The Effect of Elaeis Guineensis Residue on CO2 and SO2 Emissions from Coal Pellets Combustion

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Abstract. The increase in emission of greenhouse gases generated by fossil fuels such as coal has informed the need for cleaner and renewable sources of energy. Therefore, in order to mitigate the negative effect of continued coal combustion, it is essential to identify more carbon neutral fuels such as biomass. 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. Consequently, this study was carried out to determine the effect of elaeis guineensis residue on CO2 and SO2 emissions from coal pellets during combustion. Samples of coal and elaeis guineensis residue (i.e. palm kernel shell, PKS) were collected and pulverized. Pellets were produced mechanically using optimized mixing ratios (i.e. 90%C:10%R, 80%C:20%R, 70%C:30%R, 60%C:40%R, 50%C:50%R). 100%C pellet was also produced. The pellets were thereafter characterized (i.e. proximate and ultimate analyses) in accordance to ASTM Standards. From the results, quantitative analysis of optimized pellets showed that elaeis guineensis palm kernel shell has potential tendency of reducing percentage combustion CO2 and SO2 emissions from the 100%C pellets. The least optimized pellet (i.e. 90%C:10%R) has a percentage reduction of 3.01% CO2 and 42.86% SO2 on dry basis.

Keywords: Elaeis guineensis, Coal, Pellets, Combustion, Emission

1. Introduction
In Eric and Clara [1], coal was reported as the largest fuel source for power generation in the world and coal-fired power plants constitute a large majority of all emissions related to power generation. In the National Emission Inventory Report, NEIR [2], coal-fired power plants generate power through the rotation of a steam turbine when coal combustion occurs under high-pressure. Eric and Clara further reported that coal-based power generation is the most utilized method of electricity generation in the world, however, it releases very high concentration of particulate, gaseous, and metallic pollutants into the environment due to its exothermic reaction produced. NEIR [2] also reported that in the United States, 60% of all sulphur dioxide, 50% of mercury, 60% of arsenic, and 13% of nitrogen oxide emissions are from coal-fired power plants. Hao et al., [3] reported that in China, a total of 75% of power generation is reliant on coal, which accounts for nearly 50% of the total SO2, 27% of NOx emissions in China. Furthermore, National Emission Inventory Report (NEIR) further stated that coal emissions from power plants represent the number one anthropogenic source of greenhouse gases (GHG) in the world. In the United States for instance, approximately 81% of all GHG emissions are due to coal-fired power plant emissions, primarily carbon dioxide and to a lesser extent, nitrous oxides [2]. In Yu et al., [4], they also reported that coal-fired power plant has been considered as a very important source of regional air pollution and ecosystem acidification, due to its huge emissions of acidic pollutants. According to Esen and Tahsin [5], humanity’s development has been directly related to energy production, both for use as electricity and for thermal applications in recent times. The increase in emission of greenhouse gases generated by fossil fuels such as coal, oil and natural gas is due to the increase in energy production. Yilmaz and Hasan [6] also reported that for over the past 60 years, CO2 production has grown from the range of 4 million tons/year to more than 28 million tons/year. Essentially, due to high levels of CO2 emissions, global warming and the rising cost of fossil fuels, the need to find clean and renewable new sources of energy has become imperative. Asadullah [7] stated that this is reason for the increase in investment in asthma projects all over the world. Additionally, Batidzirai et al., [8] also reported that this has informed the creation and development of new technologies and industries which are committed to power generation from renewable sources. Batidzirai et al further stated that this represents more than 3% of the global energy produced from all sources. In Baxter [9], it was reported that when considering the reduction of greenhouse gas (GHG) emissions during the combustion of coal in coal-fired
boilers, cofiring of coal with biomass is a viable option. Rohan [10] additionally stated that for coal-fired power plant, biomass cofiring reduces the net CO\textsubscript{2} emissions. He also reported that biomass cofiring enables coal power plant to reduce SO\textsubscript{2} emissions because less sulphur is contained in biofuels than coal. Furthermore, in Khalidah et al., [11], it was again reported that biomass is a clean alternative fuel to coal in terms of carbon, NO\textsubscript{x}, and SO\textsubscript{2} emissions in the power generation sector.

Gottlieb et al., [12] reported that modern day coal power plants pollute less than older designs due to new technologies that filter the exhaust air in smoke stacks; nevertheless, emission levels of various pollutants are much more than the emission from natural gas power plants. Atmospheric pollution from coal-fired power plants comes from the emission of gases such as CO\textsubscript{2}, SO\textsubscript{2} and NO\textsubscript{x}. According to Hong and Slatick [13], for a complete combustion, 1 pound of carbon (C) combines with 2.667 pounds of oxygen (O\textsubscript{2}) to produce 3.667 pounds of CO\textsubscript{2}. Hong and Slatick again stated that going forward by one step, coal with a carbon content of 78% emits about 204.3 pounds of CO\textsubscript{2} per million Btu of heat generated by complete burning. Hence, about 2.86 tons of CO\textsubscript{2} will be produced from a complete combustion of 1 ton of coal. According to Sambo [14] as reported in ECN [15], coal is abundant in Nigeria; though formally used in the 1960s; however, in recent decades, it doesn’t contribute to the Nations power sector due to issues of pollution emanating from its emission during combustion and the discovery of natural gas for power plants. Essentially, the review of related literature such as Nihad et al. [16], Jun et al. [17] and Ndibe et al. [18] suggests that coal has been cofired with woody biomass but the research gap is that it has not been cofired with elaeis guineensis residues (PKS). In view of this background and the clamour for the backward integration of coal into the Nigeria energy mix, the aim of this study is to investigate the effect of elaeis guineensis PKS on the combustion performance CO\textsubscript{2} and SO\textsubscript{2} of coal pellets. The findings in this study will encourage coal energy for power generation in Nigeria.

2. Materials and Experimental method

Samples of coal and PKS were collected from the Southern part of Nigeria. The samples were pulverized using a grinding machine. Optimization of mixing ratios was considered so as to get the best mixing ratio for the samples of coal and elaeis guineensis for pelleting. Mixing ratios of 90 % C: 10 % R, 80 % C: 20 % R, 70 % C: 30 % R, 60 % C: 40 % R and 50 % C:50 % R reported in Kuti [19], Yuhazri et al. [20] and Ajiboye et al. [21] were used for pellet production. Coal represents “C” while elaeis guineensis residues represent “R”. The pulverized samples were mixed and pellets were produced mechanically with the aid of a screw press pelleting machine. The machine operational capacity is 5kg/hr. and press was at an average pressure of 1.2 x 10\textsuperscript{3} N/m\textsuperscript{2}. 100 % C pellets were also produced in other to compare with the optimized ratios, making six pellet samples. The pellets are shown in Figure 1a to 1f respectively. However, the difference in the Figure is not clear because of the dominating black nature of coal over the light brown of elaeis guineensis residues. The pellets were naturally dried at temperature range of 28 °C to 32 °C for 48 hrs. and thereafter characterized (i.e. proximate and ultimate analyses) in accordance to ASTM standards. The data obtained from the characterisation analyses were used to theoretically determine the potential CO\textsubscript{2} and SO\textsubscript{2} emission. Results obtained were compared.

![Figure 1a: 90%C:10%R](image1a.png)
![Figure 1b: 80%C:20%R](image1b.png)
![Figure 1c: 70%C:30%R](image1c.png)
![Figure 1d: 60%C:40%R](image1d.png)
![Figure 1e: 50%C:50%R](image1e.png)
![Figure 1f: 100% C](image1f.png)

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 ASTM standard D5373-02 (2003) was adopted for the proximate analysis.
2.1.1 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 °C to a constant weight for 3 hours. The formula is given in Equation (1):

\[ \text{% MC} = \frac{(g - x)}{g} \times 100 \]  
(1)

Where, \( g \) = mass of sample, \( x \) = mass of dry matter, \( g - x \) = loss in mass

2.1.2 Volatile Matter
For the volatile matter analysis, the samples weighed accurately and oven dried at 105°C for 3hrs. Each sample was cooled and later placed in a muffle furnace maintained at 600°C for 20mins. The sample was weighed after it has cooled. Equation (2) was used to calculate the percentage volatile matter and expressed as;

\[ \text{% V. M} = \frac{y}{g} \times 100 \]  
(2)

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

2.1.3 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 (3) was used to calculate the percentage fixed carbon.

\[ \text{% F. C} = 100 - (\text{% V. M} + \text{% Ash} + \text{% MC}) \]  
(3)

2.1.4 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 (4) was used to calculate the ash content and expressed as:

\[ \text{% Ash} = \left( \frac{y}{g} \right) \times 100 \]  
(4)

where, \( g \) = mass of sample, \( x \) = mass of ash

2.2 Determination of Ultimate Analysis
The ultimate analysis is the chemical properties of the fuel and is basically the breakdown of the fuel into its elemental components through an analysis of the products that remain after the complete combustion of a small fuel sample and it consists of the carbon content, oxygen content, hydrogen content, nitrogen content and sulphur content. The ASTM standard D3176 and formula used in Jenkins et al. [22] was used for determining the constituent of the ultimate analysis.

2.2.1 Carbon content
Data was obtained from laboratory analysis while equation (5) was used for the calculation of the percentage carbon.

\[ \text{% Carbon} = \frac{(B - T) \times M \times 0.003 \times 100 \times 1.33}{g} \]  
(5)

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

2.2.2 Nitrogen content
Data was obtained during analysis and equation (6) was used for the calculation of the percentage nitrogen content.

\[ \text{% Nitrogen} = \frac{(T \times M \times 0.014 \times DF)}{g} \times 100 \]  
(6)

where, \( M \) = molarity of the acid used, \( g \) = mass of sample, \( T \) = titre value, \( DF \) = dilution factor diluted

2.2.3 Sulphur content
Data was obtained from lab analysis. Equation (7) was used to calculate the percentage sulphur content.

\[ \text{% Sulphur} = \frac{x \times 0.1373}{g} \times 100 \]  
(7)

where, \( g \) = mass of sample, \( x \) = mass of BaSO₄
2.2.4 Hydrogen content
Data was obtained from the lab analysis. Equation (8) was used for the calculation of the percentage hydrogen content.

\[
\% \text{ Hydrogen} = \frac{\text{wt of } H_2O \times 0.119 \times 100}{\text{wt of pellet}} \quad (8)
\]

2.2.5 Oxygen content
Equation (9) was used for the calculation of the percentage oxygen content, which is 100 percent minus the total summation of other constituents.

\[
\% \text{ Oxygen} = 100 - (C + H + N + S + \text{Ash}) \quad (9)
\]

2.3 Combustion CO2 and SO2 Analysis
To evaluate the combustion CO2 and SO2 of the fuel pellets, there is need to determine the chemical formula of the various optimized pellets. Therefore, from the ultimate analysis of each pellet, there contain carbon, hydrogen, oxygen, nitrogen and sulphur. Thus, the equivalent formula would be calculated using (10):

\[
C_x H_y O_z N_a S_b \quad (10)
\]

The combustion analysis would be evaluated using equation (11). Now, since the oxygen is supplied as air, the associated N2 will appear in the equation as:

\[
C_x H_y O_z N_a S_b + x O_2 + x (79/21) N_2 \rightarrow pCO_2 + qH_2O + rSO_2 + sN_2 \quad (11)
\]

3. Result and Discussion
3.1 Proximate Analysis of Pellets
Table 1 presents the results of the proximate analysis of the pellets.

| Proximate Analysis | 100%C | 90%C:10%R | 80%C:20%R | 70%C:30%R | 60%C:40%R | 50%C:50%R |
|--------------------|--------|------------|------------|------------|------------|------------|
| % Moisture         | 7.90   | 7.67       | 7.06       | 6.76       | 6.56       | 6.38       |
| % Volatile Matter  | 68.26  | 68.87      | 75.47      | 78.06      | 78.73      | 80.13      |
| % Ash              | 14.77  | 13.93      | 12.98      | 11.84      | 9.83       | 9.64       |
| % Fixed Carbon     | 9.07   | 9.53       | 4.49       | 3.34       | 4.88       | 3.85       |

From Table 1, the percentage moisture content of the various pellets showed that 50C:50R pellet has the lowest moisture content of 6.38%, while 100%C, 90%C:10%R, 80%C:20%R, 70%C:30%R and 60%C:40%R pellets has 7.90%, 7.67%, 7.06%, 6.76% and 6.56% respectively. However, the one with the highest moisture content is the 100%C pellet. The moisture content result agrees with the report in Bureau of Energy Efficiency, which stated that good moisture content is between 8 -12% and less. The moisture content result is also in line with the report of Berit et al., [23]. Again in Table 1, it was observed that the optimized pellets have the highest percentage volatile matter, while the 100%C has the least percentage. In other words, optimized pellets will have a better ease of ignition during combustion of the fuel than the 100%C. The percentage ash content revealed that the optimized pellets have the tendency of reducing ash content in 100% coal. The pellet with the highest ash content was the 100%C. Slagging in boilers is caused by high percentage ash content of fuels. The ash content results also agree with the report in Bureau of Energy Efficiency which stated that the percentage ash content for boilers ranges between 5 – 40 percent. Essentially, from the proximate analysis, it was revealed that elaeis guineensis residue (PKS) had the tendency to reduce ash content and increase volatile matter of coal pellets during combustion.

3.2 Ultimate Analysis of the Pellets
Table 2 presents the results of the proximate analysis of the pellets.

| Ultimate analysis | 100%C | 90%C:10%R | 80%C:20%R | 70%C:30%R | 60%C:40%R | 50%C:50%R |
|-------------------|--------|------------|------------|------------|------------|------------|
| % Carbon          | 36.71  | 39.90      | 43.89      | 45.49      | 47.08      | 48.68      |
| % Nitrogen        | 0.26   | 0.32       | 0.43       | 0.45       | 0.46       | 0.48       |
| % Sulphur         | 0.11   | 0.10       | 0.08       | 0.08       | 0.07       | 0.07       |
| % Hydrogen        | 5.12   | 5.12       | 5.09       | 5.07       | 5.03       | 5.02       |
| % Oxygen          | 35.20  | 32.97      | 30.47      | 30.31      | 30.25      | 29.73      |
In Table 2, it was observed that the carbon content increases with increase in the elaeis guineensis residues in the optimized mixing ratios. The 50%C:50%R has the highest percentage carbon content while the 100%C has the lowest percentage carbon content. It was observed that the percentage sulphur content of coal was greatly influenced by the presence of elaeis guineensis residue (PKS). The 50%C:50%R and 60%C:40%R pellets has the lowest percentage sulphur contents of 0.07%, while 80%C:20%R and 70%C:30%R pellets has 0.08% each and 90%C:10%R pellet has 0.10%. The 100%C pellet has the highest value of sulphur. High sulphur content rapid corrosions in boilers during combustion. Hence, fuels with high tendency of corrosion, usually causes high maintenance and operation cost. Therefore from the results, elaeis guineensis residue (PKS) is a good fuel cleaner for coal pellets and a reducer of corrosion in boilers.

3.3 Chemical Analysis of Pellets

From the results of the ultimate analysis, the equivalent chemical composition (molecular formula) by mass of each of the pellets is $C_xH_yO_zN_s S_f$. Thus, data containing the various elements was used to evaluate the unknown variable (i.e. $a, b, d, e$ and $f$) so as to determine the chemical formula of each pellets.

3.3.1 Chemical Formula of 90%C:10%R

12, 1, 16, 14 and 32 are the molecular mass of carbon, hydrogen, oxygen, nitrogen and sulphur respectively.

\[ \begin{align*}
\text{For Carbon:} & \quad 12a = 39.90; \quad a = 3.325 \\
\text{For Hydrogen:} & \quad 1b = 5.11; \quad b = 5.11 \\
\text{For Oxygen:} & \quad 16d = 46.90; \quad d = 2.93125 \\
\text{For Nitrogen:} & \quad 14e = 0.32; \quad e = 0.02286 \\
\text{For Sulphur:} & \quad 32f = 0.10; \quad f = 0.003125
\end{align*} \]

Hence, the chemical formula of the 90%C:10%R pellets is $C_{3.325}H_{5.11}O_{2.93125}N_{0.02286}S_{0.003125}$. The calculation for 80%C:20%R, 70%C:30%R, 60%C:40%R, 50%C:50%R and 100% pellets are same as above. The equivalent chemical composition of 80%C:20%R pellets is $C_{3.6575}H_{5.09}O_{2.715625}N_{0.0307}S_{0.0025}$; 70%C:30%R pellets is $C_{3.7908}H_{5.07}O_{2.634375}N_{0.0321}S_{0.0025}$; 60%C:30%R pellets is $C_{3.9233}H_{5.03}O_{2.505}N_{0.03286}S_{0.0021875}$; 50%C:50%R pellets is $C_{4.0567}H_{5.02}O_{2.460625}N_{0.0343}S_{0.0021875}$ and 100% pellets is $C_{3.0592}H_{5.12}O_{3.11875}N_{0.01857}S_{0.0034375}$.

3.4 Combustion Emission CO2 and SO2 Analysis of Pellets

The data obtained from the chemical formula of the optimized pellets was used to analyse theoretically, the combustion emission CO2 and SO2 of the pellets.

3.4.1 Combustion Emission CO2 and SO2 Analysis of 100%C pellets

The stoichiometric equation for the combustion of 100%C pellets $[C_{3.0592}H_{5.12}O_{3.11875}N_{0.01857}S_{0.0034375}]$ using air as the oxidant is given by:

\[ C_{3.0592}H_{5.12}O_{3.11875}N_{0.01857}S_{0.0034375} + y_1 \left[ O_2 + \frac{(79/21)N_2}{} \right] \rightarrow p_1CO_2 + q_1H_2O + r_1SO_2 + [t_1 + y_1 \left( \frac{79}{21} \right)N_2] \]

(12)

Thus, balancing the equation, the combustion in air becomes:

\[ C_{3.0592}H_{5.12}O_{3.11875}N_{0.01857}S_{0.0034375} + 2.7833\left[ O_2 + \frac{(79/21)N_2}{} \right] \rightarrow 3.0592CO_2 + 2.56H_2O + 0.0034375SO_2 + 10.48907952N_2 \]

For wet base analysis:

The products of combustion are:

\[ 3.0592CO_2 + 2.56H_2O + 0.0034375SO_2 + 10.48907952N_2 \]

For dry basis analysis:

The total amount of substance of dry products is:

\[ = 3.0592CO_2 + 0.0034375SO_2 + 10.48907952N_2 \]

Thus, using Equation (14), the percentage composition of the gases (i.e. wet and dry basis) was obtained and shown in Figures 2 and 3 respectively.
The percentage composition of wet gases in the 100%C pellets is presented in Figure 2. The analysis showed that CO2 and SO2 emissions are 18.99% and 0.021% respectively.

Similarly, the percentage composition of dry gases in the 100%C pellets is illustrated in Figure 3. The results indicated that CO2 and SO2 emissions are 22.57% and 0.03% respectively.

3.4.2 Combustion CO2 and SO2 Analysis of 90%C:10%R Pellets

Using equation (14), the stoichiometric equation for the combustion of 90%C:10%R pellets using air as the oxidant is given by:

\[
\begin{align*}
C_{3.325}H_{5.11}O_{2.93}N_{0.02}S_{0.003} & \rightarrow p_2CO_2 + q_2H_2O + r_2SO_2 + [t_2 + y_2 (79/21)]N_2 \\
\end{align*}
\]

(14)

Now, balancing the both sides of the combustion equation, we get:

\[
\begin{align*}
C_{3.325}H_{5.11}O_{2.93}N_{0.02}S_{0.003} & \rightarrow 3.325CO_2 + 2.56H_2O + 0.003125S_2O_3 + 11.84464571N_2 \\
\end{align*}
\]

For Wet Base Analysis:
Total amount of substance of wet products = 17.73277071kmol

For Dry Base Analysis:
The total amount of substance of dry products = 15.17277071kmol

Figures 4 and 5 illustrate the percentage composition of wet and dry gases in the 90%C:10%R pellets. In the wet analysis, the potential CO2 and SO2 emissions during combustion of the 90%C:10%R pellet showed 18.75% and 0.0176% respectively while for the dry analysis, the CO2 and SO2 emission is 21.91% and 0.021% respectively.
3.4.3 Combustion CO2 and SO2 Analysis of 80%C:20%R Pellets

The stoichiometric equation for the combustion of 80%C:20%R pellets \( [C_{3.6575}H_{5.09}O_{2.715625}N_{0.0307}S_{0.0025}] \) using air as the oxidant is given by:

\[
C_{3.6575}H_{5.09}O_{2.715625}N_{0.0307}S_{0.0025} + y_3 \left[ O_2 + \left( \frac{79}{21} \right) N_2 \right] \rightarrow p_3 CO_2 + q_3 H_2O + r_3 SO_2 + \left[ t_3 + y_3 \left( \frac{79}{21} \right) \right] N_2
\]

Thus, balancing the equation, the combustion in air becomes:

\[
3.6575 \text{CO}_2 + 2.545 \text{H}_2\text{O} + 0.0025 \text{SO}_2 + 13.4783393 \text{N}_2
\]

For wet base analysis:
The total amount of wet products = 19.682834kmol

For dry base analysis:
The total amount of substance of dry products = 17.137834kmol

![Figure 6: Wet gases for 80%C:20%R pellets](image)

![Figure 7: Dry gases for 80%C:20%R pellets](image)

In Figure 6 and Figure 7, the percentage composition of wet and dry gases in the 80%C:20%R pellets is presented. In the wet analysis, the results showed that the CO2 and SO2 emissions is 18.58% and 0.01% respectively while for the dry analysis, the CO2 and SO2 emissions is 21.34% and 0.015% respectively.

3.4.4 Combustion CO2 and SO2 Analysis of 70%C:30%R Pellets

Again, the stoichiometric equation for the combustion of 70%C:30%R \( [C_{3.7908}H_{5.07}O_{2.634375}N_{0.0321}S_{0.0025}] \) using air as the oxidant is given by:

\[
C_{3.7908}H_{5.07}O_{2.634375}N_{0.0321}S_{0.0025} + y_4 \left[ O_2 + \left( \frac{79}{21} \right) N_2 \right] \rightarrow p_4 CO_2 + q_4 H_2O + r_4 SO_2 + \left[ t_4 + y_4 \left( \frac{79}{21} \right) \right] N_2
\]

Thus, balancing the equation, the combustion in air becomes:

\[
3.7908 \text{CO}_2 + 2.535 \text{H}_2\text{O} + 0.0025 \text{SO}_2 + 14.1152136905 \text{N}_2
\]

For wet base analysis:
The products of combustion = 20.4435136905kmol

For dry basis analysis:
The total amount of substance of dry products = 17.90851369kmol
In Figures 8 and 9, the percentage composition of wet and dry gases in the 70%C:30%R pellets is presented. In the wet analysis, the results showed that CO\textsubscript{2} and SO\textsubscript{2} emissions are 18.54\% and 0.0122\% respectively while for the dry analysis, CO\textsubscript{2} and SO\textsubscript{2} emissions are 21.17\% and 0.014\% respectively.

3.4.5 Combustion CO\textsubscript{2} and SO\textsubscript{2} Analysis of 60%C:40%R pellets

Again, the stoichiometric equation for the combustion of 60%C:40%R pellets \(\left[C_{3.9233}H_{5.03}O_{2.505}N_{0.03286}S_{0.0021875}\right]\) using air as the oxidant is given by:

\[
C_{3.9233}H_{5.03}O_{2.505}N_{0.03286}S_{0.0021875} + y_5 \cdot O_2 + (79/21)N_2 \rightarrow \]
\[
p_5CO_2 + q_5H_2O + r_5SO_2 + t_5 N_2 \]  
\( (17) \)

Again, balancing the equation, the combustion in air becomes:

\[
C_{3.9233}H_{5.03}O_{2.505}N_{0.03286}S_{0.0021875} + 3.998 \cdot [O_2 + (79/21)N_2] \rightarrow 3.9233CO_2 + 2.65H_2O + 0.0021875SO_2 + 15.07295524N_2
\]

For wet base analysis:
If the products of combustion = \(21.6484\)\%kmol

For dry basis analysis:
The total amount of substance of dry products = \(19.0181\)\%kmol

In Figures 10 and 11, presents the percentage composition of wet and dry gases in the 60%C:40%R pellets. In the wet analysis, the results revealed that CO\textsubscript{2} and SO\textsubscript{2} emissions are 18.12\% and 0.01\% respectively while for the dry analysis, CO\textsubscript{2} and SO\textsubscript{2} emissions are 20.63\% and 0.012\% respectively.

3.4.6 Combustion CO\textsubscript{2} and SO\textsubscript{2} Analysis of 50%C:50%R pellets

Again, the stoichiometric equation for the combustion of 50C:50R pellets \(\left[C_{4.0567}H_{5.02}O_{2.4606}N_{0.0343}S_{0.0021875}\right]\) using air as the oxidant is given by:
Balancing the equation on both sides, the combustion in air becomes:

\[
\begin{align*}
C_{4.0567}H_{5.02}O_{2.4606}N_{0.0343}S_{0.0021875} & \rightarrow \\
p_1CO_2 + q_1H_2O + \frac{r_1}{y_6}(79/21)N_2
\end{align*}
\]

For wet base analysis:
The total amount of products of combustion = 21.96522655kmol

For dry basis analysis:
The total amount of substance of dry products = 19.45522655kmol

In Figure 12 and Figure 13, the percentage composition of wet and dry gases in the 50%C:50%R pellets is presented. The results showed that in the wet analysis, CO\(_2\) and SO\(_2\) emissions are 18.47% and 0.01% respectively while for the dry analysis, CO\(_2\) and SO\(_2\) emissions are 20.85% and 0.011% respectively. Generally, the overall combustion gases between the wet and dry analyses showed that the percentage wet composition of CO\(_2\) and SO\(_2\) emissions from the various pellets (i.e. optimized and 100%C pellets) is lower than the dry composition analysis. Quantitatively, comparing the results of the 100%C and the optimized pellets, the 90%C:10%R pellets showed on wet basis, a reduction of CO\(_2\) by 1.26% and SO\(_2\) by 16.2%; while on dry basis, CO\(_2\) was reduced by 2.92% and SO\(_2\) by 30%. For the 80%C:20%R pellets, it was observed that there was a reduction of 2.15% in CO\(_2\) and 38.1% in SO\(_2\) for wet basis and a reduction of 5.45% in CO\(_2\) and 50% in SO\(_2\) for the dry basis. Again, for the 70%C:30%R pellets, in the wet basis, it was observed that there was a 2.37% reduction in CO\(_2\) and 41.9% reduction in SO\(_2\). In the dry basis, there was a reduction of 6.2% in CO\(_2\) and 53.3% in SO\(_2\). Also, in the 60%C:40%R pellets, for wet basis, it was again observed that there was a reduction of 4.57% in CO\(_2\) and 52.4% in SO\(_2\). There was a reduction of 8.6% in CO\(_2\) and 60% in SO\(_2\) in the dry basis. However, for the 50%C:50%R pellets (wet basis), it was observed that the comparative reduction in CO\(_2\) is 2.74%, while SO\(_2\) is 52.4%; while on the dry basis, CO\(_2\) reduction is 7.62% while SO\(_2\) is 63.3%. This means there is a drop in comparative reduction in CO\(_2\) on wet and dry basis while there is an increase in reduction of SO\(_2\). In other words, comparative reduction in CO\(_2\) will continue to rise until it gets to 50%C:50%R mixing ratio. Furthermore, the results presented thus far has shown that 100%C pellets releases higher combustion CO\(_2\) and SO\(_2\) emissions as reported by Eric and Clara [1], Yılmaz and Hasan [6] and Baxter [9]; than when it is co-pelletized with biomass residue (i.e. PKS) as reported in Rohan [10], Khalidah et al. [11] and Vamvuka et al. [24]. Essentially, the findings of this study also show that increase in the percentage mixing ratio of elaeis guineensis (PKS) in coal pellets, has the potential tendency in reducing the combustion CO\(_2\) and SO\(_2\) emissions of 100% coal except at 50%C:50%R mixing ratio when comparative reduction CO\(_2\) begins to drop. This study also validates the work of Baster [9], Rohan [10], Khalidah et al. [11] and Vamvuka et al. [24] which reported that 10% and 20% biomass addition to coal/biomass blend are typical of cofiring applications. In other words, coal can be treated and better utilized with elaeis guineensis residues so as to reduce the CO\(_2\) and SO\(_2\) emissions during combustion.
4. Conclusion
The essence of this study was to investigate the effect of elaeis guineensis residue (PKS) on the combustion CO$_2$ and SO$_2$ of coal pellets. Experimental results and combustion analyses from the optimized pellets revealed that pelletizing residue of elaeis guineensis (PKS) with coal would significantly reduce the combustion CO$_2$ and SO$_2$ emissions of 100% coal pellets. The results also revealed that if the optimized pellets are fired in boilers, corrosion rate of boilers would be reduced. Thus, reducing the cost of maintenance of boilers in steam power plants. Essentially, this study has been able to establish that pellets from optimized mixing ratio of elaeis guineensis residue (PKS) with coal has potential tendency to reduce the percentage CO$_2$ and SO$_2$ emissions of 100% pure coal during combustion.

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