



Preparation and Characterisation of Bio-Oil Produced from Sawdust of Selected Wood Species

Idowu Abimbola Adegoke^{1,*}, Rotowa Odunayo James²

¹Department of Forestry and Wildlife Management, Faculty of Agriculture, Federal University Gashua, Gashua, Nigeria

²Department of Forestry and Wildlife Management, Faculty of Agriculture, Nasarawa State University, Shabu-Lafia Campus, Nasarawa, Nigeria

Email address:

adegokeabimbola4u@yahoo.com (I. A. Adegoke)

*Corresponding author

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Abstract: Renewable energy is of growing importance in satisfying environmental concerns over fossil fuel usage. The study was carried out to determine bio-fuel characteristics of pyrolytic oil produce from sawdust of selected wood species (*Gmelina arborea*, and *Nesogordonia papaverifera*). Sawdust samples of 200 grams each were collected from Forestry Research Institute of Nigeria sawmill and oven-dried at $103\pm 2^\circ\text{C}$ for 24 hours to 12% moisture content. While four replicates of bio-oil were produced at each temperature regime for each of the samples, two different temperature regimes were used (500°C and 600°C). The metallic container (pyrolytic chamber) was filled with 200 grammes of the samples of each species and placed inside the Reactor which was connected to a condenser. Using standard test, physical properties, chemical and thermal characterization of bio oil and proximate analysis of the Bio-Char were assessed. Analysis of Variance (ANOVA) in Randomized Complete Block Design (RCBD) was used to ascertain significance difference in the oil yield produced at different temperature. The result shows that there was general increase in the volume of oil yield as the temperature increases. The volume of the oil ranged between 35.97 ± 1.82 to 49.33 ± 3.21 and 52.93 ± 0.51 to 63.63 ± 5.83 , the highest and least mean of the pH of pyrolytic oil yield ranged from 3.52 ± 0.02 to 3.54 ± 0.02 and 3.64 ± 0.36 to 3.73 ± 0.01 for *G. arborea* and *N. papaverifera* respectively. There was significant difference in the means of the volume of bio-oil obtained as pyrolysis temperature increases. It further shows that the sawmill wood residues differs significantly at $P < 0.05$ within the two temperature regime. The study established that pyrolysis is an efficient way to produce liquid fuels from biomass. The physical properties of the bio-oil obtained from sawmill wood residues falls within the acceptable range for fuel production. The selected wood species are therefore suitable for production of bio-oil with acceptable physical and chemical properties. Based on the result of the study, it is therefore among others recommended that residence time be taken for each temperature range to convert the feedstock to oil, and quantity of oil yield per specie.

Keywords: Temperature, *Gmelina Arborea*, Pyrolysis, *Nesogordonia Papaverifera* and Bio-Oil

1. Introduction

Biomass is the general terminology to describe all organic materials stemming from green plants that store solar energy in chemical bonds through photosynthesis. Wood and other forms of biomass have served as major fuels for thousands of years since mankind first began to use fire for heating and cooking. Recently, interest in biomass utilization has increased owing to growing concern over the depletion of

fossil fuels and global warming caused by greenhouse gas production from fossil fuel combustion. Growing interest in renewable technologies has led to the development of hydroelectric, solar, wave, geothermal, and wind power plants that can potentially displace fossil fuel based energy production [1]. However, existing infrastructures require hydrocarbons for manufacturing goods ranging from plastics and chemicals to fuel oil, lubricating oil, and hydraulic fluids. This has led many to look towards biomass as the only sustainable alternative to fossil fuels capable of yielding

petroleum like products [2, 3]. As is the case with all potentially disruptive technologies, though, proper environmental mitigation and lifecycle planning must be included when considering the production and use of biofuels

[4, 5]. Hydrocarbons can be produced from biomass via biological, biochemical, and thermochemical processes as shown in Figure 1 [6].

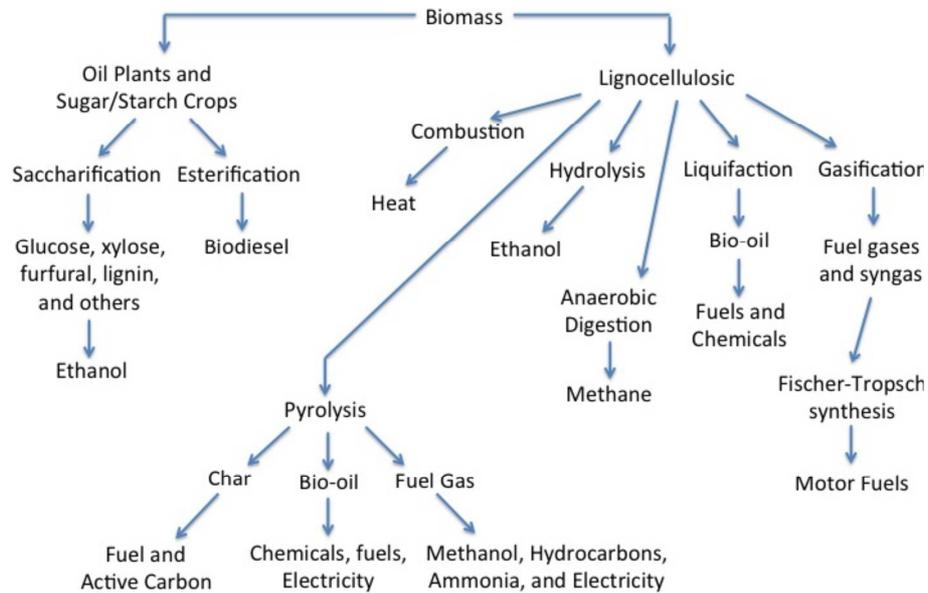


Figure 1. Schematic of Biomass Conversion Technologies.

Pyrolysis is the thermal decomposition of fuel into liquids, gases, and char (solid residue) in the absence of oxygen. It is usually understood to be anhydrous (without water). Pyrolytic products can be used as fuels, with or without prior upgrading, or they can be utilized as feedstock for chemical or material industries. Because of the nature of the process, yield of useful products is high compared to the other processes. In general, pyrolytic products are more refined and therefore can be used with greater efficiency. Materials suitable for pyrolysis processing include coal, animal and human waste, food scraps, paper, cardboard, plastics, rubber and biomass [7]. Pyrolysis is believed to be one of the most promising thermochemical technologies with the potential to convert cheap, local, and abundant lignocellulosic biomass such as grasses and trees into a useful form [8, 9], and commercial scale plants. Thermal technologies include direct combustion, gasification, liquefaction, and pyrolysis, all of which have the benefit of using lignocellulosic materials. Only pyrolysis and liquefaction produce a liquid product, and although recent work on liquefaction has shown promising results [10, 11, 7], it is currently a nascent technology with high capital costs due to the high pressures required. Pyrolysis has the advantage of low capital investment and a liquid final product that can be transported and converted via catalysis to fuels and valuable products such as food flavorings, fertilizers, resins, and other specialty chemicals that are fully compatible with existing petroleum infrastructure. This provides significant economic advantages over ethanol that requires parallel infrastructures. Furthermore, all pyrolysis products can be utilized in the pyrolysis system. The alarming poor energy supply and distribution has necessitated renewed research into

alternative source of energy. Although, Nigeria is an oil producing country, but it concentrated on exporting of crude oil and import refined petroleum products since refineries in the country operate below 10% production capacity. [12]. The high prices of oil which has a disproportionate impact on the country economy requires diversification of the energy sector and improve economic power of individuals through the use of biofuel as an alternative energy source. Also, there are serious environmental pollution problems associated with the use of fossil fuel. There is therefore need to identifying the sustainable energy options for energy production without polluting the environment.

2. Materials and Methods

2.1. Sample Collection and Preparation

Sawdust samples of *Gmelina arborea*, and *Nesogordonia papaverifera* (200 grammes each) were collected from Forestry Research Institute on Nigeria sawmill, the sawdust were oven-dried at $103 \pm 2^\circ\text{C}$ for 24 hours to 12% moisture content. Four replicates of bio-oil were produced at each temperature regime for each of the samples.

2.2. Bio Oil Production

The metallic container (pyrolytic chamber) was filled with 200 grammes of the samples of each species and placed inside the Reactor which was connected to a condenser. Two different temperature regimes were used i.e. 500°C and 600°C . The evolving gas was distilled in the condenser to form pyrolytic oil which was collected inside a conical flask.

2.3. Esterification of Bio-Oil (Up Grading)

The process used was transesterification process using acid

catalyst.

The reaction sequence is as follow.

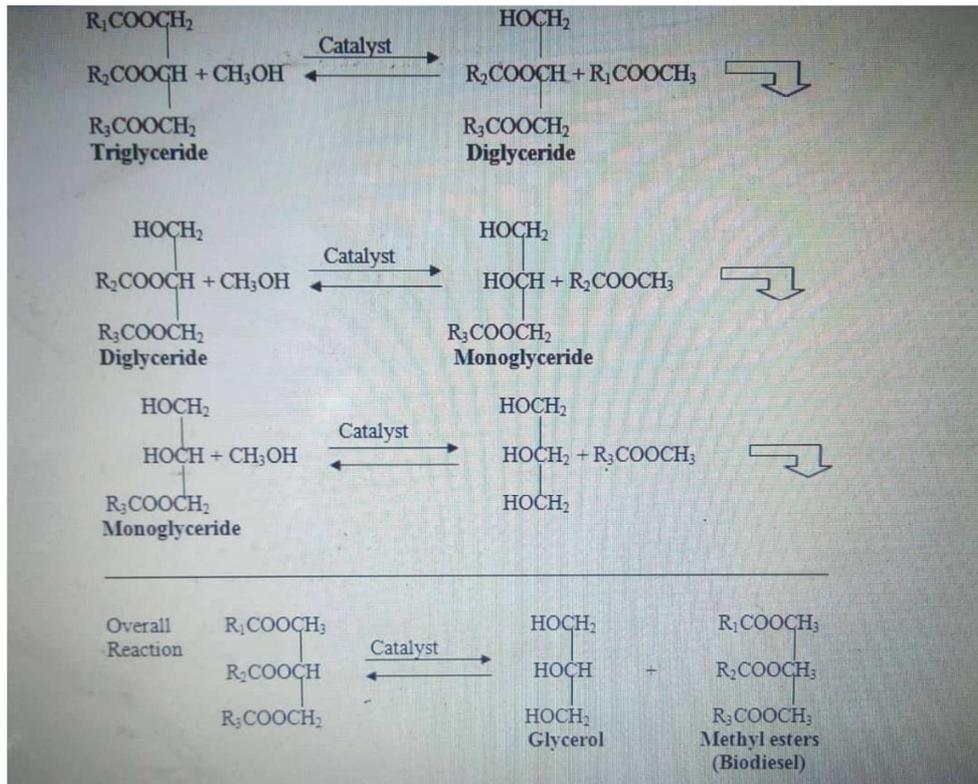


Figure 2. Transesterification reaction of Glycerides with Methanol.

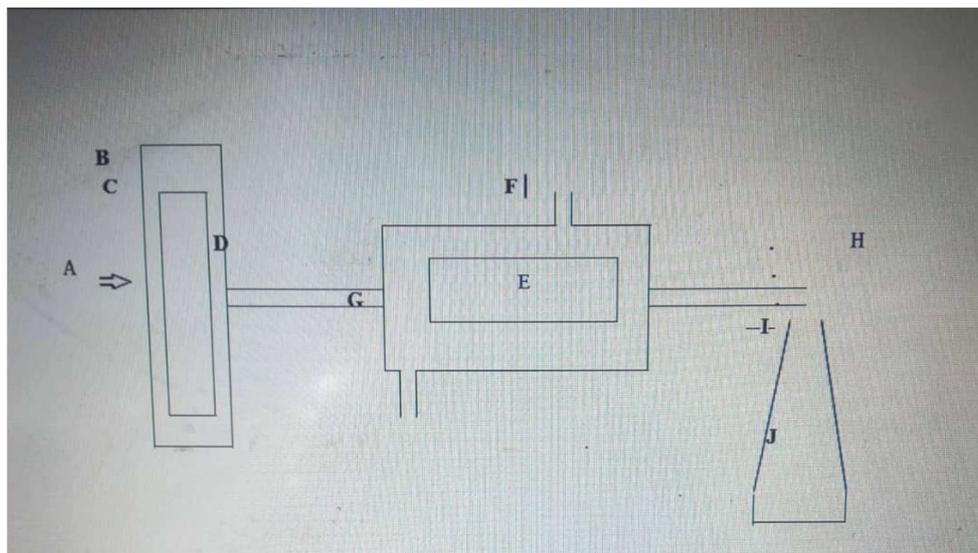


Figure 3. Schematic diagram of Pyrolyser experimental set-up.

- A: Feedstock (sawdust).
- B: Pyrolytic chamber (Reactor).
- C: Furnace.
- D: Chamber rod (Liquid passage).
- E: Condenser.
- F: Cold water inlet.
- G: Cold water outlet.
- H: Emitted gas.
- I: Pyrolytic oil and tar.
- J: Conical flask.

2.4. Fuel Characterization Examination

To characterize the bio oil and char, the following tests were performed using standard test.

2.4.1. Physical Properties Characterization of Bio Oil

i. pH Determination

The pH of the condensate was determined with the use of MICROFIED SM-3H pH meter which has an electrode that was calibrated with two buffer solutions.

ii. Density Determination

The density of a material is defined as mass per unit volume of sample. Electronic weighing balance was used to weigh the samples while measuring cylinder was used to determine the volume.

$$\text{Density (g/cm}^3\text{)} = \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

Where: M = mass of the bio-oil obtained (g), V = volume of bio-oil obtained (cm³)

2.4.2. Proximate Analysis of the Bio-Char

Proximate analysis was carried out to determine the following:

1. Percentage Ash Content.
2. Percentage Volatile Matter.
3. Percentage fixed Carbon.
4. Heating Value.

i. Percentage Ash Content

Two grams of oven dried sample was kept in furnace at temperature of 550°C for three hours and was weighed after cooling. The percentage ash content was calculated thus:

$$\% \text{Ash} = \frac{D \times 100}{B} \quad (2)$$

Where: %A = Percentage ash, D = Weight of ash, B = weight of oven dried sample.

ii. Percentage Fixed Carbon

The percentage fixed carbon was calculated by subtracting the value of percentage volatile matter and ash content from 100%. It was calculated according to the formula below:

$$\% \text{ fixed carbon} = 100 - (\%V + \%A) \quad (3)$$

Where %V = Percentage Volatile Matter.

% A = Percentage Ash Content.

iii. Percentage Volatile Matter

Two grams of pulverized sample was weighed into crucible before transferred into muffle furnace at 550°C. This was left for 10minutes; the content was later cooled in dessicator and weighed to determine the percentage volatile matter with the formula below:

$$\text{Volatile Matter (\%)} = \frac{B - C \times 100}{B} \quad (4)$$

Where B = Weight of oven dried samples, C = Weight of sample after 10minutes in the furnace at 550°C.

iv. Heating Value

The heating value or calorific value of a substance,

usually a fuel or food is the amount of heat energy released during the combustion of a specified amount of sample. The calorific value is a characteristic for each substance. It is measured in unit of the substance, usually mass, such as Kcal/kg, KJ/kg, J/mol, and Bt/m³. Heating value is usually determined by the use of a bomb calorimeter but due to in availability of bomb calorimeter estimation method was used. Heating value was calculated using the formula below:

$$\text{HV} = 2.326 (147.6C + 144V) \text{ KJ/kg} \quad (5)$$

Where HV = Heating Value, C = Percentage fixed Carbon
V = Percentage Volatile Matter

2.4.3. Chemical and Thermal Characterization of Oil

i. Determination of acid value

This was done according to Pearson (1976). Two grams of oil was weighed into a dried 250ml Erlenmeyer flask. Thirty millilitres of a solution made of equal volumes of 95% ethanol and diethyl ether was added to dissolve the oil. The sample solution was then titrated with 0.1N methanolic potassium hydroxide solution with the addition of 0.5ml phenolphthalein solution until a slight pink colour persisted for 15 seconds. Blank titration without oil was also carried out under the same condition.

$$\text{ACID VALUE} = \frac{\text{Titration (ml} \times 5.61\text{)}}{\text{Wt of sample used}} \text{ mg KOH/g oil} \quad (6)$$

ii. Pour Point

The temperature at which the oil pour was determined by putting samples inside test tube, then placed in a freezer and the lowest temperature at which the pouring occur was recorded as the pour point.

iii. Elemental Analysis of Bio-Oil

Ultimate analysis is performed to determine the elemental composition of the materials. It was carried out using a LECO CHNS 932 elemental analyzer which provides carbon, hydrogen, nitrogen, sulphur percentage composition of the selected samples. When the summation of these compositions is subtracted from 100, it gives oxygen percentage composition.

iv. Compositional Analysis (FT-IR)

Spectroscopic analysis using photo spectrometer was performed using PERKIN ELMER 1600 series model to know the functional group present in the bio-oil.

2.5. Data Analysis

Analysis of Variance (ANOVA) in Randomized Complete Block Design (RCBD) was used to ascertain significance difference in the oil yield produced at different temperature. Duncan Multiple Range Test (DMRT) was used for any variables (temperature and wood specie) that are significant at 5% level of probability as follow-up test. Ten Chemical properties were assessed for each specie.

3 Result and Discussion

3.1. Results

3.1.1. Physical Properties and Proximate Analysis of Pyrolytic Oil

The pyrolytic oil yield from the selected wood species (*Gmelina arborea* and *Nesogodonia papaverifera*) at two different temperature regimes (500°C and 600°C) was shown in Table 1. The physical properties which includes bio-oil yield (g/cm³), pH, Acidic value, pour point and Density (g/cm³) of the pyrolytic oil were assessed. The table also shows the result of proximate analysis of the species where percentage fixed carbon, percentage ash content, Percentage, volatile matter, heating value and bio char were assessed.

3.1.2. Pyrolytic Oil Yield

There was general increase in the volume of oil yield as

Table 1. Physical properties and Proximate analysis of pyrolytic oil produced from the selected wood species (mean±standard deviation).

Physical properties	Temp (°C)	<i>Gmelina arborea</i>	<i>Nesogodonia papaverifera</i>
Bio-oil yield (cm ³)	500	35.97±1.82 ^c	52.93±0.51 ^c
	600	49.33±3.21 ^c	63.63±5.83 ^b
pH	500	3.52±0.02 ^a	3.64±0.36 ^a
	600	3.54±0.02 ^a	3.73±0.01 ^a
Acidic value	500	3.91±0.27 ^b	2.54±0.14 ^c
	600	5.49±4.82 ^a	1.37±0.47 ^d
Pour point	500	-0.78±0.03 ^a	-0.85±0.05 ^a
	600	-0.80±0.00 ^a	-0.12±0.29 ^a
Density of bio-oil (g/cm ³)	500	0.91±0.02 ^a	0.98±0.01 ^a
	600	0.93±0.03 ^a	1.04±0.11 ^a
Proximate analysis			
% Fixed carbon	500	25.00±8.66 ^b	28.33±2.89 ^b
	600	61.67±2.89 ^a	56.67±15.28 ^a
% Ash content	500	40.00±5.00 ^a	40.00±5.00 ^a
	600	25.00±5.00 ^c	26.67±7.64 ^c
% Volatile matter	500	35.00±5.00 ^b	31.67±2.87 ^b
	600	13.33±5.77 ^c	16.67±7.64 ^d
Heating value	500	20305.98±1737.90 ^b	20333.89±1695.70 ^b
	600	25637.17±1674.89 ^a	25037.06±2686.09 ^a
Bio char	500	74.70±2.46 ^b	97.17±0.15 ^a
	600	60.30±0.89 ^b	67.60±3.12 ^b

Mean with the same superscript alphabet in a column are not significantly different at 5% level of probability.

3.1.4. Acidic Value of Bio-Oil Yield

The highest and lowest mean value for acidic value of liquid produced from *Gmelina arborea* and *Nesogodonia papaverifera* ranged from 3.91 ± 0.27 to 5.49 ± 4.82 and 1.37 ± 0.47 to 2.54 ± 0.14 respectively (Table 1). The analysis of variance showed that two was significant difference in the acidic value of the pyrolytic liquid at temperature of 500°C and 600°C (Table 2).

3.1.5. Pour Point of Bio-Oil Yield

The mean result of pour point revealed the highest and lowest mean values for the pour point of liquid produced which ranged from -0.78 ± 0.03 to -0.80 ± 0.00 and -0.85 ± 0.05 to -0.12 ± 0.29 were recorded in *Gmelina arborea* and *Nesogodonia papaverifera* respectively (Table 1). The result also revealed that there is significant difference in the pour point of bio-oil yield at the two temperature regimes adopted for pyrolysis (Table 2).

the temperature increases. The volume of the oil ranged between 35.97 ± 1.82 to 49.33 ± 3.21 and 52.93 ± 0.51 to 63.63 ± 5.83 for *Gmelina arborea* and *Nesogodonia papaverifera* respectively (Table 1). There was significant difference in the means of the volume of bio-oil obtained as pyrolysis temperature increases. This further shows that the sawmill wood residues differs significantly at P < 0.05 within the two temperature regime (Table 2).

3.1.3. pH Value of Bio-Oil Yield

The highest and least mean of the pH of pyrolytic oil yield which ranged from 3.52 ± 0.02 to 3.54 ± 0.02 and 3.64 ± 0.36 to 3.73 ± 0.01 for *Gmelina arborea* and *Nesogodonia papaverifera* respectively were presented in Table 1. There is significant difference in the pH of bio-oil liquid produced at 500°C and 600°C for the selected sawmill wood residues at P < 0.05 level of significance (Table 2).

3.1.6. Density of Bio Oil Yield

The result of density of bio oil yield shows that *Gmelina arborea* had higher mean density yield of 0.91 ± 0.02 to 0.93 ± 0.03 (g/cm³) and *Nesogodonia papaverifera* had a lower yield of 0.98 ± 0.01 to 1.04 ± 0.11 (g/cm³) as shown in table 1. The result also revealed that there was significant difference in the density of bio-oil yield at the two temperature regimes adopted for pyrolysis (Table 2).

3.2. Proximate Analysis of Bio-char Produced from Selected Sawmill Wood Residues

3.2.1. Percentage Fixed Carbon

The result of mean percentage fixed carbon is presented in Table 1. The result from analysis of variance shows that there is no significant difference between the selected sawmill wood residues used at different temperature range (Table 2). The percentage fixed carbon values ranged from 25.00 ±

8.66 to 61.67 ± 2.89 and 28.33 ± 2.89 to 56.67 ± 15.28 for *Gmelina arborea* and *Nesogodonia papaverifera* respectively.

Table 2. ANOVA of Physical properties and Proximate analysis of pyrolytic oil produced from the selected wood species.

SV	df	SS	MS	F-cal	Remark
Physical properties					
Bio-oil yield					
Treatment	2	821.56	410.78	39.54	*
Temperature	1	1705.28	1705.28	164.14	*
Trt*Temp	2	502.62	251.31	24.19	*
Error	12	124.67	10.39		
Total	17	3157.13			
pH					
Treatment	2	0.086	0.043	61.43	*
Error	15	0.005	0.0007		
Total	17	0.091			
Acidic value					
Treatment	2	68.183	34.091	4.005	*
Error	15	127.677	8.512		
Total	17	195.86			
Pour point					
Treatment	2	0.506	0.253	281.11	*
Error	15	0.013	0.0009		
Total	17	0.519			
Density					
Treatment	2	0.024	0.012	4.00	*
Error	15	0.043	0.003		
Total	17	0.067			
Proximate Analysis					
% fixed carbon					
Treatment	2	19.444	9.722	0.175	Ns
Error	15	833.333	55.556		
Total	17	852.777			
% Ash content					
Treatment	2	158.333	79.167	33.934	*
Error	15	350.000	2.333		
Total	17	508.333			
% volatile matter					
Treatment	2	277.778	138.889	5.952	
Error	15	350.000	23.333		
Total	17	627.778			
Heating value					
Treatment	2	17483899.60	8741949.79	3.15	Ns
Error	15	41661313.30	2777420.89		
Total	17	59145212.90			
Biochar					
Treatment	2	705.95	352.97	2.04	Ns
Error	15	2594.86	172.99		
Total	17	3300.81			

* Significant at 5% level of probability, Ns = Not significant at 5% level of probability.

3.2.2. Percentage Ash Content

The result of percentage ash content for both temperature regimes shows that *Nesogodonia papaverifera* had the highest mean percentage ash content (40.00 ± 5.00 to 26.67 ± 7.64) while *Gmelina arborea* had the less mean percentage ash content which ranged from 40.00 ± 5.00 to 26.67 ± 7.64 (Table 1). The result from analysis of variance shows that there was significant difference between the selected feedstocks at different temperature (Table 2).

3.2.3. Percentage Volatile Matter

The result of mean value for percentage volatile matter shows that at 500°C *Gmelina arborea* had 35.00 ± 5.00 and *Nesogodonia papaverifera* had 31.67 ± 2.87 meanwhile

Nesogodonia papaverifera recorded higher mean value of 26.67 ± 7.64 and *Gmelina arborea* had 13.33 ± 5.77 at 600°C (Table 1) The result from Table 2 indicated that there was significant difference in the percentage volatile matter between the different sawmill wood residues at different temperature.

3.2.4 Heating Value of the Bio-Char

The result also revealed that the higher mean for the heating value of the bio char which ranged from 20305.98 ± 1737.90 to 25637.17 ± 1674.89 (Kj/kg) was recorded in *G. arborea* and 20333.89 ± 1695.70 to 25037.06 ± 2686.09 (Kj/kg) which is less was recorded in *N. papaverifera*. (Table 1). The result of analysis of variance

indicated that there was no significant difference in the heating values of the bio char (Table 2).

3.2.5. Bio Char Yield Component

The result of the proximate analysis presented in table 1 also reveals that *Gmelina arborea* had the lesser mean of bio char recovery after pyrolysis process and it ranged from 74.70±2.46 to 60.30±0.89 while 97.17±0.15 to 67.60±3.12 was recorded in *Nesogodonia papaverifera*. The result of analysis of variance indicated that there was no significant

difference between the left over char as the pyrolytic temperature increases from 500°C to 600°C between the selected wood species.

3.2.6. Elemental Analysis of the Bio-oil

The results of the elemental composition of the pyrolytic oil is presented in Table 3. This revealed the carbon, hydrogen, nitrogen, sulphur and oxygen content of the selected sawmill wood residues.

Table 3. Elemental components of pyrolytic oil.

Parameter (%)	<i>Gmelina arborea</i> 500°C-600°C	<i>Nesogodonia papaverifera</i> 500°C -600°C
Carbon	51.2-50.8	49.9-50.02
Hydrogen	7.08-8.27	6.85-6.76
Nitrogen	0.2-0.1	< 0.1-< 0.1
Sulphur	0.6-0.04	--
Oxygen	41.46-40.43	43.15 43.22

3.2.7. Compositional Analysis of the Bio-Oil

The result of FT-IR spectrum of the liquid obtained from pyrolysis of *G. arborea* and *N. papaverifera* wood residues from sawmill at different temperature range are shown in 4 and 5 indicated the functional groups of the two selected sawmill wood residues with their corresponding frequencies (cm⁻¹) that were identified from FT-IR spectrum.

Table 4. Functional groups present in wood residue of *G. arborea* and *N. papaverifera* as determined by FT-IR analysis.

Temperature (°C)	Frequency (cm ⁻¹)	Functional Groups	Class of compounds
500	3600-3200	O-H stretch	Phenol, primary amine, secondary and water impurities
		N-H stretch	
	3300-2500	O-H stretch	Carboxylic acid
		2500-2000	C≡N
	1775-1650	C=O stretch	Carboxylic acid, ketones, aldehyde, esters, benzene derivatives
	1680-1575	C=C stretch	Alkanes
	1570-1515	N-H bend	Secondary amide
	1490-1325	C-H bend	Alkanes
		O-H bend	Alcohols, phenols
	1300-950	O-H bend	Alcohols, phenols, aromatics
C-H stretch		Esters, alcohol	
900-650	≡C-H bend	Alkynes	
	C=C	Aromatic compounds, alkenes	
600	3600-3200	O-H stretch	Phenol, secondary alcohol
		N-H stretch	
	3300-2500	O-H stretch	Carboxylic acid
		C-H stretch	Alkanes, alcohols, ethers
	2500-2000	C≡N	Benzo-nitrile
	1775-1650	C=O stretch	Carboxylic acid, ketones, aldehyde, esters, benzene derivatives
	1650-1575	C=C stretch	Alkanes
	1490-1325	C-H bend	Alkanes
		O-H bend	Alcohols, phenols
	1300-950	O-H bend	Alcohols, phenols, aromatics
C-H stretch		Esters, alcohol	
900-650	C=C	Alkenes, aromatics	
	≡C-H bend	Alkynes	
<i>N. papaverifera</i>	3600-3200	O-H stretch	Phenol, sec. Alcohol, water impurities
		N-H stretch	
	2500-2000	C≡N	Benzo-nitrile
	1775-1650	C=O stretch	Carboxylic acid, ketones, aldehyde, esters
	1650-1575	C=C stretch	Alkenes
		C-H bend	Alkane
	1490-1325	O-H bend	Alcohols, phenols
	1300-950	O-H bend	Alcohols, phenols
		≡C-H bend	Alkynes
	900-650	C=C	Aromatic compounds, alkenes

Temperature (°C)	Frequency (cm ⁻¹)	Functional Groups	Class of compounds
600	3600-3200	O-H stretch	Phenols, sec. Alcohol
		N-H stretch	Primary amine
	2500-2000	C≡N	Water impurities
		C=C stretch	Benzo-nitrile
	1650-1575	O-H bend	Alkenes
		C-H bend	Alcohols, phenols
	1490-1325	C-H bend	Alkanes
		O-H bend	Alcohols, phenols
1300-950	C-O stretch	Alcohols	
	900-650	≡C-H bend	Alkynes, and aromatic compounds

4. Discussions

4.1. Physical Properties of Pyrolytic Oil

The study revealed that the bio-oil yield was higher at 600°C for *Nesogodonia papaverifera* pyrolysis. At this condition the mean yield of *Nesogodonia papaverifera* was 63.63g/cm³ compare to 49.33g/cm³ yield recorded in *Gmelina arborea*. There was general increase in the volume of oil yield as the temperature increases. According to [13] the bio-oil derived were not standardized products and can exhibit a wide range of properties and composition according to the feedstock and pyrolysis technique employed. Considerable experimental evidence suggested that there is increase in yield between liquid and gas and reduction in carbon solids (char) during wood pyrolysis which depends on the heating conditions [14, 15]. Reported that the cell structure may affect the pyrolysis behaviour of biomass, The liquid yield were high showing the potential of reconversion liquid hydrocarbon from the fast pyrolysis of biomass. The liquid appeared brownish dark with a strong acidic smell. Heavy condensate or tar was also formed and adhered to the inner wall of condenser, liquid collectors and connecting pipes. At the initial stage, biomass is decomposed and depolymerized to small compounds by dehydration, dehydrogenation, deoxygenation and decarboxylation and these compounds may rearrange through condensation, cyclization and polymerization to form new compounds.

The characteristics of the oils derived from these three species were very similar to the characteristics of other biomass pyrolytic oils. The most prominent characteristic is the nature of the oil due to high oxygen content as agreed with [16]. A low pH range value of 3.52- 3.73 is a common feature in the sampled species derived liquid and they are therefore very corrosive. The result of the density presented in table 2 revealed that there is significant difference in the values obtained for *G. arborea* and *N. papaverifera* with *N. papaverifera* having the highest density value of 1.04 g/cm³ which was high when compared with report of [13] with approximated value of 1.2 g/cm³. Upon pyrolysis in the temperature range of 500°C -600°C, the bio-oil yield of wood samples was higher. Its maximum value was reached at a higher temperature. Upon pyrolysis at 600°C, the formation of new, thermally more stable bonds occurs. This result agrees with [17], whose results also reported higher yield of

the char residue and increase in the amount of non-condensing gases upon pyrolysis of the samples. The result of the pour point revealed that *G. arborea* had the highest pour point value of 0.85±0.05at temperature of 600°C which will not cause any trouble in most of the tropical regions but in colder regions with sub zero climate it may have freezing problems.

4.2. Proximate Analysis of Bio-Char Produced from Selected Sawmill Wood Residues

Proximate analysis is the quickest and simplest way of investigating the fuel quality of solid materials. After pyrolysis the volatile matter content of the selected sawmill wood species reduces between the different samples at different temperature with *G. arborea* having the highest volatile matter content of 35%, which indicates higher biomass to liquid fuels from this species. The result of the percentage ash content presented in table 1 indicated that *N. papaverifera* has the highest ash content (26.67±7.64) when compared with *G. arborea* (25.00±5.00) and this may be due to its chemical composition and presence of high extraneous materials percentage ash content, fixed carbon and volatile matter were the required prerequisite for the determination of heating value of the samples. It was observed that there is no significant difference in the percentage fixed carbon between the species and differed significantly for percentage ash content and volatile matter between the species used.

Ash is an impurity that will not burn which reduces handling and burning capacity, it increases handling cost and affects combustion efficiency causes clinkering and slagging. The heating value range for the bio-char produced from *Gmelina arborea* and *Nesogodonia papaverifera* were obtained as 20305.98 - 25637.17 and 20333.89 - 25037.06 (Kj/kg) respectively. It is further shown that significant variations are not found among selected sawmill residues. This denotes high heating values as good combustion characteristics for energy generation and to acquire alternative source of bio- briquette for domestic and industrial application [18] Hence, any of these species can be use for industrial combustion needs.

4.3. Compositional Analysis of the Bio-Oil

The elemental analysis of the oil is an important criterion for the design of a combustion plant utilizing the oil. The ultimate analysis showed the variations in the elemental

composition of the selected sawmill wood residues (Table 3). The analysis showed significant variation in carbon and oxygen content whereas there were slight variations in hydrogen, nitrogen and sulphur content. Some of the oxygen in the original feedstock is thought to have turned into H₂O, CO and CO₂. The high oxygen content results in a low energy density of the bio oils. It was observed that changing the temperature causes a slight change in the elemental content of the bio-oil samples. However, no particular trends in the elemental composition were found within the range of reaction temperatures used.

4.4. Chemical Properties of Pyrolytic Liquid (FT-IR Analysis)

The FT-IR analysis suggested that the functional groups like alcohols, ketones, carboxylic acids, esters, alkanes, alkenes, alkynes, amide, nitriles, nitro compounds, ethers, aromatic rings were present in the bio-oil from *G. arborea* and *N. papaverifera*. The FT-IR spectra of bio-oil samples obtained from different temperatures exhibited the same peaks but these spectra differed in the relative intensity of some bands. It has to be confirmed with gas chromatography results. The functional groups of the two and various class of compounds that were identified from the FT-IR spectrum are presented in Table 4. The FT-IR spectra were recorded in the transmission mode between 3600 and 600 cm⁻¹ for all samples. All the residues have similar aromatic and aliphatic functional groups but with different vibrating frequencies (cm⁻¹).

At 500°C, the O–H stretching vibrating frequency between 3600 and 3200 indicated the presence of phenols and alcohols (–OH in alcohols and phenols). The group and class –NH₂ in aromatic amines, primary amines and amides indicate the NH stretching vibrations. The absorbance between 2500 and 2000 represent the presence of benzonitrile with C≡N. The C=O deformation vibration between 1775 and 1650 cm⁻¹ indicates the presence of carboxylic acid, ketones, aldehyde, esters and benzene derivatives. The absorption between 1680 and 1575 cm⁻¹ indicated the presence of alkanes. The absorbance peaks between 1575 and 650 represent N–H bend, C–H bend, ≡C–H bend and C=C which further indicated the presence of alkanes, alcohols, aromatic compounds and alkynes. The rise in these bands suggests an increase in aromatic structures, nitrogenous compounds and alkanes. The weaker bands suggest a decrease in carbonyl groups (COOH, Ketones and aldehydes) as well as aliphatic groups.

[19] Recognized the formation of aromatic compounds, when cellulose was thermo-chemically converted in an alkali solution. They suggested that these aromatic were formed by condensation or cyclization of unstable intermediate fragments, which were generated by degradation of the cellulose. These changes observed by FT-IR indicate that bio oil possess both the aliphatic structures and aromatic components. The changes of intensity of the bands indicated the decrease in aliphatic structure and increase in aromatic components with increasing reaction temperature. At 600°C similar functional

groups were observed in the FT-IR spectrum in all the selected wood species without any effect of temperature regimes used during pyrolysis. [20, 21] reported that high oxygenated compounds present in biomass pyrolysis oil is responsible for differences in the properties and behaviour of bio-oil. Hence, it is important to deoxygenate the liquid by some upgrading technology.

5. Conclusion and Recommendations

5.1. Conclusion

Pyrolysis is an efficient way to produce liquid fuels from biomass. The quality of bio-oil has to be improved before it can be used as a traffic fuel or combusted in boilers. During pyrolysis process the solid content in the bio-oil can be reduced by efficient char removal. The bio-oil obtained showed comparable fuel properties and can be treated as moderate grade commercial fuels. In order to utilize it as commercial transportation fuel certain enhancement in properties like density and corrosiveness have to be normalized. The bio-oil obtained contains chemical compounds of varying carbon chain length from C₄ - C₂₇ and functional groups such as alkanes, alkenes, alkynes, alcohols, ketones, aldehyde, aromatic rings, amides and nitrile compounds. Bio-char (charcoal) obtained has good calorific value, thus can be used as alternative fuel (briquette production) but it cannot be used as adsorbent as its surface area was quite low. The physical properties of the bio-oil obtained from sawmill wood residues falls within the acceptable range for fuel production. The selected wood species are therefore suitable for production of bio-oil with acceptable physical and chemical properties. The thermal degradation processes (pyrolysis), may help to reduce environmental pollution, deforestation at the same time providing greater amounts of desirable, renewable fuel and chemical source.

5.2. Recommendations

Based on the output of this work, the following recommendations are therefore suggested:

1. Residence time taken for each temperature range to convert the feedstock to oil, and quantity of oil yield per specie.
2. Research should be directed to know the effect of particle (feedstock's) size on the yield of bio-oil.
3. Determination of the chemical components in the pyrolytic oil using Gas Chromatography-Mass Spectroscopy (GC-MS).
4. Upgrading of the bio-oil produced to high grade liquid fuel for further use in internal combustion engines and other applications.
5. More research should be conducted on conversion of indigenous wood residues for the production of pyrolytic oil and the following findings should be considered.

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