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Comparative analysis of gum Arabic and molasses (binders) in briquettes produced from millet husks

Arzika A. Tambuwal[1*], Abdulhameed Salihu[2], Yunusa M. Boyi[1], Sani Garba[3], Adamu S. Muhammad[1], Yusuf Sahabi[3], Hauwa'u Umar[3] and Mubarak Muhammad[3]

[1]Department of Chemistry, Shehu Shagari College of Education, Sokoto – Nigeria.

[2]Department of Physical Sciences, Niger State Polytechnic, Zungeru, Niger - Nigeria.

[3]Department of Science Laboratory Technology, College of Science and Technology, Umaru Ali Shinkafi Polytechnic Sokoto – Nigeria.

*Corresponding author's email:

arzikatambuwal1982@gmail.com

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The study was carried out to investigate the effects of binders (molasses and gum Arabic) on millet husk in the production of briquettes. Fixed quantities of millet husk were used to produce briquettes with varying percentage of binders (10%, 20% and 30%). Low pressure fabricated briquetting machine was used for compression to produce the briquettes, after sun drying to reduce the moisture content to minimum value. The proximate analysis conducted, indicated the range of moisture content% (2.1-3.0) ash content% (7.8-11.4) volatile matter% (61.9-76.6) and fixed carbon% (13.0-26.5). The physical properties had the values ranging from (0.52-0.60), (0.18-0.24) (1.69-1.80), (2.31-3.14), (3.5-23.2), (4.7-30.2) for compressed density (g/cm^3), relaxed density (g/cm^3), compaction ratio, relaxation ratio, durability (%) and water resistant (sec) respectively. The fuel density included ignition time (sec), after glow(sec), boiling time (minutes) and calorific value (J/kg) with the value ranging from (2.3-8.3), (2.0-24.4), (16.10-19.13) and (29830.95-30119.84) respectively. The study shows that millet husk with gum Arabic serves as a better combination for the production of briquettes.

Keywords: Millet husk, Gum Arabic, Molasses.

1. Introduction

Briquetting is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel (Ahmad, 2010). The intention for complete substitution of wood fuel by other sources will certainly take a few decades to materialize. In the interim, the development, production and active utilization of agro-residue briquettes will certainly be a step in the right direction. The briquetting of agro-residues is one of the numbers of ways that has been developed to solve the problem of over dependence on wood as source of fuel. Briquetting thereby puts the huge volume of waste from agriculture and agro processing to some useful purposes (Ikelle *et al.,* 2017).

Briquettes are made by compressing loose particles to give a firm, homogenous and compact material. This is achieved with the help of binders. Binders are adhesive substances, which cause mechanical interlocking between particles and hold them together firmly. The strength of the binder's adhesion is aided by the application of pressure and sometimes, increased temperature. The aim of a binder is to bring together different particles to give a densified bulk material. The product must be firm and solid enough to withstand rough handling without disintegrating. The densified material (briquettes) should have a bulk density greater than the original loose material. Beyond these, a good binder should make a better fuel with higher calorific value. Ultimately, the binder becomes part of the briquette and cannot be removed.

The type of binder used to make a briquette impacts on it fuel properties. Generally, organic binders contain less ash because they are combustible. This increases the calorific value per unit weight of the briquette. Hence, organic binders have a net positive impact on the briquette's physico-chemical and heating properties. Inorganic binders have the advantage of low smoke emission when compared to organic binders. They also make more solid and firm briquette, but whose combustion produces a lot of ash. This is because of the high mineral content the inorganic binder adds. This reduces the calorific value of the briquette and makes it less, a quality fuel. (Sani, 2008).

The best binder to use in making briquettes depends on the locality, on the character of the biomass material, and on the purpose for which the briquettes are intended. It also depends on how the binders affects the quality of briquettes made, its durability, heating value, relaxed density, etc. Extra care is necessary in drying and handling these briquettes, and this adds to their cost. The main problem in briquetting using binders is to find a suitable binding material at sufficiently low cost that will improve the quality of the briquettes (Nkemdirim, 2014).

The aim of this research therefore is to study the effect of some selected binders (Acacia gum and Molasses) in the production of briquettes from millet husk using a manual low pressure compressor. Millets are a group of small seeded species of cereal crops or grains widely grown around the world for food and fodder. They are prevalent in semi-arid tropics of Asia and Africa. Millet husk is gotten from the harvest of millet before it is being sold in the market (Jimoh *et al*., 2013).

2. Materials and Methods

2.1 Preparation of the Briquettes

A cylindrical mould of 18.6cm in height, 8.5cm internal diameter and a metal piston of 8.5cm in height, 8.4cm diameter was constructed and used for the production of briquettes. Briquettes of various compositions were produced using the biomass residues and gum Arabic, molasses as binders. The biomass sample millet husk and the binders (gum Arabic and molasses) were thoroughly mixed separately, in order to obtain a uniformly blended mixture. The mixtures were prepared by combining fixed weight of the millet husk (350g) to 10%, 20% and 30% molasses (35g, 70g and 105g respectively) the same quantities were used for millet husk and gum Arabic. The samples were separately hand-fed into the mould, compressed and compacted. The dwell time of 5 minutes was used. According to the design of the mould only a briquette was produced per batch. The pressure will then be released gradually to eject the compressed briquettes. After each successive operation whereby shaped briquettes were obtained, the products were sun dried in open space to remove the inherent moisture content to a tolerable level (Ayodele, 2014).

2.2 Proximate Analysis of the Briquettes Produced

The proximate analysis was carried out on the same sample according to standard methods of the American Society for Testing and Materials (ASTM) as reported in Ayodele (2014). This includes moisture, ash, volatile matter and fixed carbon contents.

2.3 Determination of Fuel Parameters of Millet Husk Briquettes

2.3.1 Determination Calorific Value/Heating Value

The heating values of the briquette samples were determined using AC-350 calorimeter. In the experiment, 1.00 gram of the briquette sample was weighed and placed in a crucible with a fuse wire tied across at two ends and carefully put into a bomb. Oxygen gas was introduced into the bomb at a pressure of 450 Psi and then placed in the combustion chamber containing 200 ml of distilled water. On closing the combustion chamber, the stirrer was put on to ensure homogeneous temperature in the chamber. The electronic thermometer measured the difference in water temperature during the combustion of the sample in bomb. The result (calorific value) was displayed on the screen. (Ryemshak *et al.,* 2015)

2.3.2 Water Boiling Test (WBT)

This was carried out to compare the cooking efficiency of the briquettes. It measures the time taken for each set of briquettes to boil an equal volume of water under similar conditions. During the process, 70g of millet husk briquettes sample were used to boil 200 ml of water using small stainless cups and domestic briquette stove (Ikelle *et al*., 2017)

2.3.3 Ignition Time

The samples were ignited in a wind free corner. The fuel samples were clamped 5cm over a burner (stove). The time between exposure to the heat source and the first visible flame is the ignition time (Ayodele, 2014).

2.3.4 Afterglow Time

After the ignition of the briquettes, it was further heated for 30 seconds. At that point, there was a flowing stream of gas and a glow in the briquette. The briquette was removed from the heat source. The time between the removal and the last perceptible glow is the afterglow time (Ayodele, 2014).

2.4 Determination of Physical Properties of Millet Husk Briquettes

2.4.1 Compaction Ratio

This was determined as the ratio of the depth of the mould to the height of briquette produced. This was done using a measuring tape (Sotande and Alandele, 2010).

2.4.2 Compressed Density

The mean compressed density was determined immediately after removal from the mould, as a ratio of measured mass (g) over calculated volume (cm^3) (Olorunsola, 2007). The mass was obtained using a weighing scale and venire calliper was used to obtain the linear dimensions for calculated volume. The ratio of measured mass over calculated volume was then determined using the formula

$V = \pi r^2 h$ ---------------------- (1)

Where: V = Volume, h = Height, π = Constant, r = Radius

2.4.3 Relaxed Density

The relaxed density of the briquettes was determined using sun dried briquette samples. Relaxed density is also known as spring back density. The relaxation density was calculated as the ratio of the briquette's weight (g) to the new volume (cm^3). (Olorunsola, 2007)

2.4.4 Relaxation Ratio

The relaxation ratio of the briquettes was determined in the dry condition of the briquettes after sun drying. The relaxation ratio was calculated as a ratio of the compressed density to the relaxed density (Olorunsola, 2007). This helps observe the relative stability of the briquettes after compression.

2.4.5 Durability

The briquette sample was dried to a constant weight and then dropped from a height of 1.5meters onto a metal base. The fraction of the briquette that remained un-shattered, was used as an index of briquette durability in percentage, (Suprin *et al.,* 2008)

The durability was calculated using equation

% Durability = (Ma/Mb) x 100 ----------- (2)

Ma = mass of briquette after dropping

Mb = mass of briquette before dropping

2.4.6 Water Resistance

Water resistance of the briquettes was tested by immersing the briquette in a container filled with cold tap water and measuring the time required for the onset of dispersion in water. The higher the water resistance values, the more stable the briquettes are in terms of weathering resistance (Richards, 1990).

3. Results and Discussion

The results from the study are presented in Tables 1 to 4 below.

Table 1: Proximate Composition of Millet Husk Briquettes (Moisture content, Ash content, volatile matter and fixed carbon of briquettes produced)

Materials	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)
MH 10% MO	2.8	10.0	67.5	19.7
MH 20% MO	2.7	9.0	69.4	19.0
MH 30% MO	3.0	8.6	61.9	26.5
MH 10% GA	2.1	11.4	71.8	14.7
MH 20% GA	2.6	7.8	76.6	13.0
MH 30% GA	3.0	8.3	67.4	21.3

MH: Millet husk, MO: Molasses, GA: Gum Arabic.

Table 2: Compressed density, relaxed density, compaction ratio and relaxation ratio of briquettes produced

Materials	Compressed Density (g/cm^3)	Relaxed Density (g/cm^3)	Compaction Ratio	Relaxation Ratio
MH 10 % MO	0.52	0.19	1.71	2.69
MH 20% MO	0.58	0.24	1.80	2.37
MH 30% MO	0.56	0.24	1.69	2.31
MH 10% GA	0.56	0.18	1.79	3.14
MH 20% GA	0.60	0.20	1.71	3.01
MH 30% GA	0.60	0.20	1.72	2.93

MH: Millet husk, MO: Molasses, GA: Gum Arabic.

Table 3: Ignition time, Afterglow time and water resistance and durability of briquettes produced.

Materials	Ignition time (sec)	Afterglow time (sec)	Water resistance (sec)	Durability
MH 10 % MO	8.3	3.7	9.0	5.9
MH 20% MO	5.5	2.0	7.6	23.2
MH 30% MO	6.4	3.0	4.7	5.1
MH 10% GA	2.8	18.2	30.2	3.5
MH 20% GA	3.6	24.4	23.1	17.1
MH 30% GA	2.3	13.3	22.7	14.3

MH: Millet husk, MO: Molasses, GA: Gum Arabic.

Table 4. Calorific value and water boiling test of briquettes produced.

Materials	Calorific value (KJ/kg)	Water boiling test (g/min)
MH 10 % MO	29372.08	17.04
MH 20% MO	29372.15	16.10
MH 30% MO	29830.95	16.89
MH 10% GA	29095.75	16.97
MH 20% GA	30119.84	14.46
MH 30% GA	29887.89	19.13

MH: Millet husk, MO: Molasses, GA: Gum Arabic.

3.1. Proximate Analysis of Briquettes Produced

Table 1 gives the results for proximate analysis of the produced briquettes. The moisture content of the briquettes were below the required range of 5 and 10% for successful densification as recorded by Bianca *et al*., (2014). The moisture content of all the briquettes produced were between the range of 2.1% - 3.0%. This may be as a result of the high level of heat experienced during sun drying. The moisture content is below the required range which has the effect of making the briquettes to be weak and fragile within a short period of time according to Nkemdirim, (2014), the briquettes still have the advantage of high combustibility and high flame temperature.

The volatile matter for briquettes made from millet husk and molasses, gum Arabic binders ranges from 61.9-69.4% and 67.4-76.6% respectively. Ikelle and Mbam, (2014), stated that when the particles of a combustible material are loose, the briquettes produced would have more volatile matter during pyrolysis. The result indicates that the volatile matter increases as the percentage binder increases which shows that the binders had the influence of increasing the volatile matter.

Fixed carbon is a measure of the solid combustible material in solid fuel after the expulsion of volatile matter Adekunle *et al*., (2015). High fixed carbon implies high calorific value. The increase in fixed carbon when compared to the overall constituents is most likely due to the concentration of binder in the briquette preparation Onukak *et al*., (2017). From the results, the briquettes produced from millet husk to (Molasses or gum Arabic) binders have the percentage fixed carbon value of 19.0-26.5% and 13.0 – 21.3% respectively. From the result it can be deduced that millet husk with molasses had better fixed carbon, therefore may have higher calorific value. The result also indicates decreases in the percentage fixed carbon with increase in binder ratio.

Onukak *et al*., (2017) stated that high ash content decreases the burning rate and reduces the heating value of fuel. The briquettes with higher ash contents are due to the presence of more non-combustible compounds; as such they had lower calorific values Ikelle and Mbam, (2014). The lower the ash content the better the quality of fuel briquettes. High ash content results in high dust emissions which lead to air pollution and affects the combustion volume and efficiency. The general values of ash content may appear in a range of 5-20% (Ige *et al*., 2018). The ash content values obtained in this work were within the general value.

3.2. Physical Properties of Briquettes Produced

Results for the physical properties of the produced briquettes are shown in Table 2. From the table, the density of the compressed mixture increased with reduction in the particle size and increased with an increase in the binder ratio level. The compressed density of the briquettes, which is the density obtained immediately after compression Olorunnisola, (2007). It was also observed that the higher the compaction pressure, the higher the density Oladeji and Enweremadu, (2012).

The results shows that increase in the binder ratio, the better the compressed density obtained. Both binders competed almost equally in this regard. One of the parameters used to characterize briquettes is relaxed density, i.e. the density of briquette after removal from the press **(**Olorunnisola, 2007). The increase in volume with fixed mass will ultimately result in reduction in the density. The briquette that expands more after extrusion will have the least relaxed density and vice versa Bamgboye and Bolufawi, (2008). High density is an indication of longer burning time Babajide*et al.,* (2018). The result shows that the briquettes produced increase in relaxed density as the binder increases.

Higher compaction ratio implied more void in the compressed materials. Higher value indicates more volume displacement, which is good for packaging, storage and transportation and above all, it is an indication of good quality briquettes. It was observed that the compaction ratio increased with increasing pressure and decreased with increasing binder ratio Oladeji, (2012). The result shows that the compaction ratio decreases with increase binder ratio. It also indicates that millet husk with gum arabic had higher value, therefore serves as a better combination in terms of compaction ratio. The higher density and the lower relaxation ratio may perhaps be due to the plasticity and better bonding nature of binder enabling the briquetted materials to form stronger bond, consequently resulting in a denser and more stable product during compaction Frank and Akhihiero, (2013). There is significant effect of particle size and of binder ratio on the relaxation ratio Joshua, (2017). According to the result, it is apparent that the more the binder the lower the relaxation ratio.

3.3. Fuel Properties of Briquettes Produced

The analyses conducted for the determination of fuel properties include: Ignition time, afterglow time and water boiling test. Table 3 gives the results for the fuel properties of the briquettes.

The results show that the briquettes produced generally increase in durability as the binder ratio increases, which conform to the statement of Davies and Davies, (2013) that the amounts of binder used have significant influence on the durability rating of the briquettes.

Hygroscopic property of briquettes at different binder proportions showed a decrease in water absorption capacity with increased quantity of utilized binder (Davies. and Davies, 2013). The result shows that the millet husk with the two binder types agrees with the statement above. That is to say increase in water resistance was observed as binder ratio increases and millet husk with gum arabic serves better in this regard. The obtained trend of the ignition time indicated that ignition time increased with increased binder proportion. The low ignition time 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. Furthermore, briquettes compressed to a higher density will tend to have a lower porosity, and thus elongate the ignition time Davies and Abolude, (2013)**.** It can be observed from the result that ignition time increases with increase in the quantity of the binder. It can also be observed that the millet husk with gum arabic combination had lower values of ignition time, which could be due to low bonding force.

Pressure has minimal influence on the duration of lighting briquettes Onchieku, *et al*., *(*2012). The afterglow time decreases with increase in binder except in the case of 20% gum arabic ratio. This could be due to irregular application of pressure during compression which is contrary to the statement of Onchieku, *et al*., *(*2012). Heat value or calorific value determines the energy content of a fuel. It is the property of biomass fuel that depends on its chemical composition and moisture content. The most important fuel property is its calorific or heat value Aina *et al*., (2009). The higher the fuel's ash content, the lower the calorific value. The higher the number of carbon content of the briquettes the higher the calorific values, while the briquettes with low carbon content do have lower calorific values (Ikelle, *et* al., 2017).

The result in Table 4 shows that the briquettes produced increase in calorific value as the binder increases. Also the abnormal values obtain can be as a result of the irregular pressure applied during compression. The fuel briquette's density will affect its bulk thermal properties, the thermal conductivity will be reduced as the density is decreased (increased fuel porosity), but the lower the density, the less heat is required for a specific volume of fuel to reach the ignition temperature (Ikelle and Mbam, 2014).

Okia*et al.,* 2017 states that biomass having highest calorific value does not guarantee shortest water boiling time. The result in table 4 shows that the briquettes with gum arabic binder boil water faster than those with molasses binder. The binder ratio's influence could not be ascertained, which may be due to the irregular pressure during compaction.

4. Conclusion

Biomass briquettes are efficient and effective alternative source of fuel that will mitigate the felling of trees especially in rural areas. The challenges facing the environment can also be reduce through the use of briquettes. In this study, the briquettes produced shows that millet husk with molasses have better qualities and efficiency in adding to the physical strength while millet husk with gum arabic serves better with regards to proximate analysis and fuel property.

Conflict of Interest

The author declares that there is no conflict of interest.

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