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COMBUSTION CHARACTERISTICS OF BIO-DEGRADABLE BIOMASS BRIQUETTES

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Abstract

This paper reports on the combustion characteristics of biodegradable biomass briquettes prepared from charcoal, sawdust and sugarcane bagasse. The three materials were mixed in respective ratio of 20:20:60, 20:30:50, 20:40:40, 20:50:30 and 20:60:20. The briquettes were produced using Budenberg dial gauge hydraulic compression machine with the formation of briquettes under 64 MPa pressure with 120 seconds dwell time. Combustion characteristics such as proximate analysis, fuel-burning rate, fuel ignition time and afterglow time of the produced briquettes were determined. Results show that briquette with sample composition of 20:50:30 has better calorific value of 24613.69 kJ/kg and sample with ratio 20:30:50 has lowest calorific value of 22500.3 kJ/kg, while sampling with ratio 20:30:50 has better physical properties with shatter resistance of 99.61% and porosity index value of 47.40%.

Keywords: Biodegradable, Briquette, Calorific value, Combustion characteristics, Solid.

1. Introduction

Recently, serious interest in research and development (R & D) in other to exploit the renewable energy sources (green energy), both for environmental and economic reasons [1]. Biomass is naturally abundant in rural communities and presents a renewable energy opportunity that could serve as an alternative to fossil fuel [1-3].

High-energy consumption has been associated with better quality of life, which has a direct relationship with Gross National Product (GNP). The economy of a nation amongst nations has drawn interest to global energy resource inventories and regional energy source endowments. Every nation excavates its own resources in the search for suitable, sustainable, reliable and more importantly renewable energy sources [4].

The requirement for renewable and sustainable alternative sources of energy are on the rise as a result of depletion of the non-renewable fossil energy resources and the demerit associated with fossil fuels which include; global warming, increasing price and intermittent supply. In light of this, biomass is of great interest because of its availability, low price, carbon dioxide neutral feature, and high potential [4-7].

The use of sawdust, water hyacinth, sugarcane bagasse, rice husk, corn cob as composite materials for solid fuel briquettes has been found to be good sources of renewable energy for domestic cooking [8]. Similarly, the conversion of agricultural by-products like wood waste and coal dust to high-energy value briquettes for cooking and drying purposes have been investigated and found to be feasible [9].

Many researchers have carried out studies on varieties of biomass materials with the aim of utilizing waste materials (i.e. agro-waste and another type of waste) as alternative sources of energy. Among these researchers are; Emerhi [7] carried out a study on briquettes produced from a mixture of sawdust of three tropical hardwood species (Afzelia africana, Terminalia superba and Melicia elcelsa) with starch, cow dung and wood ash independently used as binders. He mixed the sawdust in the ratio of 50:50 with the binder using a different ratio. He studied the combustion-related properties such as percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of the briquettes. He concluded that briquette produces from a sample of Afzelia africana and Terminalia superba combination bonded with starch is more suitable for an alternative source of energy, having a highest calorific value of 33116 kcal/kg.

Zubairu and Gana [10] carbonized agricultural biomass (corn cobs) in a metal kiln of 900mm height and 600mm diameter. They produced four different grades of charcoal briquettes using a locally sourced tapioca starch as a binder at concentrations of 6.0, 10.0, 14.0 and 19.0% w/w. Their briquettes were characterized and compared with bagasse and wood charcoal; it concluded that carbonizing corn cobs biomass resources into briquettes charcoal is an effective means of managing solid wastes and a viable means of alternatives energy source.

Davies et al. [11] investigated the combustion characteristics of briquettes produced from water hyacinth with plantain peel used as binders, red mangrove wood, charcoal and anthronotha macrophylla (firewood). The characteristics investigated were calorific value, ignition time, burning rate, specific fuel consumption, fuel efficiency and water boiling time. Their results showed that water hyacinth competes favourably with charcoal, firewood and red mangrove wood for having a fuel efficiency of 28.17±0.88%, which was surpassed only by charcoal with fuel efficiency value of 31.29±0.19%. They concluded that water hyacinth briquettes are a good alternative source of energy with high material strength as well as high-value combustible fuel. In a related work of Adetogun et al. [12], they examined combustion properties of briquettes produced from maize cob sieved into different mesh sizes of 2.30 mm, 4.75 mm and 6.30 mm with starch as a binder. They observed from their result that the calorific value is directly proportional to the maize cobs particle size. Therefore, they concluded that sample with a particle size of 6.30mm has the highest calorific value of 24970 kcal/kg.

It can be observed from the above-highlighted work that charcoal, sawdust and sugarcane bagasse are rarely combined to be used as solid fuel. Therefore, this study is to investigate the combustion and physical characteristics of combinations of charcoal, sawdust and sugarcane bagasse for production of solid fuel briquettes with a mixture of sodium silicate and molasses used as a binder.

2. Experimental Procedure

2.1. Materials preparation

The materials (Fig. 1) used in this study are charcoal, sawdust and sugarcane bagasse. The samples were dried for 7 days for constant mass. The charcoal was pulverized using ingredient milling machine while sugarcane bagasse was grinded with a grinder. The materials were then sieved (Fig. 2) through the screens of 0.7 mm (for charcoal and sawdust) and between 1.5 and 2.41 mm (for sugarcane bagasse). Sodium silicate and molasses were combined as a binding agent.

(a) Charcoal (b) Sawdust (c) Sugarcane bagasse

Fig. 1. Materials used for the study before processing.

(a) Charcoal (b) Sawdust (c) Sugarcane bagasse

Fig. 2. The materials after processing.

2.2. Production of briquette samples

The briquettes were produced using Budenberg dial gauge hydraulic compression machine (Fig. 3) with maximum compression capacity of 1560 kN used for densification together with a cylindrical mould (Fig. 4) of 64mm internal diameter. Briquettes of varied biomass proportions were produced by blending the materials; charcoal, sawdust and sugarcane bagasse in various proportions of 20:20:60, 20:30:50, 20:40:40, 20:50:30, and 20:60:20 respectively. For each proportion of briquette, three pieces were produced and 13.8% (18 g) Sodium silicate (Na_2SiO_3) and 9.2% (12 g) molasses based on total mass of 130 g combined together was used as binder. A pressure of 64 MPa with 120 seconds dwell time was maintained throughout the briquettes production. The briquettes produced is shown in Fig. 5

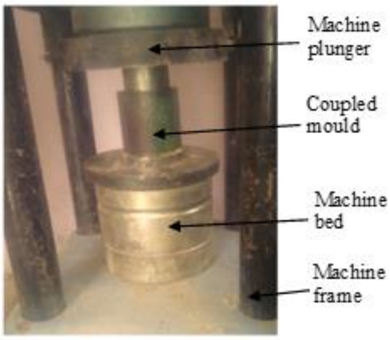

Fig. 3. Briquetting process.

Fig. 4. Mould used.

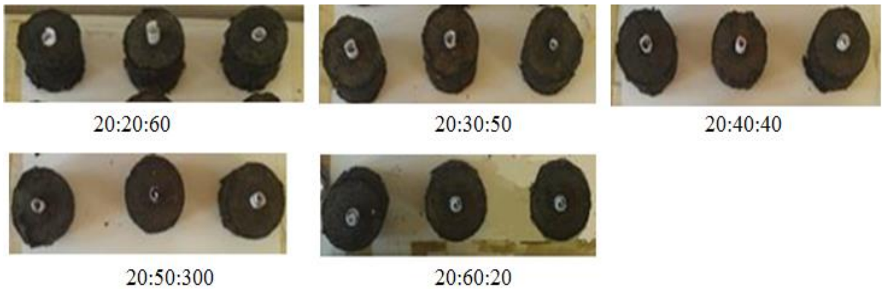

Fig. 5. Briquettes produced.
(All proportions are in charcoal, sawdust and sugarcane bagasse respectively)

2.3. Experimental methods for analysis of briquette

2.3.1. Proximate analysis

Proximate analysis is important to determine the calorific value of a fuel, and it comprises of the determination of the moisture content, ash content, volatile matter and fixed carbon content of the fuel.

2.3.2. Moisture content

The presence of moisture in a fuel usually have the resultant effect of high ignition time, low calorific value and it also makes the fuel to evolve excessive smoke. The mass of the samples was taken immediately after compression and noted and the mass taken after 5 days of drying in still air at room temperature when a constant mass was attained. The moisture content was determined using Eq. (1) [13].

$$\%\ Moisture\ loss = \left(\frac{m_b - m_a}{m_b}\right) * 100\% \quad (1)$$

where m_b is the mass of fuel immediately after compression and m_a is the mass of fuel after drying in still air.

2.3.3. Percentage ash content

The ash content of the solid fuel is the amount of non-aqueous residue that remains after a fuel sample has been burned completely. The Percentage ash content was determined according to [14, 15] by heating 2 g of the briquette samples in a furnace at a temperature of 550°C for two hours (2 hrs) when it was found to be completely converted to ash. The mass of the fuel was noted before burning in a furnace, and the weight of the ash was measured with a digital weighing scale after cooling in a natural convection air. The percentage ash content was determined using Eq. (2) [15].

$$Percentage\ ash\ content = \frac{A-C}{B-C} \times 100 \quad (2)$$

where *A* is the mass of the crucible with the ash, *B* is the mass of the crucible with the briquette, and *C* is the mass of the crucible.

2.3.4. Volatile matter

The volatile matter of the produced briquette was determined in line with [16]. The residual dry sample from moisture content determination was heated at 300ºC in a furnace for 30 minutes to drive off the volatiles. The volatile matter was obtained using Eq. (3) according to Onuegbu et al. [13].

$$Volatile\ matter\ (\%) = \frac{E-F}{E} \times 100 \quad (3)$$

where *E* is the mass of the briquette before heating, and *F* is the mass of the briquette after heating.

2.3.5. Fixed carbon content

Fixed carbon represents the amount of burnt carbon in a material by drawing air through hot bed of a fuel. The fixed carbon content of the samples was obtained using Eq. (4) as used by [13].

$$FC\ (\%) = 100 - (MC\ (\%) + VM\ (\%) + AC\ (\%)) \quad (4)$$

where *FC* (%) is the percentage of fixed carbon content, *MC* (%) is the percentage of moisture content, *AC* (%) is the percentage of ash content, and *VM* (%) is the percentage of volatile matter.

2.3.6. Calorific value

The calorific value is also known as heating value or energy value of a briquette is the amount of heat liberated per unit mass of the briquette. Calorific values were calculated using the fixed carbon content and volatile matter of the briquettes according to the method and Eq. (5) presented in [12].

$$HV = 2.326(147.6FC + 144\,VM)kJ/kg \tag{5}$$

where HV is the calorific value, FC is the percentage of fixed carbon content, and VM is the percentage of volatile matter.

2.3.7. Fuel burning rate

Briquette burning rate was determined using the method used by Onuegbu et al. [17]. Briquettes of known mass were ignited (Fig. 6) over the flame from a Bunsen burner. Throughout the combustion process, a stopwatch was used to take the time, until the briquettes were completely burnt. The fuel-burning rate was then computed using Eq. (6) as used by [9]:

$$B_r = \frac{W_T}{T_T} \tag{6}$$

where B_r is the fuel-burning rate, W_T is the weight of fuel burnt, and T_T is the time taken.

(a) Samples set-up during burning the test

(b) Burning of a sample **(c) Burnt sample after the test**

Fig. 6. Fuel burning rate test.

2.3.8. Ignition time

Ignition time is the total time measured in seconds, that it will take a briquette to start burning when in contact with flame. It was carried out on each briquette sample to determine the required time for each sample to ignite as specified by [11]. The test was carried out at room temperature, each sample was ignited using flame from a Bunsen burner, and stopwatch used to record the time. The time was measured from immediately the briquette come in contact with the flame, until a uniform flame was establish on the briquettes. The time required for the flame to ignite the briquette was recorded as the ignition time.

2.3.9. Afterglow time

Afterglow is the glow that remains after the light has gone off and the time it takes for the light to go out is known as afterglow time. Afterglow time was determined by igniting the fuel briquettes using the flame from a Bunsen burner as specified by [11]. The flame was extinguishing after consistent flame has been established on the fuel, thereafter, the time in seconds within which the glow is perceptible was taken as the afterglow time.

3. Results and Discussion

3.1. Moisture content

Table 1 shows the result of the moisture content of different percentage combination by weight of charcoal, sawdust and sugarcane bagasse used in this study. According to Ajobo [18], the ideal operating ranges of moisture content should be between 10-15% for making briquette, also Thailand Industrial Standards Institute (TISI) mandates that the moisture content of solid fuel briquettes not exceed 8% by weight [19, 20]. It can be observed from Table 1 that the fuel with proportion 20:50:30 has the minimum moisture of 13.66%, which is within the value recommended [18], other fuels proportions have moisture content above this value, especially in 20:40:40 where it is observed to be highest. This can be said to be as a result of the hygroscopic nature of both sawdust and sugarcane bagasse and the method used in processing the raw material (sun drying) may likely to be responsible. According to Psomopoulos [15] moisture content for solid fuel depends on the target market as the moisture content that a solid fuel produced for industrial purpose is expected to be lower than that of a solid fuel produced for commercial purposes and also, moisture content of commercial briquette depends on country policy on the refuse developed fuel as Finland, Italy and United Kingdom requires that the moisture content by percentage weight (% wt.) of solid fuel should be maximum of 35%, 25% and 28% respectively [15]. If these standards are adopted, then the moisture content obtained in this study is generally acceptable by the standard.

Table 1. Moisture content.

Sample ratio C:Sa:Su	Mass of fuel before drying (g)	Mass of fuel after drying (g)	Moisture content (%)
20:20:60	115.00	93.67	18.55
20:30:50	115.33	95.33	17.34
20:40:40	115.67	92.67	19.88
20:50:30	114.67	99.00	13.66
20:60:20	116.33	95.67	17.75

C for Charcoal, Sa for Sawdust and Su for Sugarcane bagasse

3.2. Ash content

Ash, which is the inorganic matter left out after complete combustion of biomass was found to be between the ranges 11.18% and 16.25% as it can be seen in Table 2. This is the percentage of impurity that will not combust during and after combustion of the fuel. Biomass of higher ash content tends to consume more fuel than the biomass of lower ash content [21]. According to Kishor and Singh [22], percentage ash content is one of the factors that affect specific fuel consumption of the fuel negatively, the percentage ash content as reported by [22] for coal was 18.23%, while the present study recorded ash content that is generally below this value. Jekayinfa and Omisakin [23] reported the ash content values for some agricultural wastes as follows; Palm oil effluent 10.97%, Corn cob 4.85%, Yam peels 4.56%, Mango peels 4.33% and Orange peels 2.66%. Prasityousit and Muenjina [24] were able to record values between 9.84% and 14.39% of ash content for some municipal waste, while [15] recorded 22.5% ash content for rubber and [25] recorded 36% ash content for briquettes made from fibre material and refuse-derived fuel (RDF). The present study ash content values, which are generally below 16.4%, were within the range of these values for obtained ash contents. The low ash contents indicate that the fuel briquettes are generally suitable for thermal utilization.

Table 2. Ash content.

Sample ratio C:Sa:Su	Mass of fuel (g)	Mass of ash (g)	Ash content (%)
20:20:60	2	0.22	11.00
20:30:50	2	0.33	16.50
20:40:40	2	0.28	14.00
20:50:30	2	0.28	14.00
20:60:20	2	0.29	14.50

C for Charcoal, Sa for Sawdust and Su for Sugarcane bagasse

3.3. Volatile matter

The result of volatile matter obtained for this study is shown in Table 3. The volatile matter was observed to be maximum in the fuel ratio 20:40:40 and lowest in the fuel ratio 20:20:60.

Table 3. Volatile matter.

Samples ratio C:Sa:Su	Mass before heating (g)	Mass after heating (g)	Volatile matter (%)
20:20:60	2.00	1.48	26.00
20:30:50	2.00	1.49	25.50
20:40:40	2.00	1.45	27.50
20:50:30	2.00	1.47	26.50
20:60:20	2.00	1.46	27.00

C for Charcoal, Sa for Sawdust and Su for Sugarcane bagasse

3.4. Fixed carbon content

The fixed carbon content obtained is tabulated in Table 4. The fixed carbon content for this work is observed to be highest in the fuel with ratio 20:50:30 and lowest in the fuel with ratio 20:40:40, this result is influenced by the percentage moisture content, ash content and volatile matter present in these fuel briquettes as the fixed carbon contents is dependent on these factors.

Table 4. Fixed carbon content.

Samples ratio C:Sa:Su	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon content (%)
20:20:60	18.55	11.00	26.00	44.45
20:30:50	17.34	16.50	25.50	40.66
20:40:40	19.88	14.00	27.50	38.62
20:50:30	13.66	14.00	26.50	45.84
20:60:20	17.77	14.5	27.00	40.75

C for Charcoal, Sa for Sawdust and Su for Sugarcane bagasse

3.5. Calorific value

The average result for calorific values obtained in this work is 23296.04 kJ/kg (5564.164 kcal/kg) as shown in Table 5. The calorific values in this study are lower compared to that obtained by [7] for briquettes made from Afzelia Africana bonded with starch; this may likely due to the fact that [7] carbonized his materials. The calorific value obtained in this study compared favourably with those recorded for coconut husk by [23] and that of maize cob with a calorific value of between 20930 kJ/kg and 24970 kJ/kg obtained by [12].

In this study, the average heating value obtained is higher than the calorific value of bagasse at 20567 kJ/kg, wood charcoal at 8270kJ/kg, 19534kJ/kg recorded for briquettes from a mixture of palm kernel cake (PKC) with sawdust and 18936 kJ/kg recorded for sawdust with some hardwood species [26]. This is higher than the recommended standard value of 17500 kJ/kg for a material to be regarded as having adequate calorific value Austria Standard (ONORM M7135), Sweden Standard (SS 187120) and Germany Standard (GS/DIN51731). This implies that the calorific values obtained are reasonable for thermal utilization.

Table 5 Calorific value.

Samples ratio C:Sa:Su	Volatile matter (%)	Fixed carbon (%)	Calorific value (kJ/kg)	Calorific value (kcal/kg)
20:20:60	26.00	44.45	23969.01	5710.14
20:30:50	25.50	40.66	22500.34	5394.62
20:40:40	27.50	38.62	22469.89	5366.84
20:50:30	26.50	45.84	24613.69	5864.12
20:60:20	27.00	40.75	23030.25	5485.10

C for Charcoal, Sa for Sawdust and Su for Sugarcane bagasse

3.6. Fuel burning rate

The burning rate values of the energy sources ranged between 0.4386 (g/min) and 0.5173 (g/min) as presented in Table 6. The rate is observed to be lowest in the fuel ratio 20:40:40. This observation could be adduced to porosity (even though its porosity is less than that of 20:50:30 and 20:60:20) exhibited between inter and intra-particles which enable easy infiltration of oxygen and outflow of combustion briquettes. It is also believed that briquettes with higher density will have longer burning time [11], it is observed that the burning rate is highest in the fuel ratio 20:50:30 and 20:60:20 where the ratio of sawdust is more pronounced.

Prasityousit and Muenjina [24] used rejected material of municipal waste composting for solid fuel production and they obtained a burning time that ranges between 188 min and 211 min, [27] also obtain a burning rate between 1.63 (g/min) and 2.25 (g/min) for briquettes made from water hyacinth and phytoplankton scum as binder, [22] obtain the burning rate values of 1.5 (g/min) to 3.5 (g/min) for coal briquettes made from spear grass (Imperata Cylindrica) and [28] obtained values between 0.97 (g/min) and 2.05 (g/min) as burning rate for briquettes made from water hyacinth. A low burning rate like that obtained in this work is of great advantage compared to the past work because the briquettes do not burn-out rapidly, as a result, it continues to generate useful energy for a longer period of time.

Table 6. Burning characteristics of fuel briquettes.

Sample ratio C:Sa:Su	Ignition time (s)	Fuel burning rate (g/min)	After glow time (s)
20:20:60	120.6	0.5099	306.6
20:30:50	129.0	0.5005	312.0
20:40:40	94.8	0.4386	439.8
20:50:30	123.6	0.5173	366.0
20:60:20	126.6	0.5170	307.8

C for Charcoal, Sa for Sawdust and Su for Sugarcane bagasse

3.7. Ignition time

The ignition time of the studied fuels varied between 94.8 seconds for the fuel ratio 20:40:40 and 126.6 seconds.for fuel ratio 20:60:20 as can be observed in Table 6. According to [29-31] briquettes for domestic use must be easily ignitable, with low porosity index, low volatile content and low ash content. The values of ignition time obtained in this work falls between the ranges of ignition time of 84.33±0.28 and 138.29±0.19 seconds reported by [11], the values of between 33 seconds to 186 seconds obtained by Kishor and Singh [22] and that of Hassan et al. [21], which is between 65 and 273 seconds. The results of this work can be said to be reasonable and acceptable.

3.8. Afterglow time

Table 6 shows the result obtained for the afterglow time characteristics of the briquette produced in this work. Afterglow time of 375 seconds is reported by [30] for solid fuel briquettes produced from cassava and yam peel, this is somehow averaged the values of 306.6 seconds and 439.8 seconds obtained in this study. These results show that the afterglow time is good for the burning characteristics of the fuel produced.

4. Conclusions

Some concluding observations from the investigation are given below.

- Sample with charcoal, sawdust and sugarcane bagasse in the proportion of 20:40:40 has the lowest ignition time of 94.8 seconds, lowest fuel-burning rate of 0.4385g/min, highest afterglow time of 439.8 seconds.
- It can be concluded that briquette fuel of ratio 20:40:40 has good thermal utilization properties based on its best performance in combustion characteristics tests.
- Sample with charcoal, sawdust and sugarcane bagasse is the proportion of 20:50:30 has the highest calorific value of 24613.69 kJ/kg.
- Briquette fuel with ratio 20:30:50 has the lowest calorific value of 22500.3 kJ/kg.
- It can be concluded that all the fuel samples produced are good for thermal utilization because the lowest calorific values recorded in this work is higher than the minimum calorific value set by Germany standard (GS/DIN 51731), Sweden standard (SS 18 71 20) and that of Austria standard (ONORM M7135).

Nomenclatures

A	Mass of the crucible with ash, g
AC	Ash content, %
B	Mass of the crucible with the briquette, g
Br	Fuel burning rate, g/min
E	Mass of the fuel briquette before heating, g
F	Mass of the fuel briquette after heating, g
FC	Fixed carbon, %
HV	Calorific value, kJ/kg
MC	Moisture content, %
Sa	Sawdust
Su	Sugarcane bagasse
TT	Time taken, s
VM	Volatile matter, %
WT	Weight of fuel burnt, g

Abbreviations

AS	Austria Standard
GNP	Gross National Product
GS	German Standard
PKC	Palm Kernel Cake
RDF	Refuse Derived Fuel
SS	Sweden Standard
TISI	Thailand Industrial Standards Institute

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