Physical and Thermal Properties of Briquetted Fuel of Carbonized Faecal Waste with Different Binders

Abich S. Otieno, Nyaanga D.M., Kabok P. Aguko

***Abstract*- Solid biomass fuels are widely used in developing countries as a source of energy. In Kenya for instance, the forest cover is 7.8% and is in decline with annual population growth rate of 2.7%. The demand for wood-based biomass is thus expected to surpass the supply as an estimated 90% of the population of developing nations depends on it. Thus it is important to find a supplementary energy source that works with existing cooking and heating methods. The objective of the study was to analyze the physical and combustion characteristics of briquettes from human faecal matter mixed with different binders. The faecal matter briquettes were prepared by carbonization and then compression of dried faecal waste put in a muffle furnace at 650^{0}C for 7 hours. Molasses, red soil, oil gum and starch binders were used at 15% to mass of the carbonized faecal waste and extruded at a pressure of about 5 MPa. It was found that all the binder-feacal waste combinations are possible heat energy sources. The red soil briquettes had better qualities, though variables assessed were significantly different at five percent level of probability. Additional research may need to be done with different binders and binder percentages for socio economics and environmental concerns.**

***Index Terms*—Binders, Carbonization, Environment, Faecal Matter Briquettes**

I. INTRODUCTION

Biomass is a biological material derived from living organisms (plants and animals) [1]. Solid biomass fuels are useful and conveniently available renewable energy source, widely used in developing countries [2]. These fuels have favour today over fossil fuels due to environmental aspects. Their disadvantage is being locality based; for example, the agricultural residues are based on crop seasonality that creates an unsteady biomass supply [3].

High population growth and increase in urbanization has resulted in worldwide concern regarding sustainable development, climate change and need for energy substitution and efficient use of the conventional fuels [4]. An estimated 90% of the population of developing nations depend on wood fuel and suffers from insufficient access to reliable energy supplies[5].

Sustainable, affordable and reliable energy for all citizens is a key factor in realization of the the Kenyan Vision 2030 and identifies energy as an infrastructure enabler of its socio-economic pillar. Reference [6] noted the annual demand of fuel wood (also twigs and charcoal) in Kenya to be 18,700,000 tonnes which accounts for 70% while petroleum and electricity constitutes 21% and 9% of total energy consumption. Traditionally fuel wood is the major source of energy and provides 90% of rural and 85% urban households' energy requirement [6].The Kenya's current forest cover of 7.8% and annual population growth rate of 2.7%setsthe demand for wood-based biomass to surpass the supply [7]. This over- dependence on firewood and charcoal are factors to ecological deterioration; deforestation, increased erosion, and higher levels of air pollution [8]. People also spend most of their valuable time to collect wood fuels for cooking in rural communities due to cost and lack of sustainable fuels [9].

It is therefore important for a practical supplementary energy source in a solid form to be developed that works with existing heating methods. Recent studies have examined the use of biochar from animal manure as a fuel. Other studies have examined the pyrolysis of human faeces, but not with a view of using biochar as a fuel source [10]. Consequently, little knowledge is available on the physical and combustion characteristics of faecal matter briquettes mixed with different binders.

The briquetting process involves compressing a material to increase its density for enhanced handling characteristics. Lignin plasticization requires elevated temperature of between 160 ^{0}C to 280 ^{0}C and pressures of 4 Mpa to 60Mpa [10]. Biomass briquette can be prepared at ambient temperature and moderate pressure by compressing the biomass using a binder. In some methods, the biomass is first carbonized before briquetting [11].Common binders include and are not limited to starch (roots and cereals), molasses, clay and oil gum. According to [10] cohesion takes place chemically between the biomass particles during briquetting as a result of the surface of the particles forming absorption layers which are not free to move and which are in constant contact due to Van der Waals forces and the lignin component of the biomass. Lignin acts as gluing agent in the briquette when cooled.

By use of the abundant local materials (like faecal waste) with desirable energy content and binding characteristics, briquetted fuel could be an economic and ecologic viable

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substitute for conventional fossil fuels [12] in the world. This would be useful for the developing world.

II. MATERIALS AND METHODS

A. *Preparation of Raw Materials*

This study was carried out at the Department of Animal Science Laboratories, Egerton University, which is located at longitude 0°22'11.0"S and latitude 35°55'58.0"E near Nakuru town; located in latitude0°15'Sand longitude 36°04'E in Kenya. Human faeces were collected from Nakuru Water Services and Sanitation Company treatment plant and binders (molasses, red soil, gum oil and starch)were obtained in the Nakuru town. Liquid gum oil was collected from a food processing industry in Nakuru Town. Molasses and starch were purchased from the local shops. The red soil material was collected from the Egerton University farm. These materials were chosen because they are locally available in the Kenyan peri-urban, urban and in the rural areas.

B. *Methods of briquette production*

The faecal waste at a moisture content of 40% were dried in the sun to a moisture content of 12% then carbonized by putting it in a muffle furnace at 650^{0}C for 7 hours. The binder (molasses, red soil, oil gum and starch) concentration used in the experimental studies was 15% of weight of the carbonized faecal waste. The materials were mixed homogeneously by using 15% by weight of water until mould-condition was achieved before briquetting. This process was carried out by hand feeding faecal waste -binder mixtures into a screw thread briquetting machine and extruded at a pressure of about 5 MPa. The output briquettes were subjected to indoor drying for 7 days from a moisture content of 30% to a stable dry status before being analysed in the laboratory.

i.Density

The density of the briquettes was determined as described by [13]. Briquettes were weighed using a digital weighing scale of precision of ±0.01g. The volume was calculated by taking the linear dimensions (diameter and length) of the briquette using vernier calipers. The mean compressed density of the briquettes was determined as a ratio of measured weight to calculated volume [13]. The density was then determined by use of (1) below;

$$\rho = \frac{m}{v} \tag{1}$$

Where ρ– is density (g/cm^3)

m - is the mass (g)

V- is the volume of the briquette (cm^3)

ii.Moisture Content

The moisture content was determined in accordance with ASTM D-3173 Specification [14]. Empty crucibles were heated at 104^{o}C for 1 hour and the lids cooled in a desiccator for 30 minutes. Samples of briquettes were picked randomly then pulverized by pounding (using pestle and mortar), weighed using a digital weighing scale of precision of ±0.01gand put into the crucibles. The crucibles were quickly transferred to an oven at temperature of 104- 110^{o}C and after 24 hours, they were cooled in desiccator. The weights of the samples were hence taken and the percent moisture in the samples determined by (2);

$$MC = \frac{A-B}{A} \tag{2}$$

Where; A- Weight of sample used (g),

B- Weight of sample after heating (g)

iii.*Volatile matter content*

Empty crucibles were heated at temperature of between 450-500^{o}C for 30 minutes and covers placed and cooled in desiccator for 1 hour. Samples of pulverized briquettes were then put in crucibles of known weight and closed tightly with fitting. The content was inserted into the furnace chamber, ignited and temperature allowed to rise and maintained at 950 ± 20 ^{0}C for 7 minutes. The crucibles were then removed from the furnace, cooled in desiccators and weighed. The weight loss was calculated by use of (3);

$$Weight\ loss\ (\%) = \frac{A-B}{A} \times 100\% \tag{3}$$

Where;A- Weight of sample (g);

B- Weight of sample after heating (g)

The volatile matter content was then calculated by use of (4);

$$Volatile\ matter\ (\%) = C - D \tag{4}$$

Where;C- Percent weight loss;

D- Percent moisture content

iv.Ash content

The ash content was determined in accordance with ASTM D-3173 Specification [14]. Empty crucibles were heated to temperature 500^{0}C for 30 minutes andtheir covers placed on and cooled in a desiccator for 1 hour. Pulverized briquette samples were put on the weighed crucibles, covers placed and heated for 1 hour to a temperature of 500^{0}C. In the second hour, the samples were heated to temperature of 750^{0}C. The crucibles were removed from the furnace, cooled in desiccator before weighing. The percentage ash content was calculated by use of (5);

$$Ash\ content(\%) = \frac{A-B}{C} \times 100\% \tag{5}$$

Where; A-Weight of crucible with cover and ash residue (g); B- Weight of empty crucible with cover (g); C - Weight of analysis sample used (g).

v.Fixed carbon (%)

This was calculated by subtracting the sum of % volatile matter and % ash content from 100 as in (6)

$$\%Fc = 100\% - (\%VM + \%Ash) \tag{6}$$

vi.Calorific Value

This was calculated according to [15] using the formula as in (7);

$$Hv = 2.326(147.6c + 122v) \tag{7}$$

Where c is the percentage fixed carbon and; v is the percentage volatile matter.

The experiment was laid out using the Completely Randomized Design (CRD).The data were subjected to two-way analysis of variance at 0.05 probability level. Where significant differences were encountered, means were separated using the Fisher's LSD method.

III. RESULTS AND DISCUSSION

Table 3.1 shows the output of two-way analysis of variance that was for identification of any significant difference in the briquette properties according to the binders. The ANOVA results reveal that there were significant differences ($p>0.05$) in the qualities of the briquettes produced from the different binders with reference to the parameters studied. Different binders hence imparted different qualities to the briquettes. A significant difference between treatment means occur when $F_{calculated}$ is greater than $F_{critical}$. For instance, from Table 3.1, the density of red soil bonded briquettes were significantly different from those of the briquettes made from the other binders (molasses, oil gum and starch).The densities of briquettes made using these binders were also significantly different from each other at 0.05 probability level.

Table 3.1: Effects of binders on the physical and combustion properties of the briquettes

Parameter	Source of variation	df	Sums of Squares	MS	F-test	Prob> F	LSD
Density (kg/m^3)	Total	19	1.671347				
	Treatments	3	0.77749	0.25916	4.63905	0.01616*	0.31691
	Error	16	0.89385	0.05587			
Moisture Content	Total	19	12.18423				
	Treatments	3	10.83327	3.61109	42.7674	7.24073E-08*	0.38961
	Error	16	1.35097	0.08444			
Volatile Matter Content (%))	Total	19	797.56637				
	Treatments	3	740.25001	246.75001	68.8809	2.29776E-09^	2.53773
	Error	16	57.31636	3.58227			
Ash content (%))	Total	19	1250.53815				
	Treatments	3	1238.60064	412.86688	553.371	2.29209E-16*	1.15814
	Error	16	11.93751	0.74609			
Fixed carbon (%))	Total	19	204.11796				
	Treatments	3	164.47016	54.82339	22.1242	6.15268E-06*	2.11065
	Error	16	39.6478	2.47799			
Calorific Value	Total	19	2488491938				
	Treatments	3	2465280128	821760043	566.443	1.90512E-16*	1614.955
	Error	16	23211810.16	1450738.1			

*Significant

The effects of binders on briquette qualities are as presented in Table 3.2 below.

Table3.2: Mean Values of Physical and Combustion Properties Briquettes

Briquette binder type	Density (g/cm^3)	Moisture Content (%)	Volatile Matter Content (%)	Ash Content (%)	Fixed carbon (%)	Calorific value (KJ/kg)
Red Soil	1.0438	3.2959	15.5578	2.4862	18.2709	48047.8335
Oil gum	0.7947	1.3548	6.0838	3.4858	12.463	26428.3001
Starch	1.1135	1.8871	6.0128	5.0206	10.6183	23678.9379
Molasses	1.3479	2.6334	20.0355	5.1066	12.6322	46223.2828

i. Density

Density is one of the indices for assessing the combustion characteristics and ignition behavior of briquettes. High density is an indication of higher energy per volume ratio [16]. Based on Table 3.2 molasses bound briquettes had the highest average density of 1.3479 g/cm^3. This implies that bonding of adjacent particles was better in molasses and would signify that their briquettes give higher energy per unit volume. The others as shown in the Table 3.2 respectively implying lower energy per volume ratio compared to the molasses briquettes. Figure 3.1 re-emphasizes the differences.

ii. Moisture Content

According to [17] and [18] briquettes burn well when moisture content is between 5 to 10%. When higher than 10% it will result in swelling and disintegration of briquettes [19]. The moisture in biomass reduces the final usable energy during combustion and thus the efficiency of the energy system, contributing at the same time to increased emission pollutants. Above 67% moisture content, the moisture in the biomass makes it not to burn in a self-sustaining manner and any thermo chemical process is impossible [20] [21]. The moisture is considered a contaminant for thermo chemical processes and must be removed through physical or thermal drying [19].

The results in Table 3.2 and Figure 3.2 showed that red soil bonded briquettes had the highest moisture content of 3.7551%. The slightly higher moisture content in red soil briquettes compared to other briquettes could be due to it being more porous than the other materials. The produced briquettes were therefore, within the prescribed moisture content limits as fuel.

iii. Volatile Matter Content

From the results obtained Figure 3.2 and table 3.2, volatile matter ranged between 6.0128 – 20.035 %. Reference [16] asserted that good quality charcoal should have volatile matter range from 20 to 25%. The amount of volatile matter is a reflection of the ignitability of fuel. High volatile charcoal tends to be stronger, heavier, harder and easier to ignite but may burn with smoky flame while low volatile charcoal is difficult to ignite and burns with less smoke [18]. From figure 3.2, the briquettes produced with molasses as binder had the highest percentage volatile matter of 20.0354% but were within the acceptable range according to [19].

iv. Ash Content

The higher the fuel's ash content, the lower its calorific value [10] and according to [20] good quality briquette should have ash content between 3 to 4%. The ash is a byproduct depending on the chemical composition [22]. Biomass ash contains useful plant nutrients such as K, Mg, and P but it also contains heavy metals and therefore it is not possible for recycling to agricultural fields [23]. Ash content in the briquettes normally causes increase in the combustion remnant in the form of ash which lowers the heating effect of the briquettes. Briquettes produced with molasses as binder had the highest value of ash (5.1066%) which is significantly higher than those produced with other binders as in Table 3.1. These values are higher than those obtained by [15], High ash content results into dust emissions which lead to air pollution that affects the combustion volume and efficiency.

v. Carbon Content

Red soil binder gave the highest percentage (18.2709%) of fixed carbon compared to the others in Figure 3.2, suggesting the reasons as to why high calorific values were exhibited by these briquettes**.** The fixed carbon of the briquette is a percentage of carbon (solid fuel) available for char combustion after volatile matter is distilled off or lost to the atmosphere. Therefore, fixed carbon gives a rough estimate of the heating value of fuel and acts as the main heat generator during burning [24].The low fixed carbon in starch briquettes indicates prolonged cooking time but with low heat released.

vi. Calorific value

The calorific value is the energy released during combustion of unit mass of fuel. It forms the basis for determining the performance of energy system. [23]. As shown in Table 3.2, in all binder types and amount, red soil bonded briquettes had higher calorific values which could be due to enhanced characteristics. Red soils and clay have been observed by different researchers to have bake oven effect and fuel-saving effect with contribution to heat released from the briquettes [25]. The red soils used in this study comprised mainly small clay plates [26].

Reference [26] further stated that the type of binders used is one of the important factors which should be considered during briquetting with aim of enough heat released. They obtained calorific value of 11300 and 26 800 kJ/kg for rice husk/ bagasse briquettes while [27] found 14100 kJ/kg and 27000kJ/kg for maize cobs and lignite briquettes (with bio-binder), respectively. The calorific values obtained during this study of 13100 to 26.03 MJ/kg are comparable to the above findings as in Table 3.1 and Figure 3.3. All the briquettes produced from the binders used fulfilled the requirement for making commercial briquettes which require a minimum calorific value of 17.5MJ/kg.

IV. CONCLUSIONS AND RECOMMENATIONS

This study examined the physical and combustion characteristics of briquettes produced from carbonized faecal waste using different binding agents. Based on the findings, the following conclusions and recommendations are suggested:

i. Good quality and highly storable briquettes can be produced from the blend of carbonized faecal waste with all the binders. This is because the briquettes produced have sufficient density.

ii. This study found that the physical and combustion characteristics of the produced briquettes were significantly affected by the type of binder used..

iii. Out of the binders examined, molasses and red soil bonded faecal waste briquettes exhibited the most positive attributes for density, per cent volatile matter, fixed carbon and calorific value than the starch and oil gum binders. Though molasses and starch bonded faecal matter briquettes had higher ash content.

iv. The best strategy in this study would be pressing a blend of faecal waste with red soil.

v. More research could be undertaken with varied binder percentage and other binders to lower the effect of ash content to an acceptable level.

vi. Research should also be conducted on social acceptability of the products and sustainable local availability of the raw materials.

APPENDIX

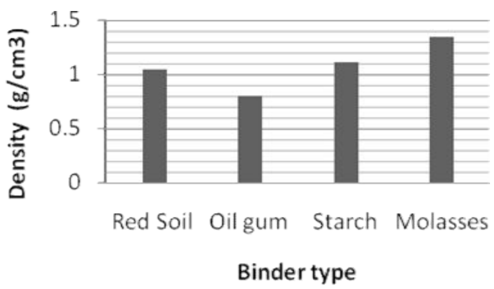
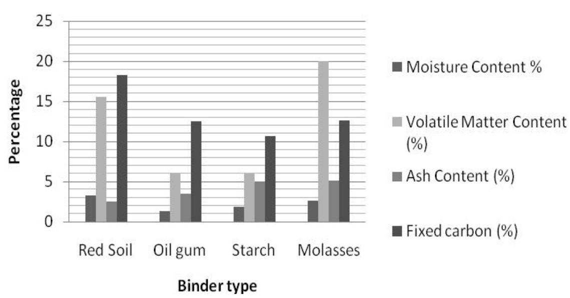


Figure 3.1: Mean densities of briquettes



.Figure 3.2: Percent moisture, volatile matter, ash and fixed carbon contents

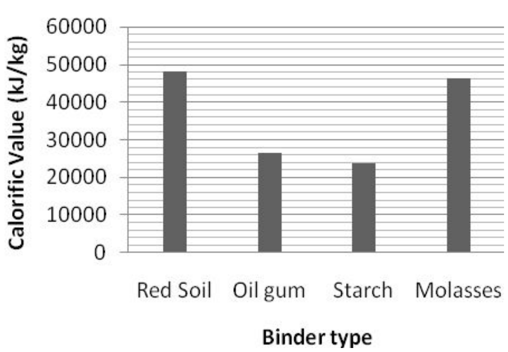


Figure 3.3: Calorific value

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