Ignition and Burning Rate of Water Hyacinth Briquettes

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Authors' contributions

This work was carried out in collaboration between all authors. Author RMD designed the study, performed the statistical analysis and wrote the final draft of the manuscript. Authors DSA rendered editorial. All authors read and approved the final manuscript.

ABSTRACT

Aims: The study was conducted to investigate the effect of compaction pressure, binder proportion and particle size on ignition time and burning rate of fuel briquettes produced from a mixture of water hyacinth and plantain peel.
Study design: The experimental design for this study was 5x3x4 Randomized Complete Block Design.
Place and Duration of Study: The samples were collected from Port-Harcourt, Niger Delta, located between latitudes $4^0\,2'$ and $6^0\,2'$ North of the equator and longitudes $5^0\,1'$ and $7^0\,2'$ East of the Greenwich meridian, between Jan 2009 and March 2010. The laboratory work was conducted in the Mechanical Engineering Department, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.
Methodology: The experimental design for this study was 5x3x4 Randomized Complete Block Design. This study involved three particle sizes of dried and ground water hyacinth (D_1, D_2, D_3) at levels 0.5, 1.6 and 4mm, pressure (P_1, P_2, P_3, P_4) at level 3.0, 5.0, 7.0 and 9.0MPa with plantain peels were used as binder (B_1, B_2, B_3, B_4, B_5) in the ratio of 10, 20, 30 40 and 50% by weight of residue. They were arranged in Randomize Complete Block Design with three replications per experiment.
Results: The effect of particle size, binder ratio and compaction pressure on burning rate

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of the briquettes varied from 0.92±0.03 g^{-1}min (D_1) to 2.66± 0.05 g^{-1}min (D_3), 1.57±0.11g^{-1}min (B_5) and 2.30±0.15g^{-1}min (B_1) and1.68±0.11 g^{-1}min (P_4) and 2.13±0.13 g^{-1}min respectively.

Conclusion: It could be concluded that Increased in compaction pressure, binder ratio and decreased in particle size caused decrease in the burning rate but elongated the ignition time of the briquettes.

Keywords: Deforestation; fossil fuel; densification; combustion; aquatic plant and Nigeria.

1. INTRODUCTION

The demand for fuel wood is expected to be risen to about $213.4x10^3$ metric tonnes, while the supply would have decreased to about $28.4x10^3$ metric tonnes by the year 2030 [1]. The demand for traditional energy in Nigeria (mostly fuelwood and charcoal) is 39 million tonnes per annum (about 37.4% of the total energy demand and the highest single share of all the energy forms) [2,3]. It is projected to increase to 91 million tonnes by 2030. The deforestation rate will continue to increase if nothing is done to discourage the use of fuelwood and promote the use of alternative energy sources. It was also reported that fossil fuel shortage, fuel increasing price, global warming including other environmental problems are critical issues. Therefore, biomass energy has been attracting attention as an energy source since almost zero net carbon dioxide accumulation in the atmosphere from biomass production and utilization can be achieved. The carbon dioxide released during combustion process is compensated by the carbon dioxide consumption in photosynthesis.

The world's energy supply is grossly inadequate by fossil fuel mainly coal, crude oil, and natural gas. Fossil fuel, which is non renewable, provides about 80% of man's energy sources now and this may start to depreciate in the next twenty to thirty years [4]. Densification and utilization of agricultural waste products as bio-energy have not been successful in areas like Nigeria and other developing countries, the markets for briquette have not been explored in this area and with materials locally available, production cost will be low and hence reduce dependence on and costs in purchase of kerosene and charcoal [4,5].

Many researchers have reported on the combustion properties of briquettes fuel for various agricultural waste products such as charcoal briquettes from neem wood residue [6], two paired of biomass species [7], polymeric waste material briquettes [8]. Also, production of fuel Briquettes from Waste Paper and Coconut Husk admixtures densified [9], rice husk and saw dust [10], composite Sawdust Briquettes [11], palm kernel briquettes [12], energy production of some agricultural wastes as local fuel materials briquettes [13]. Briquettes from corncob and rice husk residues [14], sawdust briquettes [15] and briquette of *Afzelia africana, Terminalia superba, Melicia elcelsa* [4].

The understanding of thermal properties of fuel briquettes is pertinent in order to investigate factors affecting the combustion rate and ignition time and temperature. Heat is transferred from burning briquettes in three different ways: thermal conduction, convection of heat by the flow of volatile gases, and radiation within pores inside the solid. The efficient utilization of biomass or agro-waste briquettes as biofuel require the understanding of combustion such as ignition time and burning rate, moisture content, ash content, density, volatile matter, and heating value among others [4]. The objective of this study is therefore to investigate; the

optimum compaction pressure, binder proportion and particle size require to produce an acceptable briquette with best burning rate and ignition time.

2. MATERIALS AND METHODS

The experimental design for this study was 5 x 3 x 4 Randomized Complete Block Design. This study involved three particle sizes of dried and ground water hyacinth (D_1, D_2, D_3) at levels 0.5, 1.6 and 4.0mm, compaction pressure (P_1,P_2,P_3,P_4) at level 3.0, 5.0, 7.0 and 9.0MPa with plantain peels used as binder (B_1, B_2, B_3, B_4, B_5) in the ratio of 10, 20, 30 40 and 50% by weight of water hyacinth residue. They were arranged in Randomize Complete Block Design with three replications per experiment. A total of 180 experiments were conducted.

2.1 Preparation of Briquette Sample

The pre-treatment processing of briquette sample for this study comprised of drying, size reduction and compaction operations. The raw materials were sun dried for 5-7days. The dried raw materials were chopped using chopper (knives) and ground using hammer mill. The particle size distribution was achieved by using Particle Size Analysis Equipment consisting of sieve shaker and Tylers sieves of various diameter or particles size openings. This equipment vibrated and forced the material through the screens with mesh. For this experiment, sieves size corresponding to 0.5, 1.6 and 4.0mm were chosen. Each of the aggregate was subdivided into three equal parts, while binder (ground plantain peels) in the ratio of 10%, 20%, 30%, 40% and 50% by weight of the residue stock was added to each of the subdivided residue rations. The agitating process was done in an electric mixer to enhance proper blending prior compaction. The blends were briquetted under ambient condition in a manually operated hydraulic powered press having capacity of 20 tonnes.

2.2 Compaction Tests

Compaction tests on the blend samples were carried out using hydraulic press machine. A steel cylindrical die of dimension 14.3cm height and 4.7cm in diameter was used for this study. The die was freely filled with known amount of weight (charge) of each sample mixture and be positioned in the hydraulic powered press machine for compression into briquettes. The piston was actuated through hydraulic pump at the speed of 30mm/min of piston movement to compress the sample. Compacted pressure ranged from 3.0 – 9.0MPa. A known pressure was applied at a time to the material in the die and was allowed to stay for 45 seconds (dwell time) before released and the briquette formed was then extruded and labelled. Stop watch was used for purpose of timing.

2.3 Moisture Content Determination

The moisture content of the ground material before and after compaction was determined using ASAE [16] standard S 352.2 involving the use of oven drying methods. The initial weight of the sample was determined (W_1), and placed in an oven set at 103ºC for 24hours. The samples was removed and cooled in a dessicator, reweighed (W_2). Moisture content of the sample was calculated from the following expression,

$$MC = \frac{W_1 - W_2}{W_1} \times 100$$

Where, W_1= weight of sample before drying, (gram)
$\quad\quad$ W_2= weight of bone dried sample, (gram)

2.4 Burning Rate

This determines the rate at which a certain mass of fuel is combusted in air. Fuel burning rate was determined [4,17]. The insulator, bursen burner, tripod stand and wire gauze were arrange on the balance and their weight was recorded. Briquette sample of known weight was placed on wire gauze and the burner ignited. This was positioned on top of a mass balance (Avery Berkel HL122) and rate at which the briquette was burning was monitored at every 10 seconds throughout the combustion process using stop watch. Until the briquette was completely burnt and constant weight was obtained. The weight loss at specific time was computed from this expression:

$$B_R = \frac{Q_1 - Q_2}{T}$$

Where,
B_R = Burning rate, g/min
Q_1 = Initial weight of fuel prior to cooking (g)
Q_2 = Final weight of fuel prior to cooking (g)
T $\quad$ = Total burning time (min)

2.5 Ignition Time

In each test a single briquette was placed alone in the centre of a steel wire mesh grid resting on two supporting fire retardant bricks, allowing the free flow of air around the briquette. Bursen burner was placed directly beneath this platform. Bursen burner was adjusted to blue flame and it was also ensure that the whole of the bottom surface of the briquette was ignited simultaneously [18]. Caution was taken to avoiding flame spread in the transverse directions. The burner was left in until the briquette was well ignited and had entered into its steady state burn phase.

2.6 Data Analysis

The analysis of variance, Duncan Multiply Range Tests and descriptive statistics were used. All the analyses were carried out with SPSS statistical software.

3. RESULTS AND DISCUSSION

The effect of binder on ignition time of the briquettes varied from 66.61 ± 3.88 sec (B_1) to 107.92 ± 2.92sec (B_5) as shown in Fig. 1. The obtained trend of the ignition time indicated that ignition time increased with increased binder proportion. The recorded lowest ignition time (66.61 ± 3.88 sec) recorded for (B_1) could be attributed to high porosity exhibited between inter and intra – particles which enable easy percolation of oxygen and out flow of combustion briquettes due to low bonding force. The values were significantly difference at all levels of binder (P<0.001). The influence of compaction pressure on ignition time varied from 74.64 ± 3.54sec (P_1) to 98 ± 3.19sec (P_4) as shown in Fig. 2. A direct proportional relationship was established between compaction pressure and ignition time and was significant at P<0.001. Increased in compaction pressure automatically increased the density of briquettes and consequently, delayed the ignition time of the briquettes. Furthermore,

briquettes compressed to a higher density will tend to have a lower porosity, and thus elongate the ignition time.
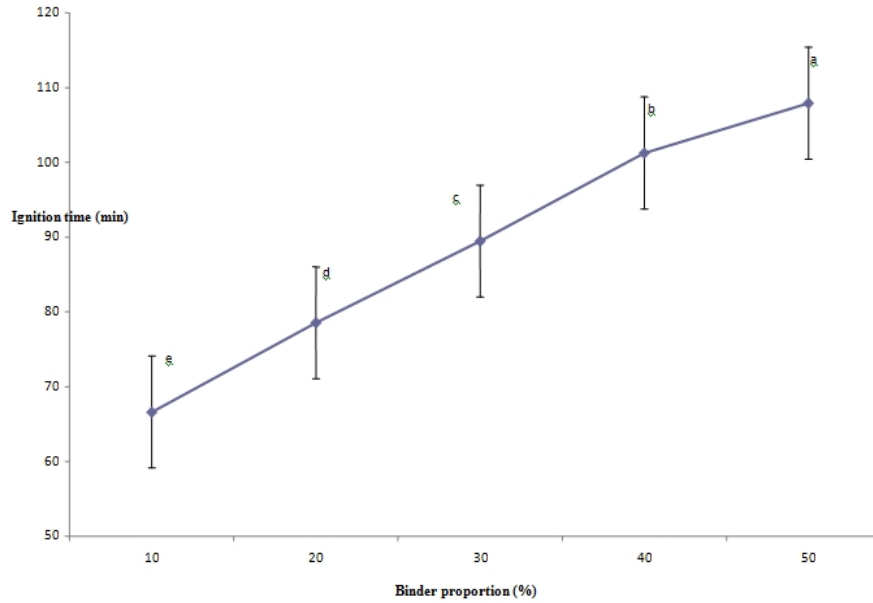

Fig. 1 Ignition time and binder proportion

Means of different letter are significantly different (P<0.001)
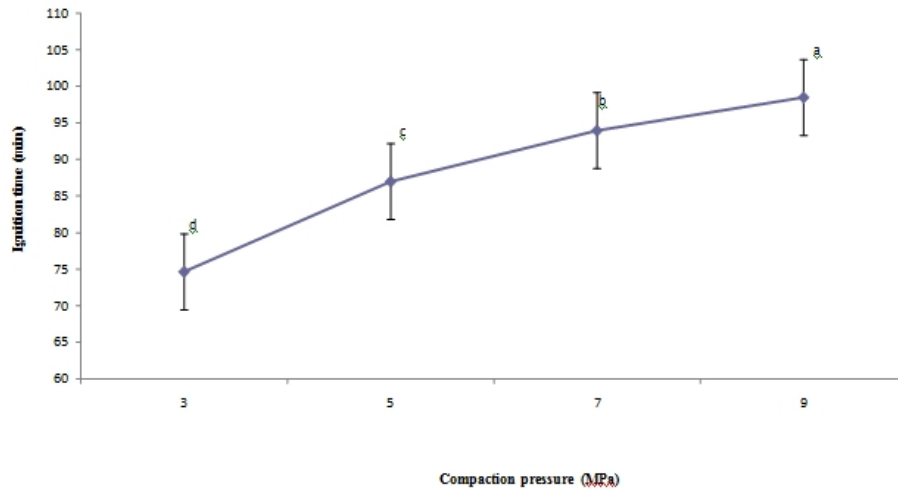

Compaction pressure (MPa)
Fig. 2 Ignition time and compaction pressure

Means of different letter are significantly different (P<0.05)

The values of the ignition time ranged from 67.60 ± 2.62sec (D_3) to $104.28 \pm 2.01.19$sec (D_1) (Fig. 3). ANOVA and DMRT showed a significant decreased in ignition time as the briquette particle size increased (P<0.001). From the results, it was apparent that particle size of the briquettes had negative impact on the ignition time of the briquettes. This observation might be adduced to the fact that bigger particle sizes could have more pronounce pore spaces in

between the particles than the finer particle sizes. Thus, increase the porosity index of the briquettes which might cause reduction in time taken for the briquettes to be ignited. This implied inverse relationship between ignition time and the studied particle sizes. The variations in values are within the corresponding values of 19-186seconds for bio-coal briquettes produced by blending the materials at different concentration of 10 -50% with coal [18]. Briquettes for domestic use must be easily ignitable, but with low porosity index, low volatile content and low ash content [10,17].
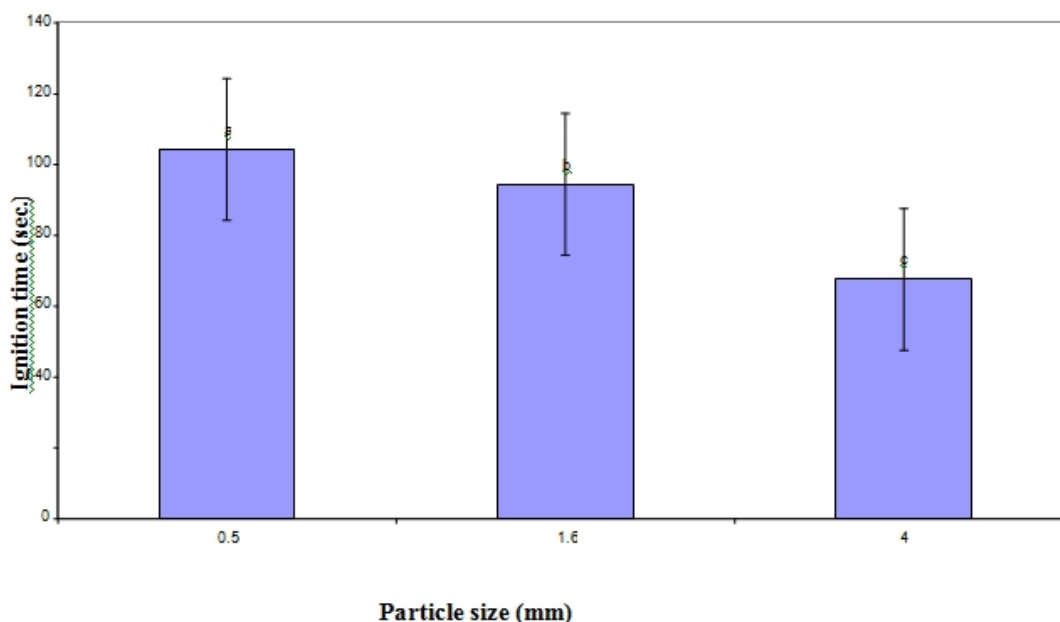

Particle size (mm)
Fig. 3 Ignition time and particle size

Means of different letter are significantly different (P<0.05)

The burning rate of the sampled briquettes was determined in a controlled burning chamber. The effect of binder on the burning rate was studied. From Fig.4, burning rate of water briquettes significantly varied between $1.57\pm0.11 \text{gmin}^{-1}$ (B_5) and $2.30\pm0.15 \text{gmin}^{-1}$ (B_1) (P<0.001). The obtained burning rate values of the briquettes decreased with increased binder proportion. The implication of this observation is that more fuel might be required for cooking with briquettes produced from B_1 than B_5. The briquettes produced from 50% binder level had the lowest burning rate. Ajayi and Lawal [20] studied the effect of binder on the burning rate of the sawdust briquettes with palm oil sludge as binder. That study discovered that the binding of the sawdust by the sludge prevented the fast burning of the briquettes hence experienced reduction in the weight loss as the sludge content increases. Briquettes without binder burned faster than the one with binder for the two types of sawdust (Arere and Opepe species). Chin and Siddiqui [21] have conducted an experiment to study the effect of compaction pressure on combustion rate of briquettes contain different biomass materials such as rice husks, sawdust, peanut shells and coconut fibres. The compaction pressure was within the range of 1 to 7 MPa. It was found that the burning rate increased as the binder content increased. The binding agents used in their experiment were molasses and starch.
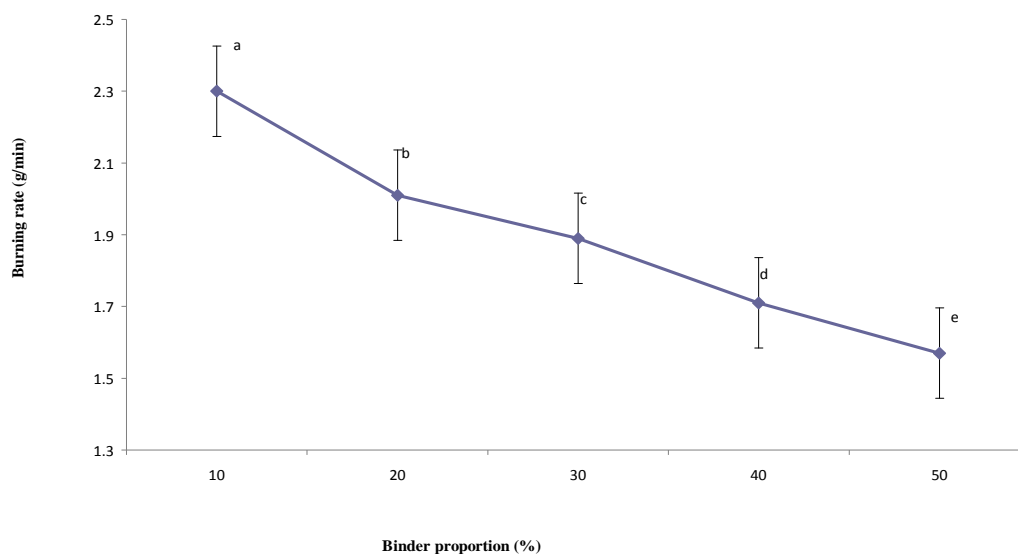
Fig. 4 Burning rate and binder proportion

Means of diifferent letter are significantly different (P<0.05)

The values of burning rate of the briquettes ranged between 1.68±0.11 g^{-1}min (P_4) and 2.13±0.13 g^{-1}min (P_4) and the observed trend was significant (P<0.001) (Fig. 5). The rate at which the fuel briquettes burn increased with decreased compaction pressure. Chin and Siddique [21] studied the effect of pressure on the burning rate of some biomass briquettes. The study reported that increased densification pressure decreased the burning rate of the briquettes. In addition, the research elucidated that increased binder proportion from 10% to 30% increased the burning rate of briquettes from 1.6g/min to 2.0g/min for coconut fibre, 1.8g/min to 2.4g/min for sawdust, 2.4g/min to 2.5g/min for palm fibre and 2.0g/min to 2.3g/min for rich husk.

The burning rate of the briquettes varied from 0.92±0.03 g^{-1}min (D_1) to 2.66± 0.05 g^{-1}min (D_3) (Fig. 6). DMRT and ANOVA indicated significant difference for the recorded burning rate values at the different particle sizes (P<0.05) (Fig. 6). The particle sizes demonstrated direct relationship with burning rate of briquettes. The present observation could be attributed to porosity exhibited between inter and intra–particles which enable easy infiltration of oxygen and out flow of combustion briquettes. Furthermore, the obtained value for finer particle size based on the combustion tests might possibly be attributed to lower porosities and this hindered mass transfer, such as drying, devolatilization and char burning processes, due to fewer free spaces for mass diffusion (for examples water vapour, volatile matter, and carbon dioxide outflows and simultaneously oxygen infiltration). Consequently, its burning rates (briquette weight reduction rates) might be reduced. The present study indicated that the particle sizes of the briquettes increased with increased burning rate. Onuegbu et al. [18] reported factors that could be responsible for burning rate of biomass (briquettes) such as chemical composition and geometry (bulk and packing orientation) of the biomass. Saptoadi [22] investigated the effect of particle size on the burning rate of coal briquettes and discovered that the briquettes from the largest particle size burnt only for 19-25 minutes, while those from the smallest particle size reacted until 28 minutes. Furthermore, more unburned carbon was left at the combustion termination, that is, only 16% for briquettes from

the largest particle size compared to 33% for briquettes from the tiniest particles. The average burning rate of palm biomass briquette was 0.43 g/min [23]. However, the present study observation contradicted this finding.
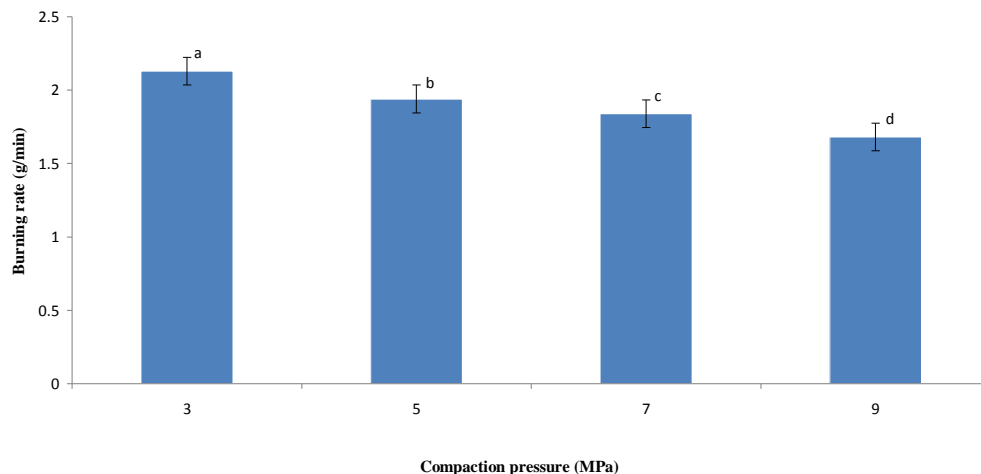

Fig. 5 Burning rate and compaction pressure (MPa)

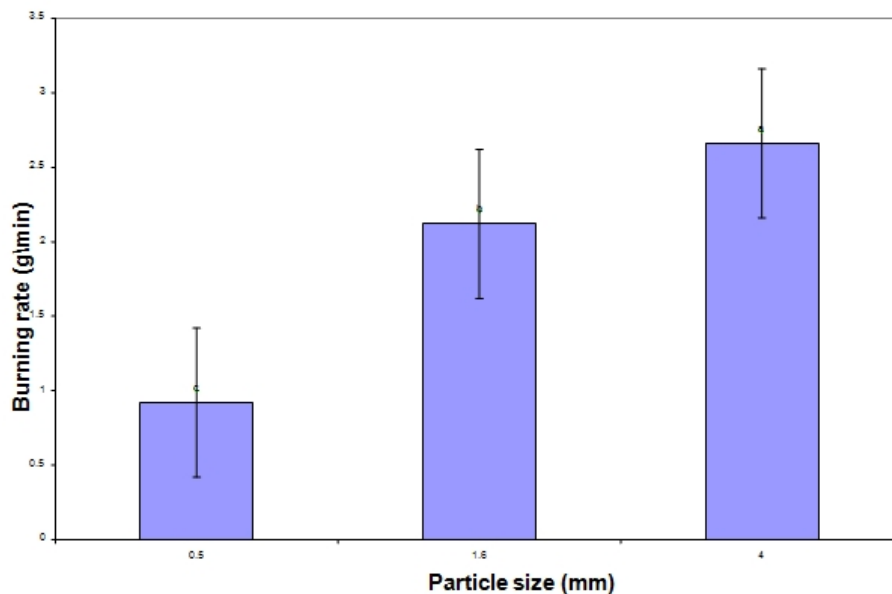Means of different letter are significantly different (P<0.05)

Fig.6 Burning rate and particle size of briquettes

Means of different letter are significantly different (P<0.05)

4. CONCLUSION

The conclusions drawn from this study are as follows:

i.   The results suggest that briquettes produced from mixture of water hyacinth and plantain peel briquettes could be good biofuel than one from water hyacinth alone.

ii   The effect of pressure, binder proportion and particle size on the burning rate and ignition time revealed significant different at 5% probability level.

iii   Increased in compaction pressure caused decrease in the burning rate but elongated the ignition time of the briquettes.

iv   The burning rate of the briquettes decreased with increased binder proportion. The implication of this observation is that more fuel might be required for cooking with briquettes produced from B_1 than B_5. The briquettes produced from 50% binder level had the lowest burning rate and as well as highest ignition time.

RECOMMENDATION

The production of briquettes from mixture of water hyacinth and plantain peel and its utilization could be advocated since its usage as solid biofuel, will alleviate the menace caused by this aquatic plant. This will be perhaps the best method to both control and harvest. This could also enhance: rural economic development, farm income, market diversification, reduction in agricultural surplus, international competitiveness, reduced negative environmental impact and creation of employment opportunities in the area of production, harvesting and utilization.

COMPETING INTERESTS

Authors declare that there is no competing interest concerning this work.

REFERENCES

1.   Adegbulugbe AO. Energy-environmental issites in Nigeria. International Journal of Global Energy Issues 6. 1994;7-18.

2.   Energy National Commission of Nigeria (1996-2005). Project of Government of Nigeria. Project Document ECN, Abuja Adegoke CO. Preliminary investigation of sawdust as high grade solid fuel. Journal of Renewal Energy. 1999;1&2:102-107.

3.   Sambo AS. Strategic developments in renewable energy in Nigeria. International Association for Energy Economics. 2009;1-23.

4.   Emerhi EA. Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders. Advances in Applied Science Research. 2011;2(6):236-246.

5.   Akinbami JFK. Renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework. Mitigation and Adaptation Strategies for Global Change. 2001;6:155-181.

6.   Sotannde OA, Oluyege AO, Aba GB. Physical and Combustion of charcoal briquettes from neem wood residues. Int. Agrophysics. 24:189-194.

7.   Jindaporn, J, Chadchawan P, Aurawan T, Songchai W. Physical properties and combustion performance of briquettes produced from two pairs of biomass species. ENETT49-137. 2005;27-29.

8.   Jaan K, Priit K, Aare A, Viktor L, Peter K, Lubomir Š, Ülo K. Determination of physical, mechanical and burning characteristics of polymeric waste material briquettes. Estonian Journal of Engineering. 2010;16:307–316. Doi: 10.3176/eng.2010.4.06.

9.   Olorunnisola AO. Production of fuel briquettes from waste paper and coconut husk admixtures. Agricultural Engineering International: the CIGR Ejournal. Manuscript EE 06 066. Vol. 1X. 2007.

10. Bhattacharya SC, Bhatia R, Islam MN, Shah N. Densified Biomass in Thailand: Potential, Status and Problems. Biomass. 1998;8:255-266.

11. Kuti OA. Performance of Composite Sawdust Briquette Fuel in a Biomass Stove under Simulated Condition. AU J. T. 2009;12:284-288.

12. Kuti OA. Impact of Charred Palm Kernel Shell on the Calorific Value of Composite Sawdust Briquette. Journal of Engineering and Applied Sciences. 2007;2:62-65.

13. Jekayinfa SO, Omisakin OS. The energy production of some agricultural wastes as local fuel materials in Nigeria. Agricultural Engineering International the CIGR E-Journal of Scientific Research and Development Vol. VII, Manuscript EE 05 003: 10pp; 2006.

14. Oladeji JT. Briquettes Produced from Corncob and Rice Husk Resides. The Pacific Journal of Science and Technology. 2010;11:101-106.

15. Olorunnisola AO. The performance of sawdust briquettes combusted in a convectional coal stove. Journal of Forestry. 1998;28:15-18.

16. American Society of Agricultural and Biological Engineering (ASABE). Cubes, pellet and crumbles definitions and methods for determining density, durability and moisture content. St. Joseph, MI, America. 2003.

17. Ndirika VIO. Development and Performance, Evaluation of a Baking Oven Using Charcoal as Source of Energy. Nigeria Journal of Renewable Energy. 1998;12:83-91.

18. Onuegbu TU, Ekpunobi UE, Ogbu IM, Ekeoma MO, Obumselu FO. Comparative Studies of Ignition Time and Water Boiling Test of Coal and Biomass Briquettes Blend. IJRRAS 7. 2011;153-159.

19. Demirbas A, Sahin A. Evaluation of Biomass Residue Briquetting Waste Paper and Wheat Straw Mixtures. Fuel Processing Technology. 1998;18:223-228.

20. Ajayi OA, Lawal CT. Hygroscopic and Combustion Characteristics of Sawdust Briquettes with Palm Oil Sludge as Binder. Journal of Agricultural Engineering and Technology. 1997;5:29-36.

21. Chin OC, Siddiqui KM. Characteristics of some biomass briquettes prepared under modest die pressures. Biomass and Bioenergy. 2000;8:255–266.

22. Saptoadi H. The Best Biobriquette Dimension and its Particle Size. Asian J. Energy Environ. 2008;9:161-175

23. Nasrin AB Ma, Choo AN, Mohamad YM, Rohaya S, Azali MH A, Zainal Z. Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production. American Journal of Applied Sciences, 2008;5:179-183.

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