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# Effect of the Briquette Sizes and Moisture Contents on Combustion Characteristics of Composite Briquettes

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**Abstract**

The prevailing energy shortage and environmental issues have lead to exploitation of renewable energy resources. One of the energy resources particularly for Kenya is agricultural residues. These residues are available, indigenous and environmental friendly but majority of them cannot be used for during direct combustion due high moisture content and low volumetric energy. By briquetting these characteristics are enhanced. Rice husk and bagasse were carbonized in a muffle furnace at 450$^{o}$C, grounded, sieved and mixed with charcoal dust at different mixture ratios. The mixtures were bonded with different types of binder at varying amount before briquetting at 5MPa using hydraulic press into different sizes. Physical and combustion tests were conducted according to standard procedures. It was observed that density, ignition and burning time increased with moisture content at all sizes of briquettes. However, briquettes sizes had no significant effect on the calorific value. It was concluded that by mixing carbonized agricultural residues with charcoal dust the combustion characteristics improved.

***Key word:*** **briquettes, carbonized, combustion characteristics**

## INTRODUCTION

The energy demand has been a major challenge facing most of the developing countries including Kenya. Reliance on fossil fuel is hampered by continuous escalation of prices, depleting oil reserves and greenhouse effects (DOE, 2009; DOE, 2008; MOE, 2005). According to DOE (2008) report, oil reserves are expected to deplete in the next 47 years. This anticipated crisis has prompted the search for alternative sources of energy to meet increasing demand.

Although Africa accounted for 12% of the world population, it consumed only 4% of global energy in 2005 (Ardayfio, 2006) Within the continent, the rate of consumption varies. For example in Nigeria, renewable energy accounted for 51% of total energy consumption in 2001 (Akinbami, 2001). Similarly, Matiru (2007) noted the annual demand of fuel wood in Kenya to be $18.7\times10^6$ tonnes which accounts for 70% while petroleum and electricity constituted 21% and 9% of total energy consumption respectively.Wood in form of fuel wood, twigs and charcoal provides 90% and 85% of rural and urban households' energy requirements respectively (Matiru, 2007).

Chin and Siddiqui (2000) andGrover and Mishra (2006)observed that several kinds of agricultural residues such as coconut shell, wood chip and wood waste can be used as fuel. However, majority of them are inappropriate for direct combustion because of low density, high moisture content and low volumetric energy. Such properties cause problems in transportation, handling, storage and are attributed to particulate emission during direct combustion. One of the promising technologies for upgrading agricultural residue is by briquetting. The technology which is termed densification enhances physical and combustion characteristics. The piston-and-die type of briquetting technology is preferred for low pressures (Grover and Mishra, 2006). Briquetting using this technology have been extensively studied (Ndiema *etal.,* 2002; Husain *et al*., 2002; Heinz *et al*., 2003; Grover and Mishra, 2006). The findings show that characteristics of briquettes are influenced by process and material parameters such as die pressure and moisture content. Studies have been done on the use of carbonized agricultural residues for briquettes such as corn cob (Medhiyanon *et al.*, 2006), sawdust (Rotich, 1996), rice husk (Jindaporn and Songchai, 2007), cotton stalk (Onaji and Siemons, 2003) and hazelnut shell charcoal (Demirbas and Sahin, 2001). This research provided greater understanding on the physical and combustion characteristics of the composite briquettes.

## MATERIALS AND METHODS

Collected bagasse and rice husks were hammer milled and sieved with 2mm screen. The rice husk and bagasse being used in this study was carbonized in a muffle furnace.

### Preparation of Raw Materials

The rice husk and bagassewere dried in the sun; thereafter same quantity (20g) weighed using digital electronic weighing scale and put into crucibles. The crucibles were then loaded into a muffle furnace and ignited at a preset temperature of 450$^{o}$C for 45 minutes. The crucible and contents were unloaded and placed in desiccators to fully cool down as recommended by Martin et al. (2008). The carbonized bagasse and rice husk were put in labelled plastic bags to avoid absorbing moisture from the atmosphere. The three materials (charcoal dust, rice husk and bagasse) dust were weighed and mixed at the mass ratios as shown in Table 3.1. The binder ratios upto 25% as recommended by Jindaporn and Songchai (2007) was then added to the materials and mixed until bonding was achieved.

In this study, 6 mixture ratios (treatments) and charcoal dust (a control) were used. Five replications of each were carried out.

**Table 3. 1: Mixtures of charcoal dust, rice husk and bagasse dust**

| Treatments | Mixtures | Ratios | Mass (gm) |
|---|---|---|---|
| 1 | charcoal dust: rice husk: bagasse | 1:0:0 | 40 |
| 2 | charcoal dust: rice husk: bagasse | 6:3:1 | 40 |
| 3 | charcoal dust: rice husk: bagasse | 2:2:1 | 40 |
| 4 | charcoal dust: rice husk: bagasse | 2:5:3 | 40 |
| 5 | charcoal dust: rice husk: bagasse | 6:1:3 | 40 |
| 6 | charcoal dust: rice husk: bagasse | 2:1:2 | 40 |
| 7 | charcoal dust: rice husk: bagasse | 2:3:5 | 40 |

Three levels of the binder namely; 10%, 15% and 25% (by mass) were used in the study. The binders were measured and mixed thoroughly with the materials until moulding conditionwas achieved before the briquetting process was conducted.

Moulds of 20mm, 40mm and 60mm in diameter by 100 mm high were made from mild steels by drilling to the required diameters and properly polished to achieve smooth internal surfaces. Holes were drilled on the moulds to about one third of the height, so that water could drain easily during briquetting processas recommended by Dahlam *et al*. (2001). The dies of slightly smaller diameters than the moulds were machined and used to reduce frictional force during briquetting process.

Fourty grams of the materials-binder mixtures were hand-fed into the mould and compacted to pressure of 5MPa using a hydraulic press and held for 5 minutes as recommended by Onaji and Siemons (2003).

The produced briquettes (at the ratios of 6:1:3) using moulds of 20mm, 40mm and 60mm in diameters were firstly oven dried to moisture content of 5%. Moisture contents were then regulated to 8% and 12%in other sets by adding known quantities of distilled water to the samples followed by storing in air-tight plastics bags for 48 hours to allow for uniform distribution of moisture as by Mani *et al*.(2006) and Krizan *et al. (*2009). Three tests samples at each condition were prepared for the experiments before physical and combustion characteristics done. Standard procedures was used to determine physical and combustion procedure..

## Data Analysis

The SAS (Statistical Analysis Software) was used for data analysis whereas the experimental design adopted was completely randomized design (CRD). Analysis of variance (ANOVA) was performed on the treatments means for each parameter. But to examine whether there was significance difference in the means, Least Significance Difference (LSD) was performed at 95% level of significance.

## RESULTS AND DISCUSSIONS

### *Density*

Table 4.10 shows the effect of briquette sizes and moisture contents on the density of the briquettes.

**Table 4. 1: Effect of briquette sizes and moisture content (mc) on density of briquette**

| Briquettes size (mm) | Briquette density (g/cm$^3$) | | | | LSD |
|---|---|---|---|---|---|
| | 5% mc | 8%mc | 12% mc | mean | |
| 20 | 0.803 | 0.835 | 0.856 | 0.831$^a$ | N/A |
| 40 | 0.754 | 0.795 | 0.814 | 0.787$^b$ | N/A |
| 60 | 0.738 | 0.762 | 0.775 | 0.785$^c$ | N/A |
| LSD | N/A | N/A | N/A | 0.002 | N/A |
| Mean | 0.765$^z$ | 0.797$^y$ | 0.815$^x$ | N/A | 0.002 |

*Means with the same letters are not significantly different atα=0.05 using Least significance difference (LSD).Means followed with the same letter (x, y, z) in the same row and column (a,b,c) are not significantly different at α=0.05, N/A = not applicable.*

The mean density was 0.831g/cm$^3$, 0.787g/cm$^3$ and 0.758g/cm$^3$for 20mm, 40mm and 60mm diameter briquettes, respectively. At all moisture contents, similar trends were observed but higher density was obtained at 12% moisture contents. Reduction in the density with increase in the briquette sizes might have been due to reduced pressure per unit area since constant pressure of 5MPa was maintained during briquetting process. The mean density of three briquette sizes was 0.765g/cm$^3$ at 5% moisture content but increased steadily upto 0.815g/cm$^3$ at 12% moisture level. This could be due to enhanced bonding between adjacent particles that created a strong bond resulting in reduced expansion of briquettes after extrusion. The results that the mean density of different briquette sizes at varied moisture content was significantly different at $\alpha$=0.05; LSD of 0.002 suggesting that moisture content and briquette size have effect on the density. The interaction between size of briquette and moisture had minimal effect which is reflected by F value of 49.00.

The increase in the mean densityabove with moisture contentagree with Krizan *et al.*(2009) observation who noted that the density of briquettes to increase with moisture content upto 15% since water acts as a binder and have gluing effects.Marrero and Butler (2001) further reportedthat when briquetting constant mass of material, density of briquettes tend to be higher for smaller diameter at a given pressure as observed here.

**Calorific Value**

The results on the effect of briquettes sizes and moisture contents on the calorific value are shown in Table 4.11 The mean calorific values reduced from 24.56MJ/kg to 18.47MJ/kg at 5% and 12% moisture contents respectively, for 20mm diameter size. Low calorific values at high moisture contents (12%) could be attributed to the presence of more water which might have absorbed heat liberated during combustion.However there were no changes in calorific value with increases in briquettes sizes. At 5% moisture content, the calorific value was 24.56MJ/kg, 24.57MJ/kg and 24.54MJ/kg at 20mm, 40mm and 60mm diameters. Similar trends were observed at other moisture contents which suggest that heat liberated do not depend on the size of briquettes.

**Table 4. 2: Effect of briquette sizes and moisture content (mc) on calorific value (MJ/kg)**

| Briquettes size (mm) | Calorific value (MJ/kg) 5% mc | 8%mc | 12% mc | mean | LSD |
|---|---|---|---|---|---|
| 20 | 24.56 | 22.50 | 18.47 | 21.84[ab] | N/A |
| 40 | 24.57 | 22.53 | 18.46 | 21.85[a] | N/A |
| 60 | 24.54 | 22.51 | 18.48 | 21.84[ab] | N/A |
| LSD | N/A | N/A | N/A | 0.009 | N/A |
| Mean | 22.60[z] | 22.50[y] | 18.47[x] | N/A | 0.009 |

*Means with the same letters are not significantly different atα=0.05 using Least significance difference (LSD).Means followed with the same letter (x, y, z) in the same row and column (a,b,c) are not significantly different at α=0.05, N/A = not applicable.*

Reduction in calorific value with moisture contents agrees with the findings of Jenkins *et al.* (2008) who mentioned that calorific valueis influenced by the type of biomass, chemical composition and moisture content. The results obtained fall within the findings of Rotich (1996) who reported that firewood has heating value of about 15 - 17 MJ/kg (on wet basis) and 19 - 22 MJ/kg (oven dry biomass) but increased to 23 - 24MJ/kg for partially carbonized charcoal.

## Ignition Time

Table 4.12 show the results on the effect of briquette sizes and moisture content on the ignition time of the composites briquettes.

**Table 4. 3: Effect of briquette sizes and moisture content (mc) on ignition time (min)**

| Briquettes size (mm) | Ignition time (min) 5% mc | 8%mc | 12% mc | mean | LSD |
|---|---|---|---|---|---|
| 20 | 15.0 | 21.0 | 25.7 | 20.6[c] | N/A |
| 40 | 21.7 | 26.0 | 32.0 | 26.6[b] | N/A |
| 60 | 27.0 | 33.3 | 37.3 | 32.6[a] | N/A |
| LSD | N/A | N/A | N/A | 1.25 | N/A |
| Mean | 21.2[z] | 26.8[y] | 31.7[x] | N/A | 1.25 |

*Means with the same letters are not significantly different atα=0.05 using Least significance difference (LSD).Means followed with the same letter (x, y, z) in the same row and column (a,b,c) are not significantly different at α=0.05, N/A = not applicable.*

At 5%, 8% and 12% moisture contents, the mean ignition time was 21.2, 26.8 and 31.7 minutes. The increase in the ignition time with moisture contents was due to increase in the density.Increase in diameter of briquettes from 20 to 60 mm resulted in increases in time taken to ignite from 20.6 to 32.6 minutes. The low ignition time witnessed in smaller briquette sizes could be attributed to increased surface areas to volume which facilitated more oxygen bonding with carbon in the briquettes hence enhanced combustion reaction time. But as the briquette sizes increased, the activation energy for combustion increased resulting in longer time to ignite. The size of briquettes and moisture content had significant effect on the ignition time but the interaction had no effect with F value of 0.70 at $\alpha$= 0.05%.

Yang *et al*. (2001), Zaror and Pyle (2002) observed that the burning rate decreases with increase in density since the residence time of the gases within the char matrix of compressed briquettes increases due to low porosity seems to support these findings.

***Burning Time***

The results of burning time followed similar trends as ignition time. The burning duration increased with the moisture content and the briquettes sizes. At 5%, 8% and 12% moisture contents the mean burning time was 48.0, 55.8 and 61.9 minutes respectively. Similarly at 20, 40 and 60mm diameters, it was 45.6, 55.9 and 64.2 minutes respectively. The moisture content greatly influenced the burning property of the fuel. The size of briquettes also affects the surface area to volume that provides oxygen to bind with carbon hence the combustion rate of smaller sizes tends to be faster. The results that the mean density of different briquette sizes and moisture content was significantly difference at $\alpha$=0.05; LSD of 1.264 suggesting that moisture content and briquette size have effect on the burning time but interaction between briquette size and moisture content had minimal effect (F value of 16.74). Table 4.13 shows the burning time of briquettes at different moisture contents.

**Table 4. 13: Effect of briquette sizes and moisture content (mc) on burning time (min)**

| Briquettes size (mm) | Burning time (min) | | | | LSD |
|---|---|---|---|---|---|
| | 5% mc | 8%mc | 12% mc | mean | |
| 20 | 37.3 | 45.7 | 53.7 | $45.6^{c}$ | N/A |
| 40 | 46.0 | 57.7 | 64.0 | $55.9^{b}$ | N/A |
| 60 | 60.7 | 64.0 | 68.0 | $64.3^{a}$ | N/A |
| LSD | N/A | N/A | N/A | 1.26 | N/A |
| Mean | $48.0^{z}$ | $55.8^{y}$ | $68.9^{x}$ | N/A | 1.26 |

*Means with the same letters are not significantly different at$\alpha$=0.05 using Least significance difference (LSD).Means followed with the same letter (x, y, z) in the same row and column (a,b,c) are not significantly different at $\alpha$=0.05, N/A = not applicable.*

Saptoadi (2008) reported that small briquettes have better combustion characteristics (especially combustion rate) due to larger specific area available for reaction that provides more oxygen to bind with carbon hence reduce the time taken to ignite and burn. This support the low ignition time at obtained in smaller sizes of briquette.

**Conclusions**

The calorific value reduced with increase in moisture contents but was not significantly influenced by briquette size. Density, ignition and burning time increased with moisture contents but reduced with briquette sizes. The mean density, ignition and burning time at 5% moisture contents were 0.765g/cm$^3$, 21.2 and 48.0 minutes, respectively but increased to 0.815g/cm$^3$, 31.7 and 61.9 minute at 12%.

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