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# Chemical, Ultimate and Proximate Analyses of Mixed Wood Sawdust from Igbinedion Sawmill, Okada, Edo State

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**ABSTRACT:** Sawdust, also known as wood dust, is a significant by-product of the wood processing industry. While it has the potential to cause environmental pollution, it also holds practical value. In the context of modern interest, sawdust, as a form of biomass, can be converted into clean fuels, thereby mitigating environmental pollution. Its utilization as a feed in thermochemical processes not only addresses waste management concerns but also contributes to the improvement of the country's energy-mix. The characteristics of the biomass play a crucial role in its conversion into bio-energy. Through biomass analyses, we can enhance our understanding of the economic and environmental implications of the biomass conversion process. Proximate analysis reveals moisture, ash, volatile matter, and fixed carbon contents of 6.93%, 2.03%, 38.5%, and 52.54% by weight, respectively. Ultimate analysis indicates carbon, oxygen, nitrogen, hydrogen, and sulfur contents of 61.5%, 29.52%, 0.67%, 7.68%, and 0.63% by weight, respectively. Furthermore, chemical analysis demonstrates cellulose, hemicellulose, and lignin contents of 68.7%, 27.3%, and 4.0% by weight, respectively.

**Keywords**: Biomass, energy, environment, sawdust, thermochemical process
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## INTRODUCTION

Existing global supply of energy depends on non-renewable fuels such as crude oil, gas and coal formed naturally beneath the earth's crust. However, the amount of fossil fuel is depleting fast due to the growing population of the world; the consumption of energy per capita also, is increasing rapidly. Thus, the necessity for finding alternative sources of energy is evident. In addition, the use of petroleum fuel affects the environment by generating large amounts of carbon dioxide ($CO_2$) emission and other pollutants such as nitrogen oxides ($NO_X$) and sulphur oxides ($SO_X$) (Hu & Gholizadeh, 2019). Biomass meets such requirement, because biomass is carbon-neutral and its use produces less $SO_X$ and $NO_X$, due to its much lower content of nitrogen and sulphur. Biomass has proven to be an important option for several applications including energy and chemicals production, because it is economically viable and environmentally acceptable. For thermochemical conversions (like gasification, pyrolysis and torrefaction), chemical (polymeric) parameters, proximate parameters and ultimate (elemental) parameters are used to evaluate its suitability as feedstock in biomass pyrolysis. Biomass is an organic matter derived from living things. They include wood, forest residue, waste from food crops, horticulture, food processing, animal farming and processing, sewage among others. Biomass can be changed into a clean fuel by a variety of technologies. In addition to producing clean fuels, these technologies can lead to significant reductions in the total amount of biomass waste requiring final disposal which can be better managed by safe controlled disposal while meeting pollution control standards. Sawdust (or wood dust) is a by-product in the wood processing industries.

Sawdust can cause environmental pollution concern, though it is not without practical uses (Onochie, Orhorhoro, & Oyiboruona, 2018), such as producing fuel briquettes or pellets for cooking and other heating purposes. It is also used to make particle board and for wood pulp. For modern interest, biomass (sawdust) is converted to clean fuels which curbs environmental pollution. Its possible use as feed in thermochemical process solves waste management concerns and simultaneously improves the country's energy-mix. In the literature (Vuppaladadiyam, Memon, Raheem, Dupont, & Zhao, 2019; Ali, Saif, & Wahid, 2020) the values for these parameters vary (probably due to the source and type of the sawdust). The sawdust at a saw mill is mixed-wood sawdust, and it is the most abundant form of sawdust. The phrase "*mixed-wood*" which qualifies this type of sawdust needs brief explanation. The operations at a saw mill include splitting logs of wood into smaller pieces and planning a piece of wood to a desired shape or size. These operations produce sawdust, as by-product. But a saw mill processes wood from a variety of trees, so the sawdust at a saw mill is mixed (not by conscious design but as a consequence of its mode of operation).

Cellulose, hemicelluloses and lignin are the three main components of lignocellulosic biomass (to which mixed wood sawdust belongs). Furthermore, biomass also contains other organic compounds, called extractives (which are non-structural compounds), including paraffin, fat, resin, tannin, starch, pigments, etc. (Chen, Liu, & Yang, 2012). There are also a number of inorganic metal salts, consisting mainly of alkali and alkaline earth metals. The physical and chemical properties of biomass are closely related to the composition and relative content of cellulose, hemicellulose and lignin, as well as extractives and inorganic salts. Cellulose is a linear polysaccharide (that is, a complex carbohydrate), consisting of 3000 or more glucose unit linked together by β (1→4) glucosidic bonds. Hemicelluloses are branched heterpolymers with monomers units that include pentose (arabinose and xylose), hexose (glucose, galactose, mannose, rhamnose and fructose) and uronic acids (galacturonic, glucuronic and methylglucuronic) (Partiama, 2018; Cheng, 2010). Lignins are amorphous, complex, aromatic polymers of phenylpropane units (Rowell, 2005). The building blocks of lignin biosynthesis are p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol. Extractives are a group of low-molecular-weight organic compounds that do not constitute cell walls or layers (Wang & Luo, 2017). The inorganic content of a wood is usually referred to as its ash content, which is an approximate measure of mineral salts and other inorganic matter in the ash of biomass, whose content and composition vary with the type of biomass. The characteristics of the biomass affect the conversion of biomass into bio-energy. It is important to know the characteristics of biomass, to maximize its value in the bio-energy field. Biomass analyses results can improve our understanding of the economics and environmental impact of biomass conversion processes. Proximate analysis gives the gross composition of lignocellulosic biomass in terms of gross components, namely, moisture content (MC), volatile matter (VM), ash (ASH) and fixed carbon (FC) (Basu, 2013). The ultimate analysis of biomass gives the basic elements present in the organic component of the biomass in terms of carbon (C), oxygen (O), hydrogen (H), nitrogen (N) and sulphur (S) (Basu, 2013). (Ash content may also be determined.) With the percentages of carbon, hydrogen and oxygen in a biomass we can calculate the hydrogen-to-carbon (H/C) ratio and oxygen-to-carbon (O/C) ratio. These atomic ratios help us understand the heating value of the biomass. Chemical analysis (also called polymeric analysis) gives the percentages (or fractions) of extractives, cellulose, hemicelluloses and lignin in a biomass sample (Basu, 2013). The behaviour of a biomass during pyrolysis can be predicted using knowledge of the ratios (cellulose-to-lignin and hemicellulose-to-lignin) of the lignocellulose biomass components. The aim of the to characterize the mixed wood sawdust.

## MATERIALS AND METHODS

The sawdust was taken from Igbinedion Sawmill Okada, Edo State using a 10kg bag. The collected sawdust was sun-dried by spreading it on a nylon sheet 7 hours a day, for 5 days. This procedure exposes the sawdust to air and sun to remove moisture. 1kg of the sundried was ground and sieved through a 500μm sieve. Samples of the fine sawdust powder were then analysed following approved methods (methods of the American Society for Testing and Materials (ASTM), the International Organization for Standard (ISO) and others) for its physiochemical characteristics.

### Proximate analysis procedure

The following procedures have been performed on the samples for proximate analysis. These procedures are as given in Basu (2013).

### Moisture content

Moisture content was determined in an air-tight oven. A quantity of the powdered sample was placed in an evaporating dish and was subjected to a temperature of 105 − 110˚C for 3 hours in the absence of air, until a constant weight was attained. The weight percent of moisture content (MC) was estimated thus:

$$MC = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

Where $M_i$ is the initial mass and $M_f$ is the final mass.

**Volatile matter content**

Volatile matter is the material that is driven off when biomass is heated to a high temperature in the absence of air under specified conditions. A quantity of powdered sample of the sawdust was weighed and covered in a 50 ml platinum crucible. The sample was subjected to a temperature of 500˚C in a muffle furnace for 7 minutes. The weight percent of volatile matter (VM) content was estimated thus,

$$VM = \frac{M_i - M_f}{M_i} \times 100 \quad (2)$$

Where $M_f$ is the mass after volatile matter is removed, and $M_i$ is the initial mass of sample.

**Ash content**

A quantity of powdered sample was weighed into a platinum crucible and subjected to a temperature of 600˚C in a muffle furnace for about 2 hours. The furnace was then switched off and the sample was left inside for about 60 minutes for the temperature to drop, it was then removed and placed in a desiccator where the temperature was allowed to drop to ambient temperature. The weight percent of ash content (ASH) was estimated thus:

$$ASH = \frac{Mass\ of\ Ash}{Mass\ of\ Sample} \times 100\ , \quad (3)$$

**Fixed carbon content**

The fixed carbon content of a sample is the carbon found in the sample after volatile materials are driven off. This differs from the ultimate (or total) carbon content of a sample because some carbon is lost in hydrocarbons with the volatiles. The weight percent of fixed carbon content (FC) was estimated thus:

$$FC = 100 - (MC + VM + ASH)\ , \quad (4)$$

where *MC* is the moisture content, *VM* is the volatile matter and *ASH* is the ash content, in weight percents. After the weight percent of fixed carbon content has been calculated, it is necessary to cross check the sum of *ASH, FC, MC* and *VM* if it will total 100.

**Ultimate analysis procedure**

The following procedures have been performed on the sample for ultimate analysis. These procedures are as given in Onochie et al., (2017).

**Hydrogen content**

A quantity of powdered sample was measured, put into a 100 ml evaporating dish, placed in an air-tight oven and heated. The weight of moisture driven off was noted. The weight percent of hydrogen content was estimated thus,

$$Hydrogen\ \ content = \frac{weight\ of\ H_2O \times 0.1111 \times 100}{mass\ of\ sample} \quad (5)$$

**Nitrogen content**

Nitrogen content was determined by Kjeldahi method. A quantity of powdered sample was measured and turned into a 250 ml conical flask and 5 g of copper (II) sulphate ($CuSO_4$) added as catalyst with 20 ml of hydrogen (II) tetraoxosulphate (VI) acid ($H_2SO_4$). The mixture was swirled gently, placed on a hot plate and warmed for several minutes until a clear solution was obtained. It was cooled and diluted with 100 ml of distilled water. The content was stirred with a glass rod and transferred into a 500 ml flat bottom flask and connected to a distillation unit and a conical flask containing 25 ml of 4 % boric acid solution was attached to the condenser outlet. 50 ml of 40 % sodium hydroxide (NaOH) was carefully dispensed into the flask containing the sample and distillation was carried out for 10 minutes. The ammonium borate solution formed was titrated with 0.1 M of hydrochloric (HCl) acid solution to get a purplish-grey end point using methyl red indicator. The weight percent of nitrogen content was estimated thus:

$$Nitogen\ content = \frac{(S - B) \times N \times 1.4007}{w}, \quad (6)$$

where *N* is the normality of acid, *S* is the titre value of sample, *B* is the titre value of blank, and *w* is the mass of sample digested.

**Sulphur content**

6 ml of bromine water was added to a quantity of the sample in a 500 ml capped beaker. After 10 minutes of heating, 15 cc of concentrated nitric acid was added. The mixture was heated slowly and then boiled to remove bromine and nitric acid after the strong reaction. After adding 2.5 g of sodium chloride (NaCl) to prevent sulphuric acid loss, the mixture was evaporated to half its content. Evaporation was repeated three times; after each evaporation 5 ml of strong hydrochloric (HCl) acid was added, allowed to dry and heated gradually. The residue was taken up with 5 ml of weak hydrochloric acid and 10 ml of water, and the insoluble residue was filtered using a Whatman filter and washed on filter paper with hot water. In a 500 ml volumetric flask, the filtrate was

diluted and mixed. 100 ml of aliquot was measured and poured into a beaker, heated to boiling point, then 100 ml of barium chloride ($BaCl_2$) solution was added drop-by-drop with steady stirring. After stirring, the solution was filtered and calcined at 700˚C in a crucible with a muffle furnace. The residue (barium sulphate, $BaSO_4$) was washed clean of chlorides with boiling water, dried and weighed. The weight percent of sulphur content was estimated thus,

$$Sulphur\ content = \frac{0.1374 \times M_1}{M} \times 100\,, \qquad (7)$$

where $M_1$ is the mass of barium sulphate insoluble residue, and $M$ is the initial mass of the sample.

**Carbon content**

Carbonisation method was used to determine the carbon content of the powdered sample. A quantity of powdered sample was weighed and turned into a 100 ml crucible and placed into a muffle furnace set to heat at 400˚C and allowed to carbonize for 60 minutes. The crucible was placed in a desiccator until the temperature reduced to ambient temperature. Then the mass of the residue was weighed and recorded. The weight percent of carbon content was estimated thus;

$$Carbon\ content = \frac{M_s - M_c}{M_s} \times 100 \qquad (8)$$

where $M_s$ is the initial mass and $M_c$ is the final mass.

**Oxygen content**

Oxygen content was estimated by difference using the equation:

$$Oxygen\ content = 100 - (C + H + N + S + ASH) \qquad (9)$$

where $C$ is the carbon content, $H$ is the hydrogen content, $N$ is the nitrogen content, $S$ is the sulphur content, and $ASH$ is the ash content in weight percents. After the percentage of the oxygen has been calculated, it is necessary to check that the sum of *ASH, C, H, N, O* and *S* is 100.

**Chemical analysis procedure**

The following procedure has been performed on the sample for chemical analysis. The procedure is as given in Carrier et al., (2011). To remove the hemicellulose content, a quantity of mixed wood sawdust sample was heated at 100˚C with 500ml of 0.5M sodium hydroxide (NaOH) solution for 2 hours and the residue which is the cellulose and lignin content were filtered and washed with plenty amount of distilled water until pH 7 was obtained. The residue was dried in an oven at 105˚C to completely remove water and weighed. The mass of hemicelluloses is obtained by difference. The lignin content was removed from the dried residue by boiling the residue in 250ml 0.1M tetraoxosulphate (VI) solution ($H_2SO_4$) for 2 hours under reflux and allowed to remain soaked for 24 hours at ambient temperature. The un-dissolved residue (cellulose) was washed with plenty amount of water until pH 7 was attained. The residue was dried at 90˚C for 4 hours, cooled in a desiccator and weighed. The mass of lignin is obtained by difference. The mass of cellulose was estimated thus:

$$C_m = B_m - H_m - L_m \qquad (10)$$

where $C_m$ is the mass of cellulose, $B_m$ is the mass of biomass, $L_m$ is the mass of lignin, and $H_m$ is the mass of hemicellulose. The masses of hemicellulose and lignin were estimated, sequentially, by weight difference.

## RESULTS AND DISCUSSION

**Proximate analysis**

Proximate analysis is used to explore fuel quality and is a good indicator of the burning and heating properties of solid biomass (Varma & Mondal, 2016). The proximate analysis of the mixed wood sawdust sample is shown in (Table 1). Elehinafe, Okedere, Odunlami, Mamudu, & Bamidele (2019) report the result on proximate analysis of a hundred Nigerian woods. Their study gives the range for values of ash, moisture, fixed carbon and volatile matter to be 0.08 – 5.09, 7.92 – 15.96, 77.51 – 93.59 and 9.58 – 18.44, wt %, respectively. A significant observation from their report is that for all the 100 Nigerian woods they studied, the weight percent of fixed carbon is greater than that of volatile matter. The proximate analysis results in our study also demonstrate this characteristic. Furthermore, our ash content (2.03 wt %) and moisture content (6.93 wt %) fall within the range reported by Elehinafe et al. (2019).

However, it is important to mention that the observation of the weight percent of fixed carbon being greater than that of volatile matter may be a feature of Nigerian woods, only. Sharma and Mohanty (2021) working in India report proximate analysis data of mango (*Mangifera indica*) wood with the weight percent of the fixed carbon less than that of volatile matter, while for the same wood Elehinafe et al. (2019) report the opposite. The above observations are summarized in (Table 1).

The mixed wood sawdust sample shows high volatile matter content (38.50 wt %), which indicates the suitability of sawdust to be devolatilized and to give high bio-oil yield (Ali et al., 2020). Volatile matter represents

**Table** 1: Proximate analysis of mixed wood sawdust.

| ASH | MC | FC | VM |
|---|---|---|---|
| 2.03 | 6.93 | 52.54 | 38.50 |

the constituents of hydrogen, oxygen and carbon present in a solid biomass that when heated changes to vapour, usually a mixture of hydrocarbons (Chaney, 2010). Volatile matter content affects the thermal characteristic of solid fuels (Van & Koppejan, 2008) and influences the structure and bond within the solid fuel. Ash content of 2.03 wt % is low, and this is favourable for pyrolysis process. Low ash content in biomass favours thermochemical conversion processes and reduces slag formation problems, fouling and corrosion in pyrolysis reactors (Ali et al., 2020; Czajczynska, Anguilano, Ghazal, Krzyzynska, Jouhara, 2017).

Moisture content of 6.93 wt % is low, and within the range of 7.92-15.96 wt % reported by Elehinafe et al. (2019). Aina, Adetogun, & Iyiola (2009) reports that low moisture content implies a high calorific value, which is a major parameter that determines solid bio-fuel quality. Moisture content affects the internal temperature history and total energy that is needed to bring the solid up to the pyrolytic temperature (Zaror & Pyle, 1982). Low moisture content means that water in biomass can be removed with small energy expenditure during a thermochemical process.

The fixed carbon content of 52.54 wt %, is high compared to that of some (Nigerian) coal species which range between 20.0 − 46.3 wt% (Ugwu, 2012; Obernberger, Brunner, & Barnthaler, 2018). The fixed carbon content of a fuel is the percentage of carbon available for char formation (Elehinafe et al., 2019). From this study, we can say that the mixed wood sawdust sample stores chemical energy more in form of fixed carbon than volatile matter. The value for fixed carbon gives a rough estimate of the heating value of fuel. Also, fuels of with high fixed carbon content are more reactive and much easier to ignite and burn (Lewandowski & Kicherer, 2010).

## Ultimate analysis

The ultimate analysis of the mixed wood sawdust sample is shown in (Table 2). It is observed that the values are of same order of magnitude, though our value for elemental carbon (61.5%) is slightly higher (which is consistent with the high fixed carbon content). The results show that nitrogen (0.67 wt %) and suslphur (0.63 wt %) contents are low. So, the mixed wood sawdust sample contains low amount of sulphur oxides ($SO_X$) and nitrogen oxides ($NO_X$) which corresponds to low pollutant effect of the biomass (Ali et al., 2020). Though our biomass sample is mixed wood sawdust, we include an empirical formula for it. To do this we calculate the atomic ratios H/C, O/C, and N/C using ultimate analysis data, obtaining approximately 0.494, 0.078, and 0.011, respectively, for O/C, H/C, and N/C. Thus, the empirical formula for our mixed wood sawdust may be written as $CH_{0.078}O_{0.494}N_{0.011}$.

**Table** 2: Ultimate analysis of mixed wood sawdust.

| C | H | N | S | O |
|---|---|---|---|---|
| 61.5 | 4.80 | 0.67 | 0.63 | 30.37 |

## Chemical analysis

The chemical analysis result of the mixed wood sawdust sample is shown in (Table 3). The result from this study replicates the common trend in the relative values, in wt %, of various lignocellulosic components: cellulose > hemicelluloses > lignin (Vuppaladadiyam et al., 2019; Guida et al., 2019; Sharma & Mohanty, 2021). The result from this study show a slightly higher amount of cellulose and a much lower amount of lignin, compared to published results in the literature (though, it should be remembered that this study used mixed wood sawdust). Ordinarily, one expects the extractives fraction to be included in the result. Guida et al. (2019) and Zanzi (2001) report a similar polymeric components distribution (with nil for extractives).

**Table** 3: Chemical analysis of mixed wood sawdust.

| Hemicelluloses | Lignin | Cellulose | Extractive |
|---|---|---|---|
| 27.3 | 4.0 | 68.7 | - |

## Conclusion

The mixed wood sawdust sample has cellulose, hemicellulose and lignin weight percents 68.7, 27.3 and 4.0, respectively. The weight percents of carbon, hydrogen, oxygen, nitrogen and sulphur are, respectively, 61.5, 7.68, 29.52, 0.67 and 0.63. While its ash content, fixed carbon, moisture content and volatile matter content are, respectively, 2.03, 52.54, 6.93 and 38.5 weight percents. The mixed wood sawdust sample has fixed carbon content greater than its volatile matter content. This finding corroborates the result on the 100 Nigerian woods, and seems to be a feature peculiar to Nigerian woods. Overall, one can conclude that the mixed wood sawdust sample from Igbinedion Sawmill, Okada, is can be used a as feedstock in biomass pyrolysis. Though, it seems that this feedstock will yield more bio-char than bio-oil (the desired product in pyrolysis). Note that fixed carbon content is greater than volatile matter content in this mixed wood sawdust sample. Thus, the mixed wood sawdust from Igbinedion Sawmill, Okada, should be more appropriate as feedstock in torrefaction (where bio-char is the desired product) or, better still, as raw material for

producing sawdust briquettes.

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