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Impact of Polyvinyl alcohol on thermo-physical properties of Rice-husk and Sawdust Briquette

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ABSTRACT: Briquette production from farm wastes offers a sustainable and renewable form of energy source. However, optimizing some of the desired properties in these briquettes has been under study for as long as binders used can have impacts on these desired properties. This study investigates the impact of Polyvinyl alcohol on these desired properties. Farm wastes were prepared by sieving the particles to ensure even particle size and sun-dried to remove any moisture. Polyvinyl alcohol was prepared in varying masses of 20 g, 30 g, 40 g, 50 g, and 60 g with a constant volume of water (250 ml). A constant mass of 200 grams of rice husk and sawdust was added separately to the prepared PVA poured into a mold and compressed for 60 minutes. After that, the produced briquette was dried in an oven for further analysis. The results obtained, the calorific value of the sawdust with polyvinyl alcohol binder was found to range from 26.354 kJ/kg to 30.132 kJ/kg and rice husk to be 25.832 kJ/kg to 28.872 kJ/kg and the combustion rate to ranges from 0.0032 kg/min to 0.0040 kg/min and 0.022 kg/min to 0.062 kg/min for sawdust and rice husk respectively. The impact of PVA as a binder on the calorific and combustion properties of rice husk and sawdust briquette was increased with an increase in the polyvinyl alcohol value.

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1- Introduction

In the present world, most human activities involve the application of energy (heat). The latest research indicates an excessive consumption of carbonated and non-renewable forms of energy, such as fossil fuels, etc., and these have greatly added to the imperative global challenges in environmental control [1-3]. In most developed industries, a considerable amount of fossil fuels is being consumed [4]. For example, the Environmental Protection Agency (EPA) of the United States of America reported in 2022 that 65% of the increase in global greenhouse gas emissions in the last three years was due to the high consumption of fossil fuel products [5]. Numerous studies have underscored the critical need for a transition to renewable energy sources to combat these challenges [6-7]. The adoption of sustainable practices, including wind, solar, and hydropower, can significantly reduce our reliance on fossil fuels and help mitigate the detrimental effects on the environment. This transition is pivotal for a sustainable future [8]. The energy sector, among many other sectors, is the major contributor to the climatic and environmental challenges [9]. Renewable energy like solar has emerged as a pivotal solution in our quest for sustainable and environmentally responsible energy sources [10-11]. The world is drifting away from fossil fuels and shifting attention to renewable energy sources such as biomass.

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. At present, biomass forms of energy are ranked as the second most commercially used renewable energy source in the world [11]. Additionally, the growing importance of biomass is reflected in the increasing research and development initiatives focused on optimizing its conversion technologies for efficient energy generation [12]. Furthermore, the utilization of biomass for energy production not only contributes to a more sustainable energy mix but also aids in waste management by repurposing agricultural residues [6]. In this quest, biomass energy has taken the lead as a promising avenue. 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), as shown in Fig. 1. 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 [13].

Production of briquettes in Nigeria has recently received

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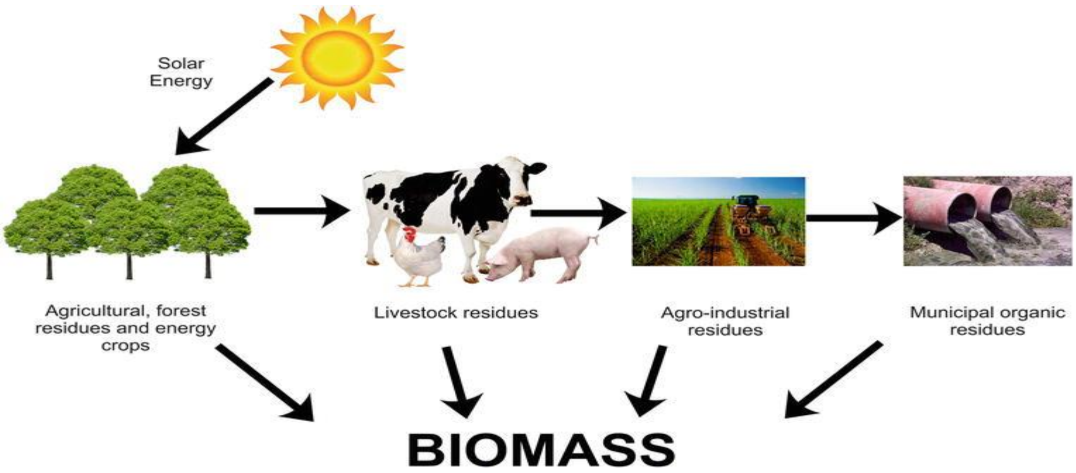

Fig. 1. Biomass Sources

a lot of attention, and most industries are interested in both production and profit maximization [14]. 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 utilizing a 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. 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 [12].

The quality of briquettes in terms of energy provision has advanced because of the manufacturing process and the constituents [15], this can be attributed to the increase in the demand for sustainable and cleaner forms of energy, which will in turn spur innovation in their production and application [16]. Polyvinyl alcohol (PVA) is a water-soluble synthetic polymer derived from vinyl acetate. Excellent film-forming qualities and adhesive strength allow it to be used in a variety of industries, including adhesives, packaging, textiles, and pharmaceuticals [17]. PVA is an environmentally friendly material that is non-toxic and biodegradable. It is used in water-soluble products like laundry bags and single-dose packaging [18]. It is used as a thickening, dispersing, and binder in many different industries, such as pharmaceuticals, ceramics, and cosmetics. PVA-based hydrogels are used in medicine to treat wounds and administer medications [19]. The uniqueness of PVA gives it diverse usefulness in different fields which include drug delivery, tissue engineering, and also in wound treatment due to its hydrophilicity and biocompatibility [20]. The adhesive property of polyvinyl alcohol makes it more suitable for this study, especially when treated with some degree of temperature.

The purpose of this study is to compare the thermal and physical characteristics of briquettes made from rice husk and sawdust with those of briquettes made with the traditional binder, cassava starch, and to assess how the binder, PVA, improves these characteristics.

2- EXPERIMENTAL SET-UP

2- 1- Study Design

For this study, five samples were prepared for each case. Each sample has a different combining ratio of polyvinyl alcohol. A total of 30 briquettes were produced, both for polyvinyl alcohol-rice husk and polyvinyl alcohol-sawdust. In each case, the average results were presented in the results section.

2- 2- Materials

The materials required in the development and characterization of briquettes made from rice husk and sawdust using polyvinyl alcohol are listed below.

2- 2- 1- Sawdust

Sawdust, also known as wood dust, is a by-product of woodworking operations such as sawing, sanding, and milling. The sawdust will be sieved to ensure even-sized particles. Shows the sawdust during sieving to achieve homogeneity.

2- 2- 2- Rice husk

Rice husk was collected from a nearby farm as a waste material. The rice husk was dried in the sun for three days to remove any moisture that influenced the physical properties of the produced briquette.

2- 2- 3- Polyvinyl Alcohol

Polyvinyl alcohol (PVA) is a synthetic polymer known for its water solubility and diverse applications. The PVA was measured and added to 250 ml of water and stirred for homogeneity. The mixture was heated for 3 mins at about 200 ^{0}C and cooled for about 5 hours.

Table 1. Showing the cost analysis for the briquette production

S/N	Materials	Total Quantity	Quantity/briquette	Unit Cost
1	Rice husk	3 kg	0.2 kg	Farm waste
2	Water	7.5 L	250 ml/briquette	Water
4	sawdust	3 kg	0.2 kg	Farm waste
		Polyvinyl Alcohol (PVA)		
Samples	Rice Husk briquette		Sawdust briquette	
	Quantity	Cost	Quantity	cost
1	0.02 kg	₵ 3.0	0.02 kg	₵ 3.0
2	0.03 kg	₵ 4.5	0.03 kg	₵ 4.5
3	0.04 kg	₵ 6.0	0.04 kg	₵ 6.0
4	0.05 kg	₵ 7.5	0.05 kg	₵ 7.5
5	0.06 kg	₵ 9.0	0.06 kg	₵ 9.0
Total	0.2 kg	₵ 90	0.2 kg	₵ 90

2- 2- 4- Electronic Weighing Balance

An electronic weighing balance with a scale between 0 – 5000g was used for highly sensitive and accurate measurements and readings.

2- 2- 5- Measuring Cylinder

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

2- 3- Cost analysis

Although most of the materials used were free from farm waste, some other materials were purchased, and Table 1 shows the cost per unit of briquette produced. From the analysis presented in Table 1 below, the cost of producing one briquette varies from ₵ 3.0 to ₵ 9.0 due to the different amounts of PVA used in each sample. This cost estimation was done based on the exchange of naira to a dollar as of the 29th of October, 2024.

2- 4- Methods

2- 4- 1- Mixing Preparation and Proportion

The rice husk and the sawdust were sieved properly to ensure even size and then dried in the oven for about 3 minutes at 35°C. This is to remove any moisture from the rice husk and sawdust before the introduction of the binder. Also, 20g of polyvinyl alcohol was prepared in a separate beaker using an equal volume of water (250 ml).

The prepared polyvinyl alcohol gel was then mixed with a constant mass each of 200 g of rice husk and sawdust and mixed thoroughly until the mixture became evenly damped. The dampened rice husk was then poured into the compacting mold (14 cm × 5 cm × 10 cm) to be compacted for 60 minutes to ensure that the binder (PVA) held the briquette particles in place to avoid any falling apart. The same was done with the dampened sawdust.

The process was repeated with a constant mass of rice husk, sawdust, and 30g, 40g, 50g, and 60g polyvinyl alcohol, respectively. For each case, three samples were made.

2- 5- Sample characterization

2- 5- 1- Determination of Percentage Moisture Content (PMC)

Moisture content is the amount of water in the produced briquettes. To determine the average amount of moisture content, the freshly produced briquette was weighed and the value was recorded as W_1, the samples were then dried in an oven at 105°C for 3 hours until a constant weight was achieved, and the new weight W_2 is recorded. Water content is then calculated using the equation:

$$PMC = \frac{w_1 - w_2}{w_1} \times 100 \quad (1)$$

W_1 = initial weight of briquette
W_2 = final weight of briquette after drying

2- 5- 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:

$$PAC = \frac{W_3}{W_2} \times 100 \quad (2)$$

W_3 = Ash weight of briquette after burning

Determination of Briquettes Density

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

$$Density = \frac{w_2}{v} \quad (3)$$

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

$$V = \text{calculated volume of the briquettes } L \times W \times H \quad (4)$$

L = length

W = width

H = height

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:

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

The process was repeated using all the samples.

Determination of Calorific Value

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.

3- Results and Discussion

Tables 2 and 3 present the findings of a comparative investigation of the properties of the two briquettes that were produced using sawdust and rice husk. The features displayed in Tables 2 and 3 for sawdust and rice husk briquettes, respectively, are the average weight before and after drying, the average weight after drying, percentage moisture content, densities, combustion rates, ash content, and their calorific values.

From Table 2, the average mass (W_1) of the wet briquette from sawdust produced is increasing with values of 0.34 kg, 0.44 kg, 0.54 kg, 0.65 kg, and 0.78 kg for samples 1, 2, 3, 4, and 5, respectively, with the binding agent. Also, from Table 3, similar trends can be observed in the masses of the

Table 2. Characteristics of Sawdust briquettes using Polyvinyl alcohol

Samples	Amount of PVA (kg)	$W_{1(avg)}$ (kg)	$W_{2(avg)}$ (kg)	PMC (%)	Density (kg/m³)	C_r (kg/min)	Ash content (%)	Calorific Values (kJ/kg)
1	0.02	0.34	0.29	14.71	414.29	0.0032	2.58	26.354
2	0.03	0.44	0.39	11.36	557.14	0.0033	3.0	27.278
3	0.04	0.54	0.49	9.26	700.00	0.0037	3.18	28.164
4	0.05	0.65	0.59	9.23	842.85	0.0038	3.30	29.354
5	0.06	0.78	0.72	7.69	1028.57	0.0040	3.33	30.132

Table 3. Characteristics of Rice husk briquettes using Polyvinyl alcohol

Samples	Amount of PVA (kg)	$W_{1(avg)}$ (kg)	$W_{2(avg)}$ (kg)	PMC (%)	Density (kg/m^3)	C_r (kg/min)	Ash content (%)	Calorific Values (kJ/kg)
1	0.02	0.38	0.32	9.23	457.14	0.022	2.87	25.832
2	0.03	0.48	0.42	7.69	600.00	0.033	6.05	27.801
3	0.04	0.57	0.51	6.90	728.57	0.043	6.28	27.342
4	0.05	0.68	0.62	6.14	885.71	0.058	6.29	28.132
5	0.06	0.79	0.73	5.50	1128.57	0.062	6.35	28.872

rice husk briquettes produced with the same binding agent (polyvinyl alcohol) the mass tends to increase as the amount of polyvinyl alcohol is added to the rice husk, which produces masses of 0.38 kg, 0.48 kg, 0.57 kg, 0.68 kg, and 0.79 kg in samples 1, 2, 3, 4, and 5, respectively. Figure 2 below shows the graphical relationship between the wet briquettes of rice husk and sawdust with polyvinyl alcohol binder.

From Table 2, the average mass (W_2) of the dry briquette produced is increasing with values of 0.29 kg, 0.39 kg, 0.49 kg, 0.59 kg, and 0.72 kg for samples 1, 2, 3, 4, and 5, respectively, when polyvinyl alcohol was as binding agent on sawdust briquettes. Also, from Table 3, similar trends can be observed in the masses of the rice husk briquettes produced with the same binding agent (polyvinyl alcohol) the mass of dry briquette tends to increase as the amount of polyvinyl alcohol is added to the rice husk increases. The masses are 0.32 kg, 0.42 kg, 0.51 kg, 0.62 kg, and 0.73 kg in samples 1, 2, 3, 4, and 5, respectively. Figure 3 below shows the graphical relationship between the dry briquettes of rice husk and sawdust with polyvinyl alcohol binder.

The average mass (W_1) of the wet briquette produced for sawdust was lower than that of the ones produced for rice husks despite using the same constant mass (200 g) and also with the addition of an equal quantity of polyvinyl alcohol to the same sample. The disparity in masses may be due to the difference in densities of rice husk to that of sawdust. Although the same quantity was used, rice husk appears denser than sawdust. The values of the obtained masses of sawdust with polyvinyl alcohol are slightly higher than the values obtained by [21], which range from 0.011 kg to 0.48 kg for sawdust with starch and 0.016 kg to 0.067 kg for rice husk with starch as binder.

From Table 2, the percentage moisture content (PMC) of the briquette produced is decreasing with values of 14.71%, 11.36%, 9.26%, 9.23%, and 7.69% for samples 1, 2, 3, 4, and 5, respectively, when polyvinyl alcohol was added as binding agent on sawdust briquettes. Also, from Table 3, similar trends can be observed in the percentage of moisture content of the rice husk briquettes produced with the same binding agent (polyvinyl alcohol) which increases as the amount of polyvinyl alcohol is added to the rice husk decreases. The values are 9.23%, 7.69%, 6.90%, 6.14%, and 5.50% in samples 1, 2, 3, 4, and 5, respectively.

Figure 4 below shows the graphical relationship between the percentage of moisture content of briquettes of rice husk and sawdust with polyvinyl alcohol binder.

The percentage moisture content (PMC) of the two briquettes was reduced as more polyvinyl alcohol was added to the constant mass of sawdust and rice husk, and this could be attributed to the increase in matter (polyvinyl alcohol) as a constant volume of water was used in preparing each weight of polyvinyl alcohol. The values of the PMC obtained from the study are slightly higher than the ones obtained by [22], with an average value of 5.04% with starch as binder. The increase in the value of the percentage of moisture content compared to other binders used (especially starch) in this study can be attributed to the hydroxide group (OH) present in the polyvinyl alcohol, which has the chemical ability to increase water contents.

From Table 2, the densities of the briquette produced are increasing with values of 414.71 kg/m^3, 557.14 kg/m^3, 700.00 kg/m^3, 842.85 kg/m^3, and 1028.57 kg/m^3 for samples 1, 2, 3, 4, and 5, respectively, when polyvinyl alcohol was added as a binding agent on sawdust briquettes. Also, from

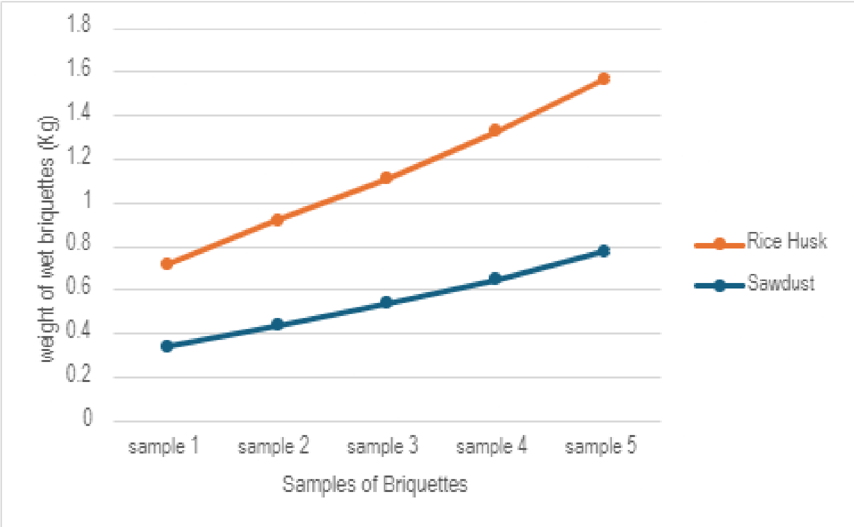

Fig. 2. Weights of wet rice husk and sawdust briquettes.

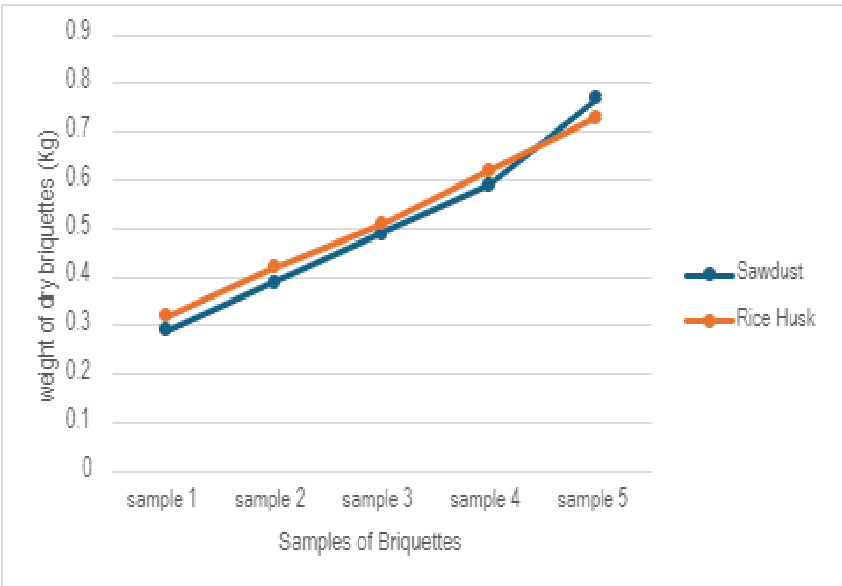

Fig. 3. Weights of dry sawdust and rice husk briquettes.

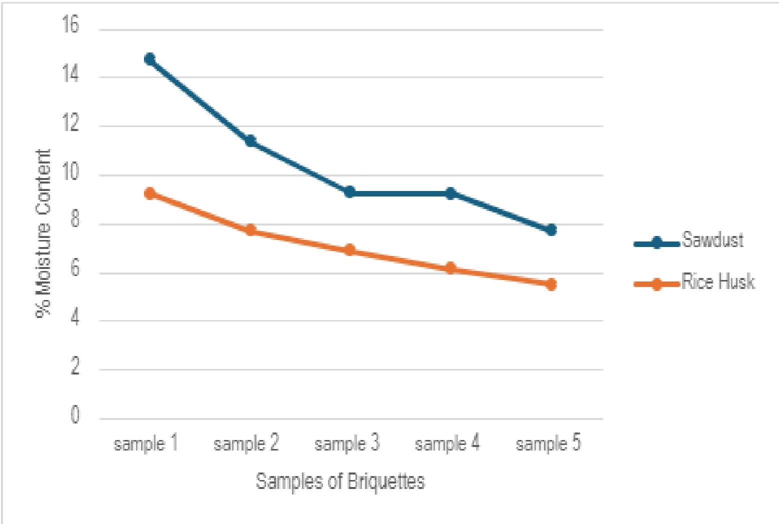

Fig. 4. Percentage of moisture content of rice husk and sawdust briquettes.

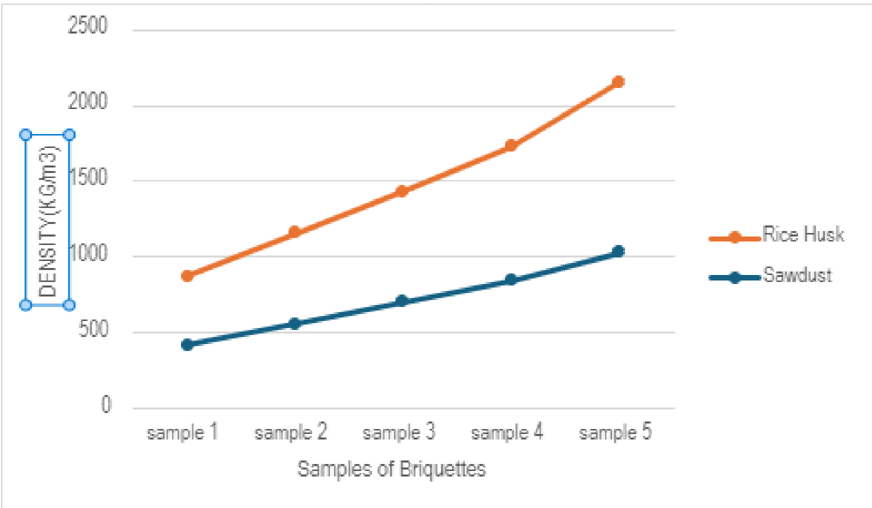

Fig. 5. Densities of rice husk and sawdust briquettes.

Table 3, similar trends can be observed in the percentage of moisture content of the rice husk briquettes produced with the same binding agent (polyvinyl alcohol) which increases as the amount of polyvinyl alcohol is added to the rice husk increases. The values are 457.14 kg/m^3 600.00 kg/m^3, 728.57 kg/m^3,885.71 kg/m^{3,} and 1128.57 kg/m^3 in samples 1, 2, 3, 4, and 5, respectively.

Figure 5 below shows the graphical relationship between the densities of briquettes of rice husk and sawdust with polyvinyl alcohol binder.

The density of the briquette produced increases with an increase in polyvinyl alcohol for both rice husk and sawdust, and this could be due to the increase in the weight of the dry briquette produced, which was increased with an increase in the masses of polyvinyl alcohol added to the constant mass of rice husk and sawdust. The values of the densities of rice husk briquette obtained in this study are slightly higher than the 860 kg/m^3, which was obtained by [23].

From Table 2, the combustion rate of the briquette produced is increasing with values of 0.0032 kg/min,

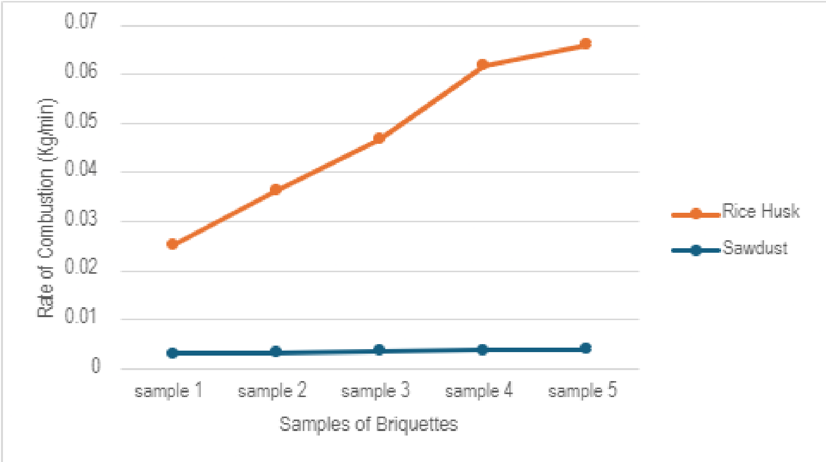

Fig. 6. Combustion rate of rice husk and sawdust briquettes.

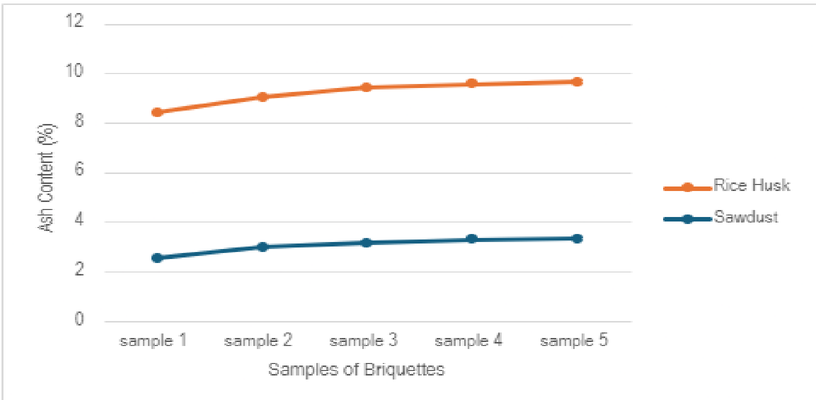

Fig. 7. Ash content of rice husk and sawdust briquettes.

0.0033kg/min, 0.0037 kg/min, 0.0038 kg/min, and 0.0040 kg/min for samples 1, 2, 3, 4, and 5, respectively, when polyvinyl alcohol was added as a binding agent on sawdust briquettes. Also, from Table 3, similar trends can be observed in the percentage of moisture content of the rice husk briquettes produced with the same binding agent (polyvinyl alcohol) which increases as the amount of polyvinyl alcohol is added to the rice husk increases. The values are 0.022 kg/min 0.033 kg/min, 0.043 kg/min, 0.058 kg/min, and 0.062 kg/min in samples 1, 2, 3, 4, and 5, respectively. Figure 6 below shows the graphical relationship between the rate of combustion of briquettes of rice husk and sawdust with polyvinyl alcohol binder.

The combustion rate of the briquette produced increases with an increase in polyvinyl alcohol in both the rice husk and the sawdust. The increase in the combustion rate could be attributed to the addition of polyvinyl alcohol (PVA), which contains alcohol. The alkanol group of the hydrocarbon supports combustion and can be seen from the trend as the PVA is being added. The obtained value by [23] is 0.0005 kg/min, which is slightly lower than the obtained values in this study. From this study, it is obvious that the addition of PVA to sawdust does not have any effect on the combusting properties as shown in Figure 6.

From Table 2, the ash content of the briquette produced increases with values of 2.58 %, 3.0 %, 3.18 %, 3.30 %, and 3.33 % for samples 1, 2, 3, 4, and 5, respectively, when polyvinyl alcohol was added as a binding agent on sawdust briquettes. Also, from Table 3, similar trends can be observed in the ash content of the rice husk briquettes produced with

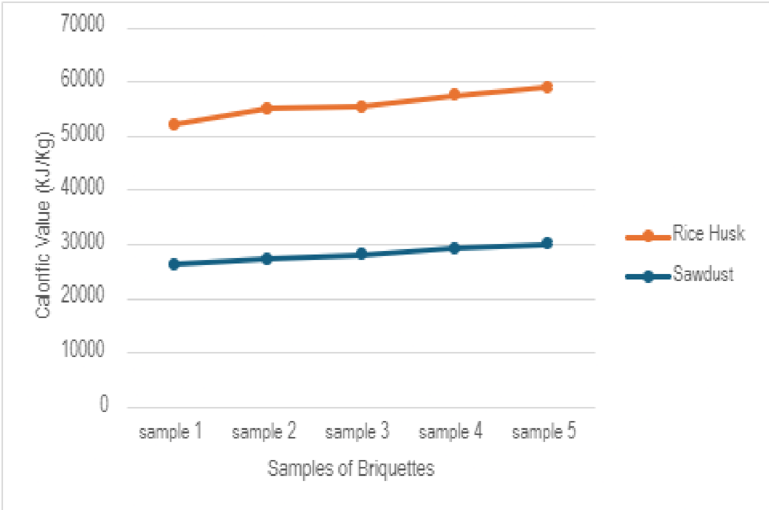

Fig. 8. Calorific values of rice husk and sawdust briquettes.

the same binding agent (polyvinyl alcohol) which increases as the amount of polyvinyl alcohol is added to the rice husk increases. The values are 5.87%, 6.05%, 6.28%, 6.29% and 6.35% in samples 1, 2, 3, 4, and 5, respectively. Figure 7 below shows the graphical relationship between the ash content of briquettes of rice husk and sawdust with polyvinyl alcohol binder.

The ash content of the briquettes produced increased with an increase in the addition of polyvinyl alcohol, and this could be caused by the addition of matter (PVA), which increases the general mass of the briquettes, thereby increasing the amount of deposited mass after combustion. The ash content obtained from sawdust briquettes in this study is slightly lower than the obtained value by [22], which is 3.85% using starch as a binder. However,[22] obtained a much higher ash content value from rice husk using starch as a binder with an average of 45.6%. Polyvinyl alcohol leaves less residue (ash) compared to starch because of its internal combustion ability.

From Table 2, the ash calorific values of the briquette produced are increasing with values of 26.354 kJ/kg, 27.278 kJ/kg, 28.164 kJ/kg 29.354 kJ/kg, and 30.132 kJ/kg for samples 1, 2, 3, 4, and 5, respectively, when polyvinyl alcohol was added as binding agent on sawdust briquettes. Also, from Table 3, similar trends can be observed in the percentage of moisture content of the rice husk briquettes produced with the same binding agent (polyvinyl alcohol) which increases as the amount of polyvinyl alcohol is added to the rice husk increases. The values are 25.832 kJ/kg, 27.342 kJ/kg, 27.801 kJ/kg, 28.132 kJ/kg, and 28.872 kJ/kg in samples 1, 2, 3, 4, and 5, respectively. Figure 8 below shows the graphical relationship between the calorific values of briquettes of rice husk and sawdust with polyvinyl alcohol binder.

The higher heating value (HHV) or calorific value of the briquette produced also increased as the polyvinyl alcohol was added to the sawdust and rice husk. This could be attributed to the internal HHV or calorific value of PVA; the alkanol group in PVA supports combustion and could be responsible for the higher calorific value obtained when compared to the values of sawdust and rice husk briquette obtained by [22-23], respectively. However, Kumar *et al*.,[20] obtained a higher calorific value with composite biomass like rice husk-sawdust-paper (RSP) and groundnut-sawdust-paper (GSP), with values as high as 0.16 MJ/kg.

4- Economic Implication

The results obtained and discussed in this study showed that rice husk and sawdust with polyvinyl alcohol (PVA) as a binder can improve fuel efficiency in briquettes and offer the following benefits economically.

1. Lower fuel costs: Briquettes, an alternative fuel source, are less expensive than traditional fuels like kerosene, firewood, and charcoal. This is particularly true in impoverished places where access to fuels is limited or nonexistent or where the cost of the available fuels is prohibitive. Consequently, the amount spent on domestic energy is greatly reduced.

2. Increased revenue opportunities: based on the cost analysis covered previously in this study, briquette manufacture and sales can be carried out with minimal financial resources, which in turn can lead to the creation of jobs, particularly in developing and undeveloped areas.

3 Reduced deforestation: The traditional means of fuel in most rural areas are firewood and charcoal, which are

often obtained through unsustainable logging practices. This helps conserve forests and mitigate deforestation-related environmental problems.

4. Waste reduction: Rice husks and sawdust are agricultural waste products that are often disposed of in landfills or burned, contributing to pollution. Briquette production helps recycle these waste materials, reducing waste disposal costs and environmental impact.

5. Improved air quality: Compared to traditional fuels, briquettes produce less smoke and particulate matter, leading to improved air quality and reduced respiratory health problems.

5- Conclusion

5- 1- Conclusion

In conclusion, from the results obtained in the study of the impact of polyvinyl alcohol (as binders) in briquettes made from rice husk and sawdust, it can be concluded that the combustion rate, as well as the calorific value, is positively impacted by using PVA as a binder when compared to other binders, especially starch, which is the common binder used. In addition, other physical properties of the briquettes were also impacted positively by PVA, properties like densities of briquettes and the percentage moisture content of the briquettes, which decreased with the addition of PVA, giving the briquette more heating value. However, the ash content of the produced briquette obtained from this study increases with an increase in PVA, and this does not have a good impact on the briquette as it leaves more waste after combustion. In addition, the economic implications of rice husk and sawdust briquettes are largely positive, contributing to reduced fuel costs, increased income opportunities, environmental conservation, and improved air quality.

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