ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 15 N° 2 2019
pp. 30-37

A STUDY OF COMBUSTION PROPERTIES OF BRIQUETTES PRODUCED FROM A BLEND OF SAWDUST - BANANA LEAVES AND COW DUNG IN NIGERIA

Ebenezer IYIOLA*
PhD student - School of Forestry, University of Canterbury, Christchurch, New Zealand
Address: 20 Kirkwood Ave, Upper Riccarton, Christchurch 8041, New Zealand
E-mail: eaiyiola@futa.edu.ng Tel: +64 22 468 7558

Motunrayo OGUNLEYE
Federal University of Technology, Akure- Dept of Forestry and Wood Technology
Address: P.M.B 704, Akure City, Ondo State, Nigeria
E-mail: ogunleyemotunrayo84@gmail.com

Babatola OLUFEMI
Prof - Federal University of Technology, Akure- Dept of Forestry and Wood Technology
Address: P.M.B 704, Akure City, Ondo State, Nigeria
E-mail: bolufemi@futa.edu.ng

Jacob OWOYEMI
Dr - Federal University of Technology, Akure- Dept of Forestry and Wood Technology
Address: P.M.B 704, Akure City, Ondo State, Nigeria
E-mail: jmowoyemi@futa.edu.ng

Samuel AYANLEYE
MSc student- University of British Columbia- Faculty of Forestry
Address: 2619- 2424, Main Mall, Vancouver, BC, Canada
E-mail: ayanleyeoluwafemi@yahoo.com

Abstract:
The study was undertaken to evaluate the combustion properties of briquettes from wood and agricultural wastes. *Terminalia superba* sawdust and banana leaves were used and cow dung acting as binder in varying mixing ratios**.** The briquettes were produced using an automatic press at a constant compaction pressure of 1.77kN/m^2 and the substrate were combined at ratios 5:1:4, 4:4:2, 3:2:5, and 2:5:3, the briquettes produced were subjected to combustion tests. Combustion related properties such as percentage volatile matter, percentage ash of the briquettes were determined. The compressed density ranged between 517.09 ± 35.40kg/m^3 and 571.29 ± 28.73kg/m^3, while the reduction in density which signifies the rate at which the briquettes reduced in density after compression and relaxation ranged between 46.82±2.56kg/$m^3$and 55.81±1.80kg/m^3 respectively. The result from this study shown that briquette in ratios of 2:5:3 and 3:2:5 show better combustion properties than others.

***Key words**: briquette; combustion; terminalia superba; ash content; heat value.*

INTRODUCTION

The potential use of briquette as a source of energy has brought about renewed interest in the use of biomass, agricultural and forestry residues offer much potential for renewable energy sources in form of biomass. With advances in biotechnology and bioengineering, some resources which could have been classified as waste now form the basis for energy production (McKendry 2002). Although, Africa accounts for only 4% of the global energy use, the high demand for wood fuel has led to crisis in fuel use in Nigeria (Ardayfio-Schandorf 1996, Himraj 1993). It has been estimated that Nigeria has about 71.2 million hectares of available agricultural land, out of which about 36 million hectares of land are being currently utilized for agricultural production (FOS 2005).

The large quantities of agricultural residues produced in Nigeria can play a significant role in meeting the energy needs of the country. Although, most of these residues are from biomass which contains enormous amount of energy (Fapetu 2000b), the manure resources from animals account for a large percentage of agricultural wastes (Bamigboye & Oniya 2003). Most of these manures are obtainable from poultry while some are produced by human beings. The quality of the manure is a function of the environment from which they are recovered. In the arid regions of Nigeria, cattle waste in form of dung are used for energy resources for domestic heating and cooking (Oladeji 2011). On the other hand, wood can be

* Corresponding author

utilized as a good source of energy especially for its renewability. The productivity of Nigeria forest areas ranges between 12-36 million hectares per year as opposed to a productivity of 3-9 million hectare per year in the grasslands (Fapetu 2000a). Fuelwood is used by over 60% of Nigerians living in the rural areas in Nigeria making most of the rural inhabitants dependent on fuel wood for domestic uses. Nigeria consumes over 50 million metric tons of fuel wood annually. Traditionally, wood in form of fuel wood, twigs and charcoal are predominantly sources of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Rotimi *et al.* 2013).

The demand for fuel wood has been projected to rise to about $213.4\text{x}10^3$ metric tonnes whereas the supply would have decreased to about 28.4 x10 metric tonnes by the year 2030; this reason therefore necessitates a transition to a sustainable energy in the developing countries such as Nigeria (Stout & Best 2001). Forestry residues are known to be generated by operations such as thinning, extracting stem wood for pulp and timber. In sawmills, wood products processing generates significant volumes of residues in the form of sawdust, chips, off cuts, and bark. The wood residues such as sawdust and chips which are usually generated in sawmills in very large quantities can be converted into good quality, storable and high-grade solid fuel briquettes that can be utilized for both domestic and industrial energy production for heat generation (Aina *et al*. 2009). 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*. 2010a; Rousseta *et al.* 2011).

Briquetting biomass is done using various techniques which may or may not include the use of binder. The common binders used in producing briquette include starch, gum arabic, clay, lignin, animal dung or waste paper. Biomass briquettes are mostly used for cooking, heating, barbequing and camping in developed countries such as the United States of America, Australia, Japan, Korea and Taiwan and countries in the European Union. Although, biomass briquettes are mainly for domestic use in developing countries (Sotannde *et al*. 2010). The use of briquettes in energy generation will help to reduce rate of deforestation as the rate of felling of trees in the forest will be greatly reduced and thus mitigating the effects of climate change (Adekoya 1989). However, combustion of biomass fuels emits pollutants that contribute to over 1.6 million annual deaths globally, of which 400,000 occur in sub-saharan Africa where women and children suffer the most, thus often labelled as - killer in the kitchen (Bailis & Kammen 2005). If the patterns of energy use for household cooking do not change, it is estimated that diseases attributable to indoor air pollution will cause 9.8 million premature deaths by 2030 (Bailis 2005). Carbon monoxide (CO) and particulate matter (PM) are the major pollutants released from incomplete combustion of solid fuels used by households (Doggalia *et al.* 2011). CO indirectly affects global warming through atmospheric photochemical reactions that in turn affect GHG levels. CO has higher global warming potential per kilogram of carbon, than CO2 (Pennise *et al.* 2001). There is therefore the need to link knowledge on fuel briquette quality to indoor and outdoor air pollution.

PROCUREMENTS OF MATERIALS AND SAMPLE PREPARATION

The raw materials used for this study which is *Terminalia superba* (Afara) was collected from a local sawmill at Ondo road Akure in Nigeria while the cow dung and banana leaves were collected from animal production and health cattle ranch Obakekere, FUTA campus; banana leaves, cow-dung, distilled water, crucible, 200ml measuring cylinder, bowls, sieve of 2mm mesh size, desiccators, weighing balance, oven, briquette extruding machine, and muffle furnace used in the production of the briquettes were all obtained from the Faculty of Agriculture laboratories at the Federal University of Technology, Akure, Nigeria. The equipment used for briquette production was sited at Mechanical Engineering Central workshop and Wood Technology Laboratory, Federal University of Technology, Akure, Nigeria.

The saw dust was spread and air dried inside an opened room for 7days to achieve accelerated drying and was later sorted using a sieve of 2mm mesh size to obtain uniform grain size for the saw dust sample. The banana leaves were air dried under normal room temperature (23^oC) in an opened room for 7 days and milled to a particle size of 2.00 mm while the cow dung was sun dried for 14 days thereafter, the cow dung was crushed with improvised mortar and pestle, foreign materials was separated from the dung and the separated dung was crushed into a powdery form and then sieved with 1.00mm mesh size. The mixtures were prepared at substrate to binder ratios of 3:2:5, 4:4:2, 2:5:3 and 5:1:4 respectively. In each case, a fixed quantity mixture was hand-fed into the manually operated extruding machine press. The briquettes were produced by compacting the mixture of sawdust and binder into the moulds at a constant compaction pressure of $1.77KN/m^2$ ($0.00177N/mm^2$). This was used to determine the effect of binder concentration on physical and fuel properties of the briquettes produced.

DETERMINATION OF PHYSICAL AND COMBUSTION PROPERTIES

Density

The weights of briquettes were determined on the weighing balance with a precision of 0.001g in the laboratory. Then, the volumes of briquettes were determined by the calculation based on the direct measurement of dimensions (length, width and thickness) of the briquettes.

Compressed density of the briquettes was determined immediately after removal from the briquetting machine as a ratio of measured weight over calculated volume. The relaxed density of the briquettes is defined as the density of the briquette obtained after the briquette remained stable. This is known as spring back density.

Density can therefore be expressed using Eq 1:

$$\text{Density (kg/m3)} = \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

The relaxation ratio of briquettes was then computed from the Eq 2:

$$Relaxation\ Ratio = \frac{\text{Compressed Density}}{\text{Relaxed Density}} \quad (2)$$

Moisture Content

2g of the sample was weighed into a previously weighed crucible. The crucible plus sample taken was transferred into the oven set at 80°C to dry to a constant weight for 24 hours overnight. At the end of the 24 hours, the crucible plus sample was removed from the oven and transferred to desiccators with a silica gel, to be cooled for ten minutes and weighed.

The moisture content can then be expressed using Eq 3:

$$\%\ Moisture\ Content = \frac{W1 - W3}{W0} * 100 \quad (3)$$

where: W_o = mass of empty crucible;
W_1 = weight of crucible plus sample;
W_3 = weight of crucible plus oven – dried sample.

Percentage Volatile Matter (PVM)

5g of each briquette sample was placed in a crucible of known weight and oven dried to a constant weight after which it was heated in the furnace at a temperature of 550°C for 15 minutes. The percentage volatile matter was then expressed as the percentage of loss in weight to the oven dried weight of the original sample.

Percentage Volatile Matter can be expressed using Eq 4:

$$Percentage\ Volatile\ Matter = \frac{A - B}{A} * 100 \quad (4)$$

where: A is the weight of the oven dried sample and B is the weight of the sample after 15min in the furnace at 550°C.

Ash Content

1g of the briquette sample was weighed into a porcelain crucible. This was transferred into the muffle furnace set at 550°C, left for about 4 hours and it was turned to white ash. The crucible and the content were first cooled in the furnace and then transferred to room temperature in desiccators and weighed. The formula for determining ash content is stated in Eq 5.

$$Ash\ Content = \frac{\text{Weight of ash}}{\text{Initial weight of sample}} * 100 \quad (5)$$

Percentage Fixed Carbon

The percentage fixed carbon was estimated using the procedure by Bailey & Blankenhovn (1982) and is expressed using Eq 6:

$$\% \, Fixed \, Carbon = 100 - (\% \text{ volatile matter} + \% \text{ ash content}) \qquad (6)$$

Heat Value

The heat value was also obtained using the expression given by Bailey & Blankenhovn, (1982) which can be expressed using Eq 7:

$$\text{Heat Value} = 2.326\,(147.6\text{C} + 144\text{V}) \qquad (7)$$

where: C - % fixed carbon;
V = % volatile matter.

DATA ANALYSIS

The experimental design used for this experiment was Completely Randomized Design, the binder, agricultural and wood wastes were combined in different proportion. The data were subjected to two-way Analysis of Variance at 0.95 significance level. Duncan Multiple Range Test procedure was used for the follow-up analysis to recommend the briquette sample with the best fuel properties.

RESULTS AND DISCUSSION

The combustion properties of the briquettes examined in this study were moisture content, densities (relax density, compressed density and reduction in density), percentage volatile matter, ash content, percentage fixed carbon and the heating or calorific value. The results of the proximate analysis are presented in the relevant tables and charts.

Table 1

The Mean and Standard Deviation at different mixing ratios of substrate

mixing ratio	means ± std.
2:5:3	76.67±2.3[b]
3:2:5	76.67±1.15[b]
5:1:4	85.33±1.53[a]
4:4:2	85.67±2.08[a]

Table 2

Analysis of Variance of Ash Content for the Briquettes

Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Mixing ratio	234.250	3	78.083	23.425	.000*
Error	26.667	8	3.333		
Total	260.917	11			

** = Significant while ns = not significant (p>0.05)*

Table 3

Duncan Multiple Range Test (DMRT) on mixing ratio percentage fixed carbon of the briquettes

Mixing ratio	Mean ± std.
3:2:5	14.28±1.44[a]
2:5:3	11.79±5.90[ab]
5:1:4	5.69±1.60[bc]
4:4:2	4.33±2.30[c]

Values with the same letter are not significantly different at 0.05 % prob. level

Moisture Content

The moisture content of the briquettes (sawdust, banana leaves and cow dung) produced at varying mixing ratio are reported. The values ranged between 7.10±17% and 8.36±56% (the reason for this value was because the substrate were blended and combined in dry mass) and the result of ANOVA shows that there was significant difference in the mixing ratio leading to an effect on the moisture content of the briquettes (P < .05). Frank & Akhihiero (2013) reported that the equilibrium moisture content M_{emc}, ranged between 10.5% and 15.1% and that there was gradual decrease in M_{emc} of the briquettes with increase in the quantity of cow dung in mixture with water hyacinth. The observed M_{emc} values fall within the range of values (5.4%-13.4% wet basis). Although, for good storability and combustibility of briquettes, values within the range of 12-20% wet basis have been recommended. (Carre *et al.* 1988) noted that M_{emc} more than 20% would result in considerable loss of energy needed for water evaporation during combustion at the expense of calorific value of the fuel. Collins & Solomon (2016) reported 0.9% moisture content for rice husk and saw dust in the production of Refuse Derived Fuel (RDF) often referred to as pellets which is also in agreement with the outcome of this study. The moisture content used for this study was between 0.7% and 0.8%, this can be associated to the fact that the substrates were combined on dry basis with 250ml of water and varying the mixing ratio of which the highest percentage was recorded in the mixture with high percentage of sawdust which are 5:1:4 and 4: 4: 2. Wiseman (2017) reported that the value of moisture content indicates how easily and efficiently briquettes will burn, low moisture content contributes significantly to the high calorific value because the presence of high moisture content leads to loss of energy during combustion as latent heat of vaporization. Aina *et al.* (2009) also reported that briquettes produced using 100% sawdust of *Albizia zygia* had a moisture content of 7.10% which was higher than those obtained in this study. Although, the values obtained from *Azadirachta indica* briquettes bonded with gum arabic and starch are in the range of 2.50 to 6.76% and 2.59 to 3.58% as reported (Sotannde *et al.* 2010), these values are also higher to those obtained in this study. The mixing ratio had a significant difference thus influencing the moisture content of the briquettes. The differences could be attributed to the nature of the material and difference in climatic condition since M_{emc} is a function of relative humidity and temperature of the surrounding air (Sotannde *et al.* 2010). The relatively low moisture content obtained in this study is expected to influence the heating value of the briquettes.

Compressed and Relaxed Density

The compressed density of all the briquettes at the varying mixing ratio ranged between 517.09±35.40Kg/m^3 and 571.29±28.73Kg/m^3 obtained in this study while relaxed density ranged between 232.40±10.95Kg/$m^3$and 278.63±9.42 Kg/m^3 and reduction in density ranged between 46.82±2.56Kg/m^3 and 55.81±1.80Kg/m^3. The ANOVA result shows that there was no significance difference for compressed density in the mixing ratio. For relaxed density, the mixing ratio varies significantly thus influencing the relaxation density while reduction in density shows that there was significant difference in the mixing ratio used for the study. Sotannde *et al.* (2010) also reported the values of 0.546±0.17g/cm^3, 0.464±0.06g/cm^3, respectively as compressed density and relaxed density for *Azadirachta indica* briquettes bonded with starch. The results from this study shows that there was no significant difference in the compressed density of the mixing ratio while the relaxed density was significant with an increase in cow dung and banana content of the mixture. For the reduction in density ratio, 2:5:3 reduced in composition than other ratios which leads to lowest density after relaxation while ratio 4:4:2 and 5:1:4 retained their composition better than others. Briquettes produced by using 100% sawdust of *Albizia zygia* was reported to have a density of 850-1200kg/m^3 which are higher than those obtained in this study (Aina *et al.* 2009).

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 15 N° 2 2019
pp. 30-37

Ash Content

The ash content of the briquettes shows the distribution of the ash at different mixing ratio (Fig. 1). The varying mixing ratio ranged between 76.67±2.3% and 85.67±2.08% (the result was the combination of three substrates). The ANOVA result shows that there was significant difference between ratio 4:4:2 and 5:1:4 and between ratio 3:2:5 and 2:5:3 (Table 2). Although, in previous studies, the ash content of rice husk briquette was 18.62% lower than the values obtained in this study (Oladeji 2010). Maia *et al.,* (2014) also reported ash content of banana leaves briquette to be 10.70±1.03%. Briquettes from *Azadirachta indica* sawdust ranges between 3.40% to 5.80% in briquettes bonded with gum arabic and 2.40% to 4.40% in briquettes bonded with starch (Sotannde *et al.* 2010). Frank & Akhihiero (2013) reported that water hyacinth and cow dung mixture ash content to be 24.6% and cow dung ash content to be 19.1%, although these values are lower than the ash content obtained in this study, but the increase in ash content could be attributed to the combination of three biomasses.

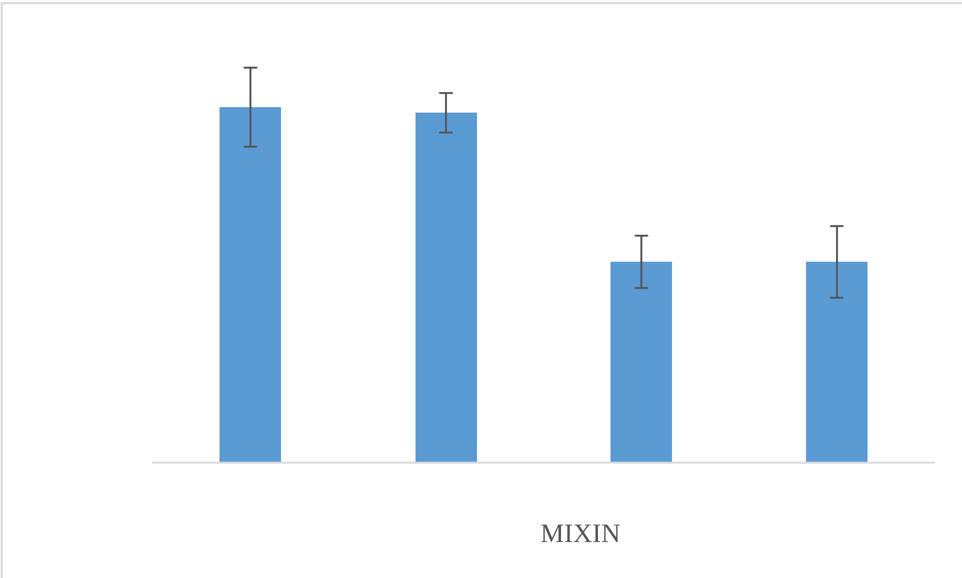

Fig. 1.
Ash Content at varying mixing ratio.

Percentage Volatile Matter

The Percentage Volatile Matter of the briquettes ranges from 8.98±0.62% to 11.55±5.74% as obtained from this study. The Analysis of Variance (ANOVA) shows that there was no significant difference in the mixing ratio (P > .05). The volatile matter obtained in this study ranges between 8.98 % and 11.55% which is in line with the work on the volatile matter of *Azadirachta indica* briquettes bonded with starch and gum Arabic (Sotannde *et al.* 2010). The volatile matter of briquettes produced increases in percentage as the content of the banana leaves increases, this shows the amount of volatile gases that will be emitted during ignition or burning process of briquettes. Ogwu *et al.* (2014) reported volatile matter of 85.60% at 30% starch level for *Daniella oliveri* and rice husk, the volatile matter obtained for corncob was (86.53%), and for rice husk briquette was 67.98% as reported by Oladeji (2010). In contrast, these results are higher than those obtained in this study. However, it is worthy of point to know that the level of volatile matter in the briquettes directly affects their burning efficiency; Bernice *et al.* (2017) reported that low volatile matter is of importance as high volatile matter may result in high release of emissions during burning which contributes to release of harmful gases into the atmosphere.

Heat Value

The heating value of the briquettes ranges between 4960.18±523.95Kcal/kg and 7934.91±785.03Kcal/kg as obtained from this study. The Analysis of Variance (ANOVA) shows that there was significant difference in the mixing ratio which therefore affects the heating value of the briquettes (Table 2). Bernice *et al.* (2017) reported in their study that the calorific value determines the amount of energy released during complete combustion of a unit mass of briquette. It was further reported that a good quality and efficient fuel briquette depends on low moisture content, volatile matter and ash content with a higher fixed carbon content. Aina *et al.* (2009) produced briquettes using 100% sawdust of *Albizia zygia* and obtained very high calorific values of 4.723kcalkg^{-1} which is similar to the mixing ratio 5:1:4 and 2:5:3 obtained in this study. The heating value of briquettes from agricultural residues such as corncob (20,890KJ/kg), rice husk (13,389KJ/kg), 35mm groundnut shell (18.6MJ/kg), banana leaves (17.7MJ/kg) are reported respectively (Oladeji 2010, Singh *et al.* 2007, Maia *et al.* (2014). Sellin *et al.* (2013) reported the value of 14.90MJ/kg for banana pseudo stem briquettes and Onuegbu *et al.* (2012) reported 18.22MJ/kg for *Terminalia superba* briquettes but was not in accordance with the results from this study.

The high ash content value in the mixing ratio resulted in lower heating values as compared to other ratios with lower ash content which gives higher heating value of 7934.91Kcal/kg and 7914.06Kcal/kg.

Percentage Fixed Carbon

The percentage fixed carbon of the briquettes ranged between 14.28±1.44% and 4.33±2.30%. The Analysis of Variance (ANOVA) result shows that there was significant difference in the mixing ratio influencing the percentage fixed carbon of the briquettes. The Duncan Multiple Range Test (DMRT) on mixing ratio also revealed that there was significant difference in carbon content in the mixing ratio ($P < .05$).

Bianca *et al.* (2014) reported fixed carbon of banana leaves to be 14.00%, also, Sellin *et al*. (2013) reported pseudo stem of banana briquettes to be 18.45% while Oladeji (2010) reported 13.40% and 12.07% for rice husk and corn cob respectively. The fixed carbon obtained in this study ranges between 4.33% and 14.28% which are in conformance with past studies (Sellin *et al*. 2013; Oladeji 2010). Ogwu *et al.* (2014) also reported *Daniella oliveri* and rice husk FC to be 5.78% at 30% starch level, *Afzelia africana* and rice husk gave 12.19% and combination of all the two substrates to be 6.01% at 30% starch level of the briquettes produced which are also in accordance with what was obtained in this study. The ANOVA result shows that the significance of the mixing ratios; it was observed that the carbon content at ratio 3:2:5 (14.28%) and 2:5:3 (11.79%) was high which could be attributed to high percentage of banana leaves and cow dung in the mixture. However, Bianca *et al.* (2014) reported the fixed carbon for banana leaves as 14% which means that the increase in fixed carbon of the briquettes produced is a result of increase in percentage of sawdust and cow dung and increase in cow dung and banana leaves (mixing ratio 2:5:3 and 3:2:5). Therefore, there is an increase in percentage of fixed carbon with an increase in both sawdust and cow dung percentage or increase in banana leaves and cow dung.

CONCLUSION

It can be concluded that the heat value of the briquettes produced is in line with the standard at the varying mixing ratio especially at ratios of 4:4:2 and ratio 3:2:5 where heating value is of importance, this is because high energy is required in combustion for domestic use. Furthermore the volatility content of the briquettes produced was very low which guarantees safety emission of gases during the burning of briquettes. In lieu of this, the volatile matter emitted does not contribute to the release of harmful gases into the environment and briquettes produced at ratio 2:5:3 emitted lowest volatile matter.

Also, the best mixing ratio for ash content was ratios 3:2:5 and 2:5:3, this is because low ash content is required in domestic use to reduce ash slagging which inhibits the combustion process by supporting overheating of the burning device and subsequently its corrosion. Finally, the results from this study shows that ratios 2:5:3 and 3:2:5 show good combustion properties than others which is important in the final end-use of briquette and ratio 3:2:5 and ratio 4:4:2 are recommend where high heating value is of utmost importance. Also, the use of briquettes as an alternative energy use should be encouraged especially in rural communities in Africa.

ACKNOWLEDGEMENT

I acknowledge the moral and academic support of my supervisor Prof B. Olufemi throughout the course of this research, I also appreciate some of my lecturers who contributed significantly to the work, Dr. Owoyemi and Mr. Iyiola for the analysis and proof-reading of the final draft, I also appreciate Mr. Ayanleye that contributed significantly to the literature review and the first draft of the paper.

REFERENCES

Adekoya LO (1989) Investigations into Briquetting of Sawdust. The Nigerian Engineer 24(3):1-10.

Aina OM, Adetogun AC, Iyiola KA (2009) Heat Energy from Value-Added Sawdust Briquettes of Albizia Zygia. Eth J Environ St Mgt 2(1):42-49.

Ardayfio-schandorf E (1996) The fuel wood/energy crises in sub-saharan Africa. In: George Benne. William B. Morgan and Juha I. Uitto (EDS), sustaining the future economic, social and environmental change in sub-sharan African. The united nation university, ISBN: 0585229996, pp. 365-380.

Baileys RT, Blankenhorn PR (1982) Calorific and porosity development in carbonized wood. United States: N. Web.

Bailis R (2004) Wood in household energy use, URL:
http://environment.yale.edu/posts/downloads/ag/EoE_Bailis_Uncorrected_proof-1.pdf.

Bailis R, Ezzati M, Kammen D (2005) Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa Sci 308:98-103.

Bamigboye AI, Oniya O (2003) Pyrolytic Conversion of Corncobs to Medium-Grade Fuels and Chemical Preservatives. FUTAJEET (2):50-53.

Bernice A, Josiane N, Solomie G, Elsie O, Mary N (2017) A Review on Production, Marketing and Use of Fuel Briquettes. international water management Institution.

Carre J, Lequeux P, Herbert J, Lacrosse L (1998) Biomass densification. A research project report published by the Commission of European Communities, Directorate General for Development Belgium. 150 pp.

Collins NN, Solomon GO (2016) Investigation of Bio-Waste as Alternative Fuel for Cooking. 3rd international conference on African development issues. ISSN: 2449 075X.

Doggalia P, Kusabab H, Einagab H, Bensaidc S, Rayalua S, Teraokab Y, Labhsetwara N (2011) Low-cost catalysts for the control of indoor CO and PM emissions from solid fuel combustion. J Hazardous Mat 186:796-804.

Fapetu OP (2000a) Management of Energy from Biomass. NJEM (1):14-18.

Fapetu OP (2000b) Production of charcoal from Tropical Biomass for Industrial and Metallurgical Process. Nig J Eng Mgt 1(2):34-37.

FOS (2004/2005) Federal Office of Statistics Agricultural Survey Federal Ministry of Agriculture.

Frank OO, Akhihiero TE (2013) Fuel Briquettes from Water Hyacinth-Cow Dung Mixture as Alternative Energy for Domestic and Agro-Industrial Applications. J Energy Technol Policy 3(6).

Himraj D (1993) Environmental management. 19(3):283-288.

Maia BD, Souza O, Marangoni C, Hotza D, Oliveira AD, Sellin N (2014) Production and characterization of fuel briquettes from banana leaves waste. Che Eng Trans 37:439-444 DOI: 10.3303/CET1437074.

McKendry P (2002) Energy production from biomass (part 1): Overview of Biomass. Bioresource Technol (83):37-46.

Ogwu IY, Tembe ET, Shomkegh SA (2014) Comparative analysis of calorific value of briquettes produced from sawdust particles of daniella oliveri and afzelia africana combination at binary and tertiary levels with rice husk, jfewr Publications.

Oladeji JT (2011) The Effects of Some Processing Parameters on Physical and Combustion Characteristics of Corncob Briquettes. Ph.D. Thesis of the Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

Onuegbu TU (2010) Improving Fuel wood Efficiency in Rural Nigeria: A case for Briquette Technology. National Magazine of the CSN 5(4):35–39.

Pennise D, Smith K, Kithinji J, Rezende M, Raad T, Zhang J, Fan C (2001) Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. J Geophy Res 106(20):24.143-24.155.

Rousseta P, Caldeira-Piresb A, Sablowskic A, Thiago-Rodriguesd T (2011) LCA of eucalyptus wood charcoal briquettes. J Clean Prod (14):1647-1653.

Rotimi MD, Onome AD, Usman SM (2013) Combustion Characteristics of Traditional Energy Sources and Water Hyacinth Briquettes. Int of Sci Res Env Sci (IJSRES) 1(7):144-151.

Sotannde OA, Oluyege AO, Abah GB (2010) Physical and combustion properties of charcoal briquettes from neem wood residues. Int Agrophys 24:189-194.

Sellin N, Oliveira BG, Marangoni C, Souza O, Oliveira AN, Oliveira TN (2013) Use of banana culture waste to produce briquettes Chem Eng Trans 32,349-354,DOI: 10.3303/CET1332059.

Stout BA, Best G (2001) Effective energy use and climate change: needs of rural areas in developing countries, Agricultural Engineering International: the CIGR E-journal of Sci Res Dev. Vol. III 19pp.

Wiseman TN (2017) Production of Briquette from *Prosopis juliflora* stem and Anthill soil. International Journal of Novel Research in Physics, Chemistry and Mathematics. Vol. 4(2):22-27.