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Comparative study and experimental analysis of pellets from biomass sawdust and rice husk

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ABSTRACT

Sawdust and rice husk are available in abundance and indigenous in Nigeria but have not been exploited because they cannot be used directly in combustion processes due to their loose form unless by pelleting or briquetting. This experimental study assesses the potential of pellets from sawdust (SD) and rice husk (RH). Pallet samples collected from mills were thereafter optimized in ratios (i.e. 90%RH:10%SD, 80%RH:20%SD, 70RH:30%SD, 60%RH:40%SD, 50%RH:50%SD, 100%RH and 100%SD) using mixing ratio optimization model. Seven samples were produced using a manual screw press machine and were subsequently categorized in terms of calorific value (CV), proximate and ultimate analyses using the ASTM standards. Results showed that the 100%RH pellets have higher CV of 31,026.3kJ/kg and the 100%SD a value of 26,088.3kJ/kg while the optimized pellets range from 25,867.39kJ/kg to 27,063.60kJ/kg. The CV decreases with increasing ash content of the pellets. It was also observed from the proximate analysis that the 100%RH has low percentages of moisture content, volatile matter and ash content compared to others. The optimized pellets showed that SD has the tendency to reduce the sulfur content in RH; hence, a promising alternative source of energy to the conventional fossil fuel.

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1. Introduction

The availability of energy is the basic infrastructure for economic development of any nation. Nishant et al. [1] reported that all sectors of the economy, which involve businesses, engineering and household need energy. In Nigeria, energy demand is increasing and its dependency is basically on fossil fuel such as natural gas and oil. As reported in [2], biomass, solar and wind energy are the area of interest for researchers in view of emerging technologies [1]. Kumar and Patel [3] reported that biomass is renewable, reliable and is an alternative source of energy.

In sustaining the earth's ecological balance, biomass acts as a fundamental medium, which helps in balancing the CO_2 in the atmosphere. Moreover, biomass in the 21st century, has justifiable capacity for power generation [4]. Again, biomass has good prospects for providing high grade energy [5]. Biomass is stored energy; however, it has issues with energy storage when compared to solar and wind. Essentially, biomass is regarded as a versatile fuel that can produce liquid fuels, biogas and electricity [6].

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Biomass resources vary from agricultural crop residues such as oil palm residues and rice husk etc., municipal solid wastes, residues from paper industries and food items, forestry and industry wood wastes. In addition, energy crops can be harnessed for the generation of heat and electricity as well as other forms of bioenergy. Kamble et al. [7] reported that in India, 5000 million units of electricity are generated from biomass energy with annual employment in excess of 10 million man-days in remote areas. According to [8], biomass waste is projected to contribute of about 10–14% of the global energy supply in 2015 [9], [10].

In [11], it was reported that agricultural residues such as sawdust, rice husk, groundnut husk, cotton stalk and corn stover are some of the most suitable combustion fuels based on their annual availability in substantial quantities. However, according to [12] as reported in [11], there are a lot of combustion issues when utilizing loose biomass residues for energy purposes due to their low bulk density, high moisture content, low heating value and excessive emissions during combustion. Suhartini et al. [13] and Wilaipon [14] reported that pelleting technology is one of the appropriate techniques of improving the heating value of loose biomass such as sawdust, rice husk and other agricultural residues, which is in abundant in Nigeria.

In Nigeria as well as other developing countries, the issues associated with the dumping of sawdust around sawmills constitute a huge problem to the local environment. Pelleting this sawdust for energy use can solve and mitigate this problem. Loss of fuel, low thermal efficiency, as well as extensive air pollution are characteristics of direct burning of biomass residues such as rice husk, sawdust, groundnut shells, palm kernel shells, and so on [15]. To mitigate these problems will require the compression of this waste into pellets, which will thereby reduce storage and transportation cost and also enhance energy generation by improving their net calorific value of the unit [16].

Similarly, in Nigeria, rice husks are produced in large quantity annually; the wastes are burned or left to rot away [17]. It was reported [18] that these residues could be utilized for the generation of heat for industrial cottage and domestic applications. Different technologies for converting agricultural biomass into energy were presented in [19]; pelleting technology is more environmentally and economically viable and most feasible. Another study [20] reported that pelleting improves the properties (physical, chemical as well as combustion) of the raw materials. Again, in [21], pelleting was defined as a densification process that can drastically reduce the demand for wood; hence, mitigates deforestation.

The objectives of this study are to conduct a comparative study on rice husk and sawdust pellets through experimental findings and to evaluate their energy potential using optimization method.

2. Methodology

Samples of sawdust were collected from sawmill in Ikpoba Hill, Benin City while rice husk was collected from a rice mill in Abakaliki, Nigeria. The samples of sawdust and rice husk are presented in Fig. 1.

Fig. 1 100% sawdust and rice husk residues

The rice husk (RH) and sawdust (SD) samples were thoroughly mixed and sieved to attain uniform size. Waste paper and cassava starch were mixed and used as a binding agent. The mixture was thereafter optimized and seven different pellets were produced with the aid of a manually operated screw pelleting machine. The pellets were produced in ratios (90%RH:10%SD, 80%RH:20%SD, 70RH:30SD, 60%RH:40%SD, 50%RH:50% SD, 100%RH and 100%SD) as presented in Fig. 2.

Fig. 2 Produced pellets

The produced pellets were thereafter oven dried to constant weight and characterized. The American Society for Testing and Materials (ASTM) standard D5373-02 of 2003 reported in [22] was used to conduct the proximate analysis while for the ultimate analysis, ASTM analytical technique was utilized. In this study, the "mixing ratio optimization model" was used to establish the calorific values, proximate and ultimate analyses of the pellets produced. The reason for these analyses was to evaluate the presence of other component of the pellet so as to determine how environmentally friendly they are during combustion and to draw necessary conclusion from the results obtained.

2.1. Moisture Content (MC)

Mass of 10g of each sample was placed in the porcelain separately and measured. The content on the porcelain were oven dried for 3 hours at 105°C. Eq. (1) is the formula for the percent moisture content (γ_{MC}):

$$\gamma_{MC} = \frac{M_{sample} - X_{DM}}{M_{sample}} \times 100 \quad (1)$$

where, (M_{sample} - X_{DM}) is the loss in mass (g), M_{sample} is the mass of sample (g), M_{DM} is the mass of dry matter (g) and M_{sample} is the mass of sample (g).

2.2. Calorific Value Calculation

Equation (2) was utilized to determine the calorific value (CV) (kJ/kg) using the data obtained from Laboratory analysis.

$$CV = \frac{E\Delta T - \Phi - V}{g} \quad (2)$$

Where, V is the volume of alkali in calorimeter (kJ), E is the energy equivalent of the calorimeter (= 13,039.308 kJ/°C), Φ is equal to 2.3 × length of burnt wire (kJ), ΔT is the change in temperature (°C) and g is the mass of sample (kg).

2.3. Proximate Analysis

This analysis consists of the volatile matter, ash content, moisture content as well as the fixed carbon. It is the physical properties of the fuel.

Volatile Matter (VM): Samples were weighed and oven dried at 105°C for 4 hours. Thereafter, cooled and placed in a muffle furnace at 600°C for 20 minutes. The samples were measured after cooling. The percentage volatile matter, γ_{VM} is deduced as follows:

$$\gamma_{VM} = \frac{M_{dm} - M_r}{M_s} \times 100 \quad (3)$$

where, M_{dm} is the mass of dry matter (g), M_s is the mass of sample (g), and M_r is the mass of residue (g).

Ash Content: Measured samples were placed in a muffle furnace for 4hrs at 700°C. The crucible containing only ash was cooled, and the weight of the ash was calculated after weighing the crucible. The percentage ash content, γ_{Ash} is expressed as:

$$\gamma_{Ash} = \left(\frac{M_a}{M_s}\right) \times 100 \quad (4)$$

where, M_a is the mass of ash (g) and M_s is the mass of sample (g).

Fixed Carbon: Fixed carbon is simply 100 minus the addition of moisture content, volatile matter and ash content. The percentage fixed carbon, γ_{FC} is expressed as:

$$\gamma_{FC} = 100 - (\gamma_{MC} + \gamma_{VM} + \gamma_{Ash}) \quad (5)$$

2.4. Ultimate Analysis

The formulas used in [22] were adopted for calculating the constituent of the ultimate analysis, which is the chemical composition of the fuel that comprise carbon, hydrogen, nitrogen and sulfur and oxygen. The percentage content of constituents (carbon, hydrogen, nitrogen, sulfur and oxygen) was deduced using the data obtained from laboratory analysis, respectively as follow:

$$\gamma_C = \frac{(B-T) \times M \times 0.003 \times 100 \times 1.33g}{M_S} \quad (6)$$

$$\gamma_H = \frac{wt\ of\ H_2O \times 0.1119 \times 100}{wt\ of\ pellet} \quad (7)$$

$$\gamma_N = \frac{(T \times M \times 0.014 \times DF)}{M_S} \times 100 \quad (8)$$

$$\gamma_S = \frac{M_{BaSO4} \times 0.1373}{M_S} \times 100 \quad (9)$$

$$\gamma_{O_2} = 100 - (\gamma_C + \gamma_N + \gamma_S + \gamma_H + \gamma_{Ash} \quad (10)$$

where, *B* is the blank titer value (g/mol), *T* is the sample titer value (g/mol), *M* is the molarity of the acid used (mol/g), *wt* is the weight, M_s is the mass of sample (g), *DF* is the dilution factor diluted (g), M_{BaSO4} is the mass of $BaSO_4$ (g) and γ_x is the percentage constituent of x.

3. Results and Discussion

3.1. Proximate Analysis of Pellets

The results of the proximate analysis of the 100% rice husk, 100% sawdust and the optimized pellets (i.e. 90RH:10SD, 80RH: 20SD, 70RH:30SD, 60RH:40SD, 50RH:50SD) are presented in Table 1.

According to [23], the quality of a pellet lies in the extent of its moisture content (MC). That is, a higher calorific value depends on how low the moisture content is. As shown in Table 1, the percentage MC of the various pellets showed that rice husk pellet (i.e. 100%RH) has the lowest moisture content (4.28%), while sawdust pellet (i.e. 100%SD) has 4.8%. This is in agreement with the work of Wamukonya and Jenkins [23], which suggests that low moisture content of 5% is good for storability and combustibility of the pellets. Similarly, the value obtained for the MC validates the 5% MC [24] for the durability of sawdust pellets. It was also observed from the optimized pellets that as the percentage ratio of sawdust content increases in the pellets, the moisture content gets higher. Hence, for the optimized pellets, the 50%RH: 50%SD has the highest moisture content while the 90%RH:10%SD has the lowest moisture content.

Akowuah et al. [11] and Salisu et al. [25] have shown that good moisture content is between 5-12% and less. In [25], it was reported that the volatile matter (VM) and low char content of biomass residue is usually about 70% to 86%. Loo and Koppejan [26] also stated that due to the high VM, biomass is highly reactive which is why combustion rate is faster during the devolatization phase than other fuels such as coal. Also, from Table 1, it was observed that pellet from 100%RH has the highest γ_{VM} of 86.16% while the pellet from 100%SD has 73.02%. In other words, pellet from 100%RH validates the statement made in [24] since all pellets (both the optimized) are within the range of 70% to 86%. This also indicates that the 100%RH pellet will have a better ease of ignition during combustion and will volatize and burn as gas than the others. Kim et al. [27] reported that ash has a negative effect on the heat transfer to the surface of the fuel as well as the diffusion of oxygen to the surface of the fuel during combustion. Similarly, [11] reported that the higher the percentage ash contents of a fuel, the lower its CV. High percentage ash content of fuels causes slagging in boilers during combustion. In Table 1, it was also revealed that the percentage ash content of 100%RH pellets has the lowest ash content of 3.21% while pellet from 100%SD has a higher percentage of 14.31%. This is in agreement with the reports of Bureau of Energy Efficiency, which states that γ_{Ash} for boilers range between 5% and 40%. Therefore, pellet from 100%RH is more suitable than the others when considering boiler application.

3.2. Ultimate Analysis of Pellets

The results of the ultimate analysis of the 100% rice husk, 100% sawdust and the optimized pellets (i.e. 90RH:10SD, 80RH: 20SD, 70RH:30SD, 60RH:40SD, 50RH:50SD) are presented in Table 2. The chemical composition analyzed pellets (including the optimized) showed 42.25% to 46.28% carbon, 5.0% to 5.12% hydrogen, 32.37% to 48.83% oxygen, 0.29% to 0.45% nitrogen and 0.04% to 0.14% sulfur. This result in Table 2 validates the report of Chaney [28] who showed that for biomass analysis, the principal constituent, carbon, comprises between 30% and 60% of dry matter and oxygen contains about 30% to 40%.

Table 1 Proximate analysis of pellets

Proximate Analysis	100% RH	100% SD	90RH:10SD	80RH:20SD	70RH:30SD	60RH:40SD	50RH:50SD
γ_{MC}	4.28	4.80	4.59	4.60	4.69	4.77	4.99
γ_{Ash}	3.21	14.31	14.79	14.20	13.01	11.66	11.48
γ_{VM}	86.16	73.02	73.02	74.45	75.22	76.73	76.73
γ_{FC}	6.35	7.87	7.20	6.66	7.00	7.02	7.19

Table 2 Ultimate analysis of pellet

Ultimate Analysis	100% RH	100% SD	90RH:10SD	80RH:20SD	70RH:30SD	60RH:40SD	50RH:50SD
γ_C	42.25	47.88	43.09	43.89	44.69	45.49	46.28
γ_N	0.45	0.29	0.42	0.41	0.39	0.37	0.36
γ_S	0.14	0.04	0.12	0.11	0.10	0.10	0.08
γ_H	5.12	5.11	5.09	5.07	5.07	5.03	5.02
γ_{O_2}	48.83	32.37	33.93	36.32	36.74	37.35	36.77

Table 3 Calorific value of pellets

Items	100% RH	100% SD	90RH:10SD	80RH:20SD	70RH:30SD	60RH:40SD	50RH:50SD
CV (kJ/kg)	31,026.3	26,088.3	25,867.39	26,153.59	26,534.99	26,999.50	27,063.60

Chaney further reported that the third major constituent, hydrogen, consists about 5% and 6%, while sulfur and nitrogen has less than 1% of the dry biomass. Furthermore, the percentage carbon and hydrogen result also agrees with the work of Musa [29] who reported that higher constituents of both will contribute significantly to the combustibility of the pellets. The result of the sulfur content also agrees with the report of Bureau of Energy Efficiency, which stated that normal sulfur content for fuels ranges between 0.5 to 0.8%. The optimized pellets also showed that sulfur content in rice husk pellet could be reduced using sawdust. Enweremadu et al. [30] suggested below 1% sulfur and nitrogen contents in their report. This study is agreement with their report. This signifies low nitrogen oxides and sulfur into the atmosphere, thereby reducing the effect of pollution.

3.3. Calorific Value Analysis of Pellets

The result of the calorific value is presented in Table 3. Aina et al. [24] reported in their study that the most significant property of a fuel is its CV. In other words, the higher the CV, the better the burning efficiency.

From Table 3, the calorific value results as presented showed that the pellets from 100%RH has the highest CV (i.e. 31,026.3 kJ/kg) while 100%SD has the lowest (i.e. 26,088.3 kJ/kg). Similar result for 100%RH pellet was obtained by Food and Agricultural Organization [31] as reported in Akpenpuun et al. [32]. It was also observed from the optimized pellets that the 90RH:10SD pellet has the lowest calorific value (25,867.39kJ/kg) while the 50%RH:50%SD has the highest calorific value (27,068.60 kJ/kg). Essentially, the calorific value (CV) result shown in Table 3 and the result from the ash content presented in Table 2 validates the statement made by Loo and Koppejan [26] reported in [33], which states that for a fuel, the higher the percentage ash content, the lower its CV.

4. Conclusion

This study comparatively and experimentally analyzed the energy potential of 100%RH pellet, 100%SD as well as the optimized pellets. The experimental result as presented revealed that pellet from 100%RH have better calorific value than the 100%SD and the optimized pellets. The findings from this study, essentially, showed that optimization of these residues in form of pellets are a promising alternative source of energy to the conventional fossil fuel. The result also revealed that it is economically and environmentally friendly and also a way of mitigating pollution associated with agro-wastes disposal.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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