Effect of Elaeis Guineensis Biomass Residues in the Production of Coal Pellets

UCHE ONOCHIE (onochieuche@yahoo.com)
ALEX EKWUEME FEDERAL UNIVERSITY NDUFU ALIKE
HENRY EGWARE
University of Benin
FRANCIS ONOROH
University of Lagos

Research

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EFFECT OF ELAEIS GUINEENSIS BIOMASS RESIDUES IN THE PRODUCTION OF COAL PELLETS

Onochie U. P [1*], Egware O. H[2], Onoroh F[3]

[1*]Department of Mechanical Engineering, Alex-Ekwueme Federal University, Ndufu Alike, Nigeria
[2]Department of Mechanical Engineering, University of Benin, Benin City, Nigeria
[3]Department of Mechanical Engineering, University of Lagos, Akoka, Nigeria
Corresponding e-mail address: onochieuche@yahoo.com

ABSTRACT

In this study, the effect of elaeis guineensis in the production of pellets from coal was investigated. Coal and elaeis guineensis were collected and pulverised. A locally fabricated screw press machine was used to produce three types of pellets in the same ratio (i.e. 80C:20R) while the fourth pellet is100% coal. These pellets are: coal palm kernel shell (CPKS), coal palm fibre (CPF), coal empty fruit bunch (CEFB) as well as raw coal (C). Thereafter, the pellets were sundried and characterised base on ASTM Standards. These include the calorific value, proximate and ultimate analysis. From the results, it was observed that the calorific value of CPKS, CPF, CEFB and *C were 28033.38kJ/kg, 27695.4kJ/kg, 27687.5kJ/kg and 22021.99kJ/kg respectively. The sulphur content of the pellets is 0.7%, 0.71%, 0.73% and 0.76% respectively. The results revealed that the 100% coal pellet has the lowest percentage CV and the highest percentage sulphur and ash content. Essentially, this study has been able to established that elaeis guineensis residues is a good energy source for enhancing the calorific value of coal and also has the tendency of reducing the sulphur and ash contents of coal especially the PKS.*

***Keywords**: Analysis, Elaeis Guineensis, Coal, Pellets, Effect*

1.0 INTRODUCTION

In Legendpower [1], it was reported that wind power costs approximately \$133 per MW/h to produce, while gas and coal can cost up to \$208 and \$295 MW/h each. However, in 2007, the International Energy Agency, IEA [2] reported that the proportion of electricity generated from coal is increasing, especially in developing countries**.** Sambo et al., [3] reported that though coal is in abundance in Nigeria, however, it doesn't contribute to the electricity generation in the country. The Energy Commission of Nigeria (ECN) [4], in her National energy policy, reported that coal reserves in Nigeria is about 639 million tonnes while the inferred reserves are about 2.75 billion tonnes, consisting approximately of 49% subbituminous, 39% bituminous, and 12% lignitic coals.

As a matter of fact, coal was formally utilized for electricity generation in Nigeria before the discovery of crude oil. It was jettisoned due to the fact that it is quite dirty compared to a cleaner fuel like the natural gas. However, in recent times, there is increasing clamour for the backward integration of coal into the Nigeria energy mix for generation of adequate power. Several researches have been conducted and it's been scientifically proven that coal can be treated to become a better and cleaner fuel through cofiring with biomass materials in form of pellets.

According to Baxter [5], cofiring of coal with biomass is a viable option when considering the reduction of greenhouse gas emissions during the combustion of coal in coal-fired boilers. Biomass materials, such as agricultural residues from elaeis guineensis are also in abundance in Southern Nigeria and often used as fuel for steam boilers in oil palm processing industries. However, a lot of these residues are not used and disposed-off through open burning system which causes environmental pollution. Again, elaeis guineensis residues not used as fuel generally decay to form CO_2 and often smaller quantities of other much more potent greenhouse gases. Therefore, there is need to channel these elaeis guineensis residues into useful energy, by combining it with coal to produce pellets for electricity generation.

Rohan [6] in his work reported that for coal-fired plants, biomass cofiring reduces the net CO_2 emissions. He also stated that biomass cofiring enables coal plants to reduce SO_2 emissions because less sulphur is contained in biofuels than coal. Rohan further reported that volatile matter in biofuels is higher than in coal which of course results in less NO_x formation in low NO_x burners. In Tillman et al., [7] as reported in Baxter et al., [8], the use of biomass in a coal-fired boiler does not affect or at worst slightly decreases the overall generation efficiency of a coal-fired power plant. Chukwu et al., [9] reported that few studies on characterisation such as proximate and ultimate analyses, calorific value have been conducted on the Nigeria coal. However, to the best of our knowledge, cofiring coal with Elaeis Guineensis residues [i.e. Palm Kernel Shell (PKS), Palm Fibre (PF) and Empty Fruit Bunch (EFB)] is yet to be carried out. The objective of this study therefore, is to determine the effect of Elaeis Guineensis residues in the production of coal pellets (using waste paper and cassava starch as binder) with focus on the physiochemical properties of the pellets produced.

2.0 METHODOLOGY

2.1 Collection and Preparation of Samples

Raw coal was collected from Enugu State and blended with residues of Elaeis Guineensis [i.e. Palm Kernel Shell (PKS), Palm Fibre (PF) and Empty Fruit Bunch (EFB)] which was collected from the Nigeria Institute for Oil Palm Research, NIFOR. The raw and blended (pulverised) Elaeis Guineensis residues and coal are shown in Figure 1a to 1c. Pellets were thereafter produced using a screw press pelletizer. The pellets are shown in Figure 2. However, in other to provide options for flexibility in terms of mixing ratio, it was necessary to use a design experiment to optimize the mixing ratios between coal and elaeis guineensis with focus on durability and combustion sustainability. Hence, pellets were produced using mixing ratios of 90C:10R, 80C:20R, 70C:30R, 60C:40R and 50C:50R respectively.

Figure 1a: Raw Elaeis Guineensis (PKS, EFB and PF)

Figure 1b: Blended (pulverised) raw Elaeis Guineensis (PKS, EFB and PF)

Figure 1c: Raw coal before and after blending (Pulverised coal) **Figure 2:** Elaeis Guineensis-Coal Pellets

2.2 Design Experiment of Fuel Pellets

The two properties considered for this experiment are: durability of pellets and combustion sustainability of pellets.

2.2.1 Durability Test Analysis

In this analysis, the drop test method reported in Al-Widyan and Al-Jalil [10]; Khankari et al., [11]; Sah et al., [12]; and Shrivastava et al., [13] was used. A single pellet was dropped from a 1.85m height on a metal plate for four times. Percentage durability was obtained using Equation 1 and presented in Table 1.

$$\%\ \text{Durability} = \frac{\text{Final mass of pellet after four drops (kg)}}{\text{Inital mass of pellet (kg)}} \times 100 \qquad (1)$$

Table 1: Durability test

% Durability	90C:10R	80C:20R	70C:30R	60C:40R	50C:50R
CPKS	86.0	88.7	90.0	92.7	95.3
CPF	89.2	91.7	92.9	94.8	96.6
CEFB	87.5	88.3	89.1	91.4	92.7

2.2.2 Combustion Sustainability Test Analysis

For the combustion test, the method reported in Varun et al.,[14] was used. Pellets from the mixing ratios were subjected to combustion under the same adequate inlet air condition, using a locally fabricated prototype boiler as shown in Figure 3. The rate of burning of pellets to complete combustion was calculated using Equation 2 and presented in Table 2.

$$\text{R} = \frac{\text{Mass of pellet}}{\text{Total time take in combustion}} \qquad (2)$$

Table 2: Combustion test

Combustion rate (g/min)	90C:10R	80C:20R	70C:30R	60C:40R	50C:50R
CPKS	15.12	14.31	12.94	11.96	9.89
CPF	12.78	11.20	9.95	8.77	7.45
CEFB	11.56	10.32	9.12	8.25	7.15

Figure 3: Combustion test of pellets in a locally fabricated boiler

In Table 1, the durability test showed that the 50C:50R mixing ratio has the best percentage durability while the 90C:10R has the least. Pellets handling during transportation cause losses in some of its particle which could affect its sustainability during combustion. Hence, the durability of pellets is an important property of a solid fuel. However, in Table 2, it was observed that 90C:10R mixing ratio has more sustainability in terms of combustion time. This was followed by 80C:20R, 70C:30R, 60C:40R and 50C:50R in descending order.

2.2.3 Selection of mixing ratio for characterisation

Given the two properties in focus (durability and combustion sustainability), it is important to note that in as much as durability is important, combustion sustainability cannot be compromised. Hence, in other to accommodate both properties for the pellets, 80C:20R mixing ratio was chosen as the option for characterisation analysis. This was done so that some level of durability will be accommodated while giving more priority to the combustion sustainability.

2.3 Characterisation of pellets

The pellets from the 80C:20R mixing ratio were thereafter sundried for two weeks while laboratory experiments were conducted on each sample to determine their calorific values, moisture content as well as proximate and ultimate analyses. The experiments were conducted according to the American Society for Testing and Materials Standards ASTM E870-82 [15] and ASTM D4442-07 [16].

2.4 Determination of Calorific Value of Pellets

The equipment used in determining the calorific value is the oxygen bomb calorimeter. About 1g of each residue was accurately weighed into a crucible with a known nickel fuse wire stretched between the electrodes. This was to ensure that the fuse wire had a firm contact with the fuel residue. However, in order to absorb the product of combustion such as sulphur and nitrogen, 2ml of water was measured and poured into the bomb. 25atm of pure oxygen was thus supplied to the bomb through the valve. Thereafter, the bomb was placed in the calorimeter that contains the already measured water. After ensuring that all necessary electrical connections were in place, the stirring was initiated. After achieving a steady temperature, the fuel residue was fired and the temperature readings were taken and recorded for about 30 seconds until the maximum temperature is attained. Thereafter, the bomb is removed while the pressure is slowly released through the exhaust valve to enable the content of the bomb to be measured for further analysis. The heat energy that was released by the fuel residue was absorbed by the surrounding water contained in the calorimeter. Combustion heat of each fuel residues was analysed. Data was obtained during the analysis while equation (1) was used to calculate the calorific value of the elaeis guineensis – coal pellets [i.e. (i) Coal Palm Kernel Shell (CPKS), (ii) Coal Palm Fibre (CPF), (iii) Coal Empty Fruit Bunch (CEFB) and (iv) Coal (C) respectively].

$$CV\left(\frac{kJ}{kg}\right) = \frac{E\Delta T - \Phi - V}{g} \tag{3}$$

where, E = Energy equivalent of the calorimeter = 13,039.308 (kJ/^{o}C), ΔT = Change in temperature (^{o}C), Φ = 2.3 × length of burnt wire (kJ), g = mass of sample (kg), V = volume of alkali in calorimeter (kJ)

2.5 Determination of Proximate Analysis

The proximate analysis is the physical properties of the fuel of the elaeis guineensis – coal pellets [i.e. (i) Coal Palm Kernel Shell (CPKS), (ii) Coal Palm Fibre (CPF), (iii) Coal Empty Fruit Bunch (CEFB) and (iv) Coal (C) respectively] and it consist of the moisture content, ash content, volatile matter as well as the fixed carbon.

2.5.1 Moisture content

Each sample of mass 10g were measured and placed in the porcelain separately. The porcelain and its content were then oven dried at 105^{o}C to a constant weight for 3 hours. The formula is given in Equation (4):

$$\%\ MC = \frac{(g-\chi)}{g} \times 100 \tag{4}$$

where, g = mass of sample, x = mass of dry matter, (g - x) = mass of water loss

2.5.2 Volatile Matter

For the volatile matter analysis, the samples were weighed accurately and oven dried at 105^{o}C for 4hrs. Each sample was cooled and later placed in a muffle furnace maintained at 600^{o}C for 20mins.

The sample was weighed after it has cooled. Equation (5) was used to calculate the percentage volatile matter and expressed as;

$$\% \mathrm{V.M} = \frac{x - y}{g} \tag{5}$$

where, g = mass of sample, x = mass of dry matter, y = mass of residue

2.5.3 Ash Content

For the ash content analysis, an accurately measured sample was burnt up in a muffle furnace receiving adequate air at 700°C for 4hrs. The crucible containing only ash was cooled, and the weight of the ash was calculated after weighing the crucible. Equation (6) was used to calculate the ash content and expressed as:

$$\% \mathrm{Ash} = \left(\frac{x}{g}\right) \times 100 \tag{6}$$

where, g = mass of sample, x = mass of ash

2.5.4 Fixed carbon

For the fixed carbon analysis, each of the samples was calculated from other proximate analysis properties, which is the sum of moisture, ash, volatile matter and fixed carbon, whose percentages make up 100. Fixed carbon is simply 100 minus the addition of volatile matter, ash and moisture content. Equation (7) was used to calculate the percentage fixed carbon.

$$\% \mathrm{F.C} = 100 - (\% \mathrm{V.M} + \% \mathrm{Ash} + \% \mathrm{MC}) \tag{7}$$

2.6 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. The formula used in Jenkins et al., [17] was used for determining the constituent of the ultimate analysis.

2.6.1 Carbon content

Data was obtained from laboratory analysis while equation (8) was used for the calculation of the percentage carbon.

$$\% \mathrm{Carbon} = \frac{(B - T) \times M \times 0.003 \times 100 \times 1.33}{g} \tag{8}$$

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

2.6.2 Nitrogen content

Data was obtained during analysis and equation (9) was used for the calculation of the percentage nitrogen content.

$$\% \mathrm{Nitrogen} = \frac{(T \times M \times 0.014 \times DF)}{g} \times 100 \tag{9}$$

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

2.6.3 Sulphur content

Data was obtained from laboratory analysis. Equation (10) was used to calculate the percentage sulphur content.

$$\% \mathrm{Sulphur} = \frac{\chi \times 0.1373}{g} \times 100 \tag{10}$$

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

2.6.4 Hydrogen content

Data was obtained from the laboratory analysis. Equation (11) was used for the calculation of the percentage hydrogen content.

$$\% \text{ Hydrogen} = \frac{\text{wt of } H_2O \times 0.1119 \times 100}{\text{wt of pellet}} \qquad (11)$$

2.6.5 Oxygen content

Equation (12) was used for the calculation of the percentage oxygen content, which is 100 percent minus the total summation of other constituents.

$$\% \text{ Oxygen} = 100 - (C + H + N + S + H_2O) \qquad (12)$$

3.0 RESULT/DISCUSSION

3.1 Calorific Value of Pellets

Figure 4 presents the calorific value of the various elaeis guineensis - coal pellets [i.e. Coal Palm Kernel Shell (CPKS), Coal Palm Fibre (CPF), Coal Empty Fruit Bunch (CEFB) and Coal (CPKS, CPF, CEFB and C)].

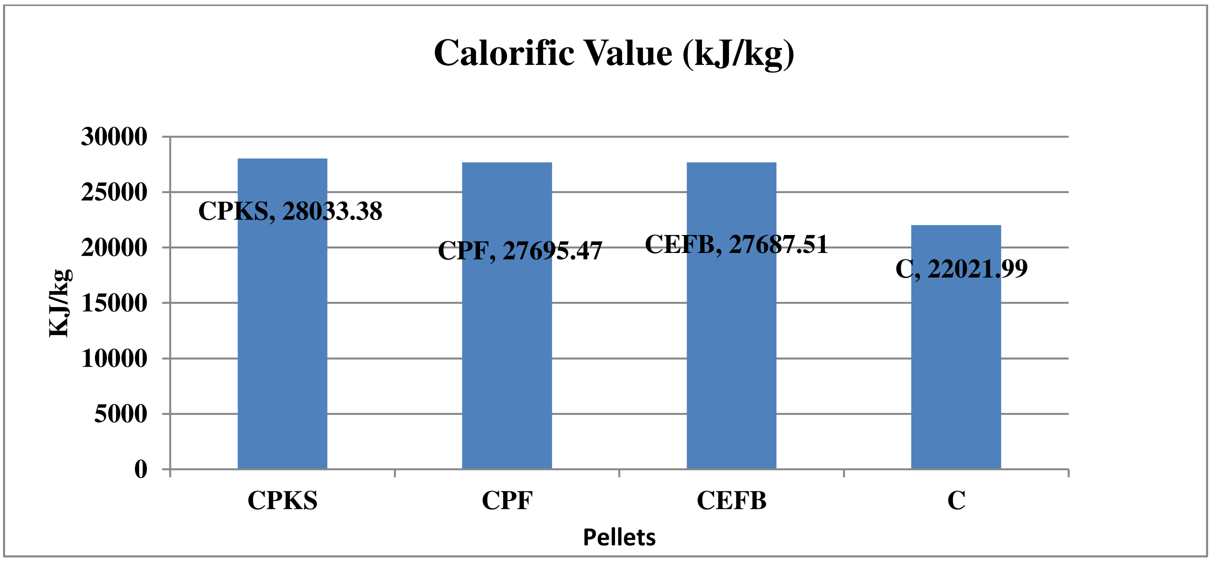

Figure 4: Calorific value of elaeis guineensis - coal pellets

From the results of the calorific value analysis in Figure 4, it was observed that the CPKS pellet has the highest energy content of 28033.38kJ/kg while the 100% coal pellet has the lowest energy content which is 22021.99kJ/kg. The result also showed that the presence of elaeis guineensis positively affects the calorific value of the 100% coal pellet. In other words, with elaeis guineensis residues blended with raw coal, there would be increase in calorific value of pellets thereby increasing its combustion sustainability in boilers.

3.2 Proximate Analysis of pellets

Data was obtained from the laboratory analysis for the parameters (moisture, ash, volatile matter and fixed carbon) while equations (4), (5), (6) and (7) in the methodology were used to obtain the percentage composition of each parameter. Figure 5-8 presents the result obtained from the fuel pellets [Coal Palm Kernel Shell (CPKS), Coal Palm Fibre (CPF), Coal Empty Fruit Bunch (CEFB) and Coal].

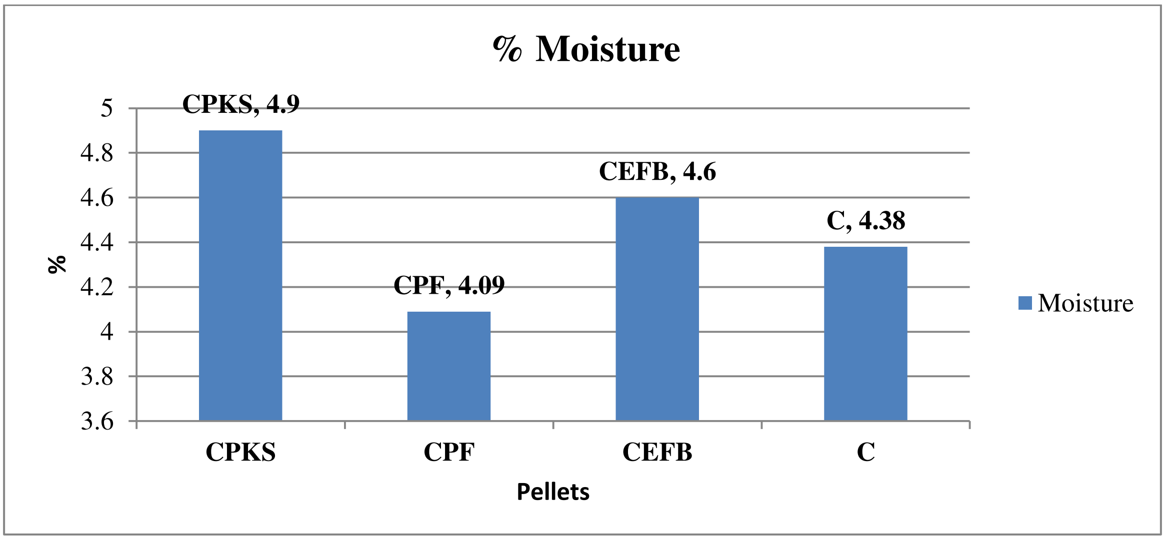

Figure 5: % Moisture of Pellets

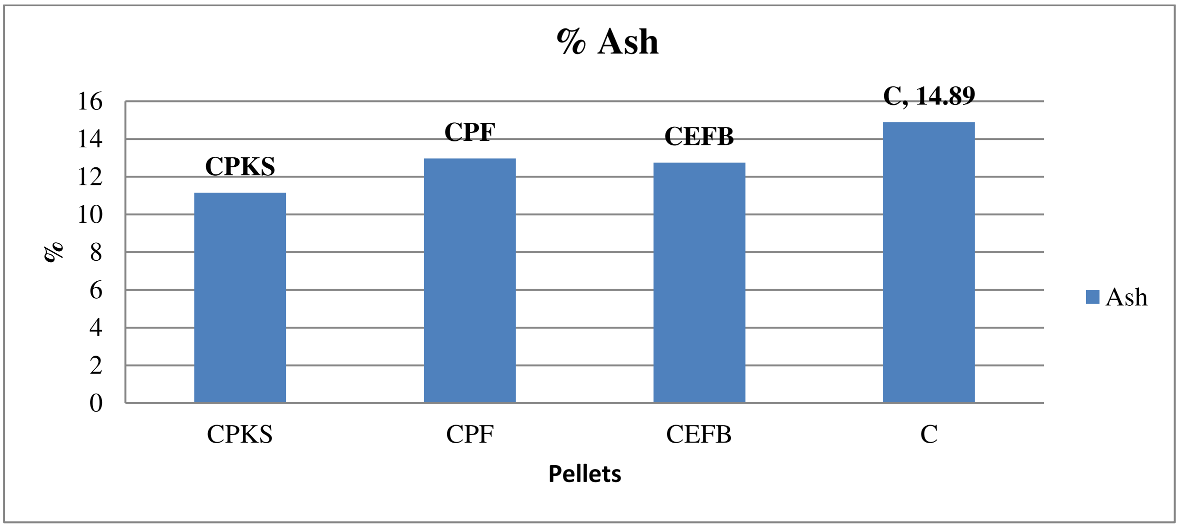

Figure 6: % Ash of Pellets

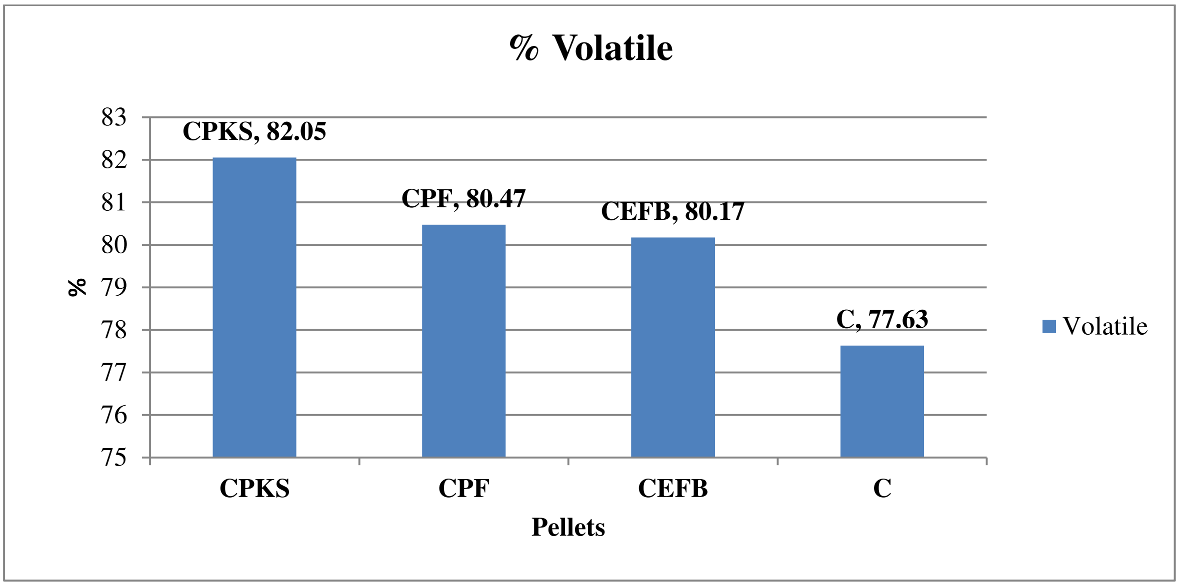

Figure 7: % Volatile matter of Pellets

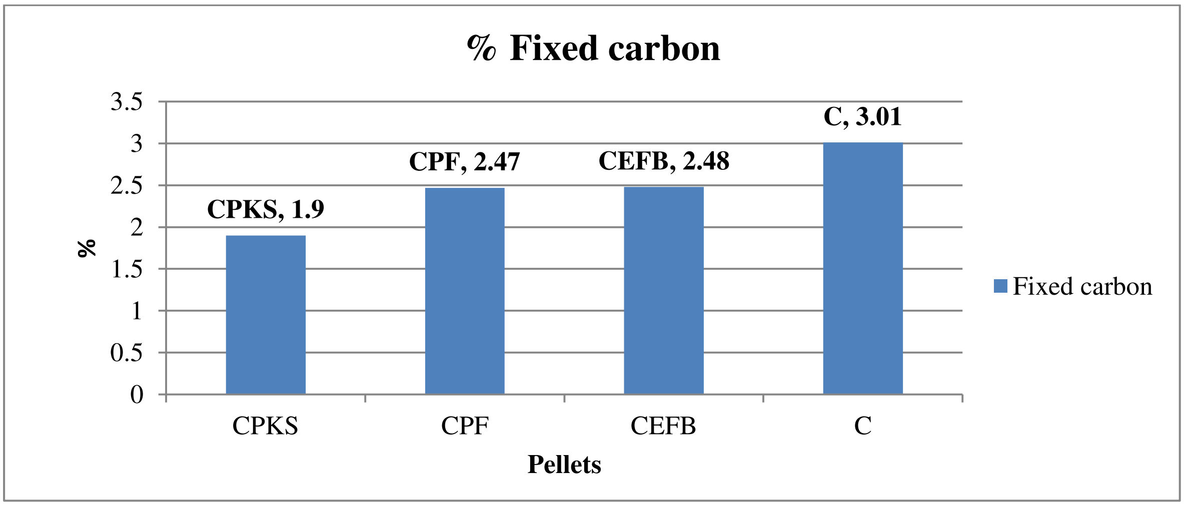

Figure 8: % Fixed carbon of Pellets

In Abdu and Sadiq [18] as reported in Unwaha et al. [19], the energy value and combustion performance of a fuel is influenced by the content of moisture in it. In other words, lower moisture content would boost the energy and combustion performance of such fuel. Research studies such as Kuti [20], Chin and Shiraz [21]**,** Idah and Mopah [22] reported that good moisture content ranges between 8-12% and less. From Figure 5, it was observed that the percentage moisture content ranges from 4.09% to 4.90% with CPF and CPKS pellets having the highest and lowest moisture content respectively. This result again falls within the range of values reported in [18][19][20][21][22]. In Figure 6, it was observed that the 100% coal pellet has the highest percentage ash content of 14.89% while the CPKS pellets has the lowest ash content. Figure 7 also showed that the pellet with the highest volatile matter was CPKS and the lowest was the 100% C pellet, with percentage values of 86.05% and 77.63% respectively. Essentially, these results showed that the presence of the residues of Elaeis Guineensis in the production of coal pellets would reduce the ash content and increase the ease of combustion of the pellets due to the higher volatile matter observed in the results for the CPKS, CPF and CEFB respectively. Again, in terms of sustainable combustion in boilers, low moisture and ash contents as well as high volatile matter are considered as key performance indicators for pellets.

3.3 Ultimate Analysis of pellets

Again, data was obtained from the laboratory analysis for the ultimate analysis parameters (carbon, hydrogen, nitrogen, sulphur and oxygen) while equations (8), (9), (10), (11) and (12) in the methodology were used to obtain the percentage composition of each parameter. Figure 9-13 presents the result obtained from the fuel pellets [Coal Palm Kernel Shell (CPKS), Coal Palm Fibre (CPF), Coal Empty Fruit Bunch (CEFB) and Coal].

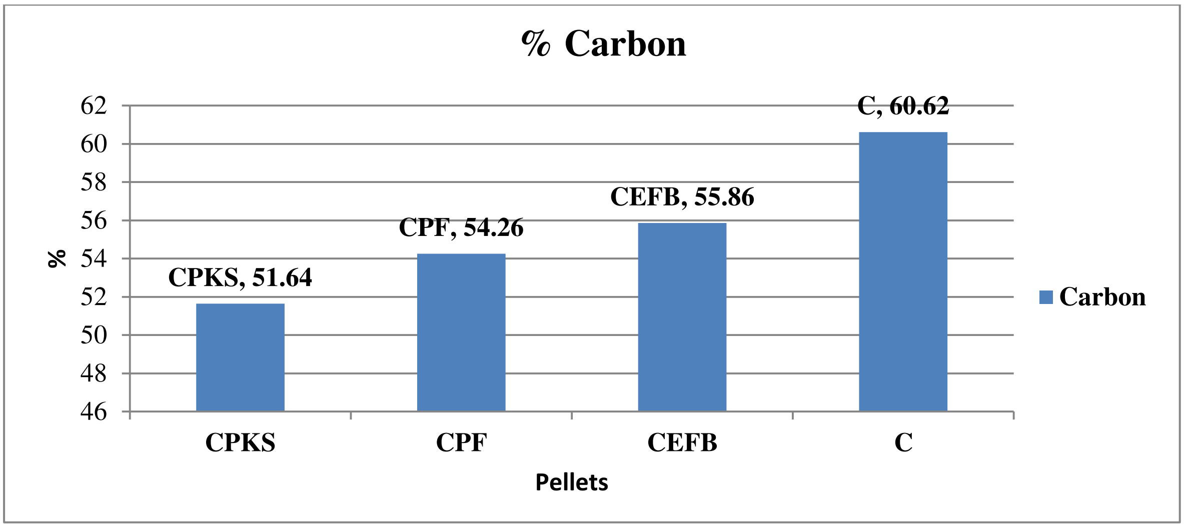

Figure 9: % Carbon of Pellets

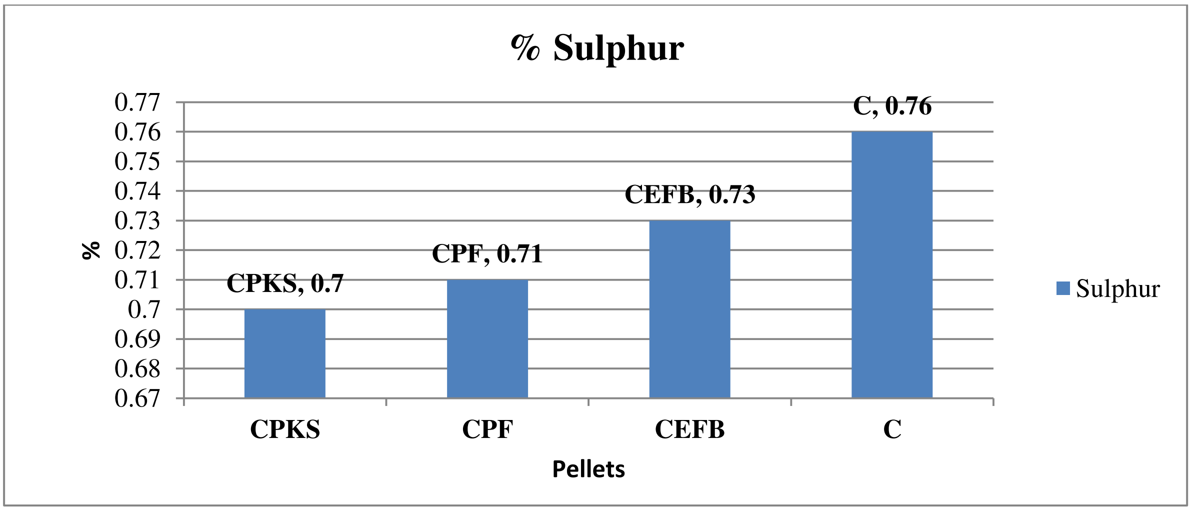

Figure 10: % Sulphur of Pellets

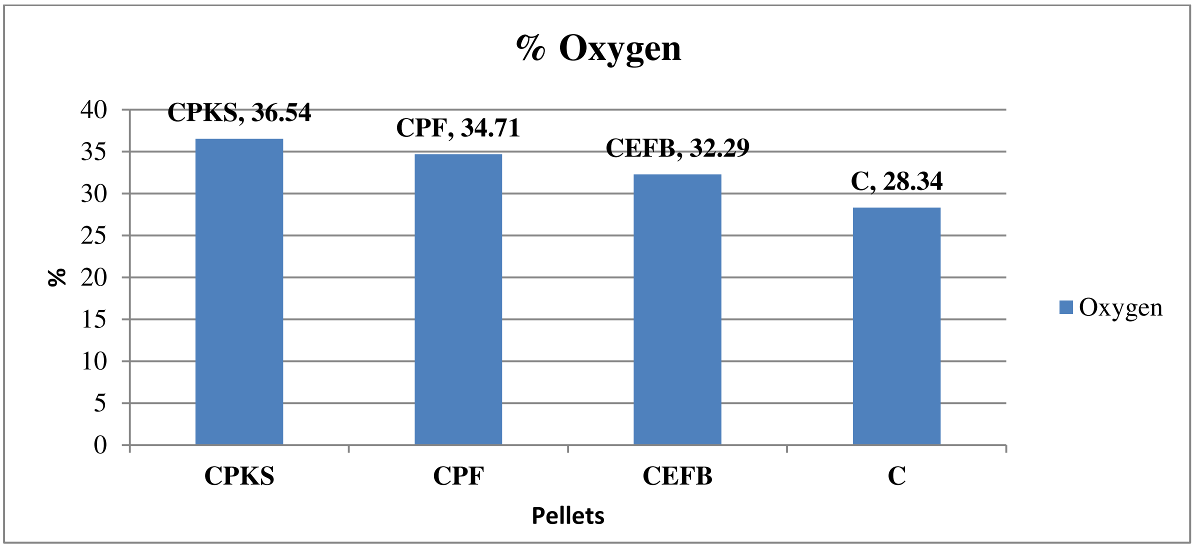

Figure 11: % Oxygen of Pellets

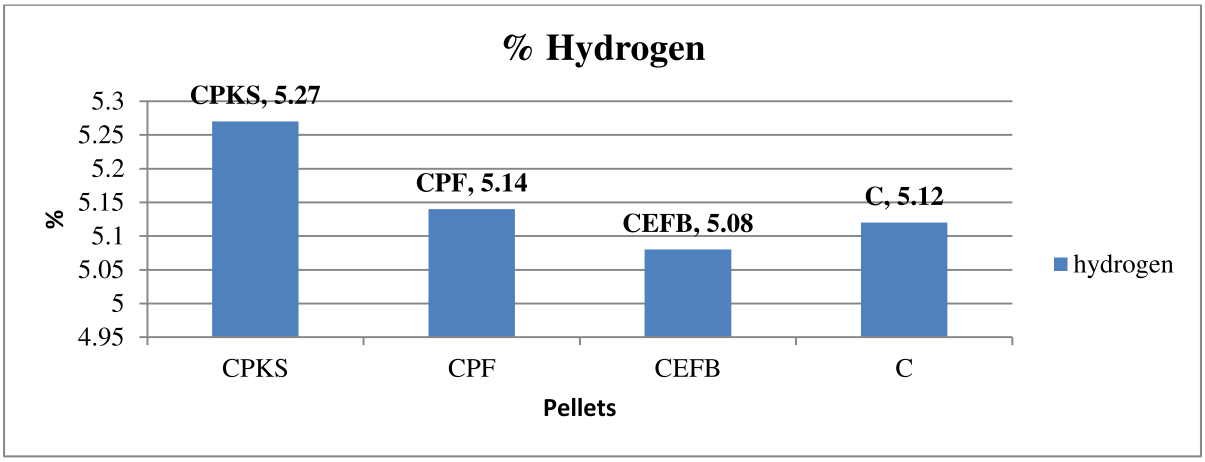

Figure 12: % Hydrogen of Pellets

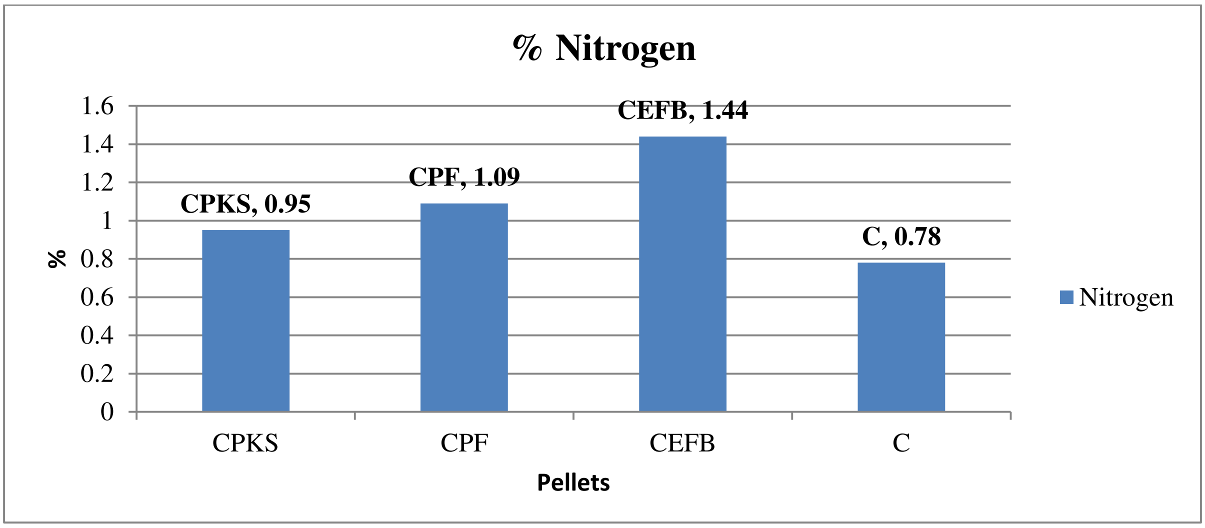

Figure 13: % Nitrogen of Pellets

The carbon content analysis results showed that CPKS, CPF and CEFB pellets have high carbon content. However, for a common fossil fuel such as pure coal C, the carbon content is expected to be higher. The consistency shown in the carbon content of the ultimate analysis results and the fixed carbon from the proximate analysis for the pellets is therefore, accepted as a form of validation of the results. In Figure 10, the sulphur content is 0.7%, 0.71%, 0.73% and 0.76% for CPKS, CPF, CEFB and C respectively. According to Bureau of Energy Efficiency, normal sulphur content for fuels ranges between 0.5 to 0.8%. Thus, the percentage sulphur content falls within the range of acceptability. The result also revealed that the percentage sulphur content of the 100% Coal pellet is higher than the others. In other words, the presence of elaeis guineensis reduces the sulphur content in coal pellets which causes slagging in boilers. High calorific value, less ash and sulphur contents are considered as essential parameter for combustion in boilers. Thus, quantitatively, in comparing the coal pellets produced from the various residues of elaeis guineensis, it was observed that the CPKS pellets have higher calorific value, less ash and sulphur contents than the other pellets (i.e. CPF, CEFB and C). However, it has higher moisture content than others. This can be ignored as the value still falls within the recommended values for moisture content of fuel reported in Bureau of Energy Efficiency. The percentage ash and sulphur contents of CPKS pellets also showed that the PKS residue has a better effect on the production of pellets from coal than the PF and EFB. This is because high ash and sulphur content causes slagging and rapid corrosion in boilers as stated earlier. Therefore, the PKS residue of elaeis guineensis is most recommended for cofiring with coal in boilers. Essentially, the results presented revealed that elaeis guineensis residues have the potential to mitigate ash and sulphur contents in raw coal pellets through blending.

4.0 CONCLUSION

The results of the calorific value, proximate and ultimate analyses as presented revealed that the effect of elaeis guineensis in coal pellets is positive. This is evident in the increase in the calorific value of the various pellets containing samples of elaeis guineensis. It therefore means that the energy value of 100% coal pellet can be enhanced through the addition of samples of elaeis guineensis, especially the PKS. The sulphur content also falls within the range of values reported in Bureau of Energy Efficiency. Corrosion is the main disadvantage of high sulphur content due to sulphuric acid formed during and after combustion, and condensing in cool parts of the chimney, economiser and air pre heater. Therefore, utilizing samples of elaeis guineensis would reduce the sulphur content of coal thereby resulting to slow corrosion rate in boilers. The results also revealed high percentage ash content for the 100% coal pellet without the presence of elaeis guineensis.

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Figures

Figure 1

Raw Elaeis Guineensis (PKS, EFB and PF)

Figure 2

Blended (pulverised) raw Elaeis Guineensis (PKS, EFB and PF)

Figure 3

Raw coal before and after blending (Pulverised coal)

Figure 4

Elaeis Guineensis-Coal Pellets

Figure 5

Combustion test of pellets in a locally fabricated boiler

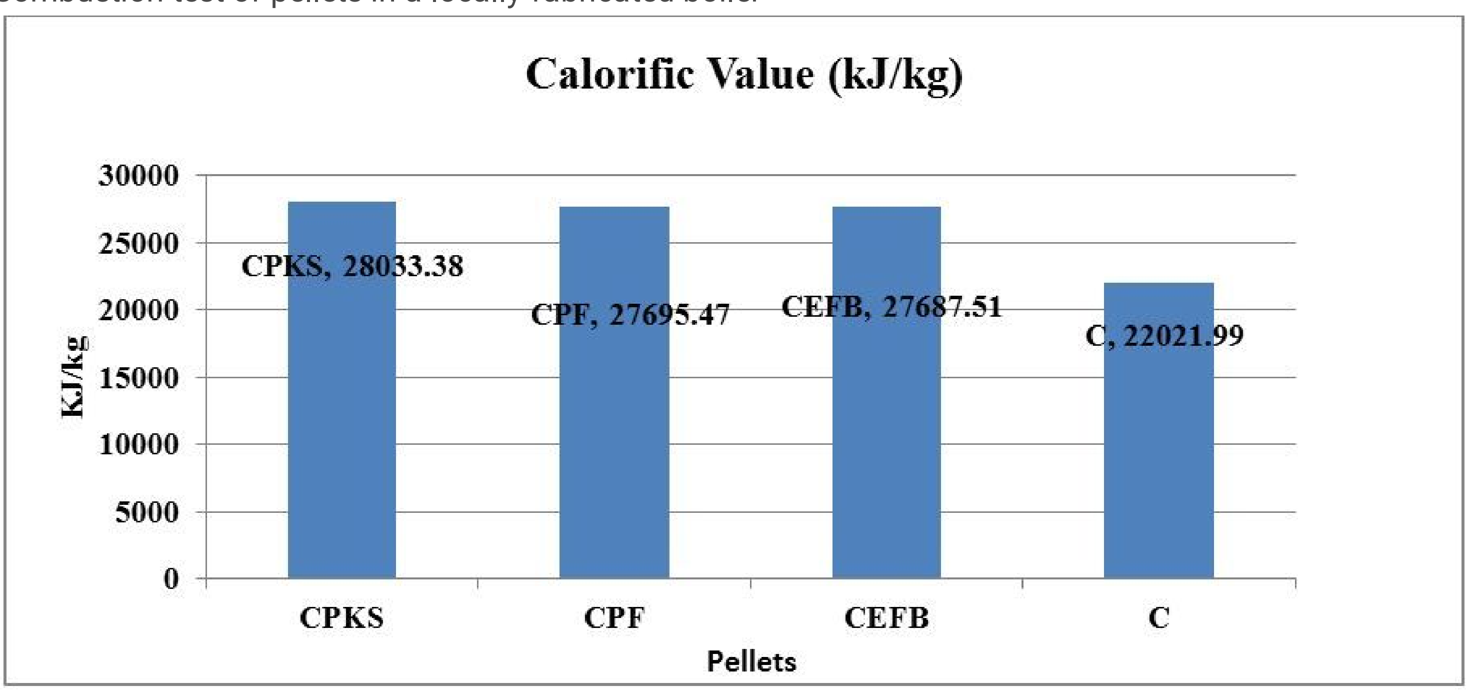

Figure 6

Calorific value of elaeis guineensis - coal pellets

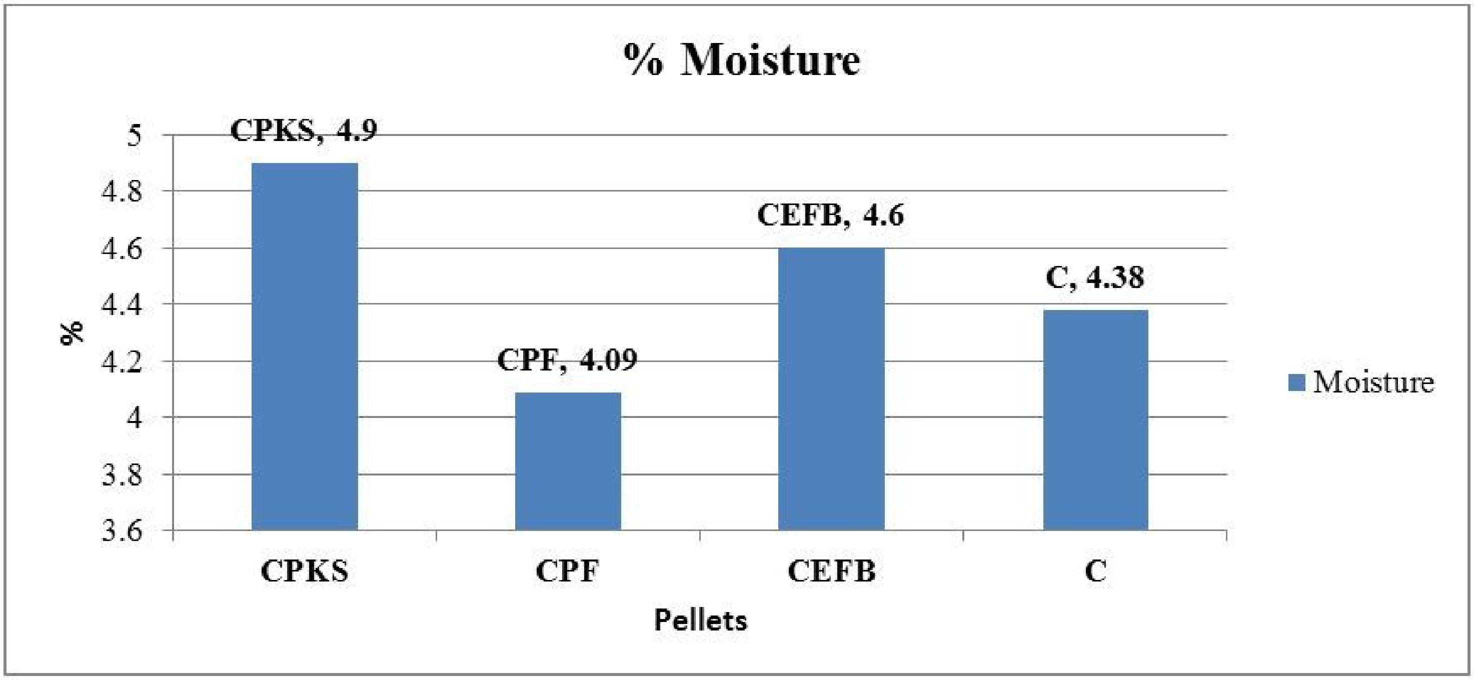

Figure 7

% Moisture of Pellets

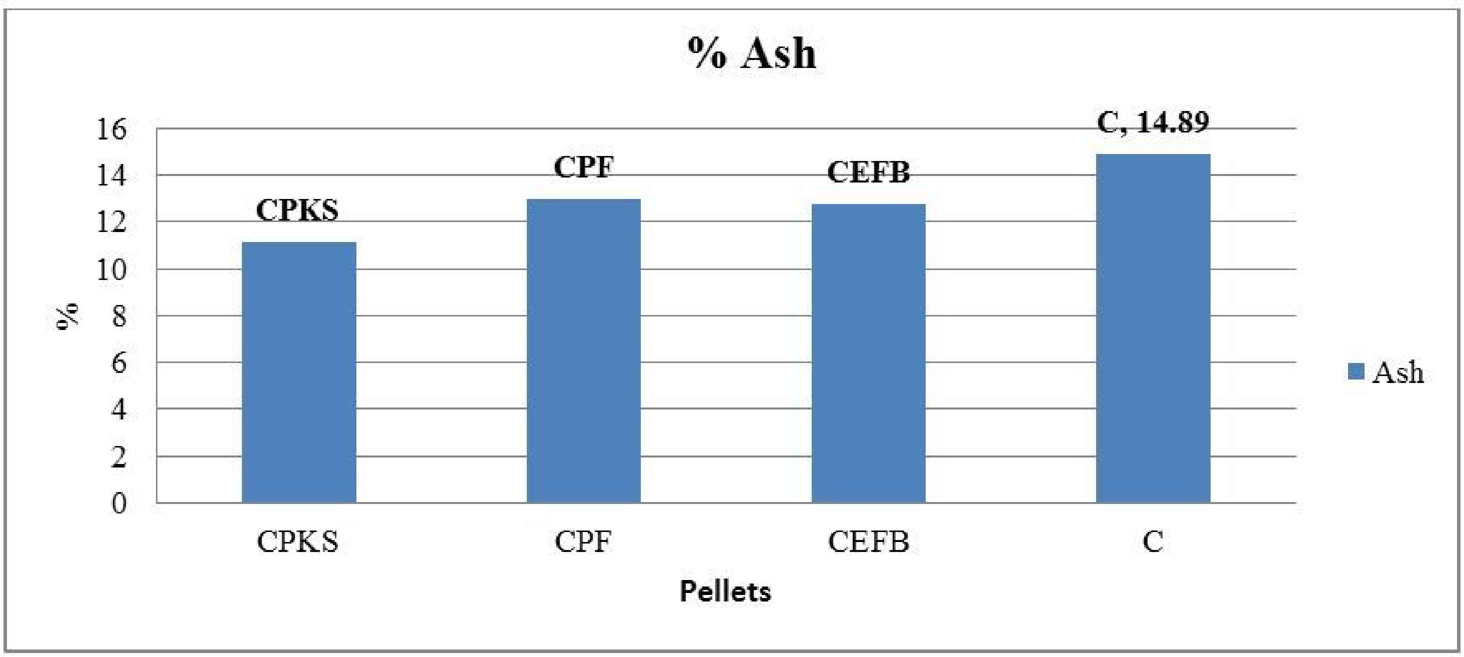

Figure 8

% Ash of Pellets

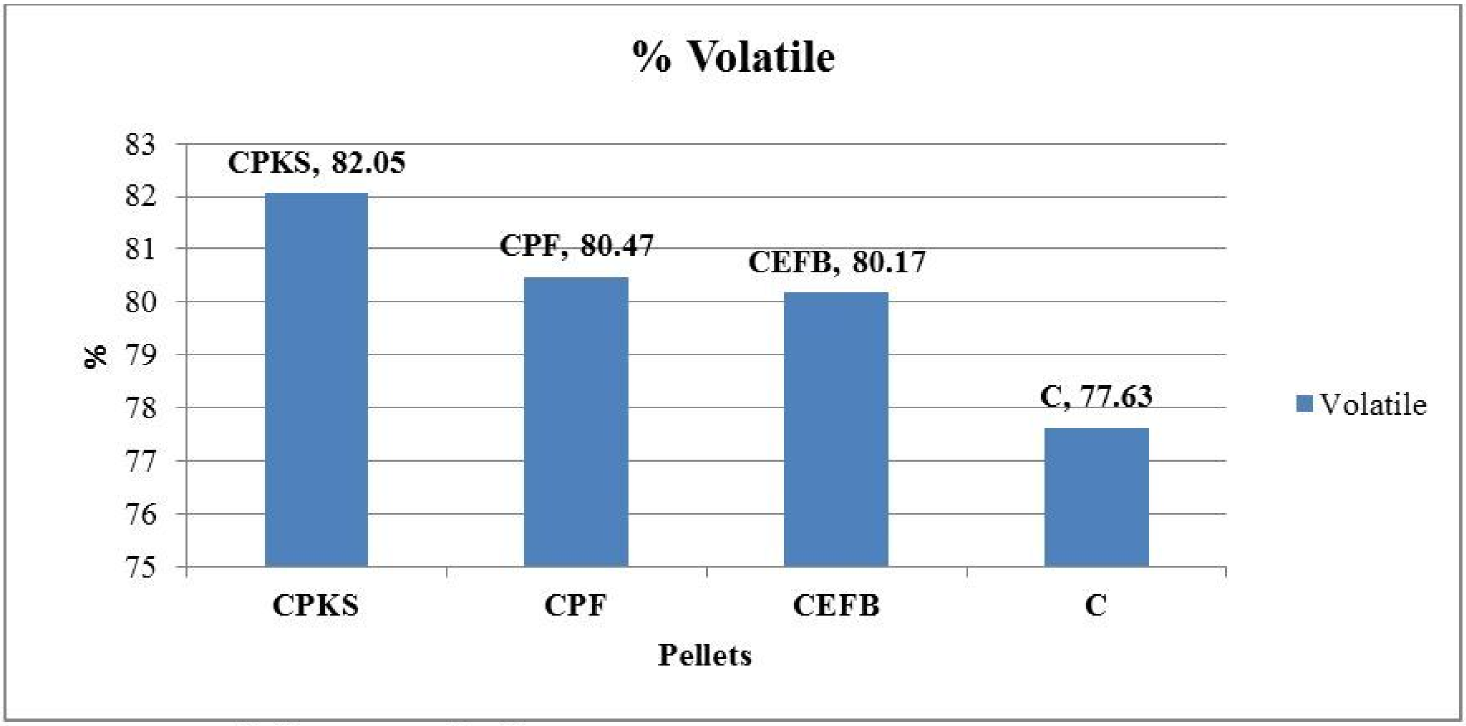

Figure 9

% Volatile matter of Pellets

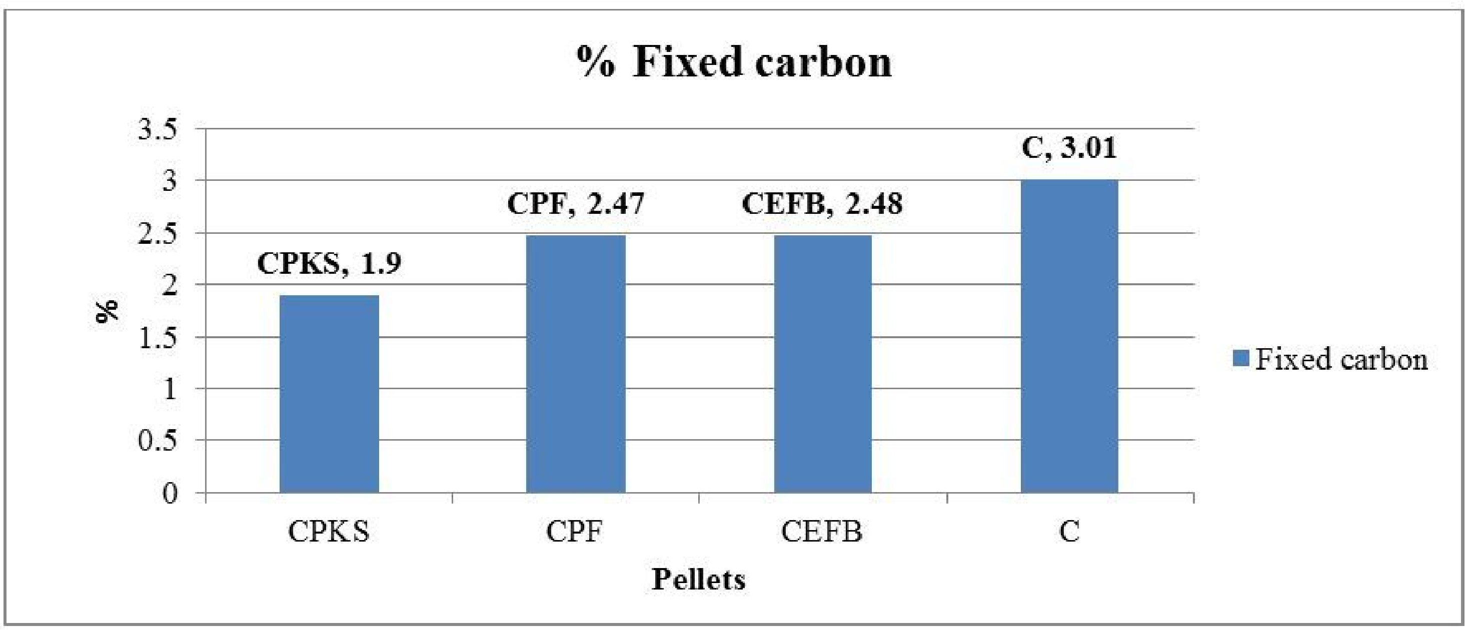

Figure 10

% Fixed carbon of Pellets

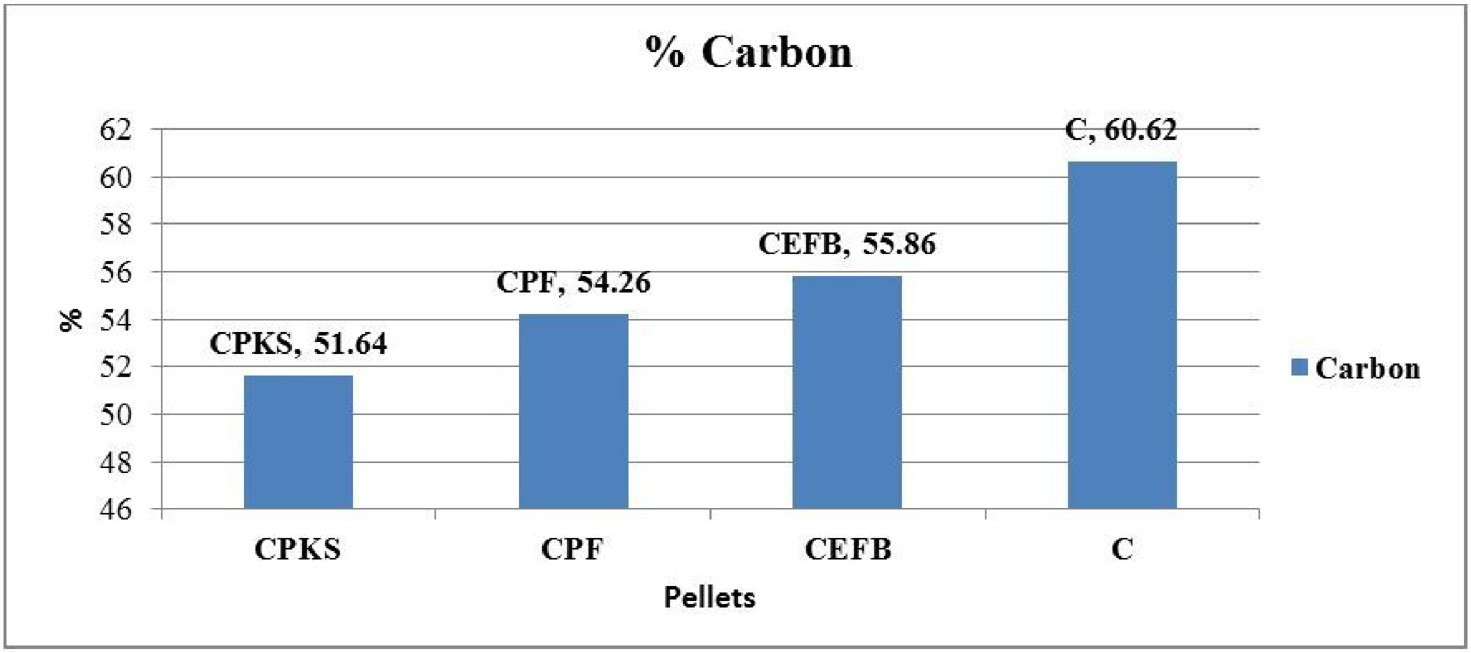

Figure 11

% Carbon of Pellets

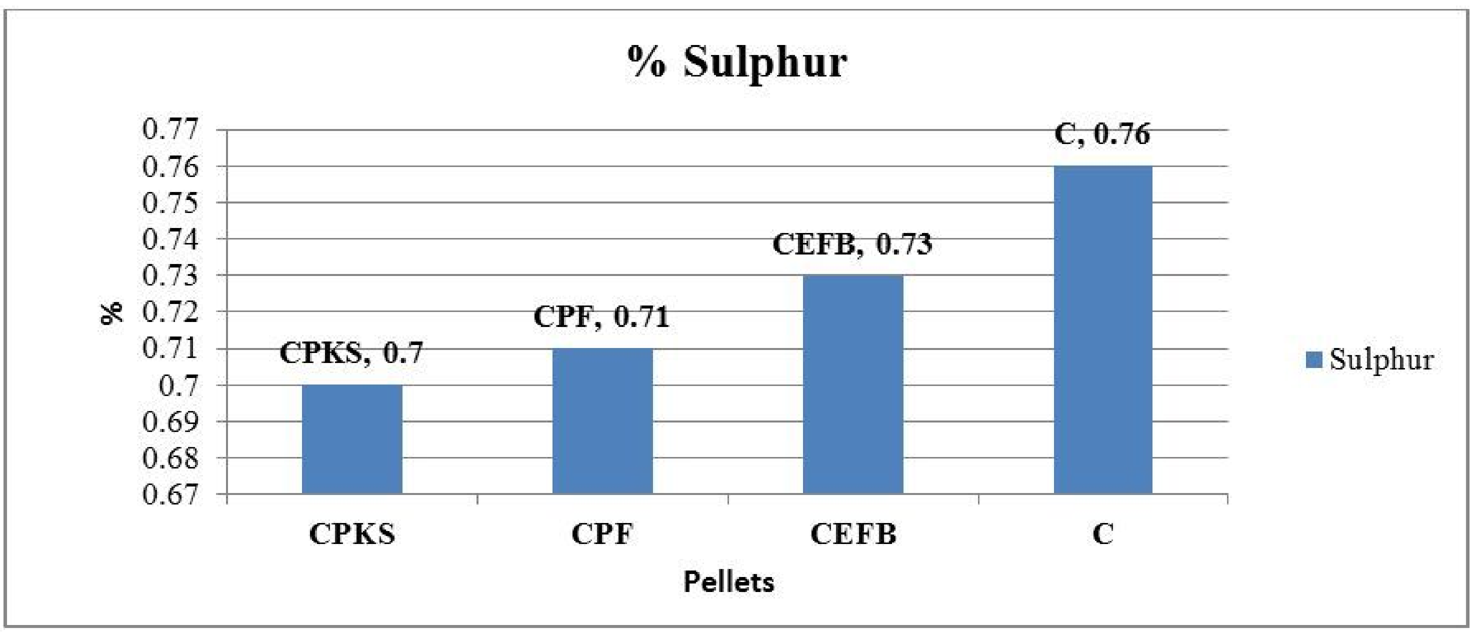

Figure 12

% Sulphur of Pellets

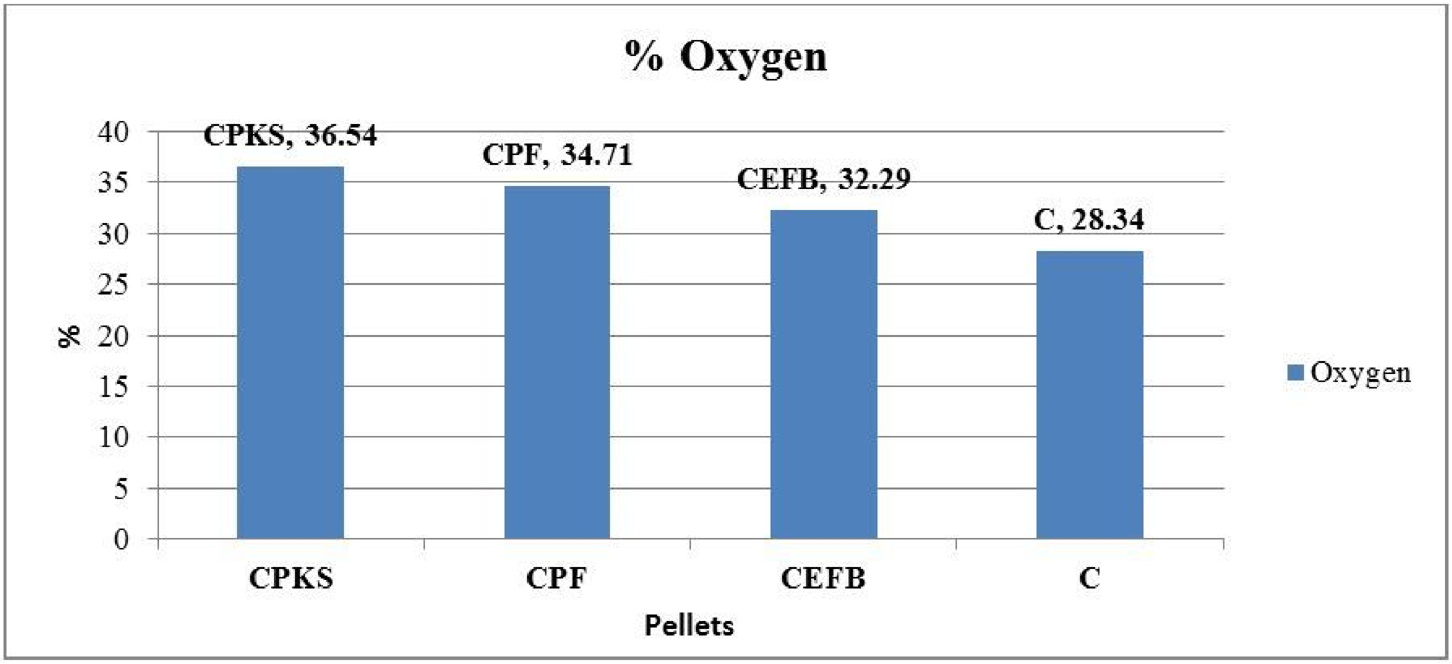

Figure 13

% Oxygen of Pellets

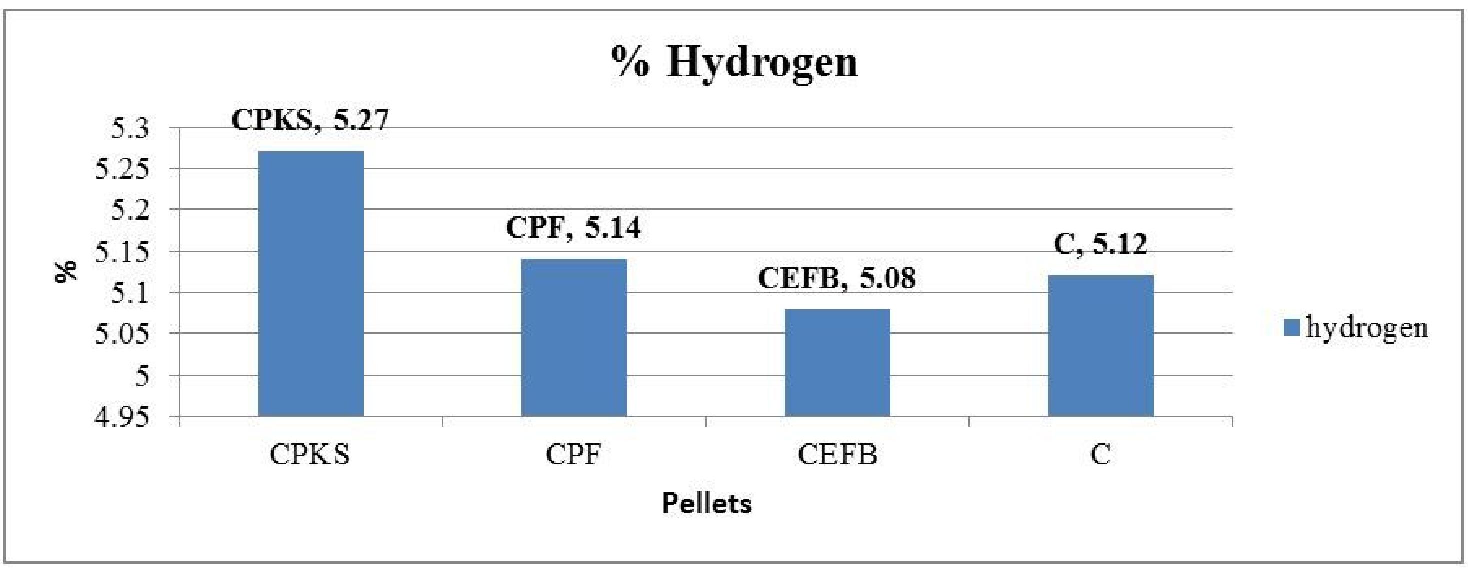

Figure 14

% Hydrogen of Pellets

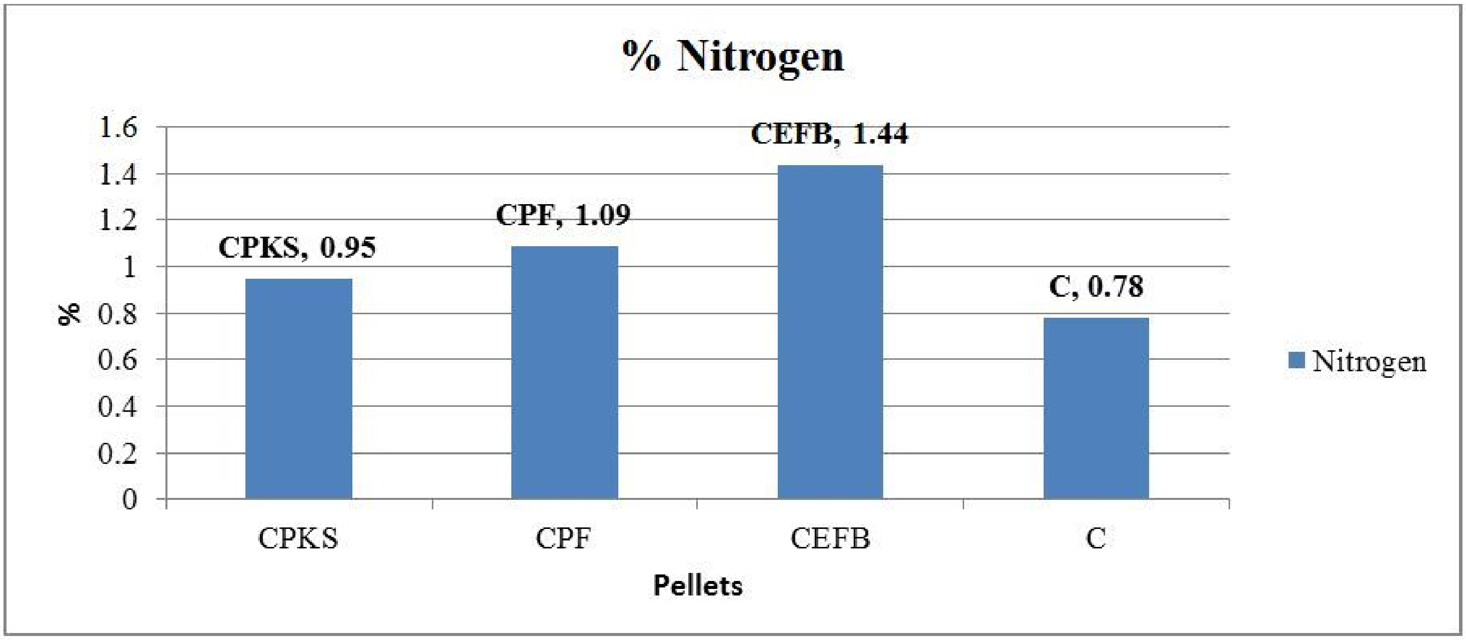

Figure 15

% Nitrogen of Pellets