Investigation of Combustion Properties of Some Selected Fuelwood Species in Nigeria

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ABSTRACT

Investigation of combustion properties of five selected indigenous fuel wood samples was carried out in this study. Combustion properties such as high heating value (HHV), proximate and ultimate analysis, density/specific gravity, thermal conductivity, particle size, flame temperature and porosity were obtained using standard experimental procedures for the selected wood samples. The higher heating values of the five wood samples varied from 2282.117 – 4461.9326 Kcal/kg (9.55 – 18.682 MJ/kg). These values were better than some reported values in literature. The flame temperature for the five samples ranged from 531 – 700 $^{\circ}$C. Proximate analysis results revealed that the ash content for the five samples varied from 6.79 to 48.24 %, fixed carbon varied from 9.45 to 21.30 %, volatile matter varied from 64.23 to 66.64 %, moisture content varied from 3.01 to 5.63 %. Ultimate analysis result revealed that hydrogen, oxygen, and nitrogen contents also range from 3.1128 to 5.5642 %, 22.9981 to 40.6901 % and 0.3630 to 0.65221 % respectively. Some of the values of density/specific gravity, porosity, thermal conductivity, particle size obtained were within values reported by other researchers. The result of the fuel rating properties revealed that *African Prosopis* has the best fuel property with fuel rating of 1.68 and *Quassia undulate* the worst with fuel rating of 3.68 compared to the other samples.

1.0 INTRODUCTION

In many Sub-Saharan African countries, fuel wood is among the most important drivers of deforestation and particularly forest degradation. Deforestation and degradation of forests constitute the most important sources of greenhouse gas emissions and the smokes from burning wood contain hundreds of toxic substances, including carbon monoxide and dioxins and furans which are the most toxic compounds to science. Finding the right type of fuel wood samples will go a long way assessing the potential of efficient fuel wood cooking to mitigate the negative impacts of fuel wood harvesting on forests in Nigeria, and at the same time reduced major health risk associated with the pollutants from these fuel woods.

Fuel wood remain the commonest in Nigeria partly due to its accessibility, affordability, convenience, tradition and vegetation distribution as other sources are either uncommon, modern, costly, sophisticated or required high levels of education and technology to explore, exploit, refine, distribute, store, utilized and maintained [1]. It was also reported that circa three billion people worldwide depend on biomass for cooking food and heating and that approximately 50- 60% use wood, subjecting themselves to daily exposure to high concentrations of smoke from the stove inside the kitchen, making a big impact on health [2]. Hence, concerted efforts are required to change this trend and to protect the environment. The long-term aspiration in respect of cooking energy is the complete substitution of wood-fuel by other sources such as gas, kerosene, solar and electricity, but these changes may take a few decades to materialize [3].

According to [4], alternatives to fuel wood as cooking fuel are generally expensive and hardly available in sub-sahara Africa. As a result, the demand for fuel wood in rural communities' remains inelastic as long as the resource continues to be available to these communities. Investments in direct fuel saving solutions are thus needed to combat the unsustainable use of fuel wood and an important strategy is the determination of some selected fuel wood species that allow for significant savings of fuel wood without the need to introduce sophisticated technologies or to change cooking habits.

The main focus here is the investigation of combustion properties and toxic substances such as carbon monoxide, nitrogen oxide etc. of five selected indigenous fuel wood species used intensively for cooking with a view of establishing and recommending more fuel efficient fuel wood towards discouraging indiscriminate and arbitral falling of fuel wood for cooking application.

2.0 MATERIAS AND METHODS

Materials Used

The materials and equipment used in this research include the following:

The fuel wood samples; *Copaiba oliveri, Prosopis Africana, Quassia undulate, Vitellaria paradoxa* and *Hymenocardia*; improved stove, infrared thermometer, digital balance, bomb calorimeter, oven, crucibles, sieves and sieve shakers.

Methods

The fuel wood samples were identified, collected around University of Agriculture, Makurdi and some remote parts of

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Makurdi, the capital city. They were sun- dried for one month in order to reduce the moisture content. They were then used to carry out the following analysis.

Determination of Combustion Properties

High Heating Value (HHV):

The high heating value of the 5 fuel woods species, which is the heat liberated when a unit quantity of the fuel wood is completely burnt, was determined according to ASTM D 2015-85 using bomb calorimeter model e 2k.

Flame Temperature

The flame temperature of each fuel wood under study was measured with the aid of an Infrared thermometer model EUROLAB 8811A. The meter consists of precise non-contact measurements, built-in laser pointer, automatic selection $(0.1^oC/1^oC, \ ^oC/^oF)$ switchable button, automatic data hold button and backlit LCD display.

Two kilograms of samples of wood A (*Copaiba oliveri*), B (*Prosopis Africana*), C (*Quassia undulata*), D (*Vitellaria paradoxa*) and E (*Hymenocardia*) were separately measured and placed in the combustion chamber of the experimental stove (shown in Plate 1) ignited using matches.

Plate 1. The experimental stove.

The infrared thermometer was positioned at the blue zone of the flame of each combusting fuel wood samples by holding the meter by it handle grip and pointing towards its. The trigger was pulled and held in order to turn the meter and begin the testing. The scan display was displayed on the left hand corner of the LCD while measuring, thus displaying the measured result in degree Celsius after releasing the trigger. The test procedures were replicated after 2 minutes for a period of 12 minute and the final result for each fuel wood was the mean of the replicated attempt.

Proximate Analysis and Ultimate

The samples were collected with due care in order to obtain the most representative samples. The samples were reduced to powder form using hammer mill and sieved to obtain up to 250 mm grain size according to ASTM D2013-86 standard method.

Moisture content

One gram of the sieved sample A (*Copaiba oliveri)* was introduced into pre weighed platinum crucibles and passed to the drying oven at 105 ^oC for a period of one hour, the weight was recorded after cooling in the dessicator. The moisture content was calculated using equation (1) according to [5].

$$MC = \left(\frac{P_i - P_s}{P_i} \ x \ 100\right) \tag{1}$$

Where,
MC is the moisture content
P_i, the initial weight,
P_s, the weight of the charcoal after subjecting to 105^oC

This procedure was repeated for samples B (*Prosopis Africana*), C (*Quassia undulata*), D (*Vitellaria paradoxa*) and E (*Hymenocardia*) to obtained the moisture contents.

Volatile Matter

One gram of the sieved sample A (*Copaiba oliveri*) was introduced into pre weighed platinum crucibles, covered with lid and placed into the furnace at 950 ^oC according to ASTM D 2013 and maintained at that temperature for about seven minutes. The weight was recorded after cooling in the dessicator and the volatile matter was calculated using equation (2) [6]

$$VM = \left(\frac{P_S - P_V}{P_S}\right) x \ 100 \tag{2}$$

Where,
VM is the volatile matter, P_S, the weight of charcoal after subjecting to 105 ^oC,
P_V, the weight of the charcoal after subjecting to 950 ^oC

The same procedure was repeated for samples B (*Prosopis Africana*), C (*Quassia undulata*), D (*Vitellaria paradoxa*) and E (*Hymenocardia*) to obtain the volatile matter.

Ash Content

One gram of the sieved sample A (*Copaiba oliveri)* was introduced into pre weighed Platinum Crucibles, placed into the furnace at 950 ^oC and was allowed to burn completely to a constant weight. The lost in weight was recorded and the volatile matter was calculated using equation (3) [6]

$$A = \left(\frac{P_a}{P_v}\right) \times 100 \tag{3}$$

A is the ash content
P_a, the weight of the ashes
P_V, the weight of the charcoal after subjecting to 950 ^oC

Fixed Carbon

Percentage of fixed carbon (FC) was determined by the difference between 100 % and the sum of the percentages of moisture content, ash content and volatile matter, using equation (4) [7].

$$FC = 100 - (MC + VM + A) \tag{4}$$

Where,
FC is the fixed carbon
MC is the volatile matter,
A is the ash content

Ultimate Analysis

A correlation for calculating elemental composition from proximate analysis of the test samples was used to generate ultimate analysis result using relations in equations 5-7 [7].

$$C = 0.637FC + 0.455VM \tag{5}$$
$$H = 0.052FC + 0.062VM \tag{6}$$
$$O = 0.304FC + 0.476VM \tag{7}$$

Where;
C is carbon;
H is hydrogen; and
O is oxygen.

Density/ Specific Gravity

The volume displacement method was adopted since the shapes of the slices of the samples were irregular. Length of 3 cm was obtained from each of the five samples and was attached to a needle on a thread with blue tack added to the thread just above the specimens to help small piece of wood to hang straight. A beaker with water was placed on an electronic balance and the balance set to 0, and the thread was then use to immerse the wood segment into water. The mass of water displaced (the mass determined while the wood is

immersed in the water while on the balance) is measured (M_2). The mass of water displaced by the wood segment (M_2-M_1) was equivalent to the fresh volume of the wood segment, assuming that the density of water was 1000 kg/m^3. And the density and specific gravity were calculated using the relationships equations (8-9):

$$density = \frac{Weight\ of\ wood\ sample}{Volume\ of\ wood\ sample} \qquad (8)$$

$$specific\ gravity\ (Sg) = \frac{Density\ of\ wood\ sample}{Density\ of\ water} \qquad (9)$$

Thermal Conductivity

The average thermal conductivity of the five species of the wood understudy were determined by using the relationship in equation 10 [8];

$$k = S_g(0.1941 + 0.406M) + 0.01864 \qquad (10)$$

(Wm^{-1}K^{-1})

Where S_g is the specific density based on volume at the current moisture content and weight when oven dry; M is moisture content, dry basis.

Particle Size

The ASTM E828-81 standard for sieve analysis was employed to determine the particle size. The wood samples were grounded into powder using a hammer mill, and the products were graded using a set of BS 410 standard sieves, and the fractions retained based on the sizes were determined for the five different species of the wood.

Porosity

The five samples from the species of wood chosen were cut to the same size and their initial weights determined separately. They were wholly immersed in water for period of 24 hr. Then the samples brought out and their weights measured using digital balance to determine the mass of water absorbed into the specimens. The porosity which is based on the amount of water absorbed was calculated from the equation,

$$Porosity = \frac{final\ mass\ of\ water\ absorbed - initial\ mass\ of\ water\ absorbed}{initial\ mass\ of\ water\ absorbed} \times 100$$

3.0 RESULTS AND DISCUSSION

Higher Heating Values

The higher heating values (HHVs) of the five wood samples as presented in Figure 1 varied from 2282.117 – 4461.9326 Kcal/kg (9.55 – 18.682 MJ/kg). The HHVs of the five wood samples were 3925.6208 Kcal/kg (16.437 MJ/kg) for sample A (*Copaiba oliveri*), 4461.9326 Kcal/kg (18.682 MJ/kg) for sample B (*Prosopis Africana*), 2282.1400 kcal/kg (9.555 MJ/kg) for sample C (*Quassia undulata*), 4400.1173 Kcal/kg (18.423 MJ/kg) for sample D (*Vitellaria paradoxa*) and 3974.1641 Kcal/kg (16.640 MJ/kg) for sample E (*Hymenocardia*). Sample B (*Prosopis Africana*) was observed to have highest HHV of 4461.9326 Kcal/kg (18.682 MJ/kg) followed by samples D with 4400.1173 Kcal/kg (18.423 MJ/kg), E with 3974.1641 Kcal/kg (16.640 MJ/kg), A with 3925.6208 Kcal/kg (16.437 MJ/kg) and C with 2282.1400 kcal/kg (9.555 MJ/kg).

The HHVs obtained from samples B and D (18.682 MJ/kg and 18.423 MJ/kg) were better than the values of 18.60 MJ/Kg, 18.56 MJ/kg, 18.24 MJ/kg, and 18.22 MJ/kg for Gmelina, Iroko, Danta mahogany and White afara reported by [9]. Also, the value were higher than the limit (≥18.0 MJ/kg) by Australia national standards and fell within the limit (17.5 – 19.5 MJ/kg) set by German national standard for biomass fuel as reported by [5]. However, the values of 16.437 MJ/kg and 16.640 MJ/kg foe samples A and E were lower than the values reported by [9], but close to the

values of corncob (17 MJ/kg) and tobacco stems (17.8 MJ/kg) reported [10]. The HHV of sample C (9.55 MJ/kg) was found to be lower than some values of well-known biomass fuels such as *celtis mildbreadii* (20.16 MJ/kg), *Ceiba pentandra* (20.33 MJ/kg) reported [5]. The lower HHV could be attributed to the higher ash content 48.24 % exhibited by sample C, as high ash content has negative effect on the fuel characteristics as reported by [10]. This could also be attributed to the fact that variability of different woods heating values is associated with the variations in the characteristics of their extractives as reported by [11].
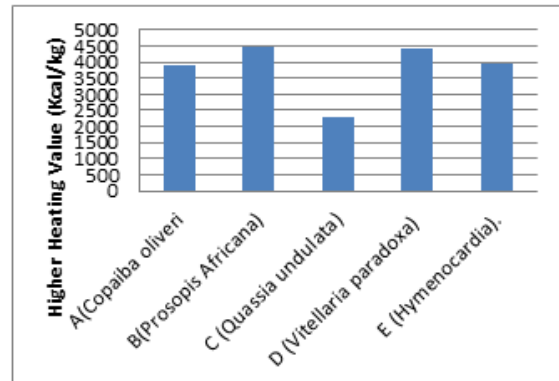

Figure 1. Higher heating values of the wood samples.

Flame Temperature

The flame temperature for the five samples as shown on Figure 2 varied from 531 ^{o}C (C *Quassia undulata*) – 700 ^{o}C (B *Prosopis Africana*). It was observed that sample B (*Prosopis Africana)* generated the highest flame temperature 700 ^{o}C. The values of flame temperature obtained from all the samples were higher than the values of 106 108.7 and 112 ^{o}C reported by [12]. The variation in combustion temperature could be influenced by the size of the wood pieces, its geometry, voilage and moisture content as reported by [12]. It was also observed that the calorific value increased with flame temperature.
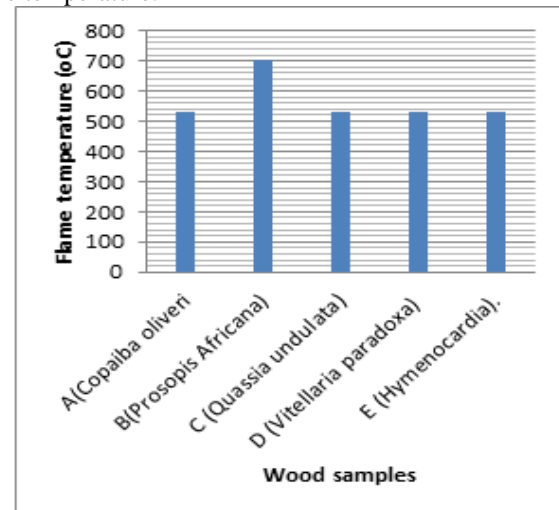

Figure 2. Flame temperature of the wood samples.

Proximate Analysis

Ash Content

The ash content (shown in Figure 3) for the five samples (A – E) varied from 6.79 % (B, *Prosopis Africana*) to 48.24 % (C, *Quassia undulata*). It was found that sample B (*Prosopis Africana*) gave the least ash content (6.79 %) with other samples D (*Vitellaria paradoxa*), E (*Hymenocardia*), A (*Copaiba oliveri*), and C (*Quassia undulata*) having 7.77, 13.43, 14.79 and C 48.24 % respectively. The values of ash contents obtained by samples were not similar to those

presented by [13] who found that the ash content does not exceed 2 %. It also reported that the ash content for wood normally ranges from 0.1 to 0.5 % in a tree which did not agree with the values obtained by the samples [11]. However, the ash content of 6.79 % (B, *Prosopis Africana*), and 7.77 % (D, *Vitellaria paradoxa*) were better than the values of 8 % (Sukakari), and 11 % (Khalas) reported by [10].

According to [14], biofuel with low ash content are desirable, because it accumulates dirties in heat exchangers and obstruct the flow of flue gases, with the risk of causing problems in reactor (or stove).

Fixed Carbon

The fixed carbon (shown in Figure 3) for the five samples studied varied from 9.45 % (C, *Quassia undulata*) to 21.30 % (B, *Prosopis Africana*). Samples B (*Prosopis Africana*), and D (*Vitellaria paradoxa*) with amount of 21.30 % and 20.81 % fixed respectively were the highest values obtained.
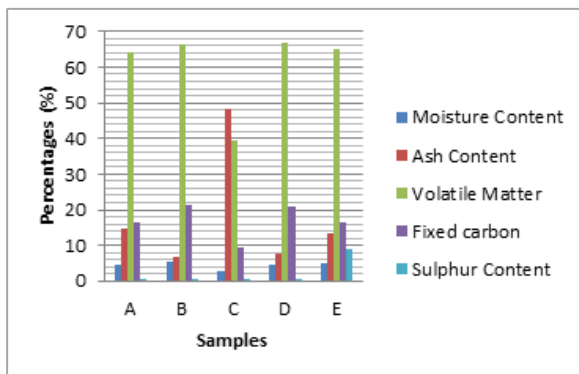

Figure 3. Proximate analysis results of the wood samples.

Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning (Mitchual *et al*, 2014). Thus, the higher the carbon content of a biomass fuel the more that the sample would have higher heating value as observed in samples A and B. It was also noted that a low fixed carbon content increases friability and fragility, thereby reducing the resistance to compression and cohesion [15].

Volatile Matter

According to]10[, volatile matter refers to the part of a biomass material that is released as volatile gases when it is heated up to 400 to 500 ^{o}C and that biomass generally has high volatile matter content of around 70 to 80 % with low char content.

The volatile matter (shown in Figure 3) for the five samples investigated varied from 64.23 % (C, *Quassia undulata*) to 66.64 % (D, *Vitellaria paradoxa*). The values of 66.25 and 66.64 % (B *Prosopis Africana*), and D *Vitellaria paradoxa*) were closed to the values of 70 to 80 % reported by [5] and higher than the values of 20 to 30 % established by Williamson (2006). It was indicated that wood species with less volatile material burn slower than those with more volatile material which clearly shows that samples B (*Prosopis Africana*), and D (*Vitellaria paradoxa)* with 66.25 and 66.64 % respectively would burn faster compared to other samples [14].

Moisture Content

The moisture content presented in Figure 9 and Appendix 1 for the five samples (A – E) varied from 3.01 % (C, *Quassia undulata*) to 5.63 % (B, *Prosopis Africana*). It was found that sample B (*Prosopis Africana*) gave the highest moisture content (5.63 %) with other samples D (*Vitellaria paradoxa*), E (*Hymenocardia*), A (*Copaiba*

oliveri), and C (*Quassia undulata*) having 4.74, 4.97 and C 3.01 % respectively. The values of moisture contents obtained by all the samples were lower than the values presented [16] who stated that dried wood for fuel typically has a moisture content of 5 – 20 %. The values of the moisture content for the five wood samples were also better than the values 25 – 30 % presented by [10]. He further explained that the moisture content of wood varies among different wood species. Under conditions of low moisture content, a product is obtained that is more resistant biodegradation, being hardly alterable to normal atmospheric conditions and less susceptible to attack by biological agents

Sulphur Content

The sulphur content (shown in Figure 3) for the five samples investigated varied from 0.029 % (C, *Quassia undulata*) to 0.06 % (E, *Hymenocardia*). The sulphur contents (0.029 and 0.06 %) were lower than values of 0.019 (*T. scleroxylon*) – 0.214 % (*A.robusta*) and lower than the limits (Sulphur content ≤ 0.08 %) set by Australia and German national standards for biomass fuel as reported by [5]. He further explained that sulphur emissions from combustion of fuels in form of SOx cause extensive damage to ecosystems/buildings and this compound can also cause acidification of soils and water closed to the values of 70 to 80 % reported by [5] and higher than the values of 20 to 30 % established by [17].

Ultimate Analysis
Hydrogen

Figure 4 presents the hydrogen content of the five wood samples investigated. It was observed that the hydrogen content ranged from 3.1128 % (C, *Quassia undulata*) to 5.5642 % (B *Prosopis Africana*). With the exception of sample C, (*Quassia undulata*) (3.1128 %), the hydrogen content of the other samples investigated fall between the range of 5 to 6% reported by [18], which he further explained that Hydrogen was the third constituent of biomass, comprising typically 5 to 6 % dry matter. The values of hydrogen contents for the samples studied (exception of sample C) were higher than the values of 3.88 to 4.21 % established by [5]. Higher hydrogen content leads to higher heating value with sample B (*Prosopis Africana*) possessing HHV of 18.682 MJ/kg with 5.5642 % hydrogen content being the highest values obtained.

Oxygen

Figure 4 presents the oxygen content of the five wood samples Studied. It was shown that the oxygen content ranged from 22.9981 % (C, *Quassia undulata*) to 40.6901 % (B *Prosopis Africana*) and samples B and D (*Vitellaria paradoxa*) gave the highest values of 40.690 and 40.3031 % respectively. These values fall between the range of 40 to 44% reported by [16]
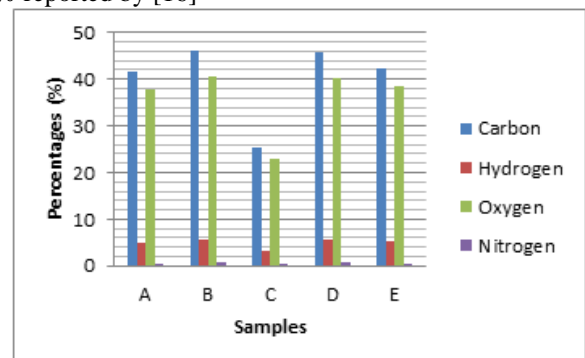

Figure 4. Ultimate analysis results of the wood samples.

It was stated that the effect of oxygen is to reduce the calorific value of the wood to about one half that of conventional fossil fuel. During combustion this oxygen is incorporated into the water and carbon dioxide in the combustion product gases [19]. However, the result obtained contradicts the statement as the oxygen content tends to increase HHVs of the samples investigated. The contradiction perhaps could be due to the species involved.

Nitrogen

The nitrogen content as presented in Figure 4 for the five wood samples studied ranged from 0.3630 % (C, *Quassia undulata*) to 0.65221 % (B *Prosopis Africana*). Samples A (*Copaiba oliveri*), D (*Vitellaria paradoxa*), and E (*Hymenocardia*) gave nitrogen content values of 0.51961, 0.6453 and 0.6056 % respectively. With the exception of samples C, (*Quassia undulata*) (3.1128 %) and A (*Copaiba oliveri*) (0.5961 %) the nitrogen content of the samples studied were higher than the limit of ≤ 0.6 % set by Australia national standard as reported by [5]. However, the nitrogen content values of all the samples investigated were higher than the limit of ≤ 0.3 % set by German national standard.

Correlation of Higher Heating Value with Ash, Fixed Carbon and Oxygen Contents.

The correlation of Higher Heating Values (HHVs) with ash content (A) as presented in Figure 5 showed that, the HHVs of the wood samples decreased with increase in ash content. This confirmed earlier findings by [18] who stated that wood with less than 1 % ash typically has heating value of 20 MJ/kg and increase in each 1 % ash translates roughly into a decrease of 0.2 MJ/kg. This he explained further that ash does not contribute substantially to the overall heat released by combustion, although elements in the ash may be catalytic to the thermal decomposition. Highly negative correlation was found between the HHV and ash content which gave the R^2 as 0.9944. This value of R^2 was better than the value of $R^2 = 0.79$ presented by [10]. The simple regression equation relating HHV to ash content is given as HHV = 4748.1 – 51.599A (R^2 =0.9944).
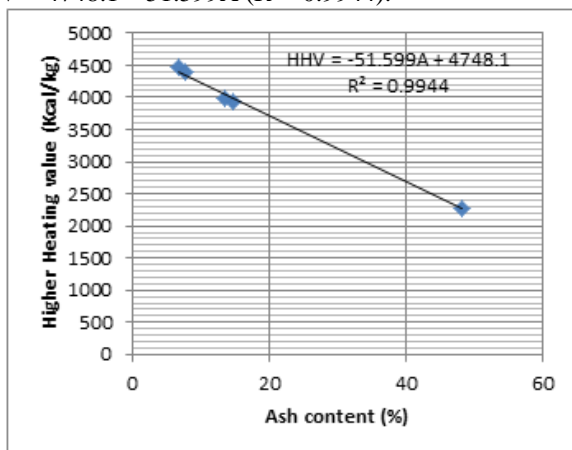

Figure 5. Variation of higher heating values with ash content.

Figure 6 presents the relationship between the HHVs and fixed carbon contents for five wood samples investigated showed that HHV increased with increasing fixed carbon content. Thus, confirming the findings reported by [11] which stated that carbon is one of the main heat producing elements and therefore biomass with high fixed carbon tends to have higher HHV. It was also reported correlation between the carbon and HHV, arriving in that every increase of 1 % carbon raises the HHV of approximately 0.39 MJ/kg.

[18].The results indicate a high positive correlation of the HHV to fixed carbon content ($R^2 = 0.9571$). The simple regression analysis which showed that the trend of the data for all the sample studied was best described by

HHV = 661.44 + 187.34FC ($R^2 = 0.9571$)

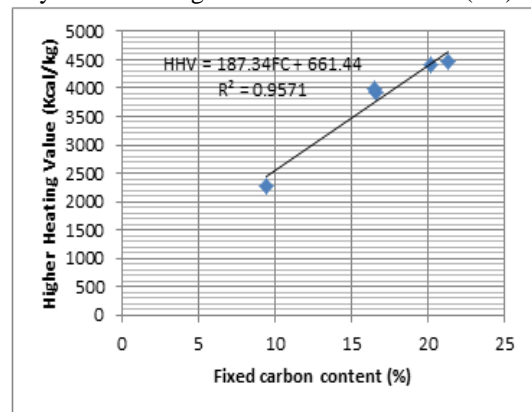This relationship means that about 95.71 % of the total variability in the heating value was fixed carbon (FC)

Figure 6. Variation of higher heating values with fixed carbon content.

The correlation between HHV and oxygen content (OC) as presented in Figure 7 clearly indicated that HHV increased with rising oxygen content thus contradicting the earlier findings by[16] that the effect of oxygen is to reduce the calorific value of the wood to about one half that of conventional fossil fuel. During combustion this oxygen is incorporated into the water and carbon dioxide in the combustion product gases. The result indicated a high correlation of the HHV to oxygen content ($R^2 = 0.9887$) with simple regression analysis which showed that the trend of the data for all the sample studied was best described by

HHV = -494.27 + 119.5OC ($R^2 = 0.9887$)

It was stated that char oxidation is the dominating reaction in a combustion environment. Since this is a surface reaction, the reaction rate depends on kinetics and diffusion of oxygen to the char surface [16]. This is perhaps the reason for the discrepancy in the observation.
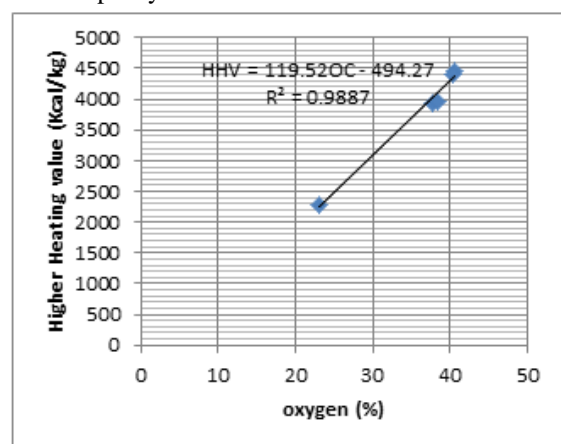

Figure 7. Variation of higher heating values with oxygen content.

Density/Specific Gravity:

The density of the wood samples investigated as presented in Figure 8 ranged varied from 214 kg/m^3 (C, *Quassia undulata*) to 256 kg/m^3 (B, *Prosopis Africana*). This result suggested that sample B (*Prosopis Africana*) was more likely to have a higher energy per unit volume than the other samples studied, as many wood species with low densities

can present low heating values when turned into coal or used for direct heating.

Denser wood are preferable for fuel because of their high energy content per unit volume and slow burning rates [17, 21]. This was affirmed by [9] that low density biomasses usually have low energy density and cooking with such biomass in a stove requires frequent fending to the fire. That is re-feeding the stove with the stove with such biomass especially for cooking that requires a long simmering phase because of its relatively low mass to volume ratio, as this may also pose unnecessary inconveniences to the users.
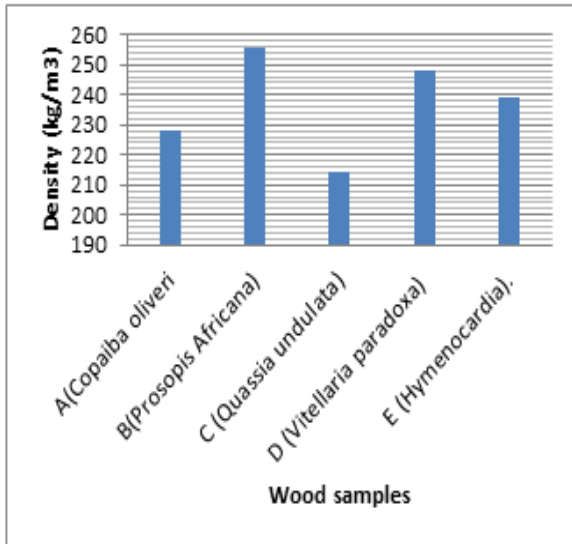

Figure 8. Density of the wood samples.

Thermal Conductivity

The thermal conductivity of the wood samples investigated as shown in Figure 9 ranged from 0.063 W/m/K (C, *Quassia undulata*) to 0.074 W/m/K (B, African *Prosopis).* Thermal conductivity for other samples A (*Copaiba oliveri*), D (*Vitellaria paradoxa*), and E (*Hymenocardia*), were 0.067, 0.072, and 0.70 W/m/K respectively. It was stated that thermal conductivity of wood increased with density, moisture and temperature and it increases with temperature at the rate of approximately 0.2 % per ^{o}C above room temperature [16]
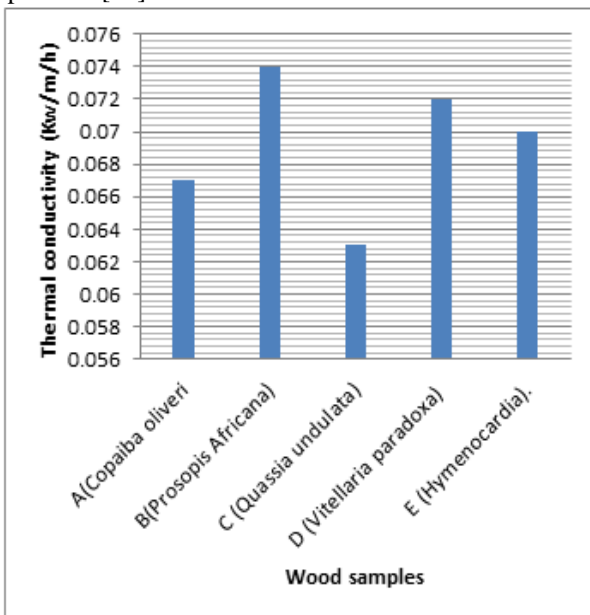

Figure 9. Thermal conductivity of the wood samples
Particle Size

The particle size of the wood samples studied as presented in Figure 9 varied from 212 μm (B, African *Prosopis)* and to 425 μm (C, *Quassia undulata*). Particle size for other samples A (*Copaiba oliveri*), D (*Vitellaria paradoxa*), and E (*Hymenocardia*), were 300, 250, and 300 μm respectively. Sample B gave the lowest particle size suggesting as it provided the highest HHV and this agreed with the findings of [17, 19]. The authors stated that particle size of wood fuels ranges from whole trees to sander dust and includes processed and pelletized fuels and that particle size dominates the influence of heat transfer, with small, thin (thermally thin) particles heating rapidly and coaser, thick (thermally thick) particles heating more slowly.

Porosity

Figure 10 presented the Porosity of wood samples defined by [21] as the fractional void volume of wood. It was observed that the porosity 38.33 % (B, *Prosopis Africana*) to 79.80 % C (*Quassia undulata*). For the other samples D (*Vitellaria paradoxa*), E (*Hymenocardia*), A (*Copaiba oliveri*), the porosities were 43.38, 32.99 and 59.35 % respectively. Porosity values of all the samples with exception of sample C were lower than the values of 67.2 – 68.9 % reported by [21]. It was also reported that the difference in porosity may arise simply from differences in the anatomy of the wood modified by the effect of extractives, and they may also derive from anatomical differences, such as in cell types and quantitative distribution, thickness of cell walls and size of cell cavities through the wood [21]. The author went further to explain that the cell wall substance adsorbs and desorbs moisture to and from the environment due to hygroscopic nature of wood. That one consequence of this is to shrinks and swells the cell wall, and that the relative proportions of cell wall substances and pore space thus varied greatly.
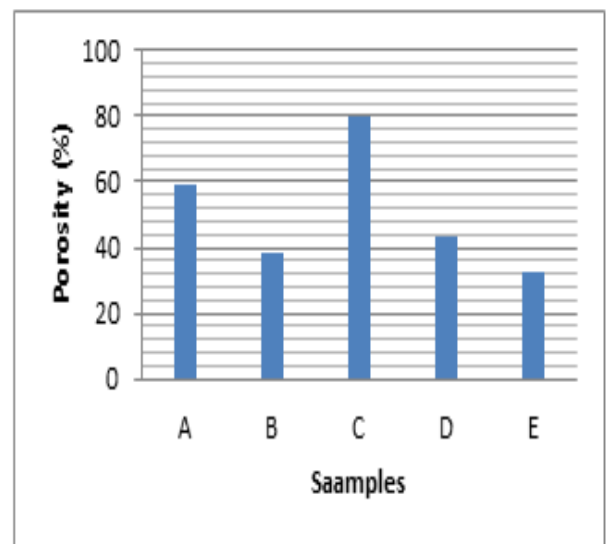

Figure 10. Porosity of the wood samples.

Ranking of the Properties of the Five Wood Samples Investigated

The method employed by [10, 11] was adopted for the rating of fuel properties of the five wood samples studied. As presented in Table 2 each property was assigned a value between 1 and 6, with sample 1 being the best and 2 being the worst. The overall rating was the mean rating of all the properties measured for each sample as reported by [5]. It was observed that sample B (*African Prosopis)* has the best fuel properties of 1.68 and the worst was C *(Quassia undulata*) with fuel rating properties of 3.68.

Table 2. **Ranking of fuel properties of the five wood samples.**

Property	A (*Copaiba oliveri*)	B (*Prosopis African a*)	C (*Quassia undulata*)	D (*Vitellaria paradoxa*)	E (*Hymeno cardia*)
Higher Heating value	4	1	5	2	3
Flame temperature	4	1	5	2	3
Ash content	4	1	5	2	3
Moisture content	2	5	1	3	4
Fixed carbon	3	1	5	2	4
Volatile matter	4	2	5	1	3
Sulphur content	4	2	1	3	5
Carbon	4	1	5	2	3
Hydrogen	4	1	5	2	3
Oxygen	4	1	5	2	3
Nitrogen	2	5	1	4	3
Density	4	1	5	2	3
Porosity	4	1	5	2	3
Thermal conductivity	4	1	5	2	3
Consumption rate	4	1	5	2	3
Rating value (Average)	**3.42**	**1.68**	**3.68**	**2.00**	**2.95**

4.0 CONCLUSION

The investigation of combustion properties of some selected indigenous fuel wood samples was carried out ant it reveals that sample B (**African Prosopis**) has the best overall fuel rating of 1.68 and sample C (**Quassia undulate)** with the worse rating of 3.68. Sample B (**African Prosopis**) can therefore be used as a fuel wood source for cooking and other heating applications.

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