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Effects of Particle Sizes and on Combustion Characteristics of Briquettes Produced from Sugar Cane Biomass

Jamilu U. IBRAHIM[1], Danladi D. USMAN[2*], Yahaya U. JAURO[3], Moses MAZZA[4], Bala G. JAHUN[5]

[12345]*Department of Agricultural and Bioresource Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria*

[1]jamiludemycof@gmail.com, [2,*]ddusman@atbu.edu.ng, [3]omarjyahya@gmail.com, [4]mosesmazza@gmail.com, [5]bgjahun@yahoo.com

Abstract
The Effects of Particle Sizes and on Combustion Characteristics of Briquettes Produced from Sugar Cane Biomass was studied to determine the effect of particle size (0.25, 0.50 and 1.00 mm) on the combustion characteristics of Briquettes Produced from Sugar Cane waste (bagasse). The bagasse and molasses were collected from savannah sugar company Numan and gum Arabic was brought from Muda-Lawan market Bauchi. Briquettes were produced at Xpediant Global vision Bauchi and combustion characteristics were determined at industrial design workshop Abubakar Tafawa Balewa University Bauchi. Ignition time and burn time were measured with a stop watch, while burn rate, flame propagation rate, and calorific value of bagasse briquettes were determine based on the standard equations and water boiling test was measured with a thermometer. SPSS 23 was used as a statistical tool to analyze the data obtained from the laboratory experiment. The proximate composition of sugarcane bagasse was ash content 16.52%, volatile matter 65.67%, moisture content 7.77% and carbon 10.04%, while ultimate composition of sugarcane bagasse was, carbon (C) 42.54%, nitrogen (N) 13.92%, oxygen (O) 35.48%, sulphur (S) 1.52%, hydrogen (H) 6.50%. The most effect of Combustion characteristics for the corresponding particle sizes: ignition time(0.5mm) 52.7±33.8s, burn time(0.25mm) 53.2±19.7min, burn rate(0.25mm) 0.44±0.15g/min, flame propagation rate(0.25mm) 2.4±1.1mm/min, water boiling test(0.25mm) 81.0±7.2°C and calorific value (1.00mm) 32.2±1.2 MJ/kg. The results obtained showed that particle size of 0.25mm had most effect on three combustion characteristics: burn time, burn rate and flame propagation rate, while particle size of 0.50mm had most effect on two combustion characteristics: ignition time and water boiling test, and particle size 1.00mm had most but insignificant effect on calorific value. The particle size of Sugarcane biomass has been proven to be significant on five combustion characteristics, while caloric value for sugarcane biomass has been proven to be effective. The study concluded that particle size 0.25mm had the most significant effect on combustion characteristics of bagasse briquettes.

Keywords: *Bagasse, biomass, calorific value, flame propagation rate, particle size, volatile matter.*

1.0 Introduction

Due to the present world's energy crisis and its related environmental issues as well as increasing trend of fossil fuel prices, renewable energy sources are an essential matter. Biomass briquettes are a renewable source of energy, and they avoid adding fossil carbon to the atmosphere. They are made from agricultural waste and are a replacement for fossil fuels and can be used to heat boilers in manufacturing plants, and also have applications in developing countries, Teerapot *et al* (2010).

In a developing country like Nigeria, the household cooking sector is the largest consumer of energy. According to the International Energy Agency, about 73% of cooking energy is mainly derived from biomass (67% fuel wood and 6% charcoal), Obi *et al*, (2014). Women, being the chief cooks, spend more than six hours each day collecting and preparing fuel wood to make meals, significantly, time is lost in the process and it results in low production, incomes and household food insecurity. Biomass materials include products, by-products, residues and wastes from agricultural and forestry activities; non-fossil and biodegradable fractions waste from municipal and industrial wastes (Demirbas, 2010). Classical examples are trees, grasses, agricultural crops, agricultural wastes, wood waste and their derivatives, bagasse, municipal solid waste, wastepaper, waste from food processing as well as aquatic plants and algae animal wastes (Demirbas, 2010).

Wilaipon (2008) and Olorunnisola (2007) described briquetting as a process of compaction of residues into a product of higher density than the original material, while Kaliyan and Morey (2009) described briquetting as a densification process. The briquetting process can be classified as briquettes without binder and briquettes with binding agent depending on whether binder is used or not. According to the magnitude of the applied compaction force, there is a low-pressure and high-pressure technique briquetting process. Many researchers like (Kaliyan and Morey, 2009; Wilaipon, 2008; Olorunnisola, 2007) had carried out a lot of work on briquetting process. Their efforts were focused on three areas, which are development of machines, investigation of

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residues that could be subjected to briquetting process and those factors that could affect briquetting process as well as quality of produced briquettes.

Briquettes are a form of solid biofuel made from biomass resources including agricultural residues that can be burned for energy. They are made of different qualities and dimensions depending on the raw materials, mold and technologies applied during production (Oladeji, 2015 and Asamoah, 2018). They are typically cylindrical in shape with a diameter of between 25 and 100 mm and lengths ranging from 10 to 400mm, Kristoferson *et al* (1986). Other shapes of briquettes include square, rectangle and polygon and also in different sizes. The use of agricultural residues to produce briquettes can reduce waste of resources and consumption of fossil fuels Wang *et al* (2017). Production of briquette helps to solve the problem of residue disposal and deforestation which eases the pressure on the forest reserve, Bhattacharya *et al* (2002). The physical characteristics of briquette also known as the densification characteristics, are those physical properties of a briquette to include bulk density, relaxed density, compaction ration, relaxation ratio, compressive strength. The stated parameters have to do with the geometry and strength of the product and are usually obtained through physical measurement.

The combustion characteristics are the ignition time, burn time, burn rate, flame propagation, water boiling test and caloric value. Oyelaran *et al*, (2015), reported that ignition time decreases with increased in the content of ground nut shell within a range of 41.34 – 48.84s, they reported that the more the ground nut shell content in the briquette the more the pores which create opening for the decrease in ignition time observed as the ground nut shell increases. Hence, the study will determine the effects of particle size on combustion characteristics of briquettes produced from sugarcane biomass.

2.0 Material and Method

The biomass (bagasse) was collected from Savannah Sugar Company Limited (SSCL) Numan, which is located at latitude 9°35′48.3786′′ and longitude 11°54′3.074′′, 18km Yola-Gombe highway; about 35kg of bagasse and 20 liters of molasses binder was collected and transported to Bauchi state, while gum Arabic binder was purchased from Muda-Lawan market within Bauchi metropolis.

Other equipment and apparatus used include: stop watch for measuring ignition time and burn time of bagasse briquette, stove for energy source to ignite bagasse briquette, wire mesh to support bagasse briquette during ignition time and burn time testes, tripod stand to support bagasse briquette in combustion test, measuring cylinder to measure the appropriate quantity of water and gum Arabic binder, digital thermometer to measure the temperature of water boiling test, Venier caliper to measure the geometry of the bagasse briquette, containers, electric ovum to obtained the oven dried weight of bagasse briquette, universal testing machine to determine the compressive strength of bagasse briquette, standard sieves to sort bagasse various particle sizes, standard pots to carry out water boiling test and digital weighing balance to measure the weight of bagasse briquette.

2.1 Determination of ignition time

The Ignition time of the briquette produced was obtained by taking time on a stop watch from when a single briquette placed in the centre of a steel wire mesh grid resting on a metallic tripod stand, allowing the free flow of air around the briquette over a Kerosene stove (the stove adjusted to blue flame) to the time the whole of the circular bottom edge of the briquette ignites as reported by Onuegbu *et al.*, (2011) and Oyelaran *et al*, (2015).

2.2 Determination of burn time

The burn time of briquette was obtained subsequently after the briquette ignites and just entered into its steady burning state, the briquette was allowed to burn completely, the time for the briquette to burn completely was measured with a stop watch and recorded as reported by Davies and Abolude (2021).

2.3 Determination of burn rate

The burn rate of the briquette produce was obtained by taking a briquette of a known weight then place on wire gauze and the briquette will be ignited and burnt completely. The ratio of the weight loss to the specific burn time will be obtained on a stop watch per briquette burnt was computed from equation (2) as reported by Davies and Abolude (2021).

$$Br = \frac{Q_1 - Q_2}{T_b} \quad (1)$$

Where Br = Burn rate of briquette (g/min), Q_1 = Initial mass of briquette (g), Q_2 = Final mass of briquette (g), T_b = Burn time of briquette (min).

2.4 Determination of flame propagation rate

The flame propagation rate was determined by placing the dried briquette on a gauze wire against a tripod stand. The burn time was recorded right from after the briquette ignites, to the time the combustion reaches the complete relaxed length (L') of the briquette, with the use of a stop watch, the briquette length will be measured with a Venier caliper and the flame propagation rate was calculated using equation (2) as reported by Musa (2023).

$$Fp = L'/T \qquad (2)$$

Where Fp = Flame propagation rate of briquette (mm/min), L' = Relaxed length of briquette (mm), T = burn time to burn the relaxed length of briquette (min).

2.5 Determination of water boiling test (WBT)

The procedure for water boiling test was carry out as reported by Kyauta *et al* (2015). In each test 100g and 200g of briquette produced was placed on a steel wire mesh grid resting on a metallic stove, allowing the free flow of air around the briquette. The set up was set to blaze, heating a metallic pot containing clean water of 850ml and 1700ml respectively. The highest water temperature was read with a digital thermometer recorded and the time taken for the water to hit the highest temperature was also recorded by the use of a stop watch. The time interval for the temperature drop was also observe and recorded.

2.6 Determination of calorific value

The calorific value was determine using equation (3) as reported by Arkadiusz, (2015),

$$Q = Qs - 206(H)\big(1 - 0.01(W)\big) - 23(W) \qquad (3)$$

where Q = Calorific value of briquette (MJ/kg), Qs = Combustion heat of fuel (kJ/kg) used for Methane (CH4) at 55MJ/kg, H = Hydrogen content of bagasse (%), W= Relative humidity of environment (%).

3.0 Result and Discussion

3.1 Proximate analysis of sugarcane bagasse

Table 1 shows the proximate analysis results for the bagasse with different percentage composition. The ash content, volatile matter, moisture content and carbon have 16.52, 65.67, 7.77 and 10.04 % respectively. Volatile mater has the highest (65.67 %) and moisture content the least (7.77 %). This result indicate that the bagasse will have high energy content and produce more heat. Similar result was reported by Musa (2023) and Onuegbu *et al.,* (2011).

Table 1: Proximate Composition of Sugar-cane Bagasse

Parameter	Composition (g/kg)	Percentage (%)
Ash Content	218.11	16.52
Volatile Matter (VM)	867.04	65.67
Moisture Content (ϴ)	102.63	7.77
Carbon (O.C)	132.52	10.04

3.2 Effect of Particle size on Combustion characteristics of bagasse briquettes

Table 2 are results showing the mean effect of 0.25, 0.50 and 1.00mm particle sizes on combustion characteristics of biomass briquettes found respectively for; ignition time were 52.7±33.8, 47.3±20.9 and 52.8±33.3s; burn time were 53.2±19.7, 41.3±19.4 and 46.6±17.3min; burn rate were 0.44±0.15, 0.45±0.15 and 0.47±0.23 g/min; flame propagation rate were 2.4±1.1, 3.0±1.2 and 2.9±1.2mm/min; water boiling test were 81.0±7.2, 81.8±5.6 and 80.3±5.8^{o}C and calorific value were 31.1±1.1, 31.3±1.3 and 32.2±1.2MJ/kg respectively.

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Table 2: Mean values for effect of particle sizes on combustion characteristics of briquettes

PS (mm)	IT (s)	BT (min)	BR (g/min)	FPR (mm/min)	WBT (°C)	CV (MJ/kg)
0.25	52.7 ± 3.38	53.2±19.7	0.44 ± 0.15	2.4 ± 1.1	81.0 ± 7.2	31.1 ± 1.1
0.50	47.3±20.9	41.3 ± 19.4	0.45 ± 0.15	3.0 ± 1.2	81.8 ± 5.6	31.3 ± 1.3
1.00	52.8 ± 33.3	46.6 ± 17.3	0.47 ± 0.23	2.9 ± 1.2	80.3 ± 5.8	32.2 ± 1.2

PS=particle size, IT=ignition time, BT=burning time, BR=burning rate, FPR=flame propagation rate, WBT=water boiling test, CV=calorific value

3.2.1 Effect of Particle Size on Ignition Time of Bagasse Briquettes

Figure 1 shows the effect of particle sizes of bagasse briquettes on ignition time had significant differences. The mean ignition time obtained were in descending order of 1.00>0.25>0.50mm particle sizes at 52.8±33.3 >52.7±33.8 >47.3±20.9s respectively. It was suggested that 0.50mm particle size briquette have lowest mean density ratio as in table 2, hence decreasing the ignition time. Ignition time was reported to be between the ranges of 200 to 300 seconds, based on the figure, the smaller the particle size of raw material, the longer the ignition time of briquettes, (Sutrisno *et al* 2017).

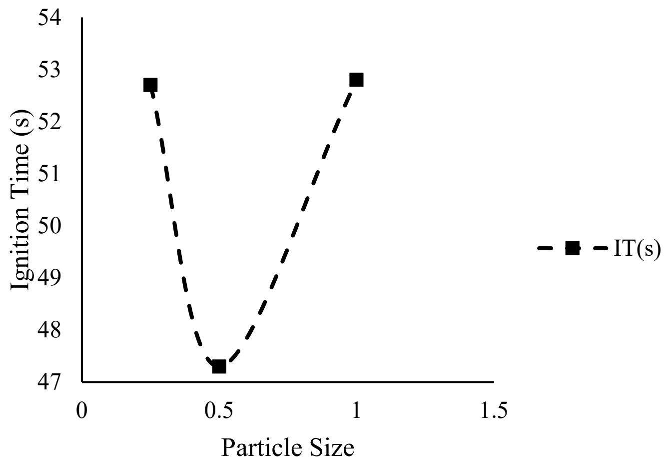

Figure 1: Graph showing effect of particle size on ignition time

3.2.2 Effect of Particle size on Burn Time of Bagasse Briquettes

Figure 2 shows the effect of particle sizes of bagasse briquettes on burn time had significant difference. The mean burn time obtained was in descending order of 0.25>0.50>1.00mm particle sizes at 53.2±19.7>46.6±17.3>41.3±19.4min respectively. It was suggested that burn time increased with decreased particle size of bagasse probably due to high mean relaxed density and compressive strengths (Jamilu 2019). The burning time of briquettes at three different sizes was 105, 116.66 and 128.33min as reported by (Willyanto *et al*, 2018), raw materials with a smaller particle size will have a longer burning time.

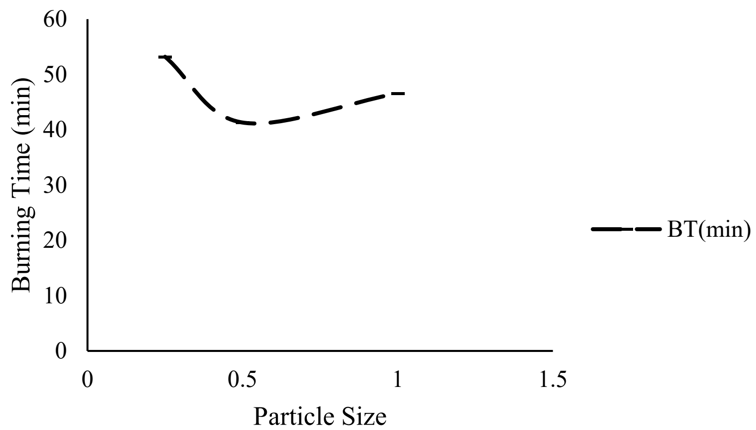

Figure 2: Graph showing effect of particle size on burning time

3.2.3 Effect of Particle Size on Water Boiling Test of Bagasse Briquettes

Figure 3 shows the effect of particle sizes of bagasse briquette on the water boiling test had no significant difference. The mean of water boiling test were at an increasing order of 1.00<0.25<0.50mm particle size at 80.3±5.8<81.0±7.2<81.8±5.6°C. It was suggested that the water boiling test was not a function of particle size. Water boiling test result obtained for groundnut shell briquette as reported by Kyauta (2015), hence concluded that the quantity of fuel directly influences the time of heating water, it was faster to heat water to 98°C in 14min than that reported by Onuegbu *et al* (2011), that the water boiling test of coal and biomass briquette blend was highest in Elephant grass 100% and Spear grass at above 25 mins each sample treatment.

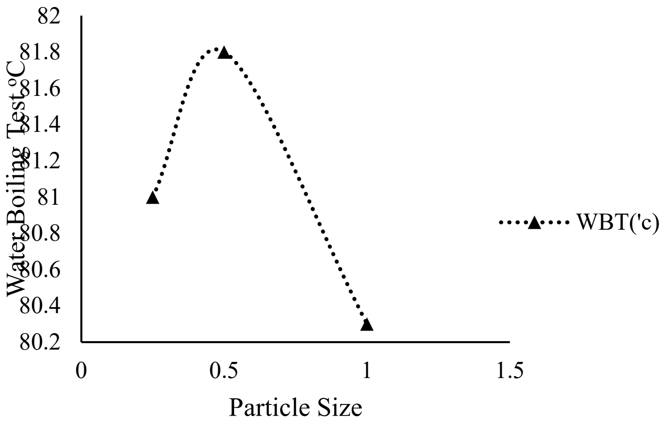

Figure 3: Effect of particle size on water boiling test

3.2.4 Effect of Particle Size on Burn Rate of Bagasse Briquettes

Figure 4 shows the effect of particle sizes of bagasse briquettes on burn rate had no significant difference. The mean burn rate at an increasing order of 0.25<0.50<1.00mm particle sizes were 0.44±0.15<0.45±0.15<0.47±0.23g/min respectively. Jamilu (2019) that burn rate increased with increased particle sizes, probably due to high mean relaxed density and compressive strength of 0.25mm particle size briquettes as in table 3. Burning rate was reported to be 0.0024 to 0.003g/min by Sutrisno *et al.* (2017).

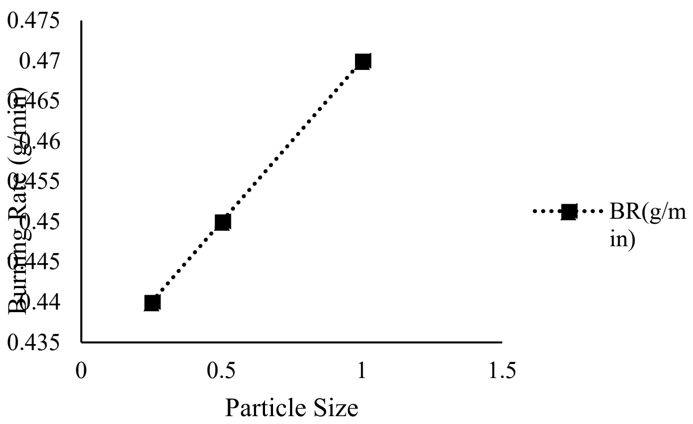

Figure 4: Effect of particle size on burning rate

3.2.5 Effect of Particle Size on Flame Propagation Rate of Bagasse Briquettes

Figure 5 shows the effect of particle sizes of bagasse briquettes on the flame propagation rate had no significant difference. The mean flame propagation rate obtained in descending order of 0.50>1.00>0.25mm particle size were 3.0±1.2>2.9±1.2>2.4±1.1 mm/min. It was suggested that the flame propagation rate increased with increased particle size, due to the 0.25mm briquettes high mean compression strength as in

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table 3. Reported in a study by (Olajide, 2012), the flame propagation rate of briquettes from corncob, yam peel, groundnut shells, melon shells and cassava peels were found to be 0.12, 0.10, 0.10, 0.13, and 0.16mm/min respectively which is less than the result from table 2 above.

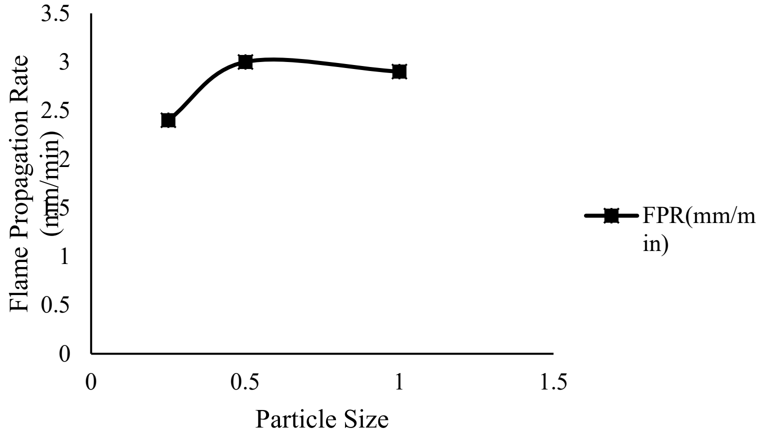

Figure 5: Effect of particle size on flame propagation rate

3.2.6 Effect of Particle Size on Calorific Value of Bagasse Briquettes

Figure 6 shows the effect of particle sizes of bagasse briquettes on the calorific value had significant difference. The mean calorific value occurred in descending order of 1.00>0.50>0.25mm particle size at 32.2±1.2>31.3±1.3>31. 1±1.1MJ/kg. It was suggested that the caloric value increased with increased particle sizes. Idah and Mopah (2013) reported that briquettes made from groundnut shells using cassava peel as binder gave the highest energy value 32.432MJ/kg. The values obtained were higher than reported by Yazdam and Mohammad (2015) that fine rice husk mix fine hilly sawdust in ratio 52.5:22.5:25 incubated at 90^{o}C accorded the highest caloric value of 25.75MJ/kg.

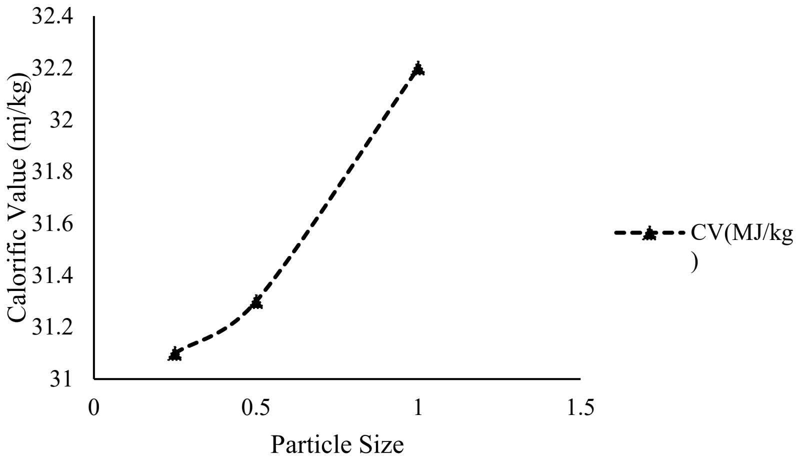

Figure 6: Effect of particle size on calorific value

4.0 Conclusion

The effect of experimental variables on ignition time of bagasse briquettes was concluded that: 0.50mm particle size briquettes have lowest mean density ratio, hence decreasing the ignition time. The effect of variables on the burning time on bagasse briquettes was concluded that: burning time increased with decreased particle sizes of bagasse briquettes, which was due to high mean relaxed density and compressive strengths.

The effect of variables on burn rate of bagasse briquettes produced are concluded that: burn rate increased with increased particle sizes, which was due to high mean relaxed density and compressive strength of 0.25mm particle size briquettes. The effect of experimental variables on flame propagation rate on bagasse briquettes produced is concluded that: flame propagation rate increased with increased particle size, due to the 0.25mm briquettes high mean compression strength.

The effect of variables on water boiling test of bagasse briquettes produced is concluded that: water boiling test was not a function of particle size. The effect of variables on the calorific value of bagasse briquette produced was concluded that: caloric value increased with increased particle sizes.

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The recommendation for the study for future projection is the study limitations among important parameters such as, combustion characteristics of bagasse such as specific fuel consumption, thermal efficiency; physical characteristics such as drop test, smoke test and other defining characteristics are to be explored, ultimately studying the effect of variable parameters such as binder, biomass binder ratio and briquettes mould sizes on the combustion characteristics.

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