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Comparative Thermal Analysis of the Properties of Coal and Corn Cob Briquettes.

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Abstract: *The work involved the production of smokeless briquettes of various compositions from coal and corn cob using $CaSO_4$ and starch as binders, while $Ca(OH_2)$ was used as desulphurizing agent. The briquettes were produced in the following ratio of coal and rice husk such as 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100 respectively. The proximate analyses of the raw coal sample yielded the following: ash content 12.56%, moisture content 7.03%, volatile matter 39.21%, fixed carbon 41.2% and calorific value 117.18 KJ/g. The corn cob gave the following values, ash content 12.56%, moisture content 7.03%, volatile matter 39.21%, fixed carbon 41.2% and calorific value 61.46 KJ/g. The prepared briquettes were sun dried for seven days, subjected to various tests to assess their fuel quality. Of the briquettes produced, the 80% coal: 20% corn cob briquettes produced using starch as binder had the following values; ash content 21.70%, fixed carbon 45.01%, moisture content 2.87%, density 0.482 g/cm^3, volatile matter 30.42%, porosity index 40.12%, calorific value 153.23 KJ/g, water boiling test 1.65 minutes, burning time 24.42 minutes, ignition time 41.22 seconds and sulphur content 6.05%. For briquettes produced with $CaSO_4$ as binder, 80% coal: 20% corn cob had the following values; ash content 27.69 %, fixed carbon 41.63 %, moisture content 2.77 %, density 0.503 g/cm^3, volatile matter 27.91 %, porosity index 41.11 %, calorific value 134.46 KJ/g, water boiling test 1.71 mins, ignition time 41.40 secs, burning time 25.91 mins and sulphur content 7.42 %. The briquettes showed improved properties but with regards to combustible property, the briquettes made using starch as binder do have better qualities than those of produced with $CaSO_4$ as binder.*
***Key words**: briquette, binder, coal, corn cob.*

I. Introduction

Briquetting is also a densification process of loose organic materials such as rice husks, sawdust, coffee husk and coal aimed at improving handling and consumption characteristics for domestic and industrial use (Ogbuagu *et al.*, 1999). At present two main high pressure technologies; ram or piston press and screw extrusion machines, are used for briquetting. While the briquettes produced by a piston press are completely solid, screw press briquettes on the other hand have a concentric hole which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogenous and do not disintegrate easily. Having a high combustion rate, these substitute for coal in most application and in boilers (Belonio *et al.*, 1991). Coal is a readily combustible black or brownish-black sedimentary rock normally occurring in rock strata in layers or veins called coal beds or coal seams. The harder forms, such as anthracite coal, can be regarded as metamorphic rock because of later exposure to elevated temperature and pressure. Coal is composed primarily of carbon along with variable quantities of other elements, chiefly sulphur, hydrogen, oxygen and nitrogen (Mitchell, 1997). Corn cobs are one of the potential agricultural biomass feed stocks for renewable energy industries in the United States to abate the current energy and the greenhouse gas problems (Christiansen, 2009). About 15 to 20% of above ground corn residues (non-grain) are corn cobs (Sokhansanj *et al.*, 2002). Corn cobs can be used for producing heat, power, gas/liquid fuels, and a wide variety of chemical products such as furfural, xylitol and activated carbon (Jiang and Morey, 1992).

II. Objective Of The Study

To produce smokeless briquettes from coal and corn cob using $CaSO_4$ and starch as binders, carryout comparative thermal analyses of the properties of the briquettes to determine the briquette sample that possesses optimum thermal ability.

III. Materials

Pulverised coal, corn cob, $CaSO_4$, starch, calcium hydroxide, electronic weighing machine, manual briquetting machine, electric milling machine, stop watch, muffle furnace, oxygen bomb calorimeter machine model-OSK 100A.

IV. Methods

Preparation of the coal sample

The coal sample was sun dried for five days to reduce its moisture content, broken into smaller sizes using a hammer. The coal samples were then ground in an electric milling machine to pass through 1mm sieve and stored.

Preparation of the biomass

The corn cob was collected, sun dried for five days to reduce the moisture content, ground and sieved through 1mm sieve and stored.

Preparation of the Briquette Samples

The briquettes were produced using a manual hydraulic briquetting machine with three cylindrical mould. Briquettes of coal and corn cob of different compositions were produced with a specific amount of $Ca(OH)_2$ added as desulphurizing agent based on the quantity of coal added, $CaSO_4$ and starch were added as binders to the respective briquettes produced. Specific quantity of water was added and homogenously mixed. The pressure was maintained at 5MPa throughout the production time. After production, the briquettes were sun dried for 7days before analysis.

V. Proximate Analysis Of Briquette Samples

Calorific value: The calorific value of the briquettes was determined using Oxygen Bomb Calorimeter of model-OSK 100A. The calorific value (KJ/g) of the samples under test is calculated from the temperature rise VI in the calorimeter vessel and the mean effective heat capacity of the system. (Sumner *et al*., 1983)

VI= (Ee + W1) TR–C)/S x 4.1868

Where Ee is the water equivalent of the calorimeter (581g), W_1 = quantity of water in the vessel, TR = Temperature rise ^oC, C = correction factor from ignition 154 Cal, S = weight of sample in grams (g).

Moisture content: The moisture contents of the briquettes were determined. A portion (2g) each of the samples was weighed out in a wash glass. The samples were placed in an oven for 2 hours at 105ºC. The moisture content was determined using:

$$MC = \frac{W_1 - W_2}{W_1} \times 100$$

W_1= Initial weight, W_2= weight after drying

Ash content: The ash contents of the briquettes were also determined. A Portion (2g) were placed in a preweighed porcelain crucible and transferred into a preheated muffle furnace set at a temperature of 600ºC for 1hour after which the crucible and its contents were transferred to a desiccator and allowed to cool. The crucible and its content were reweighed and the new weight noted. The percentage ash content was calculated thus:

$$AC (\%) = (W_2/W_1) \times 100.$$

W_1 = Original weight of dry sample, W_2 = weight of ash after cooling.

Volatile matter: The volatile matter of the briquettes was also determined. A portion (2g) of the sample was heated to about 300ºC for 10minutes in a partially closed crucible in a muffle furnace. The crucible and its content were retrieved and cooled in a desiccator. The difference in weight was recorded and the volatile matter was calculated thus:

$$VM = \frac{(W_1 - W_2)}{W_1} \times 100$$

W_1 = Original weight of the sample. W_2 = Weight of sample after cooling.

Fixed carbon: The fixed carbon of the briquettes was also determined. The fixed carbon was determined using the formula

FC (%) = 100 – (%VM + %AC + %MC)

Where VM = Volatile matter, AC = Ash content, MC = Moisture content (ASTM 1992).

Density: A calibrated graduated cylinder was used for the estimation of destiny. The cylinder was packed with the samples and compacted. The density was thus calculated thus:

$$\text{Density } (g/cm^3) = \frac{\text{Mass (g)}}{\text{Volume } (cm^3)}$$

Ignition time (secs): The different samples were ignited at the edge of their bases with a burnsen burner. The time taken for each briquette to catch fire was recorded as the ignition time using a stopwatch.

Burning time (mins) : This is the time taken for each briquette sample to burn completely to ashes. Subtracting the time is turned to ashes completely from the ignition time gives the burning rate.

Burning rate = Ashing time – Ignition time.

Water boiling test (mins) : 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.100g of each briquette sample was used to boil 250ml of water using small stainless cups and domestic briquette stove (Kim, *et al* 2001).

Total Sulphur content: The different samples of the briquettes was pulverized, 1g of the finely powdered samples was mixed with 5g of Na_2NO_3 and 0.2g of $NaNO_3$ in a crucible. The mixture was preheated at 400^oC for 30 minutes in an electric muffle furnance and then fused at 950^oC, after fussion, the crucible was allowed to cool and was placed on its side in a 150 cm^3 beaker. HCl was added to neutralize the Na_2CO_3 and boiled to precipitate the sulphate by treating with $BaCl_2$. The precipitate treated with drops of HF and H_2SO_4, ignited and weighed again. Total sulphur is determined by the expression (Jackson, 1988).

$$\% \text{ sulphur} = \frac{BaSO_4(g) \times 13.7}{\text{Weight of sample}} \times 100$$

VI. Results

Table1.Results of moisture content (%)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	2.47	2.78
80%CD 20% CCB	2.77	2.87
60%CD 40% CCB	3.02	3.01
40%CD 60% CCB	3.48	3.38
20%CD 80% CCB	3.89	4.05
100% CCB	4.14	5.14

Table 2. Results of ash content (%)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	29.63	22.06
80%CD 20% CCB	27.69	21.70
60%CD 40% CCB	25.30	21.00
40%CD 60% CCB	23.45	20.46
20%CD 80% CCB	23.00	19.72
100% CCB	18.88	18.67

Table 3.Results of fixed carbon (%)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	57.46	61.76
80%CD 20% CCB	41.63	45.01
60%CD 40% CCB	37.48	42.24
40%CD 60% CCB	30.93	37.47
20%CD 80% CCB	26.10	33.95
100% CCB	22.98	26.92

Table 4. Results of density (g/cm^3)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	0.824	0.724
80%CD 20% CCB	0.503	0.482
60%CD 40% CCB	0.443	0.363
40%CD 60% CCB	0.344	0.323
20%CD 80% CCB	0.303	0.284
100% CCB	0.163	0.213

Table 5. Results of volatile matter (%)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	10.44	13.40
80%CD 20% CCB	27.91	30.42
60%CD 40% CCB	34.20	33.75
40%CD 60% CCB	42.14	38.69
20%CD 80% CCB	47.01	42.28
100% CCB	54.00	49.27

Table 6. Results of porosity index (%)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	25.10	24.96
80%CD 20% CCB	41.11	40.12
60%CD 40% CCB	53.62	49.64
40%CD 60% CCB	66.78	62.88
20%CD 80% CCB	71.86	70.80
100% CCB	80.25	79.26

Table 7. Results of calorific value (KJ/g)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	142.93	164.34
80%CD 20% CCB	134.46	153.23
60%CD 40% CCB	123.36	138.62
40%CD 60% CCB	103.38	128.58
20%CD 80% CCB	83.36	104.59
100% CCB	66.58	87.45

Table 8. Results of water boiling test (min)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	1.44	1.42
80%CD 20% CCB	1.71	1.65
60%CD 40% CCB	2.24	2.05
40%CD 60% CCB	2.87	2.69
20%CD 80% CCB	3.71	3.22
100% CCB	4.87	4.92

Table 9. Results of burning time (min)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	26.84	26.21
80%CD 20% CCB	25.91	24.42
60%CD 40% CCB	22.20	20.75
40%CD 60% CCB	20.14	19.69
20%CD 80% CCB	18.01	16.28
100% CCB	16.00	15.27

Table 10. Results of ignition time (sec)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	46.66	47.33
80%CD 20% CCB	41.40	41.22
60%CD 40% CCB	37.12	34.40
40%CD 60% CCB	34.54	32.52
20%CD 80% CCB	32.50	31.44
100% CCB	30.36	29.60

Table 11. Results of sulphur content (%)

Briquette sample (%)	$CaSO_4$	Starch
100% CD	7.87	6.21
80%CD 20% CCB	7.42	6.05
60%CD 40% CCB	7.13	5.78
40%CD 60% CCB	6.98	4.98
20%CD 80% CCB	5.92	4.12
100% CCB	3.18	3.03

VII. Discussions

From the results of the proximate analyses of the briquettes produced with the different binders, the moisture content is a measure of the amount of water in the fuel material. The result shows that briquettes made using the binder $CaSO_4$ had slightly lower values when compared to those made using starch as binder. According to (Loo and Koppejan, 2008), the higher the fuel's ash content, the lower the calorific value. The briquettes of $CaSO_4$ have higher ash contents due to the presence of more non combustible compounds, as such they had lower calorific values when compared with briquettes of similar compositions produced with starch as binder. The calorific values of briquettes produced using starch as binder had higher values than those of $CaSO_4$. The value of fixed carbon of a fuel is the percentage of carbon available for char combustion, briquettes of starch had higher fixed carbon values than briquettes of $CaSO_4$, which also resulted in the higher calorific value of briquettes of starch binder. The higher the density of the fuel, the greater the energy density, for a stoked fire, this therefore influences the ratio of energy input per unit volume into a cook stove's combustion chamber. The briquettes produced using $CaSO_4$ as binder showed higher density values than those of starch and as such this effect contributes to the longer burning time of the briquettes of $CaSO_4$ than those made from starch. Calorific value is defined as the amount of heat evolved when a unit weight of fuel is completely burnt and the combustion products are cooled to 298 K (BSI, 2005). The results showed that briquettes made with starch as the binder had higher values than those made using $CaSO_4$ as binder. The water boiling test measures the time it takes a given quantity of fuel to heat and boil a given quantity of water. The results showed that briquettes produced using starch as the binder took averagely similar time to boil water when compared to the briquettes of $CaSO_4$ for the different compositions. The ignition of a briquette sample occurs when the briquette is lighted, combusts and heat propagated through the block of briquette. The briquettes produced with starch as binder ignited faster than the $CaSO_4$ briquettes because of the glucosidic bond of starch are more easily broken than the bond of briquettes produced with $CaSO_4$ as binder. The introduction of $Ca(OH)_2$ when briquetting is to reduce the sulphur content of the briquettes upon combustion. The result show that oxides of sulphur emitted is higher for the compositions of briquettes produced with with $CaSO_4$ than with starch as binder. This shows that $CaSO_4$ contains higher amount of sulphides oxides.

VIII. Conclusion

In this work the briquettes of starch ignited faster, had higher calorific value, less moisture, ash contents and lower sulphur contents, therefore starch is very suitable for use as binder. For the briquettes produced with $CaSO_4$, they had longer burning time and higher density which contributed to longer cooking time. Since the idea about the work is to reduce emission of unfriendly gases and also considering cost effectiveness, the use of $CaSO_4$ as binder for briquette production is not recommended for use in rural areas.

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