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Performance Evaluation of Biomass Briquettes Produced from Mixed Tropical Hardwood Sawdust Using Different Binding Agents

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ABSTRACT

The increasing demand for sustainable and environmentally friendly energy sources has stimulated interest in the utilization of biomass residues for renewable fuel production. This study evaluated the production and fuel quality of biomass briquettes manufactured from mixed tropical hardwood sawdust of Tectona grandis, Dalbergia sissoo, and Acacia nilotica using different binding agents. Equal proportions of the sawdust were blended to produce three combinations, namely Tectona grandis + Dalbergia sissoo, Tectona grandis + Acacia nilotica, and Dalbergia sissoo + Acacia nilotica. The briquettes were prepared through mechanical compaction, oven dried, and analyzed for volatile matter, ash content, fixed carbon, and calorific value following ASTM E711-87 procedures. A Randomized Complete Block Design (RCBD) was employed, and the experimental data were analyzed using two-way analysis of variance and Fisher's Least Significant Difference test at a 5% level of significance. the potential of mixed tropical hardwood sawdust as a valuable feedstock for producing high-quality biomass briquettes, thereby promoting efficient utilization of wood-processing residues and supporting sustainable renewable energy development.

Keywords: *Briquette, Combustion, Calorific Values, Binding Agents, Wood.*

I. INTRODUCTION

Renewable energy, and biomass energy in particular, is attracting a lot of attention right now due to rising global concern about the environmental impacts, especially climate change, caused by fossil fuel use, as well as the instability of the fossil fuel market and the necessity of a reliable energy source to support economic growth. There is a significant chance to use biomass as a feedstock for bioenergy as it is one of the most prevalent and readily available renewable energy sources. Bioenergy can be produced from a variety of sources, including crop residues (such as corn stover and rice husk), wood waste (from forestry and industry), food and paper industry residues, municipal solid waste (MSW), and dedicated energy crops (like short-rotation perennials). Many developing nations' primary renewable energy source has long been biomass fuels like firewood, twigs, and charcoal.

One of the most promising options for cooking fuels is agricultural wastes, which include sawdust, rice husk, maize stover, cotton stalk, groundnut husk, and other similar materials. This is because there are large quantities of this trash available each year. However, due to their low bulk density, limited heat release, and considerable smoke generation, these biomass wastes in their natural state present significant challenges when it comes to using them as fuel. Their raw state is inconvenient due to all of these qualities, which also make them hard to store, transport, and use. Briquetting is a technique that may be used to increase the thermal value of biomass. Fuel briquettes with improved handling features and increased volumetric calorific value are produced by densifying loose biomass in this way. Briquettes play a crucial role in expanding the use of biomass for the generation of both heat and power.

The potential of suitable technology for wood waist utilisation is demonstrated by the manufacturing of briquettes from sawdust. Briquettes, if mass-produced and easily available, might supplement firewood and charcoal in home cooking and agricultural and industrial settings. Additionally, briquettes outperform fuel wood in a number of respects, including increased heat intensity, cleanliness, use, and storage space requirements. The majority of countries where briquette operations are successful are industrialised nations. Due to operational and marketing issues, the briquettes were not generally pushed, particularly in the household sector, despite their tremendous potential as an alternative to firewood and charcoal. It is important to characterise biomass or agro-waste briquettes by assessing their density, ash content, volatile matter, heating value, and moisture content in order to use them sensibly and efficiently as fuel.

II. REVIEW OF LITERATURE

Umeocho, Chinyere et al., (2024) The purpose of this study was to find out how to make sawdust briquettes out of wasted mung beans more efficiently. In order to study the impact on mechanical parameters such as hardness, porosity index, durability, compressive strength, bulk density, and mass, sawdust briquettes were mixed with mung bean waste (MB). In order to determine if the sawdust and mung bean waste were suitable for biofuel production, proximate studies were performed on both materials before they were mixed. These analyses included moisture content, fixed carbon, ash content, volatile matter content, and calorific value. All analyses were conducted according to industry standards. Using a cassava starch binder, the briquettes were made with several ratios of sawdust to biomass, including 100%:0%, 70%:30%, 50%:50%, 30%:70%, and 0%:100%. The analysis revealed that the sawdust had a moisture content of 31.479±0.00% and the mung bean waste of 7.1796±0.00%. The ash content of the sawdust was 1.070±0.001%, whereas that of the mung bean waste was 8.25±0.002%. For sawdust, the volatile matter was 16.610±0.01%, and for mung bean waste, it was 22.976±0.00%.Sawdust had a fixed carbon content of 50.841±0.00% and mung bean waste had a fixed carbon level of 61.57±0.00%.The sawdust had a calorific value of 20.30 MJ/kg and the mung bean waste was 18.60 MJ/kg. From 44.1±0.01 (consisting of 70% sawdust and 30% biomass) to 61.1±0.90 (100% biomass), the briquette's mass rose as the biomass load increased. From 0.234±0.00 g/m3 (70% sawdust+30% biomass) to 0.421±0.007 g/m3 (100% biomass), the bulk density of the sawdust briquette rose as the biomass load increased. With a value ranging from 366±0.57 (70% sawdust + 30% MB) to 394±0.00 (100% MB), the hardness of the sawdust briquette rose as the biomass load increased. The briquette's porosity diminished as the biomass load rose, starting at 0.20±0.01 (100% MB) and going up to 0.97±0.01 (30% MB + 70% sawdust). From 0.89±0.00 (70 percent sawdust + 30 percent biomass) to 0.79±0.01 (100 percent biomass), the briquettes' durability declined as the biomass load increased. At 70% sawdust + 30% biomass, the compressive strength of the briquettes was 2.78±0.01 N/mm2. At 30% sawdust + 70% biomass, it was 3.42±0.38 N/mm2. At 100% biomass, it decreased to 2.44±0.02 N/mm2. It follows that the mechanical qualities of sawdust briquettes may be improved with the use of Mung bean waste, leading to increased efficiency.

Umeocho, Chinyere et al., (2024) The combustion characteristics of briquettes made from carbonised danta wood sawdust and those made from uncarbonized danta wood sawdust were examined in this study. The former was made by combining mung bean shell (MBS) with the latter. An assortment of sawdust to biomass ratios (100:0, 70%:30%, 50%:50, 30%:70%, and 100%:0) were used to generate the briquettes. The binder utilised was cassava starch. Use of conventional methodologies allowed for the calculation of proximate analyses (volatile matter, fixed carbon, moisture, and ash content) as well as combustion characteristics (specific fuel consumption, thermal efficiency, ignition time, burning rate, burning duration, and calorific value). The analysis revealed that the samples made entirely of sawdust briquettes had the lowest moisture content, with carbonised sawdust having a value of 4.74±0.00 and uncarbonized sawdust having a value of 6.76±0.02. In terms of fixed carbon, the 100% uncarbonized sawdust briquette samples had a value of 68.93±0.02 MJ/Kg, while the carbonised samples had a value of 87.46%. The ash content was 3.70±0.00%, while the volatile matter was 20.61±0.00 and 5.61±0.04 MJ/Kg, respectively. The calorific value was 29.401±0.0 MJ/Kg, and 32.532±0.05 MJ/Kg, respectively.For samples of carbonised sawdust briquettes, the igniting time decreases as biomass load increases, but for samples of uncarbonized sawdust, it increases. For the carbonised sawdust briquette samples, the burning time decreased from 86±0.57 minutes (70% sawdust + 30% biomass) to 70±0.57 minutes (100% biomass). In contrast, for the uncarbonized samples, the burning time varied from 68±0.00 minutes (70% sawdust + 30% biomass) to 71.6±0.57 minutes (30% sawdust + 70% biomass), and finally dropped to 68±0.57 minutes (100% biomass load). As biomass load rose, the burning rate of carbonised briquette samples declined and that of uncarbonized briquette samples increased. Both the carbonised and uncarbonized sawdust briquette samples showed a decline in specific fuel consumption as the MBS load increased. The thermal efficiency of the sawdust briquette samples that were 100% carbonised was 8.78, whereas the sample that was uncarbonized had a value of 16.47. Based on the improved combustion qualities compared to the uncarbonized sawdust samples, it can be inferred that a fuel blend consisting of carbonised sawdust and mung bean shell will yield superior results.

Jude, Ohagwu et al., (2022) Sawdust briquettes that had an Abelmoschus esculentus (okra) waste binder ingredient had their fuel and physicomechanical characteristics measured. The carbon, oxygen, and hydrogen contents of the briquettes were ascertained using elemental analysis. Factors such as ash content, heating value, density, stability, durability, resistance to shattering, and volatile matter are included. We used Abelmoschus esculentus compositions of5%,10%,15%, and 20% by weight. With the lowest ash level of 1.59% and moisture content of 7.6%, respectively, the 5% Okra briquette exhibited the greatest volatile matter and heating value of 85.46% and 17,820 kJ kg-1, respectively. The croquette containing 5% Abelmoschus esculentus (okra).

Niño, Andrés et al., (2020) The promotion of various forms of agricultural, forestry, and industrial waste as a sustainable and renewable energy source is part of the effort to meet the world's energy demands. One technologically and economically viable method of producing energy is the generation of solid fuels from biomass by densifying it to enhance its mechanical and energetic qualities. A number of variables influence the ultimate behaviour of the briquettes, which is why studying biomass mixtures is an active area of research. The effect of combining two biomasses, specifically rice husk and pine sawdust, on the mechanical characteristics of briquettes made from this mixture is investigated in this study. The experimental parameters in this mixed factorial design are the process temperature, the ratio of rice husk biomass to total mass, and the duration of compaction. The chosen independent parameters allow for the development of experimental statistical models that, when applied to the briquettes, provide a partial explanation for the behaviour of various responses that define their mechanical characteristics. For a compaction temperature of 110 °C and a proportion of rice husk that does not exceed 60% of the total biomass mixture in the briquette, it was determined that the mechanical durability of the briquettes is higher than 97.5%, meeting the existing standards such as DIN 51731, ITEBE SS187120, or ISO 17225-2. In order to get the right density and elasticity modulus in the briquettes, the compaction time was also statistically significant. The research findings are intriguing and can be used to develop the commercial procedure for densifying these two mixed biomasses.

Ogunleye, Motunrayo et al., (2019) Briquettes made from wood and agricultural byproducts were the focus of the investigation because of their potential for efficient combustion. Cow dung was utilised as a binder in various mixing ratios with Terminalia superba sawdust and banana leaves. Combustion tests were performed on the briquettes that were made using an automated press set at a constant compaction pressure of 1.77kN/m 2. The substrates were mixed in the following ratios: 5:1:4, 4:4:2, 3:2:5, and 2:5:3. It was found that the briquettes had combustion-related characteristics, including a certain amount of ash and volatile materials. The density after compression was 517.09 ± 35.40kg/í µí±¢3, while the density after relaxation was 55.81±1.80kg/í µí±¢3. The reduction in density, which indicates the rate at which the briquettes reduced in density, was 46.82±2.56kg/í µí±¢3. Briquettes with a 2:5:3 or 3:2:5 ratio exhibited superior combustion characteristics, according to the study's results.

Zhongyao, Cao et al., (2018) Charcoal briquettes made from biomass waste often have subpar physical qualities. An alternate method for producing charcoal briquettes from densified biomass briquettes by carbonisation was discussed in the article. Briquettes made from biomass, such as cotton stalk (CS), wood sawdust (WS), or a combination of the two, were carbonised in a fixed bed oven set at 400~600°C. The researchers looked at the physical characteristics of the charcoal briquettes that were made, as well as the changes in volume and mass of the biomass briquettes before and after carbonisation. Charcoal briquettes' physical characteristics, such as bulk density and compression strength, were shown to diminish at lower temperatures before increasing with higher ones. Volume shrinkage was greater in carbonised CS charcoal briquettes with superior physical characteristics compared to WS charcoal briquettes. Because of their co-pyrolysis features, CS and WS produced charcoal briquettes with worse physical attributes than anticipated.

Ogunjobi, Kayode & Gakenou, Oluwaseun (2018) The oil-palm manufacturing process and wood conversion both produce massive amounts of garbage. The careless disposal of waste materials poses a serious threat to the environment and causes widespread contamination. Making briquettes out of these byproducts will lessen the load on the forest estate, which in turn will help slow global warming. The researchers in this study found a way to turn trash into income by making briquettes out of palm kernel shell and sawdust from Albizia zygia. The palm kernel shell was densified with starch after being mixed with sawdust in varying ratios (60:0:40, 40:0:60, 50:0:50, 0:60:40, 0:40;60, 0:50:50, 70:10:20, 10:20:70, and 20:70:10) then sieved into three different mesh sizes of 0.5mm, 1mm, and 2mm. A number of combustion characteristics were identified, including the heating value, ash content, percentage of volatile matter, and fixed carbon. The combination of 20:70:10 had the lowest ash level (2.00±0.85%), whereas the palm kernel without sawdust (0:40:60) had the most volatile matter (75.50%±3.20%). The maximum volatile matter was created at 0:40:60, with the lowest carbon percentage measured at 70:10:20, and the highest at 30.00±2.45%. The heating value was 32971.00±11.10KJ/kg at the 20:70:10 sample ratio, with a close second at 10:20:70, and the lowest at 50:0:50, which had the greatest ash content, at 30391.17±616.67KJ/kg. There was a significant difference ($p<0.05$) between the effects of 0.5mm and 1.0mm and 2mm mesh size. Briquettes with the lowest ash content, maximum volatile matter, percentage carbon, and heating value were created by combining 2mm mesh size with 20% palm kernel shell, 70% sawdust, and 10% starch, according to the study.

Ajiboye, Tajudeen Kolawole et al., (2017) The relaxed densities of biomass briquettes made from sawdust and charcoal were the subject of this investigation. The briquetting process relied on cassava starch gel and orange peel as binder. The biomass materials, sawdust, and charcoal were mixed in five different ratios with 16.6% binder: 50:50, 60:40, 70:30, 80:20, and 90:10. The diameters of the particles were 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, and 1.0 mm. An analysis was conducted on the briquettes' igniting time, water boiling test, afterglow time, and shattered index. The best sizes and mixing ratios for producing briquette biomass were determined using descriptive tools. At a size of 1.0 mm and a mixing ratio of 90:10, the relax density for cassava starch gel binder and orange waste was 663.33 kg/m3, while the ignition time for cassava starch gel at a size of 0.2 mm and a mixing ratio of 50:50 was 19 seconds. In addition, at a size of 0.2 mm and a mixing ratio of 50:50, the water boiling time for cassava starch gel was 18.05 minutes, while for orange waste it was 15.00 minutes. The afterglow time, for both materials, was 321.00 seconds and 318.00 seconds, respectively, at a size of 0.2 mm and a mixing ratio of 60:40. With a 0.2 mm particle size and a 50:50 mixture, cassava starch gel and orange trash had the best shattered index retention rates of 98.21% and 96.71%, respectively.

III. MATERIALS AND METHODS

Material

The briquettes were made from sawdust gathered from several sawmill businesses. The wood used was from three tropical rainforest species: Tectona grandi, Dalbergia sissoo, and Acacia nilotica.

Methods of Briquette Production

There were three sets of material for briquette production. One set consisted of Tectona grandi and Dalbergia sissoo, the other set was Tectona grandi and Acacia nilotica, and the third set was AC, which was Dalbergia sissooa and Acacia nilotica. The sawdust from each set was thoroughly mixed in equal proportions. A moisture level of around 12% was achieved by sun-drying the sawdust. For the purpose of making briquettes, a variety of binding agents were mixed with the different combinations and then moulded using a manual press machine under high pressure. The next step was to dry the briquettes in an oven set to 1000 `C. The blend of wood species and different binding agents was replicated five times to make briquettes. The ballistic bomb calorimeter was used to re-burn them in order to ascertain their physical and calorific properties. To find out what the briquette samples contained in terms of volatile matter, ash, fixed carbon, and heating value, we used proximate analysis. Standards established by ASTM E711-87 were utilised.

Data Analysis

This study used a Randomised Complete Block Design (RCBD) layout. The sawdust mixes made by coupling the several types of wood were arranged in columns, while the binders were used to construct the blocks, or rows. A two-way analysis of variance was performed on the data at a probability threshold of 0.05. Means were split using Fisher's LSD technique when significant differences were found. We then ran some descriptive statistics on the data, which includes calculating the mean and standard error of the estimations. The statistical programme SPSS was used for all the analyses.

IV. RESULTS AND DISCUSSION

Table 1. Two-Way ANOVA for the Proximate Composition and Calorific Value of Biomass Briquettes Produced Using Different Binders and Sawdust Mixtures

Property	Source of Variation	SS	MS	F-value	P-value	F-critical
Volatile Matter (%)	Binders	1158.72	579.36	78.54	0.0001	4.46
	Sawdust Mixtures	26.81	13.41	1.82	0.214	4.46
	Error	66.38	7.38	–	–	–
	Total	1251.91	–	–	–	–
Ash Content (%)	Binders	248.36	124.18	18.93	0.0008	4.46
	Sawdust Mixtures	18.94	9.47	1.44	0.288	4.46
	Error	59.05	6.56	–	–	–
	Total	326.35	–	–	–	–
Fixed Carbon (%)	Binders	18.24	9.12	5.87	0.024	4.46
	Sawdust Mixtures	8.47	4.24	2.73	0.118	4.46
	Error	13.98	1.55	–	–	–
	Total	40.69	–	–	–	–
Calorific Value (kJ/kg)	Binders	8,624,520	4,312,260	156.82	<0.0001	4.46
	Sawdust Mixtures	148,620	74,310	2.70	0.120	4.46
	Error	247,530	27,503	–	–	–
	Total	9,020,670	–	–	–	–

Significant at $p < 0.05$; df = degrees of freedom.

A two-way analysis of variance (ANOVA) showed that the biomass briquettes' physicochemical and combustion properties were significantly affected by the binder type. With a p-value of 0.0001, there was a statistically significant difference in the volatile matter concentration among the binder treatments. There was also a statistically significant difference in the ash content ($F = 18.93$, $p = 0.0008$). There was a statistically significant variation in fixed carbon concentration among binder types ($F = 5.87$, $p = 0.024$), which contradicts several earlier findings. The significant statistical fluctuation was most pronounced in the calorific value ($F = 156.82$, $p < 0.0001$).

In contrast, there were no statistically significant variations in volatile matter ($F = 1.82$, $p = 0.214$), ash content ($F = 1.44$, $p = 0.288$), fixed carbon ($F = 2.73$, $p = 0.118$), or calorific value ($F = 2.70$, $p = 0.120$) among the various sawdust mixes made from the chosen wood species.

Table 2: Mean Proximate Composition and Calorific Value of Biomass Briquettes Produced from Mixed Tropical Hardwood Sawdust

Wood Sawdust Mixture	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)	Calorific Value (kJ/kg)
AB (Tectona grandi + Dalbergia sissoo)	74.86 ± 1.42	17.84 ± 0.91	12.48 ± 0.76	19,186 ± 164
BC (Tectona grandi + Acacia nilotica)	72.95 ± 1.26	18.56 ± 1.03	13.42 ± 0.69	19,548 ± 178
AC (Dalbergia sissooa + Acacia nilotica)	76.18 ± 1.37	19.73 ± 0.88	10.96 ± 0.58	18,954 ± 152
Mean	74.66 ± 1.35	18.71 ± 0.94	12.29 ± 0.68	19,229 ± 165

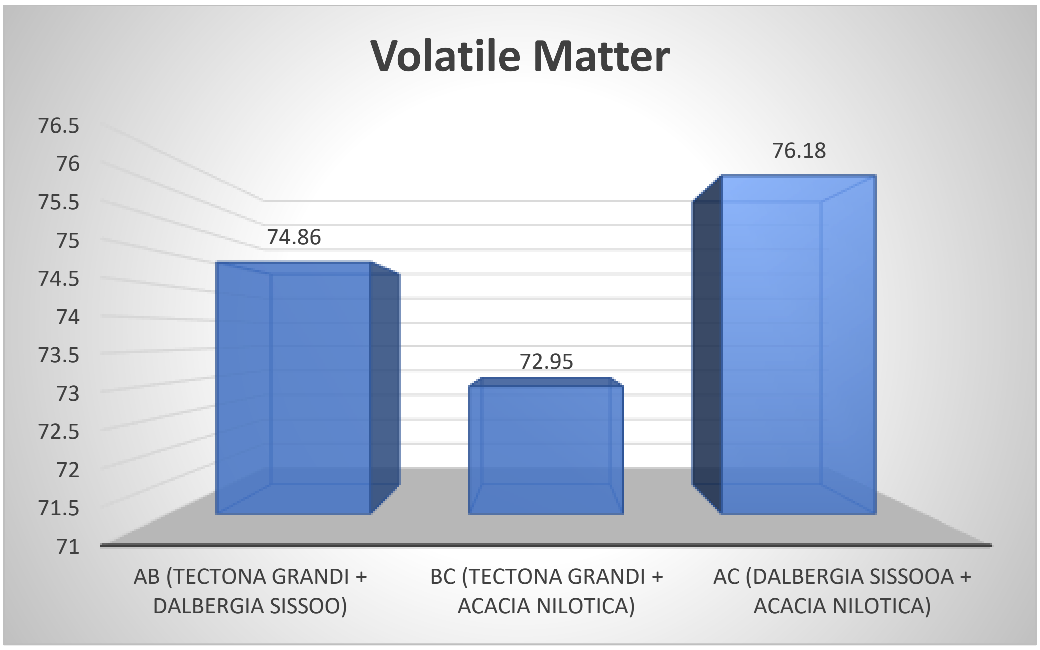

Figure 1: Volatile matter of Biomass Briquettes Produced from Mixed Tropical Hardwood Sawdust

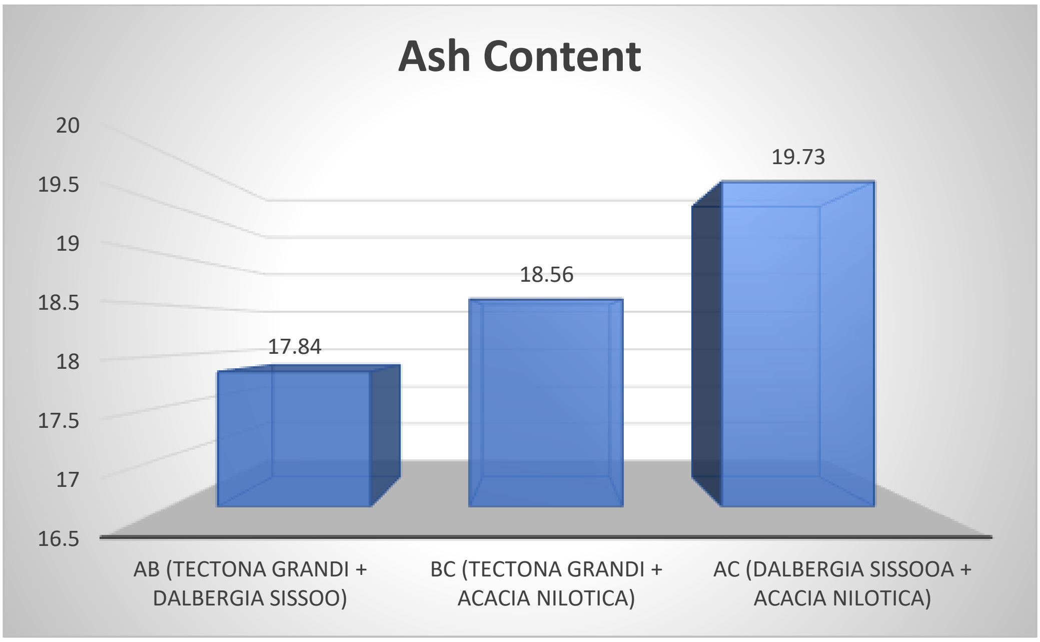

Figure 2: Ash content of Biomass Briquettes Produced from Mixed Tropical Hardwood Sawdust

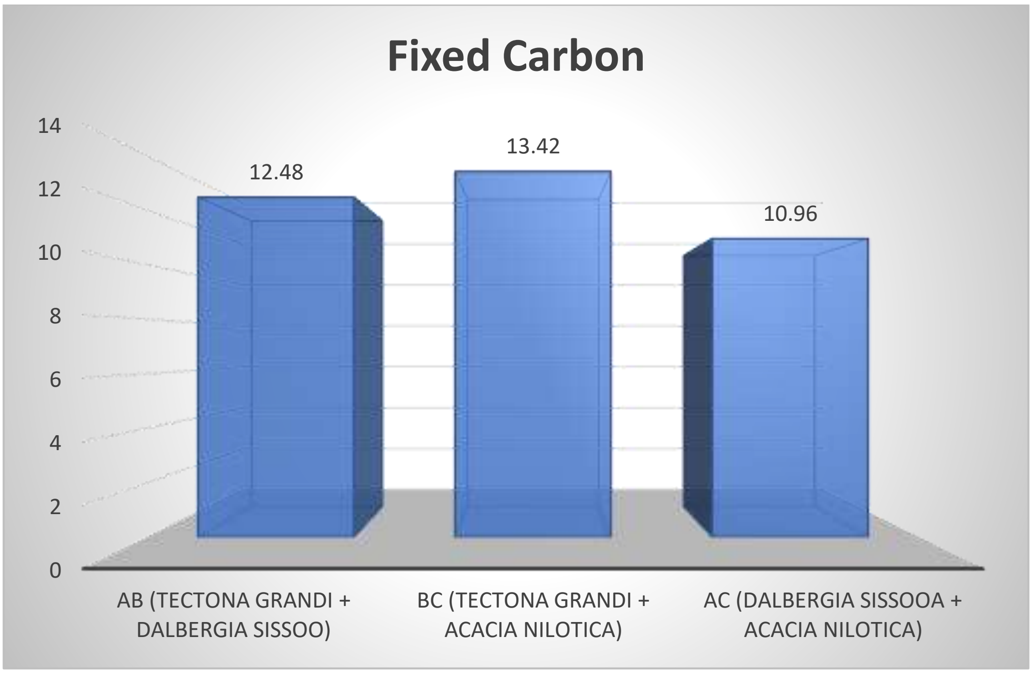

Figure 3: Fixed Carbon of Biomass Briquettes Produced from Mixed Tropical Hardwood Sawdust

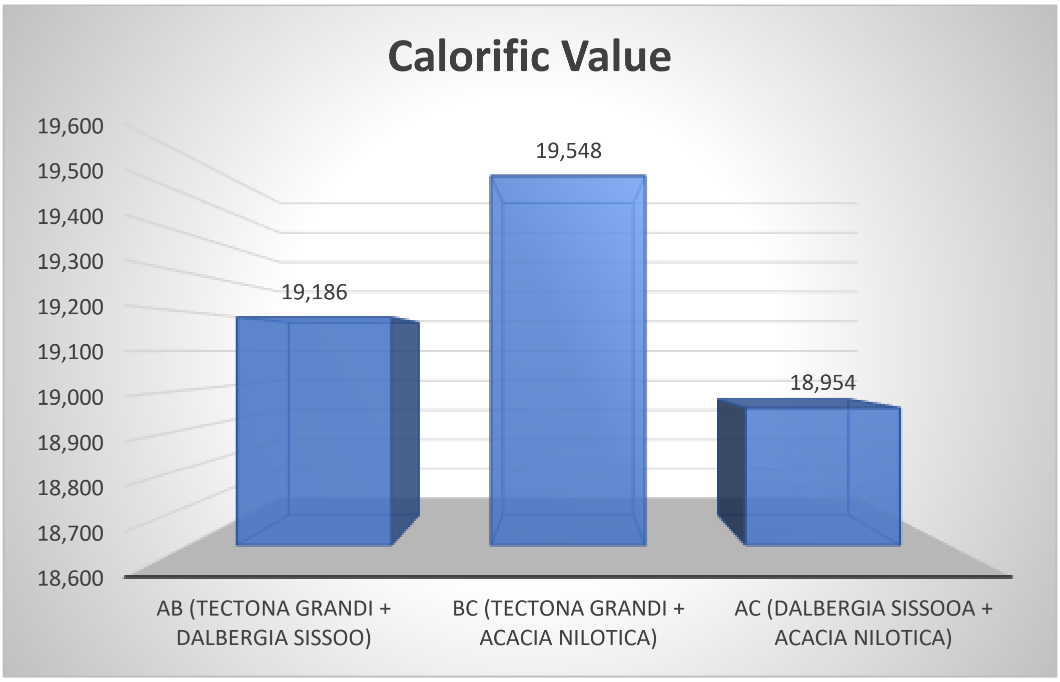

Figure 4: Calorific value of Biomass Briquettes Produced from Mixed Tropical Hardwood Sawdust

Proximate study showed that biomass briquettes made from various mixes of tropical hardwood sawdust had somewhat variable combustion properties. The average amount of volatile materials was 74.66 ± 1.35 percent. The treatment with the greatest volatile matter concentration (76.18 ± 1.37%) was the Dalbergia sissooa-Acacia nilotica (AC) combo. The Tectona grandi-Dalbergia sissooa (AB) combination revealed a value of 74.86 ± 1.42%, while the Tectona grandi-Acacia nilotica (BC) mixture had the lowest volatile matter at 72.95 ± 1.26%.

The AC combination had the greatest ash concentration and the AB mixture had the lowest, with ash content ranging from 17.84 ± 0.91% to 19.73 ± 0.88%. The solid combustible percentage responsible for prolonged heat release, the fixed carbon content, ranged from 10.96 ± 0.58% to 13.42 ± 0.69%. With its greatest fixed carbon content, the BC (Tectona grandi-Acacia nilotica) blend showed better char production and longer burning duration than any other mixture. All briquette formulations had enough carbon to sustain steady and protracted burning, as confirmed by the mean fixed carbon value of 12.29 ± 0.68%. A range of 18,954 ± 152 kJ/kg to 19,548 ± 178 kJ/kg was observed for the calorific value of the briquettes. The calorific value that was greatest, at 19,548 ± 178 kJ/kg, was produced by the BC combination. The AC combination had the lowest calorific value (18,954 ± 152 kJ/kg), whereas the AB mixture was close behind with 19,186 ± 164 kJ/kg.

V. CONCLUSION

Among the evaluated formulations, the briquettes produced from the Tectona grandis and Acacia nilotica mixture exhibited the highest fixed carbon content and calorific value, indicating enhanced combustion efficiency and improved energy output. The observed calorific values demonstrate that the developed briquettes are capable of serving as an efficient alternative solid fuel for domestic and small-scale industrial applications. The utilization of mixed tropical hardwood sawdust not only converts abundant wood-processing residues into value-added biofuel but also contributes to waste reduction, environmental protection, and the promotion of sustainable energy resources. Overall, the findings emphasize that careful selection of suitable binding agents is essential for improving briquette quality and combustion performance, providing valuable guidance for the large-scale production of high-performance biomass briquettes from forest-based residues.

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