PERFORMANCE EVALUATION OF BRIQUETTES PRODUCED FROM CORNCOB AND BAGASSE WASTE

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Abstract: The aim of this study was to examine the performance evaluation of hybrid briquettes made from bagasse and corncob waste using a low-pressure densification technique. These briquettes could be used as a sustainable energy source for domestic cooking as well as industrial applications. In the current study, biomass such as corn cob and bagasse waste were used to produce hybrid briquettes. Corncob and bagasse waste were mixed in different ratios (100:0, 0:100, 60:40, 50:50, and 40:60). Before briquetting, cassava starch (25 %) was added to each mixture as a binder. A manually operated 10-ton hydraulic piston press was used to make the briquettes at a temperature of 27 ^{o}C and a compaction pressure of less than 150 kPa. The product was evaluated in terms of density, volatile matter, moisture content, ash content, fixed carbon contents, specific heat of combustion, falls within the range of 362-470 kg/m^3, 28.03-45.18%, 28.15-31.05%, 3.05-4.10%, 63.50-72.01% and 25150-32000 kJ/kg respectively. The performance (ignition time, burning rate, and boiling time) of the hybrid briquettes was analyzed. Furthermore, a comparison was made between the ignition time as well as the water boiling tests for the hybrid-briquettes prepared by combining corncob with bagasse. The results showed that the (40:60) weight composition has the best overall properties in terms of performance compared to other mixing ratios. The results for this Briquette were 29.85 sec. for ignition time, 18.6 min. for boiling time, 2.83 g/min. burning time, and 31,560 kJ/kg for specific heat of combustion. It recommended the briquettes that were made by blending bagasse and corncob in a ratio of (40:60) had better results because they burned more slowly but had quicker ignition times and be used for briquettes production. This determines that the hybrid-briquettes produced by this investigation were productive, eco-friendly, and useful in both domestic and industrial applications.

Keywords: Bagasse, Combustion, Corncobs, Density, Hybrid-briquettes

1. INTRODUCTION

Energy is crucial for a nation's economic development. It is an essential component that influences the production of all goods and services. It also affects every facet of development, including the social, economic, agricultural, environmental, and livelihood elements. Energy access is essential for the growth of industries since it provides essential services that improve living standards. (Mohammed, et al., 2021). The importance of energy in the development and growth of a nation cannot be overemphasized. Development growth and human prosperity are heavily dependent on adequate supply, security, and efficient use of energy. The global energy crisis, coupled with the global warming menace, has called for the diversion from the sustained utilization of fossil fuels. It has been realized that without alternative means of energy, there would continue to be an energy shortage and the environment will continue to be at risk. Alternative forms of energy would include energy sources that are clean, sustainable, and renewable. An alternative energy supply is being sourced from the exploration of wind, solar, biomass, hydroelectric, ocean, and geothermal energy sources (Simeon et al, 2020).

Biomass is the term used for all organic material originating from plants including trees and crops and is essentially the collection and storage of the sun's energy through photosynthesis, (Sawsan & Ramadan 2017). However, biomass sources for energy include; Wood and wood processing wastes (firewood, wood pellets, and wood chips), Agricultural crops and waste materials (corn, soybeans, sugar cane, switch grass, woody plants, and algae, etc.), Biogenic materials in municipal solid waste (paper, cotton, and wool products, and food, yard, and wood wastes) and Animal manure and human sewage. Biomass is a renewable energy source because the plants can be replaced as oppose to the conventional fossil fuel which is not renewable. It has the potential to provide an affordable and sustainable source of energy, while at the same time help in curbing the greenhouse effect, (Tamara Posibi, 2017).

The use of wood fuel contributes to deforestation and air pollution (Inyang, et al., 2014). Also, wood burning leads to huge effects that are terribly unwanted and irritating, which emits water (H_2O) vapor, carbon (iv) oxide (CO_2), and carbon monoxide (CO) spray particulates, alongside caustic alkali fly ash that are indeed dangerous and account for causing deadly human health and climate change (Otitoju, et al., 2019). Agricultural residues not properly disposed result in unclean environment. Converting agricultural residues to useful briquettes contributes to a cleaner environment. About 31% of the world land surface is covered by forest, while in Nigeria it falls gradually from 16.6% in 1996 to 7.7% in 2015 due to deforestation (Emeodilichi, 2018). This research will contribute to addressing the air pollution and environmental problem of biomass waste disposal.

Energy content of briquettes; moisture content, ash content, flow characteristics and calorific value are main factor to be considered in the selection of raw material for bio-briquettes (Dinesha, et al., 2018). Moisture content should be limited to 10-15% in order to minimize the energy and time required for drying. Higher moisture contents reduce the combustion temperature and have an adverse effect on combustion. Ash content, which is the amount of ash produced during combustion, is significant and higher ash content for the biomass feedstock has a lower calorific value. The lower fusion temperature of ash produced from the combustion of agricultural residues results in a tendency for slag formation. When selecting the agricultural residue for briquettes, the preferred ash content is less than 4% (Dinesha, et al., 2018). Briquettes preparation; high quality and highly storable briquettes can be produced from a mixture of agricultural residues, municipal processing waste and binder; such as molasses, starch, paper, etc. maize cob and molasses can be compacted into fuel briquettes under moderate pressure. The quality of the briquettes mainly depends on the binder ratio (Tamilvanan A., 2013).

The briquettes can be usually used in several applications ranging from residential cook stoves to large scale industrial power plants. They can be easily adopted in any biomass-based energy conversion devices, such as residential boilers, residential stoves, gasifiers, industrial boilers. The table 2.2 the potential use of briquettes (Sunday et al., 2020). The increase price of the conventional fuels urges the demand for the briquettes fuel and affects briquette fuel price and the briquette machines price as the increased public awareness to the environment protection. The objective of this study was to develop the quality of the hybrid briquettes from various combination of corn cob and bagasse waste in terms of mechanical,

thermal and physical properties as an alternative energy source for domestic applications.

2. MATERIAL AND METHODS

2.1. Study Site

The experiment was carried out in Nuhu Bamalli Polytechnic, Zaria, Kaduna State, Nigeria. Zaria,
located in tropical savanna is situated between latitudes 11° 5' 7.9476" N and longitude 7° 43' 11.8020" E.

2.2. Material Collection and Preparation

The raw materials used in the production of the hybrid briquettes are corncobs and bagasse waste (Plate 1a & b), cassava starch (Plate 2c). The selection of the agricultural wastes was influenced by the abundance of corncobs and the presence of bagasse waste in the northern regions of the country. All moisture contents presented in this paper are on a % wet basis. Both materials were later chopped into small pieces and then sun dried to reduce the moisture content. A grinding machine was used to grinded the raw materials further and then sieved with a sieve to obtain the required particle size. The starch binder at a level of 25% (Tembe, et al., 2011) was prepared with 250 mL. A total of five deferent samples were prepared in varying ratios of corncobs (a) to bagasse (b) (Table 1) and each sample was mixed with cassava starch as binder (25% by weight of sample mix).



(a)



(b)

Plate 1. Samples of raw biomass waste used for the study (a) corncobs and (b) bagasse



(a) **(b)** **(c)**

Plate 2. Samples of raw biomass waste in chopped form (a) corncob (b) bagasse

(c) cassava starch

2.3. Material Characterization

Proximate analysis was carried out on the briquette sample to determine the % moisture content, % ash content, % fixed carbon and heating value of the samples. The procedures of ASME711-87 (Sunday et al., 2020) were adopted.

Table 1. Material composition of corncobs (CC) and bagasse briquettes.

S/N	Samples Name	Corncobs	Bagasse
1	A	100	0
2	B	0	100
3	C	60	40
4	D	50	50
5	E	40	60

2.4. Briquette Production

The briquettes were formed in a cylindrical mold with an inner diameter of 85 mm (3 in), a height of 90 mm and a rod with a 16 mm outer diameter placed in the center to create a hole in the middle of the briquette. The hole helps to increase oxygen supply, thus improving briquette combustion. The briquettes were produced from each sample and their initial densities were measured immediately after ejection from the mold. Plate 3, showed the briquettes.



Plate 3. Briquettes samples made from corncobs, briquettes and their mixtures using a manual press

2.5. Briquette Characterization

i) Density

The density of hybrid briquettes was calculated using the equation (1) below. However, the density of briquettes will be determined according to ASTM D2395-17, Sunday et al., (2020). The mass of the hybrid briquette was divided by its volume and the volume determined by measuring the diameter and height of the hybrid briquette using a Vernier caliper, while the mass also measured with a digital weighing balance (Model CP124S).

$$\rho = \frac{m}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, ρ = Density, m = mass of biomass briquette, V = volume of biomass briquette.

ii) Moisture Content

The moisture content was calculated using the equation (2), Sunday et al., (2020). Moisture content will be determined by oven-dried methods in accordance with ASTM D2444-16. The loss in mass, expressed as a percentage of final oven-dried mass was taken as the moisture content of the hybrid briquettes.

$$MC(\%) = \frac{W_1 - W_2}{W_1} X\ 100 \qquad (2)$$

where, MC = moisture content, W_1 = wet weight, W_2 = weight after drying.

iii) Volatile matter

2g of pulverized briquettes sample in a crucible were placed in the oven until a constant weight is obtained. The briquettes were now kept in the furnace at a temperature of 450ºC for 10 minutes and weighed after cooling and the volatile matter was determined using the equation (3).

$$VM(\%) = \frac{W_1 - W_2}{W_1} X\ 100 \qquad (3)$$

where; W_1 = weight of oven dried sample, W_2 = weight of sample after 10 min., and *VM* (%) = volatile matter.

iv) Ash Content

A 2 g of oven dried pulverized briquette (w_1). was placed in a small tray. The tray was then placed in the furnace (Model DTC 201) for 2 h at 450 °C to obtain the ash weight (w_2). Percentage ash content was calculated using Equation (4).

$$AC(\%) = \frac{W_2}{W_1} X\ 100 \qquad (4)$$

where;

W_1 = weight of oven dried sample (g), W_2 = weight of ash (g) and AC (%) = ash content.

v) Fixed carbon (%FC)

The percentage fixed carbon was calculated by subtracting the sum of percentage volatile matter and percentage ash content from 100% Equation (5).

$$(\%FC) = 100\% - (\%Vm + \%Ash) \qquad (5)$$

vi) Specific Heat of Combustion *(Hc)*

According to Emerhi, (2011), the specific heat of combustion (Hc) was determined from the formula as shown in Equation (6);

$$Hc = 0.35\ (147.6\ x\ \%FC) + (144\ x\ \%VM) + (\%Ash) \qquad (6)$$

2.6 Performance Evaluation of the Briquettes Samples

i) Ignition Time

The ignition time is the time taken for a flame to increase the briquette to its ignition point. The briquette sample was ignited at the base and was adjusted to give stable light (Okonwo et al., 2017). Different samples of the briquette were ignited in a domestic stove and the time taken for each briquette to catch

fire and burn very well without addition of heat from outside was recorded as the ignition time using a stop watch. `

ii) Burning Rate:
The burning rate was determined using equation (7). Burning rate is a measure of the combustion rate of a compound or substance.

$$Burning\ Rate = \frac{Mass\ of\ fuel\ consumed\ (g)}{Total\ Time\ taken\ (Min.)} \quad (7)$$

iii) Burning Time
Burning time is known as the time taken for each briquette sample to burn completely to ashes. The burning time of this study was determined by burning every ratio of the briquettes until they burned to ashes using stop watch.

iv) Boiling Time
Boiling time is the time taken for a briquette to boil water to 100°C. This was done by taking different blends of briquettes to boil two liters of water and the time was taken and recorded.

3. Results and Discussions

3.1 Results of the Samples of Hybrid Briquettes

The proximate testing has been done with respects to density, moisture content, volatile mater, ash content, fixed carbon, specific heat of combustion of the samples.

Table 2: Density of the Samples of the Briquettes

S/N	Mass Ratio (%)	Density (kg/m^3)
1	A	470
2	B	362
3	C	411
4	D	422
5	E	409

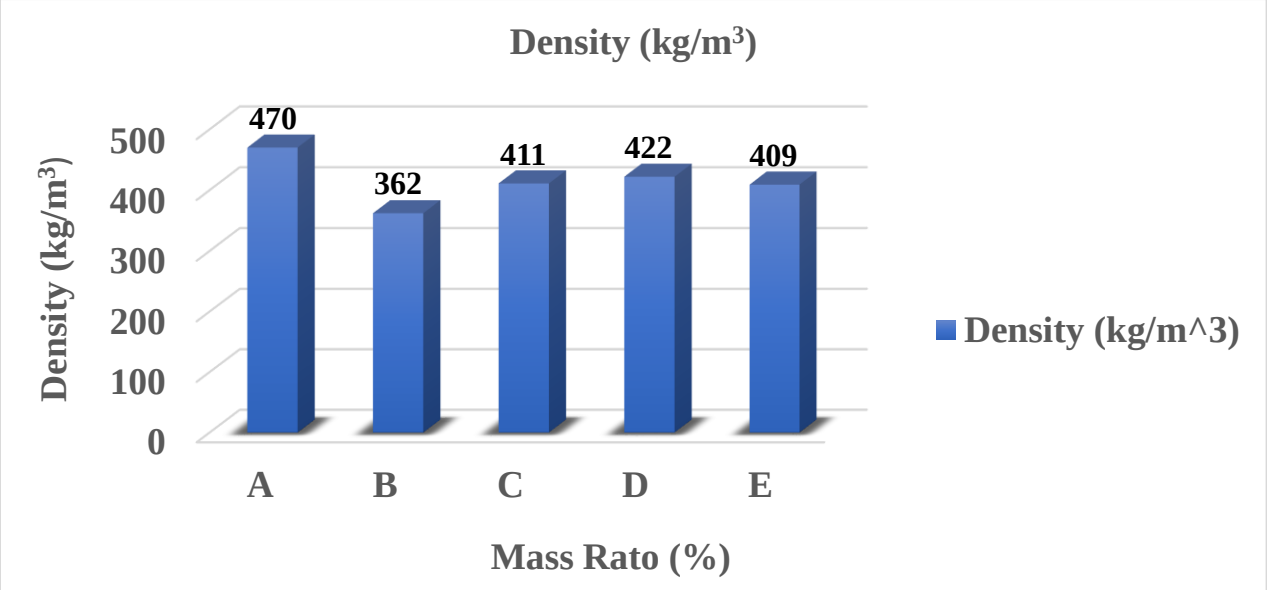

Figure 1: Density against Mass Ratio of the Samples Briquettes

Table 3: Volatile Matter of the Samples of the Briquettes

S/N	Mass Ratio (%)	Volatile Matter (%)
1	A	25.23
2	B	28.03
3	C	38.25
4	D	45.18
5	E	33.83

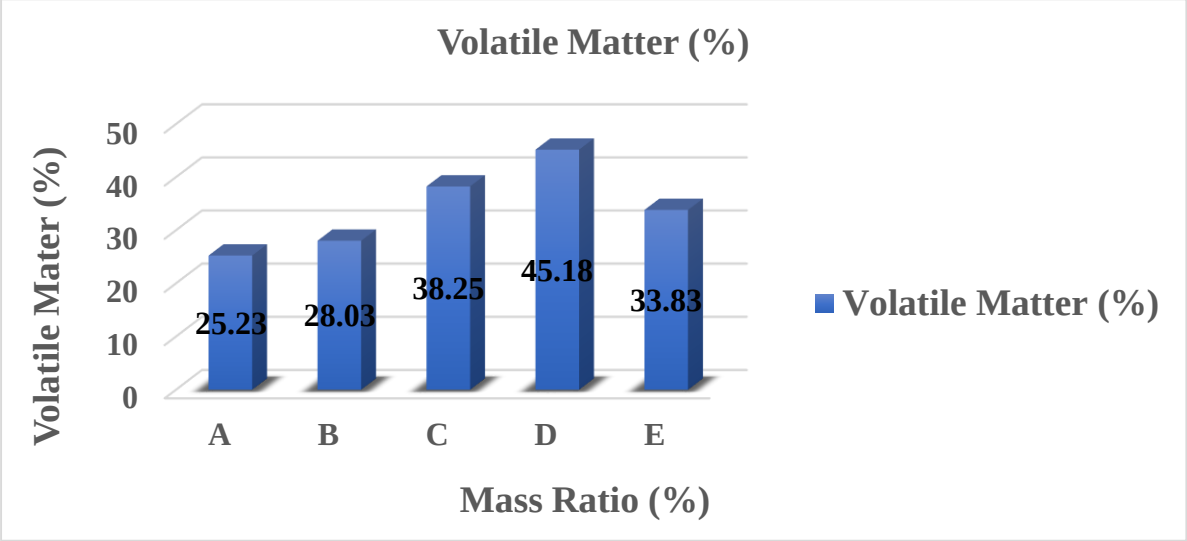

Figure 2: Volatile Matter against Mass Ratio of the Samples Briquettes

Table 4: Moisture Content of the Samples of the Briquettes

S/N	Mass Ratio (%)	Moisture Content (%)
1	A	29.85
2	B	30.01
3	C	28.15
4	D	31.05
5	E	30.55

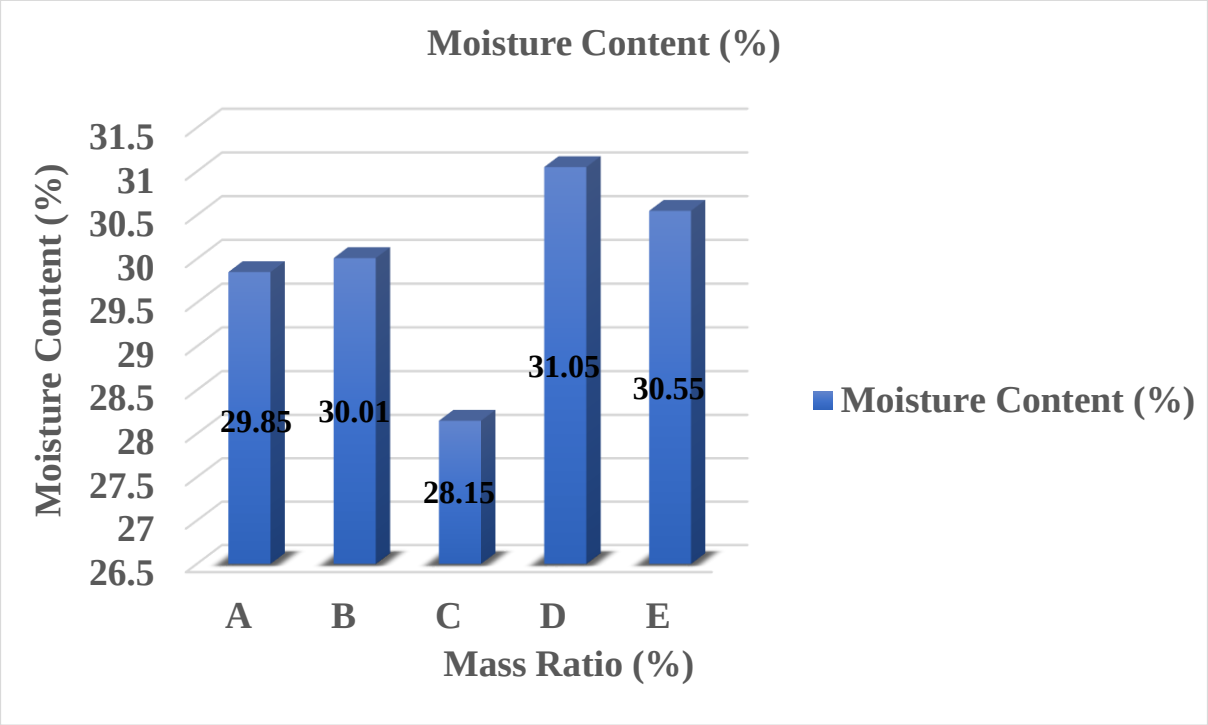

Figure 3: Moisture Content against Mass Ratio of the Samples Briquettes

Table 5: Ash Content of the Samples of the Briquettes

S/N	Mass Ratio (%)	Ash Content (%)
1	A	3.15
2	B	4.01
3	C	4.10
4	D	3.05
5	E	3.60

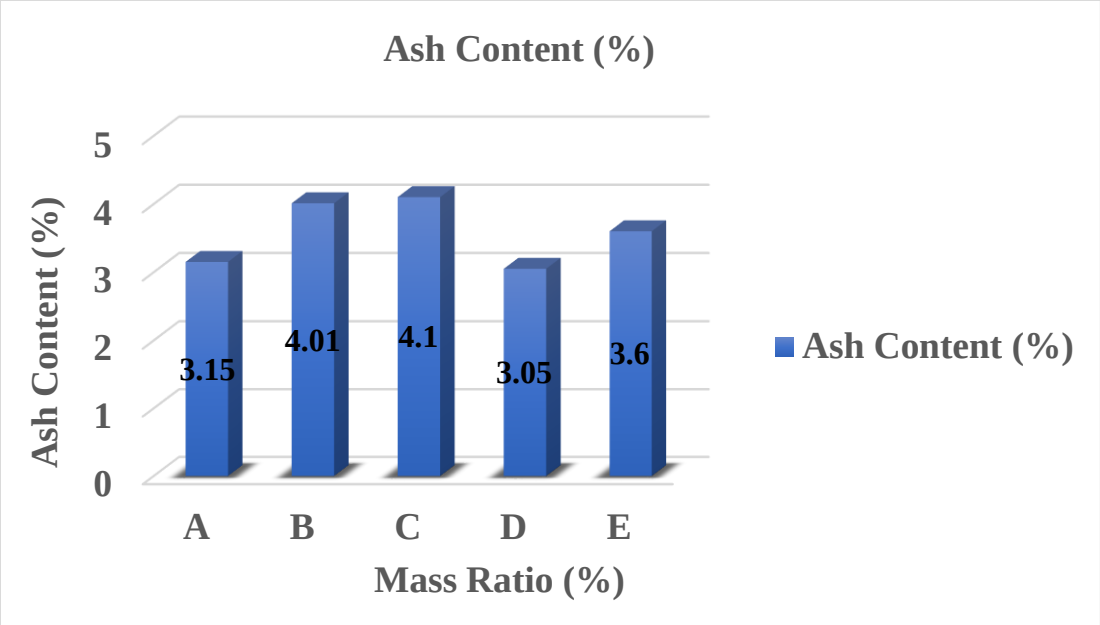

Figure 4: Ash Content against Mass Ratio of the Samples Briquettes

Table 6: Fixed Carbon of the Samples of the Briquettes

S/N	Mass Ratio (%)	Fixed Carbon (%)
1	A	70.45
2	B	63.75
3	C	67.13
4	D	72.01
5	E	63.50

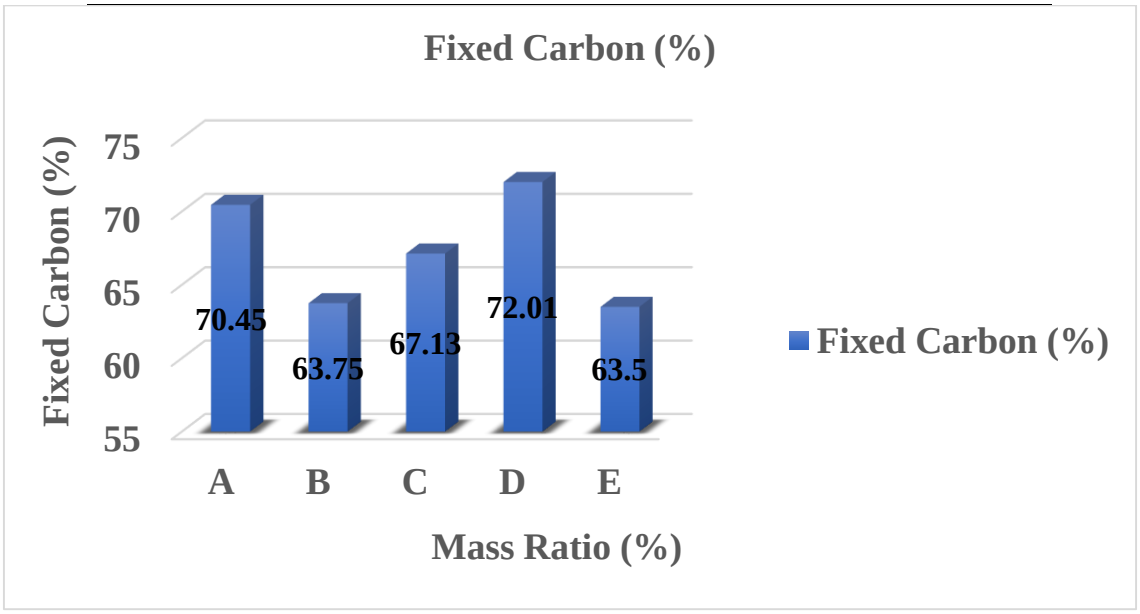

Figure 5: Fixed Carbon against Mass Ratio of the Samples Briquettes

Table 7: Specific Heat of Combustion of the Samples of the Briquettes

S/N	Mass Ratio (%)	Specific Heat of Combustion (x10^3 kJ/kg)
1	A	30.45
2	B	25.15
3	C	32.00
4	D	30.95
5	E	31.56

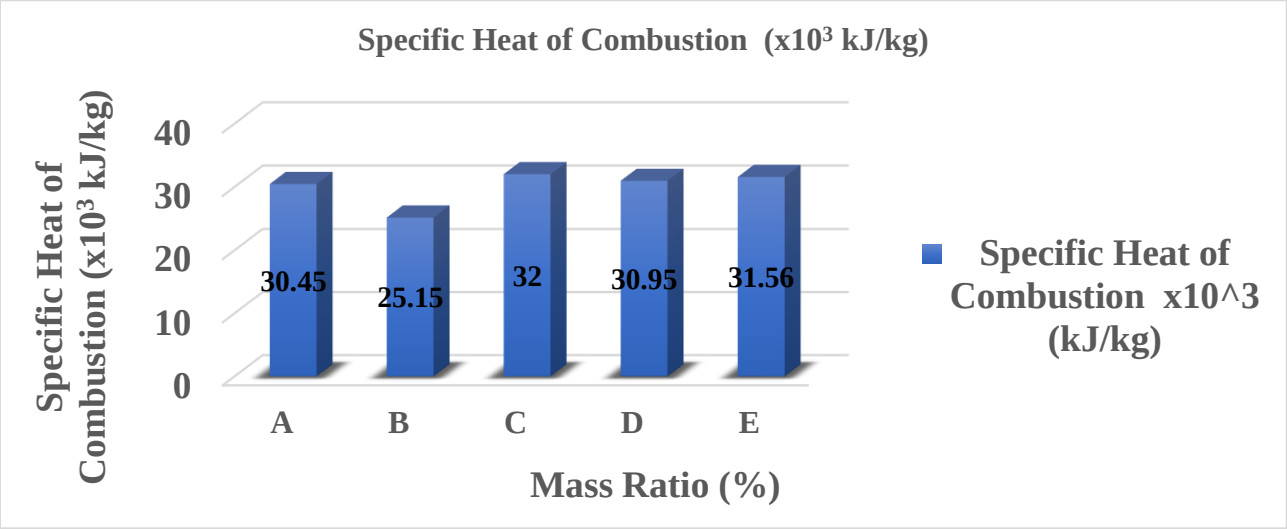

Figure 6: Specific Heat of Combustion against Mass Ratio of the Samples Briquettes

Table 8: Ignition Time and Burning Rate of the Samples of Briquettes

S/N	Mass Ratio (%)	Ignition Time (s)	Burning Time (min.)	Boiling Time (min.)	Burning Rate (g/min.)
1	A	62.15	55	21.5	3.45
2	B	36.25	34	15.5	3.62
3	C	43.05	63	26.2	2.57
4	D	38.24	58	23.6	2.64
5	E	29.85	48	18.6	2.83

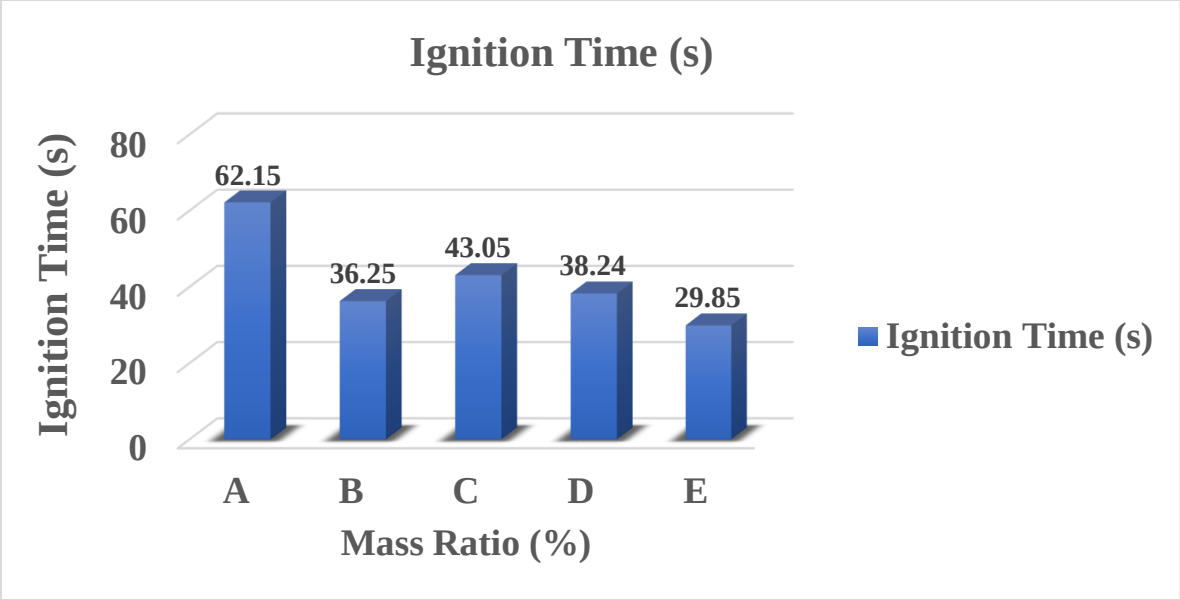

Figure 7: Ignition Time against Mass Ratio of the Samples Briquettes

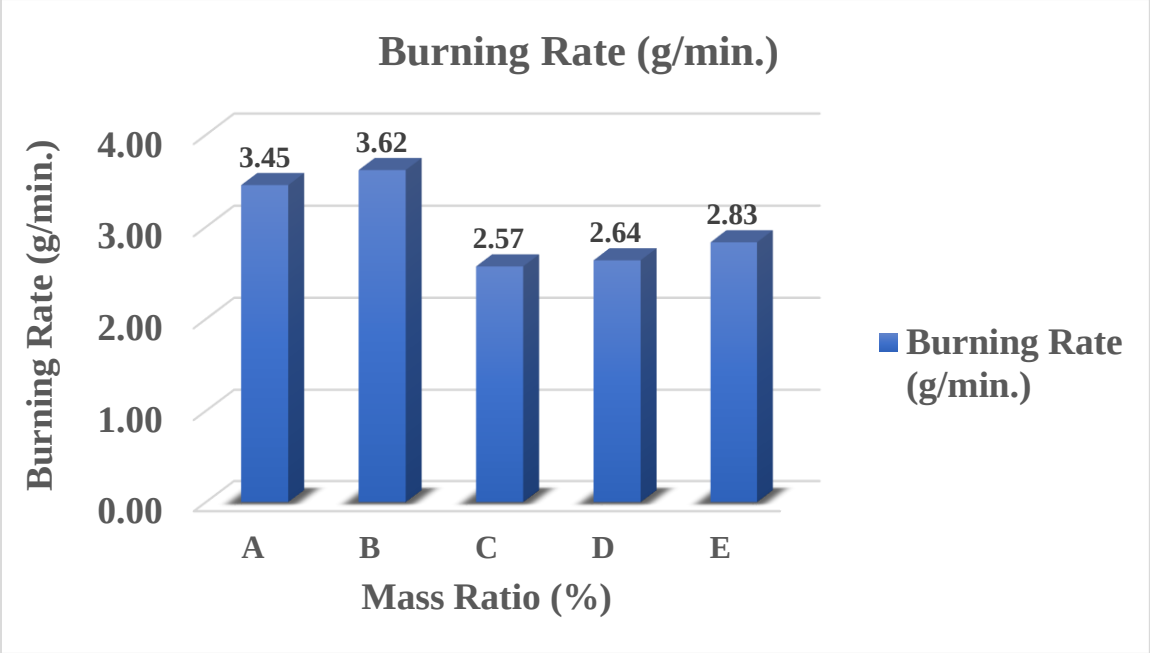

Figure 8: Burning Rate against Mass Ratio of the Samples Briquettes

3.2 Discussion

i) Density of the Briquette

The density of the briquettes ranged between 362 kg/m^3 and 470 kg/m^3 (Table 2 and Figure 1). The Briquette made with corncob had the highest density (470 kg/m^3), while briquette produced with the bagasse had the lowest (362 kg/m^3) briquette density. The higher the density in briquettes, the higher the energy/volume ratio. The burning time may be longer; however, other combustion properties of such briquettes may be negatively affected, Sunday et al., (2020). However, in this study shows that densities for the combinations of hybrid briquettes

(60:40, 50:50 and 40:60) are not significantly different (Table 2) (411, 422 and 409 kg/m^3)

ii) Volatile Matter of the Briquettes Samples:

Table 3 and Figure 1 show the results obtained for the volatile matter of the samples of the briquettes. The results show that hybrid briquettes produced from sample D (50:50) corncob and bagasse recorded the highest volatile matter of 45.18% while sample A (100:0) which is produced the lowest volatile matter of 25.23%. It can be seen from the result that corncob has a very low volatile matter, when produced with corncob 100%. This shows that the higher the corncob ratio blended with bagasse, the lower the volatile matter.

iii) The Moisture Content of the Briquettes Samples:

The moisture content of the samples of hybrid briquettes arranged for this study is shown in Table 4. It can be seen that the highest moisture content occurs at sample D (50:50) which is corncob and bagasse with 31.05%. By the way, sample C (60:40) i.e. corncob and bagasse with 28.15% of moisture content. Also, it can be seen that higher corncob to bagasse the lower moisture content in the hybrid briquettes. This means that as the ratio of corncob increases the moisture content decreases. This result is higher than the result produced by Babajide et al (2018) in their Comparative Analyses of Densities and calorific value of wood and briquettes samples.

iv) Ash Content of the Briquettes Samples:

The ash contents of the briquette samples are presented in Table 4 and shown in Figure 4. The low ash content as observed in this study is 3.15% i.e., sample A (100:0) which is produced with corncob 100% and the highest ash content recorded as 4.10% sample C (60:40). This is can be seen that bagasse has high ash content when blended with corncob. This result shows relatively with the result (AC 2.29%) produced by Sarpong et al., (2019) in their Evaluation of Briquettes Produced from Charred Sawdust, Corncob and Rice Husk.

v) Fixed Carbon of the Briquettes Samples:

In Table 5 and Figure 5 show the results of the fixed carbon of the hybrid briquettes made from corncob and bagasse. From the results, the briquettes made from corncob and bagasse, sample D (50:50) noted the highest fixed carbon content of 72.01% and sample E (40:60) recorded the lowest with 63.50%. The result shows that corncob has high carbon content while bagasse has low carbon content. The blend of corncob and bagasse (60:40) provided a significant increase of 67.13% which higher than the value of bagasse (0:100) which 63.75%.

vi) Specific Heat of Combustion

Briquette produced from the corncob and bagasse, sample C (60:40) had higher specific heat of combustion than those produced from the other blending ratios (i.e. 50:50 and 40:60). This might be relevant to its lower moisture content than the ratios. The Table 7 and Figure 6 shows the highest and lowest specific heat of combustion values are 32,000 kJ/kg and 25,150 kJ/kg respectively. This result is higher than the result produced by Babajide et al (2018). Similarly, Kumar, et al., (2016) in their study "Evaluation of Boiler Efficiency of Bio Briquettes by Indirect Method" stated a lower specific heat of combustion as 20,945 kJ/kg.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The objective of work was to evaluate the physical and composition properties of hybrid briquettes produced from corncobs and bagasse waste using cassava starch as binder. The hybrid-briquettes were produced

by collecting the materials, crushing, sieving, weighing, mixing and briquetting using manual press and drying. Also, briquettes were produced from individual materials as controls and from a mixture of both in different proportions. The experiments performed on the briquettes were in respect of their physical, mechanical and thermal properties. The evaluated density, volatile matter, moisture content, ash content, fixed carbon and specific heat combustion for the hybrid-briquettes falls within the range of 362-470 kg/m^3, 28.03-45.18%, 28.15-31.05%, 3.05-4.10%, 63.50-72.01% and 25150-32000 kJ/kg respectively. Furthermore, from the investigation of the mixing ration, the effect of the raw materials on the quality of hybrid-briquettes, at the mixing ratio, 40:60 (corncob to bagasse ratio) has a good characteristic. It was concluded that, biomass briquettes are highly recommended as an alternative fuel for both domestic and industrial application.

4.2 Recommendation

The present study was limited to evaluating the performance of briquettes produced from cob waste and bagasse, and the objective was to evaluate the physical and compositional properties of the hybrid briquettes generated. from corn cobs and bagasse waste, using tapioca starch as a binder. The production process includes raw material collection, crushing, sieving, weighing, mixing, manual pressing and drying. Briquettes made from individual materials and a variety of composite blends have been tested for their physical, mechanical and thermal properties. The results show that the density, volatile matter, moisture content, ash content, fixed carbon and combustion specific heat capacity of hybrid briquettes are within (specific range). Notably, considering the different mixing ratios, the mixing ratio is 40:60 (cobs to bagasse ratio) was determined to be particularly favorable in terms of briquette quality. These results highlight the potential of hybrid biomass briquettes as a viable alternative fuel source for domestic and industrial applications. The mixture of corn cob and bagasse waste, together with the binding of tapioca starch, offers properties that can contribute to sustainable energy and waste management practices. Therefore, this study recommends the exploration of hybrid briquettes as a practical and environmentally friendly solution to energy needs. In the future, follow-up studies may delve deeper into optimizing mixing ratios, exploring other binders, and evaluating manufacturing process scalability. By advancing our understanding of hybrid briquettes, we can move closer to a cleaner, more sustainable energy future."

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