Viability of Wood Dust Biomass of Ahun (*Alstonia congenisis* Engl.) for Solid Fuel Production

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Abstract

Nigeria has a vast amount of agriculture and forest residues that are grossly underutilized. The potentials of these biomasses considered as wastes can be tapped for energy generation. Therefore, the present study investigated the viability of wood dust biomass (*Astonia congenisis*) as feedstock for solid fuel production using a thermo-chemical conversion process such as Torrefaction process. The process was performed with an improvised torrefier. The effect of the torrefaction process on the fuel properties of the biomass was evaluated by performing the Fibre analysis (cellulose, lignin, hemicellulose), Proximate analysis (moisture content, volatile matters content, ash content, fixed carbon), Ultimate analysis (nitrogen content, carbon content, hydrogen, oxygen and sulphur content) and Energy value before (untorrefied) and after (torrefied) the torrefaction process. From the result, the energy value of 19.58 MJ/kg recorded for the untorrefied sample remarkably increased to 27.28 MJ/kg upon torrefaction at 200°C process temperature. The lignin content of the biomass increased from 30% to 64% after torrefaction. A slight increase from 39% to 40% was observed in the cellulose content of the biomass upon the thermo-chemical process. However, hemicellulose, extractives and holocellulose which were 28%, 10.50% and 67% respectively in the untorrefied sample decreased to 24%, 8.50% and 64% respectively upon torrefaction. The moisture content in the untorrefied biomass decreased from 22.50% to 17.50% after the torrefaction process. This observation was also noticed in the volatile matter composition of the biomass. Conversely, the ash content of the sample was discovered to be 2.00% in it untorrefied form and increased remarkably upon torrefaction to 4.00%. Furthermore, 17.50% fixed carbon was detected in the untorrefied (raw) biomass sample and was noticeably increased to 40.50% after torrefaction. These observations implied that torrefaction method is an effective thermo-chemical conversion process for solid fuel production from wood biomass due to its enhancing fuel properties potentials.

1. Introduction

Problems associated with shortage of conventional fuels increasingly creating human and environmental crisis such as soil erosion, deforestation, desertification, ozone layer depletion among others. These awful impacts gave rise to the need to consider alternative sources of energy for domestic and industrial applications. However, Nigeria has high amount of agro-forestry residues that are not gainfully utilized. The potentials of these biomasses considered as wastes can be harnessed for energy generation. This will reduce the rate at which wastes pollute the environment as well as curb the problems associated with energy shortages in the country.

Biomass is an organic material that is renewable over time. It is composed of carbohydrate polymers with little quantity of inorganic materials and low amount of extractives. Biomass is made up of cells which consist of cellulose, hemicellulose

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and lignin as building blocks. Cellulose is the major component of cells that dominates woody biomass. However, cellulosic material typically ranges from 65–75 wt%. Cellulose resists depolymerization than hemicellulose as it decomposes at temperature ranges between 250 and 350°C. Hemicellulose accounts for about 25–35 wt% in wood, it degrades between the temperature range of 130 and 260°C. Furthermore, lignin is found in cell wall between hemicellulose, cellulose and components of pectins. It serves as the binding agent in biomass. Lignin resists thermal degradation than either cellulose or hemicelluloses in the plant cell. It decomposes at a temperature range of 290 and 500°C. Content of lignin in a biomass has a typical amount in the range of 30-45 wt%. Moreover, the percentages of these chemical components vary biomass, depending on biomass type [1].

Wood dust biomass is being produced from primary and secondary processing mills (falling and milling). This type of residue (wood dust biomass) is widely used as domestic fuel in many homes in Nigeria due to its high energy content and heating values. However, wood dust is not at best as fuel in this form, but can be greatly enhanced through a thermochemical conversion process such as torrefaction. Conventional bio-coal are produced through torrefaction. Bio-coal produced from wood dust biomass can serve as dependable alternative fossil-sourced fuels, considering its renewability and sustainability.

Bio-coal is a form of torrefied solid material that can be burnt to release energy, which are majorly produced from various types of materials such as wood dust, animal garbage's and agricultural residues. Bo-coals are produced from these materials by exposing them to a pre-treatment process known as Torrefaction.

Torrefaction is known as mild pyrolysis. It is a thermochemical conversion technology that involves the heating of biomass under low or absence of atmospheric oxygen. However, this partially controlled and isothermal pyrolysis of biomass occurs between 200 – 300°C process temperatures [2]. Torrefaction is a conversion process that reduces moisture content and increases calorific value which makes biomass energy higher. Heating of biomass during torrefaction slightly degrades cellulose and majority of the hemicellulose decomposed via deoxygenation, dehydration and dehydrogenation reactions [3]. After torrefaction, a solid uniform product with higher energy content and lower moisture content is achieved, compared to an untreated biomass. The fibre, elemental and proximate analyses of the biomass help reveal the effect of torrefaction on chemical composition and influence on the energy value of the biomass.

2. Materials and Methods

2.1. Materials

Wood dust biomass sample sourced from Ahun (*Alstonia congenisis*) tree was used for this study. The sample was collected from Ajegunle saw mill, along Ondo road in the city of Akure, Nigeria. Sample was sundried for four (4) days. The dried samples were sieved with an analytical sieve (450 μm). Grains in the dimension of 450 microns was separated, labelled and stored for proximate, ultimate, fibre and energy content analyses.

2.2. Methods

2.2.1. Energy Content and Ultimate Analysis

The energy content was performed with bomb calorimeter (e2K combustion calorimeter). The determination was carried out accordance with ASTM D5865-04 [4]. The ultimate analysis of the sample was performed at the University of Kwazulu-Natal, South Africa with an elemental analyzer (varioEL, cube V4.0.16 CHNS Mode, serial no: 19181072. Elementar Analysen systeme GmbH). The oxygen content was determined by difference [100 – (%C+%H+%N+%S)].

2.2.2. Proximate Analysis

The proximate analysis include determination of moisture content (M.C), volatile matter (V.M), ash content (A) and fixed carbon (F.C) of the sample.

Moisture Content Determination

The moisture content of the biomass was evaluated using ASTM D-3173-03 procedure [5], as described by Duranay et al., (2019) [6]. The moisture content was calculated as follows:

$$\%M.C = \frac{(a-b)}{a} \times 100 \qquad (1)$$

Where;

a=weight of the original sample

b=weight of the oven dried sample at 105°C

Volatile Matter Determination

The volatile matter of the samples was determined using ASTM D-3175 method [7] which was also adopted by Nyoman *et al.*, (2018) [8]. The weight loss was calculated with the following equation;

$$\%V.M = \left(\frac{b-c}{a}\right) \times 100 \qquad (2)$$

Where;

a=weight of the original sample

b=weight of the oven dried sample at 105°C

c=weight of the dried sample at 950°C

Ash Content Determination

Determination of ash content of the samples was carried out by adopting ASTM D-3174 standard procedure [9]. The percentage ash of the sample was calculated as follows;

$$\%A = \left(\frac{d}{a}\right) \times 100 \qquad (3)$$

Where;

a = weight of original sample

d = weight of ash

Fixed Carbon Determination

The content of fixed carbon of the biomass sample (untorrefied and torrefied) was estimated by difference as follows;

$$\%F.C = 100 - (\%M.C + \%V.M + \%A) \qquad (4)$$

2.2.3. Fibre Analysis

Fibre components of the wood dust biomass which include lignin, hemicellulose, alpha-cellulose and extractives were determined in accordance with the standard procedures as follows described:

Extractive Content Determination

The extractives content of the biomass was determined by adopting TAPPI-204cm-97 standard method [10].

Three (3) grams of the sample were placed in a clean and contaminant-free extraction thimble of soxhlet extractor. A 1000 ml round bottomed flask was used for the extraction. The flask contained 1:2 solution of ethanol (95%) and toluene mixture and were placed on the heating mantle. The extraction was carried out for 4 h and the extract was transferred into a Buchner funnel to remove excess solvent through suction. Thereafter, the thimble and the sample were washed with ethanol to remove toluene. The extracted sample was re-extracted with 95% ethanol for another 4 h to optimize the extraction process.. After 4 h of extraction, the sample was removed from the thimble and spread out on a flat wooden surface, and allowed to dry in air until free of ethanol. The ethanol-free biomass was transferred into 1 L Erlenmeyer flask and washed successively three times with 500 ml of distilled water to ensure the sample was free of ethanol by heating the flask for 1 hour in a hot water bath at 100°C. After completing the third extraction with water, the sample was filtered in a Buchner funnel and washed with 500 ml of distilled water, it was then oven dried to a constant weight. The extractive content was calculated as follows;

$$Extractive\% = \left(\frac{Wa - Wb}{Wa}\right) \times 100 \qquad (5)$$

Where;

Wa=weight of the original sample

Wb=weight of the extractive-free sample

Lignin Content (Acid insoluble lignin) Determination

The lignin content of the biomass was determined with the sample which had been first extracted with 1:2 Ethanol: Toluene. This procedure is in accordance with TAPPI-222om-02 [11].

One gram of the extractive-free sample was placed in 100 ml beaker, 15 ml sulphuric acid (72%) was added gradually in a small proportion while stirring and macerating the sample with glass rod. After the sample has been thoroughly dispersed, the beaker was kept in a water-bath at room temperature for about 2 h while stirring. At the end of the 2 h, the content was diluted with distilled water to a total volume of 575 ml in a 1 L flask and boiled for 4 h. At the end of the 4 h, the sample was removed and kept overnight in an airtight container. The acid insoluble material (klason lignin) was filtered and the filtrate was kept for the evaluation of acid soluble lignin. The acid insoluble lignin content obtained was washed free of acid with hot water and dried to a constant weight at 105°C in the thermostatically controlled oven. The acid insoluble lignin content was calculated as follows;

$$Klason\ lignin = \left(\frac{Y}{W}\right) \times 100 \qquad (6)$$

Where;

Y= oven dried weight of klason lignin

W= oven dried weight of initial sample

Holocellulose Content Determination

The content of holocellulose was evaluated using Wise method [12].

The holocellulose content was determined from the extractive-free samples. One gram of the extractive-free sample was placed in a clean Erlenmeyer flask and 32 ml of distilled water was added. While it was slowly shaking, 160 ml of 1 M acetic acid were added and the flask was covered with watch glass and boiled at 75°C for 5 h. At every one-hour interval, 4 ml of 1 M NaClO$_2$ was added three times hourly. After cooling, the sample was filtered and washed with hot water and 50 ml acetone until the sample was free of acid. The insoluble portion (holocellulose powder) was dried overnight and was weighed repeatedly until a constant weight was achieved. The holocellulose content which is the insoluble material was calculated with the following expression;

$$\text{Holocellulose\%} = \left(\frac{\text{Wc}}{\text{Wa}}\right) \times 100 \qquad (7)$$

Where;

Wa=weight of the extractive free sample

Wc=weight of the dried insoluble material (holocellulose powder)

Alpha Cellulose

Content Determination

Alpha-cellulose content was evaluated by extraction with 17.5% aqueous sodium hydroxide of the Holocellulose powder [13]. About 25 ml of 17.5% NaOH was added to 0.5 g of the holocellulose powder and it was stirred with glass rod for 30 min. after that, the fibre suspension was diluted with 100 ml of distilled water and filtered. The filtrate was soaked into 15 ml of 10% acetic acid for 5 min. Subsequently, it was washed thoroughly with 100 ml hot distilled water twice and filtered. A constant weight was achieved by drying the insoluble material (α-cellulose) repeatedly at a temperature of 105°C. α-cellulose yield was calculated as the percentage of the original sample;

$$\text{α-cellulose\%} = \left(\frac{\text{Wd}}{\text{Wa}}\right) \times 100 \qquad (8)$$

Where;

Wd = weight of the alpha cellulose

Wa = weight of the original sample

Hemicellulose Content Determination

Hemicelluloses content was calculated by difference between Holocellulose and alpha-cellulose contents as follows:

Hemicellulose (%)=Holocellulose (%)– Alphacellulose (%)   (9)

2.2.4. Torrefaction Pre-treatment Method

The samples were pre-treated through the process of torrefaction as described by Akande *et al*., (2018) [14]. The method was also adopted by Akogun *et al*., (2019) [15].

Torrefaction experiment was carried out using a laboratory-scale torrefier. The fabricated torrefaction equipment used for the treatment consist of an air-tight container, digital thermometer, a temperature sensing probe attached to the thermometer and flame source made of gas cylinder. The prepared laboratory sample was placed in a cylindrical metal container and sealed so as for the experiment to be done under limited amount of oxygen. In the similar manner, the container was placed on the burner attached to gas cylinder for indirect heating of biomass. The temperature was read and controlled by digital thermometer and a burner. Torrefaction experiments were performed at temperature of 200°C. This process was carried out at a residence time of 45 min.
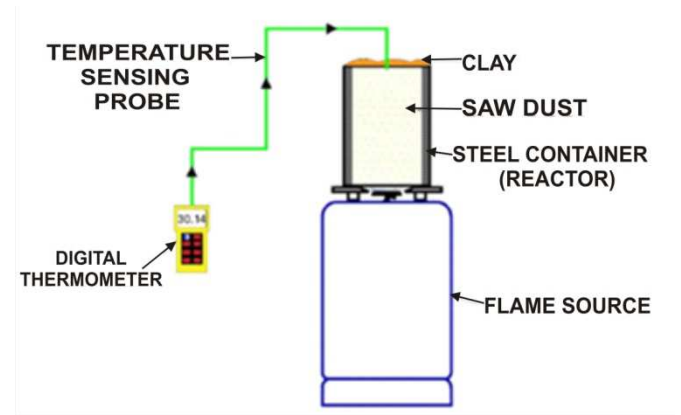

Figure 1. Schematic Diagram of Torrefaction Set-up.

3. Results and Discussion

3.1. Effect of Torrefaction on Energy Content and Proximate Composition of the Sample

The result (Table 1) clearly showed the effect of torrefaction process on the wood dust biomass.

Generally, the energy value of the torrefied wood dust biomass (*Alstonia congenisis*) sample was comparatively higher than its untorrefied counterpart. From the Table, the energy value of 19.58 MJ/kg recorded for the untorrefied sample of *Alstonia congenisis* remarkably increased to 27.28 MJ/kg upon torrefaction at 200°C process temperature. This observation confirmed the efficiency of the torrefaction treatment due to its enhancing effect on the energy value of the biomass. In addition, the increase observed in the energy value of the torrefied biomass could be as a result of the low moisture content of the biomass [16]. The effect of the torrefaction process was also noticed on the proximate composition of the untorrefied and torrefied samples of the wood dust biomass as reported in Table 1. The moisture content of the torrefied sample was significantly lower than that of the untorrefied. For instance, the moisture content of *Alstonia congenisis* which was 22.50% in its raw form was remarkably reduced to 17.50% upon torrefaction at 200°C. This observation was also noticed in the volatile matter composition of the biomass. The volatile matter of *Alstonia congenisis* wood dust biomass was 58% in its raw (untorrefied) form, which decreased to 38% upon torrefaction at 200°C process temperature. This observation implies that this treatment was effective in improving the energy value of the biomass. Furthermore, the ash content of *Alstonia congenisis* wood dust biomass sample was discovered to be 2.00% in its untorrefied form and increased remarkably upon torrefaction to 4.00% at the process temperature of 200°C.

From the Table, 17.50% of fixed carbon was detected in an untorrefied (raw) *Alstonia congenisis* wood dust sample which was increased remarkably to 40.50% upon torrefaction at 200°C. The trend of this result confirmed that high fuel property of any biomass can be achieved through torrefaction thermo-conversion process since the treatment improves the fixed carbon and energy content of the biomass with reduced moisture content. This observation consistently conforms to the report of Sadaka and Negi, (2009) [17].

Table 1. The Effect of Torrefaction on Energy Value and Proximate Composition of the Sample.

Sample	%M.C	%V.M	%Ash	%F.C	Energy Value (MJ/kg)
Untorrefied *Alstonia congenisis* sample	22.50	58.00	2.00	17.50	19.58
Torrefied *Alstonia congenisis* sample	17.50	38.00	4.00	40.50	27.28

3.2. Effect of Torrefaction on the Fibre Composition of Sample

Table 2 shows the effect of torrefaction on the fibre composition of the biomass samples sourced from Ahun (*Alstonia congenisis*) tree. The Table depicts the fibre composition of both the untorrefied and torrefied samples at process temperature of 200°C. The Lignin content was discovered to increase to 64% after torrefaction which was initially 30% in its raw form. The same trend was also observed in cellulose content of the biomass sample, 39% was detected in the biomass before treatment which was later increased to 40% upon torrefaction.

Due to the increase in lignin content, this result showed that torrefaction treatment process increases the binding property of the biomass which will immensely improve its pelletability [18]. However, hemicelluloses, extractives and holocellulose which were 28%, 10.50% and 67% respectively in their raw forms decreased to 24%, 8.50% and 64% respectively after torrefaction. This implies that the fuel properties of any biomass can be enhanced through the process of torrefaction [18].

Table 2. The effect of Torrefaction on fibre composition.

Sample	%cellulose	%lignin	%hemicellulose	%extractive	%holocellulose
Untorrefied *Alstonia congenisis* sample	39.00	30.00	28.00	10.50	67.00
Torrefied *Alstonia congenisis* sample	40.00	64.00	24.00	8.50	64.00

3.3. Effect of Torrefaction on the Elemental Composition of Sample

Table 3 shows the result of ultimate analysis of the untorrefied and torrefied wood dust biomass sourced from *Astonia congenisis* tree. The carbon content of the *Astonia congenisis* wood dust biomass sample which was 46.31% was discovered to increased to 62.10% upon torrefaction at a process temperature of 200°C. Hydrogen content of the torrefied sample was reduced to 5.37% after torrefaction which was 6.38% in its raw (untorrefied) form. This observation was also detected in the oxygen content of the biomass sample. The oxygen content of *Astonia congenisis* wood dust biomass sample was 46.91% in its raw form but decreased noticeably to 31.90% when subjected to torrefaction at process of temperature of 200°C. As shown in the table, sulphur content of the torrefied sample decreased compared to the percentage in its raw form. However, nitrogen content of the sample which was 0.35% in its raw form increased drastically to 0.62% upon torrefaction at 200°C process temperature. However, this observation shows that torrefaction process increases the carbon content of biomass while decreases the content of oxygen and hydrogen. The implication of this is that torrefaction as a treatment method was effective in enhancing the high heating value of the biomass by increasing its carbon content. Moreover, an increase in carbon content confirmed the high energy value of the biomass which will greatly enhanced its fuel properties [19].

Table 3. The Effect of Torrefaction on Elemental Composition of Sample.

Sample	%C	%H	%N	%S	%O
Untorrefied *Alstonia congenisis* sample	46.31	6.38	0.35	0.05	46.91
Torrefied *Alstonia congenisis* sample	62.10	5.37	0.62	0.008	31.90

4. Conclusion

Torrefaction is one of the promising thermo-conversion processes with high positive influence on the fuel property of biomass for solid fuel production. Energy value is a tangible factor for determining the fuel with high quality. Therefore, high energy value of the biomass upon torrefaction is an indication for the production of high quality solid fuel. However, moisture content of the torrefied sample was low

compared to its untorrefied form which possessed high amount of moisture content, the poor fuel property of the biomass is attributed to the amount of water content in the biomass; high moisture content in a biomass reduces its calorific value, hence reduces the fuel property of the biomass. The result of fixed carbon obtained from torrefied and untorrefied sample also influenced the high energy content recorded in the biomass.

Furthermore, lignin as a binding agent is a major contributor to biomass pelletability. It was detected that torrefaction increases the percentage lignin of the biomass which implies that binding property of any biomass can be enhanced through torrefaction pre-treatment method. Ultimate composition shows that high amount of water molecule can be lost as torrefaction reduce the percentage of hydrogen and oxygen content of the biomass. An increase in carbon content of biomass upon torrefaction signifies high energy content of the biomass which consequently improves the fuel property of the biomass.

Conclusively, this research findings show that forest residues considered as wastes and pollutants can be resourcefully harnessed through torrefaction pre-treatment method for the production of solid fuel such as bio-coal that can provide cheaper, cleaner and sustainable fuels both for domestic and industrial energy consumption in the nation.

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