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Omogbolade L. Adepitan
Department of Mechanical Engineering, Lead City University, Ibadan, Nigeria.

Bukola M. Adeyemi-Ekeolu
Lead City University

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ORIGINAL STUDY

Optimizing Biofuel Production in Nigeria: Evaluating Wood Species for Efficient Briquettes Using Polyvinyl Alcohol as Binder

Omogbolade L. Adepitan

Department of Mechanical Engineering, Lead City University, Ibadan, Nigeria

Abstract

Improving biofuel production in countries like Nigeria is important to the development and sustainability of the energy sector in the country. With the growing population in the country, the energy demand will increase, and conversely, the threat to climate and ecosystems will increase. To cushion this effect, attention needs to be shifted to farm wastes as a sustainable option for energy production. Briquette production has been at the focal point of researchers for many years. This study explores 12 different wood species commonly found around Nigeria with starch and polyvinyl alcohol (PVA) as binding agents. Briquettes from these wood species were made with PVA and starch separately using the same amount of mass for analysis. The results obtained from this study showed that briquettes from Ayo and Wawa sawdust produced the best calorific values of 31,760 J/g and 31,763 J/g, respectively, when polyvinyl alcohol (PVA) is used as a binder. While Afzelia sawdust briquette produced the lowest percentage moisture content (PMC) of 1.67% but a higher ash content of 3.73% with polyvinyl alcohol, which could be due to affinity for water molecules, hence the high percentage ash contents. In general, the thermo-physical properties of all the wood samples examined in this study showed that polyvinyl alcohol improved these properties when compared with common binders like starch.

Keywords: Bio-fuel, Briquettes, Optimization, Polyvinyl alcohol, Wood species

1. Introduction

In recent years, biofuels have gained significant attention as an alternative and renewable energy source to fossil fuels, particularly in developing countries such as Nigeria, where energy access remains a challenge for a large portion of the population [1]. The globally primary source of energy has been fossil fuels, which out of the 80% energy contribution to the world, the transport sector is taking over 55% of this energy from fossil fuels. The logistics (transport sector) is an integral aspect of economic development [1]. However, depletion of the origin of fossil fuels is happening very fast [2] as they are also the major contributor to climate change through their emitted gases, and the increase in demand is impacting the prices of crude oil globally with the global climate change at the receiving end of the negative impact of these greenhouse gases from transportation, the world is seeking more environmentally friendly fuel dependents [3]. In other to meet the world's green environment by the year 2020, there is an urgent need for fast reduction in the rate at which the green gases are emitted worldwide and embrace renewable forms of energy [4]. The increase in the impacts of climate change caused by the emission of greenhouse gases (GHG) has made the alternative to fossil fuels important for the fight for a cleaner and better environment.

However, there are some alternatives of energy available for the same purpose of usage, such as biofuel and briquettes [2]. The world is gradually tilting towards briquette usage as clean and sustainable energy production; the inflation of the price of energy and the quest for a cleaner environment have necessitated the use of briquettes as an affordable and efficient source of energy [5]

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E-mail address: adepitan.omogbolade@lcu.edu.ng.

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There are many ways briquettes can be produced; the source can influence the thermo-physical properties of the briquettes. Biomass briquettes are an innovative technique for reducing the pollution of the atmosphere, and they also provide a sustainable form of energy [6]. Agricultural wastes such as rice husk, straw, bagasse, sawdust, etc. are examples of biomass; furthermore, due to the different material compositions of biomass (briquettes), they tend to exhibit different features [7]. Biomass, as a renewable energy source, can be considered an alternative to meet the increasing demand from industries. Due to the lower cost of investment in biomass, demand for biomass as a form of energy by industries is on the rise. In this quest, biomass energy has taken the lead as a promising avenue [8]. Biomass as a form of renewable energy comes from basically wood and agricultural products, solid waste, landfill gas and biogas, and alcohol fuels (like ethanol or biodiesel). The chief and most readily available of these are agricultural products (wastes). Briquettes are widely used as a form of renewable energy as their raw materials are readily available from agricultural waste. Addressing the farm waste problem in Nigeria is crucial for promoting sustainable agricultural practices and achieving food security [9].

Biofuels, including solid biofuels like briquettes, are derived from biomass sources such as agricultural residues, wood, and other organic materials. In Nigeria, where biomass resources are abundant, the development of efficient biofuel production technologies has the potential to not only address energy shortages but also reduce environmental pollution and promote sustainable economic growth [10]. Production of briquettes in Nigeria has recently received a lot of attention, and most industries are interested in both production and profit maximization [11]. Among the various forms of biofuels, biomass briquettes are emerging as an important fuel source due to their high energy content, low ash production, and ability to be produced from local materials. Biomass briquettes are made by compressing biomass into compact shapes for easier handling and combustion. However, one of the major challenges in briquette production is improving the binding properties and mechanical strength of the briquettes to ensure their durability and efficiency in use [12]. Briquettes offer numerous benefits, including reduced deforestation and carbon emissions, as well as convenient handling and storage. Briquettes are a popular and sustainable source of fuel, widely used for heating and cooking applications. They are made from farm wastes such as rice husks, rice husks, etc., which are compacted together employing binder. These compact, uniform blocks of briquettes or other combustible materials are engineered to provide an efficient and eco-friendly alternative to traditional firewood or charcoal [13]. Farm waste in Nigeria is a significant agricultural challenge, characterized by the accumulation of crop residues, livestock manure, and other organic materials. Briquettes offer numerous benefits, including reduced deforestation and carbon emissions, as well as convenient handling and storage [14].

Polyvinyl alcohol (PVA), a synthetic polymer, has been identified as a promising binder for briquettes due to its biodegradable nature, low toxicity, and effectiveness in enhancing the physical properties of the briquettes. Vinyl acetate is the source of polyvinyl alcohol (PVA), a synthetic polymer that dissolves in water. It can be employed in many different industries, including as adhesives, packaging, textiles, and medicines, because of its excellent film-forming properties and adhesive strength [15]. PVA is a non-toxic, biodegradable polymer that is good for the environment. It is a component of single-dose packaging and other water-soluble goods such as laundry bags [14]. It is employed in a wide range of sectors, including medicine, ceramics, and cosmetics, as a thickening, dispersing, and binder. In medicine, PVA-based hydrogels are used to heal wounds and deliver drugs [16]. Because PVA is unique, it can be used in a variety of applications, such as tissue engineering, medication administration, and wound treatment because of its hydrophilicity and biocompatibility [17].

This study seeks to investigate and optimize the thermal and physical properties of briquettes from selected sawdust from different types of wood commonly found in Nigeria. Though many binders can be used to investigate these properties, however, the common binder used in briquette production in Nigeria is cassava starch, which is readily available and affordable. There is a need for an improved binder that would increase the thermo-physical properties of briquettes as a biofuel.

2. Materials and methods

2.1. Materials

Most materials used for this study were collected from farmlands, especially the twelve (12) different species of wood used. The following subsections of this section list the materials and equipment, as well as the methodology employed in this study.

2.1.1. Wood species

In this study, sawdust from twelve (12) different wood species was collected from wood industries, sawmills, and forests within the southwestern part of the country. The wood species are Afzelia (*Afzelia africana*), Obeche (*Triplochiton scleroxylon*), Sapele (*Entandrophragma cylindricum*), Araba (*ceiba pentandra*), Opepe (*Lophira alata*), Eku (*Brachystegia* spp.), Wawa (*Ceiba pentandra*), Ayo (*Holoptelia grandis*), Iroko (*Chlorophora excelsa*), Obobo (*Ficus mucuso*), Mahogany (*Khaya senegalensis*), and Afara (*Terminelia superba*). Sawdust samples from these different wood species were sieved using a sieve of particle size 500 mm as shown in Figure 1 to avoid uneven particle sizes and were kept in the oven at a temperature of 20^{o} C for 10 days to remove any form of moisture from the woods.

2.1.2. Polyvinyl alcohol

Polyvinyl alcohol (PVA) is a synthetic polymer known for its water solubility and diverse applications. Figure 2 shows the colorless and odorless solid (powder), which is ready to be dissolved in water for proper mixing with each sawdust sample.

2.1.3. Electronic weighing balance

An electronic weighing balance with a scale between 0 and 5000 g was used for highly sensitive and accurate measurements and readings. Fig. 3 shows the electronic weighing balance used in this study.

2.1.4. Measuring cylinder

A measuring cylinder was used to ensure an equal volume of water in the mixing process. Figure 4 also shows the measuring cylinder used.

Fig. 1. Sieved saw dust from one of the wood species.

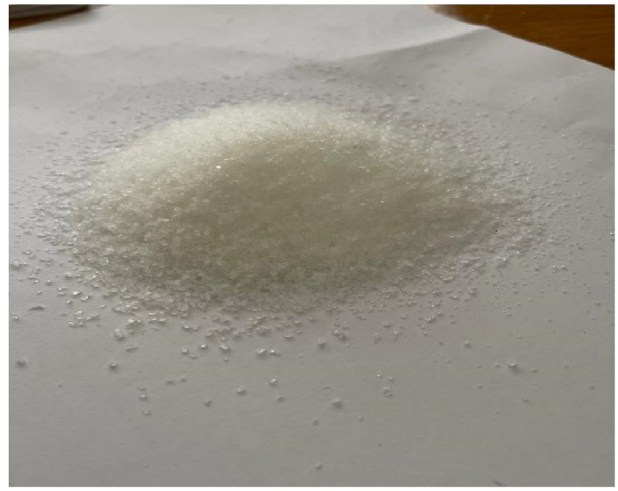

Fig. 2. Solid polyvinyl alcohol.

Fig. 3. Electronic weighing balance.

Fig. 4. Measuring cylinder.

2.2. Experimental set-up

For this study, three samples were prepared for each case of sawdust species (the average values of the analysis are used); a total of 36 samples were prepared. The starch (from cassava) and the polyvinyl alcohol (PVA) are measured separately to ensure an equal amount for all the briquette samples produced. Also, an equal amount of water (250 ml) was used to dissolve both the starch and PVA separately, which were stirred for homogeneity. The dissolved starch was heated for 3 min at about 200 °C and cooled for about 5 h, as was the dissolved PVA. The process was repeated for all the sawdust wood samples. The mixed sawdust was then poured into a cuboid-shaped mold with dimensions 14 cm × 5 cm × 10 cm, compressed, and allowed to compact for 24 h.

2.3. Sample characterization

2.3.1. Determination of percentage moisture content (PMC)

The amount of water content in the freshly produced briquettes before any treatment is done is known as moisture content. To determine the percentage value of the amount of moisture content, the freshly produced briquette was weighed and the value was recorded as M_1, the samples were then dried in an oven at 105 °C for 3 h until a constant weight was achieved, and the new weight M_2 is recorded. Water content is then calculated using the equation [17]:

$$PMC = \frac{M_1 - M_2}{M_1} \times 100 \tag{1}$$

M_1 = initial weight of briquette
M_2 = final weight of briquette after drying

2.3.2. Percentage of ash content (PAC) of the briquettes produced

The percentage ash content of the briquette can be calculated by burning up a sample in an incinerator to avoid loss of ash. The new weight, W_3, is the weight of the ash. Therefore, the ash content can be calculated using the equation below [17]:

$$PAC = \frac{W_3}{W_2} \times 100 \tag{2}$$

W_3 = Ash weight of briquette after burning

2.3.3. Determination of briquettes density

The densities of the produced briquettes were determined by using the formula below:

$$\mathbf{Density} = \frac{w_2}{v} \tag{3}$$

Where, W_2 = weight of the briquette after being dried in the oven

$$V = \text{calculated volume of the briquettes } w \times h \times h \tag{4}$$

L = length
w = width
H = height

2.3.4. Briquettes combustion rate

The combustion rates (C_r) of the briquettes produced were measured using the most common burning fuel. A known mass of sample was ignited, and a stopwatch was used to measure the time taken from ignition to the end of sample burning. The formula used to calculate the burning rate is given below [17]:

$$\text{Combustion rate } C_r = \frac{\textit{weighed dry mass of briquettes}}{\textit{total time taken for dry mass of briquette to combust}} \tag{5}$$

The process was repeated using all the samples.

2.3.5. Determination of calorific values

Calorific value is the amount of heat or heat produced from an object by a complete combustion reaction per unit mass/volume of the fuel. In this research, the calorific value was tested using a bomb calorimeter. Figure 5 shows the calorimeter used in the analysis of the calorific values.

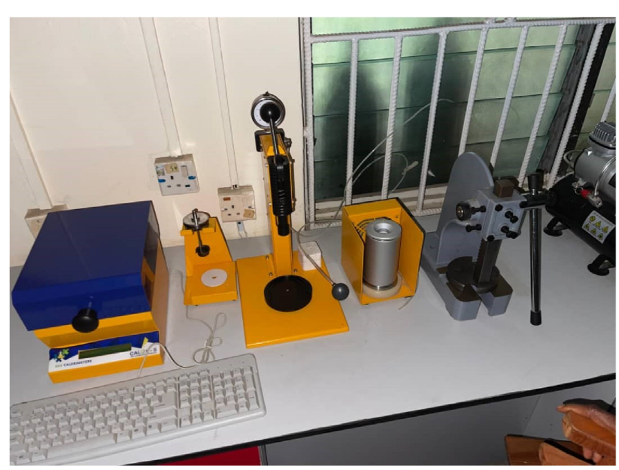

Fig. 5. Calorimeter.

3. Results and discussion

Comparative analysis of the thermo-physical characteristics of the twelve (12) sawdust from different woods commonly available in the Nigerian forest with the different binders (starch and polyvinyl alcohol) is summarized in Table 1 and Table 2. The calorific values of the samples, ash values, combustion rates, density, percentage of moisture content (PMC), and their average weights for both wet and dry samples are well outlined in Tables 1 and 2 below. Also, Fig. 6a and 6b show the plan and side view of the produced briquette from the oven respectively.

The average wet mass (M_1) of the moist briquette from samples of the sawdust from twelve (12) different woods commonly available in Nigeria are 343 g, 382 g, 541 g, 452 g, 288 g, 325 g, 297 g, 402 g, 443 g, 380 g, 381 g, and 459 g for Afara, Azelia, Araba, Ayo, Eku, Iroko, Mahogany, Obeche, Opepe, Obobo, Sapele, and Wawa, respectively, using starch binder as shown in Table 1. The results for the average mass for the same species of polyvinyl alcohol as binder are not similar with 368 g, 479 g, 618 g, 476 g, 328 g, 376 g, 367 g, 416 g, 511 g, 415 g, 525 g, and 517 g for Afara, Azelia, Araba, Ayo, Eku, Iroko, Mahogany, Obeche, Opepe, Obobo, Sapele, and Wawa, respectively, as shown in Table 2. These results showed that polyvinyl alcohol added more matter to the briquettes, with Ayo and Eku having the lowest weight and Araba with the highest

Fig. 6a. Plan view of the produced briquettes.

Table 1. Thermo-physical properties of sawdust with starch binder.

Samples	$W_{1(avg)}$ (g)	$W_{2(avg)}$ (g)	PMC (%)	Density (g/cm^3)	C_r (g/sec)	Ash content (%)	Calorific Values (J/g)
Afara	343	285	17.65	0.0197	0.053	2.58	26,354
Afzelia	382	310	22.58	0.0218	0.055	2.23	26,876
Araba	541	455	16.67	0.0317	0.034	3.18	27,987
Ayo	452	374	17.78	0.0261	0.057	2.59	29,354
Eku	288	241	14.29	0.0169	0.061	3.33	30,543
Iroko	325	264	18.75	0.0183	0.039	2.26	27,278
Mahogany	297	228	24.14	0.0155	0.047	4.12	30,045
Obeche	402	352	12.50	0.0246	0.052	3.00	28,164
Opepe	443	302	11.36	0.0275	0.028	1.97	28,231
Obobo	380	315	26.67	0.0211	0.025	3.45	27,098
Sapele	481	410	14.58	0.0289	0.046	3.30	30,132
Wawa	459	392	13.33	0.0275	0.044	2.98	31,001

Table 2. Thermo-physical properties of sawdust with polyvinyl alcohol binder.

Samples	$M_{1(avg)}$ (g)	$M_{2(avg)}$ (g)	PMC (%)	Density (g/cm^3)	C_r (g/sec)	Ash content (%)	Calorific Values (J/g)
Afara	368	315	16.22	0.0218	0.070	1.52	27,234
Afzelia	479	400	1.67	0.0282	0.085	3.73	20,760
Araba	618	543	11.29	0.0387	0.079	2.08	27,900
Ayo	476	418	12.50	0.0296	0.076	2.21	31,760
Eku	328	268	18.18	0.0190	0.067	2.13	30,543
Iroko	376	318	18.75	0.0225	0.099	2.26	26,728
Mahogany	367	288	21.62	0.0204	0.076	2.98	31,054
Obeche	416	368	12.50	0.0261	0.082	2.19	27,184
Opepe	511	468	11.36	0.0331	0.075	0.95	29,631
Obobo	415	358	26.67	0.0254	0.054	2.15	27,876
Sapele	525	467	14.58	0.0331	0.068	1.93	31,130
Wawa	517	448	13.33	0.0317	0.088	1.90	31,763

Fig. 6b. Side view of the produced briquettes.

weight. Fig. 7 below shows the graphical relationship between the weights of the wet briquettes and the two binders. The additional weight can be due to compound molecules in the binder.

In the same way, the mean dry mass (M_2) of the dry briquette from samples of the sawdust from twelve (12) different woods commonly available in Nigeria are 285 g, 310 g, 455 g, 374 g, 241 g, 264 g, 228 g, 352 g, 302 g, 315 g, 410 g, and 392 g for Afara, Azelia, Araba, Ayo, Eku, Iroko, Mahogany, Obeche, Opepe, Obobo, Sapele, and Wawa, respectively, using starch binder as shown in Table 1. The results for the average mass for the same species of polyvinyl alcohol as binder are not similar with 315 g, 400 g, 543 g, 418 g, 268 g, 318 g, 288 g, 368 g, 468 g, 358 g, 467 g, and 448 g for Afara, Azelia, Araba, Ayo, Eku, Iroko, Mahogany, Obeche, Opepe, Obobo, Sapele, and Wawa, respectively, as shown in Table 2. These results showed that polyvinyl alcohol added more matter to the briquettes, with Eku having the lowest weight and Araba with the highest weight. Fig. 8 below shows the graphical relationship between the weights of the wet briquettes and the two binders. The weight shown by Araba wood shows that the species contains more matter particles than other species of the wood samples examined. These values with polyvinyl alcohol are slightly higher than the values obtained with starch, as confirmed by [13] (see Fig. 9).

The results of percentage moisture content (PMC) by the briquettes as shown in Table 1 for starch binder are as follows; 17.65%, 22.58%, 16.67%, 17.78%, 14.29%, 14.29%, 18.75%, 24.14%, 12.50%, 11.36%, 26.67%, 14.58%, and 13.33% for Afara, Azelia, Araba, Ayo, Eku, Iroko, Mahogany, Obeche, Opepe, Obobo, Sapele, and Wawa, respectively. Whereby the results of PMC with polyvinyl alcohol as a binder are 16.22%, 1.67%, 11.29%, 12.50%, 18.18%, 18.75%, 21.62%, 12.50%, 11.36%, 26.67%, 14.58%, and 13.33% for Afara, Azelia, Araba, Ayo, Eku, Iroko, Mahogany, Obeche, Opepe, Obobo, Sapele, and Wawa, respectively, as shown in Table 2. The results showed varying values with the use of different binders. With most of the species having higher PMC with polyvinyl alcohol. The results from [18], are slightly lower when compared with the obtained results in Table 2. This could be attributed to the presence of the hydroxide group (OH) present in the polyvinyl alcohol. Fig. 3 below shows the graphical

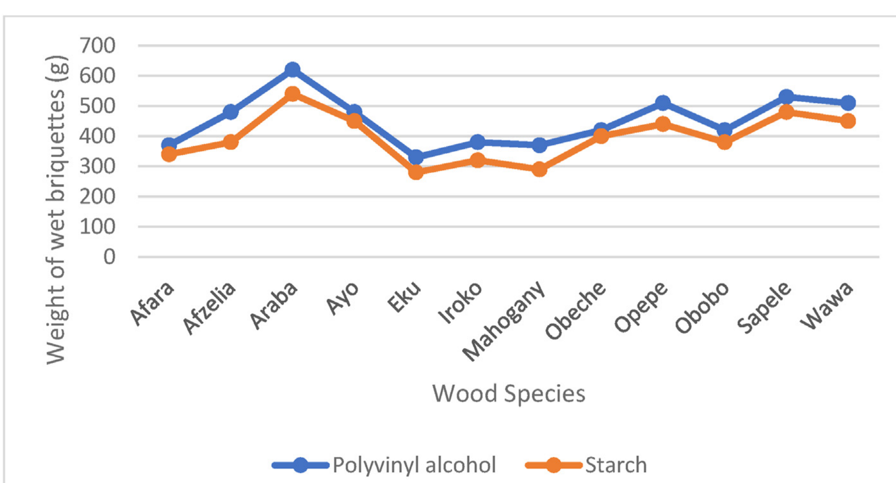

Fig. 7. Weight relationship between the wet briquettes and the two binders.

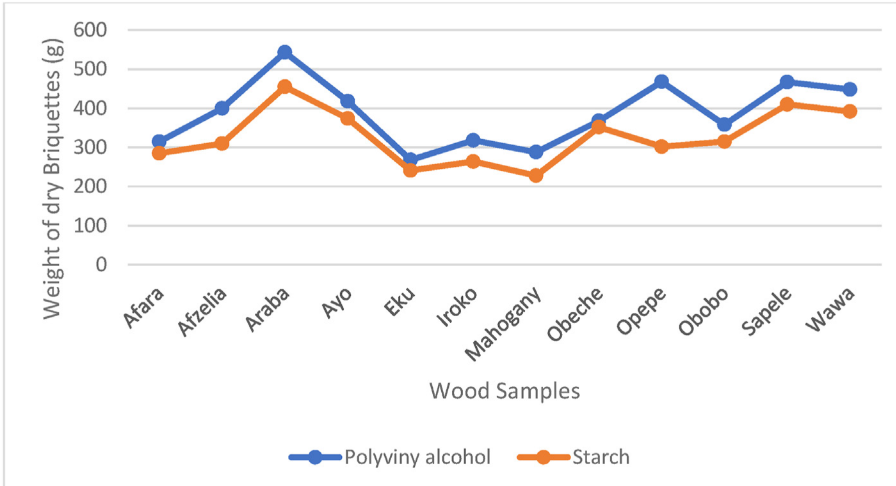

Fig. 8. Weight relationship between the dry briquettes and the two binders.

relationship between the PMC of the briquettes and the two binders.

From Table 1, the densities of the briquette produced with starch as a binder are slightly lower than the briquettes produced with polyvinyl alcohol (PVA). Polyvinyl alcohol increased the densities of the briquettes produced as shown in Table 1 and Table 2 and as illustrated in Fig. 10. The increase in these densities was a result of the additional weight on the briquettes by the molecular mass of PVA. The obtained results in this study of the densities of sawdust were slightly lower than the values obtained by [18], which makes PVA a better binder for easy transportation of the briquette products.

From Table 1, the combustion rate of the briquette produced with starch as a binder is lower than the briquettes produced by polyvinyl alcohol (PVA). The combustion rate of briquettes produced with starch ranges from 0.0155 g/s to 0.0317 g/s across all the samples as seen in Table 1, while the briquettes produced by polyvinyl alcohol have a combusting rate ranging from 0.054 g/s to 0.099 g/s across all the samples as seen in Table 2. The higher value of combusting rates in briquettes with polyvinyl alcohol was due to the alkanol group of the hydrocarbon, which supports combustion and can be seen from the trend as the polyvinyl alcohol (PVA). Fig. 11 shows the graphical illustration of these combustion rates between the briquettes. The obtained results in this study are higher than the value obtained by [19], which is 0.0005 kg/min.

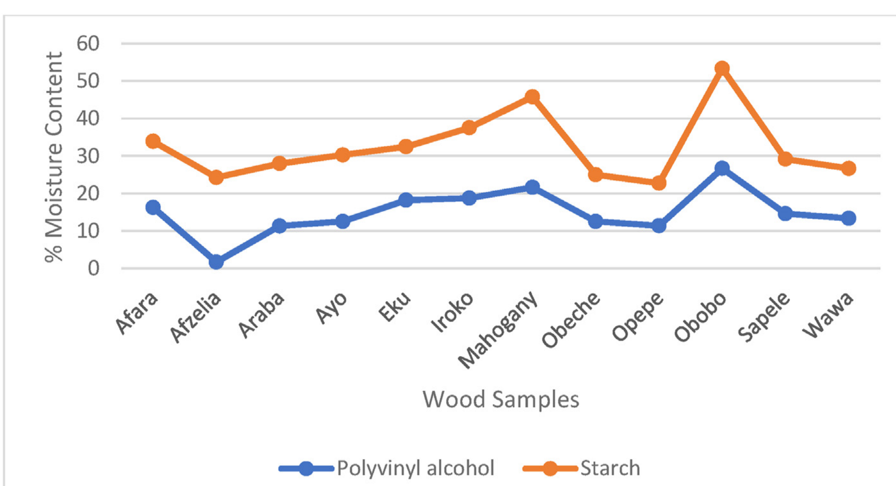

Fig. 9. Percentage moisture content (PMC) of the briquettes and the two binders.

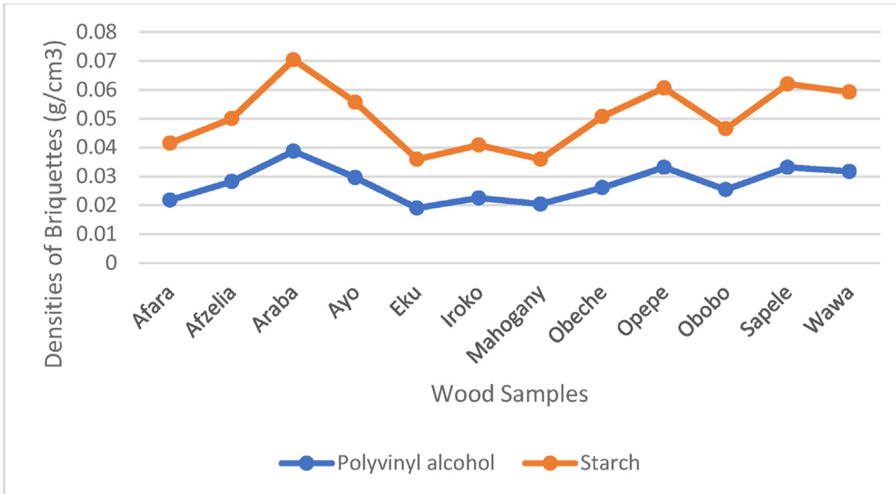

Fig. 10. Densities of the briquettes and the two binders.

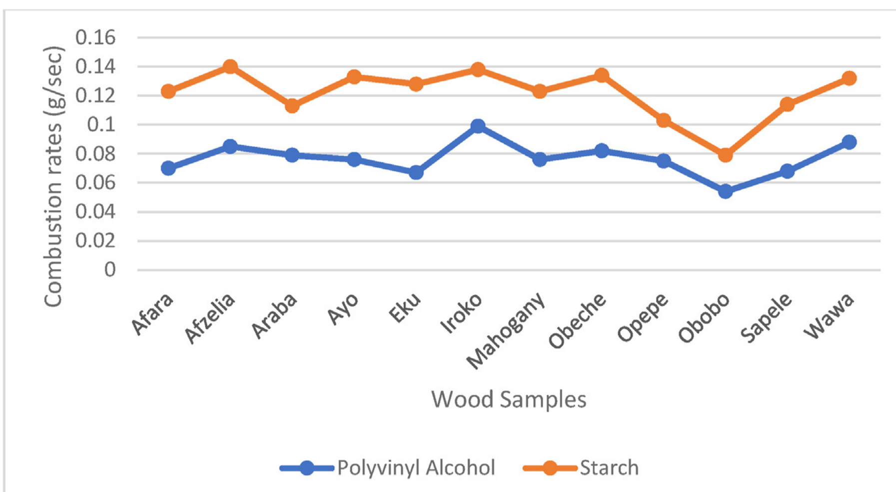

Fig. 11. Combustion rate of the briquettes and the two binders.

The comparison of the ash content from Tables 1 and 2 reveals that the results vary and were lower than the briquettes with polyvinyl alcohol. The values of the ash content or the residues after combustion of these briquettes are high for the briquettes with starch. The above results conformed with the values obtained by [20] which is 3.85% using starch as binder. However, the values obtained by [18], were much higher ash content values from rice husk using starch as a binder, with an average of 45.6%. The use of polyvinyl alcohol as a substitute binder gives little or less residue (ash) compared to starch because of the internal combustion ability of the alkanol (OH). Fig. 12 shows the graphical illustration of these ash contents between the briquettes.

The calorific content of all the sample briquettes from Tables 1 and 2 with starch and polyvinyl alcohol, respectively, shows that the impact of polyvinyl alcohol on the calorific is significantly high when compared with the corresponding starch samples. The high calorific value of the briquette produced with polyvinyl alcohol could be attributed to the alkanol group in the polyvinyl alcohol (PVA), which supports combustion and has internal heat energy (calories). The value obtained in this study is higher compared with the values obtained by [21]. However, the values obtained by [22] were with composite biomass like rice husk-sawdust-paper (RSP) and groundnut-sawdust-paper (GSP), with values as high as 0.16 MJ/kg. Fig. 13 shows the

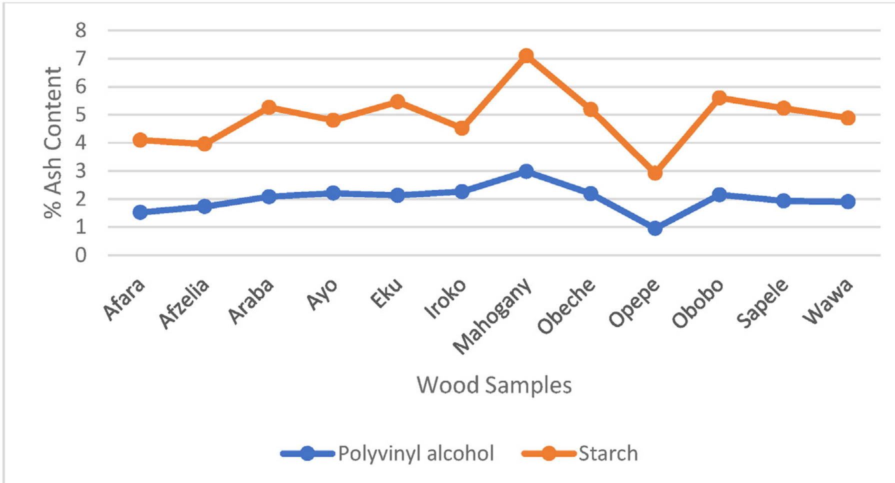

Fig. 12. Ash content of the briquettes and the two binders.

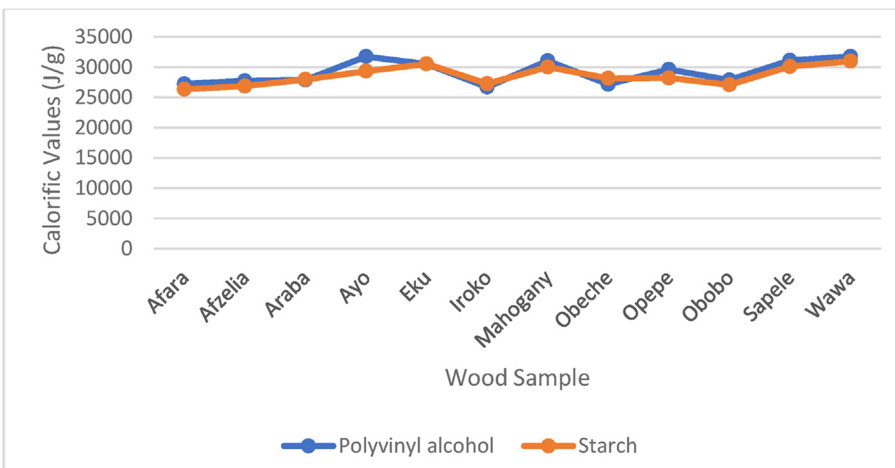

Fig. 13. Calorific values of the briquettes with the two binders.

graphical illustration of these combustion rates between the briquettes.

4. Conclusions

In conclusion, from the values of the obtained results in this study, the impact of polyvinyl alcohol (PVA) as a binder on the thermal properties of the examined wood species is significant, the calories produced, the ash contents, combustion rates, and densities, as well as the weights of dry masses of the briquettes, were greatly impacted as follows:

1. The briquettes produced by each wood species using starch as a binder showed higher weights than the briquettes produced using PVA.
2. The moisture contents of the briquettes produced by starch are more than the produced briquettes with PVA binder.
3. The densities of the briquettes produced by starch are higher than those produced using PVA.
4. The combustion rate of briquettes produced using starch as a binder is higher than that of PVA.
5. The briquettes of starch as a binder produce more ash content than the briquettes of PVA. This makes PVA suggestively preferable to starch as a binder.
6. The briquettes of PVA produce slightly higher calorific values than the briquettes of starch.

Moreover, it is recommended that further experimental investigation should be carried out using polyvinyl alcohol as a binder while the compacting pressure of the briquettes should be put into consideration as it enhances their combustion rates and other physico-chemical properties.

Ethics

There is no ethical approval received in the course of the study.

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Conflict of interest

The author has no conflict of interest to declare.

Data availability statement

The author confirms that the data supporting the findings in this study are available within the article. Raw data that support the findings of this study is available from the corresponding author, upon reasonable request.

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