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RESEARCH ARTICLE

Thermochemical Conversion of Rubber Wood Pellets via Downdraft Gasification: Syngas Composition, Heating Value Trends, and By-Product Characterization

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ABSTRACT

The increasing global energy demand, coupled with declining fossil fuel reserves, is driving the development of biomass-based renewable energy. Rubber wood (*Hevea brasiliensis*) is a potential biomass source due to its abundant availability from the rejuvenation of community gardens. This study aims to analyze the energy characteristics of rubber wood pellets as biomass fuel, analyze the composition of synthesis gas (syngas) and lower heating value (LHV), and the characteristics of ash (residue from the gasification process) using a downdraft gasifier. The study was conducted at the Forest Products Technology Laboratory, Faculty of Agriculture, University of Lampung, using 20 kg of rubber wood pellets as the raw material. The gasification procedure progresses through four fundamental stages, including drying, pyrolysis, combustion, and reduction, which are conducted within a downdraft gasifier system. Syngas analysis was performed using a portable infrared syngas analyzer (Gasboard G3100-P) to determine the concentrations of CO, CO_2, CH_4, H_2, and O_2. The results showed that the average composition of the syngas produced was 17.98% CO, 8.58% CO_2, 1.57% CH_4, 10.04% H_2, and 1.78% O_2. The average calorific value (LHV) was 725.81 kcal/m^3 with a range of 690–775 kcal/m^3. The proximate analysis results showed a moisture content of 10.93%, volatile matter 74.37%, ash content 8.60%, and fixed carbon of 6.20% in the pellet biomass, while the ash (by-product) had a moisture content of 9.58%, volatile matter 14.42%, ash content 71.61%, and fixed carbon 4.37%. The composition of the syngas produced was within the ideal range for a downdraft, indicating that rubber wood pellets have high potential as a biomass-based renewable energy fuel.

1. Introduction

In an era of globalization and increasingly sophisticated technology, Indonesia's national energy needs and dependence on fossil fuels remain very high. According to Hersaputri et al. (2024), the Indonesia's primary energy demand is projected to double between 2020 and 2050, assuming no major structural changes in the national energy mix. Meanwhile, reserves of fossil fuels such as coal, oil, and natural gas are dwindling, causing energy prices to become unstable and prone to increase. According to data from the Ministry of Energy and Mineral Resources (2023), Indonesia's oil reserves are estimated to be depleted within 10 years if no new energy sources are found, while natural gas and coal reserves are estimated to last only 20 to 60 years, respectively. On the other hand, energy demand continues to increase in line with economic, industrial, and population growth. This condition causes energy prices to become unstable and tend to increase every year (Avazkhodjaev et al., 2024).

Amid the need for environmentally friendly, sustainable energy solutions, the potential of biomass from forestry and plantation waste is one alternative that can be developed. The Ministry of Energy and Mineral Resources stated in 2023 that Indonesia has enormous biomass energy potential, amounting to approximately 146 million tons per year, equivalent to 56.97 GW of electricity, primarily derived from agricultural and forestry waste in Sumatra and Kalimantan. One type of biomass with potential for development in Indonesia is rubber. Indonesia has a rubber plantation area of 3.54 million hectares, comprising 7% state-owned plantations, 85% smallholder-owned plantations, and 8% large private plantations (Central Statistics Agency, 2023). Generally, wood biomass is large in size, so it needs to be densified into pellets to make it more practical to use (Garcia et al., 2019). Pellets as a source of biomass energy offer several advantages over other types of biomass, such as firewood and sawmill waste, particularly in terms of their density and more uniform shape (Arranz et al., 2015).

Biomass conversion technology is generally divided into three types: direct combustion, biochemical conversion, and thermochemical conversion (Lewandowski et al., 2020). Thermochemical technology converts biomass into fuel by utilizing thermal (heat) treatment, such as hydro pyrolysis/incinerators, pyrolysis, gasification, liquefaction, and carbonization (Jha et al., 2022). Gasification is the process of converting energy from solid materials (biomass) into syngas (synthetic gas), which can later be used as fuel (Molino et al., 2018). Trejo (2025) states that gasification is the most common method for converting solid materials into combustible gases (CO, CH_4, H_2) through a combustion cycle with a limited air supply, typically 20% to 40% of the stoichiometric air. The solid materials in question are solid fuels such as biomass, coal, and charcoal, which contain carbon (C).

In contrast, the gases in question are products of the gasification process, including CO, H_2, and CH_4. Raw materials for the gasification process can be biomass waste, such as sawdust, wood chips, coconut shells, rice husks or other agricultural residues, which have been converted into biomass pellets (Hoque et al., 2021). Several studies have demonstrated that rubber wood (*Hevea brasiliensis*) possesses superior characteristics as a raw material for gasification. A study by Isgiyarta et al. (2022) demonstrated that rubber wood can produce syngas with a favorable combustion gas composition, including CO_2 and H_2, and a relatively low tar content, making it suitable for use in small-scale power plants. A similar finding was reported by Siddique et al. (2024), who stated that rubber wood has a relatively high calorific value and good thermal stability, making it a potential raw material for sustainable energy conversion technologies.

However, research on rubber wood as a gasification feedstock is still relatively limited. According to Kasawapat et al. (2024), rubber wood has a high lignocellulose content that supports gasification and an adequate calorific value. This suggests that rubber wood has significant potential as an alternative energy source, particularly in rubber-producing regions such as Lampung. According to data from the Central Statistics Agency (2023), Lampung is one of the 10 largest rubber-producing regions in Indonesia. Lampung's rubber production in 2018 reached 192,133 tons with an area of 172,371 ha. Given the abundant availability of biomass but its suboptimal utilization, especially for rubber wood, further research is needed to determine the extent of this material's potential for gasification (Laosena et al., 2022). Therefore, this study aims to analyze the energy characteristics of rubber wood pellets as a biomass fuel, examine the composition of synthesis gas (syngas) and its lower heating value (LHV), and examine the properties of the ash (by-product) produced using a downdraft gasifier.

2. Materials and Methods

2.1. Time and Location

The research was conducted from April 2025 to October 2025. Preparation of tools and materials, as well as sampling and analysis of syngas composition, were carried out in the Workshop, the Forest Products Technology Laboratory, and the Integrated Laboratory of the Faculty of Agriculture at the University of Lampung.

2.2. Tools and Materials

The materials used in this study are 20 kg of rubber wood pellets (*Hevea brasiliensis*) obtained commercially from PT. IGJ Wood Pellet, Natar, South Lampung, Lampung. The tools used in this study include a 15 kWh downdraft gasifier reactor (**Fig. 1a**), a portable gas pre-treatment and portable infrared syngas analyzer (**Fig. 1b**), a generator, a flame gun, and a laptop.

(a) (b)

Fig. 1. Tools used in this study: 15 kWh downdraft gasifier reactor (a) and portable infrared syngas analyzer gasboard G3100-P (b).

2.3. Data Collection Method

2.3.1. Raw material preparation

The process begins with the provision of raw materials for sorting (separation based on size and shape). The pellets are 2.5 cm long and 6 mm in diameter. This size was obtained from sorting results conducted at PT IGJ Wood Pellet, Natar, South Lampung, Lampung. Sorting is carried out to select biomass of uniform quality. Afterward, the biomass is dried to achieve equilibrium moisture content. The main raw material used in this study is rubber wood, which is processed into pellets with a moisture content of less than 12%, in accordance with the standard specifications for industrial biomass pellets (SNI 8675:2018).

2.3.2. Gasification Process

The four main steps of the gasification process in a downdraft gasifier are drying, pyrolysis, combustion, and reduction. Each process has a different response in terms of chemical production and compound release.

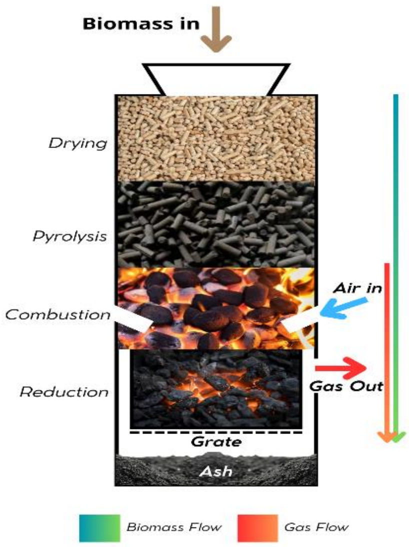

Fig. 3. Gasification process using a downdraft gasifier.

In a downdraft gasifier, as shown in **Fig. 3**, the gas and solid flows are both downward. Drying is the process of evaporating water from biomass by applying heat at 100–200 °C. Pyrolysis is the conversion of a solid/liquid to a gas without a gasification medium. Pyrolysis uses heat from an external

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source at 200–300 °C. Combustion produces flue gas, a process that occurs when the (air-fuel ratio) is greater than or equal to the stoichiometric value. The reduction of CO_2 and H_2O gases occurs over a temperature range of 400–900 °C. CO_2 gas reduction occurs via the Boudouard equilibrium reaction, and H_2O gas reduction via the water-gas equilibrium reaction, both of which are predominantly influenced by temperature and pressure. Then the final residue remaining in the gasifier is ash (Ramos et al., 2018).

2.4. Data Analysis

2.4.1. Syngas analysis

Syngas analysis was conducted to determine the concentrations of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), oxygen (O_2), and methane (CH_4). The analysis was conducted using a portable infrared syngas analyzer (Gasboard 3100P, Wuhan Cubic Optoelectronics, China), which simultaneously measures CO, CO_2, CH_4, H_2, and O_2 concentrations in syngas (synthesis gas). The measurement was logged using V2.0.12 Gas Analyzer Software. The syngas measurement flow is presented in **Fig. 4.**

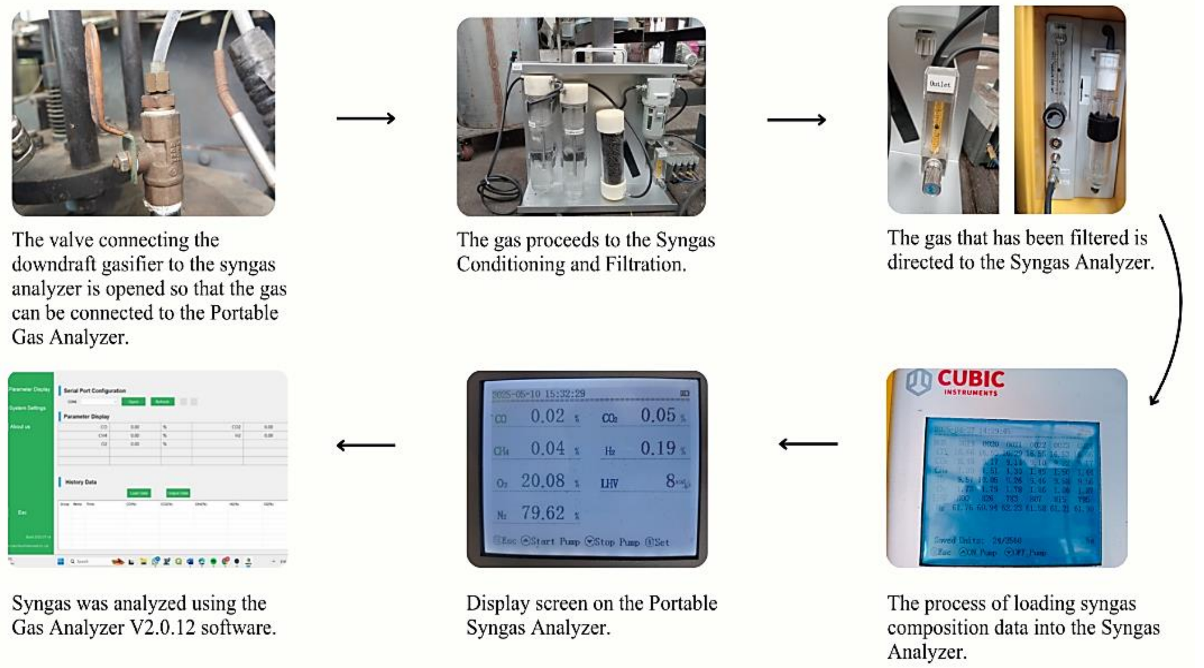

Fig. 4. Syngas measurement flow on the portable syngas analyzer.

2.4.2. Syngas lower heating value (LHV) analysis

The lower heating value (LHV) of the produced syngas was determined directly from measurements obtained using a portable gas analyzer, with calculations performed using Gas Analyzer Software version 2.0.12. The portable gas analyzer measured the volumetric concentrations (vol%) of the main combustible gas components, namely CO, H_2, and CH_4. These values were subsequently used to calculate the syngas LHV based on the standard lower heating values of each component. The syngas LHV was estimated as the sum of the volume fractions of each combustible component multiplied by their respective standard lower heating values, as expressed in Equation 1:

$$LHV\ Syngas\ (kcal/m^3) = (X_i\ CO \times LHV\ CO) + (X_i\ H_2 \times LHV\ H_2) + (X_i\ CH_4 \times LHV\ CH_4) \quad (1)$$

where X_i represents the volume fraction (% by volume) of CO, H_2, and CH_4, and LHV CO, H_2, and LHV CH_4 denote the standard LHV of 1 Nm^3 of the respective pure gases. This approach has been widely applied in previous studies and provides a reliable estimation of the calorific value of syngas produced during the gasification of rubber wood pellets (Salem et al., 2022; Rey et al., 2025).

2.4.3. Gasification ash (by-product) analysis

Ash is a residue from the gasification process (by-product). Ash sampling is carried out 24 hours after gasifier operation to ensure conditions have cooled sufficiently, as the newly produced ash is still hot and may contain flames. The collected ash is analyzed using proximate analysis. Proximate analysis is a test that includes water content, volatile matter content, ash content, and fixed carbon. The materials used are rubber wood biomass pellets and gasification ash (by-product).

a) Moisture Content

Moisture content is the percentage of water mass contained in a material compared to the total mass of the material. In this method, a sample of known weight (1 gram) is placed in a crucible with a lid and then oven-dried in a muffle furnace at 105 °C for 60 minutes (SNI 8675-2018). A muffle furnace is a laboratory device used to heat materials to very high temperatures and protect them from external contaminants or chemicals. After drying, the final mass of the sample is compared with its initial mass to obtain the water content (MC) using Equation 1.

$$MC\ (wt\%) = \frac{W - B}{W} \times 100 \quad (1)$$

where *MC* is the moisture content, *W* is the difference between the initial mass of the specimen, and *B* is the mass after drying.

b) Volatile Matter

Volatile matter is a part of biomass (such as wood pellets) that evaporates or decomposes into gas when heated in oxygen-free conditions at high temperatures. Crucible samples were reweighed at 1 g. Samples were analyzed by burning them in a muffle furnace at 950 °C for 7 minutes (SNI 8675-2018). The percentage of volatile matter in the analyzed sample was calculated using Equation 2.

$$VM\ (wt\%) = \frac{B - C}{W} \times 100 \quad (2)$$

*w*here *VM* is obtained from the difference between the mass of the specimen, *B* is the mass after the water content test, *C* is the mass of the specimen after heating in the volatile matter test, and *W* is the initial mass of the specimen.

c) Ash Content

Ash content is the percentage of unburned inorganic solids (minerals) remaining after the organic material in a sample is completely heated at a high temperature. The crucible lid is closed, and a 1-gram sample is fired in a muffle furnace at 750 °C for 1 hour (SNI 8675-2018). The ash percentage in the analyzed sample is obtained from Equation 3.

$$AC\ (wt\%) = \frac{F - G}{W} \times 100 \quad (3)$$

*w*here *AC* is the ash content, F is the ash residue, *G* is the mass of the empty crucible, and *W* is the initial specimen mass.

d) Fixed Carbon

Fixed carbon is the solid carbon remaining in a fuel after moisture, volatile matter, and ash have been removed. Fixed carbon is the slow-burning portion of the fuel and is the primary source of heat in the combustion or gasification process.

$$FC\ (wt\%) = 100 - (MC + VM + AC) \quad (4)$$

where *FC* is the fixed carbon value (%), *MC* is the moisture content (%), *VM* is the volatile matter content (%), and *AC* is the ash content (%). Therefore, the fixed carbon value reflects the energy storage potential of the solid fraction in biomass fuel.

3. Results and Discussion

3.1. Changes in Syngas Composition During the Gasification Process

The rubber wood pellet gasification process produces a mixture of synthesis gas (syngas) consisting of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), carbon dioxide (CO_2), and oxygen (O_2). The composition of each gas changes over time due to the dynamics of oxidation-reduction reactions within the reactor. The results show that CO is the main component with a concentration of 17–20%. **Fig. 5** shows that the CO content gradually decreases over time and with increasing temperature. Jothiprakash et al. (2025) explained that the initial increase in CO levels during gasification indicates that surface oxidation still predominates before being absorbed into other reactions as the temperature rises. Meanwhile, CO is formed when there is insufficient oxygen during combustion. El-Sayed et al. (2024) support these results, stating that the release and combustion/surface oxidation of volatiles in the early stages explain why CO can increase during the initial phase before subsequent gasification/char reaction mechanisms (at higher temperatures) alter the gas profile.

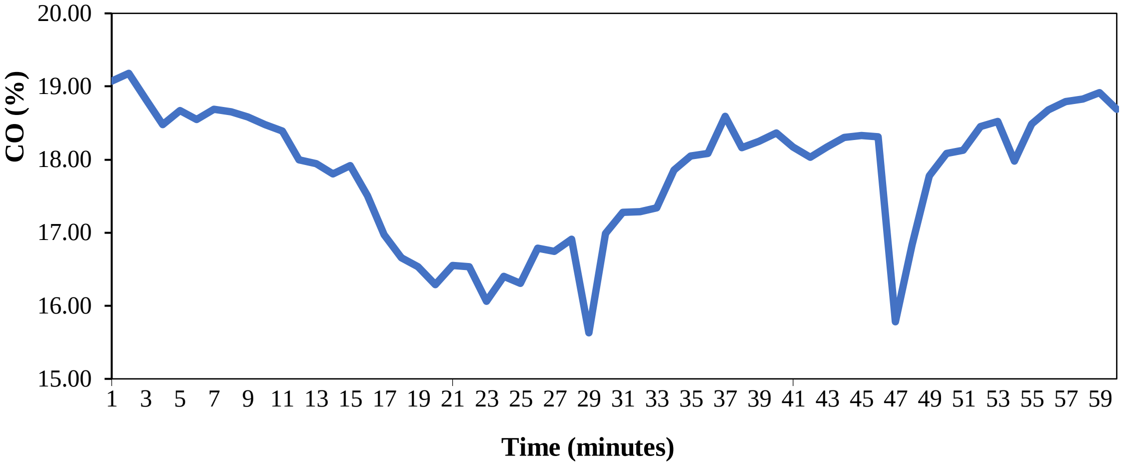

Fig. 5. Graph of changes in CO composition against reaction time.

The H_2 content showed an increasing trend in the early to mid-process, followed by fluctuations at the 45th minute before stabilizing within a value range of 10–12% (**Fig. 6**). Asencios et al. (2025) reported that temperature fluctuations significantly influenced the variation of CO and H_2 over time in the reduction zone, where increasing temperature enhanced the Boudouard reaction and water-gas shift, resulting in an increase in H_2 followed by a decrease in CO. This pattern is similar with the results of this study, where a gradual decrease followed an increase in H_2 in the early to mid-process, was followed by a gradual decrease in CO. Gao et al. (2023) and Chan et al. (2019) also reported that variations in reactor lining temperature significantly affected the dynamics of H_2 and CO formation through endothermic reactions in the downdraft gasifier system. The CO_2 content shows a stable trend of 8–10%, indicating that most of the oxidation gas has reacted to form CO and H_2 (**Fig. 6**).

The CH_4 component (**Fig. 7**) is relatively low and stable (1–2%), indicating that biomass pyrolysis proceeds effectively and that most hydrocarbon gases have decomposed into permanent gases. Chaves et al. (2024) explained that the stability of CO_2 and the low CH_4 indicate efficient pyrolysis and reforming reactions, suggesting that the system has reached a relatively stable thermochemical condition after the 40th minute of operation. Meanwhile, the O_2 content is very low (<1 %) and decreases in the early minutes, suggesting rapid oxygen consumption during the combustion phase (Frigo et al., 2024). This condition is consistent with the results of Wang et al. (2025), who reported that syngas from biomass gasification with a downdraft gasifier generally has an O_2 content of < 5%.

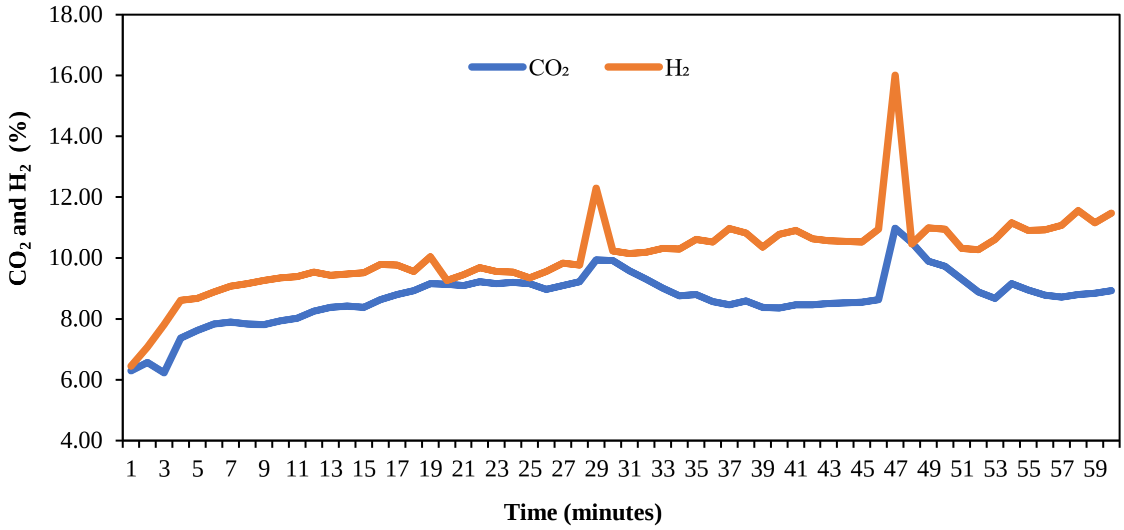

Fig. 6. Changes in CO_2 and H_2 composition against reaction time.

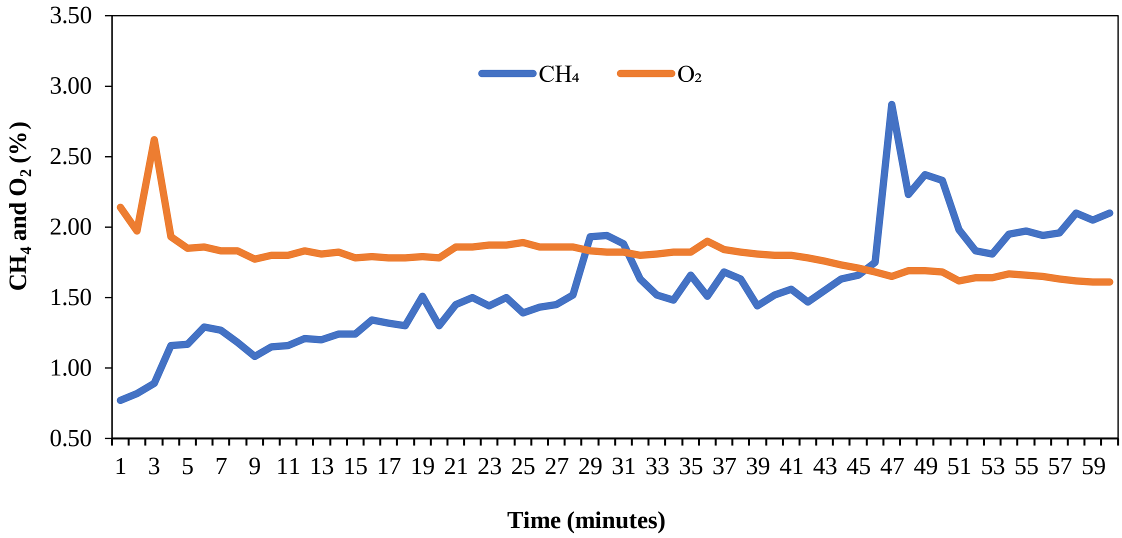

Fig. 7. Changes in the composition of CH_4 and O_2 against reaction time.

3.2. Effect of Temperature on the Lower Heating Value (LHV) of Syngas

The relationship between temperature and the lower heating value (LHV) of syngas during the gasification process is shown in **Table 1** and **Fig. 8**. The LHV value at 10 minutes was 745 kcal/m³, then decreased to its lowest point at 20 minutes (690 kcal/m³). In the initial minutes, the heating process was used primarily to dry the biomass and release moisture and volatile compounds. The gas formed in this phase still contained water vapor (H_2O) and light volatile compounds (CO_2), so the composition of combustible gases such as CO, H_2, and CH_4 was still low. As a result, the gas's calorific value (LHV) also decreased (Chojnacki et al., 2020). After that, the LHV fluctuated but gradually increased, reaching a peak of 775 kcal/m³ at 60 minutes. The increase in LHV at the end of the time indicates that the gasification process becomes more efficient over time, due to increasingly stable reactor temperature and more optimal decomposition of volatile matter (Gao et al., 2023). The results show that an increase in operating temperature is correlated with an increase in the calorific value (LHV) of syngas, in line with studies that found an increase in CO and H_2 fractions and a decrease in tar at higher temperatures, thereby increasing the LHV of syngas (Saleh and Abdul, 2021; Salem et al., 2022; Yu et al., 2016).

Table 1. Lower heating value (LHV) and temperature during the gasification process

Time (minutes)	LHV (kcal/m^3)	Temperature (°C)
10	745.14	250
20	691.43	329
30	710.24	394
40	702.25	462
50	732.03	528
60	773.75	600

The water content also influences the high or low calorific value. The drier the raw material in the biopellet, the lower the water content, so the resulting calorific value is higher. However, if the raw material is too wet in the biopellet, the water content is higher, resulting in a lower calorific value (Tiara et al., 2018). The purpose of the calorific value test is to determine the heat value of combustion of biopellets (Abdel et al., 2023). The presence of ash and fixed carbon content can affect the calorific value. A high calorific value indicates better fuel quality (Rubiyanti et al., 2019). When used as an energy source, high-calorific-value pellets produce more heat, thereby accelerating the distribution of heat energy (Kongprasert et al., 2019). This large amount of energy can produce heat for household and industrial use (Ajimotokan et al., 2019).

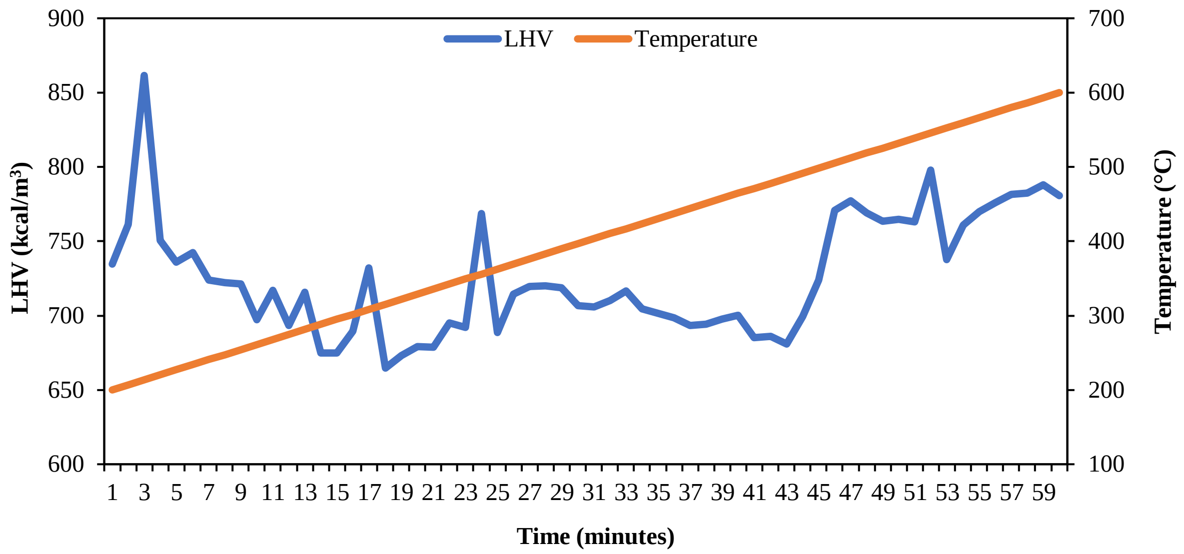

Fig. 8. Graph of changes in the lower heating value (LHV) of syngas during the gasification process.

3.3. Proximate Analysis of Rubber Wood Pellets and Ash (By-Product) of Gasification

Proximate analysis is performed to determine the combustion efficiency of biomass (fuel pellets). Biomass consists of several components, such as moisture content, volatile matter, ash content, and fixed carbon. The results of the proximate analysis are shown in **Table 2**.

Table 2. Proximate analysis of rubber wood pellets and gasification ash (by-product)

Repetition No.	Biomass				Repetition No.	Ash (by-product)			
	MC (%)	AC (%)	VM (%)	FC (%)		MC (%)	AC (%)	VM (%)	FC (%)
1	11.06	8.02	76.23	4.69	1	9.57	72.33	14.00	4.1
2	10.96	8.70	74.19	6.15	2	9.50	73.63	14.06	2.81
3	10.77	9,10	72.70	7.76	3	9.69	68.87	15.22	6.22
Average	10.93	8.60	74.37	6.2	Average	9.58	71.61	14.42	4.37

Notes: MC = moisture content, AC = ash content, VM = volatile matter, FC = fixed carbon.

The results of the proximate analysis of rubber wood pellets and ash indicate compositional changes resulting from the gasification process. The water content decreased from 10.93% in biomass to 9.58% in ash, indicating a decrease in humidity as the reactor temperature increased. The volatile matter content, initially 74.37%, decreased sharply to 14.42% after gasification, yielding a biochar that is more stable and denser in carbon. Conversely, the ash content increased sharply from 8.60% to 71.61%, indicating the dominance of inorganic materials after volatile and organic compounds decomposed. The fixed carbon value was relatively low compared to related research data, at only 4–6%, indicating that most of the biomass energy was released as gas. A comparison graph of the proximate values for rubber wood pellets as biomass and as ash (by-product) from gasification is presented in **Fig. 9**.

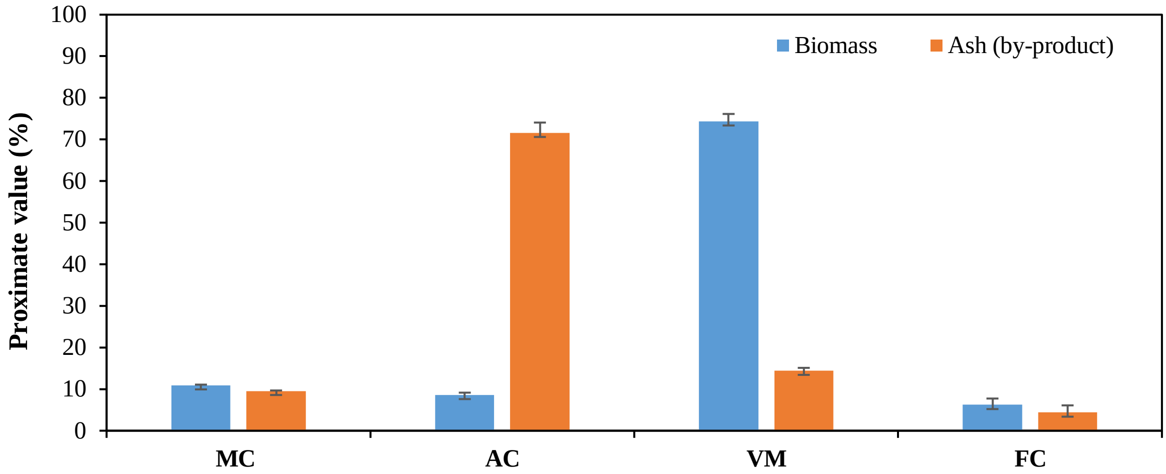

Fig. 9. Graph of the percentage of proximate values of rubber wood pellets and gasification by-product in the form of ash.

3.3.1. Moisture content

Moisture content is a key property that significantly affects the combustion characteristics of pellets. Generally, biomass moisture content directly affects its heating value and density, with higher moisture content reducing both (Saeed et al., 2015). The moisture content from the proximate test results is presented in Fig. 9. The average moisture content was 10.93%, while ash showed a lower moisture content of 9.58%. This figure indicates that gasification has successfully reduced some of the moisture, as volatiles and water contained in the biomass are partially lost during the process.

The results obtained are consistent with those of Sultan et al. (2020), who found that a moisture content of <10% is generally considered optimal for preventing heat absorption and enhancing the lower heating value (LHV) of the produced syngas. A similar study by Sultan et al. (2021) showed that a biomass moisture content of <10% also meets the requirements for gasification. Based on the analysis, slightly higher results were obtained (~12%), but the drying process during gasification reduced it to near the ash value (~10.85%). This indicates that the drying system and reactor temperature are quite effective but can still be improved to reach a value of <10%. The results show that the moisture content of the rubber wood pellets meets the specifications for biomass pellets for energy according to SNI 8675-2018, which is < 12%.

3.3.2. Volatile matter

The volatile matter content of pellets is related to their combustion calorific value. Volatile matter content can be used as a parameter to measure the amount of smoke produced during combustion. The percentage graph of volatile matter content is shown in **Fig. 9.** The volatile matter content of the tested rubber wood pellet samples was 74.37%, and in the ash sample, 14.42%. This value aligns with the test results by Stolarski et al. (2022), which yielded wood pellet volatile matter values from various types of dendromass ranging from 72–78%, indicating high thermochemical combustion quality but also the potential to produce more fumes in the early stages of gasification.

A similar study by Sultan et al. (2021) showed a volatile matter content of 75.40% through proximate analysis of rubber wood pellets. Volatile matter content can be used as a parameter to measure the amount of smoke produced during combustion. Fuels with high volatile matter content release most of their calorific value as combustion vapor (Galaraga et al., 2024). The higher the volatile matter content of a fuel, the higher the amount of smoke produced. High volatile matter content is influenced by chemical components such as volatile substances during high-temperature combustion (Rubiyanti et al., 2019). These results are in accordance with the volatile matter content specified in SNI 8675-2018, with a value range of 75–80% for biomass pellets.

3.3.3. Ash content

The residue produced after fuel combustion is called ash. Ash content is an indicator of the amount of ash produced during combustion. Ash is formed from mineral substances bound in the carbon structure of biomass during the combustion process. In addition, ash functions as an impurity in the fuel. Based on the ash content test of rubber wood pellets shown in **Table 2**, the ash content value obtained in biomass samples was 8.60% on average, and in ash (by-product) was 71.61%. The ash content in biomass pellets is lower than the ash content of ash as a by-product of gasification.

Research by Paul and Harikumar (2022) found that rubber wood pellets have an ash content of 1.0%. The ash content value obtained is higher than the SNI 8675-2018 limit of <5%. This high ash content can be attributed to contaminants, such as impurities or mixtures, which can increase the ash content (Laosena et al., 2022). A high ash content in fuel indicates a low calorific value. Conversely, a lower ash content in fuel indicates a higher calorific value.

3.3.4. Fixed carbon

The fixed carbon value of only 4–6% indicates that most of the carbon in the rubber wood pellet biomass has been released as volatile substances and gases during the gasification process. The percentage of fixed carbon is presented in **Fig. 9.** Pahnila et al. (2023) stated that raw materials with high volatile content tend to produce low fixed carbon, where the proportion of potential energy will be lost quickly through the release of volatile compounds during pyrolysis and initial oxidation, compared to storing energy in char or solid residue.

Low fixed carbon values indicate that the reduction reaction, which typically occurs in the solid (char) zone, is also suboptimal due to a lack of carbon media to react with CO_2 or H_2O. Furthermore, the ash content and mineral composition of biomass can accelerate the degradation of carbon compounds and inhibit the formation of stable fixed carbon. This results in most of the biomass energy not being stored but being directly used or released as syngas and other volatile gases.

3.4. Implications of Syngas as the Main Product of Rubber Wood Pellet Gasification

Gasification is a technology that can convert solid biomass into a usable gas. Syngas (synthesis gas) is the main product of the rubber wood pellet gasification process. It consists of several components, including carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), methane (CH_4), and other compounds. The results of the research conducted show that syngas from rubber wood pellet gasification has the potential to be an efficient, clean, and environmentally friendly renewable energy alternative to support the national energy transition. This is shown by the average syngas composition, with carbon monoxide (CO) at 17.98%, carbon dioxide (CO_2) at 8.58%, methane (CH_2) at 1.57%, hydrogen (H_2) at 10.04%, and oxygen (O_2) at 1.78%.

Syngas can be used as a fuel for various energy applications, including power generation, transportation, heating, and the production of fertilizers, hydrogen, and methanol. This material is used as fuel in gas turbines that generate electricity for households and industry (Pocha et al., 2023). Research by Murugan & Saji (2021) proved that gasified syngas can be used as a thermal energy source for cassava (tapioca) drying equipment. In addition, Ukpanyang and Terrados (2022) examined transportation decarbonization using hydrogen (H_2) derived from biomass-gasified syngas. The results showed that converting syngas to hydrogen can reduce emissions by up to 65% compared to gasoline and has an energy production cost 15–20% lower than that of hydrogen electrolysis. Therefore, this research is relevant to the development of new and renewable energy (NRE) in Indonesia, particularly in the utilization of forestry biomass.

4. Conclusion

The results of this study demonstrate that rubber wood pellets (*Hevea brasiliensis*) exhibit favorable fuel properties for thermochemical conversion in a downdraft gasifier. The gasification process produced a synthesis gas dominated by 17–20% CO, 10–12% H_2, 8–10% CO_2, 1–2% CH_4, and less than 1% O_2, indicating that both surface oxidation and subsequent reduction reactions proceeded efficiently under stable operating conditions. A progressive increase in reactor temperature from 200 °C to 600 °C led to a marked improvement in syngas quality, reflected in its lower heating value (LHV), rising from 734.81 kcal/m^3 to 780.85 kcal/m^3. This enhancement suggests that elevated temperatures promote the formation of high-energy gas species, particularly CO and H_2, thereby increasing the fuel gas's energetic potential. Characterization of ash (solid residue) revealed a substantial decline in moisture and volatile fractions, accompanied by an increase in ash content exceeding 70%. The relatively low fixed-carbon fraction (4–6%) confirms that most of the combustible carbon in the pellets was successfully converted into syngas. Collectively, these results substantiate that rubber wood pellets function as an efficient biomass fuel, while the resulting ash retains potential value for secondary applications.

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