EFFECT OF SIZE, MIXING RATIO AND BINDER ON THE CHARACTERISTICS OF BRIQUETTES PRODUCED FROM CHARCOAL AND SAWDUST

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ABSTRACT

The study assessed the effect of sizes, mixing ratios and binders on briquettes produced from mixed sawdust and charcoal bonded with two different binders (cassava starch gel and orange waste). The two materials (charcoal and sawdust) were sieved to sizes 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm and 1 mm, using a standard test sieves in accordance with British standard. They were mixed at ratios 50:50, 60:40, 70:30, 80:20, 90:10; sawdust to charcoal and binders were at 16.6%. ASTM methods were used to determine the briquettes proximate and ultimate analysis. Their heating value was determined using the Gouthal Formula. The lowest moisture contents 3.89% was found in briquettes size 0.2 mm with ratio 50:50 using cassava starch gel while 6.03% was recorded for orange wastes binder at size 0.2 mm with ratio 50:50, the highest volatile matter 48.5% was observed at size 0.2 mm with ratio 50:50 using cassava starch binder while 40.5% was recorded for orange waste binder at size 0.2 mm with ratio 50:50, the lowest ash contents 3.5% was at size 0.2 mm with ratio 50:50 using cassava starch binder while 5.5% was observed for orange waste at size 0.2 mm with ratio 50:50, the highest fixed carbon 64.55% was found at size 0.2 mm with ratio 90:10 using cassava starch gel while 65.30% was found for orange waste binder at size 0.2 mm with ratio 90:10, the highest heating value 3.90 KJ/g was calculated from briquettes size 0.2 mm with ratio 60:40 using cassava starch while for orange wastes binder was 30.03 KJ/g at size 0.2 mm with ratio 50:50.

Keywords: *Biomass, Briquette, Particle size, Cassava starch, Orange wastes*

1. INTRODUCTION

The decreasing availability of fuel like wood, coupled with the ever-rising prices of kerosene and cooking gas in Nigeria, has drawn attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country (Lucas and Akinoso, 2001). As rightly noted, a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria (Stout and Best, 2001).

Traditionally, wood in form of fuel wood, twigs and charcoal has been the major source of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Olorunnisola, 2007). Briquetting technology is yet to get a strong foothold in developing countries including Nigeria, because of the technical constrains involved and lack of knowledge to adopt the technology to suit local conditions. Overcoming the many operational problems associated with this technology and ensuring the quantity of the raw material used are crucial factors in determining its commercial success (Grover and Mishra, 1996). In addition to this commercial aspect, this technology encourages conservation of wood. Hence, briquette production technology can prevent flooding and serve as a global warming countermeasure through the conservation of forest resources (Ilochi, 2010).

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Briquettes made from materials that cost little or no money to obtain such as newspaper or partially decomposed plant waste or sawdust can be an alternate source of domestic and industrial energy to charcoal, firewood, gas, coal and electricity. Presently, the major source of energy to the rural community is fuel woods because other sources of energy (electricity, gas and kerosene) are either not available or grossly inadequate where available and they are beyond the reach of the masses. Fuel wood collection has grave consequence on forest conservation and sustainable forest resources management. Depending on materials used to make the briquettes, they may burn cleaner than charcoal and firewood. Briquettes production thereby turns waste materials into fuel source. This is therefore attractive because it is a sustainable process (Emerhi, 2011, Salman, 2014).

Briquettes made from charcoal and sawdust is a desirable fuel because it produces a hot, long-lasting and virtually smokeless fire. Briquettes are produced when charcoal and sawdust are combined with other materials and it is formed into uniform chunks. Successful briquette operations are found mostly in developed countries (Olorunnisola, 2007). An example is the industry based on carbonization of sawdust and bark in the southern USA. However, briquetting operations are not successful in developing countries like Nigeria and other African countries. This is mostly due to the high cost of production, lack of awareness on its sustainability, availability of market and poor packaging and distribution systems for the product. Despite these difficulties, opportunities of this type should be closely studied in the interest of the overall national fuel economy and biodiversity and environmental conservation (Emerhi, 2011). Briquette making has the potential to meet the additional energy demands of urban and industrial sectors, thereby making a significant contribution to the economic advancement of developing countries. Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage (Yaman *et al*, 2000, Olorunnisola, 2004). However, in order to make a significant impact as a fuel source, there is the need to improve and promote its production technology (Grover and Mishra, 1996). This is a densification process for improving the handling characteristics of raw materials and enhancing the volumetric calorific values of biomass (Ogunsanwo, 2001). In this study, different mixing ratios based on particle sizes to produce briquette with manual briquetting machine was carried out and characterized to determine parameters such as the moisture content, ash content, density, volatile matter, and heating value among others (Oladeji, 2012).

2. MATERIALS AND METHODS

The materials used for the briquette were sawdust from common wood named *Terminalia Superba* charcoal particles and natural binders (cassava starch gel and orange waste). The sawdust was collected from a local sawmill in Tanke, Ilorin while charcoal particles were bought from charcoal seller at Tanke area in Ilorin. Cassava starch was bought at cassava industry in Ibadan and orange waste was collected from orange sellers at Tanke area, Ilorin.

The material (charcoal) was crushed down and pounded with a large mortar and pestle as shown in figures 1 and 2 respectively.

Figure1: Crushing of charcoal

Figure 2: Pounding of charcoal

This was done to reduce the size of the charcoal to a smaller size that can pass through the sieve sizes 0.2 mm, 0.4 mm 0.6 mm 0.8 mm and 1.0 mm. Sieve analysis was carried out at engineering laboratory in Geology department, University of Ilorin, Ilorin, Kwara State, Nigeria. The two materials (charcoal and sawdust) were sieved in order to remove impurities and to obtain a desirable size fraction of 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm and 1 mm for sawdust and charcoal, this is shown in figures 3 and 4 respectively.

Figure 3: Sieving of sawdust

Figure 4: Sieving of charcoal

These particles sizes were determined using a standard test sieves in accordance with B.S.S (British standard sieve, 1986).

The two materials were weighed and mixed at ratios 50:50, 60:40, 70:30, 80:20, 90:10; Sawdust to charcoal. 16.6% of cassava starch gel and orange waste was used as binding agents.

The briquettes were produced and analyzed at the Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria. The produced briquettes are shown in figures 5 and 6. Three replicates of the briquettes of the mixture of the materials and two different binding agents were produced.

Figure 5: Briquettes produced

Figure 6: Moulding of briquettes

2.1 *Starch preparation*

The dry cassava starch powder obtained from the cassava industry was transformed into a smooth paste by dissolving 22.5g in 10cm^3 of water. The starch paste was then poured into 80cm^3 of boiling water while stirring continuously. The stirring was done in order to ensure that the solute dispersed in the water and prevent 'hot spots' building up in certain parts of the container to avoid uneven expansion.

2.2 *Orange waste preparation*

The orange waste was dried in the sun for five days in order to reduce its moisture content. After drying, size reduction of the orange waste to powder form was done using the household grinding machine. It was poured into pot of 80cm^3 boiling water where it was stirred continuously until it turns into paste.

2.3 Analysis of the b

Moisture Content: T 2]. A portion (2g) each ng electronic weighing re placed in an oven fo nd recorded as the final weight.

The moisture content was determined using this formula:

$$Moisture\ content\ (\%) = \frac{M_1 - M_o}{M_o} \times 100 \quad (1)$$

Where M_1 and Mo are mass of samples before drying and when oven-dried, respectively (g).

Volatile matter: This was determined in accordance with (http://pubs.caritasuni.edu.ng/download.php?file on 10/08/2015). To determine the PVM, 2g of briquettes sample was measured and placed in a crucible of known mass and were oven-dried to constant mass. The briquettes were now kept in the furnace at a temperature of 550°c for 10 minutes and weighed after cooling.

The PVM was determined with the formula:

$$PVM = \frac{B - C}{B} \times 100 \quad (2)$$

Where B is the weight of oven dried sample and C is the weight of sample after 10min in the furnace at 550°c

Ash Content: This was determined accordance with (http://pubs.caritasuni.edu.ng/download.php?file on 10/08/2015). The PAC was also determined by heating 2g of the briquette sample which was measured and placed in a crucible of known mass. It was heated in the furnace at a temperature of 550°c for 4hrs and weighed after cooling.

The PAC was determined:

$$PAC = \frac{D}{B} \times 100\% \qquad (3)$$

Where D is the weight of furnace dried sample and B is the weight of oven dried.

Fixed Carbon: was determine in accordance with (http://pubs.caritasuni.edu.ng/download.php?file on 10/08/2015). Solid, combustible residue that is the final calculation of the amount present in a biomass sample after the percentages of moisture, ash, and volatile matter has been determined.
The percentage fixed carbon (PFC) was computed by subtracting the sum of PVM, PAC and PMC from 100 (http://pubs.caritasuni.edu.ng/download.php?file on 10/08/2015).

$$PFC = 100 - (\%MC + V + \%ASH) \qquad (4)$$

Where PFC (%) is the Percentage fixed carbon
%MC = percentage moisture content
%V = percentage volatiles
%ASH = percentage ash

Calorific value or heating value: This was calculated using the equation called Gouthal Formula which is obtained from Equation below:

$$H_V = 2.326(147.6FC + 144V) \qquad (5)$$

Where FC is the percentage fixed carbon and V is the percentage volatile matter, (Onuegbu, 2011).

3. RESULTS AND DISCUSSION

3.1 Effects of binder, mixing ratio and size on moisture content

Figures 7 and 8 show the results of moisture content for sample A (cassava starch gel) and sample B (orange waste) briquettes. Sample A and sample B showed that binder type, size and mixing ratio has effects on the briquettes moisture content.

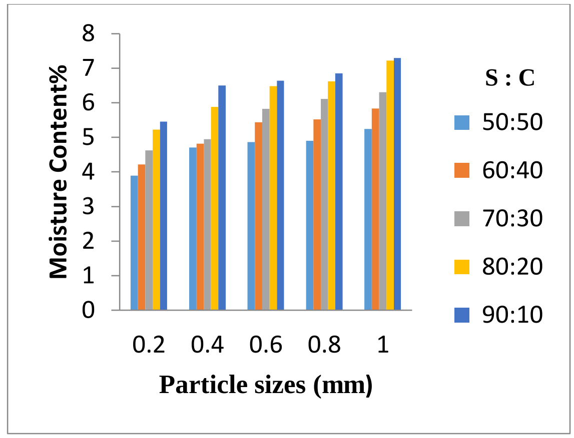

Figure 7: Effects of binder, mixing ratios and particle sizes on moisture content for briquettes sample A (cassava starch gel)

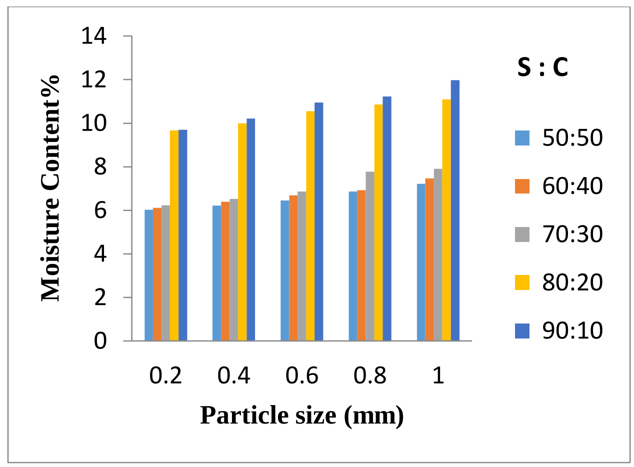

Figure 8: Effects of binder, mixing ratios and particle sizes on moisture content for briquettes sample B (orange waste)

For sample A, lowest moisture contents of 3.89%, 4.22%, 4.62% was recorded in briquette size of 0.2 mm with ratios 50:50, 60:40, 70:30, followed by 4.71%, 4.82%, 4.95% at 0.4 mm size with ratios 50:50, 60:40, 70:30 while the highest moisture contents of 7.22% and 7.29% was obtained at size 1.0 mm with mixing ratio 80:20 and 90:10. For sample B, the lowest moisture contents 6.03%, 6.11%, 6.23% was recorded in briquette size 0.2 mm with ratios 50:50, 60:40, 70:30, followed by 6.22%, 6.40%, 6.53%) at size 0.4 mm with ratios 50:50, 60:40, 70:30 while the highest moisture contents 11.98%, 11.09%, 7.90% and 7.46% was obtained at size 1.0 mm with ratios 90:10, 80:20, 70:30 and 60:40. The result revealed that the lowest moisture contents was obtained from briquettes produced with smaller particle size of 0.2 mm and 0.4 mm ratios of 50:50 and 60:40, sawdust to charcoal using both binders. The reason behind this is that briquettes produced with smaller particle sizes were more oven-dried which leads to low moisture content of briquettes than the briquettes with larger particle size. From literature review, the moisture content of biomass should be as low as 10-15% so there will be complete combustion of the briquettes (Ikelle, *et al.*, 2014). Low moisture content of biomass also helps in their storage (prevents rotting and decomposition). Furthermore, moisture content in the range of 10% will result in denser, more stable and more durable briquette (Kaliyan and Sokhansanji, 2009). The moisture contents obtained in this study compare well with most biomass briquettes; coal briquettes 3.25% and rice husk briquettes 8.48% (Ikelle, *et al.*, 2014) and corncob briquette 7.48%, groundnut shells briquettes 9.18%, melon shells 7.45%, cassava peels 8.78%, yam peels 7.98% revealed that moisture contents obtained in this study, ranged from 3.89% to 11.98% indicates that briquettes produced are safe.

3.2 Effects of binders, mixing ratios and sizes on ash content

Figures 9 and 10 show the results of ash content for sample A (cassava starch gel) and sample B (orange waste) briquettes. Sample A and sample B showed that binder type, size and mixing ratio has effects on the briquettes ash content.

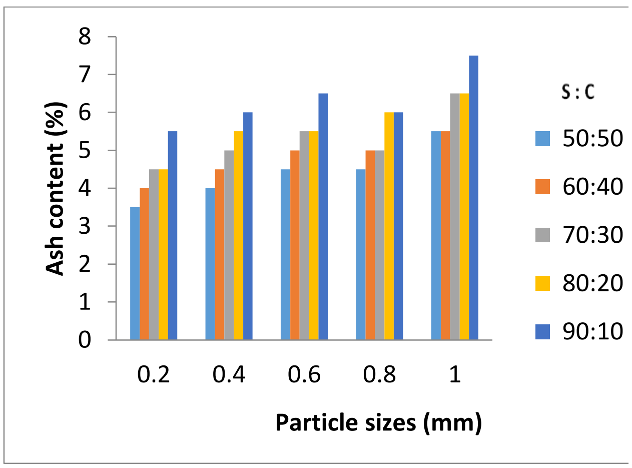

Figure 9: Effects of binder, mixing ratios and particle sizes on ash content for briquettes sample A (cassava starch gel)

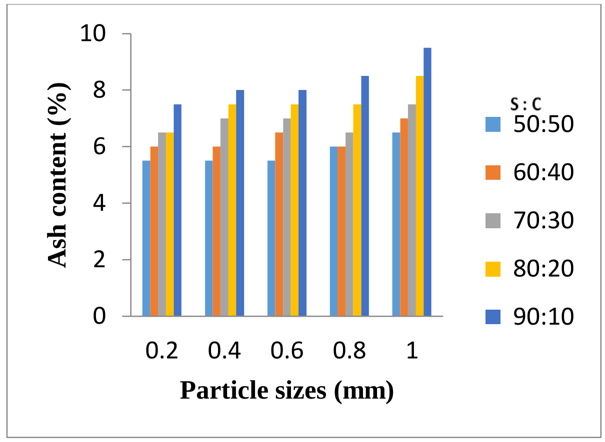

Figure 10: Effects of binder, mixing ratios and particle sizes on ash content for briquettes sample B (orange waste)

For sample A at size 1.0 mm with mixing ratios 90:10 and 80:20 had the highest percentage ash contents 9.5% and 8.5%, followed by 8.5% and 7.5% with mixing ratios 90:10 and 80:20 at size 0.8 mm while lowest ash contents 5.5% and 6.0% was recorded with mixing ratios 50:50 and 60:40 at size 0.2 mm and size 0.4 mm. For sample B, the highest ash contents 7.5% and 6.5% was observed with mixing ratios 90:10 and 80:20 at size 1.0 mm at while lowest ash contents 3.5% and 4.0% was recorded with mixing ratios 50:50 and 60:40 at size 0.2 mm. The lowest ash contents were recorded from briquettes produced with smaller particle size and when the ratio of charcoal to sawdust are equal i.e. ratio 50:50 at size 0.2 mm and 0.4 mm using both binders. The reason for these results is because briquettes produced with smaller particle size emit more heat which allows the briquettes to burn to ashes more than the briquettes with larger particle size. This low ash content recorded, show a reflection of the high heating value obtained from the briquettes used in this study.

Similarly, low ash content has been reported for good briquettes (Manis, *et al.*, 2006). The ash content obtained in this study compare favourably with ash content of coal 19.12% and rice husk 7.53% (Ikelle, *et al.*, 2014) corncob briquettes 1.40%, groundnut shells briquettes 5.00%, melon shells briquettes 6.57%, cassava peels briquettes 4.40%, yam peels briquettes 3.86% (Oladeji, 2012) shows that briquettes with lowest ash contents in this study are good for briquette production.

3.3 Effects of binders, mixing ratios and sizes on volatile matter

Tables 1 and 2 show the results of volatile matter for sample A (cassava starch gel) and sample B (orange waste) briquettes. Sample A and sample B showed that binder type, size and mixing ratio has effects on the briquettes volatile matter.

Table 1: Effects of binder, mixing ratios and particle sizes on volatile matter for briquettes sample A (cassava starch gel)

Mixing ratios (S:C)	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
50:50	48.5%	56.0%	59.0%	64.0%	67.5%
60:40	42.5%	43.5%	50.0%	53.5%	60.0%
70:30	38.0%	40.0%	47.5%	50.5%	55.0%
80:20	33.5%	36.0%	39.5%	43.0%	47.0%
90:10	24.5%	27.0%	35.5%	40.5%	44.5%

Table 2: Effects of binder, mixing ratios and particle sizes on volatile matter for briquettes sample B (orange waste)

Mixing ratios (S:C)	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
50:50	40.5%	43.5%	53.5%	58.5%	61.0%
60:40	34.5%	39.0%	46.0%	54.0%	58.5%
70:30	28.5%	31.0%	37.0%	43.5%	47.0%
80:20	24.5%	29.0%	32.5%	36.0%	40.0%
90:10	17.5%	20.5%	27.5%	32.5%	38.5%

From Table 1 the highest volatile matter of 67.7% was recorded with ratio 50:50 at size 1.0 mm, 64.0% with mixing ratio 50:50 at size 0.8 mm, 59.0% with mixing ratio 50:50 at size 0.6 mm, 56.0% with mixing ratio 50:50 at size 0.4 mm and 48.5% with mixing ratio 50:50 at size 0.2 mm while the lowest volatile 24.5% was found with mixing ratio 90:10 at size 0.2 mm followed by 27.0% with mixing ratio 90:10 at size 0.4 mm. From Table 2 the highest volatile matter 61.0% was recorded with mixing ratio 50:50 at size 1.0 mm, 58.5% with mixing ratio 50:50 at size 0.8 mm, 53.5% with mixing ratio 50:50 at size 0 6 mm, 43.5% with mixing ratio 50:50 at size 0.4 mm and 40.5% with mixing ratio 50:50 at size 0.2 mm while the lowest 17.5% was found with mixing ratio 90:10 at size 0.2 mm followed by 20.5% with mixing ratio 90:10 at size 0.4 mm. The highest volatile matter recorded for the both binders ranged from briquettes produced with smaller particle size to larger particle size i.e. size 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm and 1.0 mm with equality ratio i.e. 50:50. The reason for these results is because briquettes produced with the sizes and ratio listed above ignite more easily and burn faster which results to higher volatile matter. Fuels with lower volatiles, or conversely a very high fixed carbon value, such as coal, need to be burnt on a grate as they take a long time to burn out if they are not pulverized to a very small size (Nasrin *et al*, 2008). In conclusion, the values (48.50%, 56.00%, 59.00%, 64.00%, 67.50%) of volatile matter obtained in this study compared to other briquettes are good and acceptable; coal 43.44%, pennisetum-purpureum (elephant grass) 70.10% and imperata-cylindrical (cogon grass) 69.10% (Onuegbu, 2011).

3.4 Effects of binders, mixing ratios and sizes on fixed carbon

Tables 3 and 4 show the results of fixed carbon for sample A (cassava starch gel) and sample B (orange waste) briquettes. Sample A and sample B showed that binder type, size and mixing ratio has effects on the briquettes fixed carbon.

From Table 3, the results shows that the lowest fixed carbon 27.75% was recorded at size 1.0 mm with mixing ratio 50:50 followed by 26.60% at size 0.8 mm with mixing ratio 50:50 while the highest fixed carbon 64.55% was recorded at size 0.2 mm with mixing ratio 90:10 and 60.50% at size 0.4 mm with mixing ratio 90:10. From Table 4, lowest fixed carbon 25.28% was recorded at size 1.0 mm with mixing ratio 50:50 followed by 28.64% at size 0.8 mm with mixing ratio 50:50 while the highest fixed carbon 65.30% was recorded at size 0.2 mm with mixing ratio 90:10 and 61.28% at size 0.4 mm with mixing ratio 90:10. From this result, it is evident that briquettes with the highest fixed carbon contents were found in briquettes produced with small particle sizes of 0.2 mm and 0.4 mm with increases in ratio of sawdust and decreases in ratio of charcoal i.e. 90:10 using both binders. This is due to the compactness of the material. Low fixed content tend to prolong cooking time by its low heat release (bake-oven effect) (Van and Koppejan, 2002). It also reduced the calorific energy of the briquettes by causing what is called fuel-saving effect. The higher the fixed carbon content, the better the briquette produced because the corresponding calorific energy is usually high (Onchieku *et al., 2012*).

Table 3: Effects of binder, mixing ratios and particle sizes on fixed carbon for briquettes sample A (cassava starch gel)

Mixing ratios (S:C)	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
50:50	44.11%	35.29%	31.64%	26.60%	21.75%
60:40	57.28%	47.18%	39.56%	35.98%	28.67%
70:30	52.88%	50.05%	41.18%	38.39%	32.20%
80:20	56.78%	52.65%	48.52%	44.38%	38.78%
90:10	64.55%	60.50%	51.56%	46.65%	40.71%

Table 4: Effects of binder, mixing ratios and particle sizes on fixed carbon for briquettes sample B (orange waste)

Mixing ratios (S:C)	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
50:50	47.97%	44.78%	34.55%	28.64%	25.28%
60:40	53.39%	48.60%	40.82%	33.08%	27.04%
70:30	58.77%	55.47%	49.14%	42.23%	37.60%
80:20	59.33%	53.50%	49.15%	45.64%	40.41%
90:10	65.30%	61.28%	53.55%	47.77%	40.02%

The fixed carbon results in this study, from the lowest to the highest using cassava starch gel i.e. 21.75% to 64.55% and 25.28% to 65.30% using orange waste binder, compare well with other biomass briquettes; coal briquettes 57.51% and rice husk briquettes 41.85% (Ikelle *et al*, 2014) and corncob briquette 12.57%, groundnut shells briquettes 6.53%, melon shells 10.27%, cassava peels 2.57%, yam peels 3.29% (Oladeji, 2012), pennisetum-purpureum (elephant grass) 15.46% and imperata-cylindrical (cogon grass) 14.49% (Ikelle *et al*, 2014) revealed that fixed carbon obtained in this study ranged from the lowest 21.75% to the highest 65.30%, shows that briquettes produced are good for briquette production.

3.5 Effects of binders, mixing ratios and sizes on heating value

Tables 5 and 6 show the results of heating value for sample A (cassava starch gel) and sample B (orange waste) briquettes. Sample A and sample B showed that binder type, size and mixing ratio has effects on the briquettes heating value.

Table 5: Effects of binder, mixing ratios and particle sizes on heating value for briquettes sample A (cassava starch gel)

Mixing Ratios (S:C)	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
50:50	31.38 kJ/g	30.87 kJ/g	30.62 kJ/g	30.56 kJ/g	30.07 kJ/g
60:40	33.90 kJ/g	30.76 kJ/g	30.32 kJ/g	30.27 kJ/g	29.93 kJ/g
70:30	33.90 kJ/g	30.58 kJ/g	30.04 kJ/g	30.09 kJ/g	29.47 kJ/g
80:20	30.71 kJ/g	30.12 kJ/g	29.88 kJ/g	29.63 kJ/g	29.05 kJ/g
90:10	30.36 kJ/g	29.81 kJ/g	29.52 kJ/g	29.58 kJ/g	28.88 kJ/g

Table 6: Effects of binder, mixing ratios and particle sizes on heating value for briquettes sample B (orange waste)

Mixing Ratios (S:C)	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
50:50	30.03 kJ/g	29.94 kJ/g	29.78 kJ/g	29.42 kJ/g	29.11 kJ/g
60:40	29.88 kJ/g	29.74 kJ/g	29.42 kJ/g	29.44 kJ/g	28.87 kJ/g
70:30	29.72 kJ/g	29.42 kJ/g	29.26 kJ/g	29.06 kJ/g	28.65 kJ/g
80:20	28.57 kJ/g	28.08 kJ/g	27.75 kJ/g	27.72 kJ/g	27.27 kJ/g
90:10	28.27 kJ/g	27.90 kJ/g	27.59 kJ/g	27.28 kJ/g	26.63 kJ/g

The highest calorific values 31.38 kJ/g, 33.90 kJ/g and 33.90 kJ/g was recorded with mixing ratios 50:50, 60:40 and 70:30 at size 0.2 mm followed by 30.87 kJ/g and 30.76 kJ/g with mixing ratios 50:50 and 60:40 at size 0.4 mm while the lowest calorific values 29.05 kJ/g and 28.88 kJ/g occur at size 1.0 mm with mixing ratios 80:20 and 90:10 using sample A. For sample B, highest heating values 30.03 kJ/g and 29.88 kJ/g was recorded at size 0.2 mm with mixing ratios 50:50 and 60:40 followed by 29.94 kJ/g and 29.74 kJ/g at size 0.4 mm with mixing ratios 50:50 and 60:40 while the lowest calorific value 26.63 kJ/g was recorded at size 1.0 mm wit ratio 90:10. From this results, it is shown that briquettes with the highest calorific value were found in briquettes produced with small particle size i.e. size 0.2 mm, 0.4 mm and 0.6 mm with an increase in the ratio of sawdust and decrease in ratio of charcoal i.e. 50:50, 60:40 and 70:30 using sample A, and the same trend reoccur when sample B was used as binding agent. These results occur due to their good volatile matter. The calorific value can be used to calculate the competitiveness of a processed fuel in a given market situation. There is a range of other factors, such as ease of handling, burning characteristics etc., which also influence the market value, but calorific value is probably the most important factor and should be recognized when selecting the raw material input. The most important fuel property is its calorific or heat value (FAO, 1995). Results from other biomass briquette compared to briquettes in this study; coal 20.64 kJ/g, pennisetum-purpureum (elephant grass) 15.11 kJ/g and imperata-cylindrical (cogon grass) 14.66 kJ/g (Ikelle *et al*, 2014) revealed that calorific values obtained in this study are good for the production of briquettes in both industry and domestic.

4. CONCLUSION

In conclusion, the lowest ash contents were recorded from briquettes produced with smaller particle size and when the ratio of charcoal to sawdust are equal i.e. ratio 50:50 at size 0.2 mm and 0.4 mm using both binders. This implies that briquettes produced with smaller particle size emit more heat which allows the briquettes to burn to ashes more rapidly than the briquettes with larger particle size. This low ash content recorded show a reflection of the high heating value obtained from the briquettes under consideration which confirmed its effectiveness as good briquette products. The ash content obtained in this study compare favourably with ash content of other briquettes products. It can be inferred that the quality of the briquettes was influenced by size, mixing ratios and the type of binding agent that was used. The quality of the briquettes that were produced using starch as binder was higher than those bonded with orange waste. The use of these types of briquettes is environmental friendly, release lesser carbon to the atmosphere, reduce health hazard associated with the use of fuel wood and reduce deforestation and its attended complications.

It's therefore recommend that more attention should be given to the development of the machine since the raw materials are widely available a s waste which if adequately harness, will also make our environment friendlier in term of waste disposal and the consequence health hazard.

Acknowledgement

The authors hereby wish to thank the staff of the engineering laboratory in Geology Department, University of Ilorin, Kwara State, Nigeria where the materials were sieved and the staff of Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria where the briquettes were produced and analyzed.

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