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Insights into the Quality and Quantity of Briquette Fuels from Bone Wastes

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Abstract: *In Kenya, bone wastes are accumulating rapidly yet have no immediate potential industrial use. Accumulation of waste bones have adversely impacted land, air and water. There is a need to mop out waste bones from the environment into a valuable product. This research investigated the quality and quantity of briquettes fuel prepared from waste bones. The waste bones were pyrolyzed in a metal kiln. Three briquette samples with 75.00%, 40.00% and 20.00% binder were prepared and their calorific values compared with that of commercial charcoal samples. The bones char and binder (black clay) were characterized by Infrared Spectrometer and their combustion parameters analyzed using standard methods. The average product yield of the bone char from the bone waste was 80.00%. The bone char recorded a moisture content (MC) of 4.17%,ash content (AC) of 40.83%, volatile matter (VM) of 23.67%, fixed carbon (FC) of 31.33% and calorific value (CV) of 18.68 kJ/g. On the other hand, the binder had4.25%MC, 89.50%AC, 5.00%VM, 1.85%FC and calorific value of 2.28kJ/g. The calorific values of the three samples were 6.08 kJ/g (75.00% binder), 12.89 kJ/g (40.00% binder) and 13.91 kJ/g (20.00% binder) respectively. The calorific value of 100% bone char (18.6842 kJ/g) was higher than that of the charcoal samples (12.00-15.52 kJ/g).In conclusion briquettes fuels prepared from bone waste can complement charcoal and combat environment pollution caused by deforestation and accumulation of waste bones.*

Keywords: *briquettes, bone char, calorific values*

1.0 Introduction

Bone wastes are the materials remaining after the consumption of meat (protein), normally containing much of calcium phosphate in the form of an insoluble salt called hydroxyapatite

crystals $[(Ca)_{10}(PO_4)_6(OH)_2]$lie adjacent and bound to the organic protein matrix. sodium, Magnesium, potassium, and citrate ions are also present, conjugated to hydroxyapatite crystals rather than forming distinct crystals of their own(Von Euw et al., 2019)…..Meat consumption is increasing day by day both in the developed and developing countries(Bett*et al.,* 2012). This has led to proportionate increase in waste bones from slaughter houses, hotels and meat processing industries, accelerating the accumulation of waste bones in the environment due the lack of immediate industrial uses of these materials. The accumulated waste bones have adversely impacted the surrounding land, air and water. Land pollution occurs when waste bones are left unattended in open spaces. When precipitation takes places, these waste bones leave the land in a polluted state and part of them are washed into nearby streams. (Bergevoet & Van Engelen, 2014).

The impacts of accumulated waste bones in the environment include; provision of breeding ground for the vectors transmitting diseases, unwanted and irritating smell, attracting harmful flies, attracting scavengers and dangerous animals that might harm and injure human beings as well as distortion of environment outlook. (Mohammad, 2013). Fossil-based technology is the primary source of fuel in the world that meets the energy requirement in small as well as large industrial applications. Still 2.5 billion people around the world do not have access to modern fuels(Dioha and Emodi, 2019). The use of sequestered fossil fuels releases a lot of particulates which had been accumulated for many years into the environment (Version, 2016). Therefore, there is a need to come up with briquette fuels to mop the hazardous waste bones from the environment and give an alternative source of fuel.

Due to poverty and unemployment, communities are turning to fuel briquette making through recovering charcoal dust, among other organic by-products. Fuel briquettes are used as a compliment or substitute to charcoal. Fuel briquettes are made by compressing biomass material such as charcoal dust, sawdust and other wood residues or agricultural by-products into a uniform solid unit (Sotannde*et al.,* 2010). Briquetting biomass is done using various techniques, either with or without a binder. For charcoal and other biomass material that lacks plasticity, addition of a sticking or agglomerating material, preferably combustible is required to enable the formation of solid briquettes. Common binders include starch, gum arabica, soil, animal dung or waste paper (Garrido *et al*., 2017).

Briquetting is a technology for densification of agricultural residues and wastes to increase their bulk density reduce their moisture contents and make briquettes of uniform sizes and shapes for easy handling, transporting and storage (Oyelaran, Olorunfemi, Sanusi, Fagbemigun, & Balogun, 2018). Briquettes can be defined as a product formed from mechanical conversion of loose and small particles size materials with or without a binder into uniform or different shapes and sizes. Commercialization of briquetting technology is essential to know whether the technology is economically viable or not, (Sotannde *et al.,* 2010).

Many studies have been conducted to convert agro-residues into briquettes fuel. This research attempted to convert waste bones into a valuable briquette fuel using black clay binder. Different binder: bone char formulations were assessed vis-à-vis commercial charcoal from the South Rift region of Kenya. The research also aimed at solving the environmental problems caused by the accumulation of waste bones. These bones are abundantly present in South Rift region of Kenya.

2.0 Methods

2.1 Experimental Design

An independent measures design was hereby followed to characterize and assess the levels of different combustion parameters in bone char briquettes. Waste bones collected from various points in Narok county of South Rift region, Kenya were carbonized and bonded using black clay. The ratios of bone char to binder were varied. Thereafter, the prepared briquettes were characterized alongside the individual bone char and binders. The characterization data obtained was later compared to secondary data of bio char. The calorific values of the prepared briquettes were analyzed vis-à-vis commercial charcoal.

Carbonization and briquetting of the samples was done at Maasaimara university, Kenya while lab analysis was conducted at the university and Kenya Portland Cement, Kenya.

2.2 Materials

Waste bones were collected from different areas of Narok Town; slaughter houses, butcheries, hotels and Maasai Mara University kitchen wastes, stored, a waiting for treatment. The collected samples were washed using distilled water to removes any debris embedded on them, and dried in the sun for 3 days. A carbonization kiln (model under registered patent in Kenya), meat mincer, and briquetting machine were used to prepare the briquettes. Functional group analysis was done using FT-IR (Shimadzu 8400S). A muffle furnace (Thermofischer, M104) used for volatile matter analysis and was carried out at Kenya Portland Cement, Athi river.

2.3 Preparation of briquettes

2.3.1 Carbonization

The dried bones were carbonized using carbonizing units into bone char at a kiln temperature of about 350 – 450^{0}C). For carbonization, 20 kilograms of the collected waste bones were loosely packed into the kiln**(Figure 1)**. (The kiln capacity was about 100kg dry bones). After loading the bones into the kiln, a little amount of biomass was used for firing to ignite the bones in the kiln, the top of kiln was closed with metal lid attached to the conical chimney to start the pyrolysis process at atmospheric pressure. The process was carried out in limited air supply, burning process was slow and spreads to the waste bones through the holes in the percolated sheets(Olorunnisola, 2007)**.**

Figure 1: *Biomass carbonizing unit and a heap of bone wastes*

2.3.2 Bone Char Grinding

Carbonized waste bones ground into manageable pieces (bone char) using hand operated meat mincer.

2.3.3 Mixing

The Bone char was mixed with the binder and water in different ratios until a uniform mixture was obtained. Resulting into three different samples of briquettes, binder: bone char, 3:1;2:3; and 1:4 respectively.

2.3.4 Pressing

The uniformly mixed materials were hand pressed at atmospheric pressure into a plastic cup to obtain a uniform shape.

Figure 2: *pressing bottle*

2.3.5 Drying

The regular shaped briquettes were dried on a wire mesh, a half dried in sun and the other half under shade for 5 days (Olorunnisola, 2007).

2.4 Functional group Characterization

Bone char, and binder samples were analyzed using a Spectrum One FTIR spectrophotometer (Shimadzu 8400S). FTIR spectral analysis was performed in the transmittance mode in the range of 4000-400 cm^{-1}. Standard procedures were used in this analysis.

2.5 Analysis of Physicochemical parameters of the briquette fuels

2.5.1 Moisture Content (MC)

The moisture content of prepared bone char briquettes was determined by calculating the loss in weight **(**in percentage weight basis) of material using hot air oven drying method at 105 to 110°C for three hours and up to constant weight loss (Sengar*et al.,* 2012).

Calculation of % moisture content:

$$\text{Moisture content (\%WB)} = \frac{(W2 - W3)}{(W2 - W1)} \times 100\% \quad \textbf{(1)}$$

Whereby;

- **W1** is the weight of empty crucible.
- **W2** is the weight of crucible + sample before heating.
- **W3** is the weight of crucible +sample after heating.

2.5.2 Ash Content (AC)

The residual sample remained after combustibility of briquette fuel prepared from bone. The residual sample in the crucible was heated without lid in a muffle furnace at 700 ± 50°C for one half hour. The crucible was then taken out, cooled first in air, then in desiccators and weighed. Heating, cooling and weighing was repeated, till a constant weight obtained. The residue was reported as ash on percentage basis (%WB) (Sengar *et al.,* 2012),(Alexandrov, Reyes, & Fermin Guerrero, 2007)**.**

$$\text{Ash Content (\%WB)} = \frac{(W3 - W1)}{(W2 - W1)} \times 100\% \qquad \textbf{(2)}$$

Whereby;

- **W1** is the weight of the empty crucible.
- **W2** is the weight of crucible + sample.
- **W3** is the weight of crucible + ash.

2.5.3 Volatile matter (VM)

The dried sample left in the crucible was covered with a lid and placed in an electric furnace (muffle furnace), maintained at 925 ± 20°C for 7 minutes. The crucible was cooled first in air, then inside a desiccator and weighed again. Loss in weight was reported as volatile matter on percentage basis.(Sengar et al., 2012)

$$\text{Volatile matter (\%WB)} = \frac{(W2 - W3)}{(W2 - W1)} \times 100\% \qquad \textbf{(3)}$$

Whereby;

- **W1** is the weight of empty crucible.
- **W2** is the weight of empty crucible + sample before heating.
- **W3** is the weight of empty crucible + sample after heating.

2.5.4 Fixed carbon content (FCC)

The fixed carbon content of briquettes is the carbon found in materials after the volatile matters are driven off. Fixed carbon was used to estimate the amount of coke that will be yielded from a sample of briquettes (Sengar *et al.*, 2012).

Fixed carbon was determined by volatility test, in percentage weight basis:

% fixed carbon content = 100% - (MC%WB + VM%WB + AC%WB)**(4)**

Whereby;

- **MC%WB** is the moisture content in percentage weight basis.
- **VM%WB** is the volatile matters in percentage weight basis.
- **AC%WB** is the ash content in percentage weight basis**.**

2.5.5 Calorific value

Calorific value was determined by the following relationship formulae

Heating value = 2.326 (147.6D + 144V)(Alexandrov *et al.*, 2007) **(5)**

Whereby;

D is the percentage fixed carbon.

V is the percentage volatile matters.

3.0 Result and Discussion

3.1 Bone char yield

A mass of 16kg (kilograms) bone char was produced from 20kg, the percentages of materials that were fully carbonized into carbon (bone char) was 80% while 20% was lost on ignition. The 20% material, could be the materials that were easily vaporizes into atmosphere due to their low melting pointeg tar and gases; CO_2, CO, NO_2, $SO_2$and water vapor. The carbonization of the waste bones takes about eight hours.

3.2 Briquette Fuels

All the briquette fuels had darkened color which was that of the dark clay binder. The three samples of briquette products prepared were as shown in **figure 1**below:

Figure 3: The images of prepared bone char briquettes after sun-drying. Sample 1 has 75% binder, sample 2 has 40% binder while sample 3 has 20% binder.

It was observed that, increment in bone char ration in the briquettes intensified the dark color of the briquettes prepared. Also, it was found that, with hand pressing, the minimum binders required for effective binding of the bone char was 20%, below which the bone char granules could not bind. All other observable traits such as odor and touch did not differ.

3.3 FT-IR spectroscopic analysis

The FT-IR spectra of binder and bone char were found to have several similarities. The spectra of the binder had a peak at 1033.85 cm^{-1} associated with Si-O deformation bending bands. The binder also had a Si-O stretching band peak at 755.6 cm^{-1}owing to presence of this alkali in black clay particles. The binder also had a carboxylic OH peak at 3672.17 cm^{-1} citing presence of water molecules as well as organic impurities containing carboxylic acids. Water molecules have previously been used to glue together charcoal dust in briquette preparation. An Al-OH peak at 3670.56 cm^{-1}was also found due to abundance of alumina ions in clay. Al-OH together with Si-O-Al(peak at 524.64 cm^{-1})have been found to be excellent binders of carbon particles (Chung, 2003).Salts of both aluminum and silica have excellent heat retention properties, which is a desirable characteristic of a good briquette binder (Krewski *et al.,* 2007).In general, the binder was found to contain -OH groups, Al-OH and Si-O groups which have binding properties (adhesive material), enhancing gluing of the bone char together. Figure 2 below illustrates the FT-IR spectra of the binder and bone char samples prepared.

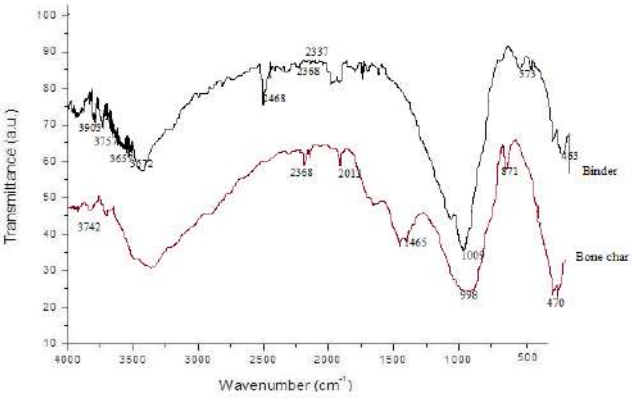

Figure 4: *FT-IR spectral of the binder and bone char used for preparation of bone char briquettes*

The carbonized bones char was analyzed to ascertain resemblance or similarities of peaks with charcoal char. Figure 2 above illustrates the FT-IR spectra of the bone char. The sample had little moisture content as witnessed by inactivity in the FT-IR spectra between 3500-4000cm^{-1}. Only one shallow peak at 3742cm^{-1} was observed. There was a peak at 3400cm^{-1} due to carboxylic OH groups. Similar peaks have been observed for charcoal and bio-char synthesized from agricultural residues (Nartey and Zhao, 2014). The bone char had traces of nitride and acetylenic groups (at 2368cm^{-1} and 2013cm^{-1} respectively) attributed to presence of chitosan and other proteins that could not fully char during carbonization. The samples also had aromatic -C=C peaks at 1465cm^{-1} and C-O peaks at around 998cm^{-1}.Similar peaks were observed in charcoal dust as well as bio char from agricultural residues (Nartey and Zhao, 2014). An out-of-plane C-H bending peak was also visible at around 871cm^{-1}. This peak was confirmed present in several types of charcoal (Sencan *et. al.,* 2015).

3.4 Combustion parameter analysis

The combustion parameters of the binder and the bone char were found to largely differ. The bone char sample had more calorific value (CV), volatile matter (VM) and fixed carbon content (FCC) while the binder samples had higher levels of moisture content (MC)and ash content (AC). The moisture content of the binder was slightly higher than that of the bone char due to presence of water molecules still intact in the binders. The deviation in moisture content values between the bone char and binder samples were however not significantly different ($p \geq 0.05$, n=5). The bone char samples having been subjected to carbonization had already lost a lot of moisture by volatilization at high temperatures. Similar moisture content values were recorded by Zhang *et al., (*2015) for red clay in their studies. The optimal moisture content for briquette fuel should range from 4% to 14% and thus both the binder and bone char were in the appropriate range(Grover, *et. al.,* 1996). High moisture content reduces adhesive property of briquettes fuel, moderate moisture content provide surface for adhesion between the carbon particles being gelled(Onukak, *et. al.,* 2017). However, too much moisture content renders the fuel dump inhibiting combustion(Onukak, *et. al.,* 2017). In their studies, Billa *et al.,* (2019) found similar moisture content values for bio char obtained from agricultural residues. Table 1 below illustrates the combustion parameters of bone char and binder analyzed.

Table 1: Bone char and binder heating properties analysis

Sample	***Combustion parameter***				
	MC (%)	AC (%)	VM (%)	FCC (%)	CV (kJ/g)
Bone char	4.17±0.29	40.83±2.12	23.67±2.08	31.33±1.76	18.68±0.16
Binder	4.25±0.35	89.50±4.48	5.00±1.41	1.85±0.35	2.28±0.59

The ash content values of binder sample were significantly higher than those of the bone char($p \geq 0.05$, n=5). The low ash content in the bone char sample could be ascribed to high carbon content in the bone char. Mythili and Venkatachalam (2015)from their research reported ash content of similar range for charcoal char. The large contrast in volatile matter levels between bone char (23.67±2.08%) and binder

(5.00±1.41%) are due to the difference in the ash and by extension the carbon content present in the two samples(Falemara, *et. al.,*2018). These findings are echoed by the significant difference (p≥ 0.05, n=5) in the fixed carbon content of the two samples. The FCC values are in correspondence with those of Ronsse *et al.,* 2015. In their studies, Ronsse *et al.,* (2015) describes this range of fixed carbon content as being optimal for briquette production. Most organic (carbon containing) matter are readily volatile thus the increased VM content in the bone char sample. The calorific value of the bone char sample was also higher (18.68±0.16kJ/g) than those of the binder (2.28±0.59kJ/g) indicating more heat in the bone char samples. These values are however lower than those of Shiferaw *et al.,* (2017) who obtained higher calorific values using charcoal dust as raw material for briquette synthesis.

The combustion parameters of the briquette samples dried under the sun or in shade using different ratios of binder are illustrated in **Table 2** below.

Table 2: Bone char briquettes fuels heating properties (S1 has 75% binder, S2 has 40% binder and S3 has 20% binder)

Mode of drying used	*Briquette type*	*Combustion parameters*				
		MC (%)	AC (%)	VM (%)	FCC (%)	CV (kJ/g)
Sun-dried	S1	9.50±0.00	72.00±0.00	12.00±0.00	6.00±0.00	6.08±0.00
	S2	10.50±0.00	52.00±0.00	19.00±0.00	19.00±0.00	12.89±0.00
	S3	10.00±0.00	48.00±0.00	20.00±0.00	21.00±0.00	13.91±0.00
Shade-dried	S1	11.00±0.00	76.00±0.00	10.00±0.00	3.00±0.00	3.79±0.00
	S2	11.50±0.00	55.00±0.00	16.00±0.00	17.50±0.00	11.38±0.00
	S3	12.50±0.00	50.00±0.00	18.00±0.00	19.50±0.00	12.72±0.00

Decrease in binder content was found to favor the increase in combustion parameters analyzed in the bone char briquettes. The combustion parameters analyzed are a function of the raw material properties as well as the briquetting and drying process(Carnaje, *et. al.,* 2018). Use of high pressure in the briquetting process increase the density of the briquettes and by extension the relative fixed carbon content and calorific value(Križan, *et. al.,* 2014).

The moisture content of the briquette samples sun-dried was quite lower than that the shade-dried ones. This implied that during shade-drying, water removal did not happen optimally(Taulbee, *et al.,* 2012). Nevertheless, both modes of drying were found to yield desired moisture content in briquette samples prepared from bone char ranging from9.50±0.00 to12.50±0.00(Taulbee, *et al.,* 2012). The ash content values of samples shade-dried were found to be insignificantly higher (p≥ 0.05, n=5) than those that were sun-dried (Tiku, *et. al.,*1967). The volatile matter, fixed carbon content and calorific values of the sun-dried samples were all higher than the shade dried ones.

The volatile matter values of samples with 40% and 20% binder were significantly higher than those with 75% binder (p≥ 0.05, n=5). Only samples with 40% and 20% binder levels had volatile matter in optimum range for efficient heat generation. Volatile matter levels less than 15% implies lower volatile carbon which are important heat conductors in fuel(Oladeji, *et. al.,*2010). Generally, the fixed carbon content of samples with 75% binder levels were significantly different from those with 40% and 20% binder levels (p≥ 0.05, n=5) irrespective whether sun-dried or shade dried (**Table 2**). Also, sun-dried samples had more FCC than the shade-dried ones, since the volatile organic compounds could not withstand the high temperatures of sun radiations (Mierzwa-Hersztek *et al.,* 2019). In their research work, Mierzwa-Hersztek *et al.,* (2019) reported FCC values of7.2% (PL) to 48.7%in briquettes prepared from bio char. The values of FCC were directly proportional to the calorific values of the briquettes(Figure 7). The best bone char briquettes as far as calorific values were concerned were those sun-dried and containing 20% binder (13.91±0.00kJ/g)(Table2). The shade-dried and containing 75% binder had the least calorific value (3.79±0.00kJ/g)(Table2). The calorific values of the bone char without a binder(18.68±0.16 kJ/g) was higher than those obtained from oil palm briquettes by Onukak *et al.,* (2017), reported caloric value of 18.1063 kJ/g. These values from the current study, lower than those of Tanui *et al.,* (2018) obtained from charcoal dust briquettes where the value was 29.031 MJ/kg. This could be attributed with the higher density of wood char, a characteristic of charcoal dust.

3.4.1Effects of binder concentration to calorific values

The calorific value of the bone char briquettes fuel was found to be inversely proportional to the binder concentration(Figure 5).This pattern was similar in both sun-dried and shade-dried briquettes(Figure 5).The binder lowers the calorific value as a result of incombustibility properties(Carnaje *et al.,* 2018). The binder had an average calorific value of 2.27 kJ/g while the bone char had 18.68kJ/g. The trending in calorific values of the briquettes with the level of binder used is as shown in(Figure 5) below:

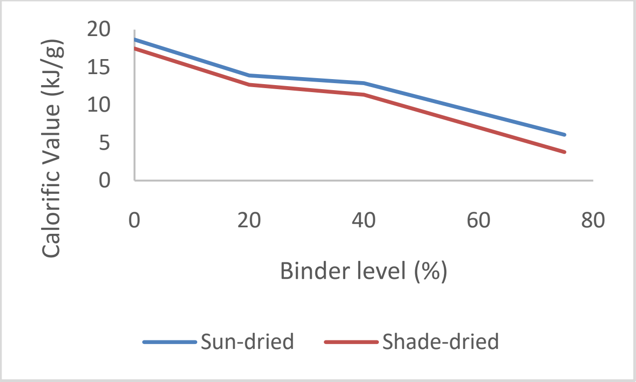

Figure 5: Trending of calorific value with binder concentration

The highest calorific value of the briquettes fuel was that with low binder content and higher bone char content(Figure 5) Sample 3 which was prepared using 80% bone char and 20% binder recorded the highest calorific value, with the briquettes dried in the sun having higher calorific value than those dried in the shade (13.91 kJ/g) and (12.72 kJ/g) respectively (Table2). Sample 1 which was prepared by 25% bone char and 75% binder recorded the lowest calorific value, and the briquettes dried under the shade had lower calorific value compared to those dried in the sun (3.79 kJ/g) and (6.08 kJ/g) respectively(Figure 5). The average difference in the calorific value for those briquettes dried in the sun and under the shade was recorded to be 2.13 kJ/g which is a significant amount of energy to go into waste. Ranjit *et al.,* (2016) noted that binder concentration has a great impact on key physical properties of fuel briquettes produced from cassava rhizomes. Properties affected such as density have a direct impact on the ultimate calorific value of the briquettes(Yaman, *et al.,* 2001).

3.4.2Correlation of ash content and calorific value of bone char briquettes

The calorific value of briquettes are a function of the total carbon content present while ash content is a primary result in most experiments, calorific value is a secondary result and prone to effects by many other physical and chemical factors(Yaman, *et al.,* 2001). Figure 4 below illustrates the correlation between the ash content of the bone char briquettes with their calorific values.

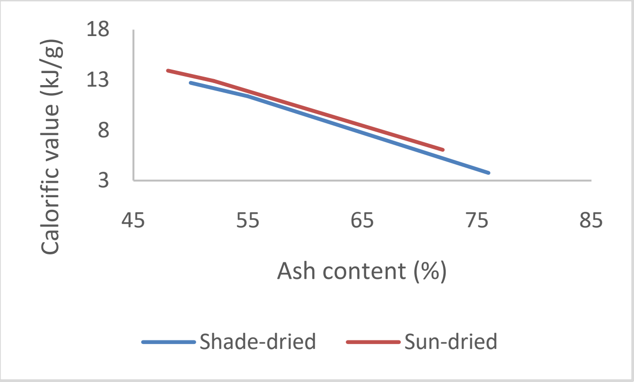

Figure 6: The correlation between calorific value and the ash content of bone char briquettes

From **figure 6** above, the calorific value of the briquettes fuel is inversely proportional to the ash content. The correlation of calorific value with ash content was R^2 = - 0.99 in the sun-dried samples and R^2 = - 0.99 in the shade-dried samples. This implies that there was a negative correlation between the two variables. The correlation of ash content with calorific value in charcoal and coal was also found to be quite negative and strong (Arun *et al.,* 2008). High calorific values imply there are more fixed carbon(Taulbee, *et al.,* 2012). The two variables are thus perfectly correlated in pure carbon and under normal conditions(Taulbee, *et al.,* 2012)The statistical correlation factor can thus be effectively used to measure impurities present. Sample 3 (80% bone char) recorded the lowest ash content and highest calorific values while sample 1(25% bone char) recorded the highest ash content and lowest calorific value (**Table 2**). Samples dried under the shade had more ash content and lower calorific value as compared to those dried in the sun. The sample 1 had lowest incombustible material (20%:80% binder: bones char) resulting to high calorific values. High ash content lowers the amount of energy released during the combustion of the briquettes fuel since it covers the briquettes minimizing the oxygen supply during combustion(Oyelaran *et al.,* 2018).From the data collected the binder had the higher ash content (89.5%) while the bone char had (40.83%). This was the reason why the increase of the binder concentration increased the ash content of the briquettes fuels and also lowered the calorific value. The best briquettes can be prepared with higher bones char and lower binder concentration in order to lower ash content and increases calorific value. Since the ash content was higher than the required standard, a binder with no or lower ash content can be used for efficient production of briquettes fuel (Wakchaure and Sharma, 2007).

3.4.3Correlation between fixed carbon content and calorific value in bone char briquettes

The fixed carbon of a fuel is the percentage of carbon available for char combustion after all the volatile matter is removed from the biomass (Ibeto, *et. al.,*2016). This is not equal to the total amount of carbon in the fuel (the ultimate carbon) because there is also a significant amount released as hydrocarbons in the volatile matter(National Research Council (US), 2000). Fixed carbon gives significant indication of the fraction of char that remains after the de-volatilization phase (Rabacal *et al.,* 2018). These carbons react with the oxygen to release heat (Pilusa *et al.,* 2013).**Figure 7** below illustrates the correlation between calorific value and fixed carbon content in the prepared bone char briquettes.

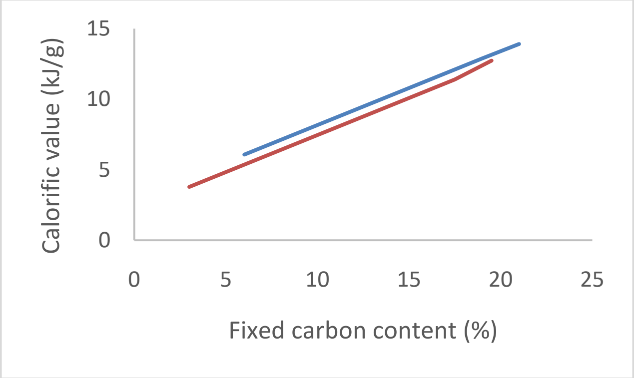

Figure 7: Correlation between the fixed carbon content and calorific values of sun-dried (blue graph) and shade-dried (red graph) bone char briquettes.

From **figure 7** above, fixed carbon content is directly proportional to the calorific value of the bone char briquettes. The bone char had higher average fixed carbon content and calorific value than the binder and binder containing briquettes. The FCC values for bone char were; 31.33%, 18.68 kJ/g and for binder were; 1.85%, 2.28kJ/gfor sun-dried and shade dried respectively. The correlation coefficient, R^2 of both sun-dried and shade-dried samples was 0.99. This indicates a perfect correlation between these two combustion parameters in bone char briquettes (Demirbas, 2003). It can thus be concluded that the calorific value of bone char briquettes is wholly dependent on the amount of fixed carbon present(Camaje *et al.,* 2018). The briquettes that were dried in the sun recorded higher fixed carbon resulting to the higher calorific value. Introduction of the binder to bones char lower the fixed carbon content as well as the calorific values (Onchieku *et al.,* 2012).

3.4.4Correlation between volatile matter and calorific values in bone char briquettes

Volatile matter represents the components of carbon, hydrogen and oxygen present in the biomass, which when heated is converted to vapor, usually a mixture of long- and short-chain hydrocarbons (Kers *et al.,* 2010). In almost all biomasses, the amount of volatile matter is higher than in bituminous coal (Quan and Gao, 2016).(Figure 8)below illustrates the correlation between volatile matter and calorific values of bone char briquettes.

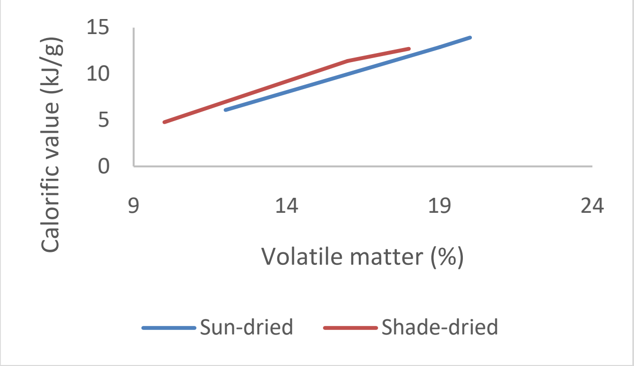

Figure 8, Correlation between volatile matters and calorific value of bone char briquettes fuels

From **Figure 8**, the volatile matters in the briquettes were directly related to the calorific value. The correlation coefficient, R^2 between these parameters was 1 in sun-dried briquettes and 0.98 in shade-dried briquettes. The correlation between volatile matter and calorific value of the briquettes in the shade-dried samples might have been affected by incomplete volatilization of the volatile compounds in a shade drying environment. However, sun-dried briquettes were exposed to optimal conditions favoring volatilization (Davies and Davies, 2013). The volatile matter in the bones char was higher than those in the binder (23.67% and 5.00%) respectively. This makes biomass efficient reactive fuel than coal, giving a much faster combustion rate during the de-volatilization phase (Brar *et al.,* 2012). Higher percentage of volatile matter is an indication of higher ignition rate (Wakchaure and Sharma, 2007). The volatile matter of the briquettes is relatively higher than conventional coals, so it enhances the burning characteristics of the fuel (Tamilvanan, 2013). The sample 1 (19% VM) was easy to ignite as compared to the sample 2 (17.5% VM) and sample 3 (11% VM). As a result, sample 1 recorded the highest calorific value.

4.0 Conclusion

Bone waste materials have a huge conversion potential into bone char, with an efficiency of 80% using a locally fabricated metallic kiln. The briquettes prepared from bone char had highest calorific value of 18.68±0.16 kJ/g, which was well within the higher range of 12.00 KJ/gto 19.00 KJ/g those of most wood chars. Combustion parameters; volatile matter, fixed carbon content and calorific value of the bone char were comparable with those of most wood chars. The binder had more moisture and ash content with relatively low calorific values (2.28±0.59 kJ/g). Bone char briquettes prepared by sun-drying had more fixed carbon content and calorific values compared to those that were shade-dried. The calorific values of the bone char briquettes were found to be positively and strongly correlated to its volatile matter (0.98 to 0.99) and fixed carbon content (0.99-1.0) for sun-dried and shade-dried bone char briquettes respectively. The highest calorific value obtained was for sun-dried bone char briquettes with 20% binder (13.91±0.00 kJ/g).Waste bones raw materials for conversion into high quality briquettes with appreciable calorific values which can effectively reduce waste bones accumulation and cutting down of trees.

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