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Modelling and simulation of mixed sawdust pyrolysis using Aspen Plus® software

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ABSTRACT

Aspen Plus® modelling and simulation of mixed wood sawdust pyrolysis has been reported. This study evaluates the suitability of mixed wood sawdust for biomass pyrolysis. Physiochemical analyses of the sawdust sample were determined in the Aspen Plus® equilibrium model of mixed wood sawdust pyrolysis. Proximate analysis of moisture, ash, volatile matter and fixed carbon contents were 6.93, 2.03, 38.5, and 52.54 wt %, respectively while ultimate analysis of carbon, oxygen, nitrogen, hydrogen and sulfur contents were 61.5, 29.52, 0.67, 7.68, and 0.63 wt %, respectively. Cellulose, hemicellulose, and lignin contents were 68.7, 27.3, and 4.0 wt %, respectively. The study reports predicted sample yields of 56.94, 30.77, and 12.29 wt % for bio-char, bio-oil, and biogas, respectively, at 500 °C and at 1 atm. In the sawdust, fixed carbon content was higher than that of volatile matter. Hypothetical biomass decomposition components used in the Aspen Plus® equilibrium model of mixed wood sawdust pyrolysis influence the predicted pyrolysis products yield.

Keywords: Aspen Plus®, modelling, simulation, wood sawdust, pyrolysis

INTRODUCTION

Today, the largest contribution of the world's energy supply is attributed to fossil fuels (Armaroli & Balzani, 2007). The use of fossil fuels raises the questions of continued availability, emission of greenhouse gases and climatic change. These concerns encourage the replacement of fossil fuels with renewable energy sources. Among the alternative energy sources, biomass is considered as one of the most promising source with a potential to replace fossil fuels and meet green and clean energy requirements (Saleem, 2022).

Biomass pyrolysis is a thermal decomposition process that converts lignocellulosic biomass into bio-oil, bio-char and biogas (Dalal et al., 2022). The pyrolysis process is a complex phenomenon involving several chemical reactions, including drying, devolatilization and char decomposition.

Cellulose, hemicelluloses and lignin are the three main components of lignocellulosic biomass (to which mixed wood sawdust belongs). Biomass also contains other organic compounds, called extractives (which are non-structural compounds), including paraffin, fat, resin, tannin, starch, pigments, etc. (Chen et al., 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 3,000 or more glucose unit linked together by β (1→4) glucosidic bonds (Butnariu & Flavius, 2022). 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) (Bajpai, 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 (Anwar et al., 2014). Proximate analysis gives the gross composition of lignocellulosic biomass in terms of gross components, namely, moisture content (MC), volatile matter, ash, and fixed carbon. The ultimate analysis of biomass gives the basic elements present in the organic component of the biomass in terms of carbon, oxygen, hydrogen, nitrogen and sulphur. It is possible to calculate the hydrogen-to-carbon (H/C) ratio and oxygen-to-carbon (O/C) ratio with the percentages of carbon, hydrogen and oxygen in a biomass. These atomic ratios help us understand the heating value of the biomass. Chemical analysis gives the percentages of extractives, cellulose, hemicelluloses and lignin in a biomass sample. The behavior 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 (Pielsticker et al., 2021).

Based on the heating rate, pyrolysis may be classified as slow, intermediate or rapid (which includes fast and flash) pyrolysis (Basu, 2013). In slow pyrolysis, biomass is pyrolyzed at about 400 °C, with a heating rate of 0.1-1.0 °C/s. In fast pyrolysis, the residence time is about 1-2 s, and the pyrolysis temperature is about 500 °C. Flash pyrolysis involves very rapid heating rate which can vary from 1,000-10,000 °C/s and the pyrolysis temperature is below 650 °C (Kabir et al., 2022).

This study aims at developing an Aspen Plus® equilibrium model of mixed wood sawdust pyrolysis and use the model to predict the pyrolysis products yield and investigate the sensitivity of the model to the components list including hypothetical biomass decomposition components used in the simulation.

MATERIALS AND METHODS

Collection and Preparation

The sawdust was taken from Igbinedion Sawmill Okada, Edo State using a 10 kg 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 loose moisture. 1 kg of the sundried was ground and sieved through a 500 µm sieve. Samples of the fine sawdust powder were then analyzed following approved methods 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

MC 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.

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.

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.

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.

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.

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.

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/g 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 HCl acid was added, allowed to dry and heated gradually. The residue was taken up with 5 ml of weak HCl 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

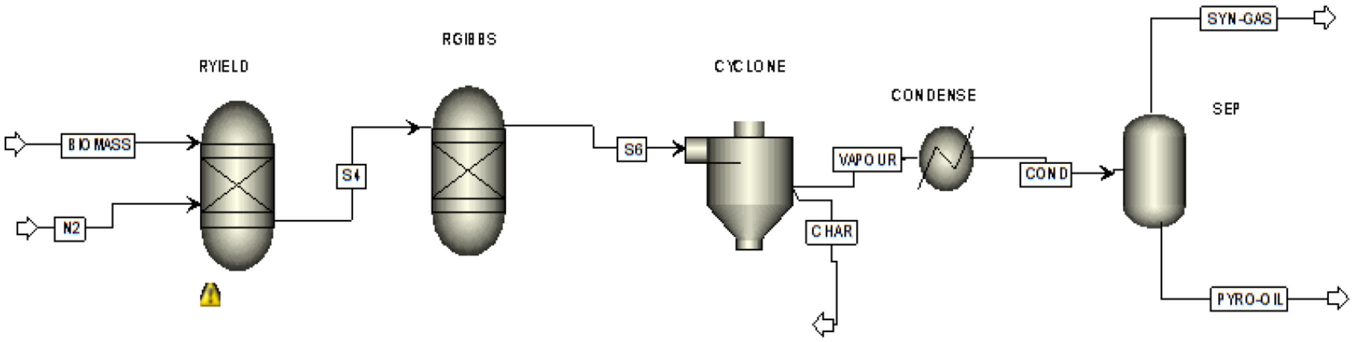

Figure 1. Flowchart of Aspen Plus® model of MWSD pyrolysis (Source: Authors' own elaboration)

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.

Carbon content

Carbonization 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.

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 sawdust sample was heated at 100 °C with 500 ml of 0.5 M NaOH solution for 2 hours and the residue which is the cellulose and lignin content was 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 250 ml 0.1 M hydrogen (II) 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.

To open Aspen Plus® simulation software interface, we click the WINDOWS START button, go to PROGRAMS and select Aspen Plus® icon (we used Aspen Plus® version 11 for this study). After the application opens, we click on NEW, then choose BLANK SIMULATION, and click on CREATE. This takes us to the simulation interface, which begins with the components specification window.

Creating a new Aspen Plus® simulation model consist of the following steps: inserting components and specifying components type; selecting property method; go to simulation; inserting unit operation blocks; connecting material streams; specification of stream class; defining feed streams; and specifying unit operations blocks. Upon going through the above steps correctly we obtain a process flowchart with all required input data completed, ready for test run (**Figure 1**) (Chaves et al., 2016; Jana, 2009).

Components specification window

All the chemical material components needed for a process simulation are inserted in the components specification window. The components may include saturated aliphatic hydrocarbons C_1-C_{25}, phenol, nitrogen, elemental carbon, hydrogen sulphide, biomass, ash, cellulose, hemicellulose, and lignin.

Cellulose, hemicellulose, and lignin are (hypothetical) decomposition products of biomass. Cellulose is represented as xylose ($C_6H_{10}O_5$), hemicellulose as xylan ($C_5H_8O_4$) and lignin (though a complex polymer) is simply represented as phenyl propane (C_9H_{10}).

Ash, biomass (sawdust) and elemental carbon are solids. Aspen Plus® differentiates between three types of solids. Pure solids (and other pure components) with molecular weight are called conventional components. Conventional components participate in both phase and chemical equilibrium. If a pure solid participates in only chemical equilibrium (but not in phase equilibrium) it is called conventional inert solid (CISOLID). If a solid (mixture) is not involved in either phase or chemical equilibrium, it is called non-conventional (NC). Ash and sawdust are NC, while elemental carbon is set as SOLID.

Multi-component solid materials (or solid mixtures) lack a molecular weight and are categorized NC. NC components are defined by specifying their elemental, proximate and sulphur analyses data, which are used to calculate the density and enthalpy of the NC component (Fonseca, 2023; Sinnott & Towler, 2009).

Methods specification window

The methods specification window allows one to choose an equation of state for a simulation model. For estimating the physical properties of the conventional components, the Peng-Robinson with Boston-Mathias (PR-BM) alpha function equation of state is used, as recommended by Aspen Technology Incorporated (2010). Alpha is a temperature dependent parameter that improves the pure component vapor pressure correlation at very high temperature (Altayeb, 2015).

Table 1. Summary of physiochemical analyses of sample (in wt %)

Proximate analysis	Ultimate analysis	Chemical analysis
MC 6.93	C 61.5	Cellulose 68.7
VM 38.50	H 4.80	Hemicellulose 27.3
AC 2.03	N 0.67	Lignin 4.0
FC 52.54	S 0.63	Extractives
	O 30.37	

Note. HHV ≈ 25.58 MJ/kg & LHV ≈ 24.53 MJ/kg

Process flowchart window

After methods specification, by clicking on the go to simulation tab we get to an empty window where the process flowchart of a simulation will be drawn. First, using the unit operations platte we select unit operation blocks and paste on the flowchart window. For this work we used RYield reactor, RGibbs reactor, SSplit block (as cyclone), heat exchanger HX (as condenser) and Flash 2 (as separator). Next, by clicking on each selected unit operation block we connect all the material streams that serve as input streams, output streams, and inter-block connecting streams. Then, the unit operation blocks, and the input and output streams are re-named.

Stream Class Specification

Here we select the global stream class as MIXCINC. This selection informs the simulation model that there are conventional components, conventional inert solids and NC components (or that the components are MIXED). The only physical properties calculated for NC components are density and enthalpy. Hence we select HCOALGEN method for enthalpy and DCOALIGT method for density calculations.

Defining feed streams

To tell the simulation model what a feed (or input) stream carriers we double-click on the stream. This opens a window where we insert data (thermodynamic condition, flow rate, composition, etc.) on the feed material. First, we choose the feed component type, as stated in the components specification. For the biomass stream we choose NC, while for the nitrogen stream we choose MIXED (which caters for conventional components). In either instance, a menu opens into which we insert feed temperature (30 ˚C), pressure (1 atm) and flow rate (100 kg/hr, for biomass). Also, we choose mass-fraction for the feed stream composition; for biomass with the NC selection, we write 1 for biomass (and ignore all other components that may appear). Then we write the component attributes, namely, data on elemental, proximate and sulphur analyses, one after the other (here we use primary data, see **Table 1**).

Afterwards, for the nitrogen feed stream we write feed temperature (30 °C), pressure (1 atm) and flow rate (0.1 kmol/hr). We choose mass-fraction for stream composition. For nitrogen with MIXED selection, we write 1 for nitrogen (and ignore all other components that may appear).

Specifying unit operation blocks

For each unit operation block on a process flowchart we specify its operating conditions (thermodynamic conditions, chemical reactions, etc.). At the core of a pyrolysis process is the pyrolizer. For reaction-based process modelling Aspen Plus® provides three categories of reactor models, namely; those based on material and/or energy balance (RStoic and RYield); those based on thermodynamic equilibrium (REquil and RGibbs); those based on reaction kinetics (RCSTR, RPlug, RBatch, and FBR). Reactor models based on balance, use material and energy balance to calculate the output of the reactor. The equilibrium reactor models calculate chemical and/or phase equilibrium and stoichiometric equations. Reaction kinetic reactor models require detailed reaction kinetic information for their calculations.

Here a pyrolizer is modelled by combining RYield and RGibbs reactor blocks. We assume that a hypothetical decomposition of biomass into its lignocellulosic components (cellulose, hemicellulose, and lignin) and/or its elemental components (C, H, O, N, and S) and ASH occurs in RYield. These components flow to RGibbs were the products of the pyrolysis process are obtained.

We double-click on the RYield block on the process flowchart to specify its operating conditions. Under SPECIFICATION tab we specify the temperature (500 °C), pressure (1 atm) and valid phases (vapor-liquid). Under the YIELD tab we choose valid option (component yield) and in the component yields we insert the mass-fractions of chemical data (i.e., cellulose, hemicellulose, and lignin) and/or elemental data (C, H, N, O, and S) and ASH. Then specify inert component (nitrogen, if not using elemental data). Also, we introduce the “ASH” in the components attribute tab of RYield, specifying sub-stream ID (NC), component ID (ASH); and attribute ID (PROXANAL ASH 100, ULTANAL ASH 100).

We double-click on the RGibbs block to specify its operating conditions. We specify the calculation option (calculate phase equilibrium and chemical equilibrium), Temperature (500 °C), pressure (1 atm), tick (merge all CISOLID species into the first CISOLD sub-stream), and write the non-reacting feed component (nitrogen) mole flow rate (0.1 kmol/hr).

The output from a pyrolizer is a vapor with entrained solid particles. Practically, these two phases are separated using a cyclone. In Aspen Plus®, the cyclone block in Solid Separator database requires a particle size distribution (PSD) specification. But a choice of MIXCINC as global stream class has no provision for PSD. Hence we have used the SSplit block from Mixer/Splitter database to model the solid-vapor separation process (though the SSplit is renamed cyclone on the flowchart).

RESULTS

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 shows the weight percents of MC, volatile matter, ash content and fixed carbon as 6.93, 38.50, 2.03, and 52.54, respectively. Elehinafe et al. (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

Table 2. Comparison of proximate analysis result with others in the literature (in wt %)

ASH	MC	FC	VM	Source
2.03	6.93	52.54	38.50	This study
0.08-5.09	7.92-15.96	77.51-93.59	9.58-18.44	Elehinafe et al. (2019) (Nigerian woods)
0.70	15.61	86.78	12.52	Elehinafe et al. (2019) (mango)
4.46	7.06	15.09	73.38	Sharma and Mohanty (2021) (mango)

woods they studied, the weight percent of fixed carbon is greater than that of volatile matter. We note that the proximate analysis result in this study, also, shows this feature. Also, our values for ash (2.03 wt %) and moisture (6.93 wt %) lie within the range given 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 2**.

The mixed 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 the constituents of hydrogen, oxygen and carbon present in a solid biomass that when heated changes to vapor, usually a mixtures of hydrocarbons (Chaney, 2010). Volatile matter content affects the thermal characteristic of solid fuels (van Loo & Koppejan, 2008) and influences the structure and bond within the solid fuel.

Ash content of 2.03 wt % is low, and this is favorable for pyrolysis process. Low ash content in biomass favors thermochemical conversion processes and reduces slag formation problems, fouling and corrosion in pyrolysis reactors (Ali et al., 2020; Czajczyńska et al., 2017).

MC of 6.93 wt % is low, and within the range of 7.92-15.96 wt % reported by Elehinafe et al. (2019). Aina et al. (2009) reports that low MC implies a high calorific value, which is a major parameter that determines solid bio-fuel quality. MC affects the internal temperature history and total energy that is needed to bring the solid up to the pyrolytic temperature (Zaror & Pyle, 1982). Low MC 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% (Obernberger et al., 2018; Ugwu, 2012). 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 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).

Table 3. Comparison of ultimate analysis result with others in the literature (in wt %)

C	H	N	S	O	Source
61.5	4.80	0.67	0.63	30.37	This study
48.7	6.04	0.94	0.30	43.99	Ali et al. (2019) mixed wood sawdust
54.6	5.98	0.27	0.01	39.14	Oyebanji et al. (2022) lophiraalata (iron wood)

Table 4. Comparison of chemical analysis result with others in the literature (in wt %)

Hemicelluloses	Lignin	Cellulose	Extractives	Source
27.3	4.0	68.7	-	This study
24.8	21.5	50.03	3.4	Vuppaladadiyam et al. (2019)
26.7	33.2	40.1	-	Guida et al. (2019)
25.0	23.75	46.25	5.0	Sharma and Mohanty (2021)

The ultimate analysis of the mixed sawdust sample shows the carbon, hydrogen, nitrogen, sulphur and oxygen contents as 61.5, 4.80, 0.67, 0.63, and 30.37, weight percents, respectively. **Table 3** is a comparison of ultimate analysis data in this study with those in the published literature. 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 sulphur (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 $CH_{0.078}$, $O0_{.494}$, and $N_{0.011}$.

The chemical analysis result of the mixed wood sawdust sample for hemicellulose, lignin, and cellulose, in wt %, are 27.3, 4.0, and 68.7, respectively. **Table 4** shows a comparison of the result from this study with the chemical analysis data of other studies in the literature. The result from this study replicates the common trend in the relative values, in wt %, of various lignocellulosic components: cellulose > hemicelluloses > lignin.

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).

Products yield obtained from the outlet streams in the flowchart are given in **Table 5**, for pyrolysis condition 500 °C and 1 atm. To obtain the values for product yield in **Table 5**, we have subtracted the amount for nitrogen purge gas introduced at the input stream. The products yield lie within the published range which the values can assume, whether one compares them with results from experiments or computer simulations.

Table 5. Products yield (in wt %) from MWSD pyrolysis model

Product	Bio-char	Bio-oil	Biogas
Yield (this study)	56.94	30.77	12.29
Yield range (experiment)	(18.0-48.4)	(19.9-54.5)	(16.2-34.62)
Yield range (simulation)	(11.89-49.6)	(19.97-75.4)	(4.44-50.0)

Table 6. Products yield (in wt %) variation with model specifications

	Chemical data		Elemental data		Chemical & elemental data	
	SET 1	SET 2	SET 1	SET 2	SET 1	SET 2
Bio-char	60.20	56.94	57.33	56.28	61.08	57.92
Bio-oil	39.29	30.77	24.60	39.65	38.97	35.72
Biogas	0.51	12.29	20.20	6.20	2.40	8.82
Total	100.00	100.00	102.13	102.13	102.45	102.46

The char yield is slightly outside the range. From the experiments we observed that fixed carbon content of the mixed wood sawdust sample is greater than the volatile matter content, a feature that seems to be greater to Nigerian woods. Thus high fixed carbon content may be what is manifesting as higher char yield.

It has been observed (Larkin et al., 2016; Peters et al., 2017) that apart from generic and typical yield patterns, validating the simulation results of a predictive pyrolysis model using data published in the scientific literature is difficult, as each model requires a set of biomass property parameters and unit operation blocks settings that are not usually completely stated in publications.

Hence, we have investigated the influence of the hypothetical biomass decomposition components and the compounds/materials which constitute the component list on predicted products yield.

We have simulated mixed sawdust pyrolysis using components list SET 1 or SET 2 with chemical analysis data plus ash, or elemental analysis data plus ash, or chemical and elemental analyses data plus ash specified as the hypothetical biomass decomposition components in RYield reactor block, at 500˚C and 1 atm as shown in **Table 6**.

Observe that the total yield is 100 wt % for chemical data (irrespective of the list of components used) but slightly greater than 102 wt % for the other two cases. This difference is due to the nitrogen gas at the model's input stream (0.1 kmol/hr is equivalent to 2.8 kg/hr). With chemical data plus ash as hypothetical biomass decomposition components in RYield, nitrogen can be (and is) specified as inert component in RYield and nitrogen does not take part in the chemical reactions that lead to the pyrolysis products. Hence, the total yield is just that of the biomass in the input stream (which is 100 kg/hr).

But, if elemental data is part of the hypothetical biomass decomposition components, one cannot specify nitrogen as inert in RYield (since nitrogen is, usually, not zero in ultimate analysis of biomass). Thus nitrogen takes part chemical reactions that lead to the pyrolysis products and increases the amount of total yield (to about 102 kg/hr, in this study).

CONCLUSION

The mixed 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, MC, 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 of Elehinafe et al. (2019) on 100 Nigerian woods and seems to be a feature peculiar to Nigerian woods. The Aspen Plus® equilibrium model of the mixed sawdust pyrolysis predicts products yield in the range 56.28-60.20, 24.60-39.65, and 0.51-20.20 weight percents, respectively, for bio-char, bio-oil, and biogas, depending on the components used in the model specifications, for pyrolysis condition 500 °C and 1 atm. The dependence of predicted pyrolysis products yield on the specific settings of the Aspen Plus® equilibrium model of mixed wood sawdust pyrolysis. This is a purely computer modelling issue that seems not to have been recognized in the published literature. But its implication is that it makes comparison of the predicted pyrolysis yield from computer simulation studies difficult. Overall, one can conclude that the mixed wood sawdust sample from Igbinedion Sawmill, Okada, is suitable 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. The findings from this study augment the knowledge on mixed wood sawdust from sawmills in Nigeria. Specifically, the higher fixed carbon content relative to volatile matter content in the sample is noteworthy. Also, the influence of the hypothetical biomass decomposition components used in Aspen Plus® equilibrium model of mixed wood sawdust pyrolysis on predicted products yield seems not to be reported in the published literature before. An experiment on pyrolysis using mixed sawdust from Igbinedion Sawmill, Okada, should be undertaken.

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