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Proximate Analysis and Performance Evaluation of Selected Blends of Biomass Briquettes

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Abstract

This study carried out the proximate and combustion tests of agricultural biomass made of coal/sawdust and rice husk/maize cob as cooking fuel alternatives. These two sets of briquettes were produced by blending various compositions of coal/sawdust and rice husk/maize cob using cold water starch as binder and calcium hydroxide as desulphurising agent. Proximate tests involving moisture content, ash content, calorific value, volatile matter and fixed carbon content of all samples of briquettes were determined. Performance evaluation of the briquettes as it concerns ignition time, burning time, burning rate and boiling time were done. The results of the proximate tests and briquettes characteristics when compared with others have overall relative improvement. For instance, $S_{60}C_{40}$ recorded 6.98% ash content, calorific value of 15620.80 kJ/kg, fixed carbon content of 15.68%, volatile matter of 54.28%. Also it took the briquettes 55.80sec to ignite and 28.28minutes to burn to ashes, and 19.32minutes to boil three liters of water. This exhibited an optimal combustion quality when compared with other composition of the briquettes produced.

Keywords: Proximate test, briquette blend, rice husk, maize cob, cooking fuel, coal, sawdust

1.1 Introduction

Biomass, particularly agricultural residues seems to be one of the most, promising energy resources of developing countries (Patomsok, 2008). Rural households and minority of urban dwellers depend solely on fuel woods (charcoal, firewood and sawdust) as their primary source of energy for the past decades. Among the available energy resource in Nigeria, coal and coal derivatives such as smokeless briquettes, bio-coal briquette and biomass briquettes have been shown to have the highest potential for the use as suitable alternative to coal/fuel wood in industrial boilers and brick kiln for thermal application and domestic purposes. Global warming has become a worldwide concern. Global warming is caused by greenhouse gasses which carbon dioxide is one of the sole contributors.

The use of fuel wood for cooking has health implications especially on women and children who are always exposed to the smoke apart from the environmental effects. Women in rural areas, frequently with young children spend one to six hours every day when cooking with fuel wood. In some areas, the exposure is even higher especially when the cooking is done in an unventilated place or where fuel wood is used for heating of rooms.

Generally, biomass smoke contains a large number of pollutants which at varying concentration pose substantial risk to human health. Exposure to biomass smoke increases the risk of range of common diseases both in children and in adult. The smoke causes acute lower respiratory infection (ALRI) particularly pneumonia in children (Smith and Samet, 2000; Ezzati and Kammen, 2001). A large number of Agricultural wastes such as maize, sorghum, millet stalks, and groundnut shell, maize husks are generated in rural areas both at the farm and from household activities. Most of these wastes are mainly deposited on farms or burnt with all Ecological problems associated with their disposal method, (Jekanyinfa and Omisakin 2005; Oladeji 2011). If one or more efficient method of using the abundant Agricultural and wood residues could be developed on a large scale, the energy situation could be sustainable and deforestation problem could be controlled. (Tembe et al, 2014)

Agro waste is the promising energy resource for developing countries like ours. These wastes have acquired considerably importance as fuels for many purposes, for instance domestic cooking and industrial heating. Some of these agricultural wastes like sawdust, rice husk, and coconut shell can be utilized directly as fuels. The use of biomass fuel such as composite sawdust briquette has been proposed as an alternative to their non- renewable counterparts such as kerosene, LPG etc, which are not keeping up to peoples' demand. Also the costs of non- renewable energy sources have made people to start deviating to the use of renewable sources for domestic cooking. Energy availability in both urban and rural dwellings has become a huge challenge with high cost of cooking gas and kerosene and environmental problems that are attached to firewood (Oladeji, 2011). Production of fossil will experience a depreciate in the next 20 to 30 years as it is the major concern of the entire world (Adegoke and Mohammed 2002) in Olawole et al (2008).

Fortunately, researchers have shown that a cleaner and affordable fuel source which is a substitute to fuel wood can be produced by briquetting sawdust, rice husk, maize cob, coal and other agricultural biomass as an alternative energy source for rural dwellers. It has been proposed that the conversion of sawdust wastes through briquetting process will go a long way reducing waste disposal problems in majority of wood processing industries. Furthermore deforestation which promotes pollution will be drastically reduced, if the use of sawdust wastes is enhanced (Olawale,2009). The production of briquettes from sawdust exemplifies the potential of appropriate technology for wood was utilization (Emerhi, 2011). Large numbers of abandoned coal deposit in Nigeria especially in Enugu can be transformed and be useful when blended with sawdust. Rice husk and maize cob have been found to cause an environmental menace especially in Abakaliki and these agro wastes can be blended and used as a cooking fuel. Coal has high calorific value, high moisture content, high ash content and low volatile matter but sawdust when blended with coal enhances the characteristics of coal due to its high volatile matter and low ash content. This tends to be an alternative for cooking fuel especially for rural dwellers.

Traditionally, wood in form of fuel such as twigs and charcoal have been the major source of renewable energy in Nigeria, accounting for 51% of the total energy consumption. The other sources of energy include natural gas (5.2%), hydroelectricity (3.1%) and petroleum products (41.3%) (Akinbami, 2001). The demand for fuel wood is expected to have risen to about 213.4 x 10^3 metric tons by the year 2030 (Adegbulugbe, 1994). The decreasing availability of fuel wood, coupled with the ever rising prices of kerosene and cooking gas in Nigeria, draw attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country. Such energy sources should be renewable and should be accessible to the poor. As rightly noted by Stout and Best (2001), a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria.

An energy source that meets sustainability requirements is fuel briquette. It is produced at low cost and made conveniently assessable to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both. Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use, and relatively smaller space requirement for storage (Singh and Singh, 1982; Wamukonya and Jenkins, 1995; Yaman et al., 2000; Olorunnisola, 2004). Briquetting can be done with or without binder. Doing it without the binder is more convenient but it requires sophisticated and costly presses and drying equipment which makes such processes unsuitable in a developing country like Nigeria. As observed by Wamukonya and Jenkins (1995), for briquetting industry to be successful in the less industrialized countries, the equipment should consist of locally designed simple, low-cost machines.

In Nigeria, large quantities of agricultural and forestry residues produced annually are vastly underutilized. The common practice is to burn these residues or leave them to decompose (Olorunnisola 1998, Jekayinfa and Omisakin 2005). However, previous studies have shown that these residues could be processed into upgraded liquid fuel products such as briquettes. A number of such locally available materials briquetted for fuel energy production include sawdust, cowpea chaff, corn cobs, and water hyacinth. Idah et al (2013) carried out a research on comparative assessment of energy values of briquettes from some Agricultural by- products with different binders, Emerhi (2011) conducted a research on physical and combustion properties of briquettes produced from saw dusts of three woods species and different organic binders and only a few to be mentioned. Other studies have shown that, briquettes were produced with the aid of binders such as cassava starch and palm oil sludge, which tend to produce smoky briquettes.

Waste paper could also be mixed with other biomass materials to produce relatively cheap and durable binder-less briquettes. Attempts have also been made in the past to create fuel from newspaper by rolling them up into ‘log’. However, it was found that the product did not burn well. Coconut husk, on the other hand, has a relatively high calorific value (between 18.1 and 20.8 MJ/kg) coupled with relatively low ash content [3.5-6%] (Jekayinfa and Omisakin, 2005). The utilization of sawdust by converting it into heat is economically justified. The calorific value of sawdust briquettes is comparable to that of lower quality class coal. The idea of producing briquettes from fine timber wastes dates back to the turn of 19th and 20^{th} centuries. The increasing demand for alternative energy sources makes the production of binder less briquettes essential. Virtually little or no work has been done and carried out on proximate and performance analysis of briquettes blended with different ratios of coal/sawdust and rice husk/maize cob. In addition some similar researches conducted and published like Tembe at el (2014) focused on the 50:50 ratio eg Rice husk/groundnut 50:50, Groundnut shell/ Oliveri 50:50 and Rice husk\Oliveri 50:50.

As it concerns biomass combustion, there is lack of literature that refers specifically to the combustion of briquetted residues, (Chaney, 2010). Hence, it becomes necessary to review general combustion literature concerning domestic wood stoves, focusing on studies relevant to comprehending the combustion of large particles of densified biomass in the form of briquettes. The burning of biomass is a complex process involving both gas phase and solid phase phenomena. In general terms, models assume that during combustion the solid fuel undergoes three stages of mass loss: drying, devolatisation and char combustion. The relative significance of each of these processes in a particular fire, is dependent on the properties of the fuel and the environment in which it is burning. On leaving the solid matrix of the briquette, the volatiles are heated and mix with oxygen and ignite. This exothermic gas phase combustion reaction results in a flame, which feeds heat to the solid surface. As the surface of the briquette becomes hotter in response to the imposed flux of heat from the gas phase reaction, the pyrolysis wave penetrates deeper and deeper into the virgin solid, causing further devolatisation (Kung, 1972). The char layer that is left behind undergoes heterogeneous combustion, reacting with oxygen, releasing heat. This is referred to in the literature as char combustion. Often, the outward flow is sufficient to prevent significant char combustion until almost all of the fuel has been pyrolysised allowing the devolatisation and char combustion processes to be modelled separately (Burnham-Slipper et al, 2007), The char burns by reaction with oxygen, giving the primary products of CO and CO_2, with the ratio of these two components determined by the temperature level Yang et al (2005). Char combustion can therefore be, to a close approximation, described as follows:

$C(s) + \Lambda O_2 \longrightarrow 2(1-\Lambda)CO + (2\Lambda - 1)CO_2$

where Λ is a value between 0 and 1 and is a function of the gas phase temperature (Chaney, 2010).

2.0 Material and methods

2.1 Materials preparation and characterization

Preparation of Raw Materials: The coal was collected from Onyeama mines, Nigeria Coal Co-operation Enugu and was sun dried and grounded with an electric milling machine sieved to ensure 4mm diameter with the use of standard laboratory sieve. The sawdust sample was gotten from Enugu timber shade and was sun dried for one week Rice Husk was collected at Abakaliki Rice mill and maize cob was collected from two different corn selling points at Enugu. The maize cob was sun dried and grinded with an electric milling machine.

Preparation of the Briquettes: The briquettes were prepared in the laboratory of National Center for Energy Research and Development, University of Nigeria Nsukka, Nigeria with the use of manual hydraulic briquetting machine of 6 (six) moulds. At first, coal briquette (100%) was formed, this implies the mixing of 600g of coal (100g for each mould) with 10% of calcium hydroxide $Ca(OH)_2$ as the di-sulphuric agent and 15% of cold starch as binder. Similarly, sawdust briquette was briquetted by mixing 600g of sawdust and 10% starch homogenously. Furthermore, the samples of coal/sawdust and rice husk/maize cob were blended with different ratios using 10% starch as binder and 10% of calcium hydroxide for briquettes containing coal. After the briquettes were formed, the briquettes were sundried for ten days before taking to the laboratory of National Centre for Energy Research and Development, University of Nigeria Nsukka for the necessary testing. Briquette different ratios $S_{100}C_{00}$, $S_{90}C_{10}$, $S_{80}C_{20}$, $S_{70}C_{30}$, $S_{60}C_{40}$ $S_{50}C_{50}$ and $C_{100}S_{00}$ each subscript representing percentage weight of saw dust (S) and coal (C) composition. The 10% calcium hydroxide it is determined by calculating 10% of coal ratio which is 10% of 120g (only for briquettes that has coal content)**.** For starch ratio, the starch ratio used in this research is 15% and it was determined as stated below

Proximate Testing of the Briquettes: The proximate testing was done in all the blended samples sawdust/coal samples and rice husk/maize cob briquettes.

Determination of Moisture Content: Moisture content of the briquette is the amount of water contained in briquette when heated under a given state. The moisture content of the briquette was determined by measuring 0.54g of pulverized briquette into a crucible. Then it was put into an automatic moisture analyzer, the percentage of moisture content was calculated by the use of standard formula as stated in equation 1.

$$\%MC = \left(\frac{g-x}{g} X \frac{100}{1}\right) \qquad (1)$$

Where g = weight of sample, x = weight of dry sample and $g - x$ = loss in weight

Determination of Ash Content: Ash content is the measure of total amount of minerals present in substance. It is seen as the remains of the minerals after an absolute combustion of a briquette. A 0.54g of oven dried pulverize sample was weighed in a crucible and was placed in the muffle furnace for 3-4 hours at 600^0c when cooled; the sample was re-weighed to determine the ash content. The percentage of ash content was calculated using the general formula for percentage of ash content in powdered material as shown in equation 3.2.

$$\%Ash = \left(\frac{x}{g}\ X\ \frac{100}{1}\right) \qquad (2)$$

Where g = weight of sample and x = weight of the ash.

Determination of Calorific Value: The calorific value of a briquette can be seen as the amount of energy per kilogram that it gives off when burnt. It is also the quantity of heat produced by the briquettes during its combustion. This was determined using bomb calorimeter shown in Figure 3.4. Equation 3.3 is the general formula for the calculation of calorific value.

$$W = \frac{\sum \Delta T - \Phi - V}{M} \qquad (3)$$

Where ΔT is change in temperature, M is the mass of sample and Φ is the specific heat capacity.

Volatile Matter: Volatile matter is the vapour and the gases driven off when a briquette is heated at a given condition in the absence of air. A pulverized sample of 1.6g was kept in an Oven for 10minutes at 400. This can be calculated using equation 4.

$$\%VM = \left(\frac{x - y}{g}\ X\ \frac{100}{1}\right) \qquad (4)$$

Where g = weight of sample, x = weight of dry matter and y = weight of residue

Fixed Carbon Content: The fixed carbon content is the summation of the moisture content, volatile matter and ash Content. This can be expressed mathematically is in equation 5.

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

Where MC - Moisture content, VM - Volatile matter and AC - Ash Content

2.2 Performance Evaluation of the Briquettes Samples

Ignition Time: Different samples of the briquette were ignited at the edge with burner in a drought free corner and the time taken for each briquette to catch fire and burn very well without addition of heat from outside was recorded as the ignition time using a stop watch.

Burning Rate: Burning rate is a measure of the combustion rate of a compound or substance. The standard formula for the calculation of burning fuel can be seen at equation 6.

$$\text{Burning Rate} = \frac{\text{mass of fuel consumed (g)}}{\text{total time take (min)}} \qquad (6)$$

Burning Time: Burning time is known as the time taken for each briquette sample to burn completely to ashes. The burning time of this research was determined by burning every ratio of the briquettes until they burned to ashes using stop watch.

Boiling Time: Boiling time is the time taken for a briquette to boil water to 100^0C. This was done by taking different blends of briquettes to boil three liters of water and the time was taken and recorded.

3.0 Results and Discussions

3.1 Produced Briquettes

Samples of some briquettes produced with different blends and ratios of coal/sawdust and rice husk/maize cob are shown in figure 1.

Figure 1: Briquettes produced from coal and saw dust

3.2 Proximate Testing Results of the Samples of Briquettes

Proximate testing has been done as regards the moisture content, ash content, calorific value, volatile matter and fixed carbon content of the samples.

Table 1: Moisture Contents of the Samples of the Briquettes

Mass Ratio (%)	Moisture (%) content	Mass Ratio (%)	Moisture content (%)
$S_{100}C_{00}$	24.07	$R_{100}M_{00}$	12.98
S_{90} C_{10}	20.00	R_{90} M_{10}	14.55
S_{80} C_{20}	18.87	R_{80} M_{20}	16.00
S_{70} C_{30}	17.65	R_{70} M_{30}	17.31
S_{60} C_{40}	15.40	R_{60} M_{40}	18.87
S_{50} C_{50}	14.94	R_{50} M_{50}	20.34
$S_{00}C_{100}$	11.77	$R_{00}M_{100}$	23.11

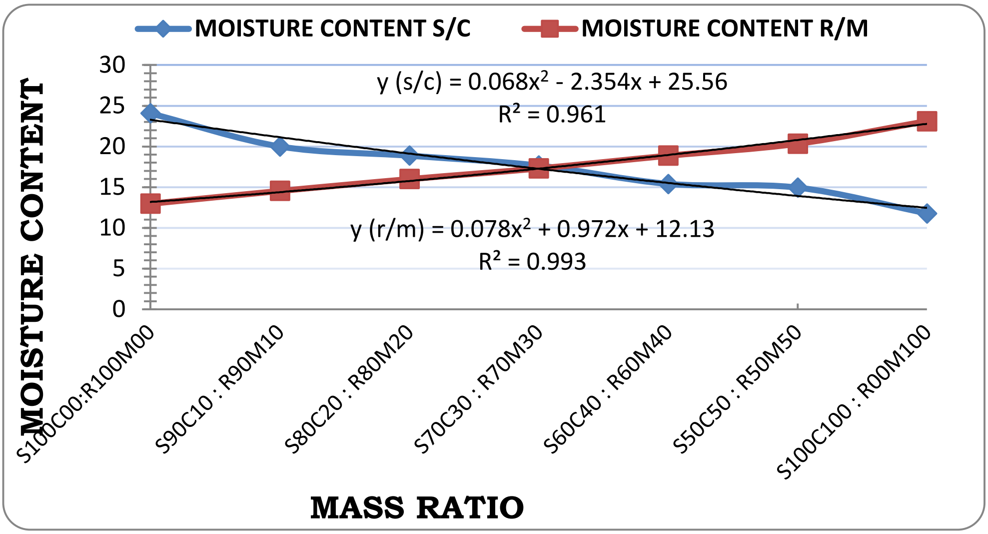

Figure 2: Moisture content against mass ratio of S/C and R/M Briquettes

Moisture Content Results: The moisture content of the samples of briquettes prepared for this study is shown in Table 1. It can be seen that the highest moisture content occur at $S_{100}C_{00}$ and $R_{00}M_{100}$ with 24.07% and 23.11% for the moisture contents, respectively. On the other hand, $S_{00}C_{100}$ as well as $R_{100}M_{00}$ have the lowest moisture contents at 11.77% and 12.98%, respectively. In other words, $S_{00}C_{100}$ as well as $R_{100}M_{00}$ are the most combustible parts of the parts. Also it can be seen that the lower the ratio of sawdust to coal, the lower the moisture content in the briquettes. Similarly, $R_{100}M_{00}$ gave 12.98% and $R_{00}M_{100}$ recorded 23.11% but R_{50} M_{50} gave 20.34% which shows the moisture content of maize is higher than that of rice. This means that as the ratio of rice decreases and maize increases, the moisture content of the briquettes increases. This result is higher than the result produced by Onuegbu et al (2011) in their Comparative Analyses of Densities and calorific value of wood and briquettes samples.

Ash Contents of Briquettes Samples: The ash content of the briquette samples are shown in Table 2 and depicted in 3.

Table 2: Ash Contents of the Samples of the Briquettes

Mass Ratio (%)	**Ash Content (%)**	**Mass Ratio (%)**	**Ash Content (%)**
$S_{100}C_{00}$	2.95	$R_{100}M_{00}$	13.40
S_{90} C_{10}	4.85	R_{90} M_{10}	12.50
S_{80} C_{20}	5.46	R_{80} M_{20}	10.92

S_{70} C_{30}	6.40	R_{70} M_{30}	8.62
S_{60} C_{40}	6.98	R_{60} M_{40}	7.40
S_{50} C_{50}	7.70	R_{50} M_{50}	6.13
$S_{00}C_{100}$	15.65	$R_{00}M_{100}$	4.24

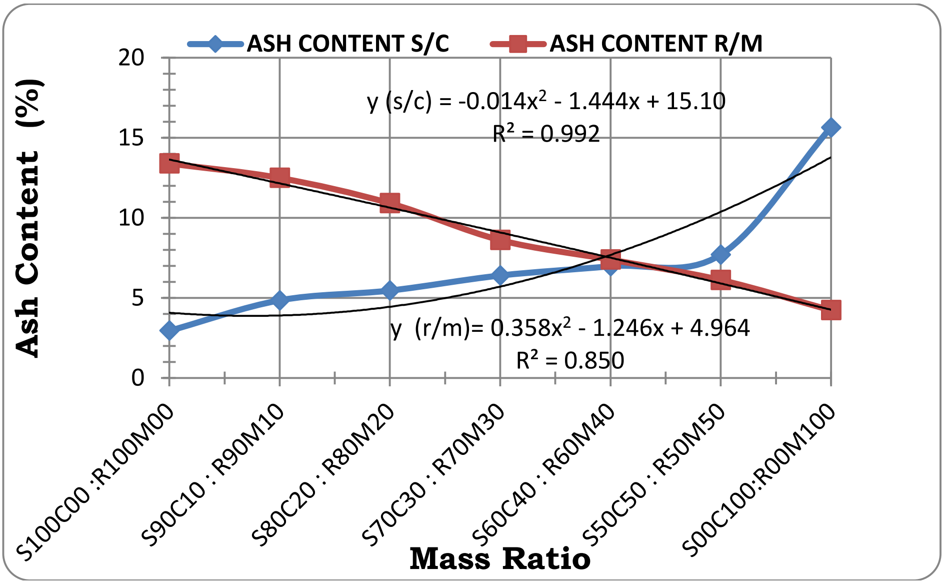

Figure 3: Ash Content against Mass Ratio of S/C and R/M

In Table 2, $S_{00}C_{100}$ recorded the highest ash content (15.65%) while $S_{100}C_{00}$ recorded the lowest (2.95%). It can be seen that coal has high ash content but when blended with sawdust, it reduces the ash content. For instance, as the sawdust ratio increases the ash content decreases such as in S_{70} C_{30} and S_{60} C_{40} having 6.40% and 6.98% ash content, respectively and the trend continues. This proved that sawdust is a good blend of coal because of the low ash content and higher heating value it offers for briquettes. The above trend was supported by Obi et al, 2013 in their study of the appropriate briquetting machine to use for rural areas.

Also for the briquette made from the blend of rice husk and maize cob, $R_{100}M_0$ recorded the highest ash content while R_0M_{100} recorded the lowest. Rice husk has a very high ash content and blending it with maize cob reduces the ash content as seen in R_{50} M_{50} and R_{60} M_{40} having 6.13% and 7.40%, respectively. As the ratio of maize increases and the ratio of rice decreases, the ash content reduces. This corresponds with the result obtained by (Tembe et al 2014) in their research of density, shatter index, and combustion properties of briquettes produced from groundnut shell, rice husk and sawdust.

Volatile Matter of the Briquettes Samples: Table 3 and Figure 4 show the results obtained for the volatile matter of the samples of the briquettes.

Table 3: Volatile Matter of the Samples of the Briquettes

Mass Ratio (%)	VM (%)	Mass Ratio (%)	V/M (%)
$S_{100}C_{00}$	70.21	$R_{100}M_{00}$	68.99
S_{90} C_{10}	65.00	R_{90} M_{10}	67.21
S_{80} C_{20}	61.51	R_{80} M_{20}	66.10
S_{70} C_{30}	58.43	R_{70} M_{30}	65.59
S_{60} C_{40}	54.28	R_{60} M_{40}	64.81
S_{50} C_{50}	46.79	R_{50} M_{50}	63.72
$S_{00}C_{100}$	28.00	$R_{00}M_{100}$	42.54

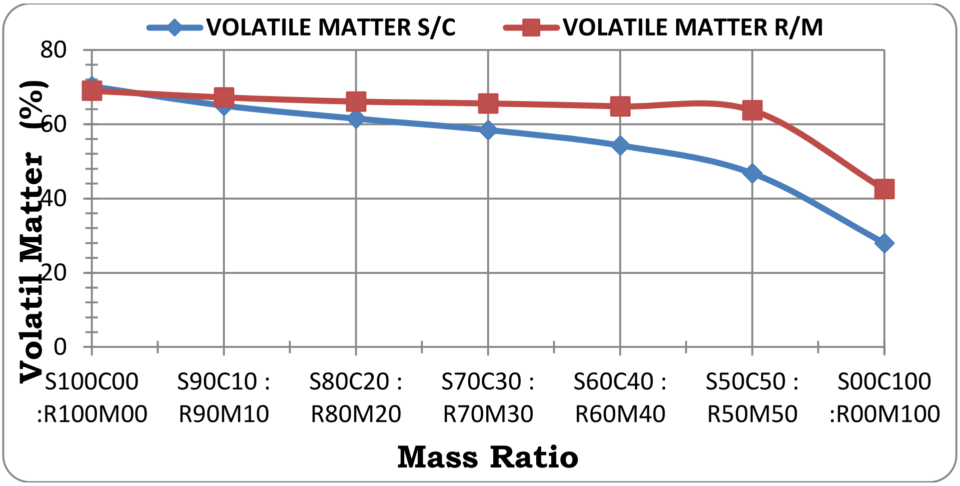

Figure 4: Volatile Matter against Mass Ratio of S/C and R/M

The results show that briquettes produced from sawdust and coal, $S_{100}C_0$ recorded the highest volatile matter of 70.21% while S_0C_{100} produced the lowest volatile matter of 28%. It can be seen from the result that coal has a very low volatile matter, but when blended with sawdust which has a very high volatile matter, produced a briquette with a good volatile matter like S_{80} C_{20} (61.51%) and S_{90} C_{10} (65. 21%). This proves that the higher the sawdust ratio blended with coal, the higher the volatile matter.

Similarly, the briquettes produced from blend of Rice husk and maize cob ($R_{100}M_{00}$) recorded the highest volatile matter of 68.99% which $R_{00}M_{100}$ recorded the lowest (42.54%). The results of Rice husk and maize cob are high compared to that of the coal and sawdust briquettes. The percentage of the volatile matters is higher than the normal value of 20% reported by Ivanon et al (2003). This result corresponds with the result gotten from Tembe et al (2014) in their research of density, shatter index and combustion properties of briquettes (56-68%) and higher than the result gotten by Ogbuagu et al (2013) in their research on production and analysis of heating properties of coal and rice briquettes (10-42%). Besides, the results proved that sawdust is a good blend of coal because the higher the ratio of sawdust, the higher the volatile matter and the higher the ratio of rice to maize cob, the higher the volatile matter of the briquettes.

Calorific Value: Table 4 and Figure 5 show the result of calorific value of the briquettes made from sawdust/coal and briquettes made from rice husk/maize cob.
From the result, the briquettes made from $S_{00}C_{100}$ recorded the highest calorific value of 24522.10kJ/kg and SD_{100} recorded the lowest with 13625.44 kJ/kg. The result shows that coal has a very high calorific value and that as the ratio of coal increases, the heat value of the briquette increases. The blend of $S_{50}C_{50}$ showcased a significant increase of 16226.92 kJ/kg which has a higher heating value than $S_{90}C_{10}$ that recorded (14119.22 kJ/Kg). Also from the briquette made from rice husk and maize cob, we have $R_{100}M_{00}$ as the highest heat value of (16842.92 kJ/Kg) while $R_{00}M_{100}$ recorded 8440.82 kJ/Kg as the lowest value. The result showed that the higher ratio of Rice husk to maize cob, the higher the increase in heat value as the heat value of maize cob is very low. The heat values are lower than 3337.46 kJ/Kg recorded by Obi et al (2013).

Table 4: Calorific Value of the Samples of the Briquettes

Mass Ratio (%)	**CV (kJ/kg) X10^3**	**Mass Ratio (%)**	**CV (kJ/kg) X10^3**
$S_{100}C_{00}$	13.63	$R_{100}M_{00}$	16.84
S_{90} C_{10}	14.12	R_{90} M_{10}	15.40
S_{80} C_{20}	14.66	R_{80} M_{20}	14.26
S_{70} C_{30}	14.98	R_{70} M_{30}	13.71
S_{60} C_{40}	15.62	R_{60} M_{40}	12.66
S_{50} C_{50}	16.23	R_{50} M_{50}	10.68
$S_{00}C_{100}$	24.52	$R_{00}M_{100}$	8.44

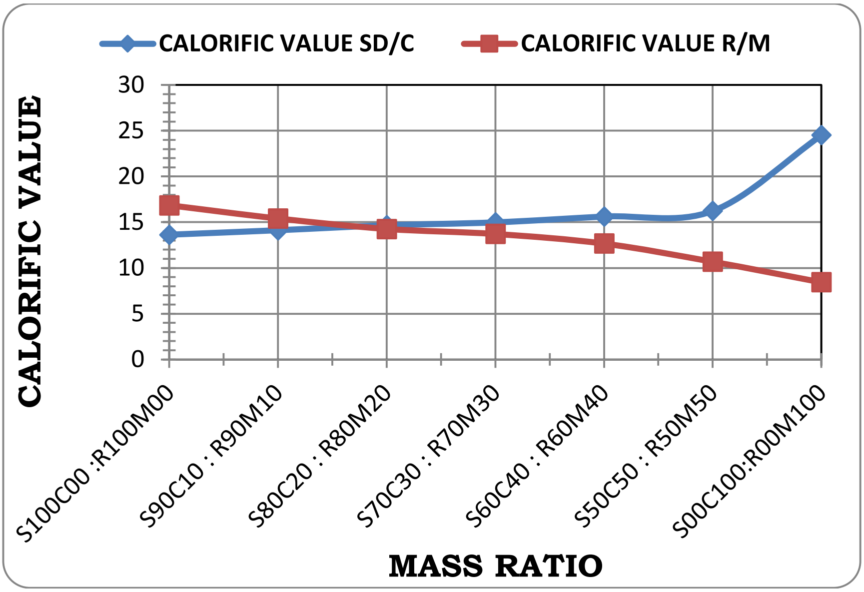

Figure 5: Calorific Value against Mass Ratio of SD/C and R/M

Carbon Content: Table 5 and figure 6 show the results of the carbon Content of the briquettes made from sawdust/coal and rice husk/ maize cob. From the results, the briquettes made from sawdust and coal, $C_{100}S_{00}$recorded the highest Carbon content of 44.58% and $S_{100}C_{100}$ recorded the lowest with 2.77%. The result shows that coal has high carbon content while sawdust has low carbon content. The blend of $S_{90}C_{10}$ and $S_{80}C_{20}$ gave a significant decrease in 10.15% and 14.16% which are lower than the values $S_{70}C_{30}$ and $S_{60}C_{40}$ which carbon content increases. As for the briquettes made of rice husk and maize cob $R_{00}M_{100}$ as the highest carbon content of (30,11%) while $R_{10O}M_{00}$ recorded 4.63% as the lowest carbon content value. The result showed that the higher the ratio Rice husks to Maize cob, the higher the Carbon content. The blend of $R_{70}M_{30}$ and $R_{60}M_{40}$ showcased a significant decrease in 13.77% and 12.77% respectively. As the ratio of maize cob increases, the carbon content of the briquettes decreases. The carbon contents are lower than 32.3% - 57.46% recorded by Ogbuagu et al (2003) in their production of coal and rice husk briquettes.

Table 5: Carbon Contents of the Samples of the Briquettes

Mass Ratio (%)	Carbon content (%)	Mass Ratio (%)	Carbon content (%)
SD_{100}	2.77	R_{100}	4.63
SD_{90} C_{10}	10.15	R_{90} M_{10}	5.74
SD_{80} C_{20}	14.16	R_{80} M_{20}	6.98
SD_{70} C_{30}	17.52	R_{70} M_{30}	8.48
SD_{60} C_{40}	23.34	R_{60} M_{40}	8.92
SD_{50} C_{50}	30.57	R_{50} M_{50}	9.81

C_{100}	44.58	M_{100}	30.11

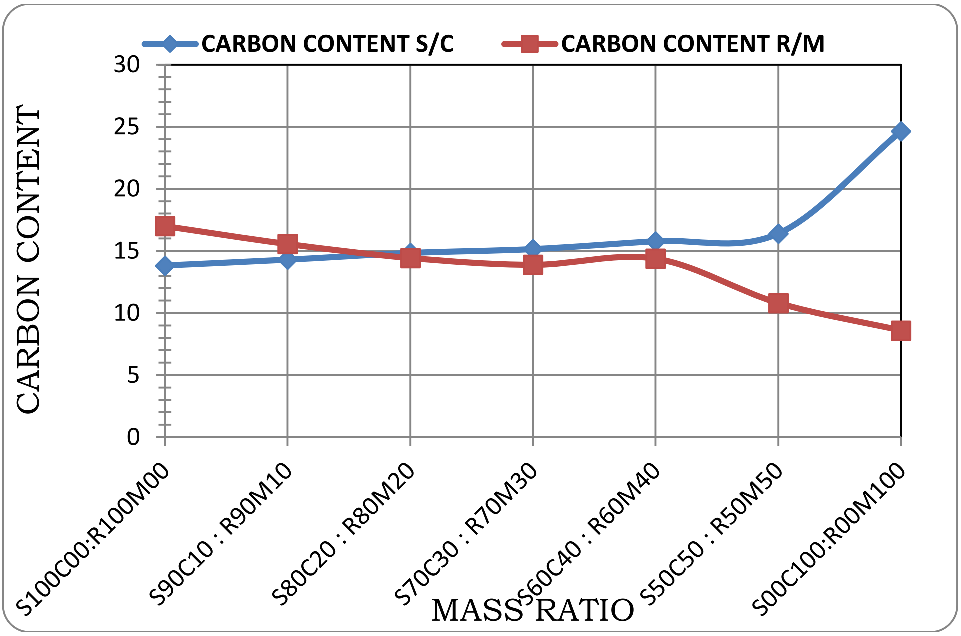

Figure 6: Carbon Content against Mass Ratio of S/C and R/M

In other to determine the performance evaluation of the briquette samples, the following parameters where determined, burning time, ignition time, burning rate, required mass of briquettes and boiling time. Tables 6 and 7 show the results of the Ignition time and Burning Rate of the briquettes made of S/C and the once made of R/M, respectively. Also, figure 7 and 8 compares the ignition time and burning rates of the two blends.

Table 6: Ignition time and Burning Rate of the Samples of Briquettes for S/C

Mass Ratio	Burning Time (min)	Ignition Time (Sec)	Burning Rate (g/min)	Boiling time (min)
$S_{100}C_{00}$	18.01	23.88	7.10	16.53
$S_{90}C_{10}$	19.17	38.80	5.50	17.95
$S_{80}C_{20}$	25.78	42.72	3.83	22.82
$S_{70}C_{30}$	27.80	46.11	3.16	23.36
$S_{60}C_{40}$	28.28	55.80	2.82	23.84
$S_{50}C_{50}$	31.16	58.28	2.24	25.24
$C_{100}S_{00}$	36.42	57.80	1.18	30.50

Table 7: Ignition Time and Burning rate of the Samples of Briquettes for R/M

Mass Ratio	Burning Time (min)	Ignition Time (s)	Burning Rate (g/min)	Boiling Time (min)
$R_{100}M_{00}$	17.77	26.14	3.89	15.20
$R_{90}M_{10}$	19.61	34.80	4.37	17.04
$R_{80}M_{20}$	22.01	38.10	3.65	19.44
$R_{70}M_{30}$	24.61	41.72	3.03	22.04
$R_{60}M_{40}$	25.99	50.16	2.75	23.42
$R_{50}M_{50}$	27.38	56.22	2.36	24.81
$M_{100}R_{00}$	29.80	58.15	1.41	27.33

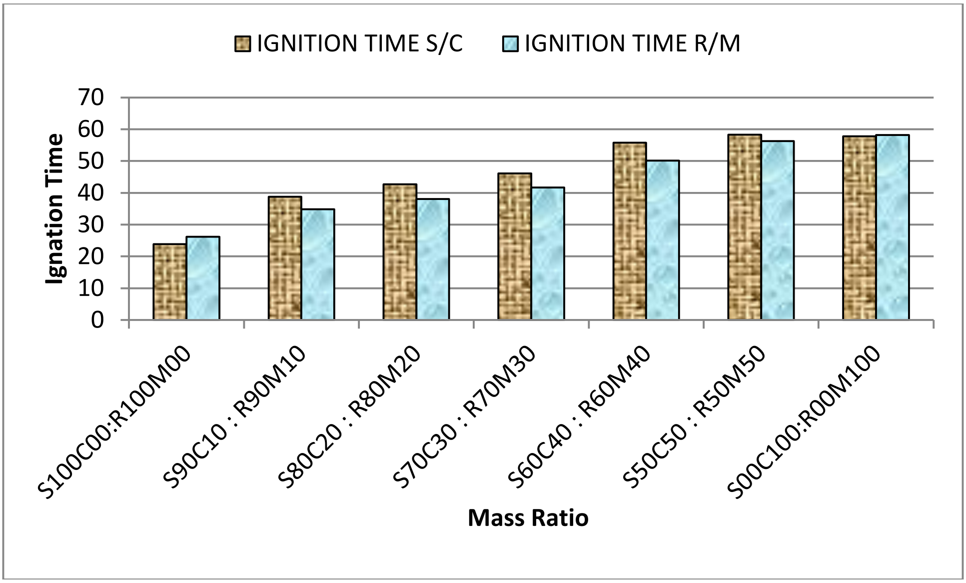

Figure 7: Ignition time of S/C and R/M against Mass Ratio of S/C and R/M

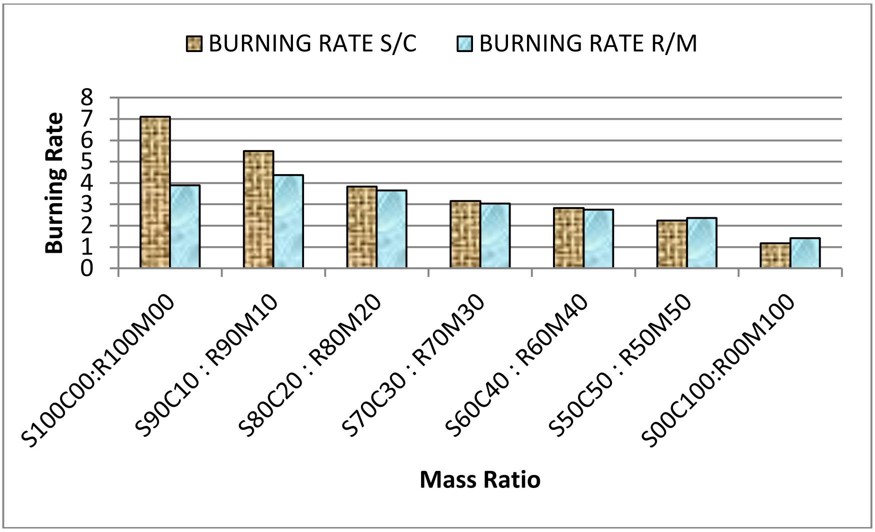

Figure 8: Burning Rate of S/C and R/M against Mass Ratio of S/C and R/M

From the results of Table 6 $S_{100}C_{00}$ yielded the optimum combustion value in ignition time and burning time giving 23.88sec and 18.01min, respectively. It took $C_{100}S_{00}$ 57.80sec to ignite. This is because coal has low volatile matter but it took $S_{90}C_{10}$ 17.95 minutes to boil 3 litres of water and 38.80sec to ignite. Briquette blended with large percentage of sawdust and small ratio of coal burns and ignites easily because of the high volatile nature in sawdust. Also the S_{100} produced the highest burning rate of 5.55 and $S_{90}C_{10}$ recorded 5.216 which also have a good burning rate. C_{100} recorded 3.171 and C_{50} SD_{50} 3.429, due to high content of coal; it takes coal a longer time to burn.

Similarly, the results show $R_{100}M_{00}$ exhibited the optimum combustion value of ignition time and burning time as 26.14 sec and 17.77 minutes respectively. It took $M_{100}R_{00}$ 58.15 sec to ignite and 19.80 minutes to burn 3 litres of water because of the average volatile nature of maize but showcased a significant optimum combustion value in ignition time and burning rate when blended in $R_{90}M_{10}$ to give 34.80 sec and 4.37 sec, respectively. As the ratio of maize increases to rice husk, the ignition time and burning time increases and the burning rate of the briquettes decreases. Furthermore, it can be seen from the result that $R_{90}M_{10}$ recorded the highest burning rate of 4.37 while $M_{100}R_{00}$ gave the lowest 2.11. $R_{100}M_{00}$ showcased the optimum combustion in ignition time of 26.14 sec while $M_{100}R_{00}$ gave 58.15 sec. It took $R_{100}M_{00}$ 17.77 minutes to burn completely to ash $R_{50}M_{50}$ 27.38 minutes to burn.

4.0 Conclusion

This work examined the physical and combustion characteristics of briquettes made from blend of coal/sawdust and rice husk/maize cob with 15% starch binder. These briquettes showcased and exhibited good calorific value of (8448.80kJ/kg – 24522.10kJ/kg). Also the briquettes produced significant ash content of (2.95% - 15%), this is however in line that low ash content offers high heating value for briquettes (Obi et al 2013). Similarly, the briquettes produced high volatile matters of 40% – 70%, moisture content of 11.77% - 23.11% and carbon content of 8.52% - 24.61%. It also produced the ignition time of (23.88 – 57.88sec) and $S_{100}C_{00}$ was so significant to ignite at 23.88sec. Also, it gave the burning time of (18.01 – 37.84minutes) and $C_{100}S_{00}$ significantly gave an optimum combustion characteristic of 37.84minutes.

Moreover, from the result of rice husk and maize cob, it can be seen that the moisture content gave (12.98 – 23.11%) and ash content of (4.24 – 13.40%) and $R_{00}M_{100}$ was so significant with 4.24% ash. It gave a volatile matter of (42.54 – 68.99%) and Calorific value of (8440 – 16840kJ/kg). Also the ignition time showcased (26.14 – 58.15sec) and $R_{100}M_{00}$ exhibited an optimum result in 26.14sec.

Furthermore, the results produced a burning time of 17.77 – 27.38 minutes and it took $R_{50}M_{50}$ 27.38 minutes to burn to ashes. Coal has been found to possess high ash content, high calorific value, high moisture content, high carbon content and low volatile matter. Using only coal as a cooking fuel brings about environmental nuisance as it will give out high carbon and ash content but when blended with sawdust as seen in the study, produced briquettes with significant heating value, less ash content, high volatile matter, and low carbon content. This is because of the high volatile matter, low ash and carbon content characteristics of sawdust. Hence, it can be deduced that from briquettes made of rice husk and maize cob, the results of this research proved that rice husk and maize cob are good blends of agricultural biomass. The higher the ratio of rice husk to maize cob, the higher the heat value and the volatile matter of rice husk was significant in the briquettes produced. This result shows how relevant and useful sawdust/coal and rice husk/maize cob can be, as cooking fuel alternative in quest for global renewable energy. Government should encourage the use of briquettes especially in rural areas as it will help to reduce the high rapid demand of fuel wood and reduce high dump of agricultural wastes which causes environmental pollution. Finally biomass briquettes is highly recommended as an alternative for cooking fuel since it has sufficient heat value, it ignites easily without harm, generates less carbon than firewood and charcoal, burns very well and gives less ash during cooking.

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