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Effect of Formulation, Binder and Compaction Pressure of Rice Husk-Bagasse Briquettes on Thermal and Physical Properties

Kerich K. Daniel[1*], Zachary O. Siagi[2] and Julius O. Ogola[3]

[1]*Energy Resources Division, Kenya Industrial Research and Development Institute (KIRDI), P.O. Box 6017, Kisumu, Kenya.*
[2]*Moi University, P.O. Box 3900, Eldoret, Kenya.*
[3]*Laboratory services Center, Kenya Industrial Research and Development Institute (KIRDI), P.O. Box 6017, Kisumu, Kenya.*

Authors' contributions

This work was carried out in collaboration among all authors. Author KKD designed the study, run the experiment, performed the statistical analysis and wrote the first draft of the manuscript. Author ZOS managed the analysis of the study and also did a greater part in literature searches. Author JOO performed and managed the laboratory analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study investigated the use of agro-wastes for the production of briquettes. It was carried out to investigate the effect of formulation, binder and compaction pressure of rice husk-Bagasse briquettes on thermal and physical properties.

Study Design: The experimental design for this study was 6x5x2 Randomized Complete Block Design

Place and Duration of the Study: Rice husks and bagasse were collected from Lake Basin Development Authority's rice mill and Kibos sugar and Allied company respectively. The binders were sourced locally in Kisumu. The study was conducted between March 2019 and February 2020. The fabrication and laboratory analysis were carried out in the engineering and laboratory

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**Corresponding author: E-mail: dankerych@gmail.com;*

departments of Kenya Industrial Research and Development institute, Kisumu.

Methodology: The experimental design for this study was 6x5x2 Randomized Complete Block Design. This study involved six formulations ratios (0:100, 20:80, 40:60, 60:40, 80:20, 100:0), five compaction pressure levels (108kPa, 180kPa, 253kPa, 325kPa, 397kPa) and two binders (clay, cassava) They were arranged in Randomize Complete Block Design with three replications per experiment.

Results: The briquettes bulk density was in the range of 849 to 1001 kg.m^{-3}, while the calorific value ranged from 5.541 kcal/g for 100% Rice husk clay binder to 7.345 kcal/g 20% Rice Husk cassava binder. Briquettes with blend ratio of 40-60% Rice Husk took longer time to burn. Briquette formulations with clay binder had burning rates ranging from 0.28 g/min to 0.15 g/min while with cassava binder from 0.52 g/min to 0.37 g/min. The ignition time of the briquettes ranged from 62 sec to 95 sec with cassava binder and 110 sec to 191sec with clay binder. The shatter index ranged from 0.94 to 0.99 with cassava and 0.9 to 0.98 with clay binder.

Conclusion: Higher compaction pressures and use of cassava binder produced stronger briquettes with higher calorific values. Briquettes with higher percentage of bagasse had low ignition time and low bulk densities. The bulk densities and ignition time showed significant rise with increase in the compaction pressure but inversely affected the burning rate. The binder used significantly affected both the thermal and physical properties of all the formulations.

Keywords: Briquette; compaction; blended; binders; calorific value and Kenya.

1. INTRODUCTION

Biomass energy accounts for about 15% of the total world energy compared to coal (12%), natural gas (15%) and electric energy (14%) [1]. In East Africa 84% of the total energy used by 90% of the population is derived from biomass sources such as charcoal, firewood, agricultural residues and animal/livestock wastes. There has been an upward trend in the consumption of charcoal over the last 10 years and this is expected to continue annually by about 5% [2].

The demand for energy in East Africa is increasing both for households, businesses and industry. Increasing populations, aggressive deforestation, expanding economies and a lack of regulation have led to increasing fuel prices and shortages, which often hits hardest the households and businesses most in need [3]. In Kenya, approximately 82% of the population cooks with biomass (wood and charcoal). Within urban areas kerosene is the most widely used fuel (44.6% of the population) followed by charcoal (30.2% of the population), while in rural areas wood is predominantly used by 88.2% of the population. Biomass fuels are also used for many institutional, commercial, and industrial applications; such as cooking in hotels and restaurants, space heating for poultry farmers, and heating applications in industrial boilers. It's projected that by 2050 70% of the populations in Sub-Saharan Africa will be in urban areas, which implies firewood and charcoal will be in short supply, this necessitate the need for alternative. To grow the biomass energy sector, countries around the world are considering biomass crops for energy purposes and have developed technologies to use biomass more efficiently [4].

Agricultural biomass residues are sources of renewable and sustainable biofuels which can contribute significantly towards mitigating the effect of greenhouse gas (GHG) emissions if properly managed and utilized [5]. Due to inefficient use and improper methods of disposal of agricultural residues, these materials tend to pollute the environment thereby posing a health risk and hazard to man and the ecology. In order to curb the menace posed by these materials, efforts should be geared towards controlling pollution resulting from these materials by converting them to briquettes. Agricultural residues in their natural forms do not bring a desired result because they are mostly loose, low density materials in addition to the fact that their combustion cannot be effectively controlled [5]. Although, there are many conversion routes through which these residues can be converted into biomass energy, one of such promising technologies is that of the briquetting process. Carbonised briquettes can act as a replacement for charcoal for domestic and institutional cooking and heating, where they are favoured for their near-smokeless use. In comparison to charcoal, they generally burn for longer and have a more consistent heat output, which is preferred by certain market segments such as restaurants, hospitals and schools. Non-carbonised briquettes on the other hand serve as a replacement to natural firewood and raw biomass fuel [6].

Kenya is an agro-based economy with agricultural operations and processes contributing over 80% of Gross Domestic Product (GDP). Agricultural operations and agro-products processing generate large quantities of agricultural, agro-industrial residues with limited industrial applications. Rice production in Kenya is estimated at about 70,000 t, 25% of which is rice husks. The husks are low density and have poor nutritional profile making it unsuitable as an animal feed [7]. This waste material is usually dumped and flared in the open fields and is hardly utilized for other economic activities. Kenya generates about 1.6 million t of sugarcane bagasse which has enormous potential for exploitation in modern commercial applications including energy use [7]. In order to upgrade biomass residues for a variety of applications, their original form which are mostly characterized by high moisture content, irregular shapes and sizes, low bulk density, difficulty in handling, transporting and storing, have to undergo some changes to make their use more practical and economical [8,9]. Some of these drawbacks can be overcome through densification of biomass residues with appropriate binders for briquette production. The potential for the exploitation of these residues for development of briquettes is enormous due to (a) rising fossil fuel prices (b) their availability in large quantities (Kenya produces over 6,400,000 tons of residues annually with an energy potential of over 51,000 TJ of heat and 1642 MW of electricity) (c) their availability at almost zero cost and (d) their contribution to environmental protection and conservation [10]. Biomass briquettes are a form of solid fuel that can be burned for energy. They are created by compacting loose biomass residues into solid blocks that can replace fossil fuels, charcoal and natural firewood; for domestic and institutional cooking and industrial heating processes. Charcoal briquettes are made by thoroughly mixing powdered charcoal (charcoal fines) produced from any organic material with a binder agent [6].

There have been several researches carried out on production of fuel briquettes for both domestic cooking and industrial applications. One of the major driving forces behind these researches is the need to address the environmental consequences and health hazards associated with the use of solid fuels (such as fuel wood and coal) and also an effective means of managing agro wastes [11]. Blending of biomass briquettes is one way of improving the fuel characteristics of certain biomass materials with those having superior fuel attributes. This helps to promote the utilization of those materials with poor energy characteristics.

For briquettes are to be used efficiently and rationally as fuel, they have to be characterized to determine their thermo-chemical characteristics such as calorific value, ash content, density, volatile matter, ignition time as well as physical characteristics including density and durability (shatter index) among other attributes.

The objective of this study therefore was to find out the effect of formulation, binders and compaction pressures on the quality characteristics of rice husk-bagasse briquettes. These processing parameters were evaluated to determine their influence on fuel properties and how these findings could guide in development of better briquettes thereby enhancing increased utilization of these agro-wastes.

2. MATERIALS AND METHODS

All the raw materials (rice husk, bagasse and binders) were sourced from Kisumu county, Kisumu city. The apparatus and equipment used were uniaxial manual briquetting press (designed and fabricated by the authors), digital weighing balance (NBL-2602e; 0.01g sensitivity), bunsen burner, stopwatch, meter rule, pulverizer, Sieve, Petri dish, bomb calorimeter (IKA C2000/Kv600) and Plastic basin. The briquettes were produced using compaction pressures of 108, 180, 253, 325 and 397kPa and compression times of 10 seconds.

The biomass materials were air-dried and a small portion (200g each) pulverized with an electric herb pulverizer machine (model: SF 250). The binder materials were air-dried and ground with a disc mill. The dried biomass materials were carbonized and the char samples pulverized and sieved to particle sizes 150-750 μm using standard laboratory sieves (model: GY-463, aperture 0.01-1mm).

A small quantity of each of the prepared carbonized material was used for proximate and calorific value analysis. Binder materials were analyzed for proximate and calorific values. Fig. 1 shows the prepared samples for analysis.

2.1 Production of Briquettes

The briquettes were produced using a uniaxial manual briquette machine (Fig. 2) with a rectangular mould 60 mm long, 40 mm wide and 85 mm high. Bagasse and rice husk char were blended at mixing ratios of 100%, 80%, 60%, 40%, 20% and formed into briquettes using 10% cassava starch and 15% clay paste as the binders. Five pressure levels; 108kPa, 180kPa, 253kPa, 325kPa and 397kPa were used. The briquettes were sun-dried for 5 days before physical and thermal properties of the briquettes were evaluated.

2.2 Analysis and Evaluation of Briquettes

The moisture and the ash content of the briquette samples were determined in accordance with ASTM-E871-82 (2013) [12] standard and the volatile matter was determined in accordance with ISO 562:2010 (2010) [13] standard. The fixed carbon percentage was calculated according to the standard procedure by Sengar et al. (2012) [14]. The ignition time was determined in accordance with ASTM- E1321-13 (2013) standard [15]. The Percentage of fixed carbon = 100 - % of (moisture content+ volatile matter + ash) wet basis.

2.2.1 Determination of calorific value

The calorific value of the raw materials and the charcoal briquettes were determined using bomb calorimeter. The calorific value of the biomass materials was determined in accordance with ASTM D5865 - 04 (2004) standard [16].

$$\text{Calorific value (Kcal/kg)} = \frac{(W+w)x(T_2-T_1)}{X} \quad (1)$$

Where:

W = weight of water in kilogram (kg),

w = water equivalent of calorimeter (kg)

T_1 = initial temperature of water (^oC)

T_2 = final temperature of water (^oC)

X = weight of fuel sample taken (kg)

2.2.2 Water boiling test

This was determined following the procedure described by Kabok et al., (2018) [17]. This measured the time taken for each set of briquettes to boil an equal volume of water under similar conditions. 450 g of each briquette sample was used to boil 1000 cm^3 of water with a domestic briquettes stove. The time taken to bring the water to 94^{o}C which is the local boiling point of water in Kisumu was recorded for each set of briquettes.

2.2.3 Determination of ignition time

This is the time it takes a briquette to get ignited (i.e. start burning). This was carried out in the laboratory on individual briquettes in order to compare effect of different formulations, binders and compaction pressure on ignition time of the briquettes.

Ignition time was determined in accordance with ASTM- E1321-13 (2013) standard test method for determining material ignition and flame spread properties [15]. Each briquette was ignited by placing a bunsen burner on a platform 4cm directly beneath the briquette hanged on a tripod stand. The bunsen burner was used to ensure that the whole of the bottom surface of the briquette was ignited simultaneously after adjusting it to blue flame. It was ensured

Fig. 1. Preparation for samples for raw and carbonized materials

Fig. 2. Uniaxial press and briquette samples produced in the Lab

that the briquette was well ignited before the ignition time was recorded with the stopwatch [18].

2.2.4 Burning rate

The method previously described by Onuegbu et al., (2011) was used [19]. The initial and final weight of each briquette was recorded before and after burning. Burning rate is the rate at which a certain mass of fuel is combusted in air. The key parameters observed to be of significance were the binder, the compaction pressure and biomass formulation. To calculate the burning rate, the two weights, W_1 and W_2 for initial and final weights (i.e. briquettes and ash) for each experiment were recorded. Time taken for complete combustion of the briquettes was also recorded for each cycle. Burning rate was then calculated using the formula:

$$B_R\ \left({}^{g}/_{min}\right) = \frac{W_1 - W_2}{T} \quad (2)$$

Where,

B_R = Burning rate, g/min

W_1 = Initial weight of the briquette prior to burning (g)

W_2 = Final weight of the fuel (ash) after burning (g)
T = Total burning time (min)

2.2.5 Bulk density

The bulk density of the charcoal briquettes was determined according to ASTM D7481-09 (2009) standard [20].

$$Bulk\ density = \frac{\textbf{Initial mass of material}}{\textbf{Volume of cylinder}} \text{gcm}^{-1} \quad (3)$$

2.2.6 Determination of shatter index

Drop test was determined according to ASTM D440:2012 - Standard Method of Drop Shatter Test for Coal (2012) [27]. Two samples from each test were used and dropped at a height of 2m. The briquette with known weight and dimension was allowed to drop on reinforced cement concrete (RCC) floor. The weight of disintegrated briquette and its size was noted. The percent loss of material was calculated. The shatter resistance of the briquettes was calculated by using the following formula:

$$\text{Percent weight loss (\%)} = \frac{W_1 - W_2}{W_1} X100 \quad (4)$$

% Shatter resistance = 100 - % weight loss

Where, w_1 = Weight of briquette before shattering

w_2 = Weight of briquette after shattering

2.2.7 Data analysis

Data analysis was done using Microsoft excel data analysis software. The data was presented as figures with three replicates used for average and two replicates for Standard Deviation.

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis of Biomass Samples

The results of proximate analyses of the raw and carbonized biomass samples are shown in Fig. 3 (a) and (b) respectively. From the results, the bagasse had enhanced fuel attributes than rice husk i.e. higher calorific values for both raw and carbonized samples, higher fixed carbon and better volatile content. On the contrary, rice husk showed much higher ash content than bagasse which is a negative fuel characteristic. These characteristic features of bagasse implied better combustion, ease of ignition and faster burning due to higher volatile matter. Blending was therefore seen as a way of enhancing the quality characteristics of briquettes from rice husk hence promoting its utilization potential.

Proximate analysis for cassava binder were: 1.30% ash, 7.04% fixed carbon and its calorific value 4.05 kcal/g while clay binder had 89.92%, 0.16% and 0.216 kcal/g for ash content, fixed carbon and calorific value respectively.

3.2 Thermo-Chemical Properties of the Briquettes

The higher the percentages of rice husk in the formulation, the lower the calorific values of the briquettes (Fig. 5). The calorific values for 100% bagasse were 7.553kcal/g and 6.941kcal/g for cassava and clay binders respectively. Cassava binder produced comparatively better fuel briquettes than clay binder for all the formulations. Fixed carbon content decreased with increasing rice husk percentage from 34.81 to 23.60% with clay binder and from 44.60 to 30.00% with cassava binder (Fig. 4). Ash content increased with increasing rice husk for both binders. To improve the fuel characteristics of rice husk and thereby promoting its increased utilization as a domestic fuel, blending with other residues could be a good option.

As explained above, the effect of higher rice husk content in the formulation on the calorific value of the blend is shown in Fig. 5.

3.3 Maximum Densities (Kg/M^3) of Formed Briquettes

3.3.1 Effect of formulation

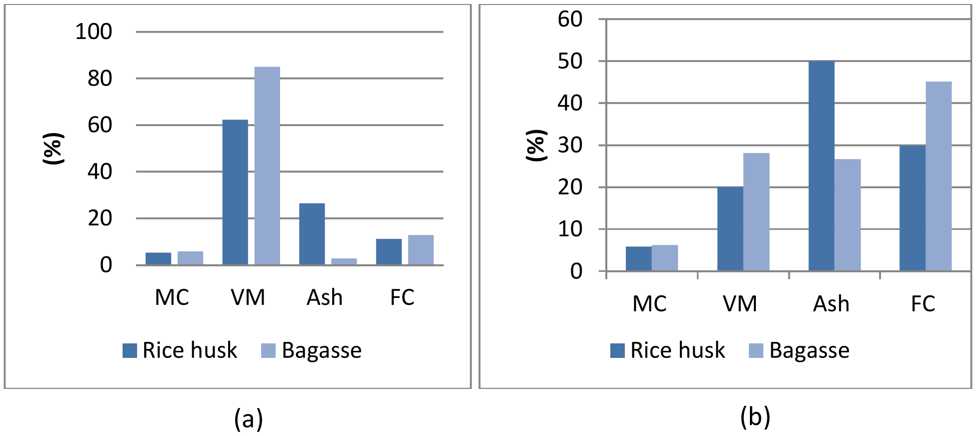
From the ANOVA, the effect of formulation on maximum densities of briquettes was highly significant (*P*<0.01) for all the briquettes

Table 1. Proximate analysis of raw biomass samples (dry basis)

Biomass	Moisture content (%)	Volatile matter (%)	Ash (%)	Fixed carbon (%)	Calorific value(kcal/g)
Rice husk	5.20	62.34	26.48	11.18	3.216
Bagasse	5.82	84.87	2.78	12.85	4.241

Table 2. Proximate analysis of carbonized biomass samples

Carbonized biomass	Moisture content (%)	Volatile matter (%)	Ash (%)	Fixed carbon (%)	Calorific value(kcal/g)
Rice husk	5.83	20.09	50.04	29.87	6.18
Bagasse	6.27	28.14	26.70	45.16	7.81



(a) (b)

Fig. 3. Proximate analysis of biomass samples: a). Raw biomass samples b). Carbonized biomass

Table 3. Thermo-chemical properties of briquettes (dry basis)

Blend	Calorific value (kcal/g)		Fixed carbon (%)		Ash content (%)	
RH:B	Clay	Cassava	Clay	Cassava	Clay	Cassava
0:100	6.941	7.553	34.81	44.60	36.47	18.40
20:80	6.542	7.345	30.51	39.37	41.59	23.93
40:60	6.159	7.131	26.43	34.99	46.73	29.28
50:50	6.113	7.016	26.22	34.48	47.28	30.85
60:40	5.900	6.814	24.68	33.53	50.87	32.95
80:20	5.668	6.537	24.02	32.58	56.00	37.38
100:0	5.541	6.264	23.60	30.00	58.74	42.09

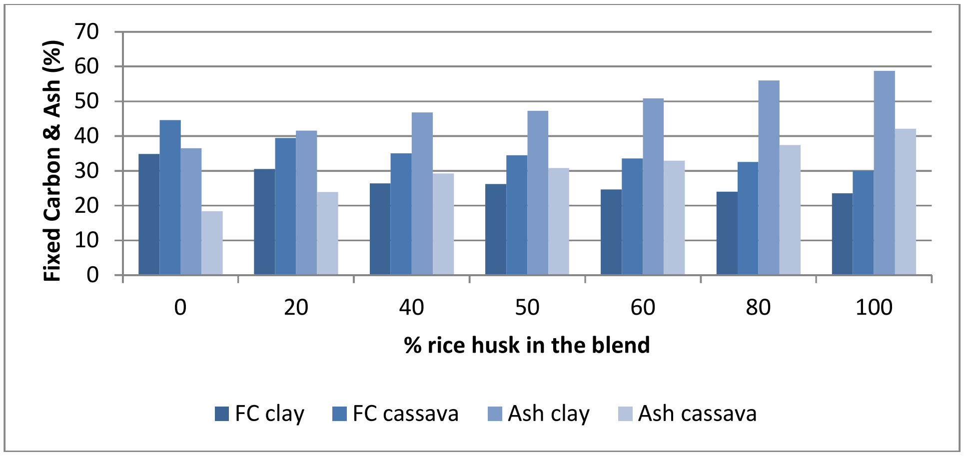


Fig. 4. Thermo-chemical properties of briquettes

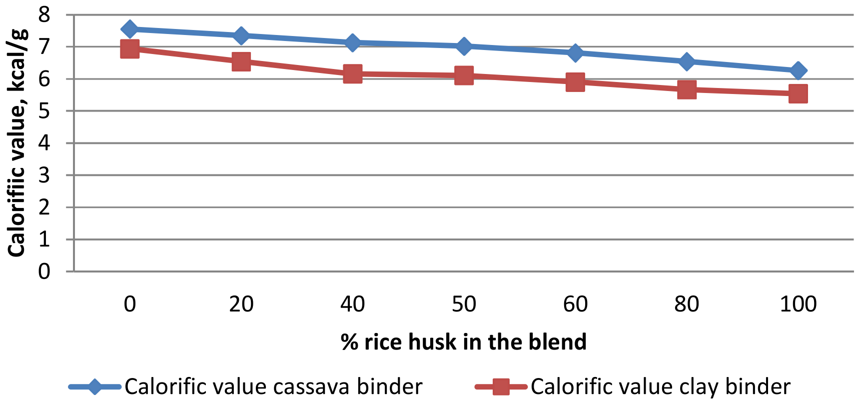


Fig. 5. Calorific value (kcal/g) of rice husk-bagasse briquettes

produced under all the pressure levels. This observation was true for briquettes formulated using both cassava and clay binders (Figs. 6 and 7). Briquettes produced with clay binder however had higher maximum densities than with cassava binder for all the pressure levels. For cassava binder the maximum densities ranged from (849-980kg/m^3) while with clay binder the maximum densities ranged from (869-1001) kg/m^3. It was also observed that the maximum densities for all the briquettes (clay and cassava) increased with increasing percentage of rice husk in the blend. The chemical composition of rice husk could be affecting its density. The chemical composition of rice husk is:cellulose (50%), lignin (25%–30%), silica (15%–20%), and moisture (10%–15%).

Table 4. Maximum densities of rice husk-Bagasse briquettes

Binder (%)	Blend ratio (RH:B)	Bulk densities (kg/m^3) at different pressures					Bulk densities of uncompressed material (kg/m^3)
		108kPa	180kPa	253kPa	325kPa	397kPa	
Cassava starch	20:80	849	867	884	902	921	343
	40:60	866	883	902	921	940	364
	60:40	882	901	921	941	960	400
	80:20	893	912	931	950	970	445
	100:0	902	921	941	961	980	480
Clay	20:80	869	888	906	924	942	349
	40:60	887	905	924	941	960	370
	60:40	903	922	939	956	974	408
	80:20	913	931	950	968	987	452
	100:0	920	941	962	981	1001	488

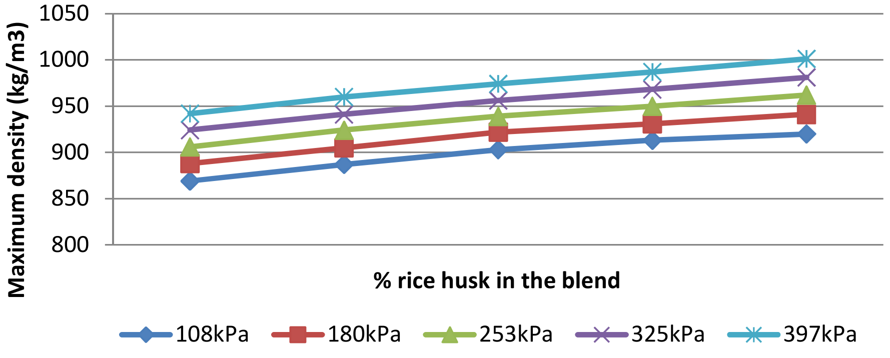


Fig. 6. Effect of pressure and formulation on maximum density of briquettes with clay binder

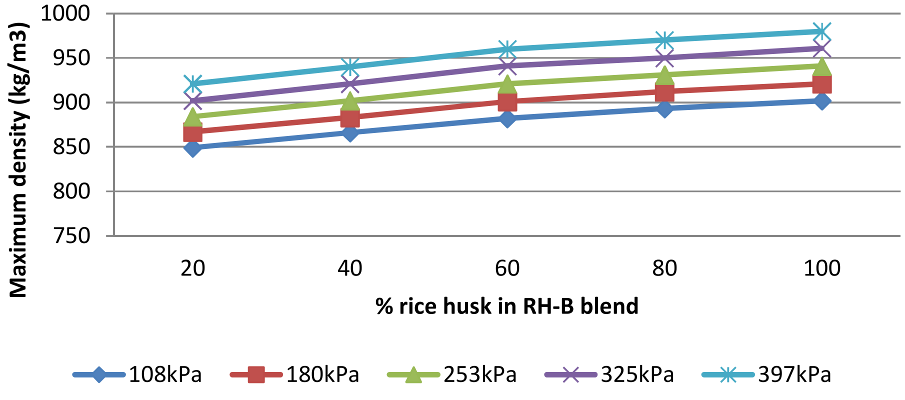


Fig. 7. Effect of pressure and formulation on maximum density of briquettes with cassava binder

When the husk is carbonized the moisture and all the organics (cellulose and lignin) are volatilized thereby raising the relative silica percentage and this significantly contributes to higher bulk densities for briquettes with higher rice husk content Gursel et al. [21] reported the content of silica in Rice Husk Ash (RHA) to be between 90 and 95%. Oladeji, [22] on the study on effects of some processing parameters on physical and densification of corn cob briquettes found that maximum and relaxed densities of briquettes increased with applied pressure from, 533-981 kg/m^3 and 307-417 kg/m^3 respectively.

3.3.2 Effect of compaction pressure

The compaction pressure had significantly high effect (P<0.01) on the maximum densities of briquettes for all the compaction pressures. This trend was observed for all the briquette formulations produced with cassava and clay binders. Increasing applied compaction pressure resulted to correspondingly higher maximum densities.

3.4 Shatter Index of Briquettes

3.4.1 Shatter index of briquettes with cassava binder

3.4.1.1 Effect of formulation

The formulation had highly significant effect (P<0.01) on shatter index for the low compaction pressures (108 and 180) kPa. The effect of formulation decreased with increasing applied pressure and there was no significant effect (P>0.05) on shatter index for the compaction pressures (325 and 397) kPa. This observation implies that higher compaction pressures had more effect on durability and produced stronger briquettes (higher shatter index) that were able to resist shattering. In all the briquette formulations 40-60% rice husk yielded stronger briquettes. From this observation, it could be concluded that the adhesive bonding forces (rice husk-bagasse) accounted more for the formation of stronger briquettes than the cohesive bonding forces (rice husk-rice husk or bagasse-bagasse).

3.4.1.2 Effect of compaction pressure

The effect of compaction pressure on shatter index was significantly high (P<0.01) for the briquette formulations 20%RH, 40%RH and 100% RH. The effect of compaction pressure decreased towards the central region of the curves (50:50) ratio of rice husk to bagasse. From data analysis there was no significant effect of compaction pressure at 60% RH (P>0.05). At this region the formulation had more significant effect than compaction pressure. This observation showed that more durable and stronger briquettes (higher shatter index) were produced from this formulation.

3.4.2 Shatter index of briquettes with clay binder

3.4.2.1 Effect of formulation

The formulation had highly significant effect (P<0.01) on shatter index of the produced briquettes for all the compaction pressures applied. The compaction pressure had less effect on durability and strength of the briquettes with clay binder as compared to cassava binder (Figs. 8 & 9). It was generally observed that stronger and more stable briquettes were produced from formulations of between 50 to 60% rice husks. Sengar, et al. 2012 did a study on the physical characteristics of briquettes from carbonized cashew shell, grass and rice husk without binder in the ratios 50:25:25, 25:50:25 and 25:25:50 for cashew shell, rice husk and grass. They obtained shatter index for the briquettes of between 94.4 – 97.3% [14] whereas the results for the current study were; 93-99% (cassava binder) and 94-98% (clay binder) which compares favorably with the results of this study.

3.4.2.2 Effect of compaction pressure

There was highly significant effect of compaction pressure (P<0.01) on the shatter index of formed briquettes of formulations 20%, 60%, 80% and 100%RH. However the effect of compaction pressure was not significant (P>0.05) for the 40% RH formulation. At this point formulation had more effect on the durability of the briquettes.

For the five tested pressure levels, the briquette formulations with cassava binder generally had higher shatter index values than with clay binder. This showed that cassava binder made stronger briquettes than clay binder.

3.5 Ignition Time

The results showed that the blending ratio of the briquettes had highly significant effect (P<0.01) on ignition time of the produced briquettes for all the compaction pressures applied. The study found that the formulations with cassava binder had less effect on ignition time of the briquettes as compared to clay binder. Generally the briquettes compacted at the lowest pressure regardless of the binder used ignited more easily as compared to the other tested pressure levels. A direct proportional relationship was established between compaction pressure and ignition time. Higher compaction pressures automatically increased the density of briquettes and consequently, delayed the ignition time of the briquettes. It was also observed that briquettes formulated with higher percentage of bagasse took less time to ignite. The briquette formulation with 80% bagasse and cassava binder had the shortest ignition time of 62 seconds.

Table 5. Shatter index of rice husk-Bagasse briquettes

Binder (%)	Blend ratio (% rice husk)	Shatter Index		
		P1 (108kPa)	P2(180kPa)	P3(253kPa)
Cassava starch	20	0.94	0.96	0.97
	40	0.96	0.98	0.98
	60	0.98	0.98	0.99
	80	0.95	0.96	0.97
	100	0.92	0.95	0.96
Clay binder	20	0.90	0.92	0.93
	40	0.94	0.95	0.95
	60	0.94	0.96	0.96
	80	0.94	0.95	0.95
	100	0.89	0.91	0.92

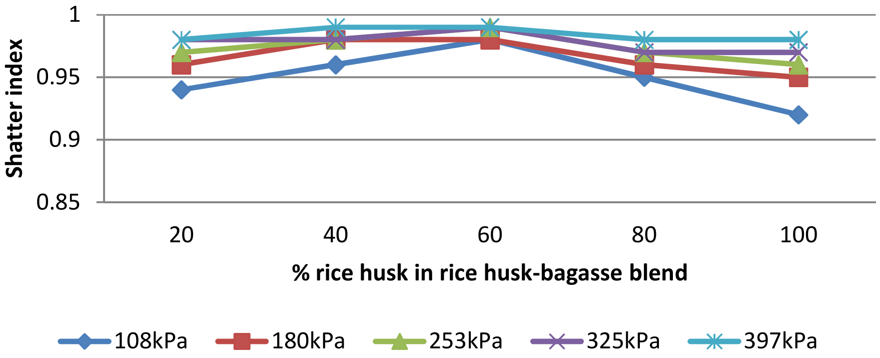


Fig. 8. Effect of pressure and formulation on shatter index of briquettes with cassava binder

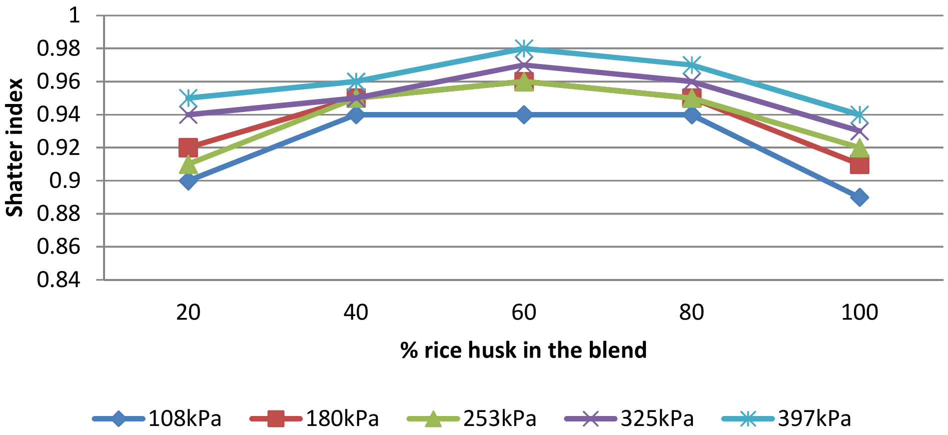


Fig. 9. Effect of pressure and formulation on shatter index of briquettes with clay binder

Similarly the effect of compaction pressure on ignition time was highly significant ($p<0.01$) for all the formulations used. Though the ignition times for the formulations with clay binder (105-123s) were significantly higher than corresponding formulations with cassava binder (60-72s), the general trend was the same as regards the effect of compaction pressure. Similarly, Davies and Abolude 2013 observed that the influence of compaction pressure on ignition time varied from 67.60 ±3.54s (P_1) to 104.28 ± 3.19s (P_4) depicting a similar trend with this study. They established a direct proportional relationship between compaction pressure and ignition time. They established that increase in compaction pressure automatically increased the density of briquettes and consequently, delayed the ignition time of the briquettes. Briquettes with higher density have low porosity and this increased the ignition time [23]. Our study found that ignition time was affected mostly by the three factors: *biomass formulation, binder* used and *compaction pressure* applied.

3.6 Burning Time and Rate

Briquettes produced from 100% bagasse combusted faster than the blended briquettes. Similarly briquettes with 100% rice husk disintergrated easily on combustion. Blended briquettes of between 40-60% rice husks recorded the lowest burning rates. As observed with the shatter index of briquettes, blending (40-60%RH) enhanced formation of stronger briquettes thereby improving the burning characteristics of briquettes by lowering the combustion rate as well as the rate of disintegration of the briquettes.

Table 6. Ignition time for rice husk-Bagasse briquettes

Binder	Blend ratio RH:B	Ignition Time (Sec) at different compaction pressures				
		108 kPa	180 kPa	253 kPa	325 kPa	397 kPa
Cassava	20:80	62	64	66	68	70
	40:60	70	74	77	81	85
	60:40	76	80	85	89	93
	80:20	80	84	88	92	95
	100:0	60	63	66	69	72
Clay	20:80	110	114	118	121	125
	40:60	129	136	141	146	151
	60:40	138	144	152	158	164
	80:20	166	174	180	186	191
	0:100	105	111	115	119	122

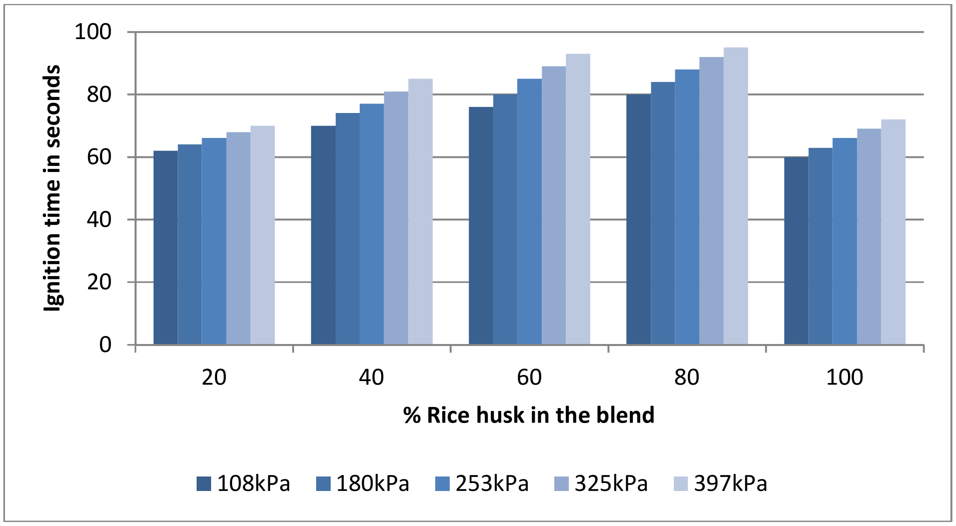


Fig. 10. Ignition time for rice husk-bagasse briquettes with cassava binder

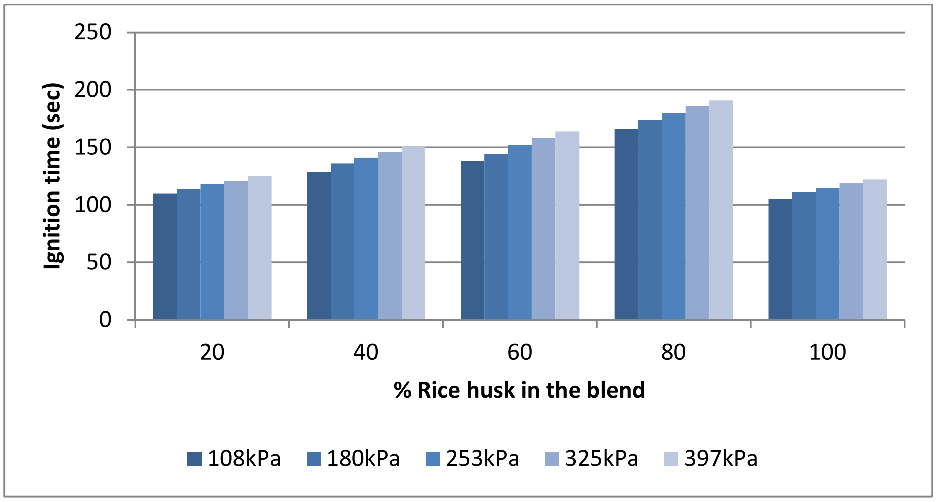


Fig. 11. Ignition time for rice husk-bagasse briquettes with clay binder

Fig. 12. Briquettes with clay binder retained shape on burning

It was noted that briquettes with clay took longer time to ignite but were able to burn longer. The calorific values of briquettes with clay were generally lower as compared to those with cassava binder.

The briquettes manufactured under lower pressures combusted faster and more easily than those compacted at higher pressures. As indicated earlier, briquettes under lower pressures tend to have more air pores than denser briquettes thereby enhancing easier flame propagation. The air pores allow more oxygen to percolate into the briquettes leading to faster combustion process hence less burning time. The results agree with the findings of Abdulrasheed et al. [24] that briquettes with low compaction have low density and burn faster than those of higher compaction. It was also observed that the flame propagation decreased with increase in density which could be explained by decrease in porosity and low oxygen penetration into the fuel. This agreed with Ajayi and Lawal [25] and Davies and Abolude [23] who observed that increase in compaction pressure reduces the void spaces of the briquettes as particles are forced closer to one another causing elongation of the ignition time.

Chin and siddiqui 2000 also studied the effect of pressure on the burning rate of some biomass briquettes. The study reported that increased densification pressure decreased the burning rate of the briquettes [26] which was also observed in this study. Compaction pressure had some significant effect on the burning rate of the briquettes. The burning rates for briquettes with cassava binder were significantly higher than those with clay binder.

3.7 Water Boiling Test

The briquettes with cassava binder took shorter time to boil equal amount of water than briquettes with clay binder (Figs. 13 and 14). The respective briquettes for both binders showed decreasing boiling time with increased compaction pressure. The observed difference in the time taken to boil the water was directly affected by the calorific values of the briquettes. Briquettes with cassava binder had higher calorific values compared to those with clay binder. Compaction pressure of the briquettes influences the volumetric calorific value of the briquettes so that the higher the density of the briquette, the higher the heat energy obtained per unit volume of the briquette.

Table 7. Water boiling test

Compaction pressure	Blend ratio RH:B	Time taken for water to boil (sec)	
		Cassava binder	Clay binder
108 kPa	20:80	720	780
	40:60	720	780
	60:40	720	840
	80:20	780	840
	100:0	840	900
180 kPa	20:80	660	720
	40:60	660	720
	60:40	720	780
	80:20	720	780
	100:0	780	840
253 kPa	20:80	600	660
	40:60	600	660
	60:40	660	720
	80:20	660	720
	100:0	720	780
325 kPa	20:80	540	600
	40:60	600	600
	60:40	600	660
	80:20	660	660
	100:0	660	720
397kPa	20:80	480	540
	40:60	540	600
	60:40	540	600
	80:20	600	660
	100:0	600	660

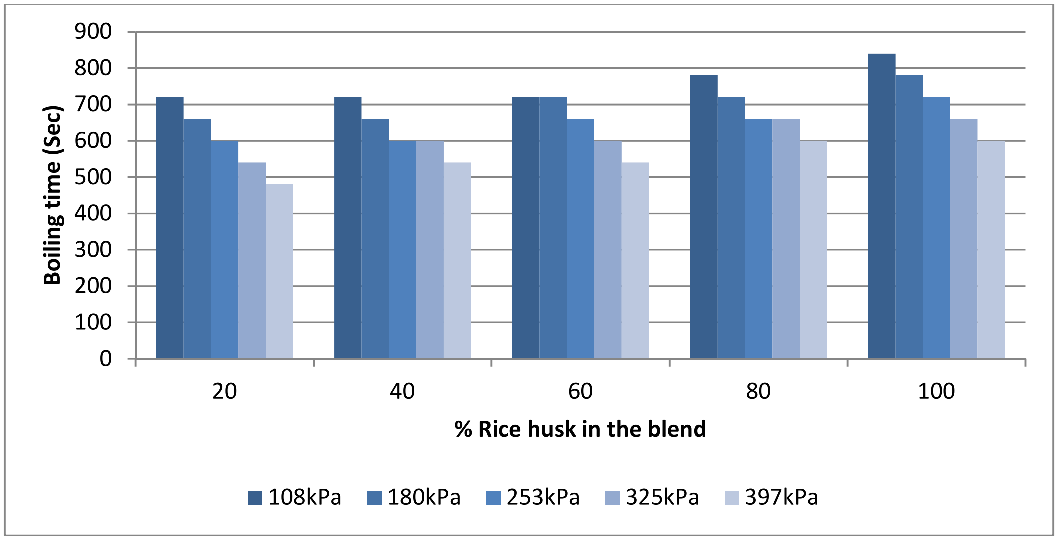


Fig. 13. Water boiling test for rice husk-bagasse briquettes with cassava binder

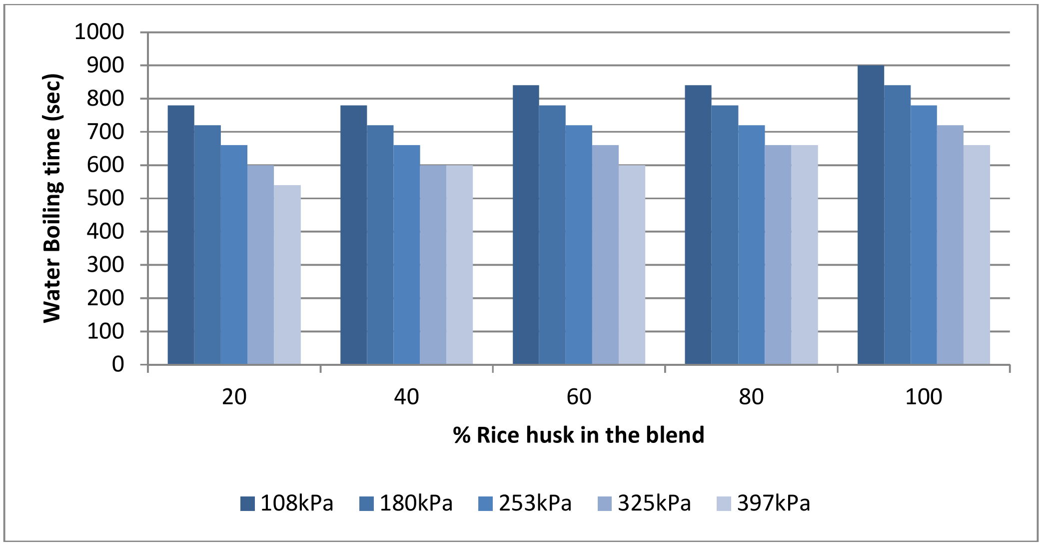


Fig. 14. Water boiling test for rice husk-bagasse briquettes with clay binder

4. CONCLUSION

The study examined the thermal and physical properties of carbonized rice husk-bagasse briquettes using cassava and clay as binding agents. The thermal properties (ignition time and burning rate) were affected by formulation and compaction of the briquettes regardless of the binder used. For the respective formulations, it was observed that the binder used had significant effect on ignition, burning rate and calorific value of the briquettes. The physical properties (shatter index and bulk densities) of briquettes were significantly influenced by the formulation, compaction and binders used. Clay binder produced denser briquettes (869- 1001 kg/m^3) which were able to burn longer but inversely took longer time to ignite (110-191 sec) and generally had lower calorific values (5.541-6.941 kcal/g) for respective formulations as compared with cassava binder which had (849-980 kg/m^3), (62-95sec) and (6.264-7.553 kcal/g) for density, ignition time and calorific values respectively. It can therefore be inferred that cassava binder is a better binder in terms of briquette durability and thermal properties (ignition and calorific value). Briquettes with lower density were easier to ignite (62-80sec and 110-166sec for cassava and clay binders respectively under 108kPa) but had a shorter burning time while higher density briquettes took longer time to ignite (70-95sec and 151-191sec for cassava and clay binders respectively under 397kPa) and burnt longer. Since the quality of any fuel briquette depends on its ability to provide sufficient heat at the necessary time, to ignite easily without any danger and to be strong enough for safe transportation and storage, the study demonstrated that improved briquettes with better attributes could be developed under higher compaction pressures. In conclusion, the longer the burning time, the better the briquette, it is hence inferred that higher density briquettes and formulations with higher bagasse ratio make better briquettes for use as alternative for charcoal. Increasing the use of these wastes in development of blended briquettes, will help in solving disposal problem in addition to providing a good and sustainable alternative to fossil fuels.

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COMPETING INTERESTS

Authors declare that there is no competing interest concerning this work.

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