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Experimental Analysis on the Characteristics of Pulverized Coal - Palm kernel Shell Fuel Blend

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This study investigates the potentials of supplementing coal with kernel shell for use in high efficiency boilers aimed at reducing greenhouse emissions and adding value to palm kernel waste. Sub-bituminous coal was obtained from Ankpa coal field in Kogi State, Nigeria while Palm Kernel Shell was obtained from an oil processing mill in Benin City, Edo State. Both biomass fuel samples were prepared separately for pelleting and further analysis. Afterwards, seven different fuel pellets lettered A to G of differing blending ratios were produced using a piston-type pelleting machine: The ratios used for this study includes 100% palm kernel shell, 100% coal and coal combined with palm kernel shell at varying masses having mix ratios of : 10 %, 20 %, 30 %, 40 % and 50 % respectively. The produced fuel pellets were characterized according to: moisture content, calorific value, proximate and ultimate analyses in order to define its property (characteristics). The calorific values fuel blends were 21714.74 kJ/kg, 28430.26 kJ/kg, 26449.16 kJ/kg, 25508.01 kJ/kg, 25017.95 kJ/kg, 22046.31 kJ/kg and 20811.92 kJ/kg for samples A to G respectively. It was seen that the calorific values of the coal-palm kernel shell blends decrease with increased co-firing rate compared with that of pure bituminous-coal which was 28430.26 KJ/Kg. The ash content obtained were 13.61 %, 14.89 %, 11.89 %, 11.15 %, 11.51 %, 11.88 % and 16.77 % for samples A to G respectively. Also, Sulphur content results showed 0.84 %, 0.76 %, 0.67 %, 0.70 %, 0.73 %, 0.82 % and 0.88 % for samples A to G respectively. The percentage ash and Sulphur contents obtained in this study were in the recommended range of: 5 - 40% for ash and 0.5 - 0.8% for Sulphur. Fuel sample D with a mix ratio 80-20 having a Sulphur content of 0.70 and the least Carbon content of 51.52 amongst the fuel samples was considered the most environment friendly. These properties were significantly lower than that of pure coal.

Keywords: Coal, Palm Kernel Shell, Sulphur, Calorific Value, Fuel blend.

1. Introduction

Coal remains a critical fuel for global energy systems and power generation because it is a cheap source of fuel and hugely in abundance with an estimated global reserve of 900 billion tons. According to the International Energy Agency report of 2019[1], coal is considered as the leading world's electricity generation source at 38% followed closely by gas at 23%. Reports of coal's terminal decline is obviously premature as over 1600 coal plants are planned or under construction in 62 countries [2]. Coal is perceived as being dirty and the major concern about its usage is air pollution. Clean coal technologies are contemporary research projects aimed at mitigating the adverse consequences of the use of coal thereby fully harnessing its positive quality for economic and social development.

The choice of biomass material as a blending agent in other to improve the firing characteristics of coal depends on a number of factors such as: high heating value, availability, storage and transportation cost. The operational performance of biomass materials can be predicted by physiochemical characterization and comparison of properties such as: moisture content, high heating value and density.

Palm kernel shell is one of the most suitable amongst a wide range of biomass materials namely: rice husk, saw dust, wood chips, sugarcane bagasse, which can be used for power generation [3], However, as reported by Basiron [4] only about 10% of the entire palm tree is used for oil production, with the remaining 90% classified as solid waste including the striped fruit bunch, fibre and the palm kernel shell (PKS). Compared with the other solid wastes, the PKS has the advantage of a higher calorific value, lower moisture content and ash content [6]

Biomass is used in power generation for combustion, either through dedicated firing or through co-firing. Co-firing of biomass has the advantage over the dedicated firing due to its higher combustion efficiency and lower capital cost [7]. Studies have shown that the addition of biomass in coal-fired plants can significantly reduce GHG emissions and reduce slagging inside the combustor [8]

Every biomass material has stored energy in chemical form which is converted to fuel on combustion. It is important to understand how coal and palm kernel shell (PKS) complement each other so has to have an insight of some key parameters to anticipate at the end of the experiment. Coal has a higher heating value than palm kernel or any other biomass material as palm kernel shell cannot burn sustainably alone over a long period of time. Coal's carbon dioxide (CO_2) emission rate is very high while Palm Kernel just like every biomass plant is said to be CO_2 neutral as the same quantity of CO_2 emitted during its combustion is equal to that used by its parent plant (oil palm) through its life span. Coal has low Sulphur and chloride content compared to Palm Kernel Shell. These constituent elements are undesirable in boilers due to their high corrosivity on heat transfer surfaces. Both fuels are readily available and cheap sources of fuel but it should be noted that renewable energy technologies are very expensive to implement.

Many researchers have carried out various studies on the subject matter. Eyad Mohammed [9] carried out a techno-economic study of the reduction of greenhouse gas emissions through biomass co-firing: the case-study was the Saskatchewan Lignite-fired power plant with co-firing rates of 5%, 10% and 20% wood chips. The objective of this study was to reduce the greenhouse gas emissions originating from coal-fired plants. The study consisted of: a technical model and an economic analysis. Aspen Plus was used to model the coal combustion and Promax for the CO_2 capture process. It was found out that 0% co-firing without CO_2 capture lowers the cost of electricity and CO_2 capture is uneconomic. From the economic and environmental perspective, the most suitable choice was 10% co-firing without CO_2 capture resulted in the reduction of CO_2 emissions being equivalent to removing 19,000 cars from the street. Dwika Budianto [10] performed a Numerical investigation of co-firing of palm kernel shell into pulverized coal combustion in which Computational Fluid Dynamics (CFD) was used to model and analyze co-firing of palm kernel shell into a 7MW existing pulverized-coal boiler. CFD is recognized as an efficient and appropriate tool to measure the performance of co-firing. Baxter [11] highlighted the benefits of biomass and coal co-combustion as low risk, low cost, sustainable, renewable energy option that promises reduction in net CO_2, SO_x and NO_x emissions along with several societal benefits, his study also mentioned challenges associated like supply, handling, storage, potential increase in corrosion, fly ash utilization etc. The study concluded that issues associated biomass combustion are manageable but require careful consideration of fuels, boiler operating conditions and boiler design.

This paper aims at studying and optimizing the blending characteristics of coal and palm kernel shell fuel, using proximate and ultimate analysis for cleaner energy usage.

2. Materials and Methods

Sub-bituminous coal was obtained from Ankpa coal mining field in Kogi state, Nigeria while palm kernel shell was obtained in a local oil processing mill in Benin City, Edo State. Both fuels were prepared separately for pelleting. A moist brush was used to clean off soil and stone particles attached to the coal during mining and transportation. The palm kernel was properly sieved to get rid of solid impurities. Both fuels were sundried for 2 weeks for ease of crushing and moisture content reduction before being crushed separately into powdery form. Fuel pellets were produced in order to prevent particle erosion, promote effective combustion and ease of handling. A piston type pelleting machine was used to produce pellets of diameter 25mm and length 50mm with starch and paper acting as binders. Seven fuel pellets samples of varying mix ratio were produced as show in table 1 below.

Table 1. Prepared Fuel Pellets Samples

SAMPLE	%PKS	%COAL
A	100	-
B	-	100
C	10	90
D	20	80
E	30	70
F	40	60
G	50	50

An oven was used in drying the samples for 3 hrs at a temperature of 105 ^oC to reduce its moisture content. A muffle furnace of combustion chamber temperature of 700 ^oC was used to burn each sample in the presence of sufficient oxygen. A post-combustion gravimetric analysis was carried out on the combustion residues obtained from combusting the same mass of fuel (about 1g) under the same conditions of pressure and temperature thereby providing an adequate basis for comparing the fuels' property. An oxygen bomb calorimeter was used to determine the calorific values of the fuel pellets. The ASTM standard D5373-02 of 2003 was adopted for the proximate analysis while the ASTM analytical method was used for the ultimate analysis as prescribed by [12]

2.1 Determination of Proximate Analysis

The proximate analysis is the physical properties of the fuel and it consist of the moisture content, ash content, volatile matter as well the fixed carbon. The formula used for determining the constituent of the proximate analysis is thus:

2.1.1 Moisture Content.

The moisture content of the fuel is given by:

$$\%\,\mathbf{MC} = \frac{(g-\chi)}{g} \times 100 \qquad (1)$$

Where,

g = mass of sample (gram)
x = mass of dry matter (gram)
(g - x) = loss in mass

2.1.2 Ash Content

The ash content of the fuel as determined from the muffle furnace is given by:

$$\%\,\mathbf{Ash} = \left(\frac{x}{g}\right) \times 100 \qquad (2)$$

where,

g = mass of sample (gram)
x = mass of ash (gram)

2.1.3 Volatile Matter

The volatile matter of the fuel is given by:

$$\%\,\mathbf{VM} = \frac{x-y}{g} \qquad (3)$$

where,

g = mass of sample (gram)
x = mass of dry matter (gram)
y = mass of residue (gram)

2.1.4 Fixed Carbon

The percentage of fixed carbon in the fuel is given by:

$$\%\,\mathbf{Fixed\ Carbon} = 100 - (\%\,\mathbf{V.M} + \%\,\mathbf{Ash} + \%\,\mathbf{MC}) \qquad (4)$$

2.2 Determination of Ultimate Analysis

The ultimate analysis is the chemical properties of the fuel and it consists of the carbon content, oxygen content, hydrogen content, nitrogen content and sulphur content.

2.2.1 Carbon Content

$$\%\,\mathbf{Carbon} = \frac{(B-T) \times M \times 0.003 \times 100 \times 1.33}{g} \qquad (5)$$

Where,

B = blank titre
M = molarity of the acid used
T = sample titre
g = mass of sample

2.2.2 Nitrogen Content

$$\%\,\mathbf{Nitrogen} = \frac{(T \times M \times 0.014 \times DF)}{g} \times 100 \qquad (6)$$

where, M = molarity of the acid used
g = mass of sample
T = titre volume
DF = dilusion factor diluted

2.2.3 Hydrogen Content

$$\%\,\mathbf{Hydrogen} = \frac{\mathrm{wt\ of\ } H_2O \times 0.1119 \times 100}{\mathrm{wt\ of\ pellet}} \qquad (7)$$

2.2.4 Sulphur Content

$$\%\,\mathbf{Sulphur} = \frac{\chi \times 0.1373}{g} \times 100 \qquad (8)$$

where, g = mass of sample
x = equivalent mass of $BaSO_4$

2.2.5 Oxygen Content

% Oxygen = 100 – (C + H + N + S + H_2O) (9)

2.3 Determination of Calorific Value

The calorific value which determines the energy content of the fuel is given by

$$\mathbf{Calorific\ Value}\left(\frac{kJ}{kg}\right) = \frac{E\Delta T - \Phi - V}{g} \qquad (10)$$

Where,

E = Energy equivalent of the calorimeter
ΔT = Change in temperature
Calibration factor, Φ = 2.3 × length of burnt wire
g = mass of sample
V = volume of alkali in calorimeter

3. Results and Discussion

3.1 Proximate Analysis of Fuel Samples

The results obtained from the proximate analysis of the fuel blend samples when equations 1-4 are applied is shown in Table 2. The volatile matter content indicates the ignition properties of the fuel, the higher the volatility, the easier the ignition, as seen in the table, all the samples have high volatile matter content with the 20% PKS blend of 82.05 been the best. The ash content is a good indicator of the fuel characteristics, a good fuel should have a low ash content as it helps to reduce slagging in water tubes in the boiler, it also reduces handling and burning capacity while affecting both the combustion and boiler efficiency, as seen in Table 2, sample D with the 20% PKS has the best ash content.

The moisture content of a fuel has a great influence on the energy value and combustion performance of the fuel. From literature, good moisture content ranges between 10% and less. This is considered as key for a good and sustainable combustion. Thus, from the result of the moisture content analysis of the samples, it shows that the pellets have a moisture content that ranges between 4.09 – 4.80% as shown in Table 1. This means that the fuel pellets have good moisture content. This will influence the energy value and combustion performance of the pellets. Fixed carbon acts as a main heat generator during burning, this in turn will have significant influence on the calorific values. This means that the sample G with 50% PKS would be more sustainable for power generation than the other samples.

Table 2: Proximate Analysis of Fuel Samples

FUEL PELLETS	A	B	C	D	E	F	G
Mix Ratio	**100 P**	**100C**	**90-10**	**80-20**	**70-30**	**60-40**	**50-50**
% Volatile Matter	77.78	77.63	80.52	82.05	80.38	79.46	62.83
% Ash	13.61	14.89	11.89	11.15	11.51	11.88	16.77
% Moisture Content	4.69	4.38	4.49	4.80	4.09	4.60	4.10
% Fixed Carbon	3.92	3.10	3.60	2.00	4.02	4.06	16.30

Table 3: Ultimate Analysis of Fuel samples

FUEL PELLETS	A	B	C	D	E	F	G
Mix Ratio	**100**	**100**	**90-10**	**80-20**	**70-30**	**60-40**	**50-50**
% Carbon	62.11	65.52	54.14	51.52	55.74	59.34	60.94
% Hydrogen	5.09	5.12	5.14	5.27	5.19	5.32	5.23
% Nitrogen	0.849	0.803	0.903	0.980	0.921	0.889	0.833
% Sulphur	0.84	0.76	0.67	0.70	0.73	0.82	0.88
% Moisture	4.69	4.38	4.49	4.80	4.09	4.60	4.10
% Oxygen	26.421	23.417	35.457	36.730	33.329	29.031	28.017

Table 4: **Calorific value analysis of Fuel Pellets**

FUEL PELLETS	A	B	C	D	E	F	G
Mix Ratio	**100**	**100**	**90-10**	**80-20**	**70-30**	**60-40**	**50-50**
Mass of sample, g	1.320	1.100	1.140	1.180	1.200	1.360	1.440
Change in temperature, $\Delta T (^oC)$	2.200	2.400	2.314	2.310	2.304	2.301	2.300
Length of Burnt Wire, B	7.3	6.5	6.4	6.5	6.4	6.2	6.5
Calibration Factor, $\phi = 2.3 \times B$	16.79	14.95	14.72	14.95	14.72	14.26	14.95
Volume of Alkali in Calorimeter (m^3)	6.2	6.1	6.2	6.4	6.3	6.2	6.3
Calorific Value (KJ/Kg)	21714.76	28430.26	26449.16	25508.01	25017.95	22046.31	20811.92

Where E = 13,039.308 KJ/^{o}C, Average change in temperature = 2.3, ϕ = Calibration Factor

3.2 Ultimate Analysis of Fuel Pellets

The results from the ultimate analysis of the fuel samples are shown in Table 3. From Tables 3, it is seen that all the fuel samples have good and considerable low sulphur contents according to Bureau of Energy Efficiency, normal sulphur content for fuels ranges from 0.5 to 0.8%

normally. Corrosion is the main disadvantage of high sulphur content by sulphuric acid formed during and after combustion, and condensing in cool parts of the chimney, economizer and air pre heater. The percentage sulphur content as obtained in the results is considerably minimal for each of the fuels (pellets and raw residues). However, the with low sulphur content in the PF pellets, it is expected that there would be slow corrosion rate in the boiler if pellets are used.

3.3 Calorific Value of Fuel Samples

Table 4 presents the calorific value of each sample which was calculated using equation 10, the calorific value measures the energy content of each fuel sample. The results show the calorific values from the experiment, as can be seen, the calorific values of the coal-palm kernel shell blends decrease with an increase in the co-firing rate compared to that of 100% coal which was 28430.26 KJ/Kg.

4. Conclusion

Proximate analysis, ultimate analysis and calorific value analysis of the fuel samples produced from different blend ratios of coal and PKS was carried out. Results obtained from the analysis were compared. It was observed that there is a significant lower moisture and ash contents in the fuel blend samples compared to either coal or PKS alone. It was also observed that the sulphur content were significantly low Essentially, the implication of the results means that blends as fuel for combustion in boilers would be more suitable than the coal for power generation. Again, another implication is that with the use of blends for firing boilers, the maintenance cost of the boiler would be low. The percentage ash and Sulphur contents obtained in this study were in the recommended percentage range of: 5 - 40% for ash and 0.5 - 0.8% for Sulphur. This is vital for the heat transfer characteristics and the life of the boiler. Fuel sample D with mix ratio 80-20 had a Sulphur content of 0.70 and the least Carbon content of 51.52 amongst the fuel samples and this was significantly lower than Sample B which was 100% coal. The calorific values of the coal-palm kernel shell blends decrease with an increase in the co-firing rate compared to that of 100% coal which was 28430.26 KJ/Kg.

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Conflict of interest

The authors declare no conflict of interest.

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