PHYSICAL AND PROXIMATEANALYSIS OFFUELBRIQUETTE MADE USING AFRICAN LOCUST BEAN(PARKIA BIGLOBOSA) PULP AS A BINDER

ABSTRACT

*This paper examines the possible use of African Locust Bean (Parkia Biglobosa) Pulp as a binding agent for the production of biofuel briquettes. Sawdust biomass was briquetted using hot and cold prepared African Locust bean pulp (SBP) and cassava starch (SBCS) as binders. Physical and combustion analysis of the fuels were performed in accordance with ASTM analytical methods and calculations to analyse the briquettes strength and aptness as a solid biofuel. The results obtained for the maximum density, relaxed density and shatter index ranged between, 802.03 to 931.87*kg/m^3*, 300.60 to 336.40*$kg/m3$ *and 89.29 to 99.77% respectively, with samples SBCS and SBP(Cold) showing a better result. The proximate analysis performed shows that, the %Moisture content (Dry basis), %Ash content, %Volatile matter and %Fixed carbon ranged between 6.52 to 8.08%, 2.60 to 5.12%, 78.21 to 86.53% and 2.79 to 10.15% respectively. The Calorific Value obtained for the material briquettes are 17,230kJ/kg, 18,270kJ/kg and 16,550kJ/kg for SBCS, SBP(Cold) and SBP(Hot) respectively. It has been observed from analysis that the strength of the briquettes descends in the order SBCS→SBP(Cold)→SBP(Hot), with a little variation between samples SBCS and SBP(Cold). The study indicates the potential of the binder for the production of biofuel and significantly improve the carbon content as well as the calorific value of the fuel.*

Keywords: African Locust Bean (Parkia Biglobosa) Pulp, Binder, Biomass, Briquette, Physical and Proximate Properties.

1. INTRODUCTION

In modern times, energy need can never be over-emphasized as it is required fundamentally for the fulfilment of basic individual and community needs. The exponential increase in the world-population growth coupled with the continuous increase in the world-energy demands, consequences arising from the use of over-stretched fossil fuel and uncertainties surrounding its market and supply chain has continued to raise concern; a development thatnecessitated a concerted effort toward searching for an alternative energysource. It has been reported that more than three-quarters (78.4%) of total world energy demands in 2012 was fulfilled by fossils (majorly coal, oil and natural gas) and the demand for these fuels is expected to rise uprightly through the next decades (Akorede, *et al.*, 2017). Burning of fossil fuels for energy generation has been identified to be responsible for lots of environmental effects ranging from greenhouse gas (GHG) emissions that causes global warming, and global dimming through by-products burning, such as sulphur dioxide, soot, and ash (Akorede *et al.*, 2012). Thus, the need to save our environment from these contaminants led to a global hunt for clean, sustainable and renewable energy sources. Renewable energy is the energy generated from natural resources such as sunlight, wind, hydrothermal, biomass, tides, and geothermal heat; natural processes that are constantly replenished. Like many other developing nations, Nigeria is yet to fully harnessed its renewable energy potential in order to play a significant role in the energy production but has since taken some steps towards encouraging its application in different economic sectors(Akorede *et al.*, 2017).

In comparison with other renewable energy options, biomass resourcesare the most common, versatile and widespread on the Earth's surface (Ladanai and Vinterbäck, 2009).Biomass as a renewable energy source shows some typical characteristics which makes it a distinct, but rather complex fuel for the future. It has been reported that 11% of the world's energy, both heat and power, is currently derived from biomass (Akorede *et al.*, 2012). Therefore, biomass is considered a potential candidate to serve as an alternate energy fuel to coal (Wei *et al.*, 2021).It has been revealed that in the year 2005, Nigeria's bio-energy reserves stood at 13 million hectares of fuelwood, 61 million tons per year of animal waste, and 83 million tons of crop residues and that harnessed biomass resource-based biofuels are projected to contribute about 800MW of energy for electricity generation in the country by 2030(Akorede*et al.*, 2017). Based on assessment and efficiency of conversion technologies biomass derived energy fuel is predicted to provide up to 15% of the total world's primary energy consumption by 2030 which enable biomass to become the extreme renewable energy resource (Zhao, 2018).

The widely accepted technology for producing a uniformly sized and shapedproduct for bioenergy applicationsis briquette making with the aid of a briquette machine (Akogun *et al.*, 2020). Briquette is a block of combustiblematerial that can be used as a fuel to start and sustain a fire which can be produced through a process known as briquetting. Briquetting process upgrade raw biomass waste into a high-density solid biofuel that can be easily ignited and possess high burning efficiency and emit less toxic substance into the atmosphere as compared to raw and fossil fuels (Araújo *et al.*, 2016). Briquetting of biomass can be achieved with or without a binder. Application of binding material in briquette making plays a vital role in sticking the briquette particles together there by improving its handling, transportation and storage characteristics.

The briquette strength, thermal stability, combustion performance and cost depend on the binding material used (Altun *et al.*, 2001). Briquette binder are categorized into: organic, inorganic and compound binders based on their composition. The briquette produced using inorganic binder has exceptional thermal stability, but the fixed carbon content and combustion efficiency are lower, ash content is added. The briquette produced with organic binder has better cold strength, high volatility, poor hot-strength and complex combustion products. Compound binders compose of two or more binders, which combine all the advantages of different kind of binders (Zhang *et al.*, 2018). Composite binder compose of industrial and agricultural waste mixed with other binders to help in handling waste safely, reduce pollution, and improve briquette quality.Starch is an ideal organic binder and the most commonly used in briquetting and can be sourced from biomass materials like corn starch, wheat starch, maize flour, wheat flour, rice flour, cassava flour, potato starch, etc (Zhang *et al.*, 2018).Biomass as a source of binder demonstrates excellent advantages which include low price, widespread sources across the globe and an appreciable heating value (Blesa *et al.*, 2003).

The efficacy attached with the application of different organic binders for briquetting has been demonstrated by many researchers;Sotannde *et al.*,(2010),usedcassava starch and gum-arabic as binders for briquette production from neem wood residues. They reported that, the percentage by weight ofbinder(s) to that of biomass residues ranged between 10-40% and concluded that both gum-arabic and cassava starch binders performed excellently in terms of quality and calorific value at 30% and 20% by weight of biomass respectively.Emerhi, (2011), assessed the physical and combustion properties of briquettes from sawdust of three (3) hardwood species using three (3) different organic binders (starch, cow dung and wood ash). He found that, briquette's quality depends on the type of binding agent used and that briquette made using starch demonstrates high quality fuel and recorded the highest calorific value of 33116 Kcal/Kg than those bound with wood ash and cow dung. Obi *et al.*, (2013), evaluated the performance of sawdust briquette made using cassava starch as abinder at different biomass-binder ratio and found that the briquette made at 35% binder level demonstrated the highest heating value of 33.37MJ/kg and lowest ash content of 0.56% making it the most suitable fuel among its counterparts.Ohagwu *et al.*, (2022), studied the Physicomechanical and fuel properties of sawdust briquettes using Abelmoschus esculentus (Okra) waste as a binder at different binder level (5%-20%). They found that briquettes produced at 5% binder level had the highest calorific value and percentage volatile matter of 17,820kJ/kg and 85.46% and at the same time recorded the least percentage of ash and moisture content of 1.59% and 7.6% respectively, and have 96% shatter resistance.

The African locust bean tree (*ParkiaBiglobosa)* is considered a valuable economic fruit tree due to its versatile applications as nearly most parts of the tree (e.g husks, pods, seeds, leaves, bean-coat, barks) are used (Arinola *et al.*, 2019). During the processing of African locust bean seeds, the pulp is habituallywashed away as a waste product in order to recover the seeds only. This yellow pulp has been reported to have contained certain properties;2.69% ash, 7.14% moisture, 72.68% carbohydrate (Arinola *et al.*, 2019) and 32.14% starch (Samson *et al.*,2004). Little information exists in the literature as regard the application of the pulp as a binding agent and such information will be needed to explore the new potentials of the pulp in briquette making and other industrial applications.

The aim of the present work is to examine the possible useof African locust bean (Parkia Biglobosa) pulp as a binder for the production of biofuel briquettes and todeterminethe physical and proximate analysis ofthe briquettes for domestic and industrial thermal applications.

2. MATERIALS AND METHOD

2.1 Materials

Sawdust residuesthat are considered wastes were obtained at no costin a sawmill industry. Traditionally made cassava starch and African locust bean pulp (Parkia biglobosa) were obtained locally. The foot-press briquette moulder used in the study was constructed with the aid of locally sourced materials which includes: Hollow pipes ($1\frac{1}{4}$ inch), Galvanized iron pipe (1inch), Vices, Oxgen-acetylene cylinder, Electric welding machine and electrode, mild steel flat bar, hinges, metal flat bar of thickness, Electric hand grinder, measuring tape among others. Laboratory test sieve (1.18mm), Muffle furnace (MF 207, Max. Temperature 1200℃), Electrothermal Thermostatic Drying Box (Temperature range 50-200℃, BKYY31-2000 of Model GZX-DH-X), Electronic digital calliper, LP502A Electronic balance (500g/0.001g), CAL3K-F Oxygen Bomb Calorimeter was also among the devices used in the study. Plates 1 (a) to (f) demonstrate cross-sections of moulder and briquette production processes:

Plate 1: A cross-section of moulder and briquette making processes: (a) Plate cutting process (b) Base plate (c) Constructed Moulder (d) Water mass measurement (e) Sawdust sieving process (f) Briquette production

2.2 Method

The sawdust residueswere screened from stones and other impurities that may hinder proper briquette production and subsequent analysis through sieving using wire mesh and sun-driedfor about 10 days with an average daily temperature of 39℃in order to reduce the moisture content to the lowestpossible value. The dry residueswere sievedand the particles that passed through laboratory test sieve model of 1.18mm were retainedand kept in an air tight container for later use. A schematic flow diagram for the experimentalprocess is shown as figure 1.

Figure1: Experimental process flow diagram

The binder was prepared by dissolving 33.33g of cassava starch residues representing (30% by weight of biomass residues) using 50ml (50g mass equivalence)of pure water for a minute and later poured inside a pot containing 250ml (250g mass equivalence)of pure water heated at 100℃ stirred and gently cooked for about 3mins to ensure homogeneity.The starch formed and the sawdust residues were mixed at the binder-biomass ratio of 1:3. Briquettes were produced by pouring 40g mixture of binder-biomass in each cavity of the moulder.The mixtures were covered, foot-pressed with a pressure calculated to be approximately 19MPa and held with a key for a residence time of 5mins. The wet briquettes were gently ejected by opening the mould cover through the key and by pressing the mould handles down-ward. The briquettes were subjected to air/sun-drying for 10 days at an average daily temperature of 38℃. The same method of briquette production was adoptedusing African locust bean pulp (Cold and hot prepared). Furthermore, briquettes were produced without heating/cooking the mixture of African locust bean pulp and sawdust residue for the purpose of comparison.Three categories of briquettes were produced: Sawdust bonded with cassava starch (SBCS), Sawdust bonded with cold-prepared African Locust bean pulp SBP(Cold) and Sawdust bonded with hot-prepared African Locust bean pulp SBP(Hot).Three runs of each experiment were carried out on each batch production and the average results were presented.

2.2.1 Determination of Physical Properties of the Briquettes

Maximum and Relaxed Densities

The Maximum density is the density of the briquettes measured immediately after ejection from the mould while Relaxed density is the density of the briquettes obtained after drying. The maximum (compressed) and relaxed densities of the produced briquettes were determined in accordance with the procedure reported by Birtwatker *et al.,* (2014). The densities were calculated by measuring the mass of each briquette with the aid of digital weighing balance and its respective volume using vernier callipers immediately (maximum density) and after drying (relaxed density).

The compaction ratio; the ratio of the maximum density to the initialdensity (density of the residue before compressing in the briquetting machine) and the density ratio (ratio of the relaxed density to the maximum) are determined as reported by (Oladeji, 2012).

Shatter index

Shatter index test is used for determining the hardness of briquettes. The briquette was dropped on concrete floor from a height of 2m for about 10 times. The weight of the fragmented briquette and its size was noted down. The percentage loss of material was calculated using the equation (Sengar *et al.,* 2012);

Percentage of weight loss = $\frac{W_1-W_2}{W_1} \times 100$
% Shattered = 100 - % weight loss (1)

where; W_1, W_2 = weight of briquette before and after shattering in grams.

2.2.2. Proximate and Combustion Analysis of the Briquettes

Moisture Content

Moisture is the quantity of water that exists in the briquettes at a given time. The moisture content of the samples was analyzed following the method ASTM (2006a). During the process, empty dried crucibles were weighed and a 2g quantity of each material briquette was placed in each crucible. The mass of the sample plus crucible were measured. The crucibles and their contents were placed inan Electrothermal Thermostatic Drying Box, set at a temperature of 110℃± 5℃ for 1hr. The contents were removed with the aid of a metal tong, allowed to cool in a desiccator and re-weighed. Thus;

Percentage of moisture content (%MC) = $\frac{W_1-W_2}{W_1} \times 100$ (2)

where;W_1, W_2 are mass of briquette before and after drying respectively.

Volatile Matter

The volatile matter content was determined by placing the dried samples left after moisture content determination inside a muffle furnace (MF 207), and heated to a temperatureof 300℃ for 10 minutes inside a moderately closed crucible. Subsequently, the crucible and its content were retrieved and cooled shortly in air and then placed in the desiccator. The difference in weight was noted and the volatile matter was calculated as per ASTM (2006b);

Percentage of Volatile Matter (%VM) = $\frac{W_1 - W_2}{W_1} \times 100$ (3)

where; W_1, W_2 are the original mass of the sample before heating and final mass of the sample after heating and cooling respectively.

Ash Content

The left-over residues after percentage volatile matter determination were further weighed and transferred into a muffle furnace set at a temperature of 600℃and heated for 2hrs, after which the crucible and its contents were put in a desiccator and allowed to cool. The crucible and its content were re-weighed and recorded. The percentage ash content was calculated using equation(4)(Ndecky *et al.,* 2022):

Percentage of Ash Content (%AC) = $\frac{M_2}{M_1} \times 100$ (4)

where;$M_1$is the initial mass of the dry sample before heating and M_2 is the final mass of the ash left after heating and cooling.

Fixed Carbon

The fixed carbon was determined using equation (5) (ASTM, 1992):

Percentage Fixed Carbon (%FC) = 100-(%MC+%AC+%VM) (5)

Calorific Value

The calorific value of the produced fuel was determined with the aid ofCAL3K-F Oxygen Bomb Calorimeter as shown in plate 2.

Plate 2: CAL3K-F Oxygen Bomb Calorimeter set up.

3. RESULTS AND DISCUSSION

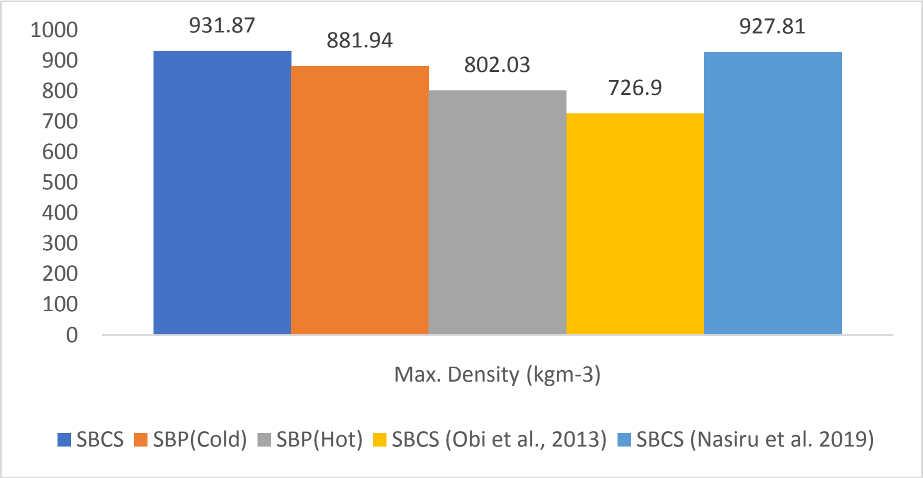

Figure 2(a): Maximum density of the briquettes

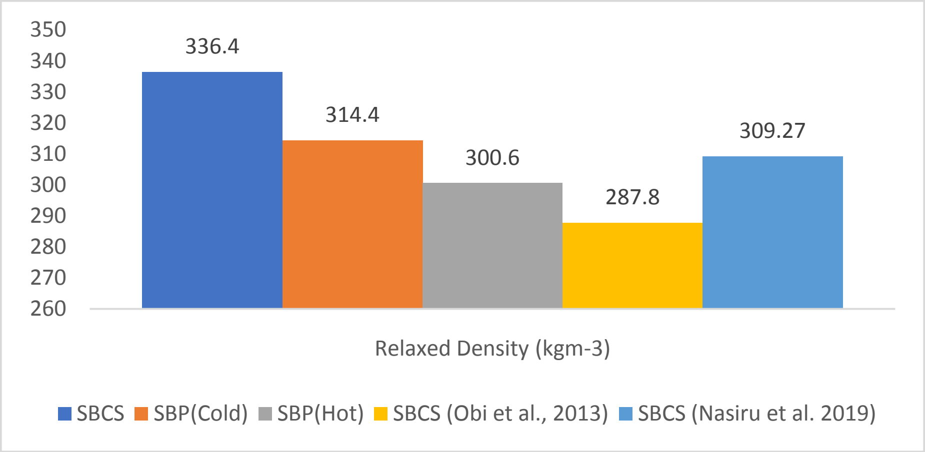

Figure 2(b): Relaxed density of the briquettes

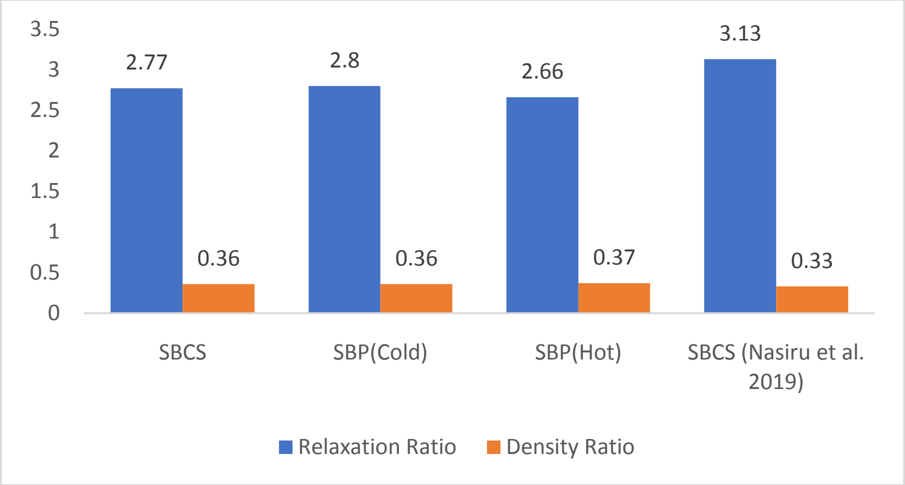

Figure 2(c): Relaxation and Density Ratio of the briquettes

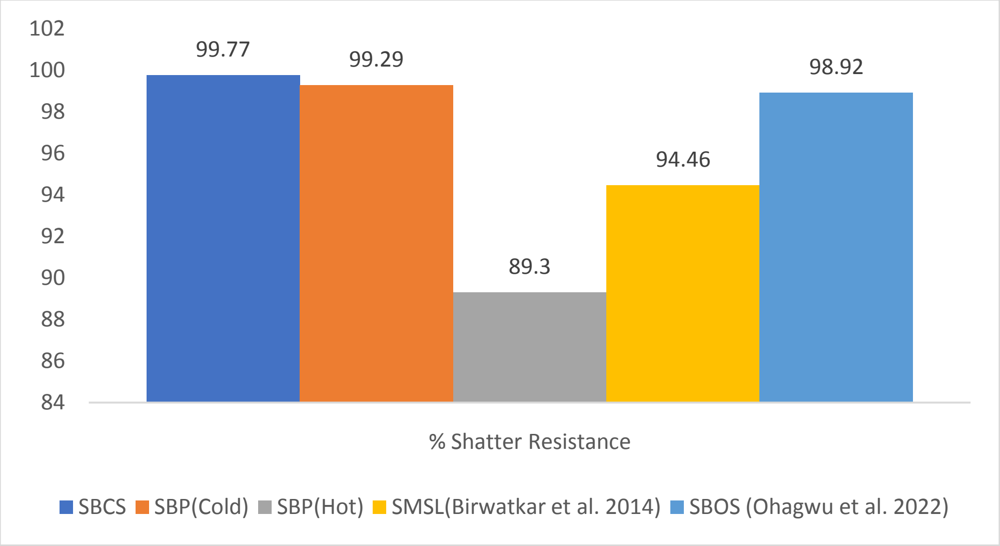

Figure 2(d): Shatter index of the briquettes

Figures2(a-d) present the results of the physical properties of the briquettes produced in the current study in comparison with some previous findings. The values obtained for maximum densityranged from 802.03 to 931.87kg/m^3. The highest value obtained is greater than the utmost values 927.81kg/m^3 and 726.90kg/m^3 obtained for sawdust briquettes bonded with cassava starch (Obi *et al.,* 2013& Nasiru *et al.,* 2019). These values are more than the recommended minimum value of 600 kg/m^3 for briquettes to make an efficient transportation and safe storage (Gilbert *et al.,* 2009).

Consequently, the relaxed density of the briquettes in the current study as shown in figure 2(b) are found to be within the range of values reported by Obi *et al.,* (2013) and Nasiru *et al.,* (2019) for briquettes that can be easily handled and transported.

Figure 2(c) present the results of relaxation and density ratio of the briquettes produced in this study. These values are found to exist closely with the relaxation ratio 3.13 and density ratio 0.33obtained for sawdust briquettes bonded with cassava starch (Nasiru *et al.,* 2019). Oladeji and Enweremadu, (2012), reported that, the higher the density ratio for a given mass, the less relaxed the briquettes. Hence, the briquettes made from starch and cold-treated pulp appears more stable than that of heat-treated pulp. However, all the briquettes formed can perform well in handling, transportation, storage and utilization.

Figure 2(d) present the shatter resistance made for the briquettes in the current study in comparison with some previous work. The briquettes produced using cassava starch and cold pulp recorded the highest percentages of 99.77% and 99.29% respectively These values are greater than the average value 94.46% recorded for sawdust in combination with Mango and Subabal leaves briquettes (Birwatkar *et al.,* 2014) and 98.92% for sawdust briquettes bonded with (Abelmuschus esculentus) Okra (Ohagwu *et al.,* 2022). This implies that the briquettes produced using cassava starch and cold treated pulp can withstand high shock and impact resistance as compared with the hot pulp bonded briquettes with shatter resistance of 89.30%. Hence, all the briquettes formed in the present study scale up the acceptable limit of above 80% considered for a briquette fuel (Adapa *et al.,* 2003).

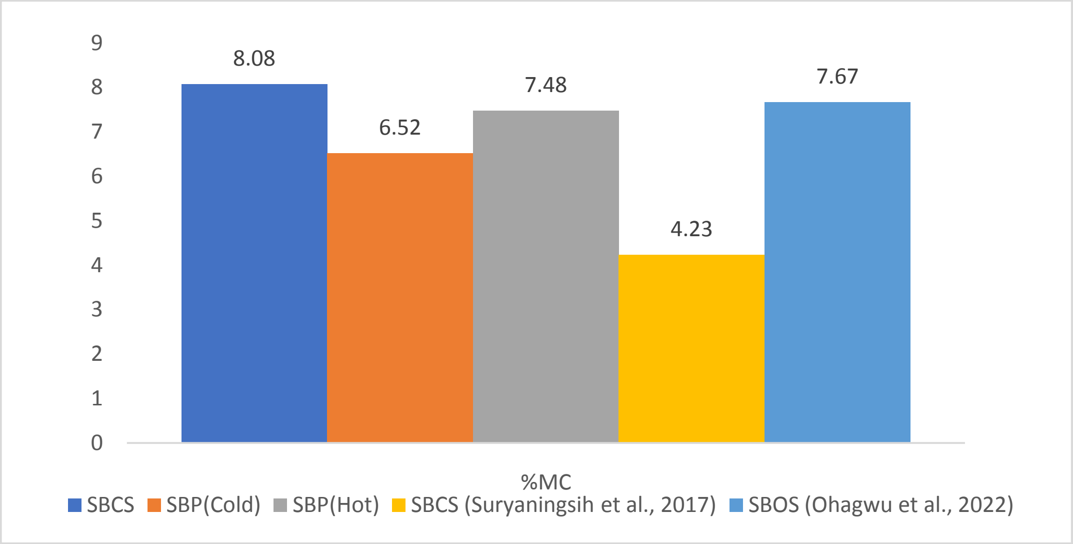

Figure 3(a): Percentage Moisture Content of the briquettes

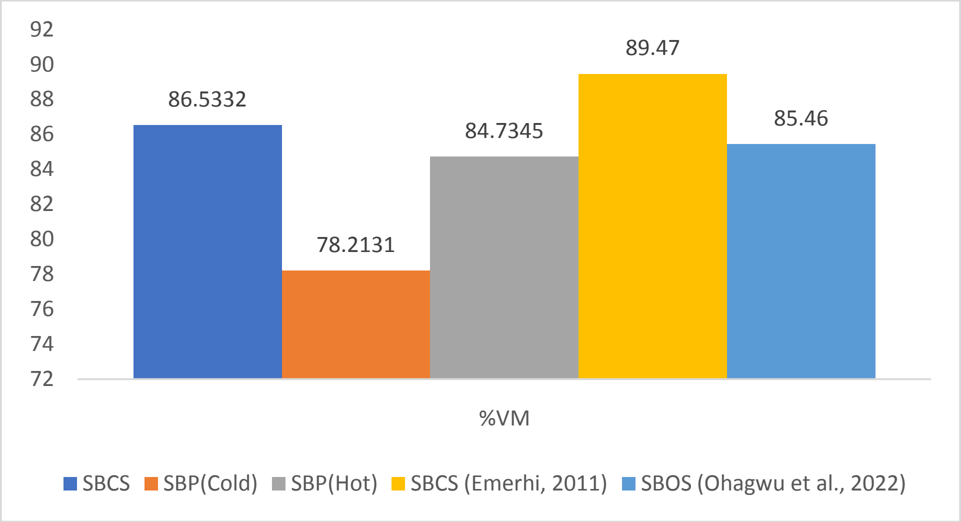

Figure 3(b): Percentage Volatile Matter of the briquettes

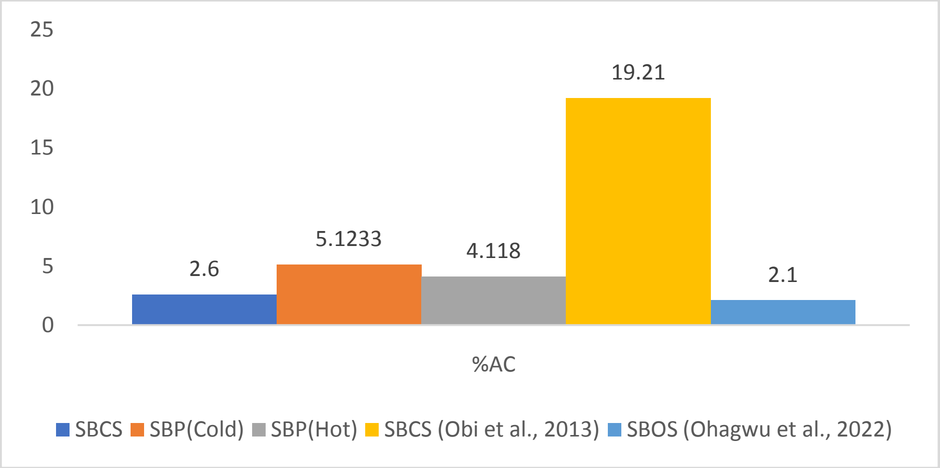

Figure 3(c): Percentage Ash Content of the briquettes

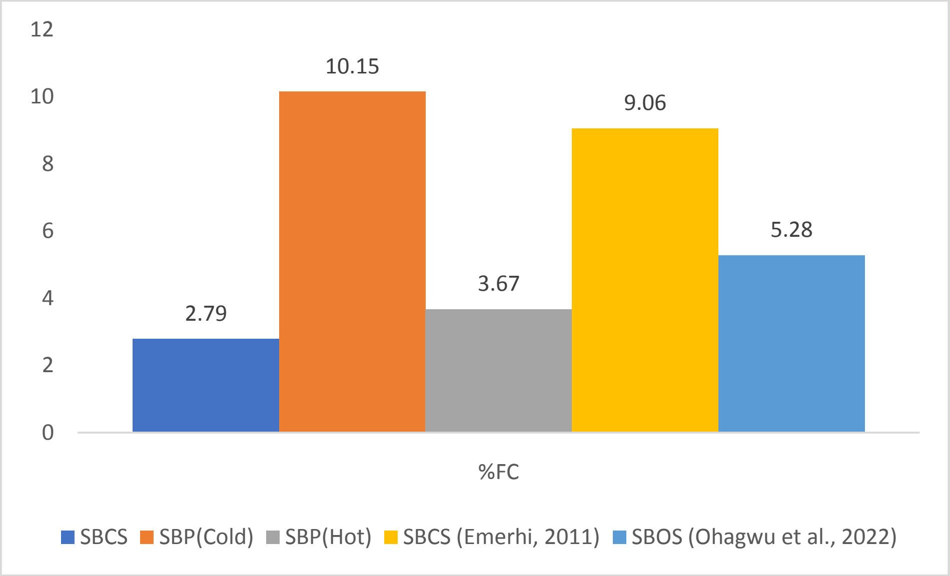

Figure 3(d): Percentage Fixed Carbon of the briquettes

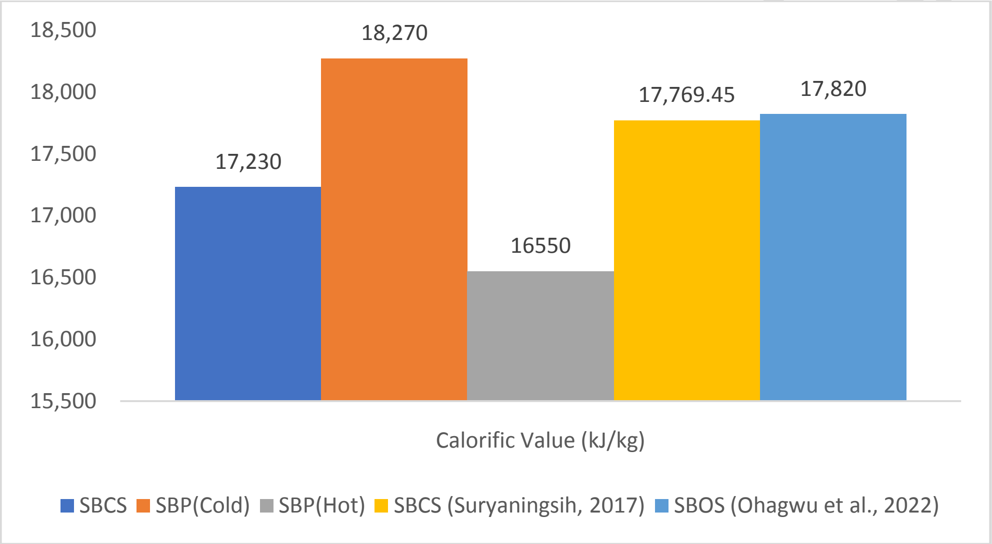

Figure 4: Calorific Value of the briquettes

Figures3(a-e) represent the results of the proximate analysis of the briquettes produced in the current study in comparison with some previous studies. As shown in figure 3(a), the percentage moisture content in the present study ranged between 6.52% for the cold pulp briquette to as high as 8.08% for the cassava starch briquette. These values exist within the recommended values 6 to 14% for an ideal briquette (Ngusale *et al.,* 2014). This indicates better drying performance of cold-treated pulp when compared with cassava starch bonded one. Since the smaller the value of water content in the bio-briquette, the better its performance (Suryaningsih*et al.,*2017). Consequently, the percentage volatile matter as shown in figure 3(b) for the current study ranged between 78.21 to 86.53%.These values exist within the range of 67.08% to 91.63% recorded for sawdust briquette bonded with cassava starch (Obi *et al.,* 2013) and closer to 85.46 recorded for briquettes made from sawdust bonded with Okra (Ohagwu *et al.,* 2022). Higher percentage of volatile matter content for a given fuel briquettes as compared with other proximate parameters(%MC, %FC and %AC) indicates an easy ignition and complete combustion briquettes (Obi *et al.,* 2013).

Ash is an inorganic substance as leftover after biomass complete combustion that mainly contains calcium, magnesium and phosphorus elements (Raju *et al.,*2014). As shown in figure 3(c), the average value calculated for the ash content in the present study ranged between 2.60% for starch bonded briquette to as high as 5.12% for cold pulp briquettes. Comparable low percentage ash content was reported for briquettes made from neem wood residues bonded with cassava starch and gum-arabic (Sottande *et al.,* 2010). These values were found to exist within the %ash content obtained for briquettes bonded with cassava starch (Obi et al., 2013) and closer to the values reported for sawdust bonded with Okra (Ohagwu et al., 2022). It has been reported that, the higher the fuel's ash content, the lower its calorific value, a development that lower the heating effect of the briquette (Obi *et al.* 2013; Suryaningsih*et al.,* 2017). The low ash content found in this study indicates the suitability of using the briquettes for thermal applications. The average percentage fixed carbon content for the current study as shown in figure 3(d) varies from 2.79 to 10.15%. with the highest value observed at SBPC. These values are in agreement with 5.28%, 9.06% and 2.67% as reported by Ohagwu *et al.,* (2022); Emerhi, (2011); Namadi & Abdullahi, (2017) for sawdust briquettes bonded with cassava starch, okra and Bagasse briquette bonded with cassava starch. It has been established from the current study that the percentage moisture content relates inversely to the percentage fixed carbon and that briquettes made from cold-treated pulp might give a better-quality fuel when compared with its counterparts. Hence, the amount of fixed carbon acts as a major generator of heat during combustion producing a high calorific value of fuel (Ajimotokan *et al.,* 2019).

Figure 4 shows the calorific values of the briquettes produced in this study in comparison with some previous studies. 17,230kJ/kg, 18,270kJ/kg and 16,550kJ/kg are the Calorific values obtained for SBCS, SBP(cold) and SBP(hot) respectively. These values exist within the range of values obtained for starch bonded briquettes made from all the husks (Coconut, Rice and Coffee), sawdust and woody charcoal (Suryaningsih *et al.,* 2017); and favourably compared with 17,380 to 17,820kJ/kg for sawdust briquettes bonded with Okra (Ohagwu *et al.,* 2022). The highest value was obtained for SBP(cold) which has been attributed to the briquette's high percentage of carbon content and relaxation ratio. The calorific values of the briquettes produced in this study are greater than the ≥16,500kJ/kg which falls within the acceptable level of the European briquette standard EN-14961-1 (Ohagwu *et al.,* 2022).

4. CONCLUSION

Solid biofuel in the form of briquette was successfully produced from sawdust using the native cassava starch and African locust bean (Parkia Biglobosa) pulp as binding agentsto serve as an alternative fuel for domestic and industrial thermal applications. The results obtained from the physical and proximateanalysis indicates that the briquettes produced can make a high-quality and durable briquette with a high heating value required for household and small-scale industrial applications.An excellent binding ability and shatter index recorded for briquettes made from cold African locust bean pulpcanfacilitate its quick acceptance in the briquette-making process; a development that can add value to its market potentials. Hence, the briquettes made from sample SBP(cold) is considered the best among its counterparts due to the high percentage of fixed carbon recorded which eventually produced the highest calorific value.Further study is recommended on the ultimate analysisof African locust bean pulp briquettes and its thermal applications in cooking and heating processes.

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