International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 06 June 2025, pp: 407-414 www.ijaem.net ISSN: 2395-5252

Production and Determination of Energy Content (Calorific Value) of Optimized Coal Blended Pellets as Fuel for Cofiring

Ekanem Diana-Abasi Okon*, Ozoekwem Obinna Raphael[2], Onwubiko Kingsley Chiemela[3]

Department Of Mechanical Engineering, Alex Ekwueme Federal University, Ndufu Alike, Ebonyi State, Nigeria

---

Date of Submission: 10-06-2025 Date of Acceptance: 20-06-2025

ABSTRACT
This study is significance in the sense that it explores how cofiring coal with coconut shells (biomass) could promote energy sustainability by reducing reliance on fossil fuels This research is concern with the production of five samples of coal blended pellets from dried coal and coconut shell that has been grounded into fine grain size, the pellets were form using a mechanical screw press with optimization ratios of 90%C10%CS, 80%C20%CS, 70%C30%CS, 60%C40%CS, 50%C50%CS, where C and CS represent coal and coconut shell respectively, the energy content or calorific value of each optimized ratio of the form pellets was determined using msw-506 digital bomb calorimeter, the results presented from the research indicated that the pellet with the optimization ratio 50%C50%CS,gave the highest calorific value of **31219**kg/kj followed by **30894**kg/kj pellet with optimized ratio 60% C40%CS, this signifies that more efficient combustion occurs when 60C%40%CS and 50C%50%CS is used. Also as the percentage of coconut shell increases in the pellets, the energy density and fixed carbon content increases, thus enhancing the overall energy content of the fuel blend which agrees with [1]..However, the research recommends that the pellets be subjected to other forms analysis such as ultimate analysis, proximate analysis and etc. to unravel others parameters that could be related with the energy content of the optimized pellets and their effect to the environment as fuel.

KEYWORDS: Cofiring, Biomass, pelletizing, Energy Content, Greenhouse gases, pyrolysis

I. INTRODUCTION

1.1BackgroundofStudy

The growing concerns over climate change and the continuous depletion of fossil fuels have led to the need for alternative energy sources. While many countries seek to reduce the effect of carbon emitting fuels on the planet through the use of less coal for energy production. One way to achieve this is through the integration of biomass materials such coconut shell with conventional fuels (coal), through a process known as Cofiring. This holds great promise for cleaner and better energy production for the environment, thereby promoting sustainability in energy production [2].Coconut shell, a biomass resource common in tropical regions, offers significant advantages. They possess high energy content, and are readily available in the locality. Using coconut shells in cofiring systems can potentially reduce the impact of carbon from coal-fired power plants [3]. The benefits of biomass cofiring are numerous and one of which is the reduction in carbon footprint when compared to the carbon dioxide emissions from pure coal combustion [4], Which is one of the greenhouse gases that contributes greatly to environmental pollution and global warming. The concept of biomass cofiring, particularly with agricultural residues, aligns with global efforts towards the diversification of energy sources with the aim of promoting, enhancing energy sustainability[5]. Also, the stability of biomass fuels, its handling, as well as the economic implications of cofiring, requires a careful study in order to ensure its feasibility and cost-effectiveness [6].The need for better and more efficient energy sources, such that would be more eco friendly and sustainable for use in our ecosystem, has led to the exploration of other forms and sources of energy [7]. This study focuses on the potential of cofiring coal and blended with coconut for energy production. Research has shown that the combustion characteristics of biomass can differ significantly from those of coal, which may affect the stability and efficiency of power generation

[8]This study is aimed at determining calorific value of pellets form via various combination ratios of coal and coconut shell as fuel for cofiring of power plant, etc. and contribute valuable insights for policymakers. This study is significance in the sense that it explores how cofiring coal with coconut shells could promote energy sustainability by reducing reliance on fossil fuels. According to [5], by using coconut shell, a renewable and locally available resource, is a way of making energy production more eco- friendly and cost-effective. Additionally, the potential of cofiring with coconut shells, how it could lower greenhouse gas emissions and reduce air pollution compared to using coal alone. This innovation is a valuable way of addressing climate change and improving air quality, showing how biomass can play a role in cleaner energy production [9]. The research also highlights the economic and operational benefits of using coconut shells for cofiring. it provides practical insights for power plants aiming to optimize performance and reduce costs through locally sourced biomass. Furthermore, it promotes the efficient use of agricultural byproducts, supporting waste reduction and sustainable practices in tropical regions. The findings can guide policymakers in creating frameworks that support renewable energy initiatives and offer useful information for researchers and students studying sustainable energy solutions.

1.2 Biomass Energy

According to [10], Biomassis any organic matter such as woody biomass(Stems, branches, shrubs, hedges, twigs,etc.), non-woody biomass (stalks, leaves, grass, etc.), Agricultural or crop residues (bagasse, husks, stalks, shells, cobs, etc.) and animal wastes, Generated through photosynthesis or other biological processes, used as an alternative fuel, in Particular, in power stations for electric power generation. Biomass are harnessed through process Such as combustion, pyrolysis (conversion of solid into biochar, bio oil and biogas), gasification (conversion of solid or liquid into gas), anaerobic digestion or biogasification (biogas production) and transesterification (biodiesel production). Combustion, pyrolysis and gasification ideally require Dry biomass, while anaerobic digestion takes wet biomass. The biomass preparations can Include chopping, mixing, drying, carbonising (i.e. charcoal making), and densification (such as briquetting, pelletizing or cubing) among others.[10].

Biomass, renewable organic materials form living or recently living organisms such as plants, agricultural residues, and waste. Biomass energy, derived from processing biomass resources, plays a crucial role in the global energy landscape. It is a renewable resource that can serve several energy needs, and also can be converted into various forms of energy, including heat, electricity, and biofuels.

1.3 Fossil Fuels

Fossil fuel is a finite, non-renewable natural fuel, formed from the remains of living organisms (in the geological past). Examples are coal, crude oil or natural gas. Fossil fuels can be harnessed through indirect energy conversion processes for electricity generation. The chemical energy released during combustion of these fuels generates heat, which can be used to power internal combustion engines such as gas turbines, spark-ignition or diesel engines. While the rotating electric generators transform the shaft work derived from these turbines into electricity and the pistons transform the derive motion from the engines or impart motion from the pumps into useful work. Because the generation of electricity from fossil fuels involves several energy conversion steps, fossil fuel power plants inefficiently generate power at about 40% efficiency. Considering also the environmental effects of electricity generation from fossil fuels, e.g. fly ashes, physical matter etc. left after the combustion of coal, pose an environmental threat to human (animal) health. It demands environmentally friendly disposal. Fossil fuels combustion also produces greenhouse gases such as carbon monoxide, carbon dioxide, sulfur dioxide, and nitrous oxides gases. These greenhouse gases contribute to acid rain and global warming effects. [10].

1.4 Energy Content

The energy content of any fuel (fossil fuel or biomass) is primarily determined by its calorific value, which is usually expressed in terms of Higher Heating Value (HHV) and / or Lower Heating Value (LHV). The energy content of biomass materials varies depending on the type of biomass and its composition[11]For example, wood pellets have a higher energy content compared to agricultural residues due to their higher density and lower moisture content [12].

1.5 Cofiring

Cofiring, which involves the simultaneous combustion of biomass with fossil fuels, are increasingly being recognized and adopted as a viable strategy for reducing greenhouse gas emissions and enhancing the sustainability of

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 06 June 2025, pp: 407-414 www.ijaem.net ISSN: 2395-5252

power generation [3].

Cofiring is a fuel blending practice commonly used for solid fuels. It refers to the practice of supplementing a base alongside a different fuel (example, wood pellets and coal). It is the practice of burning biomass alongside coal in power plants in order to partially replace coal with renewable biomass. The primary objective of cofiring is to promote sustainable energy production by reducing carbon dioxide emissions, lower dependence on fossil fuels, and utilize locally available renewable resources [13]. The efficiency and environmental benefits of cofiring depend on several factors:

1.6 Energy Density and Combustion Characteristics:

Biomass has different combustion properties compared to coal, including variations in energy density, moisture content, volatile matter, and ash composition. These differences can affect the overall performance of the power plant and require adjustments in operational parameters [14].Emission Reduction by replacing a portion of coal with biomass, which is considered carbon-neutral, cofiring can reduce the net carbon dioxide emissions from power plants. However, the effectiveness of emission reduction depends on the proportion of biomass used and the combustion efficiency [15].

1.7 Properties of Coal

Coal is an example of fossil fuel categorized into several types based on its carbon content and energy density:

a. Anthracite
b. Bituminous
c. Sub-bituminous
d. Lignite.

Each type has different combustion properties and environmental impacts. The combustion of coal produces significant energy but also emits harmful pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter [16].

1.8 Properties of Coconut Shells

Coconut shells are primarily composed of cellulose, hemicellulose, and lignin. They have a high carbon content and low ash content compared to other biomass materials, making them a promising candidate for blending with coal [17]. The high energy density and fixed carbon content of coconut shells can enhance the overall energy content of the fuel blend [1].

1.8.1Benefits of Blending Coal with Coconut Shells

1 **Improved Combustion Efficiency:** Coconut shells can improve the combustion efficiency of coal by increasing the overall calorific value of the fuel blend, resulting in more efficient energy production [5].
2 **Reduction in Greenhouse Gas Emissions:** Biomass, including coconut shells, is considered carbon-neutral, as the CO_2 released during its combustion is offset by the CO_2 absorbed during its growth. This can help reduce the green house gas emissions associated with coal combustion [18].
3 **Utilization of Waste Materials:** Using coconut shells, an agricultural by-product, as a biomass fuel aids in waste management and reduces reliance on fossil fuels [3].
4 **Enhanced Fuel Properties:** Blending coal with coconut shells can improve certain combustion properties such as ignition temperature and burn rate, potentially leading to better control over combustion processes and reduced emissions of pollutants [19].

1.9 Environmental Impact of Cofiring

1.9.1ReductioninGreenhouseGas Emissions

1. **Carbon Dioxide Emissions:** Cofiring biomass with coal can reduce overall carbon dioxide (CO_2) emissions. Biomass is considered carbon-neutral because the CO_2 released during its combustion is balanced by the CO_2 absorbed during its growth [15]. This contrasts with coal, which releases CO_2 from stored carbon. By partially substituting coal with biomass, the net CO_2 emissions from power plants can be significantly lowered.
2. **Methane and Nitrous Oxide Emissions:** In addition to CO_2, cofiring can also influence emissions of other greenhouse gases like methane (CH_4) and nitrous oxide (N_2O). Methane emissions can be reduced as biomass tends to produce less CH_4 compared to coal during combustion [15]. However, nitrous oxide emissions may vary depending on the biomass type and cofiring ratio [2].

1.9.2Air Pollutants and Particulate Matter

1. Sulfur Dioxide (SO_2) and Nitrogen Oxides (NO_x): Cofiring can reduce sulfur dioxide (SO_2) emissions, especially when biomass with low sulfur content is used. Biomass can lower SO_2 emissions compared to high-sulfur coals. However, nitrogen oxides (NO_X) emissions may remain a concern, as

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 06 June 2025, pp: 407-414 www.ijaem.net ISSN: 2395-5252

the impact of cofiring on NO_x is influenced by combustion conditions and the nitrogen content of the biomass [20].

2. Particulate Matter: The combustion of biomass can produce fine particulate matter (PM), which can contribute to air quality issues. The impact on particulate matter depends on the biomass type, combustion technology, and cofiring ratio. Effective particulate control measures are necessary to mitigate any negative effects on air quality [2]..

II. MATERIALS AND METHODOLOGY

2.1Materials

The materials used in this research work are; grounded coconut shell, Coal and negligible mass waste paper used as binder, Figure 2.0 shows the sample of coconut shell and coal before it was grounded

Coal **Coconut Shell**

Figure 2.0: sample of coal and coconut shell used in the research

Figure 2:1Grinded coconut shell and coal ready for pelletizing

2.2 Equipment/Apparatus

The Equipment/Apparatus use in this work includes:

1 Mechanical screw press
2 Grinding/Crouching Machine
3 Bomb Calorimeter and etc.

The grinding Crouching machine was used to grind or pulverized the already dried coconut shell and Coal to a fine grain size and the mechanical screw press was used for pellets made up of coal and coconut shell at various proportion for easy movement and transportation while the bomb calorimeter was used for the determination .calorific value for each of the sample. Figure 2.1 shows the mechanical screw press was used for making pellets

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 06 June 2025, pp: 407-414 www.ijaem.net ISSN: 2395-5252

Figure 2.2 pelletizing combination of various proportions of coconut shell and coal

2.3 Methodology

Coal gotten from Udi coal mine Enugu State in Nigeria and coconut shell gotten from Nifor Farm Edo State in Nigeria, were gathered and sun dried for a week to reduce moisture content and make them easier to grind, In this study, detailed mixing ratios of samples were adopted for a robust optimization and production of cofired pellets. The optimization ratios are as follows: 90%C: 10%CS, 80%C: 20%CS, 70%C: 30%CS, 60%C: 40%CS, 50%C:50C pellets were also produced and the samples calorific values were determined using a bomb calorimeter. Note: the abbreviation C is coal, while CS is Coconut Shell.

Coal(%) C	Coconut Shell(%) CS
90%	10%
80%	20%
70%	30%
60%	40%
50%	50%

Table.2: Mixing ratio of optimized pellets

III. RESULTS AND DISCUSSION

3.1 Results

Table 3.0. Presents the result obtained from the bomb calorimeter showing the calorific value of various combination ratios of coal and coconut shell pellets or optimized pellets.

TABLE 3.0 Calorific Value of Optimized C plus CS.

Samples	**90%C: 10%CS**	**80%C: 20%CS**	**70%C: 30%CS**	**60%C: 40%CS**	**50%C: 50%CS**
Calorific Value (kg/kj)	**28471**	**29317**	**29604**	**30894**	**31219**

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 06 June 2025, pp: 407-414 www.ijaem.net ISSN: 2395-5252

Combination ratios of coal and coconut shell pellets or optimized pellets.

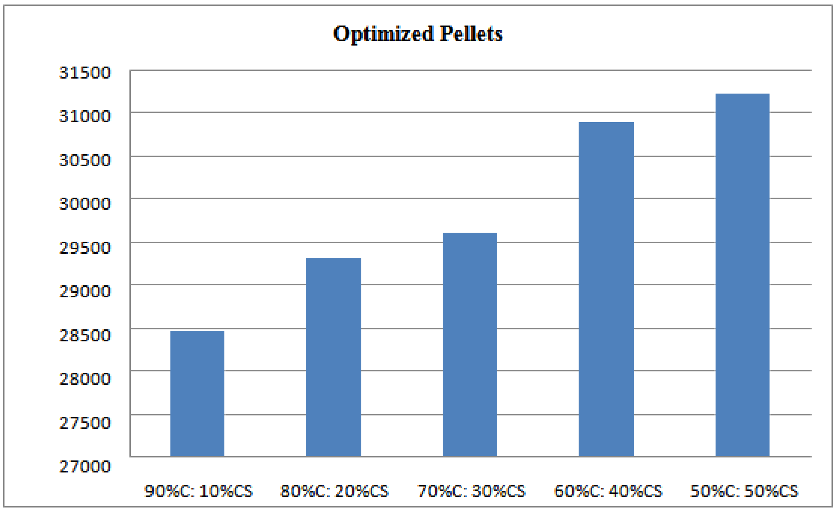

Figure 3.0 is a bar chart showing the calorific values of various

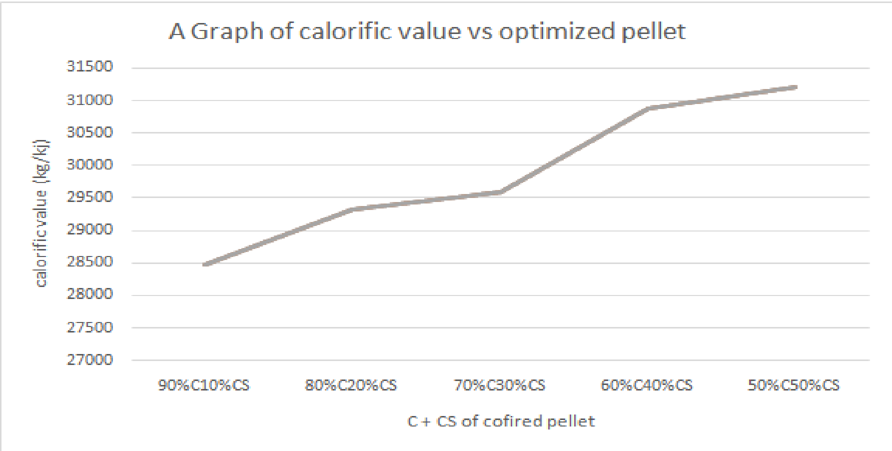

Figure 3.1 shows a Graph of calorific value against optimized co-fired pellet

3.2 Discussion of Results

The pellets were found to have calorific values ranging from 28471kg/kj to 31219kg/kj, From figure 3.1 and figure 3.2, show that as the percentage of coal Was gradually reduced by ten percent (10%), from one sample of the pellets to the other with corresponding increment of ten percent10% of coconut shell from one sample of the pellets to the other, The calorific values were found to be increasing positively as more coconut shells were blended with coal with the highest calorific of 31219kg/kj at 50%C50%CS.

However, from the bar chart in figure 3.1, it can be seen that the highest change in calorific value

Occurs between 70C%30%CS and 60C%40%CS which is 1290kg/kj (31219 − 28471)kg/kj, this signifies that more efficient combustion occurs when 60C%40%CS and 50C%50%CS is used, meaning that more heat energy will generated which can be converted to mechanical work. Also as the percentage of coconut shell increases in the pellets, the energy density and fixed carbon content increases, thus enhancing the overall energy content of the fuel blend which agrees with (Sharma et al., 2024) The high calorific value demonstrated shows that pellets can be used for heating purposes, such as in processing boilers, heat water for industrial processes, in power plant to generate electricity

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This research titled production and determination of energy content (calorific value) of optimized coal pellets as fuel for cofiring was carried out, the result obtained shows that the pellet with the optimization ratio **50% C50% CS**, gave the highest calorific value of **31219**kg/kj followed by **30894**kg/kj with pellet Optimized ratio **60% C40% CS**, this signifies that more efficient combustion occurs when 60C%40%CS and50C%50%CS are used. The combination of Fossil fuel (coal) and Biomass resources (coconut shell) as Fuel provides opportunity for the utilization of our biomass resources which were hitherto indiscriminately discharged as waste which is a cleaning form of energy resources

4.2 Recommendations

In view of the above research titled production and determination of energy content (calorific value) of optimized coal pellets as fuel for cofiring, the following are hereby recommended;

1. Pellets with optimized ratios 60C%40%CS and 50C%50%CS should be adopted as fuel for cofiring
2. The research recommends that the pellets be subjected to other forms analysis such as ultimate analysis, proximate analysis and etc. to unravel others parameters that could be related with the energy content of the optimized pellets and their effect to the environment as fuel

REFERENCES

[1]. Sharma,K.,Sharma,M.,Kaul,K.S.,Singh,G. , &Arya,S.K.(2024).Commercialwaste to energy, technologies, economics, and challenges: Stores, hotels, restaurant. In M. R. Rahimpour (Ed.), Encyclopedia of renewable energy, sustainability and the environment (pp. 29-40). Elsevier. https://doi.org/10.1016/B978-0-323-93940-9.00086-4

[2]. Gil, M. V., & Rubiera, F. (2019). Coal and biomass cofiring: Fundamentals and future trends.InI.Suárez-Ruiz,M.A.Diez,& F.Rubiera(Eds.),Newtrendsin coalconversion (pp. 117-140). Woodhead Publishing

[3]. Tillman, D. A., Duong, D. N. B., & Harding, N. S. (2012). Chapter 4- Blending coal with biomass: Cofiring biomass with coal. In D. A. Tillman, D. N. B. Duong, & N. S. Harding (Eds.), Solid Fuel Blending (pp. 125-200). Butterworth-Heinemann

[4]. Malmgren, A., & Riley, G. (2018). Biomass power generation. In Reference Module in Earth Systems and Environmental Sciences. Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11014-0

[5]. Bossink, B., Blankesteijn, M. L., & Hasanefendic, S. (2023). Upscaling sustainable energy technology: From demonstration to transformation. Energy Research & Social Science, 103, Article 103208. https://doi.org/10.1016/j.erss.2023.103208

[6]. Sami, M., Annamalai, K., & Wooldridge, M. (2001). Co-firing of coal and biomass fuel blends. Progress in Energy and Combustion Science, 27(2), 171-214. https://doi.org/10.1016/S0360-1285(00)00020-4

[7]. Variny, M., Varga, A., Rimár, M., Janošovský, J., Kizek, J., Lukáč, L., Jablonský, G., & Mierka, O. (2021). Advances in biomass co-combustion with fossil fuels in the European context: A review. Processes, 9(1), Article 100. https://doi.org/10.3390/pr9010100

[8]. Kumar,N.,Varun, &Chauhan,S.R. (2013).Performanceand emission characteristics of biodiesel from different origins: A review. Renewable and Sustainable Energy Reviews, 21, 633-658.

[9]. Hariana, Prabowo, E. H., Kuswa, F. M., Darmawan, A., & Aziz, M. (2023). A comprehensiveevaluationofcofiringbiomass withcoalandslagging-foulingtendencyin pulverizedcoal-firedboilers.AinShamsEngineeringJournal, 14(7),10200

[10]. Ajimototan H. A. (PhD) MEE 463 Course Guide, Department of Mechanical Engineering, University Of Ilorin, Ilorin Nigeria

[11]. Uzun, H., Yıldız, Z., Goldfarb, J. L., & Ceylan, S. (2017). Improved prediction of higher heating value of biomass using an artificial neural network model based on proximate analysis.BioresourceTechnology,234,122-130

[12]. Osman, A. I., Mehta, N., Elgarahy, A. M., & et al. (2021). Conversion of biomass to biofuels and life cycle assessment: A review. Environmental Chemistry Letters, 19, 4075–4118.

[13]. Lackner, K. S., Park, A.-H. A., & Miller, B. G. (2010). Chapter 6 - Eliminating CO2

emissions from coal-fired power plants. In F. P. Sioshansi (Ed.), Generating electricity in a carbon-constrained world (pp. 127-173). Academic Press.

[14]. Geng, P., Cao, E., Tan, Q., & Wei, L. (2017). Effects of alternative fuels on the combustion characteristics and emission products from diesel engines: A review. RenewableandSustainableEnergyReviews, 71,523-534.

[15]. Han,Z.,Jia,X.,Song,X.,An,P.,Fu,L.,Yue,J., Yu,J.,Liu,X.,Zhang,Z.,Jin,Y.,He, M., Bai, D., & Xu, G. (2023). Engineering thermochemistry to cope with challenges incarbonneutrality. Journal of Cleaner Production, 416, 137943

[16]. Wang, G., Dai, Y., Yang, H., Xiong, Q., Wang, K., Zhou, J., Li, Y., & Wang, S. (2020). Areviewofrecentadvancesinbiomasspyrolysis. Energy&Fuels,34(12),15557-15578.

[17]. Jenkins, B. M. (2014). Global agriculture: Industrial feedstocks for energy and materials. In N. K. Van Alfen (Ed.), Encyclopedia of agriculture and food systems (pp. 461-498). Academic Press.

[18]. Belkin, H. E. (2018). Environmental human health issues related to indoor air pollution from domestic biomass use in rural China: A review. In B. De Vivo, H. E. Belkin, & A. Lima (Eds.), Environmental Geochemistry (2nd ed., pp. 417-434). Elsevier.

[19]. Breeze, P. (2015). Chapter 7 - Carbon capture and storage. In P. Breeze (Ed.), Coal-fired generation (pp. 73-86). Academic Press.

[20]. Zhu,Y.,Liang,J.,Yang,Q., Zhou,H.,& Peng,K.(2019).Wateruseof abiomass direct- combustion power generation system in China: A combination of life cycle assessment and water footprint analysis. Renewable and Sustainable Energy Reviews, 115, Article 109396.