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The Effect of KNO_3 Addition on the Properties of Coconut Shell Charcoal Briquettes

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Abstract

This research investigates the effects of incorporating potassium nitrate (KNO_3) into coconut shell charcoal briquettes, emphasizing their physical and chemical characteristics. Briquettes were manufactured utilizing coconut shell charcoal powder, tapioca flour as a binder, and different concentrations of KNO_3 (0% and 10%) as an additive. The aim was to assess the impact of KNO_3 incorporation on the water content, ash content, volatile matter, fixed carbon, calorific value, and density of the briquettes. The findings indicated that incorporating KNO_3 resulted in elevated water and ash content, adversely affecting combustion efficiency. Briquettes with increased water content demonstrated reduced mechanical strength and inferior combustion performance. The addition of KNO_3 led to an increased volatile matter content, facilitating ignition of the briquettes while simultaneously resulting in higher smoke emissions. The addition of KNO_3 resulted in a decrease in fixed carbon content, which subsequently lowered the calorific value of the briquettes. The formulation without KNO_3 produced the densest briquette, suggesting that including KNO_3 reduced the briquette density. The inclusion of KNO_3 enhances ignition characteristics; however, it concurrently diminishes the briquettes' overall quality regarding combustion efficiency and calorific value. The Briquette B_1 exhibited the highest results in this investigation, with water content, ash content, volatile matter, fixed carbon content, calorific value, and density values of 4.97%, 1.87%, 17.25%, 80.88%, 7014 Cal/g, and 0.90 g/cm³, respectively.

INTRODUCTION

A briquette is a solid fuel made from organic materials, such as charcoal, biomass, or agricultural waste, which undergoes a compaction or densification process. This process aims to produce a more compact product that is easier to handle and has a higher calorific value (Chinyere et al., 2014; Deshannavar et al., 2018; Kaur et al., 2019; Kumar, 2020). The production of briquettes from coconut shell charcoal helps prevent environmental pollution and increases the economic value of coconut processing waste. Briquette products made from coconut shell charcoal are highly sought after in European, American, and Middle Eastern markets. In Europe and America, these briquettes are primarily used as fuel for barbecues, while in the Middle East, they

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are used as fuel for sissa (Wulandari et al., 2021). Briquette products from Indonesia are highly sought after in international markets due to their high calorific value (6,700-7,100 Cal/g) (Tsani et al., 2022), being smokeless, non-toxic, providing long-lasting embers, and being environmentally friendly (Iskandar et al., 2019). From 2022 to 2024, the total export value of coconut shell charcoal briquettes reached 469,374,397.8 USD, approximately IDR 7,665,822,664,216.32.

Coconut shell charcoal briquettes are typically composed of coconut shell charcoal, a binder, and water. The binder utilized in briquette production influences several critical properties, such as density, compressive strength, calorific value, moisture content, and ash content. In the absence of a binder, charcoal briquettes exhibit an increased tendency to disintegrate. Different binders, including molasses (Waluyo et al., 2023), cow manure (Waluyo et al., 2023), horse manure (Waluyo et al., 2023), cassava starch (Anis et al., 2024; Lubwama et al., 2020), tapioca starch (Anis et al., 2024, 2025), wheat starch (Velusamy et al., 2021), modified cassava flour (Anis et al., 2024), and corn starch (Yirijor & Bere, 2024), have been employed in briquette production.

Export-quality charcoal briquettes are required to comply with various internationally recognized standards, including the Indonesian National Standard (SNI) and those established by countries such as Japan and the United States. Research by Anis et al. (2024) indicates that export-quality charcoal briquettes should possess a moisture content of less than 8% to achieve optimal combustion efficiency. Ash content should be maintained below 8%, as elevated levels can diminish calorific value, interfere with the combustion process, and cause accumulation in combustion equipment. The optimal volatile matter content for the export market is between 15% and 30%, as increased volatile matter facilitates ignition instead may result in higher smoke emissions. A high fixed carbon content, between 60% and 80%, signifies quality, as it produces more stable and efficient energy during combustion. Briquettes are required to possess a calorific value exceeding 5000 Kcal/kg to comply with export quality standards, as an elevated calorific value correlates with increased energy release during combustion. A briquette density of at least 1 g/cm³ signifies superior quality, resulting in enhanced stability and reduced susceptibility to crumbling. Briquettes should exhibit high compressive strength and durability against damage from impact, as assessed by drop tests or friability tests. Briquettes exhibiting high compressive strength and low friability demonstrate enhanced durability and improved handling characteristics. Briquettes conforming to these specifications exhibit high quality and are prepared for international marketing, demonstrating significant competitiveness in the European, American, and Middle Eastern markets (Anis et al., 2024).

Investigating rapid ignition charcoal briquettes is essential for optimizing combustion efficiency, conserving energy, and increasing user convenience. Numerous additives, including bentonite, processed drilling mud, inorganic metal nitrates, nitrites, chlorates, perchlorates, permanganates, manganates, perbromates, chromates, dichromates, and peroxides, are utilized to manufacture fast-igniting charcoal briquettes (Jabrzemski & Nawara, 1994; Richardson & Hardisty, 1969). These briquettes facilitate efficient combustion by rapidly generating heat with minimal ignition time, decreasing energy waste. Nevertheless, the utilization of KNO_3 as an oxidizer in the briquette production process has not been thoroughly investigated. Therefore, this study aims to assess how adding KNO_3 affects the briquettes' density, calorific value, fixed carbon, ash content, water content, and volatile matter. This study aims to enhance understanding of the impact of KNO_3 on the physical and chemical properties of briquettes, while also contributing to improvements in combustion efficiency and briquette quality for applications including heating and industrial fuel. This research may contribute to the attainment of multiple Sustainable Development Goals (SDGs), specifically SDG 7 (Affordable and Clean Energy) by advancing the development of more efficient and eco-friendly fuels, and SDG 12 (Responsible Consumption and Production) by promoting the use of biomass waste and minimizing energy waste.

MATERIALS AND METHOD

The manufacturing process of coconut shell charcoal briquettes begins with the careful selection of key raw materials, including coconut shell charcoal that is ground into fine powder, potassium nitrate (KNO_3) as an additive to enhance

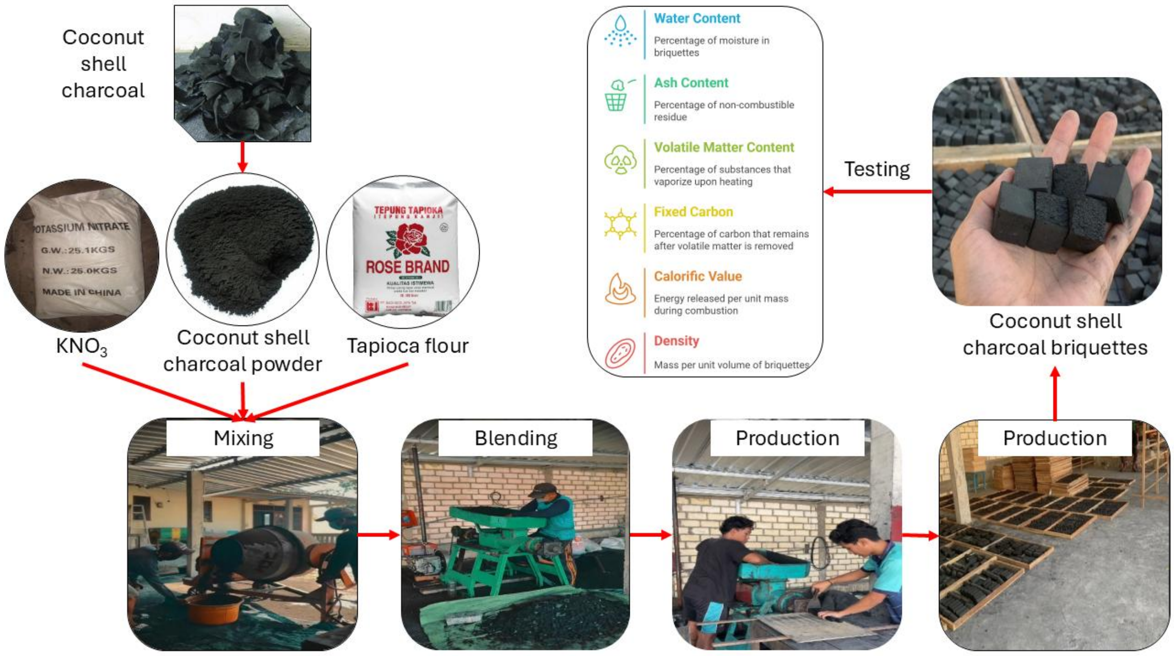

Figure 1. The experimental setup.

combustion characteristics, water, and tapioca flour as a binding agent. The experimental setup in this study is illustrated in Figure 1. This study explores the production of briquettes with different material compositions. For specimen B_1, the composition consists of 90% coconut shell charcoal powder, 10% tapioca flour, and 0% KNO_3. Meanwhile, specimen B_2 comprises 80% coconut shell charcoal powder, 10% tapioca flour, and 10% KNO_3. Following material selection, the components are mixed thoroughly in a mixer machine to create a homogeneous blend. During this process, water is gradually incorporated to achieve the desired consistency. After the initial mixing, the blend is transferred to a blending machine to ensure a more uniform mixture, ensuring the thorough integration of all components.

The homogeneous mixture is then transferred into a briquette molding machine, where it is compacted under control to form solid briquettes. The compaction step is vital to ensure the briquettes retain their shape and function effectively in combustion applications. After molding, the briquettes are arranged for the drying phase, which is designed to reduce their moisture content and improve combustion efficiency. In this study, the drying process is conducted manually through sun-drying for 24 hours. Upon completing the drying process, the briquettes are tested to determine their physical and chemical properties, including moisture content, ash content, fixed carbon content, calorific value, and density.

The water content test aims to determine the amount of water remaining in the briquettes, as high water content can reduce combustion efficiency by consuming energy to evaporate the water before the burning process begins (Aal et al., 2023; Oyelaran et al., 2018). Therefore, maintaining the moisture content at a minimum level is crucial for optimal energy production. The moisture content determination follows ASTM D-3173-17 (Anis et al., 2024, 2025). The ash content test is performed by measuring the remaining solid residue after the briquettes undergo complete combustion. The ash content value reflects the cleanliness of the fuel during combustion; a low ash content indicates better briquette quality, as it produces less residue. In contrast, briquettes with high ash content tend to leave crusts or deposits, which can reduce combustion efficiency (Kebede et al., 2022). The ash content test refers to ASTM D-3174-12 (Anis et al., 2024, 2025). Next, the volatile matter test is conducted to measure the fraction that easily vaporizes and escapes as gas when the briquette begins to burn. A higher volatile matter content results in a quicker ignition process, making the briquettes easier to ignite, which is crucial for initial combustion efficiency (Handayani et al., 2019; Otieno et al., 2022). The volatile matter test follows ASTM D-3175-17 (Anis et al., 2024, 2025). The fixed carbon test measures the portion of the briquettes that does not combust immediately during the initial stages but gradually contributes heat during the combustion process. A higher fixed carbon content indicates greater energy potential, as the material burns more slowly and steadily. This value is also positively correlated with the total calorific value of the briquettes (Kipngetich et al., 2023; Rahmawati et al., 2023). The fixed carbon determination follows ASTM D-3172-13 (Anis et al., 2024, 2025). The calorific value test measures the amount of heat energy released when a unit mass of the briquette is completely burned. The higher the calorific value, the greater the energy that can be utilized from the briquette (Azizah & Sindhuwati, 2022; Maulina et al., 2021). This test is conducted using a bomb calorimeter and follows ASTM D-240, serving as a primary indicator in determining the feasibility of briquettes as an alternative fuel (Anis et al., 2024, 2025). Additionally, the briquette density test measures how compact the particle arrangement is within the briquette. Briquettes with high density have a more compact structure, making them more stable, less likely to crumble, and able to burn for a longer duration (Kabok et al., 2018; R. S et al., 2020; Sunardi et al., 2019). Dense briquettes typically produce more controlled flames and consistent temperatures. Density measurement is conducted according to ASTM B-311-17 (Anis et al., 2024, 2025).

RESULTS AND DISCUSSION

Figure 2 presents the impact of KNO_3 addition on the water content in coconut shell charcoal briquettes. The data shown in the graph reveals that Briquette B_1 has a water content of 4.97%, while Briquette B_2 demonstrates a higher water content of 8.31%. It is generally recommended that the water content of briquettes should not exceed 8% to ensure optimal quality (Anis et al., 2024, 2025). Consequently, the incorporation of KNO_3 in coconut shell charcoal briquettes could result in water levels surpassing the recommended limit. Excessive water content can adversely affect the characteristics of the briquettes, particularly their mechanical strength and combustibility. Briquettes with higher water content tend to exhibit reduced mechanical strength and present challenges in burning efficiency. This is because the water present in the briquettes absorbs heat that would otherwise be utilized for the combustion process, thus diminishing their burning efficiency (Nurba et al., 2019).

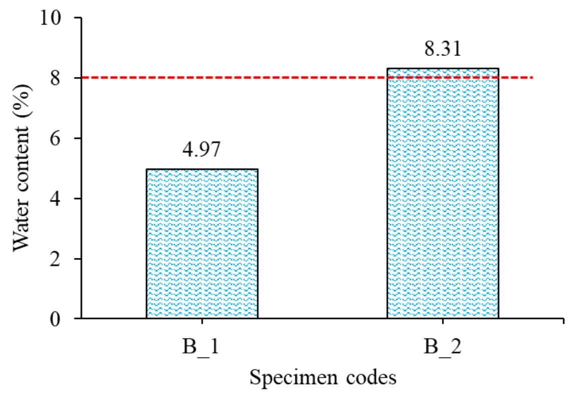

Figure 2. Effect of KNO_3 addition on the water content of coconut shell charcoal briquettes.

The findings of this study align with the research conducted by Snigdhya et al. (2024). The study indicated that briquettes with elevated water content exhibit increased ignition difficulty and lead to a reduction in overall energy efficiency. High water content in briquettes causes a portion of the energy generated during combustion to be used for evaporating the water. In contrast, briquettes with lower moisture levels burn more efficiently because more energy is dedicated to generating heat rather than evaporating water. Briquettes with high water content, such as those made from corn flour (22.77%), burn less efficiently, producing more smoke, lower heat output, and requiring a longer drying period before they can be effectively used as fuel. Conversely, briquettes with a lower water content, such as those made with cassava flour, are better suitable for use as fuel due to their increased efficiency, reduced fume production, and increased heat production (Snigdhya et al., 2024). The research by Pari et al. (2023) indicates that incorporating binders or other additives during briquette production can enhance the levels of water, ash, and volatile matter. The presence of these components can reduce the briquettes' calorific value relative to pure charcoal. The calorific value quantifies the energy released during the combustion of a substance. Consequently, increased water, ash, and volatile matter levels in briquettes correlate with diminished combustion quality and reduced burning efficiency. The study indicates that reduced water content in briquettes enhances product efficiency. Briquettes exhibiting reduced water content demonstrate a diminished specific heat capacity, suggesting that they necessitate less energy to elevate their temperature during combustion. The combustion process of briquettes with reduced water content is more efficient, requiring less energy to initiate and maintain burning.

Figure 3 depicts the effect of incorporating KNO_3 on the ash content of coconut shell charcoal briquettes. This study's results indicate that Briquette B_1 possesses an ash level of 1.87%, instead Briquette B_2 exhibits a significantly elevated ash content of 24.38%. The incorporation of KNO_3 into the coconut shell charcoal briquettes leads to a substantial elevation in their ash content. High-quality briquettes typically include an ash percentage below 8% (Anis et al., 2024, 2025). A higher amount of ash correlates with a diminished quality of the briquette. Mencarelli et al. (2023) research demonstrates that increased ash content in fuel materials adversely affects the heating value and overall fuel efficiency. The elevated ash content diminishes calorific value, reducing energy release during combustion. Moreover, elevated ash content can result in fouling of grilling apparatus, characterized by the buildup of ash and other residues on the cooking equipment, impeding effective heat transfer. The accumulation may lead to soot and slag, unwelcome by-products that impair the functionality of grills or stoves, requiring increased cleaning and maintenance. Consequently, minimizing ash level is crucial for enhancing fuel efficiency and prolonging the durability of grilling apparatus. The study by Wulandari et al. (2024) highlights the efficacy of employing palm kernel shell waste, especially in the fuel industry, for producing charcoal briquettes. Palm kernel shells have a high calorific value and low ash content, rendering them a practical resource for energy generation with minimum combustion by-products.

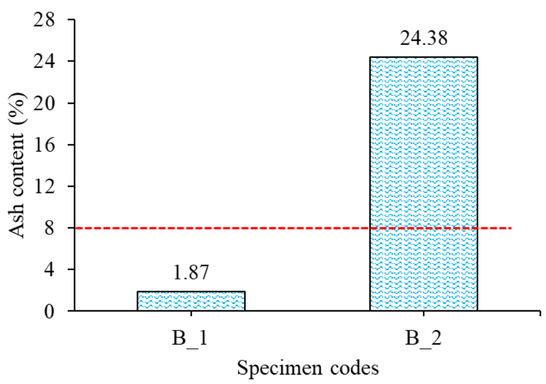

Figure 3. Effect of KNO_3 addition on the ash content of coconut shell charcoal briquettes.

The influence of adding KNO_3 on the volatile matter levels in coconut shell charcoal briquettes is shown in Figure 4. This study's results indicate that Briquette B_1 contains 17.25% volatile matter, whereas Briquette B_2 has a notably higher volatile matter level of 33.35%. The incorporation of KNO_3 into the coconut shell charcoal briquettes results in a significant enhancement in their volatile matter content. High-quality briquettes typically include a volatile matter content between 15% and 30% (Anis et al., 2024, 2025). As the volatile content increases, the quality of the briquette generally diminishes (Kebede et al., 2022). Hakim et al. (2025) found that briquettes containing a high percentage of volatile materials generate considerable smoke and ignite more readily. This results from the volatile substances in the briquettes that swiftly vaporize upon heating, producing increased smoke and enhancing combustion. Briquettes with reduced volatile matter levels are relatively more challenging to ignite, although they benefit from more uniform burning. These briquettes yield a more efficient and stable combustion, emitting less smoke and exhibiting a more regulated burning rate. The pure charcoal particle briquette has the lowest volatile matter content at 41.2 wt%, as demonstrated by the research conducted by Ajimotokan et al. (2019). Meanwhile, the pure pine sawdust briquette has a significant volatile matter level at 78.1 wt%. This suggests that augmenting the ratio of pine sawdust to the aggregated biomass results in an elevated percentage of volatile matter in the briquettes. An elevated volatile matter concentration is a crucial indicator of the fuel's ignition capability. An elevated volatile matter content in briquettes enhances igniting ease, yielding a more robust and uniform flame during combustion. This improves the briquette's thermal efficiency but increases smoke emission during combustion.

Figure 5 illustrates the impact of adding KNO_3 on the fixed carbon content in coconut shell charcoal briquettes. The results of this study indicate that Briquette B_1 contains 80.88% fixed carbon, while Briquette B_2 shows a considerably lower fixed carbon content of 42.28%. The addition of KNO_3 to the coconut shell charcoal briquettes

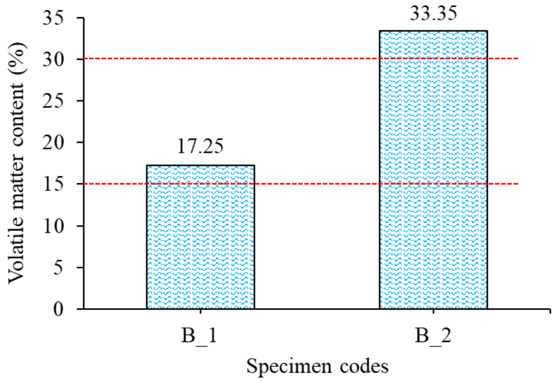

Figure 4. Effect of KNO_3 addition on the volatile matter content of coconut shell charcoal briquettes.

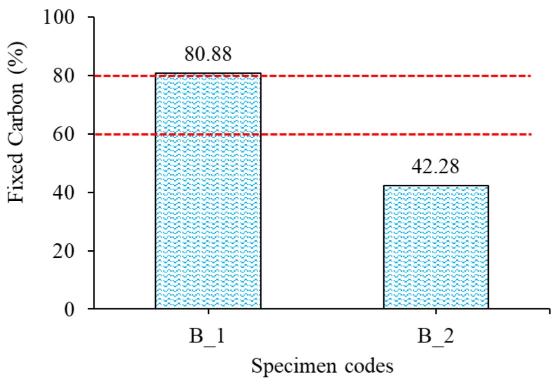

Figure 5. Effect of KNO_3 addition on the fixed carbon of coconut shell charcoal briquettes.

leads to a significant decrease in their fixed carbon levels. High-quality briquettes generally have a fixed carbon content ranging from 60% to 80% (Anis et al., 2024, 2025). The higher the fixed carbon content, the better the quality of the briquette; conversely, a lower fixed carbon content signifies a decrease in briquette quality (Manyuchi et al., 2018). The research conducted by Manyuchi et al. (2018) investigates the correlation between fixed carbon content and the characteristics of coal-saw dust-molasses briquettes. Fixed carbon denotes the solid combustible residue that persists after the briquette is heated, whereas volatile matter is emitted during heating. The results indicate that the maximum fixed carbon content, between 74% and 76%, was recorded with a sawdust composition of 25 wt.% and a molasses binder concentration of 8 wt.%. The rise in fixed carbon content results from the improved interlocking of coal, sawdust, and molasses particles during the briquetting process, thereby enhancing the structural integrity of the briquette. The elevated fixed carbon content correlates with an improved calorific value, indicating that the briquette possesses a greater capacity for heat generation upon combustion. The findings suggest that optimizing the composition of sawdust and molasses may substantially improve the performance of coal-sawdust-molasses briquettes. Fatimah et al. (2023) highlight that fixed carbon is an essential factor in assessing the quality of briquettes. A higher fixed carbon content typically signifies improved briquette quality. Recipes with higher fixed carbon content typically generate less smoke during combustion. The fixed carbon represents the part of the briquette that persists once the volatile matter has been expelled during heating. Briquettes with higher fixed carbon content are more efficient and environmentally friendly due to the stability of fixed carbon, which makes them less susceptible to emissions during combustion and results in reduced smoke production. As a result, enhancing the fixed carbon content during briquette production can elevate the quality and environmental sustainability of the briquettes.

Figure 6 depicts the effect of incorporating KNO_3 on the calorific value of coconut shell charcoal briquettes. This study's results indicate that Briquette B_1 possesses a calorific value of 7014 Cal/g, whereas Briquette B_2 exhibits a markedly lower calorific value of 4240 Cal/g. The incorporation of KNO_3 into the coconut shell charcoal briquettes results in a significant reduction of their calorific value. Excellent briquettes generally possess a calorific content of over 5000 Cal/g (Anis et al., 2024, 2025). Specimen B_1 exhibits a high calorific value due to its low water, ash, and volatile matter content. Additionally, this specimen's fixed carbon content is significantly higher than that of specimen B_2. Lestari et al. Hanum et al. (2021) discovered that a range of biomass waste materials, including coconut shell, livestock manure, sawdust, bagasse, and rice husk, are frequently used to manufacture biomass briquettes. Nonetheless, despite their common application, the calorific value of these briquettes is still comparatively low. The primary reasons are the significant water content, ash content, and volatile matter in biomass materials. The presence of high-water content diminishes the energy efficiency of briquettes, since energy is needed to evaporate the moisture during the combustion process. Similarly, a high ash content can lessen the heating value and elevate the residue remaining post-combustion. In contrast, excess volatile matter may lead to incomplete combustion, consequently reducing the calorific value. The higher the fixed carbon content, the higher the calorific value of the briquette. Nonsawang et al. (2024) determined that fixed carbon is a vital parameter associated with the thermal characteristics of briquettes, with increased fixed carbon content typically corresponding to an elevated calorific value. In their analysis, specimen TC2 demonstrated the highest fixed carbon content, signifying a substantial calorific value. In contrast, specimen TB1 had the lowest calorific value, attributable to its diminished fixed carbon content.

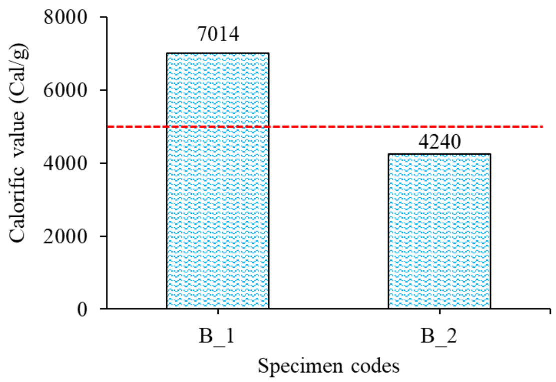

Figure 6. Effect of KNO_3 addition on the calorific value of coconut shell charcoal briquettes.

Figure 7 demonstrates the impact of KNO_3 addition on the density of coconut shell charcoal briquettes. Briquette B_1 exhibits a density of 0.90 g/cm³, whereas Briquette B_2 demonstrates a slightly reduced density of 0.74 g/cm³. Incorporating KNO_3 appears to decrease the density of the coconut shell charcoal briquettes. Briquettes of high quality typically exhibit a density exceeding 0.48 g/cm³. Consequently, B_1, displaying a higher density, indicates superior quality compared to B_2, which has a lower density due to incorporating of KNO_3. The reduction in density noted in this study can be ascribed to the enhancement of water content. Incorporating KNO_3 as an additive lead to increased water content in the briquettes. As the water content rises, the density of the briquettes diminishes. This discovery corresponds with the study by Saeed et al. (2021), which observed that elevated water content in raw materials facilitates the expansion of briquettes due to heightened residual stress post-production, resulting in elastic rebound or expansion. A comparable rationale pertains to this study; wherein briquette density reduces as water content increases. Adam et al. (2021) established that reducing water content in Charcoal Briquettes produced from Waste Rice Straw positively correlates with density and compressive strength. The study observed that a decrease in water content corresponded with an increase in the density of the briquettes. This indicates that a reduced water content in the briquettes correlates with increased density and compressive strength, enhancing briquette quality in terms of durability and pressure resistance.

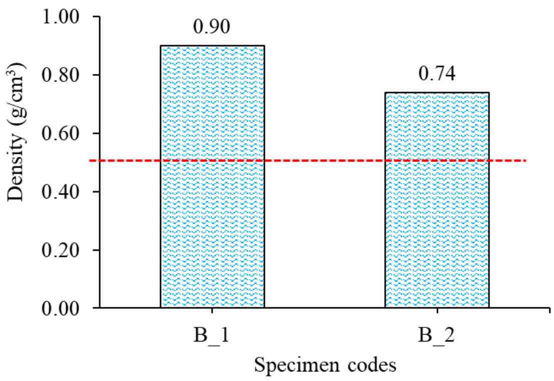

Figure 7. Effect of KNO_3 addition on the density of coconut shell charcoal briquettes.

CONCLUSION

This research examines the impact of KNO_3 addition on the physical and chemical characteristics of coconut shell charcoal briquettes. Two briquette specimens were evaluated based on their material compositions: B_1 comprised 90% coconut shell charcoal, 10% tapioca flour, and 0% KNO_3, while B_2 consisted of 80% coconut shell charcoal, 10% tapioca flour, and 10% KNO_3. The experimental results indicated that incorporating KNO_3 had significantly affected the briquettes' water content, ash content, volatile matter, fixed carbon, calorific value, and density. The research indicated that Briquette B_1, without KNO_3, demonstrated enhanced combustion properties, including decreased water content, lower ash content, and increased fixed carbon and calorific value in comparison to Briquette B_2, which included KNO_3. The inclusion of KNO_3, an oxidizing agent, increased the volatile matter content, facilitating easier ignition of the briquettes, although it also resulted in higher smoke production. Briquette B_1 exhibited a superior calorific value of 7014 Cal/g due to its higher fixed carbon content, in contrast to Briquette B_2, which had a calorific value of 4240 Cal/g. This underscores the essential function of fixed carbon in assessing the energy potential of briquettes. The addition of KNO_3 led to increased water content and reduced density, indicating that excessive moisture in the briquettes may adversely impact their combustion efficiency and mechanical strength. The results align with existing studies, suggesting a correlation between lower water content and higher fixed carbon with enhanced fuel quality.

The best results in this study were recorded for Briquette B_1, exhibiting water content of 4.97%, ash content of 1.87%, volatile matter of 17.25%, fixed carbon content of 80.88%, calorific value of 7014 Cal/g, and density of 0.90 g/cm³. The study highlights the necessity of balancing the components utilized in briquette production to enhance performance. KNO_3 enhances combustion properties, including ignition and burn efficiency, however it also influences critical factors like density and ash content, which require careful management to maintain the optimal quality of briquettes.

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