At 40 kg/cm², the ignition time was 21 s, increasing to 32 s at 80 kg/cm². Palm sugar, as a natural binder, enhances combustion due to its carbohydrate content, which decomposes readily at relatively low temperatures and promotes faster ignition [29].

Similarly, pellets with molasses exhibited even shorter ignition times than those with palm sugar. At 40 kg/cm², the ignition time was 20 s, increasing to 30 s at 80 kg/cm². Molasses contains a higher proportion of simple sugars that decompose more rapidly during combustion [30], resulting in a more pronounced effect in accelerating the ignition process.

Overall, the presence of binders, such as molasses and palm sugar, reduces ignition time compared to pellets without adhesive. These binders contribute to a more controlled and efficient combustion initiation, enabling faster ignition at higher compaction pressures. In contrast, pellets without adhesive exhibit longer ignition times, likely due to lower structural uniformity and density, which hinder heat transfer and ignition. Additionally, increasing compaction pressure produces denser pellets, which require more time to ignite. This trend is observed for all pellet types, although it is more pronounced in pellets without adhesive.

F. Flash Point

The flash point of gelam wood pellets in this study is presented in Figure 8.

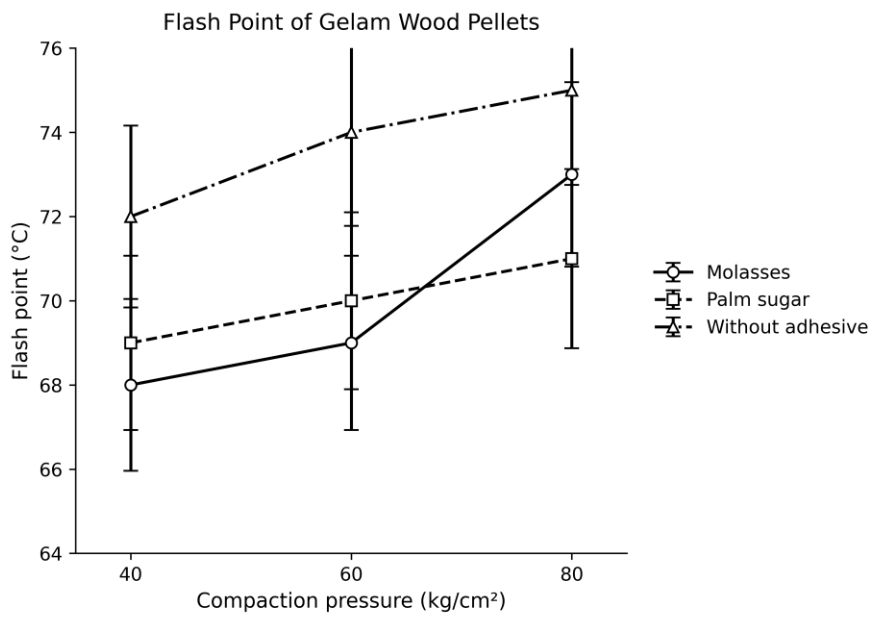

Figure 8. Flash Point Of Gelam Wood Pellets.

As shown in Figure 8, the flash point of pellets with molasses binder increases with increasing compaction pressure. The flash point rises from 68 °C at 40 kg/cm² to 72 °C at 80 kg/cm², indicating that higher compaction pressure results in higher ignition temperature thresholds.

Similarly, pellets produced with palm sugar binder also exhibit an increasing trend in flash point with increasing pressure. The flash point increases from 69 °C at 40 kg/cm² to 71 °C at 80 kg/cm². This trend is comparable to that of molasses, although it starts from a slightly higher initial value.

In contrast, pellets without adhesive show the highest flash point values at elevated pressures. The flash point increases from 72 °C at 40 kg/cm² to 75 °C at 80 kg/cm². The increase is more pronounced compared to pellets with binders, suggesting that in the absence of adhesive, the material requires a higher temperature to initiate combustion.

A higher flash point generally indicates greater resistance to spontaneous ignition at lower temperatures, which can enhance safety during storage and transportation. Conversely, a lower flash point implies that the material ignites more readily, which may be advantageous for certain energy applications requiring rapid ignition [31].

G. Burning Rate

The burning rate of gelam wood pellets represents the mass of pellets consumed per unit time during combustion. In this study, each pellet sample had an initial mass of 10 g. The burning rate was calculated using the following equation:

$$\text{Burning rate} = \frac{\text{initial mass of pellet} - \text{final mass of pellet}}{\text{time}}$$

The burning rate of gelam wood pellets in this study is presented in Figure 9.

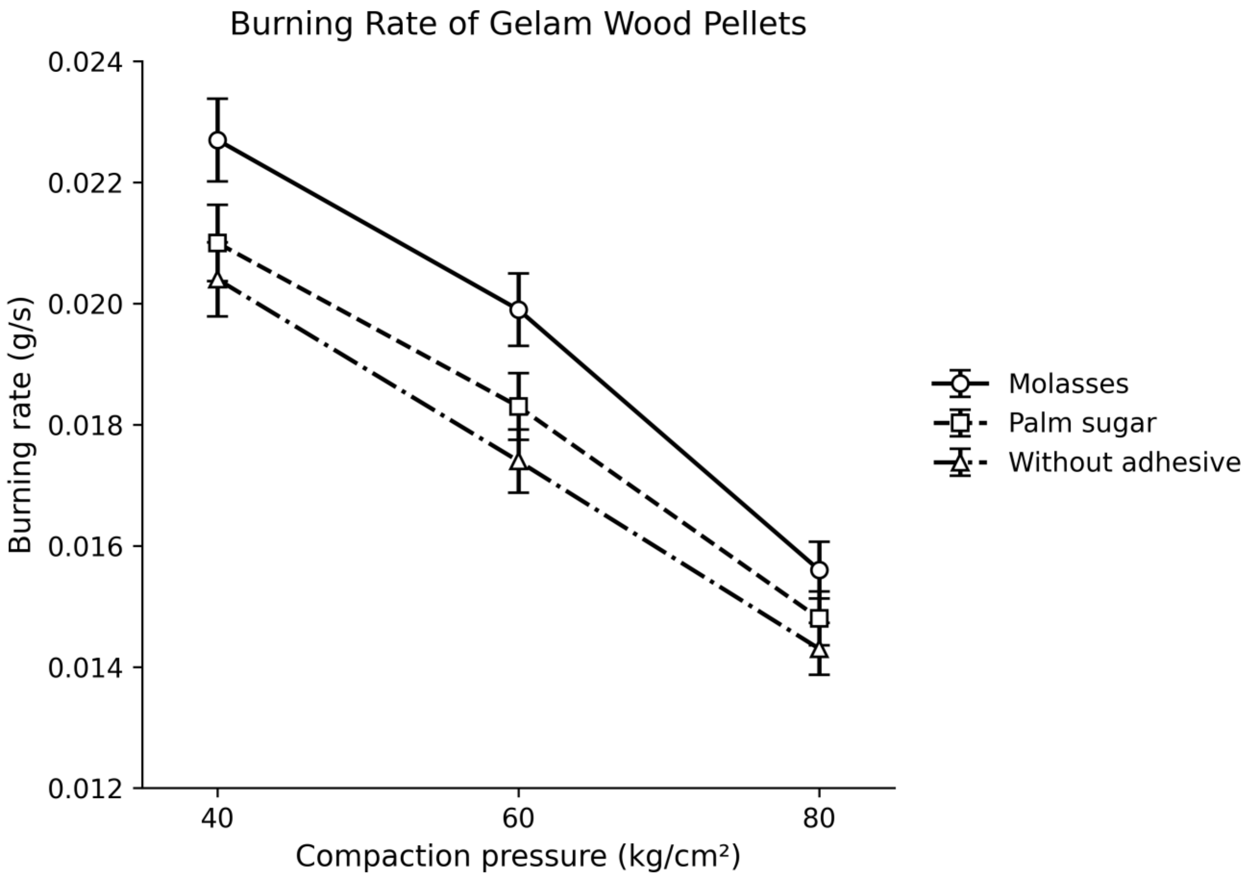

Figure 9. Burning Rate Of Gelam Wood Pellets.

Pellets with molasses binder exhibit a decreasing burning rate with increasing compaction pressure. This indicates that higher compaction pressure produces denser pellets, resulting in slower combustion rates. The burning rate decreases from 0.02273 g/s at 40 kg/cm² to 0.01553 g/s at 80 kg/cm².

Similarly, pellets prepared with palm sugar binder also show a reduction in burning rate as the pressure increases. The burning rate declines from 0.02101 g/s at 40 kg/cm² to 0.01481 g/s at 80 kg/cm². This trend is consistent with that observed for molasses, although the burning rate of palm sugar-based pellets is slightly lower at each pressure level.

Pellets without adhesive exhibit the lowest burning rate across all pressure conditions. The burning rate decreases from 0.02045 g/s at 40 kg/cm² to 0.01433 g/s at 80 kg/cm². The reduction in burning rate is less pronounced compared to pellets with binders, suggesting that the presence of binders significantly influences combustion behavior.

In general, pellets containing binders such as molasses and palm sugar demonstrate higher burning rates compared to those without adhesive. The presence of binders likely enhances material homogeneity and facilitates combustion, leading to faster burning. In contrast, pellets without adhesive tend to burn more slowly, possibly due to less uniform structure and the absence of components that promote combustion. Furthermore, increasing compaction pressure results in higher pellet density, which reduces oxygen diffusion and heat transfer, thereby slowing the burning rate [32]. This effect is observed for all pellet types, although it is more pronounced in pellets containing binders.

H. Combustion Temperature

The maximum combustion temperature of gelam wood pellets in this study is presented in Figure 10.

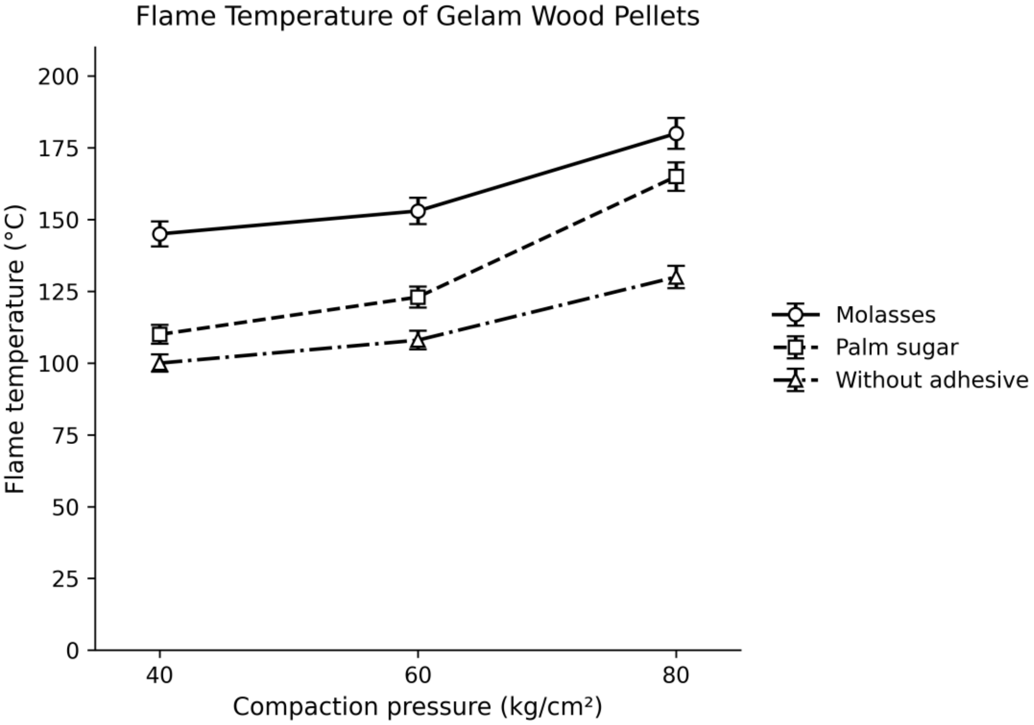

Figure 10. Combustion Temperature Of Gelam Wood Pellets.

Pellets with molasses binder exhibit a significant increase in maximum combustion temperature with increasing compaction pressure. The temperature rises from 145 °C at 40 kg/cm² to 153 °C at 60 kg/cm², and reaches 180 °C at 80 kg/cm².

A similar trend is observed for pellets using palm sugar binder, although the increase in combustion temperature is less pronounced compared to molasses. The temperature increases from 110 °C at 40 kg/cm² to 165 °C at 80 kg/cm².

In contrast, pellets without adhesive show the lowest combustion temperatures among all samples. The temperature increases from 100 °C at 40 kg/cm² to 130 °C at 80 kg/cm².

The use of molasses as a binder provides the most significant enhancement in combustion temperature. This can be attributed to its high carbohydrate content (approximately 94.75% sucrose), whereas palm sugar contains about 89.94% sucrose [33]. Sucrose, as a simple carbohydrate, decomposes and combusts readily, leading to higher combustion temperatures [34].

These results indicate that binder type plays a crucial role in influencing combustion efficiency. Furthermore, increasing compaction pressure produces denser pellets, which affects heat transfer and combustion behavior, thereby contributing to higher combustion temperatures. Pellets without adhesive tend to exhibit lower combustion temperatures, suggesting less controlled combustion at elevated temperatures due to the absence of binding agents.

IV. Conclusion

This study successfully evaluated the effect of binder type and compaction pressure on the physical and combustion characteristics of gelam wood pellets. The results show that pellets without binder (C3) exhibit superior physical properties, with the lowest moisture content (11.61%) and relatively low ash content (1.24%), while pellets with molasses (C1) present the lowest ash content (0.06%). In contrast, pellets with binders, particularly palm sugar (C2), achieve the highest calorific value (3999.65 cal/g), followed by molasses (C1) at 3996.17 cal/g, whereas C3 shows a lower value (3912.56 cal/g). The volatile matter increases from 84.41% (C1) to 90.94% (C3), indicating enhanced ignition reactivity. Combustion characteristics are strongly influenced by compaction pressure, where ignition time increases up to 34 s, flash point reaches 75 °C, and combustion temperature rises to 180 °C at 80 kg/cm². Conversely, the burning rate decreases from 0.02273 g/s to 0.01433 g/s as pressure increases, indicating slower but more controlled combustion due to higher pellet density. Among the tested binders, molasses provides the most favorable overall combustion performance, particularly in achieving higher combustion temperature and more stable burning behavior. From an industrial perspective, these findings suggest that optimizing binder type and compaction pressure can improve combustion efficiency, reduce operational issues such as ash-related fouling, and enhance fuel handling and storage performance, thereby supporting the large-scale application of gelam wood pellets as a viable alternative to conventional solid fuels.

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REFERENCES

[1] Taylor, A., Reed, D., Bergman, R., Harper, D., & Hodges, D. (2013). A life cycle inventory for switchgrass fuel pellets. Review Process: Non-Refereed (Other).

[2] Abdoli, M. A., Golzary, A., Hosseini, A., & Sadeghi, P. (2018). Wood Pellet as a Renewable Source of Energy. Tehran: Springer International Publishing.

[3] Thrän, D., Peetz, D., Schaubach, K., Backéus, S., Benedetti, L., & Bruce, L. (2017). Global wood pellet industry and trade study 2017 (No. ISBN: 978-1-910154-32-8). IEA Bioenergy Task 40.

[4] Kumar, L., Koukoulas, A. A., Mani, S., & Satyavolu, J. (2017). Integrating torrefaction in the wood pellet industry: A critical review. Energy & Fuels, 31(1), 37-54.

[5] Mola-Yudego, B., Selkimäki, M., & González-Olabarria, J. R. (2014). Spatial analysis of the wood pellet production for energy in Europe. Renewable Energy, 63, 76-83.

[6] Visser, L., Hoefnagels, R., & Junginger, M. (2020). Wood pellet supply chain costs–A review and cost optimization analysis. Renewable and Sustainable Energy Reviews, 118, 109506.

[7] Nugraha, A., Irawansyah, H., Afifudin, M. N., Muhammad, M., & Al'Arisko, R. N. (2022). The effect of particle size variation and wheat flour binder percentage on the physical properties of gelam wood pellets. Turbo: Journal of Mechanical Engineering Study Program, 11(1).

[8] Sihaloho, I. H. (2022). The effect of dolomite application and coated NPK fertilizer on the growth of gelam (Melaleuca cajuputi Powell) in peatland (Doctoral dissertation, Jambi University).

[9] Nugraha, A., Arief, M. Z., Tampubolon, R. E. M., & Rahmadani, F. P. (2025). The Effect of Variations In The Composition And Type of Adhesive For Mixed Peat And Gelam Wood Briquettes on The Physical Characteristics of The Briquettes. International Journal of Marine Engineering Innovation and Research, 10(4), 1340-1346.

[10] Proskurina, S., Alakangas, E., Heinimö, J., Mikkilä, M., & Vakkilainen, E. (2017). A survey analysis of the wood pellet industry in Finland: Future perspectives. Energy, 118, 692-704.

[11] Amrullah, A., Syarief, A., Saifudin, M. (2020). Combustion Behavior of Fuel Briquettes Made from Ulin Wood and Gelam Wood Residues. International Journal of Engineering, 33(11), 2365-2371. doi: 10.5829/ije.2020.33.11b.27.

[12] Irawansyah, H., Nugraha, A., Afifudin, M. N., Muhammad, M., & Al'Arisko, R. N. (2022). Effect of particle size (mesh) variation and tapioca binder percentage on the physical properties of gelam wood pellets. Multitek Indonesia, 15(2), 13–22.

[13] Irawansyah, H., & Nugraha, A. (2022). Analysis of combustion characteristics of gelam wood pellets using tapioca flour binder. In Proceedings of the National Seminar on Wetland Environment (Vol. 7, No. 3).

[14] Nugraha, A., Irawansyah, H., Afifuddin, M. N., & Al'Arisko, R. N. (2024). Analysis of quality and economic value of gelam wood pellets. Scientific Journal of Mechanical Engineering Kinematika, 9(2), 264–271.

[15] Lambung Mangkurat University. (2023). 65 innovative works of Lambung Mangkurat University. ULM Press, Banjarmasin.

[16] Pokhrel, G., Han, Y., & Gardner, D. J. (2021). Comparative study of the properties of wood flour and wood pellets manufactured from secondary processing mill residues. Polymers, 13(15), 2487.

[17] Goembira, F., Aristi, D., Nofriadi, D., & Putri, N. P. (2021). Analysis of PM2.5, CO, and CO_2 concentrations and fuel consumption rate of rice husk and straw biopellets in a biomass stove. Jurnal Ilmu Lingkungan, 19(2), 201–210.

[18] Vershinina, K., Nyashina, G., & Strizhak, P. (2022). Combustion, pyrolysis, and gasification of waste-derived fuel slurries, low-grade liquids, and high-moisture waste. Applied Sciences, 12(3), 1039.

[19] Borges, A. D., Matos, P., & Oliveira, M. (2025). Valorization of Cork Residues for Biomass Pellet Production: Meeting ENplus® Standards Through Strategic Blending. Clean Technologies, 7(2), 43.

[20] Siyal, A. A., Liu, Y., Mao, X., Ali, B., Husaain, S., Dai, J., ... & Liu, G. (2021). Characterization and quality analysis of wood pellets: effect of pelletization and torrefaction process variables on quality of pellets. Biomass Conversion and Biorefinery, 11(5), 2201-2217.

[21] Ungureanu, N., Vladut, V., Voicu, G., Dinca, M. N., & Zabava, B. S. (2018). Influence of biomass moisture content on pellet properties–review. Eng. Rural Dev, 17, 1876-1883.

[22] Toscano, G., Riva, G., Pedretti, E. F., Corinaldesi, F., Mengarelli, C., & Duca, D. (2013). Investigation on wood pellet quality and relationship between ash content and the most important chemical elements. Biomass and Bioenergy, 56, 317-322.

[23] Li, W., Wang, M., Meng, F., Zhang, Y., & Zhang, B. (2022). A review on the effects of pretreatment and process parameters on properties of pellets. Energies, 15(19), 7303.

[24] Nunes, L. J. R., Matias, J. C. O., & Catalão, J. P. S. (2014). Mixed biomass pellets for thermal energy production: A review of combustion models. Applied Energy, 127, 135-140.

[25] Jia, G. (2021). Combustion characteristics and kinetic analysis of biomass pellet fuel using thermogravimetric analysis. Processes, 9(5), 868.

[26] Cheng, J., Zhang, Y., Wang, T., Xu, H., Norris, P., & Pan, W. P. (2018). Emission of volatile organic compounds (VOCs) during coal combustion at different heating rates. Fuel, 225, 554-562.

[27] Komilis, D., Kissas, K., & Symeonidis, A. (2014). Effect of organic matter and moisture on the calorific value of solid wastes: An update of the Tanner diagram. Waste management, 34(2), 249-255.

[28] Kizuka, R., Ishii, K., Sato, M., & Fujiyama, A. (2019). Characteristics of wood pellets mixed with torrefied rice straw as a biomass fuel. International Journal of Energy and Environmental Engineering, 10(3), 357-365.

[29] Sonya, N. T., & Lydia, S. H. R. (2021). Analysis of reducing sugar content in palm sugar (granulated palm sugar) derived from aren sap as influenced by pH and moisture content. BIOEDUKASI: Journal of Biology Education, 12(1), 101–108.

[30] Anggraini, S. P. A., Yuniningsih, S., & Sota, M. M. (2017). Effect of pH on ethanol product quality from molasses through fermentation process. Reka Buana: Scientific Journal of Civil Engineering and Chemical Engineering, 2(2), 98–105.

[31] Bóna, D., Chovanec, D., Jaďuďová, J., Osvaldová, L. M., & Marková, I. (2025). Analysis of Spontaneous Ignition Temperature and Flash Point for Predicting Fire Risk in Biomass Fuel Pellet Storage. BioResources, 20(2).

[32] Sarker, T. R., Nanda, S., Meda, V., & Dalai, A. K. (2023). Densification of waste biomass for manufacturing solid biofuel pellets: a review. Environmental Chemistry Letters, 21(1), 231-264.

[33] Maryani, Y., Rochmat, A., Khastini, R. O., Kurniawan, T., & Saraswati, I. (2021, March). Identification of macro elements (sucrose, glucose and fructose) and micro elements (metal minerals) in the products of palm sugar, coconut sugar and sugar cane. In 2nd and 3rd International Conference on Food Security Innovation (ICFSI 2018-2019) (pp. 271-274). Atlantis Press.

[34] Pennington, N. L., & Baker, C. W. (Eds.). (1990). Sugar: user's guide to sucrose. Springer Science & Business Media.