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Research Paper

EFFECT OF BINDER TYPES AND AMOUNT ON PHYSICAL AND COMBUSTION CHARACTERISTICS

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Current energy shortage and environmental issues have lead to exploitation of renewable energy resources especially in Kenya that includes agricultural residues. These residues are available, indigenous and are environmental friendly but some can not directly in combustion process due high moisture content and low volumetric energy unless by briquetting. The research focussed on evaluating the physical and combustion characteristics of rice husk-bagasse-charcoal dust composite briquettes. Rice husk and bagasse were carbonized in a muffle furnace at 450 °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 5 MPa using hydraulic press into different sizes. Physical and combustion tests were conducted according to standard procedures. The binder types and ratios had effect on the density, calorific values, ignition and burning time that could be attributed to the incombustibles matter. It was concluded that briquettes bonded by molasses binder had better combustion characteristics. There is need to study the use of other binder materials.

Keywords: Rice husk, Bagasse, Charcoal dust, Binder, Briquettes

INTRODUCTION

Energy demand is 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; MOE, 2006). According to (DOE, 2009) 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; and Matiru, 2007) noted the annual demand of fuel wood in Kenya to be 18.7 × 10^6 tonnes which accounts for 70% while petroleum and electricity constituted

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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 With the current forest cover of 1.7% and annual population growth rate of 2.7%, the demand for wood-based biomass is expected increase (Matiru, 2007). The high and rapidly increasing demand for wood fuel is considered as one of the contributing factors to the fuel wood crisis (Himraj, 2003).

In Kenya, significant quantities of agricultural residues are available for conversion into domestic energy sources but are under-utilized due to their handling, transportation, storage and combustion characteristics (Matiru, 2007). Though Mumias and Muhoroni Sugar Companies produce 1,070,000 tonnes of bagasse, only 753,000 tonnes are used annually while the rest are disposed off in landfill (Owino, 2009). From Owino (2009) report, Kenya produces 20% rice husk from the 50,000 tonnes of rice processed annually. Like bagasse, these energy resources are often burnt or dumped in landfill without recovering energy. If utilized fully, it can substantially supplement the existing traditional energy sources.

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 *et al*., 2002; Husain *et al*., 2002). 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 (Oladeji, 2010), sawdust (Rotich, 1996), rice husk (Jindaporn and Songchai, 2007) and hazelnut shell charcoal (Demirbas and Sahin, 2001).

Most of the research done in this area focused on briquetting rice husk and bagasse alone, but little information exists on characteristics of composite briquettes. This research was aimed at investigating the effect of binder types (molasses, cowdung and clay) and amount on physical and combustion characteristics of composite briquettes.

MATERIALS AND METHODS

This research was done at Egerton University, Department of Industrial and Energy Engineering. Rice husk and bagasse were collected at Ahero Rice Scheme and Chemelil Sugar Company while charcoal dust was purchased from charcoal vendors at Njoro town. The collected bagasse and rice husks were hammer milled and sieved with 2 mm screen. Cowdung and clay binders were collected from the University farm while molasses was obtained from Chemelil Sugar Company. The rice husk and bagasse being used in this study was carbonized in a muffle furnace.

Preparation of Raw Materials

The rice husk and bagasse were dried in the sun; thereafter same quantity (20 g) 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 °C for 45 min. 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. In this study, 6 mixture ratios (treatments) and charcoal dust (a control) were used. Five replications of each were carried out.

Preparation of Binders, Moulds and Briquetting

The molasses, cowdung and clay binders were varied at 10%, 15% and 25% of mass of the mixtures (charcoal dust, rice and bagasse dust). In this case, the mixtures of raw materials were maintained at ratios of 6:1:3 due to higher calorific value and low ash content in the produced briquettes. Moulds of 40 mm 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 process as 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 5 MPa using a hydraulic press and held for 5 min. From the produced briquette composites tests were done immediately (compressed condition) and after indoor drying for 19 days (relaxed condition) as suggested by (Olorunnisola, 2007; Sotannde *et al.*, 2010), There after; the briquettes were stored in the sealed plastics bags to avoid absorbing moisture from atmosphere before tests for physical and combustion properties. The density, calorific value and ash content were determined by using standard procedures while ignition and burning time were carried as shown below.

Ignition Time

Ignition time was determined by burning 200 g of briquettes were put into charcoal stoves. Since the end-point of lighting was subjective and depended on ones judgement according to what stage the ignition has been achieved, two similar charcoal stoves were ignited at the same time by placing equal amount of paraffin on the floor of the charcoal stoves and lit using a lighter. In this process, ignition time was taken as the average time taken to achieve steady glowing fire as recommended by Rotich (1996).

Burning Time

Burning time was measured as time taken from the moment briquettes ignite until the complete burn out. 200 g of the composites briquettes were burned in charcoal stoves and the burning time measured (Rotich, 1996).

RESULTS AND DISCUSSION

Density

Table 1, shows the results on the density of composites briquettes at different binder types and amount.

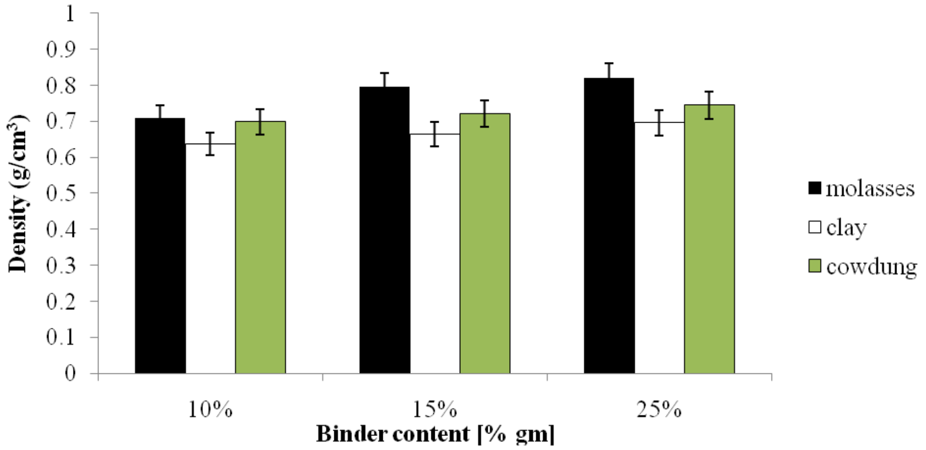
The density increased with increase in amount in the three types of binders. The mean density of briquettes at 10%, 15% and 25% amount of binder were 0.580 g/cm^3, 0.614 g/cm^3 and 0.645 g/cm^3 respectively. This implies that bonding of adjacent particles increased with binder amount. Briquettes bonded with molasses and cowdung had a density in the range of 0.628-0.703 g/cm^3 and 0.576-0.645 g/cm^3 while density of 0.537-0.586 g/cm^3, respectively was obtained for briquettes produced using the clay binder. In comparison to clay and cowdung, molasses binder had better gluing effect of adjacent particles resulting in stronger bonds hence minimal expan-

Table 1: Effect of Binder Types and Amount on Density (g/cm^3) of Composite Briquettes

Binder Amount (%)	Molasses	Clay	Cowdung	Mean Density (g/cm^3)	LSD
10	0.628	0.537	0.576	0.580^c	N/A
15	0.675	0.565	0.601	0.614^b	N/A
25	0.703	0.586	0.645	0.645^a	N/A
LSD	N/A	N/A	N/A	0.002	N/A
Average	0.669^x	0.563^z	0.607^y	N/A	0.002

Note: Means with the same letters are not significantly different at α=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.

Figure 1: Effect of Binder Types and Amount on Density of Composite Briquettes



sion of briquettes after extrusion. The binder types and amount had significant effects on the density, implying that strong bonds generated by better gluing effects resulting in minimal expansion of briquettes after withdrawn from the mould. Figure 1 show the effect of binder types and amount on the density of composite briquettes.

The density increase with binder ratios agree with the finding of (Olorunnisola, 2007; Sotannde *et al.*, 2010) observed that density of briquettes is influenced by binder type and amount.

Calorific Value

As shown in Table 2, the calorific values of briquettes bonded by molasses and clay binder ranged between 25.2-26.8 MJ/kg and 11.3-14.6 MJ/kg, respectively. But briquettes produced with cowdung binder had a calorific value of 16.1-18.5 MJ/kg. In all binder types and amount, molasses bonded briquettes had higher calorific values which could be due to enhanced characteristics.

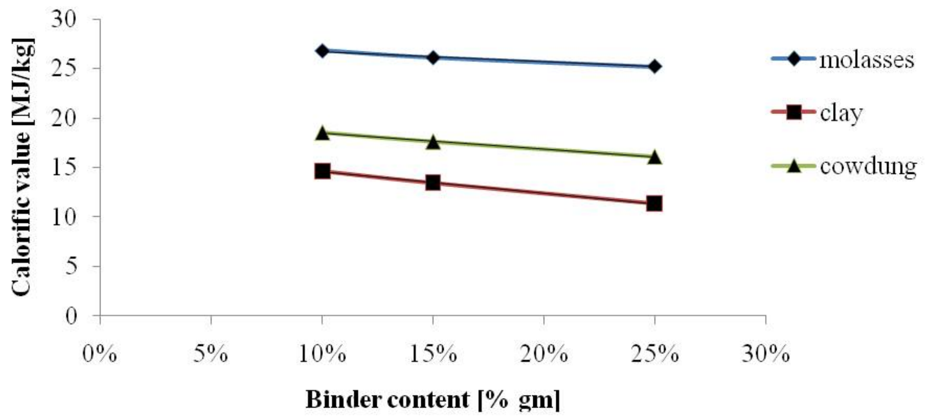
The mean densities of molasses, cowdung and clay binder were significant difference at $\alpha = 0.05$ and LSD of 0.147 suggesting that the binder types and amount have effects on the calorific value of briquettes. The effect of binder types and amount on calorific value is illustrated by Figure 2.

Table 2: Effect of Binder Types and Amount on Calorific Value [MJ/kg] of Briquettes

Binder Amount (%)	Molasses	Clay	Cowdung	Mean Calorific Value [MJ/kg]	LSD
10	26.8	14.6	18.5	19.97[a]	N/A
15	26.1	13.4	17.6	19.03[b]	N/A
25	25.2	11.3	16.1	17.53[c]	N/A
LSD	N/A	N/A	N/A	0.147	N/A
Average	26.03[x]	13.10[z]	17.40[y]	N/A	0.147

Note: Means with the same letters are not significantly different at α=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.

Figure 2: Effect of Binder Types and Amount on Calorific Value of Briquettes



Rotich (1996) obtained calorific value of 17.6-18.1 MJ/kg for rice husk briquettes while (Wilainpon, 2007; Ivanov *et al.*, 2003) found 14.1 MJ/kg and 24-27 MJ/kg for maize cobs and lignite briquettes (with bio-binder), respectively. The calorific values of 13.1-26.03 MJ/kg are comparable above findings. The briquettes produced from molasses and cowdung binder fulfilled the requirement for making commercial briquettes which the calorific value should be more than 17.5 MJ/kg.

Ignition Time

The end-point of ignition is subjective and depend on ones judgement according to what stage has ignition been achieved. In this process, ignition time was taken as the average time taken to achieve steady glowing flame. Table 3 shows the ignition time for the composite briquettes produced using different binder types and amount.

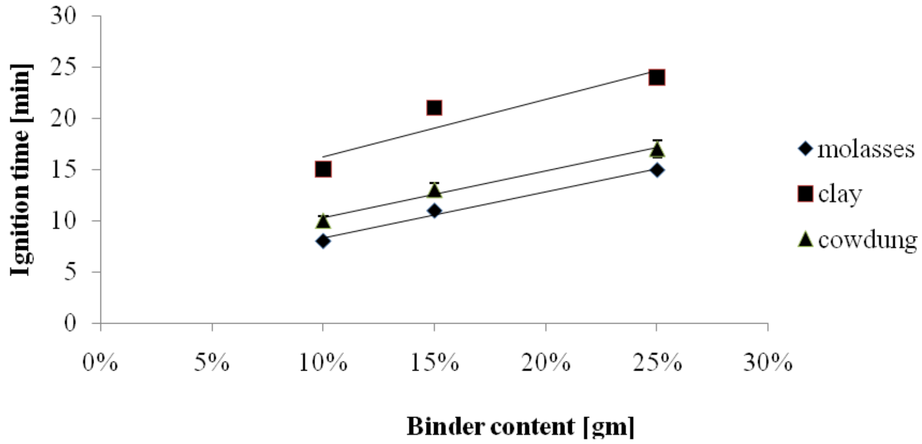
The results (Table 3) show that ignition time increases with the amount of binder in all types of binders. At 10% binder, the mean ignition time was 11 min and the longest time was witnessed in the use of clay binder while molasses bonded briquettes took only 8 min. This could be attributed to the introduced volatile matter in molasses binder. At 25% amount of binder, the mean ignition time was 18.33 min and the longest time of

Table 3: Effect of Binder Types and Amount on Density (g/cm^3) of Composite Briquettes

Binder Amount (%)	Molasses	Clay	Cowdung	Mean Ignition Time [min]	LSD
10	8.0	15.0	10.0	11.0^{c}	N/A
15	11.0	21.0	13.0	15.0^{b}	N/A
25	14.6	24.0	17.0	18.33^{a}	N/A
LSD	N/A	N/A	N/A	0.1471	N/A
Average	11.2^{z}	20.0^{x}	13.33^{y}	N/A	0.848

Note: Means with the same letters are not significantly different at α=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.

Figure 3: Effect of Binder Types and Amount on Ignition Time of Briquettes



24 min was observed in briquettes produced from clay. The increase in the ignition time with binders could be attributed to increase in density due to better bonding which might have resulted in low porosity hence reduced the infiltration of oxidant and outflow of combustion products during combustion. The presence of incombustible matter form of ash in clay bonded briquettes might have slowed down flame propagation since it has low thermal conductivity. The effect of binder types and amount on the ignition time of briquettes is further illustrated in Figure 3.

The increase of ignition time from 11minutes to18.3 min with the amount binder due to increased in density is supported by the findings of (Oladeji, 2010) who observed that the flame propagation in the briquettes was influenced by density. Low porosity in briquettes hinders drying, devolatization and char burning processes due to fewer free spaces for mass diffusion. The presence of incombustibles matter, further slow down the combustion rate. Rotich (1996) found the ignition time for the carbonized sawdust briquettes ranged between 8-12 min which are within these findings.

Burning Time

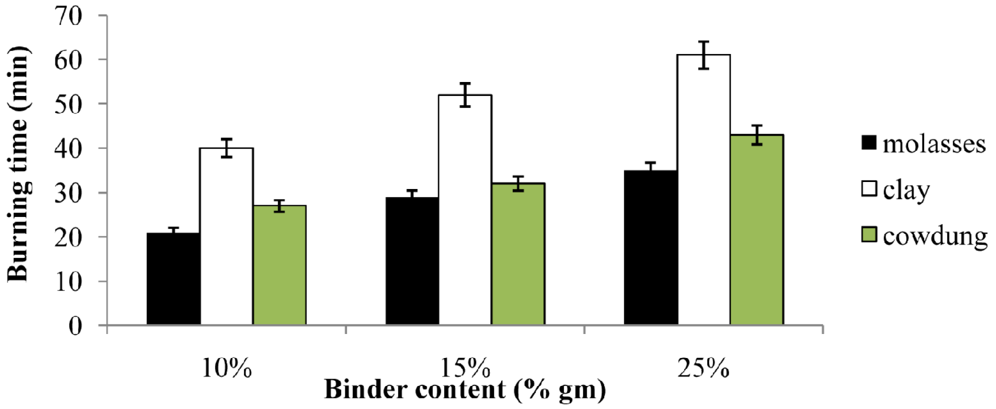
Burning time (Table 4) indicates that the burning duration of briquettes increased with amount of

Table 4: Effect of Binder Types and Amount on Burning Duration [Min] of Briquettes

Binder amount (%)	Molasses	Clay	Cowdung	Mean Burning Time [min]	LSD
10	20.8	40.0	27.0	29.27[c]	N/A
15	29.0	52.0	32.0	37.67[b]	N/A
25	35.2	61.0	43.0	46.40[a]	N/A
LSD	N/A	N/A	N/A	0.937	N/A
Average	28.33[z]	51.0[x]	34.0[y]	N/A	0.937

Note: Means with the same letters are not significantly different at α=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.

Figure 4: Effect of Binder Types and Amount on Burning Time of Briquettes



binder. With 10% binder, the mean burning time was 29.3 but increased to 46.4 min with 25% binder. The increase in burning time with the binder duration could be attributed to increase in density which resulted in reduced porosity. Reduction in air gap between the adjacent particles could have inhibited flame propagation due to low thermal conductivity.

Compared to molasses (28.3 min) and cowdung (34.0 min), clay bonded briquettes had the longest mean burning time of 51.0 min. The variation in burning time could have contributed by incombustible matters and volatile matter. Presence of incombustible matter tends to inhibit flame propagation because it slows down the diffusion of oxygen and combustion products into and out of the briquettes. Similarly, low volatile matter in briquettes is associated with difficult to ignites and burn slowly (Sotannde *et al.*, 2010).

According to Chaney (2010), combustion rate of briquettes is influenced by density due to reduced porosity which tends to hamper the rate of infiltration of oxidant and outflow of the combustion products during combustion. This supports higher combustion rates obtained at low binder ratios.

CONCLUSION

The findings of this study showed that composite briquettes which can serve as alternative sources of energy could be produced from a mixture of charcoal dust, rice husk and bagasse dust with the use of a binder. Compared to other binders, molasses bonded briquettes had better physical and combustion characteristics.

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