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Original Research Article

Effect of *Elaeis guineensis* Biomass Residues on the Production of Coal Pellets

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ABSTRACT

In this study, the effect of Elaeis guineensis on the production of pellets from coal was investigated. Coal and Elaeis guineensis residues 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 was 100% 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 28033.38 kJ/kg, 27695.4 kJ/kg, 27687.5 kJ/kg and 22021.99 kJ/kg respectively. The sulphur content of the pellets was 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 establish 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.

1. INTRODUCTION

The International Energy Agency, IEA (2007) that the proportion of electricity generated from coal is increasing, especially in developing countries. Sambo et al. (2009) 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, (2003), 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 previously 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 (Sambo et al., 2009). However, in recent times, there is increasing clamour for the backward integration of coal into the Nigeria energy mix for generation of adequate power (ECN, 2003). 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 (2005), 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 (Onochie, 2017). 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 (Onochie, 2017).

Rohan (2012) 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., (1994) as reported in Baxter et al. (2000), 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. (2016) 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 *E*laeis 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. MATERIALS AND METHODS

2.1. Collection and Preparation of Samples

Raw coal was collected from Oji River, in Enugu State, Nigeria 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, a community located Benin City, Edo State, Nigeria. 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.

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

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 an experimental design 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. Where "C" represents coal and "R" represent residues of *Elaeis guineensis*.

2.2. Characterization of Fuel Pellets

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

2.2.1. Durability tests

In this analysis, the drop test method reported in Al-Widyan and Al-Jalil (2001), Khankari et al. (1989), Sah et al. (1989) and Shrivastava et al. (1989) was used. A single pellet was dropped from a 1.85m height on a metal plate for times. Percentage durability was obtained using Equation 1.

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

2.2.2. Combustion tests

For the combustion test, the method reported in Varun et al. (2014) 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.

$$R = \frac{\text{Mass of pellet}}{\text{combustion time}} \tag{2}$$

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

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 recommended in Onochie, (2017) and Onochie et al. (2017) for good durability and combustion of pellets was chosen as the option for the production of pellets. The pellets 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 (2013) and ASTM D4442-07 (2007).

2.3. Determination of Calorific Value of Pellets

The method in Onochie et al. (2017) was used for the determination of the calorific value of pellets. Data was obtained during the analysis while Equation (3) was used to calculate the calorific value of the *E*laeis guineensis – coal pellets.

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

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)

2.4. Proximate Analysis

The proximate analysis is the physical properties of the fuel of the *Elaeis guineensis* – coal pellets and it consist of the moisture content, ash content, volatile matter as well as the fixed carbon.

2.4.1. Moisture content

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

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

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Where g = mass of sample, x = mass of dry matter, (g - x) = mass of water lost

2.4.2. Volatile matter

For the volatile matter analysis, the samples were weighed accurately and oven dried at 105ºC for 4hrs. Each sample was cooled and later placed in a muffle furnace maintained at 600ºC for 20 mins. The sample was weighed after it has cooled. Equation (5) was used to calculate the percentage volatile matter (VM).

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

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

2.4.3. Ash content

For the ash content analysis, an accurately measured sample was burnt up in a muffle furnace receiving adequate air at 700ºC 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:

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

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

2.4.4. Fixed carbon

The fixed carbon for each of the samples was calculated from other proximate analysis properties. 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 (FC).

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

2.5. 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 Equation reported in Jenkins et al. (2008) was used for determining the ultimate analysis.

2.5.1. Carbon content

ASTM analytical method was used for the carbon content analysis. Data was obtained and Equation (8) was used for the calculation of the percentage carbon.

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

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

2.5.2. Nitrogen content

ASTM analytical method was used for the nitrogen content analysis. Data was obtained and Equation (9) was used for the calculation of the percentage nitrogen content.

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

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

2.5.3. Sulphur content

ASTM analytical method was used for the sulphur conten analysis. Data obtained was analysed using Equation (10).

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

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

2.5.4. Hydrogen content

ASTM analytical method was used for the hydrogen conten analysis. Data obtained was analysed using Equation (11).

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

2.5.5. 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.

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

3. RESULT AND DISCUSSION

3.1. Durability and Combustion Tests

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. The trend in the durability of pellets is in agreement with the results obtained in Onochie et al., (2017). 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. The increase in combustion rate is as a result of coal present in the *Elaeis guineensis* mixture.

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

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

3.2. Calorific Value of Pellets

Figure 4 presents the calorific value of the various *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 28033.38 kJ/kg while the 100% coal pellet has the lowest energy content which was 22021.99 kJ/kg. The result also showed that the presence of *Elaeis guineensis* positively affects the calorific value of the 100% coal pellet. In other words, *Elaeis guineensis* residues blended with raw coal has the potential to increase the calorific value of raw coal pellets. Onochie (2017) and Onochie et al., (2017) reported that combustion sustainability highly depends on the calorific value of fuel pellets. The finding in Figure 4 show that combustion sustainability of coal pellets will increase with blended *Elaeis guineensis*.

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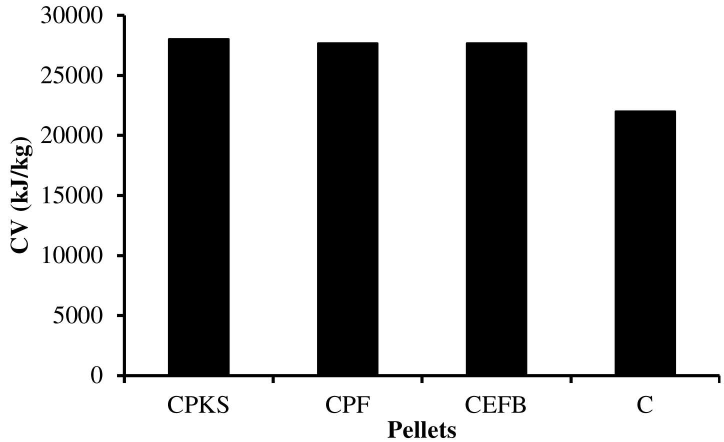

Figure 4: Calorific value of *Elaeis guineensis* - coal pellets

3.3. Proximate Analysis of Pellets

Figure 5 – 8 presents the results obtained from the fuel pellets. In Abdu and Sadiq (2014) as reported in Unwaha et al. (2015), 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 (2009), Chin and Shiraz (2013), Idah and Mopah (2013) 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 Abdu and Sadiq (2014), Unwaha et al. (2015), Kuti (2009) Chin and Shiraz (2013) as well as Idah and Mopah (2013). 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 desired properties for pellets.

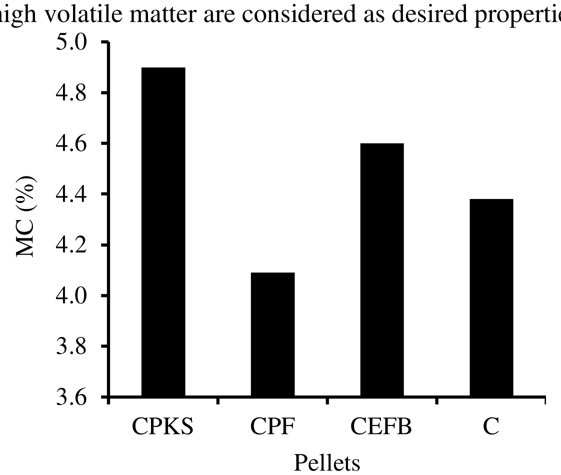

Figure 5: % Moisture content of pellets

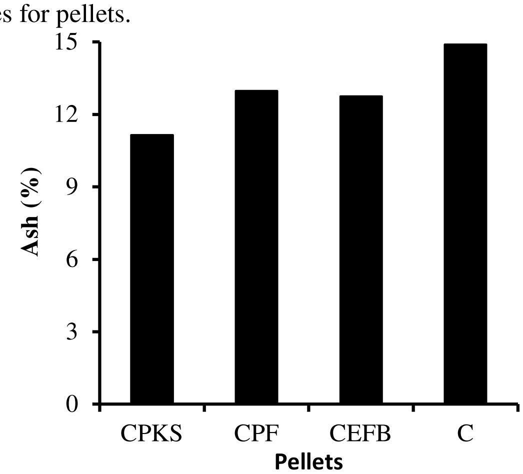

Figure 6: % Ash content of pellets

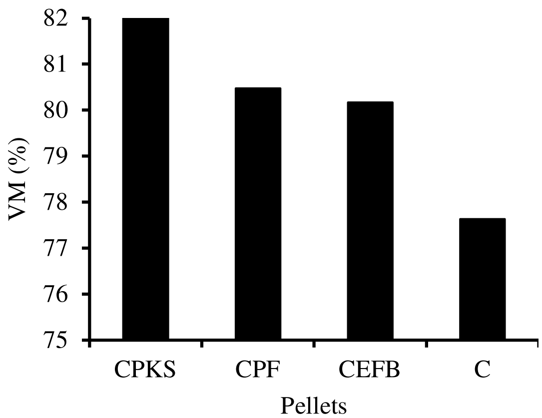

Figure 7: % Volatile matter content of pellets

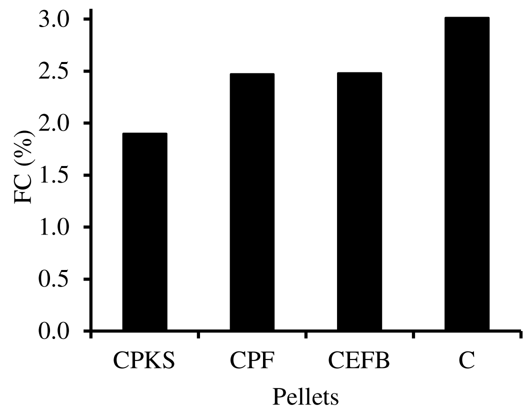

Figure 8: % Fixed carbon content of pellets

3.4. Ultimate Analysis of Pellets

Figure 9 – 13 presents the results obtained from the fuel pellets. In Figure 9, 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 was 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* reduced 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. 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 reduce ash and sulphur contents in raw coal pellets through blending. Hydrogen also contributes to the heating value of the fuel pellets. In Figure 12, it showed that PKS and PF residues from *E*laeis guineensis can influence the hydrogen content of coal except the EFB. In Figure 13 though, it was observed that *Elaeis guineensis* residues can influence the nitrogen content of coal pellets.

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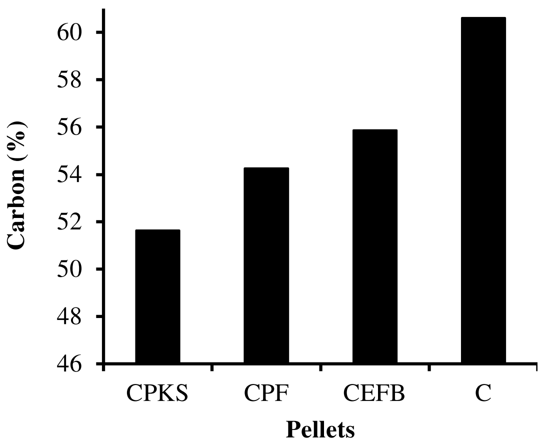

Figure 9: % Carbon content of pellets

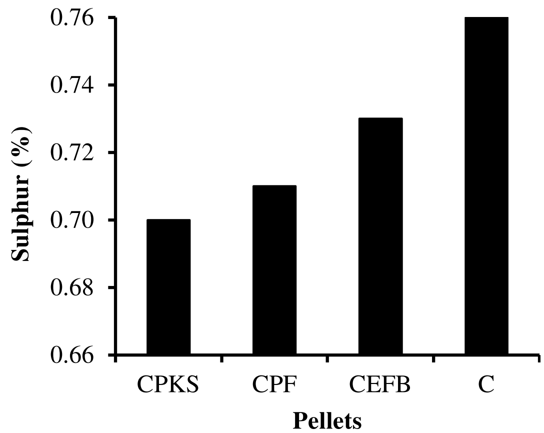

Figure 10: % Sulphur content of pellets

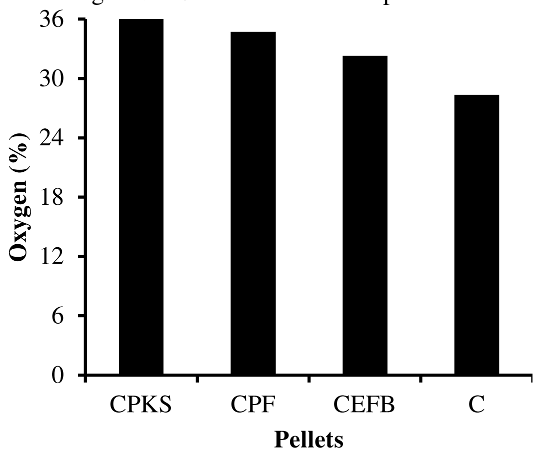

Figure 11: % Oxygen content of pellets

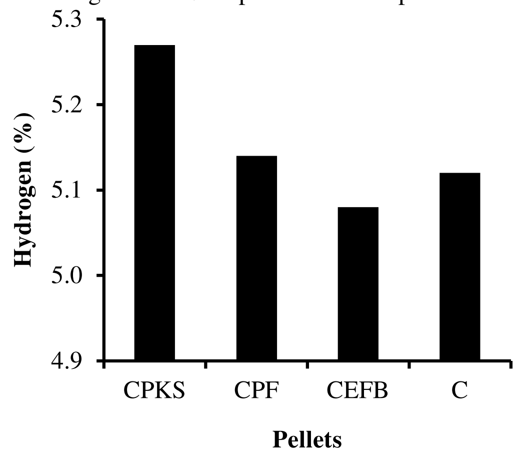

Figure 12: % Hydrogen content of pellets

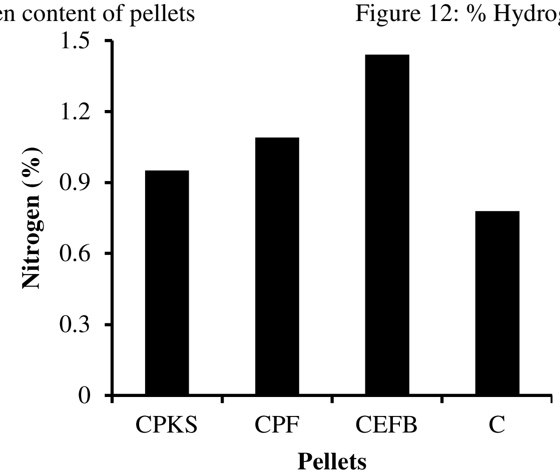

Figure 13: % Nitrogen content of pellets

4. 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 *E*laeis guineensis. It therefore means that the energy value of 100% coal pellet can be enhanced through the addition of residues of *Elaeis guineensis*, especially the PKS. The sulphur content also falls within the range of values reported in Bureau of Energy Efficiency. Utilizing samples of *E*laeis 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*.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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