International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 4 Issue 5 || May 2015 || PP.32-39

Effects Of Varying Particle Size On Mechanical And Combustion Characteristics Of Mango Seed Shell Cashew Nut Shell Composite Briquettes

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ABSTRACT :*With the ever increasing world energy demand, the dependency on fossil fuel is hampered by adverse environmental effects due to global warming created by the carbon dioxide. Majority of Kenyans rely on biomass, but its sustainability is faced with diminishing forest cover which currently stands at 1.7%. Hence, there is need to search for other alternative sources which are environmentally friendly and accessible. Presence of mango seed shells and cashew nut shells which has no economical value may be an option. Although a lot of studies have been done on the mechanical and combustion behavior of varieties of biomass, there is very little information on composite briquette produced from cashew nut shell and mango seed shells. This study focused on mechanical and combustion characteristics of cashew nut shells and mango seed shells composite briquette. Cashew nut shells and mango seed shells were collected, dried, hammer milled, carbonized in muffle furnace at 400^{o}C and cooled in desiccators. The carbonized fines were mixed at varying mix ratios and particle sizes and bonded with banana peels before compacting. Produced composite briquettes were dried and mechanical and combustion characteristics determined. As the particle sizes increased from 3mm to 11mm, the density, moisture, ash content reduced from 729.08kg/m3, 7.56%, 5.942% to 492.41kg/m3, 6.88%, 5.93% respectively but had no significant effect on calorific value. Durability index, compressive strength and carbon monoxide reduced significantly with increase in particle sizes which could be attributed on reduced voids between adjacent particles.. The produced briquettes had similar mechanical and combustion characteristics to the existing briquettes, hence could serve as alternative source of energy.*

I. BACKGROUND INFORMATION

Biomass is considered a Clean Development Mechanism for reducing greenhouse gases emissions (Li and Hu,2003). Waste from wood and agro processing units are considered as relatively cheap source but the supply is limited. Sweden is scaling down nuclear energy production and oil usage while increasing biomass production for energy (Bjorheden, 2006). According to Sokhansanj& Fenton, (2006) and Mitchel *et al*, (2007)density of biomass ranges from 60-80kg/m^3 for straws and grasses while that of woody biomass (wood and chips) is between200-400kg/m^3. They further reported that about 50% world population, mostly from low income households in Africa, Asia and South America use woody biomass. The high cost of LPG force most of these households to harvest wood from forests for use as firewood or charcoal, destroying the forest cover resulting in negative impact on environment and climate change(Mitchel *et al*., 2007).By briquetting these biomass, high density and energy concentrated solid material called briquettes are produced which can supplement existing energy sources. Close to 70% electricity supply in Kenya is hydro based. By June,2014 approximately 2.6 million Customers had been connected to electricity supply (Stima News, July., 2014) benefitting about 28% of 38.6million Kenyan population (KNBS, 2009),leaving the rest of the population to seek alternative sources of energy. Similarly, wood accounts to about 70% of total energy consumption in Kenya, benefitting 80% of Kenyan population. It serves 90% of rural households and 85% of urban households (Mugo and Kituyi,2002). About 47% of Kenyan households use charcoal of which 82% and 34% are urban households and rural households respectively (UNEP, 2006). The total annual charcoal production is 2.4 million tons, produced from the forests, but with the current forest cover of 1.7% (below the target of 10%) there is need to search for sustainable energy sources. Agricultural residues area feasible option in this provision (Mugo and Kituyi,2002). Densification of agricultural residue is one way of upgrading combustion and mechanical characteristics. Through briquetting of agricultural residues, the produced briquettes will supplement existing energy sources hence reduce the pressure on wood based biomass in the counrtry.It is projected that with usage of improved energy conversion technologies, a reduction of 36.6tg/yr of carbon dioxide (CO_2) and conservation of 76,000ha of woodlands will be realized by 2030. About 8.1 million tons of woody biomass, the equivalent of firewood and charcoal used per year will be saved in the same period (UNEP, 2006).

II. RESEARCH METHODOLOGY

2.1 Introduction

This research study was done in the Departments of Industrial and Energy Engineering, Agricultural Engineering and Animal Science at the Egerton University, Njoro and samples tested at the Kenya Bureau of Standards in Nairobi. The cashew nut shells were procured from Kilifi Cashew Nut factory while mango seed shells from mango fruit processing plant at Mtwapa with moisture content being around 28%. Banana peels were obtained from the local markets and used as a binder. The mango seed shells and cashew nut shells were chosen due their availability. The materials were carbonized in a muffle furnace in the Department of Animal Science at Egerton University at a controlled temperature of $400\,^{\circ}C$ in accordance with ASTM Standard D5865-13.Mechanical characteristics which will be determined include density, durability index and compressive strength since they affect packaging, handling, transportation, storage and usage of solid fuels. Combustion characteristics determined include calorific value, ash content and flue gas due to their importance on quality of fuels and availability of testing equipment. The equipment used in determining the above characteristics were bomb calorimeter, muffle furnace, flue gas analyzers and an improvised stove (at KEBS),oven drier, desiccators, digital weighing scale and Vanier caliper which are available Department of Animal Science while screens and hammer mill are in the department of Agricultural Engineering at Egerton University.

2.2 Production of the briquettes

2.2.1 Preparation of raw materials

Cashew nut shells and mango seed shells collected were sun dried separately to 5% moisture content and hammer milled before carbonizing at 400^{o}C for 5 minutes in the muffle furnace according to Gimba and Turoti (2008). The carbonized materials were then cooled to room temperature using the desiccators. After cooling the materials were sieved to different particle sizes of 3mm, 5mm, 7mm and 10mm as recommended by Zhang *et al.* (2012).The sieved materials were packed and sealed in separate labeled plastic bags to avoid absorbing moisture from the atmosphere. Based on the size of the mould to be used(50mm by 100mm),50g of CNS and MSS mixtures was prepared and mass verified using digital weighing scale as shown in Table 3.1. The banana peel paste binder which was50% of the 50g mixture of raw materials was used, the 20% binder ratio did not produce good quality briquettes hence the ratio was increased by trial and error method to 50% and made in paste form. For each treatment and particle size, five replications were done and the average values computed.

2.2.2 Preparation of moulds and dies

Cylindrical moulds of 50mm by 100mm were produced from mild steel materials. The cylindrical mould of 75mm in diameter by 100 mm in length was clamped in lathe machine drilled at the centre to produce an internal hole of 50mm. The surface finishing of the internal hole was smoothened to reduce friction during briquetting process.

2.3 Effect of particle sizes on mechanical characteristics of briquettes

Briquettes made from particle sizes of 3mm, 5mm, 7mm and 10 mm at different mixture ratio at 50% banana peels binder were produced at 5MPa using a cylindrical mould of 50mm in diameter. The produced briquettes will be dried then put in labeled plastics bags before mechanical and combustion characteristics are determined

2.3.1 Density

This is one of the most important mechanical and combustion characteristics which show handling, storage, and transportation characteristics of solid fuel. Density of briquette was determined according to ASAE S269.4 standards. Since density is property of mass against volume, the process of determining density of briquette was as follows: Measure both the height and diameter of a briquette at six positions at 90^{0} to each other using Vanier calipers. Take the average of the measurements, which were treated as the height (h) and diameter (d) in each case. Determine the volume of the briquettes. Density of briquettes was determined using equation 3.1.

$$\rho = \frac{m}{v} \qquad 3.1$$

Where ρ– is density (g/cm^3)

m - is the mass (g)
v - is the volume of the briquette (cm^3)

2.3.2 Durability tests
The durability of the briquettes was determined in accordance with the chartered index described by Suparin*et al.* (2008). The briquette samples were dropped repeatedly from a height of 1.5 m onto a solid base. The fraction of the briquette retained was used as an index of briquette breakability. The durability rating of the briquette was expressed as a percentage of the initial mass of the material remaining on the metal plate. Result to be recorded as per the table below:

2.3.3Compressive test
The compressive strength is a criterion of briquette durability (Richard, 1990). The compressive strengths of the briquettes was determined using an Instron Testing Machine with an accuracy of $\pm$ 0.5% and a maximum force of 50KN,according to ASTM D 2166-85.The flat surface of the briquette sample will be placed on the horizontal metal plate of the machine. A 2 kN- load will be applied at a constant rate of 0.5 N/s until the briquette failure by cracking just occurs. The compressive strength was computed using the force and the cross sectional area at the cracking point. Five samples obtained from each experiment were tested and average values analyzed. It was done as illustrated by Figure 3.1 below

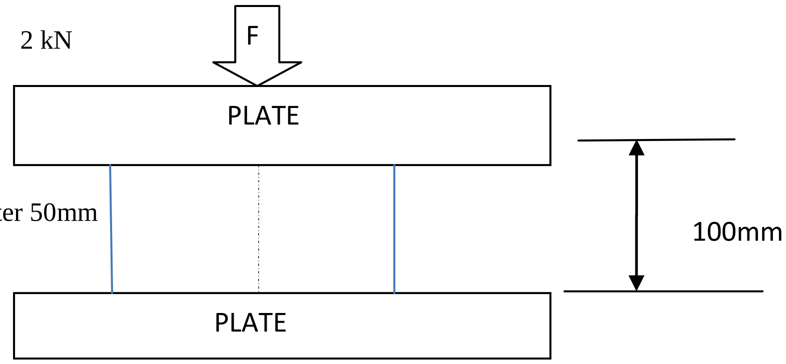

Fig.3. 1 compressive strength tests

2.4 Effect of particle sizes on combustion characteristics of briquettes
In order to ascertain the quality of the briquettes as a fuel, the key combustion characteristics tested as per objective number one were moisture content, calorific value and flue gas emissions.

2.4.1Determination of moisture content
Moisture content was determined as per ASTM D3173-11 standard where empty crucibles were heated under the same conditions meant for drying the samples (105℃, 1 hr duration).The crucibles were removed from the oven, covered and cooled immediately in a desiccant for 30 minutes. One gram of each of the samples was weighed, put in the crucibles then dried in ovens at 105℃ for 24hours.The crucibles were cooled in desiccators to room temperature then weighed again. Difference in mass is the moisture content. This was expressed as shown in wet basis

$$\text{Moisture content} = \left(\frac{wet \quad weight \quad - dry \quad weight}{wet \quad weight} \right) \times 100 \ \% \ldots\ldots\ldots \ \ldots\ldots\ldots\ldots \ \ldots\ldots\ldots \ 3.2$$

2.4.3 Determination of calorific value
Calorific (heating) value of biomass is indicative of the energy content of the fuels. The gross calorific value (higher heating value, HHV)and the net calorific value (lower heating value, LHV) at constant pressure measures the enthalpy change of combustion with and without water condensed, respectively (Demirbaş, 2007). A Parr 6200 oxygen bomb calorimeter (ParrInstrument Company, Moline, IL) was used to determine the gross calorific value of the briquettes. One gram was placed in a stainless steel crucible, and the material in the vessel (bomb) ignited by a cotton fuse. The vessel was filled with oxygen and surrounded by a water jacket. Upon ignition, the released heat transfers to the water jacket. The temperature rise in the water jacket was used by the calorimeter to calculate the heating value of the sample. Tests on each sample were replicated five times. ASTM StandardD5865-13 test method for gross calorific value of coal and coke was used as a guideline for this experiment.

2.4.2Determination of ash content

Ash refers to the residue after burning of biomass. The determination of ash content was done in accordance with the standard (ASTM E 830-87) where one gram of the sample was placed into a weighed uncovered crucible. The uncovered container with sample in it was placed into the muffle furnace and gradually heated to temperature of725^{o}C and kept inside the furnace for a period of 1 hour. The crucible was removed and put in desiccators to cool to room temperature. It was then weighed and difference in weight is the ash content, determined using equation 3.4.

$$\text{Ash content (\%)} = \left(\frac{A - B}{C} \right) \times 100 \ \% \ - - - - - - - - - - - - - - - - - 3.4$$

Where

A is the mass of the crucible ash and residues (g)

B is the mass of empty crucible (g)

C is the mass of the sample used (g)

2.4.4Determination of emission tests

To evaluate emission tests, three blocks of briquettes weighing about 100 g were placed over an improvised charcoal stove ignited in the hood located in the petroleum laboratory at KEBS ,until steady flame was observed. Two flue gas analysers ,having been calibrated ,were placed next to the stove to record the flue gases emitted from the combustion process. The two were : a $CO_2$and CO analyser; an analyser for SO_2,NO_x; HCl; H_2S. Both analyzers had systems to record temperature and amount of emissions for each gas as captured by the inbuilt probes. The data was suitably captured in the inbuilt computer systems for the analyzers and recorded. This was replicated for other mixture ratios and particles sizes.

2.5 Data analysis

The experimental design for this study was a Randomized Complete Design. This study involved six mixture ratios, five particle sizes and five compaction pressures of composite briquettes. They were arranged in Randomize Complete Design with five replications per experiment. The analysis of variance, Duncan Multiply Range Tests and descriptive statistics were used. All the analyses were carried out with SAS statistical software. For separation of means, Least Significant Difference method LSD will be done α = 0.05.

III.RESULTS AND DISCUSSIONS

31.Combustion characteristics

3.1.1Moisture content

Moisture content is important combustion characteristics. From the results obtained in Table 4.1, it showed that there was indirect correlation between the particle sizes and the moisture content. The moisture content was 7.560% at particle size of 3mm and reduced to 6.880% at particle size of 11mm. From statistical data, it showed significant effect at smaller particles sizes but no significant effect at particle sizes of 9mm and 11mm.

Table 3.1: Effects of particle size on moisture content (mc) of briquette

Particle size (mm)	Mean mc (%)
3	7.560^{a}
5	7.360^{b}
7	7.274^{c}
9	7.164^{d}
11	6.880^{d}
LSD	0.0431
Mean	7.249

Means followed by the same letter(s) (a,b,c,d) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

The results in Fig 4.1 showed the reduction in moisture content as particle sizes increased with the correlation coefficient of 86.1%

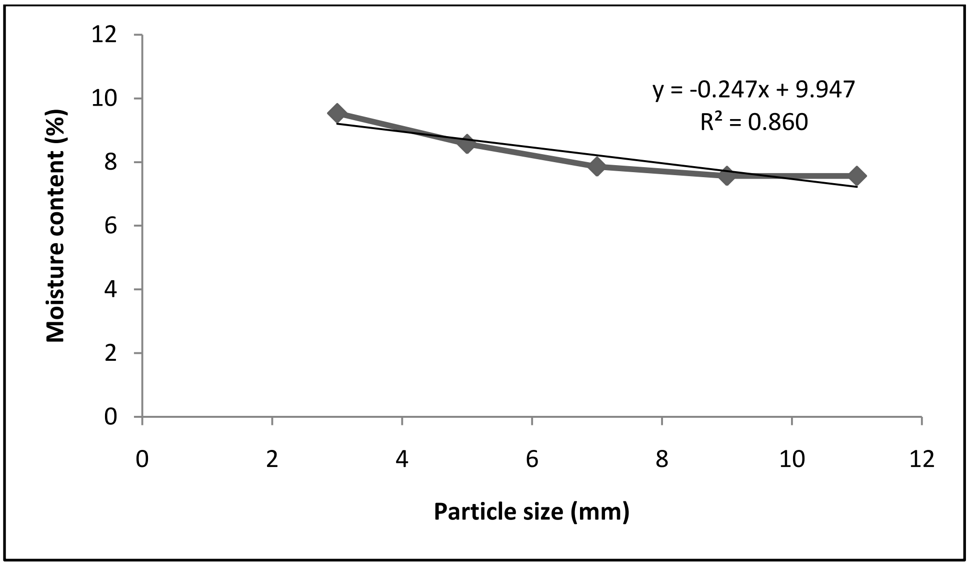

Fig 3.1: Effects of particle size on moisture content (mc) of briquette

From other studies, the percentage of moisture in the feed biomass to extruder machine is a very critical factor. In general, it has been found that when the feed moisture content is 8-10 %, the briquettes will have 6-8% moisture. At this moisture content, the briquettes are strong and free of cracks and the briquetting process is smooth. But when the moisture content is more than 10%, the briquettes are poor and weak and the briquetting operation is erratic. Excess steam is produced at higher moisture content leading to the blockage of incoming feed from the hopper, and sometimes it shoots out the briquettes from the die. Therefore, it is necessary to maintain optimum moisture content.

3.1.2Ash content

The ash content of different types of biomass is an indicator of slagging behaviour of the biomass. Generally,the greater the ash content, the greater the slagging behaviour. But this does not mean that biomass with lower ash content will not show any slagging behaviour. The temperature of operation, the mineral compositions of ash and their percentage combined determine the slagging behaviour.

The results in Table 4.2 show that there was no significant effect of the ash content as the particle sizes was varied from 3mm upto11mm.At 3mm the ash content was 5.942% while at 11mm particle size it increased insignificantly up to 5.928%.

Table 3.2: Effects of particle size on ash content (ac) of briquette

Particle size (mm)	Mean mc (%)
3	5.942[a]
5	5.942 [a]
7	5.930 [a]
9	5.928 [a]
11	5.9260 [a]
LSD	0.0519
Mean	5.808

Means followed by the same letter(s) (a,b,c,d,e.f,g) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

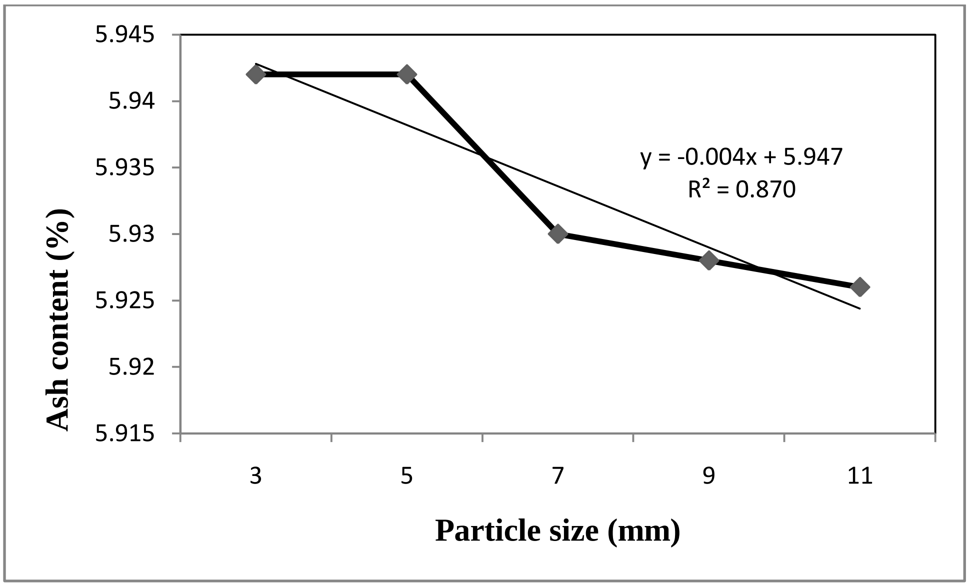

Fig 3.2: Effects of particle size on ash content (as) of briquette

The results obtained are comparable with what has been found such in the case of groundnut shell the ash content ranges between 2-3% which make it a good material for briquetting.

3.1.3 Density

The results tabulated in Table 4.3 show that density reduced with increased in particles size. At 3mm, the density was 729.08 kg/m^3 but reduced to 492.41kg/$m^{3.}$. This could be attributed to the fact that high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area. The application of external force such as pressure may increase the contact area causing the molecular forces to transmit high enough which increases the strength of the bond between the adhering partners. Another important binding mechanism is van der Waals' forces. They are prominent at extremely short distances between the adhesion partners. This type of adhesion possibility is much higher for powders. Fibres or bulky particles can interlock or fold about each other as a result forming interlocking or form-closed bonds. To obtain this type of bond, compression and shear forces must always act on the system. The strength of the resulting agglomerate depends only on the type of interaction and the material characteristics.

Table 3.3: Effects of particle size on density (d) of briquette

Particle size (mm)	Mean mc (%)
3	729.08^{a}
5	629.01^{b}
7	583.58^{c}
9	557.68^{d}
11	492.41^{d}
LSD	0.0519
Mean	609.836

Means followed by the same letter(s) (a,b,c,d,e.f,g) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

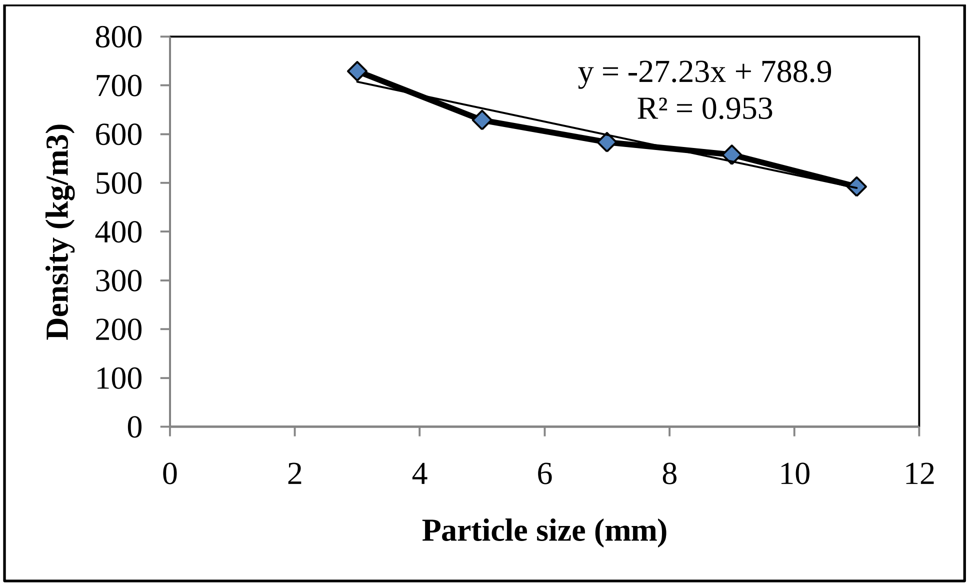

Fig 3.3: Effects of particle size on density of briquette

From the statically analysis, it showed that as the particle sizes increases, it had significant effect on the density at all particles size. The correlation coefficient was 95.3% at α=0.05 and least significant difference of 0.0519.

3.1.4 Calorific value

From the results obtained it shows the calorific values at particle size of 3mm was 25.64MJ/kg but increased insignificantly to 25.740MJ/kg for 11mm particle size. This suggests that the caloric value of a fuel in composition depended but do not vary significantly with particle size.

Table 3.4: Effects of particle size on caloric value (cv) of briquette

Particle size (mm)	Mean cv (MJ/kg)
3	25.640 ^{c}
5	25.680 ^{bc}
7	25.688 ^{bc}
9	25.714^{ab}
11	25.740^{a}
LSD	0.0495
Mean	25.69244

Means followed by the same letter(s) (a,b,c,d,e.f,g) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

Fig 3.4 show the graphical view of the variation of the calorific value with the particle sizes. Even though there was rise of the calorific value with increase in particle sizes, statistical analysis at α=0.05 indicated that the changes of calorific value was insignificant.

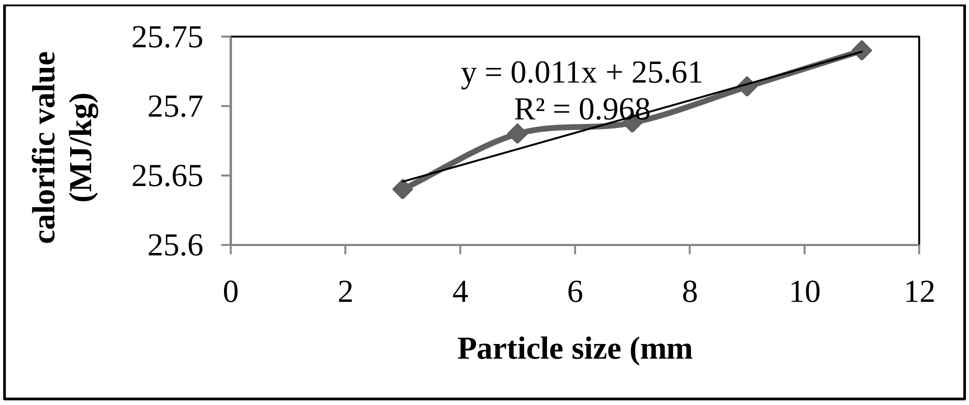

Fig 3.4: Effects of particle size on calorific value (cv) of briquette

Based on the figure below, it is found that most of the briquettes fulfill the minimum requirement of calorific value for making commercial briquette (>17500 J/g), as stated by DIN 51731. Besides, there is no significant difference when the briquette with same mixture undergoes different compaction pressure.

3.1.5 Carbon Monoxide (CO)

The carbon monoxide was 5.64 at particle size of 3mm and 5mm but slightly reduced to 5.21ppm at particle size of 11mm. Even though there was slight reduction as the particle was increased, the effect was insignificant. This could be attributed to the fact that the amount of carbon monoxide is a function of the availability of oxygen during combustion process.

Table 3.5: Effects of particle size on carbon monoxide (CO) of briquette

Particle size (mm)	Mean CO(ppm)
3	5.640[a]
5	5.640[a]
7	5.460[b]
9	5.238 [c]
11	5.210[c]
LSD	0.0929
Mean	5.4376

Means followed by the same letter(s) (a,b,c,d,e.f,g) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

The Fig 3.5 show the trend of carbon monoxide as the particle sizes was varied. Even though there was reduction,

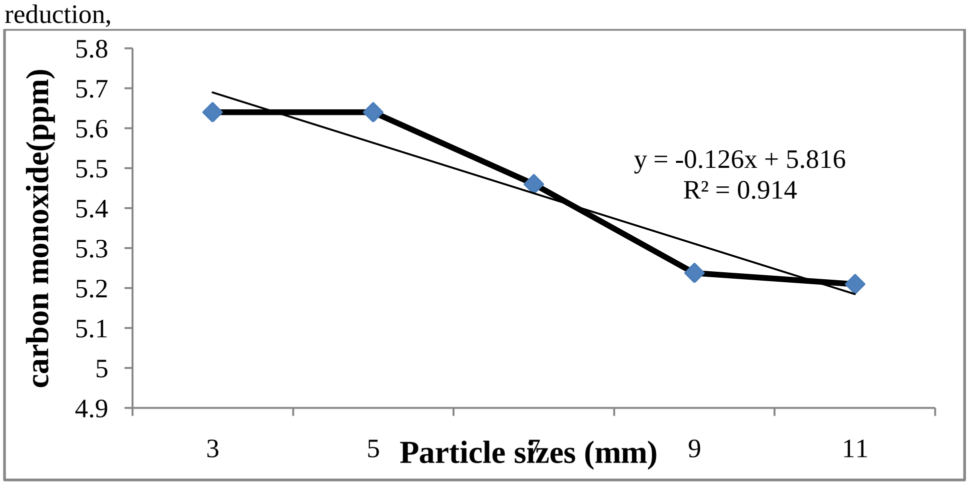

Fig 4.5: Effects of particle size on carbon monoxide (CO) of briquette

3.2 Mechanical characteristics

3.2.1 Durability index (di)

From the results in Table 4.6, the durability index at particle size of 3mm was 98.412% but reduced to 95.524 at particle size of 11mm. This showed that durability (mechanical strength) of briquettes are inversely proportional to particle size since smaller particles have greater surface area resulting in increased gelatinization and better binding. Therefore, the major contributing factors to the bond formed during this densification may be the mechanical interlock of the fibres of the biomass and adhesive force between the particles resulting in the formation of a stronger bond.

Table 3.6: Effects of particle size on durability index (%) of briquette

Particle size (mm)	Mean di (%)
3	98.412[a]
5	97.614[ab]
7	96.748[bc]
9	96.189[c]
11	95.524[c]
LSD	0.3745
Mean	96.897

Means followed by the same letter(s) (a,b,c,) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

From the analyzed data, the least significant difference was 0.6378 at α=0.05 and at all particle sizes the difference was significant suggesting that particle sizes has effect on the durability properties of the briquettes.

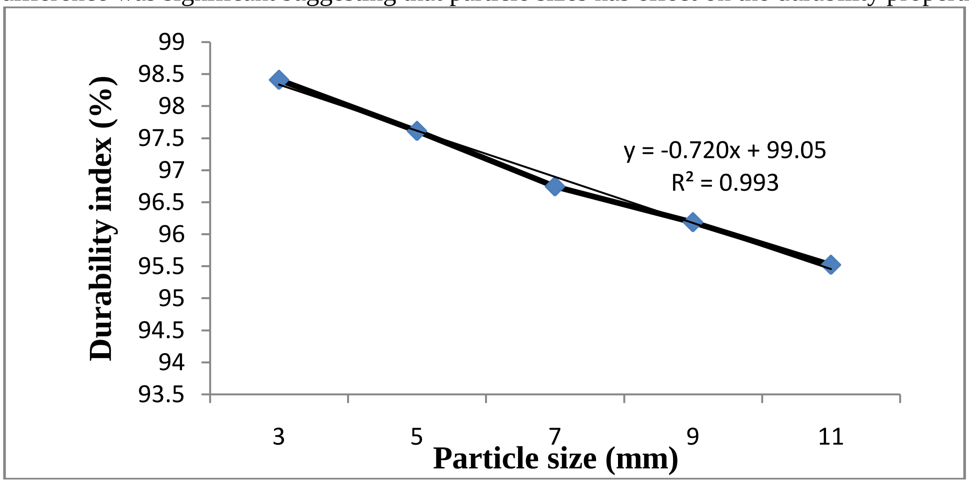

Fig 3.6: Effects of particle size on durability index (%) of briquette

3.2.2 Compressive strength

As shown in Table 4.7 and Fig 4.7, the compressive strength of briquette increased reduced with increase in particle sizes. The compressive strength was 7.748 KN/m^2 and 6.370KN/m^2 at particle sizes of 3mm and 11mm respectively. Therefore, the result shows that the mechanical characteristics of briquette are competitive with local produced briquette.

Table 3.7: Effects of particle size on compressive strength (KN/m^2)of briquette

Particle size (mm)	Mean cs (%)
3	7.748[a]
5	7.7440[a]
7	6.928[a]
9	6.682[a]
11	6.370[a]
LSD	0.0369
Mean	7.0336

Means followed by the same letter(s) (a,b,c,) in same column; (x,y) in same row are not significantly different α=0.05 using LSD, N/A = not applicable

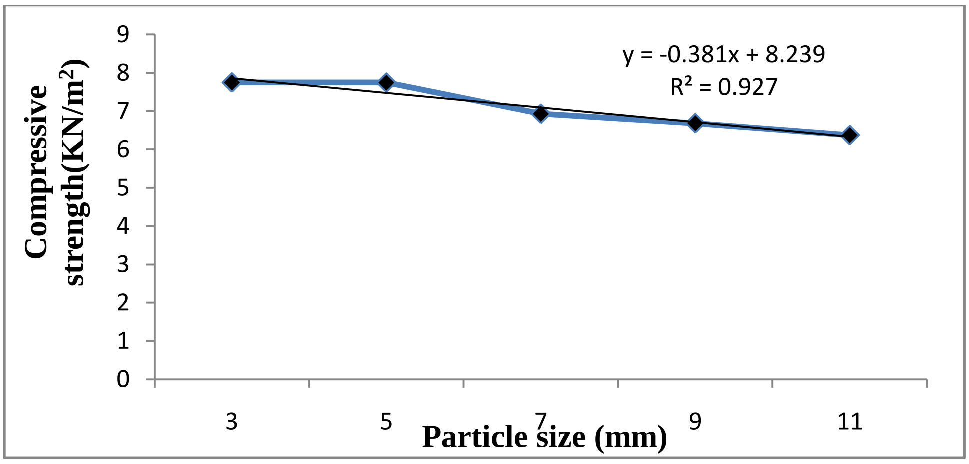

Table 3.7: Effects of particle size on compressive strength (KN/m^2)of briquette

IV. CONCLUSIONS

As the particle sizes was increased from 3mm to 11mm, the density, moisture, ash content reduced from $729.08Kg/m^3$, 7.56%, 5.942% to $492.41Kg/m^3$, 6.88%, 5.93% respectively. There was no significant effect on Calorific value as the particle sizes increased.

V. ACKNOWLEGEMENT

To my supervisors for quality guidance; Management and staff of Kenya Bureau of Standards, Material testing and chemical laboratories and Egerton University departments of Industrial and Agricultural Engineering and Animal Science, for allowing me access and use of facilities.

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