DEVELOPMENT AND PERFORMANCE EVALUATION OF A BRIQUETTE COOKING STOVE

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Development and Performance Evaluation of a Briquette Cooking Stove

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ABSTRACT

In this work, a briquette cooking stove was designed, fabricated, and tested using a mixture of sawdust from Cordia milleni and cow dung briquette as the fuel material. The briquette stove was designed and fabricated using locally sourced materials to provide heat conservation (insulated walls), ash collection, and sufficient air supply (6W rechargeable fan) for efficient combustion of the briquettes in the stove. The principal parts of the briquette cooking stove are the combustion chamber, ash pit, and pot support. The performance of the stove, in terms of cooking duration, thermal efficiency, and specific fuel consumption, was compared with that of the conventional kerosene stove and a traditional metallic charcoal-burning stove. The cooking duration, thermal efficiency, and specific fuel consumption of the briquette cooking stove were found to be 26.51 minutes, 86.34percentand 0.151 respectively. Results obtained showed that it takes less time and fuel material to cook with a briquette-burning stove than with a charcoal-cooking stove. It was also found out that the appropriate design of the briquette cooking stove configuration is critical for better performance.

1. INTRODUCTION

In a country where the prices of fossil fuels used for domestic applications have risen considerably beyond the affordability of many Nigerians who reside in the rural and sub-urban areas of the country, it is crucial to explore renewable domestic fuels, as alternative sources for use in homes. Fossil fuels cannot be renewed, therefore renewable sources of energy must be sought. Biomass energy is a source of energy that can be harnessed in homes for heating and cooking. It is cheap, safe, easily available and easy to use. Biomass materials such as groundnut shells (Oyelaran *et al.* 2015), palm kernel (Ugwu and Agbo, 2010), millet straws, wheat straws, sorghum stalks, maize stalks, corn cobs (Karunanithy *et al.* 2012), coconuts shells, rice husks (Oladeji, 2010), cotton wastes, sugarcane bagasse, water hyacinth (Davies and Abolude, 2013) can be transformed into fuel briquettes for direct burning to generate heat for cooking. The project provides a means for efficient combustion of densified agro-waste residues such as rice husk, maize husk and groundnut shells, otherwise known as briquettes. Briquettes are compressed blocks or solids of combustible biomass materials used as fuel and for kindling of fire (Olorunnisola 2007). They are made by densifying organic fibres at low pressure after it has been mixed with a suitable binder. The common forms of biomass briquettes used are ellipsoidal, perforated or holley cylinders and cylinders (Sari and Yusri 2019). The use of briquettes must be accompanied by the use of a stove with the type and size of the furnace adjusted to the size and need of the briquette. Most briquette stoves that have been sold in the market have not attracted the public's interest due to their complicated use and pollutant gas produced from the briquette burning process.

In previous research, the stove produced still had shortcomings such as baked ceramic stoves and burnt stoves easily cracked, and also slagging takes place due to poor ash removal of the existing stoves (Sari *et a*l 2020). Briquette combustion is usually associated with smoky flames, unsteady combustion and low thermal efficiency due to stove structure. The project involves the modification of the briquette combustion system, so as to obtain improved burning characteristics, such as steady combustion, higher calorific value, high thermal efficiency, no smoky and bluish flame. This paper presents a report on the development and performance evaluation of a briquette burning stove.

MATERIALS AND METHODS

Design Consideration

The following factors were considered in the design of the stove;

1. Thermal efficiency:
   The thermal efficiency of the cooking stove depends on the efficiency of convective heat transfer of the hot gases to the pot (Clarke 1983). Minimal distance was ensured, so as to minimise heat losses. The thermal efficiency was also improved by using a lightweight material such as mild steel that would absorb minimal heat during the combustion of the fuel. The thermal efficiency of the stove could be improved by wall insulation (glass-fibre).
2. Cost of Production:
   The cost raw materials and cost of fabrication of the briquette cooking stove was low, so as to achieve affordability by low-income households in rural and suburban communities.
3. Ash Removal:
   Ash collection improves the burning characteristics of the fuel, the ash collection chamber is located at the bottom of the stove and the ash falls into it due to the force of gravity.
4. Ease of manufacturing and subsequent maintenance:
   The stove's configuration allows for easy development for home use with little expertise.
5. Portability:
   The briquette cooking stove was designed to be compact and small in size, so as to allow for easy movement.
6. Regulated Air Inflow:
   A regulated fan was installed in the stove to provide auxiliary air or induced draught needed for the complete combustion of the briquette.
7. Sufficient load support:
   It was required that the stove be able to sufficiently bear the load equivalent of 25kg. The design ensured that appropriate material was selected for the construction.

Design

(i) Volume of Stove Chamber: The diameter of the chamber is expected to be higher than that of the briquette biomass. Assuming an internal diameter of 205mm for the stove, since it was to contain the briquette.

Therefore, $V = \pi r^2 h$ **(1)**

r= Radius of the chamber= 205/2= 102.5mm

h= height of the half of the chamber= 130mm

$= 3.142 \times 102.5^2 \times 130 = 4{,}291{,}382.88\ mm^3$

Volume of Chamber= $4{,}291{,}382.88\ mm^3$, Volume of Briquette= $1{,}525{,}833.75mm^3$

Since volume of Chamber is larger than the volume of Briquette, the design is sufficient.

(ii) Stress on the combustion chamber of the Briquette Stove: The stress developed in the stove structure can be computed through the following steps.

Force on stove =m x a (2)

m= mass of pot and content

a= acceleration = $9.81m/s^2$

Therefore, the force on the stove is

Force = 20 x 9.81= 196.2N

Area of Briquette stove= Cross sectional area of a hollow cylinder = $\pi R^2 - \pi r^2$ (3)

R = Outer radius of cylinder = 215 mm/2 = 107.5mm

r = Inner radius of cylinder = 205 mm/2 = 102.5mm

h = height of chamber = 130

Substituting the values in equation (3.17) and (3.18)

Area of stove= $3.142 \times (107.5^2 - 102.5^2)$

= 36,309.74 – 33,010.64

= $3{,}299.1\ mm^2$

Therefore, Stress on stove= $\frac{Force}{Area}$ (4)

$= \frac{196.2N}{3299.1mm2}$

$= 0.0594\ N/mm^2$

Since stress on the stove is less than the allowable stress on the stove structure (137.5MPa) according toMechanic of materials, sixth edition by Ferdinand P. Beer, *et al.*, 2012.

Description and fabrication of Briquette stove parts

The front and plan view of the briquette burning stove are shown in figure 1. It is cylindrical in shape and it consist of three compartments, namely; combustion and heat conservation unit, ash pit and air circulation unit, and separating. These and other component parts of the stove are discussed below

1. The Pot support: There are three 40mm pot supports at equal distances around the circumference of the field bed. It was fabricated using 1mm thick aluminium plates with three angle iron bars attached at three equidistant points on the plate.
2. The combustion chamber:
   This is a $2.71 \times 10^{-3} m^3$ perforated mild steel enclosure designed to accommodate a briquette of average diameter of 15cm and an average height of 5cm. A screen accommodating 19cm diameter holes was provided at the base to allow for free air intake by auxiliary draft and the passage of ashes produced during combustion n. The combustion chamber was made of a double layered wall with insulating material (glass fibre) between the wall plates.
3. Air Vents:
   For proper combustion of the briquettes, provision was made for adequate ventilation within the stove. Five air vents of 10mm diameter were uniformly distributed along the circumference of the combustion chamber. The air flow rate through each vent at maximum air velocity of 4m/s was calculated to be 0.097m/s. Air vent was also provided at the base of the ash pit using a 40 by 40 mm rectangular steel pipe which provides passage for the auxiliary air draft provided by the a 6W rechargeable fan.
4. Ash Collection:
   This is a light metal tray that collect ashes during the combustion of the fuel for disposal. It was fabricated by bending a 127 mm by 254 mm mild steel sheet into a cylindrical form and welding it.
5. The stove stand:
   These are three 50mm high box-like metallic structures located at equal distances around the circumference of the bottom of the stove. They were provided to prevent rusting and attendant heat loss through leakages occasioned by direct contact between the stove bottom and the ground.

The stove components were assembled together according to the drawings shown in fig 1 to fig 3 while the stove assembly is shown fig 4

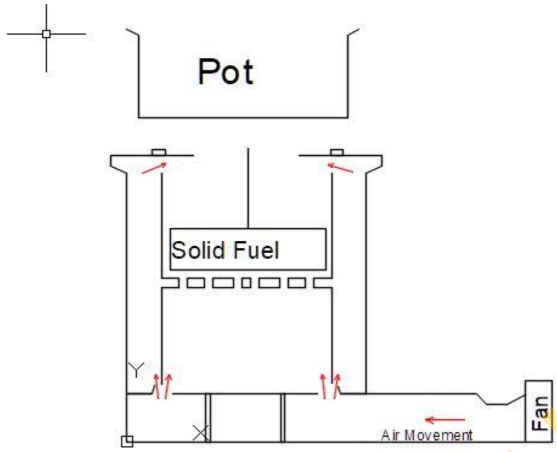

Fig 1 Schematic of Briquette cook stove

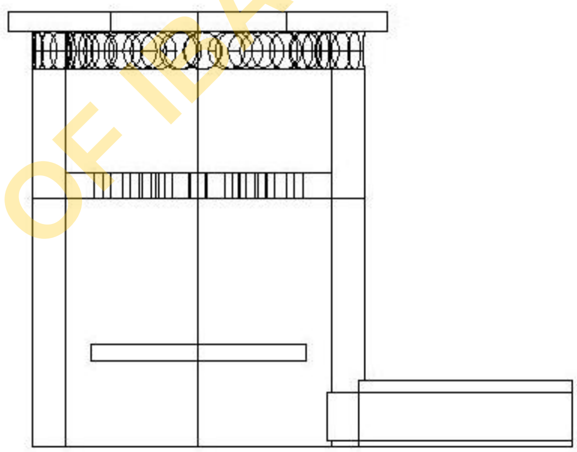

Fig 2 Side View of Briquette Stove

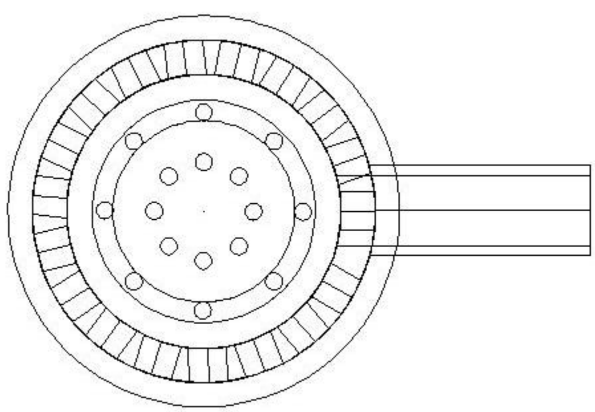

Fig 3 Top View of Briquette Stove

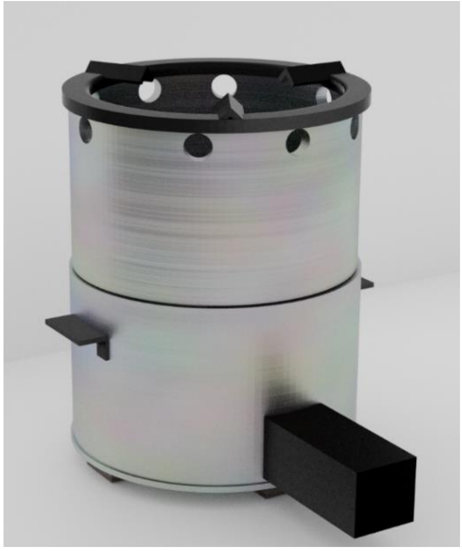

Fig 4 Rendered view of Briquette stove assembly

2.4 Operation of the Briquette cook stove

Fuel briquette is loaded from the top of the stove into the combustion chamber. The briquette pieces are of size D = 150mm and H = 55mm (Plate 1). The fuel briquette was suitably placed in the combustion chamber with the flat base resting on the grate to facilitate better air draft and more efficient combustion of the briquettes. The briquette was lit with fire and kerosene.

Plate 1.0 Briquette used in testing of Stove

Plate 1.1 Loaded Briquette stove

Performance evaluation of the Briquette cookstove

The performance of the briquette stove was evaluated based on comparison with the thermal efficiency, fuel consumption, and cooking duration of conventional kerosene cook stove and metallic charcoal stove. Water boiling test was carried out according to the method adopted by Obi *et al* 2016.

Water Boiling test:

The dry weights of experimental objects such as the pot and stove were taken and recorded during the water boiling test (WBT). The pot was filled with a known weight of water at the start of the experiment, and the same weight was maintained throughout. The temperature of the water was measured at five-minute intervals until the water reached a strong boil. The WBT yields numerous indicators for assessing cookstove performance, among which are thermal efficiency (H), Specific Fuel Consumption of the stove per unit of water boiled, and briquette burn rate (Anenberg *et al* 2013).

a. Thermal efficiency

In any thermodynamic system, thermal efficiency is a measure of the proportion of total energy that is used productively. This is the proportion of work done by heating evaporating water to energy consumed by burning wood. According to Olorunnisola (1999), a cooking stove's thermal efficiency is largely determined by how well heat is transported from the hot gas fuel line to the pot or vessel on the stove (convective heat transfer). The percentage heat utilized (PHU) or specific fuel consumption is used to calculate thermal efficiency.

$$\eta th(100\%) = Burn\ rate\ x\ PHU$$

b. Specific fuel consumption

The specific fuel consumption is the amount of solid fuel equivalent used in completing a particular task divided by the task's weight is known as specific fuel consumption. It can be written as:

PHU = Mass of fuel consumed/Total mass of cooked food

c. Briquette burn rate

The approach used by Onuegbu *et al*. (2012) to determine briquette burn rate was used in the experiment. A known-weight briquette sample was ignited using a burner, and the weight loss was monitored every 10 seconds with a stopwatch throughout the combustion process until a constant burnt weight was attained. The weight reduction at a certain time was calculated using the following formula:

Burn rate = Total weight of burnt briquette (kg)/Total time taken (hr)

RESULTS AND DISCUSSIONS

The stove chamber was designed to be cylindrical and it could accommodate a volume of 4719653 mm^3. The combustion chamber walls was made of a double layer of 3mm thick mild steel stuffed with fibre glass at the centre to reduce heat loss to the surrounding. A screen (separating grate) accommodating twenty-five 10 mm diameter holes is also provided at the base of the combustion chamber for air intake up by draft and the passage of the ashes down to the ash pit during combustion. The Ash pit is responsible for collection of the ash that results from the combustion of the briquette and the channelling of the air by secondary draft (auxiliary fan) to the briquettes. The pot support and stand were made of mild steel. It had a diameter of 225 mm and has three equally spaced 50 mm long angle iron attached at an equidistant on its circumference. The stove stand gave the stove a height projection of 50 mm. The stand prevents rusting and heat losses through leakage occasioned by direct contact between the stove base and the ground surface. The components of the fabricated Briquette stove are shown in plate 1.2 to 1.6.

Plate 1.2 Insulated wall of Combustion chamber

Plate 1.3 Air circulation and Ash Collection pit

Plate 1.4 Separating Grate

Plate 1.5 Pot support

Plate 1.6 Briquette Cooking stove

3.1 Specific fuel consumption, Thermal efficiency and Briquette burn rate

Water boiling test was carried out to determine the indicators of the briquette stove performance (Specific fuel consumption, Thermal efficiency and Briquette burn rate), as shown in plate 1.7.

Plate 1.7 Water boiling test

The testing of a briquette stove involved two phases; cold testing and hot testing phase. The result for the cold and hot testing phase were tabulated and shown in table 1.2 and 1.3. Water boiling test was carried out to determine the briquette burn rate, specific fuel consumption, thermal efficiency of the stove according to Olorunnisola 1999. When tested with different briquette samples of similar moisture content (±2%), the stove exhibited average thermal efficiency, briquette burn rate and SFC of 86.34%, 577.87 g/hr, and 0.151 respectively. The thermal efficiency of the briquette stove improves as the moisture content of the briquette material decreases, whereas the specific fuel consumption rises as the moisture content decreases. This means that the quality of the fuel material has a significant impact on stove performance. Likewise, it is clear from the results that the fuel burn rate has a considerable impact on the stove's thermal performance. If thermal stove performances are to be optimized, the ability to adjust fuel burn rate is crucial, and there is an ideal fuel burn rate that might deliver maximum stove efficiency for any given situation (Bello and Onilude, 2020).

The results of the WBT using the three stoves; briquette (Plate 1.7) kerosene cookstove (Plate 1.8) and metallic charcoal stoves (Plate 1.9) are presented in Table 1.2 to 1.3. It took lesser time to boil water on the briquette stove than on the other two cookstoves. It took 26.51 mins, 28 mins and 40 mins respectively to boil 1000g of water on the briquette cookstove, kerosene cookstove and metallic charcoal stove respectively.

Table 1.2 Cold testing phase

Performance parameters	**Briquette cookstove**	**Conventional Kerosene cookstove**	**Metallic charcoal stove**
Thermal efficiency (%)	86.34	89	93
Specific fuel consumption ()	0.151	0.147	0.713
Fuel burn rate (g/hr)	577.87	152.03	436
Time to boil (mins)	26.51	28	40

Table 1.3 Hot Testing phase

Performance parameters	**Briquette cookstove**	**Conventional Kerosene cookstove**	**Metallic charcoal stove**
Thermal efficiency (%)	89.86	91	93.3
Specific fuel consumption ()	0.153	0.146	0.427
Fuel burn rate (g/hr)	579.40	152.03	467.21
Time to boil (mins)	20.21	27.2	28.3

The calorific value of the briquette burned and the volume of air allowed into the combustion chamber determine the briquette stove's thermal efficiency. According to results obtained by Sotannde *et al.* 2010, a thermal efficiency of 85 percent was sufficient for a cookstove, the briquette stove's thermal efficiency, specific fuel consumption, and fuel burn rate were all within acceptable norms (Sotannde *et al.* 2010). The stove also boiled water faster than a traditional kerosene cookstove or a metallic charcoal stove, which are common in rural areas. As indicated in Table 1.2, the briquette cookstove's specific fuel consumption value (0.151) was lower than the charcoal cookstove's (0.713), but not considerably higher than the Kerosene cookstove's (0.147). The relevance of this finding is that utilizing the briquette stove, less briquettes would be required to boil the same amount of water. Using the briquette stove may save more money if briquettes and charcoal products have similar market values.

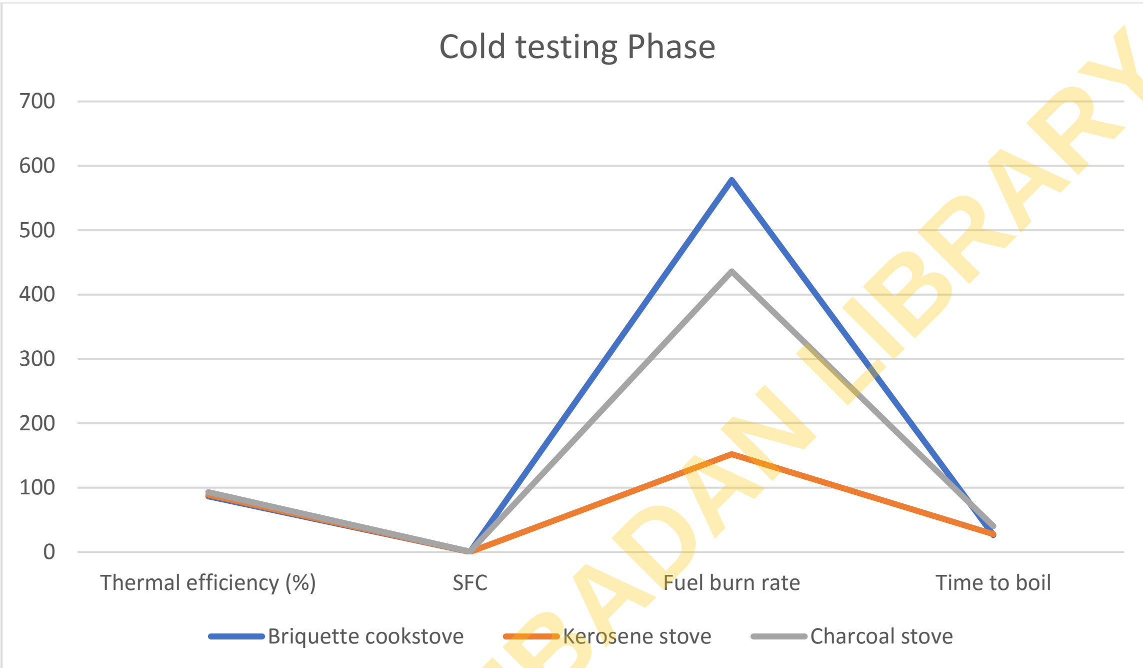

Fig 1 Cold testing phase

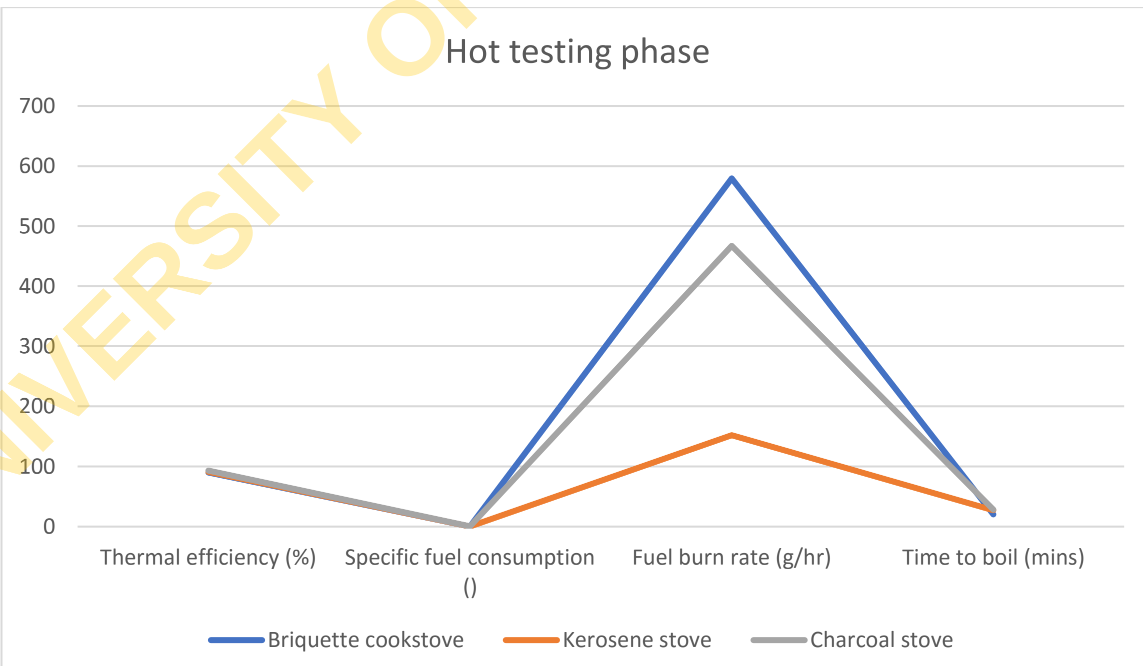

Fig 2 Hot testing phase

The thermal efficiencies and specific fuel consumption of the three cookstoves differed less significantly because the values were on the same plot line of the graph, but the burn rate and time to boil/cook were found to be the most significant differences in the stove performance, as shown in Fig 1 and Fig 2.

CONCLUSION

An improved performance briquette stove that provides an efficient environment for the combustion of biomass briquette was successfully developed and the performance characterised.

REFERENCES

Anenberg, S.C.; Balakrishnan, K.; Jetter, J.; Masera, O.; Mehta, S.; Moss, J.; Ramanathan, V. Cleaner Cooking Solutions to Achieve Health, Climate, and Economic Cobenefits. Env. Sci Techno. 2013, 47, Pp. 3944–3952.

Bello R. S., Onilude M. A. (2020): Combustion Characteristics of High Density Briquettes Produced from Sawdust Admixture and its Performance in Briquette Stove. London Journals Press. Volume 20, Issue 3, Compilation 1.0. Pp 85-87

Clarke R., 1985. Wood-stove Dissemination. Proceedings of the Conference held at Wolfheze, The Netherlands. Intermediate Technology Publications, 9 King Street, London. pp 97-102.

Davies, R.M and Abolude, D.S. (2013). Ignition and Burning Rate of Water Hyacinth Briquettes. Journal of Scientific Research and Reports. 2 (1):111 -120

Karunanithy, C., Wang, V., Muthukumarappan, K., and Pugalendhi, S. (2012). Physiochemical Characterization of Briquettes Made from Different Feed Stocks. Biotechnology Research International. pp 7-12.

Obi O.F., Okongwu K.C.H. (2016): Characterization of fuel briquettes made from a blend of rice husk and palm oil mill sludge. Biomass Conversion and Biorefinery, 6, Pp. 449–456

Oladeji, J.T. (2010) Fuel Characterization of Briquettes Produce from Corncob and Rice Husk Residue. The Scientific Journal of Science and Technology. 2 (1): 101- 106

Olorunsola, A.O., 1999. The development and performance evaluation of a briquette burning stove. Nigerian J. Renewable Energy, 7(1), pp.91-95.

Olorunnisola A. (2007): Production of Fuel Briquettes from Waste Paper and Coconut Husk Admixtures. Agricultural Engineering International: the CIGR Ejournal. Manuscript EE 06 006. Vol. IX. Pp. 5

Onuegbu T.U., Ekpunobi E., Ogbu I.M., Ekeoma M.O, Obumselu F.O. (2012): Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. International Journal of Research & Reviews in Applied Sciences, Vol.7, 5. Pp.153–159

Oyelaran O. A. Bolaji B. O. Waheed M. A. and Adekunle M. F. (2015). An Experimental Study of Combustion Characteristics of Groundnut Shells and Waste Paper Admixture Briquettes. KKU Energy Journey; 42(4): 283-286.

Sari E, Humaira A, Yusri F. 2019.Effect of pressure and mold shape on the quality of the bio-briquette from the durian peel biomass mixture. Research report. Bung Hatta University, UBH. Padang.

Sari. E, Burmawi., Khatab. U., Rahman. E.D., Panindi. A., Andriyati. E., Amri. I. (2020):Design of Biomass Briquette Stoves: Performance Based onMixed of Durian Bark, Coconut Shell and Palm Shells as Materials of Bio Briquette. The 5th Engineering Science & Technology International Conference. Materials Science and Engineering (990). Pp 1-2

Sotannde, O. A., Oluyege, A. O. and Abah, G. B. (2010). Physical and Combustion Properties of Briquettes from Sawdust of Azadirachta indica. Journal of Forestry Research, 21(1): Pp. 63 – 67.

Ugwu K.E and Agbo K.E., (2010). Briquetting of Palm Kernel Shell. Federal University of Technology Owerri, (FUTO) Alternative Energy International Conference 2010. Owerri, Nigeria.