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Temperature Regime and Its Effect on Energy Potentials of Bio-Oil From Ficus Exasperata Wood Residue

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Abstract

This study was to determine the ultimate and proximate analysis of bio-oil produced from sawdust of *Ficus exasperata*. A vacuum reactor was used to extract bio-oil from sawdust at three temperature regime; 500, 550 and 600ºC for use in energy generation and other value added products. Physical properties, Ultimate analysis (C,H,N,O), heating value, GC-MS of bio-oil were determined using standard procedure. Result shows that bio-oil at 500°C had highest yield (42.4%) with lowest bio-char (21.7%), density (1.12Kg/dm^3), pH (3.43), Moisture content (25.85%) and Kinematic viscosity (299.92cSt). Average content of CHNO was 77.42, 4.77, 0.10 and 17.81% respectively. Proximate analysis at 500ºC shows highest %Ash and lowest HV as 0.09%, and 34.08Mjkg^{-1} respectively, while lowest %Ash and highest HV of 0.05% and 34.10Mjkg^{-1} respectively were obtained at 600ºC. GC-MS peaks showed that the bio-oil was composed of hydrocarbons and oxygenated compounds while oxylic, carboxylic and benzoic acids were detected.

Keywords: Wood residue; pyrolysis, physical properties, heating value, GC-MS.
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1. INTRODUCTION

Solid waste management present a major challenge in developing county like Nigeria where rapid population growth, social and cultural change and limited financial resources all contributes to environmental degradation and waste disposal challenges. The wood residues (sawdust) from most of the Sawmills are being burnt and dumped on water ways thereby causing environmental problem/pollution.

General observation and research shows that wood waste have potential in production of fuels (energy) and chemicals. They are said to be in abundance and doesn't alter or contend with food supply Sukumaran *et al.* (2010). In order to minimize over reliance on fossil fuels there is need for energy conservation and utilization of renewable energy resources. However, a more conducive method is the reduction in the CO_2 present in the atmosphere by generating energy from bio-oil, which is a product of biomass pyrolysis Brown *et al.* (2011). Biomass utilization is one of the most cost-effective routes to carbon-neutral energy and is expected to be the source of huge practical value to produce renewable liquid fuels He *et al.* (2009).

Biomass is an attractive energetic source, since it is renewable, available in most countries and can replace fossil fuels. For its efficient application to energy conversion processes, the knowledge on its physical-chemical properties is very important and determines the behaviour of the fuels in processes such as combustion, gasification and pyrolysis (Kazagic and Smajevic, 2007). In addition, identification and classification potential biomass based on its potential value, will allow higher quality of its integration and optimized result (Lim *et al*., 2013).There are several routes of biomass conversion: generation of heat energy, transport fuel and chemical feedstock. Sawdust can be utilized and channel for energy generation through pyrolysis. The bio-oil collected can be used as ingredient in the manufacturing of many chemical and also as liquid fuels

This study is aimed at production and characterization of bio-oil for energy production and other value-added products

2. MATERIALS AND METHOD

2.1 Sample Preparation and Bio-oil Extraction

Wood residue (sawdust) of *Ficus exasperata* was collected and sieved (5-9mesh). Samples of 1200 grams were oven-dried at 103±2°C for 24 hours to 12% moisture content. A fabricated vacuum pyrolysis Chamber was used to convert sawdust to bio-oil. Three replicates of the oil were obtained at different temperature regime 500ºC, 550ºC and 600ºC. The evolving gas was distilled in the condenser to form bio-oil which was collected inside a conical flask.

2.2 Determination of Bio-oil yield and Char

2.2.1 Bio-oil yield was calculated as the percentage of the sawdust fraction of the feed that was condensed as bio-oil, using Equation:

$$Bio-oil\,yield = \frac{Weight\,of\,bio-oil}{Weight\,of\,sawdust}x100 \text{ ....1}$$

2.2.2 Char yield was calculated as the percentage of the sawdust fraction, which is converted to a solid carbonized (char), using Equation.

$$Bio-Char = \frac{Weight\,of\,char}{Weight\,of\,sawdust}x100 \text{ ....2}$$

2.3 Physical Properties of Bio-Oil

2.3.1 pH determination:

This was carried out using a pH meter from Eutech Instruments, a type of pH tutor which has an electrode that was calibrated with two buffer solutions. The electrode was directly dipped into the bio-oil sample expressed as a pH of bio-oil.

2.3.2 Density:

The density of a material is defined as mass per unit volume of sample and this was determined according to (ASTM D 4052) using digital density meter. One 1 mL of bio-oil was injected into density meter at 25°C and repeated three times. The average of the recorded values was expressed as density in g/cm^3.

2.3.3 Kinematic Viscosity:

Is a measure of the resistance to gravity flow of a fluid. Viscosity of a liquid is an important property since it affects the flow of the liquid through pipelines. The viscosity was measured with a Cannon–Fenske up–flow viscometer. A sample (20 ml) of each of the bio-oils was placed in the viscometer and the flow was observed at 40°C. The unit of measurement is centistokes (cSt).

2.3.4 Flash point:

Is a measure of the volatility of the oil, as well as its ease of ignition. The higher the number, the safer the handling of the oil and lowers the risk of accidental vapor ignition. The flash point was determined by heating a sample of the fuel in a stirred container and passing a flame over the surface of the liquid (ASTM D-93).

2.3.5 Cloud point

This was carried out using a cryostat. The cryostat was switched on and the automatic temperature was also turned on. The temperature of the surrounding outside the cryostat was recorded. Another thermometer was inserted into the fluid bath in order to take the temperature of the content of the fluid bath (methanol). As the temperature of the surrounding (bath fluid) dropped, with the test jar in the cooling bath, the oil sample in the test jar was checked intermittently for the temperature at which a significant amount of cloud was present in test jar (Cloud point). The test jar was removed and the temperature recorded.

2.3.6 Pour point:

After recording the value of the cloud point, the thermometer was removed from the test jar and capped with a wooden cork. The test jar was carefully placed into a metal air and the well was covered to prevent heat loss. The oil sample was allowed to freeze completely and was taken out of d metal well. The wooden cork was removed and at about 90°C the test jar was tilted horizontally for 5sec to check for surface movement. Close observation was made to see at what point the frozen bio oil would pour. The temperature at which the bio oil poured was taken.

2.4 Ultimate Analysis

This was carried out using ASTM 3174-76. 2g of oil sample was weighed into platinum crucible and placed in a leibig-pregle chamber containing magnesium percolate and sodium hydroxide. The sample was burnt off to produce carbon dioxide and water. The CO_2 was absorbed by Sodium hydroxide while water was absorbed by magnesium percolate. The result of Carbon, Hydrogen and Nitrogen where obtained while oxygen was calculated by difference using formular

$$\%O = 100 - (\%C + \%H + \%N) \text{ ....3}$$

2.5 Proximate Analysis of Bio-oil

2.5.1 Percentage volatile matter determination: The amount of volatile present is equal to loss in weight which is calculated using the formula

$$\%V\ at\ 900°C = \frac{Wi-\mathrm{Wf}}{Wi}x\frac{100}{1} \text{..Equ (4)}$$

Where = W_i = Initial mass of the sample,

W_f= Final constant mass of the sample.

2.5.2 Percentage ash content determination: The amount of residual white grey matter is determined by difference.

$\%Ash\ content = \frac{Ma-Mo}{Ms}\ x\ \frac{100}{1}$ …………………………………………………...Equ(5)

Where M_a= Mass of Crucible plus ash,
M_o= Mass of empty crucible,
M_s= Mass of sample

2.5.3 Percentage fixed carbon determination: The amount of fixed carbon is calculated using the formula

$100 - (\%moisture + \%\ Ash + \%\ Volatile\ matter)$………………………..Equ (6)

2.5.4 Heating value (calorific value): The calorific value of bio oil was determined in according to ASTM D-4809 by burning a weighed sample in an oxygen-bomb calorimeter, Leco AC-350 under controlled conditions.

2.6 Gas Chromatography-Mass Spectrometry Analysis

The oil obtained was methylated and analysed using Gas Chromatography-Mass Spectroscopy. The GC-MS analysis was done using the instrument Trace GC Ultra Thermo Scientific DSQ II, equipped with a VF-5ms fused silica capacity column of 30m length, 0.25mm diameter and 0.25um film thickness. For GC-MS detection, an electron ionization system with ionization energy of 70Ev was used. Helium gas 99.99% of purity was used as a carrier gas as well as an eluent. The flow rate of Helium gas was set to 1.5mL/min. the sample injector temperature was maintained at 200°C. Initially oven temperature was maintained at 140°C for 1 minute, and the temperature was gradually increased up to 300°C for 5 minutes. 1ul of sample was auto injected for analysis.

In identifying the various components, the relative percentage amount of each component was calculated by comparing its average peak area to the total areas. The detection employed by using the NIST (National Institute of Standards and Technology) library ver.2.0 (2005) (Lafferly 1980; and Stein's 1990). Interpretation of GC-MS was conducted using the database of NIST library having more than 62,000 patterns. The spectrum of the component was compared with that of a known spectrum, the components were saved in the NIST library ver. 2.0. The name, molecular weight and molecular formula of components of the test materials were ascertained.

3. RESULTS AND DISCUSSION

3.1 Bio-Oil Yield

The yield of bio-oil decreased with increased in pyrolysis temperature. The average values of 42.4, 41.0 and 40.3% were recorded at pyrolysis temperature of 500ºC at 550ºC and 600ºC respectively, while the quantity of bio-char slightly increased with increase in temperature with average values of 21.71, 21.84 and 21.97% at pyrolysis temperature of 500ºC, 550ºC and 600ºC respectively (Fig 1).

Pyrolysis of *F. exasperata* residue at 500ºC gave highest bio-oil yield of 42.4% with lower bio-char, this result is in agreement with the range of 40-48% oil yield recorded in pine wood by Nanda *et al.* (2014). The result also compare favourably with the values obtained by Thangalazhy *et al. (*2010); Ingram *et al.* (2008). It was observed that high temperature produces more gas than oil, it is therefore said that bio-oil yield decrease with increase in temperature.

3.2 Physical Properties of Bio-oil

The result presented in Table 1 shows the mean values of the physical properties of bio-oil produced from *F. exasperata* wood residues. pH and density of the oil increased with decrease in temperature while moisture content increases with increase in temperature. The average value of 3.43, 1.12 kg/cm^3 and 25.85% were obtained for bio-oil pH, density and moisture content respectively. A trend of increase was also observed in pour point, cloud point and flash point of the bio-oil with increase in pyrolysis temperature having average values of 87.69, 8.33 and 4.50˚C respectively. On the other hand, increase in temperature reduces viscosity of the bio-oil with average values of 299.92cSt. The pH value of the bio-oil is in line with the result recorded by Bridgwater *et al.* 1999 that is, bio-oil generally contains considerable amount of organic acids such as formic and acetic acid which provides the bio-oil its low pH of about 2-3. Bio-oil generally behaves just like acidic and they comprise also diverse amounts of organic acids (Czernik and Bridgwater, 2004; Oasmaa and Czernik, 1999).

As a vital property (physical) that can be used in the characterization of bio-oil products, the density of pyrolysis oil is in agreement with the range of 1.2-1.3kg/dm^3 recorded by Oasmaa and Peacocke (2001), and it is influenced by water content of bio-oil. Density is said to be high when the temperature increase and by some polar solvents addition such as acetone or methanol (Czernik and Bridgwater, 2004).

Generally, when the water content in bio-oil is high, there is usually decrease in density (Oasmaa *et al*., 1997). However, moisture content of bio-oil in this study is higher than 18-19% reported by Mohamad *et al.* (2009) though it all depends on the production conditions. Also, the quantity of moisture in a product depends largely on the process parameters (Mohamad *et al.,* 2009). The low viscosity is a sign of low pour point (Oasmaa and Peacock, 2001). Oasmaa *et al*. (1997) stated that flash point values of pyrolysis liquids change from 40- 100°C.

3.3 Ultimate Analysis

Average Carbon, Hydrogen, Nitrogen and Oxygen content in the oil was 77.42, 4.77, 0.10 and 17.81% respectively. However, variation in temperature of bio-oil showed that N content decreased from 0.13% at 500°C to 0.08% at 600^0C. The percentage of H content in the oil was higher 5.13% at 500^oC and lower value of 4.41% was obtained at 600^oC. The content of C decreased with increase in temperature from 78.45% at 600^oC to 76.39% at 500^oC. Oxygen content of 18.48% was higher at 500^oC compared to 17.1%3 obtained at 600^oC (Table 1).

The average values of H, N and O obtained in this study was lower compared to the result obtained in bio-oil of pine wood H-5.31, N-1.12 and O-53.13 Fei *et al*. (2007) while C content in the Pyrolysis oil of *F. exasperata* is higher than 45.95% obtained in bio oil of pine sawdust, Braz and Cmkovic (2014).

The result shows that the bio-oil contains trace of Nitrogen 0.10% which is an indication that the oil is environment friendly. On the other hand, the amount of Oxygen content in the bio-oil is as a result of the water content present in it (Bardalai and Mahanta, 2015). Though high oxygen content in oil has some negative effects such as, reduction in heating value of the liquid and it is also responsible for corrosive nature and instability of the bio-oil. Oxygen content in this study is less than 20%, not different from oxygen content in fossil fuel, therefore, the oil is said to be considerable because of the low oxygen content Kiky *et al*. (2015); Czernik and Bridgwater (2004). It could be inferred that temperature influenced the chemical characteristics of the bio-oil Nanda *et al*. (2014).

3.4 Proximate Analysis

It was observed that bio oil produced at 500^oC gave the highest %ash content of 0.09%, but lowest %ash content of 0.05% was recorded at 600^oC. However, heating value increased with increase in temperature. The highest heating value of 34.10Mjkg^{-1} was obtained at 600^oC while lowest value of 34.08 Mjkg^{-1} was recorded at 500^oC (Table 1).

The heating value or the calorific value of any oil indicates the energy content present in it, which is a very important factor for choice of the oil for a specific application (Bardalai and Mahanta, 2015). The heating value obtained in this study is higher than the result obtained for oil from pine sawdust by (Braz and Cmkovic, 2014). Also Fei *et al* (2007) recorded a lower heating value in oil produced from corn stover. According to literature, the calorific value in most bio-oils are found within 15-36 MJ/kg Biswal *et al.* (2013), Mullen *et al.* (2010), Bertero *et al.* (2014) and Demiral *et al.* (2013) which is always lower than that of conventional petroleum fuels (40-50 MJ/kg). This study shows higher heating value wss obtained at higher temperature. It could be inferred that the lower the ash content of a fuel material, the higher the fixed carbon and by extension the heating value Oluwadare *et al*. (2016).

3.5 GC-MS of bio-oil.

Table 2 shows the results of chromatogram for bio-oil produced from the wood residue of *F. exasperata*. The results were matched with NIST library to identify the compounds present; the Identification of the compounds was based on the peak area, molecular weight and molecular formula. GC-MS chromatogram in Fig 2 detected 21peaks for 500°C and prominent peaks were observed at the retention time ranging between 0.00-26.5min. The peak at 4.21 retention times has the highest percentage 13.46% peak area; this was identified as 2, 4-dimethylheptane, with molecular formula C_9H_{20} and molecular weight of 128 while the lowest peak was obtained at 18.20 retention time with percentage peak area of 2.11%, identified as 6-methyloctadecane $C_{19}H_{40}$ with molecular weight 268. The GC-MS analysis went further to show that there was no significantly different in the bio-oil produced at the varied temperature regime except for the presence of Phthalic acid, Benzoic acid, and Oxalic acid at 500°C (Table 2).

General observation made in Fig. 5 by comparing the compounds present in each bio-oil sample shows that bio-oil produced at 500°C is composed mostly of hydrocarbons; approximately 71.95% aliphatic (C_{10}–C_{21}) and 12.27% aromatic (C_7–C_{10}). Other compounds observed were 10% oxygenated and 4.99% of Ketone.

At pyrolysis temperature of 550°C, observation made on GC-MS of bio-oil in Fig 3 detected 31 peaks (Table 3). In general, the GC–MS showed that Pyrolysis 550°C is composed mostly of 43.85% Oxygenated, hydrocarbons; approximately 24.91% aliphatic (C_{10}–C_{21}) and 16.08% are aromatic (C_7–C_{10}). Other compounds observed were 5.78% Ketones, 3.93% Nitrogenated, 4.54% Alkanes and 0.81% Alkenes (Fig 5).

The Sample GC/MS result at 600°C bio-oil of Ficus sawdust was matched with NIST library to identify the compounds (Fig 4). However, 25 peaks were detected and the retention time ranges from 3.77 to 26.49 (Table 4). The identification of the compounds was based on the peak area, molecular weight and molecular formula. At 600°C, the result was not significantly different from others except for the presence of sulphurous acid. Bio-oil produced at 600°C contains mainly of hydrocarbon at highest yield: 74.42% aliphatic and 5.98% of aromatic. Others are 11.83% alkenes and 4.08% oxygenated (Fig 5).

Out of the peaks detected in the GC-MS of Bio-oil, Oxalic acid and other acids such as phthalic acid, Benzoic acid were at 500°C, with emergence of 10-12-Pentacosadiynoic acid and 1, 2-Benzenedicarboxylic acid at 550°C and Sulphurous acid at 600°C (Acikalin, 2012) with abundant hydrocarbons which are useful Co-products use in meat browning, food flavour, preservatives, adhesives and other useful chemicals (Czernik and Bridgwater, 2004). Various compounds identified were hydrocarbons (Aliphatic and Aromatic), oxygenated, Ketone (Mahinpey *et al.*, 2009). The presences of aromatic and oxygenated compounds were said to be attributed to its biopolymer textures such as cellulose and hemicellulose (Tsai *et al.*, 2006).

The presence of Oxalic acid in bio-oil is an indication that it can be used in bleaching pulp and also used in baking powder (Wilhelm, 2002); The detected Phtalic acid in bio-oil at 500°C and 600°C was found to be an important industrial chemical, especially for the large-scale production of plasticizers for plastics and Phthalic anhydride treated with cellulose acetate gives cellulose acetate phthalate (CAP) known to have antiviral activity (Neurath, 2000).

Benzoic acid detected in pyrolysis oil at 500°C is a component of an ointment used in the treatment of fungal skin disease such as ringworm, and athlete's foot (Charles *et al.*, 2004).

4. CONCLUSION

i. The observation made shows that bio-oil yield was influenced with increase in temperature. The ultimate analysis shows that pyrolysis oil of Ficus biomass is relatively not difficult to burn because the oxygen content is low and that makes the heating value to be high. High oxygen content in pyrolysis oil is not attractive for the production of fuel.
ii. The heating value of bio-oil was observed to be high; however, the low ash content of bio-oil confirmed its high heating value.
iii. Bio-oil yield, bio-oil properties and their composition changed with increase in temperature. And from the result of GC-MS obtained, functional groups were more intense at 500ºC pyrolysis due to higher degree of cross-linking
iv. Also, GC-MS peaks showed that the bio-oil was mostly composed of hydrocarbons with the presence of Oxalic, Benzoic and Pthalic acid.
v. The low temp with observed high carbon and hydrogen content at 500ºC temperature suggested high quality fuel properties compared to the bio-oil at 600ºC.

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TABLES

Table 1. Mean values of Physical Properties, Elemental and Proximate Analysis of Bio-oil at different temperature regime

Variables	**Temperature Regime**			
	500°C	**550°C**	**600°C**	**Mean**
pH	3.77	3.42	3.09	3.43
Density (kg/dm^3)	1.14	1.12	1.11	1.12
Moisture content (%)	24.06	25.80	27.63	25.85
Kinematic viscosity	513.17	299.90	86.67	299.92
Flash point °C	74.33	87.66	101.00	87.67
Cloud point °C	7.00	8.33	9.67	8.33
Pour point °C	4.00	4.50	5.00	4.50
Coradson Carbon Residue (%)	0.20	0.23	0.26	0.23
Carbon	76.39	77.42	78.45	77.42
Hydrogen	5.13	4.76	4.41	4.77
Nitrogen	0.13	0.11	0.08	0.10
Oxygen	18.48	17.80	17.80	17.81
Volatile Matter (%)	23.98	26.28	26.57	26.28
Ash Content (%)	0.09	0.08	0.05	0.07
Fixed Carbon (%)	73.93	73.67	73.61	73.67
Heating Value Mj/Kg^1	34.08	34.09	34.10	34.09

Table 2 Bioactive Compounds detected in pyrolysis oil at 500°C

Peak	**Retention Time**	**Peak Area %**	**Molecular Weight**	**Molecular Formular**	**Bioactive Compounds**
1	3.77	5.78	92	C_7H_8	Benzene
2	3.94	4.99	112	C_8H_{16}	Cyclohexane
3	4.21	13.46	128	C_9H_{20}	2,4-dimethylheptane
4	5.19	7.28	106	C_8H_{10}	1,2-xylene dimethylbenzene
5	5.58	8.96	142	$C_{10}H_{22}$	2,7-dimethyloctane
6	6.85	7.95	142	$C_{10}H_{22}$	2-methylnonane
7	8.19	5.53	142	$C_{10}H_{22}$	2,7-dimethyloctane
8	10.09	4.31	212	$C_{15}H_{32}$	4,8-dimethyldecane
9	12.18	3.75	184	$C_{13}H_{28}$	Tridecane
10	13.91	4.53	156	$C_{11}H_{24}$	2-methyldecane
11	15.51	3.82	156	$C_{11}H_{24}$	2,3,3-trimethyloctane
12	16.88	7.29	193	$C_9H_{11}N_3O_2$	Benzoic and Phthalic acid
13	18.13	2.94	184	$C_{13}H_{28}$	3,7-dimethylundecane
14	18.20	2.11	268	$C_{19}H_{40}$	6-methyloctadecane
15	19.27	2.71	341	$C_{20}H_{39}NO_3$	Oxalic acid
16	20.36	2.66	156	$C_{11}H_{24}$	2,3,3-trimethyloctane
17	21.60	2.60	170	$C_{12}H_{26}$	3,4,5,6tetramethyloctane
18	23.15	2.41	282	$C_{20}H_{42}$	2,6,10,14 tetramethylhexadecan
19	24.53	2.26	310	$C_{22}H_{46}$	8,heptylpentadecane
20	25.60	2.34	282	$C_{20}H_{42}$	Eicosane
21	26.49	2.32	226	$C_{16}H_{34}$	Hexadecane

Table 3 Bioactive compounds detected in Pyrolysis oil at 550°C

Peak	**Retention Time**	**Peak Area %**	**Molecular Weight**	**Molecular Formular**	**Bioactive Compounds**
1	5.57	1.42	136	$C_{10}H_{16}$	2,6,6-Trimethylbicyclo [3.1.1]hept-2-ene
2	6.18	0.30	136	$C_{10}H_{16}$	Bicyclo3,1,0 hexane
3	6.28	2.75	136	$C_{10}H_{16}$	6,6-dimethyl-2-methylene
4	6.37	0.44	136	$C_{10}H_{16}$	7-methyl-3-methylene-1,6 octadiene
5	7.09	5.72	136	$C_{10}H_{16}$	Cyclohexene
6	7.28	0.30	136	$C_{10}H_{16}$	1,3,6-Octatriene
7	8.21	5.48	154	$C_{10}H_{18}O$	1,6-Octadien-3-ol
8	10.72	0.65	152	$C_8H_{12}N_2O$	Benzene, 2,4-dimethoxy-1-methyl
9	11.77	0.37	136	$C_{10}H_{16}$	1,3,6-Heptatriene,
10	11.95	0.89	204	$C_{15}H_{24}$	1H-Cyclopenta[1,3]cyclopropa[1,2]benzene
11	12.40	3.98	204	$C_{15}H_{24}$	Naphthalene
12	12.59	7.14	204	$C_{15}H_{24}$	1,5-Cyclooctadiene
13	12.86	2.27	204	$C_{15}H_{24}$	1H-Benzocycloheptene
14	13.05	7.16	204	$C_{15}H_{24}$	Cyclobutene,
15	13.12	3.10	190	$C_{15}H_{24}$	1,5,9,11-Tridecatetraene 12-methyl
16	13.29	6.11	204	$C_{15}H_{24}$	1,6,10-Dodecatriene
17	13.38	2.87	204	$C_{15}H_{24}$	Cyclohexene
18	13.55	6.05	204	$C_{15}H_{24}$	1,3,6-Octatriene
19	13.93	8.08	204	$C_{15}H_{24}$	1,6-Cyclodecadiene
20	14.06	4.53	206	$C_{15}H_{26}$	Naphthalene
21	14.20	7.12	204	$C_{15}H_{24}$	1,6,10-Dodecatriene,
22	14.45	5.12	204	$C_{15}H_{24}$	Cyclohexene,
23	14.64	2.70	204	$C_{10}H_{16}$	3,7-dimethyl-1,3,6-Octatriene
24	14.98	4.31	222	$C_{15}H_{26}O$	3,7,11-trimethyl-1,6,10-dodecatrien-3-ol
25	15.20	1.86	204	$C_{15}H_{24}$	Naphthalene
26	15.61	1.74	206	$C_{25}H_{42}O_2$	10, 12-Pentacosadiynoic acid
27	15.70	2.15	220	$C_{19}H_{34}$	4,6,9-Nonadecatriene
28	15.87	1.95	222	$C_{15}H_{26}O$	Cyclohexanemethol,4-trimethyl-3-1-methylethenyl
29	16.20	0.96	166	$C_9H_{14}O$	3,5-Dimethylcyclohex-1-ene-4-carboxaldehyde
30	17.01	1.89	152	$C_{10}H_{16}O$	2,4-Cyclohexadiene-1-methanol,
31	19.84	0.60	278	$C_{16}H_{22}O_4$	1,2-Benzenedicarboxylic acid

Table 4 Bioactive Compounds detected in Pyrolysis oil at 600°C

Peak	Retention Time	Peak Area %	Molecular Weight	Molecular Formular	Bioactive Compounds
1	3.77	1.51	92	C_7H_8	1, 3, 5-Cycloheptatriene.
2	3.94	1.50	92	C_7H_{16}	Trans-1,3 dimethylCyclohexane
3	4.21	4.08	92	C_9H_{20}	2,3,4-trimethylhexane
4	5.19	2.40	92	C_8H_{10}	1,2-dimethylbenzene
5	5.58	3.58	92	C_8H_{18}	2,4-dimethylhexane
6	6.85	4.13	112	$C_{10}H_{22}$	2,7-dimethyloctane
7	8.19	4.12	112	$C_{10}H_{22}$	2-methylnonane
8	10.09	4.79	112	$C_{12}H_{26}$	2-methylundecane
9	11.65	1.94	112	$C_{11}H_{24}$	2,3,7-trimethyloctane
10	12.18	5.61	112	$C_{13}H_{28}$	Tridecane
11	13.57	1.33	114	$C_{15}H_{32}$	2,6,11-trimethyldodecane
12	13.96	6.65	128	$C_{13}H_{28}$	Tridecane
13	14.95	2.44	114	$C_{14}H_{30}$	4,6-dimethyl dodecane
14	15.51	6.56	128	$C_{14}H_{14}$	Tetradecane
15	16.88	6.17	142	$C_{16}H_{34}$	Hexadecane
16	17.50	1.75	106	$C_{18}H_{38}$	2,6,10-trimethylpentadecane
17	18.12	5.27	106	$C_{14}H_{30}$	Tetradecane
18	18.19	4.08	106	$C_{13}H_{28}$	(Sulfurous acid)
19	19.27	4.92	106	$C_{13}H_{28}$	2-methyldodecane
20	20.36	4.83	106	$C_{13}H_{28}$	Tridecane
21	21.59	4.63	128	$C_{21}H_{44}$	2-methyleicosane
22	23.14	4.72	114	$C_{20}H_{42}$	2-methylnonadecane
23	24.53	4.45	142	$C_{24}H_{50}$	Tetracosane
24	25.60	4.36	128	$C_{14}H_{30}$	2-methyltridecane
25	26.49	4.20	128	$C_{18}H_{38}$	2-methyleicosane

FIGURES

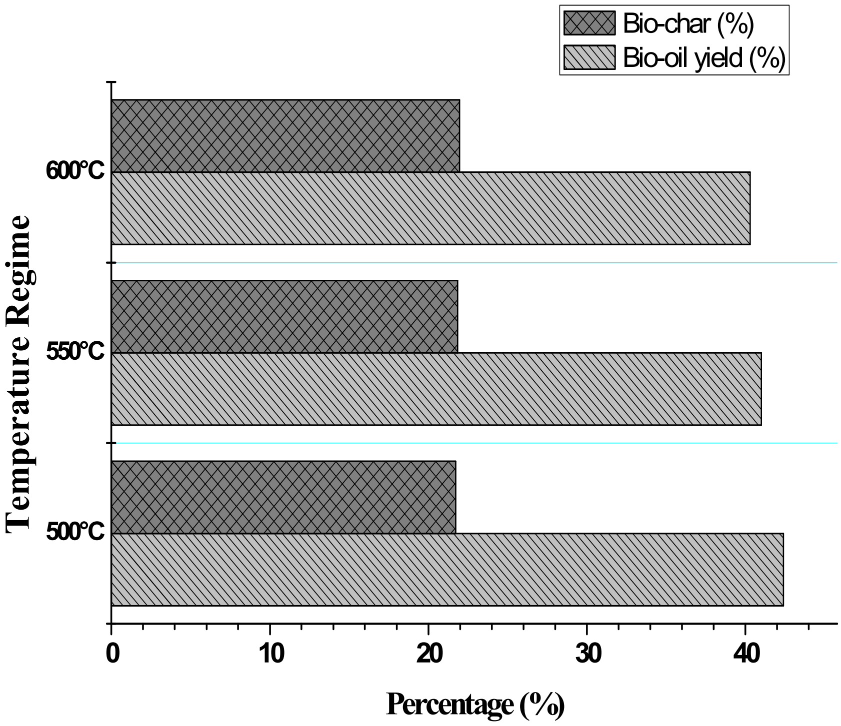

Figure 1. Percentage bio-oil yield and bio-char content

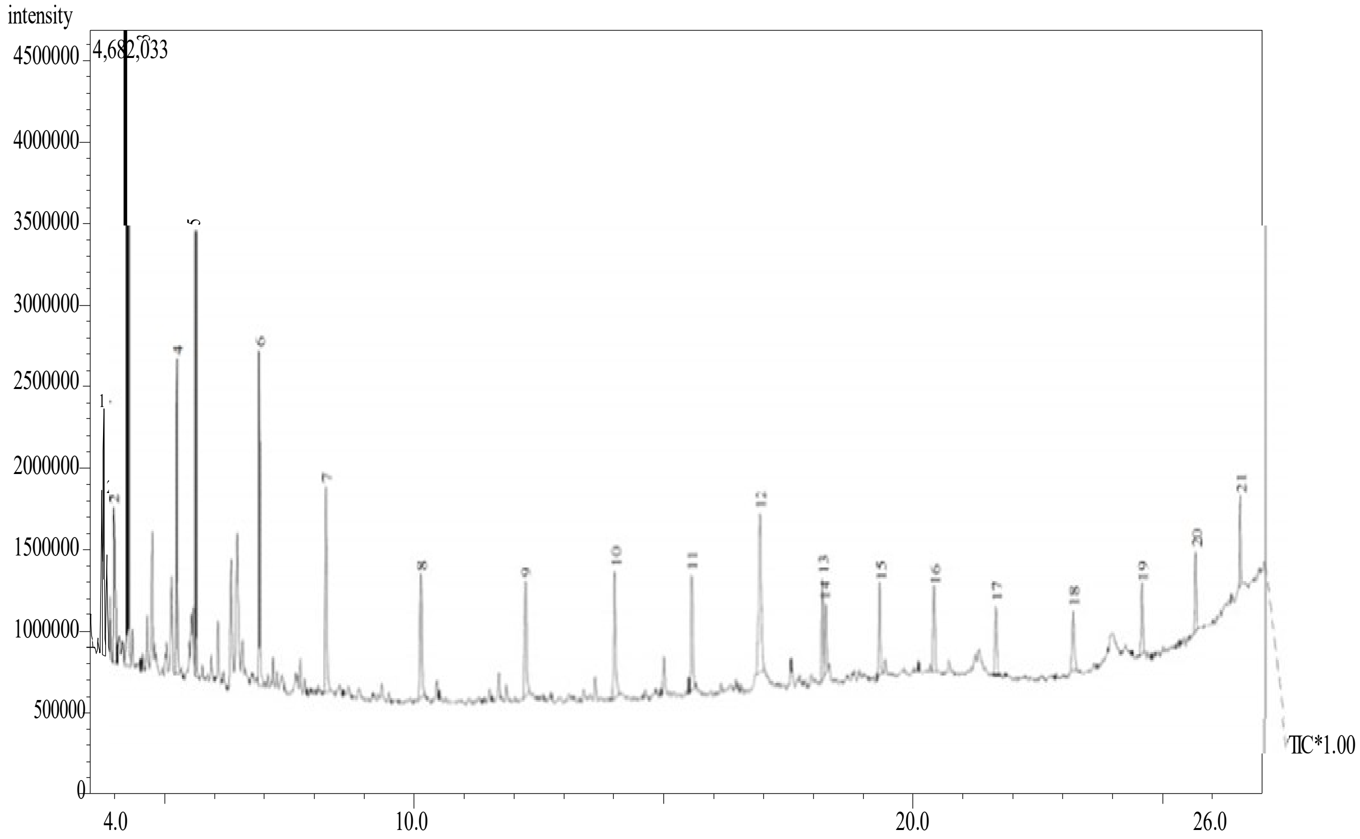

Figure 2. GC-MS chromatogram of the bio-oil produced at 500°C

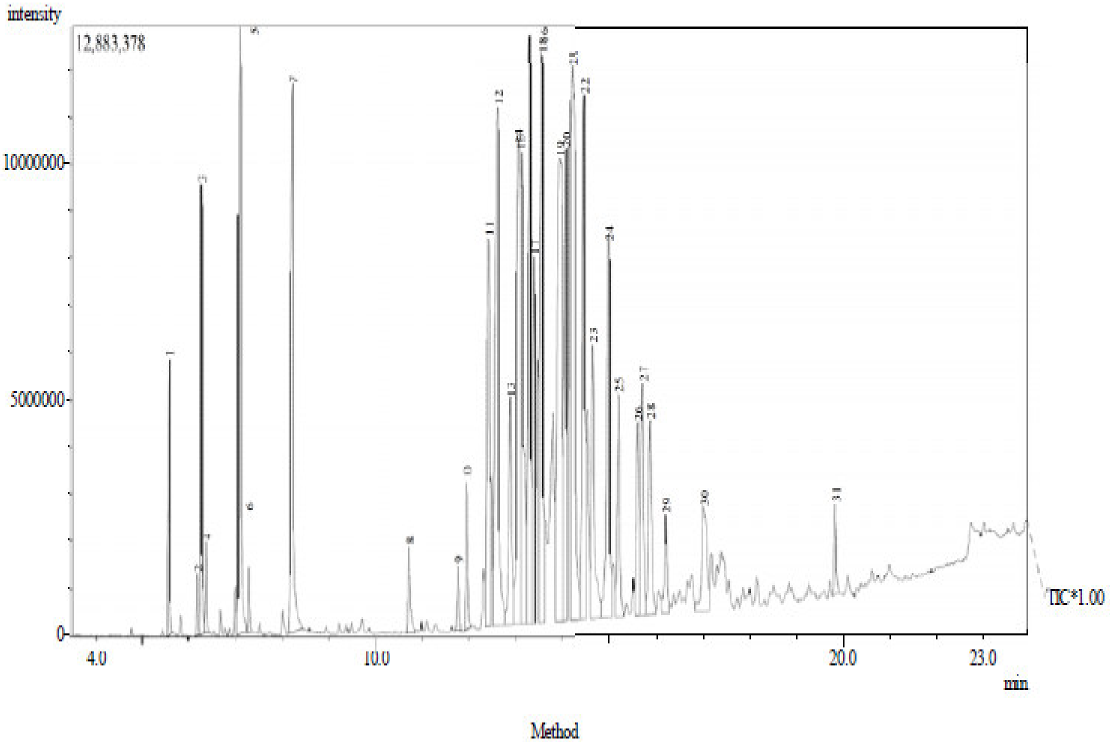

Figure 3. GC-MS of bio-oil produced at 550°C

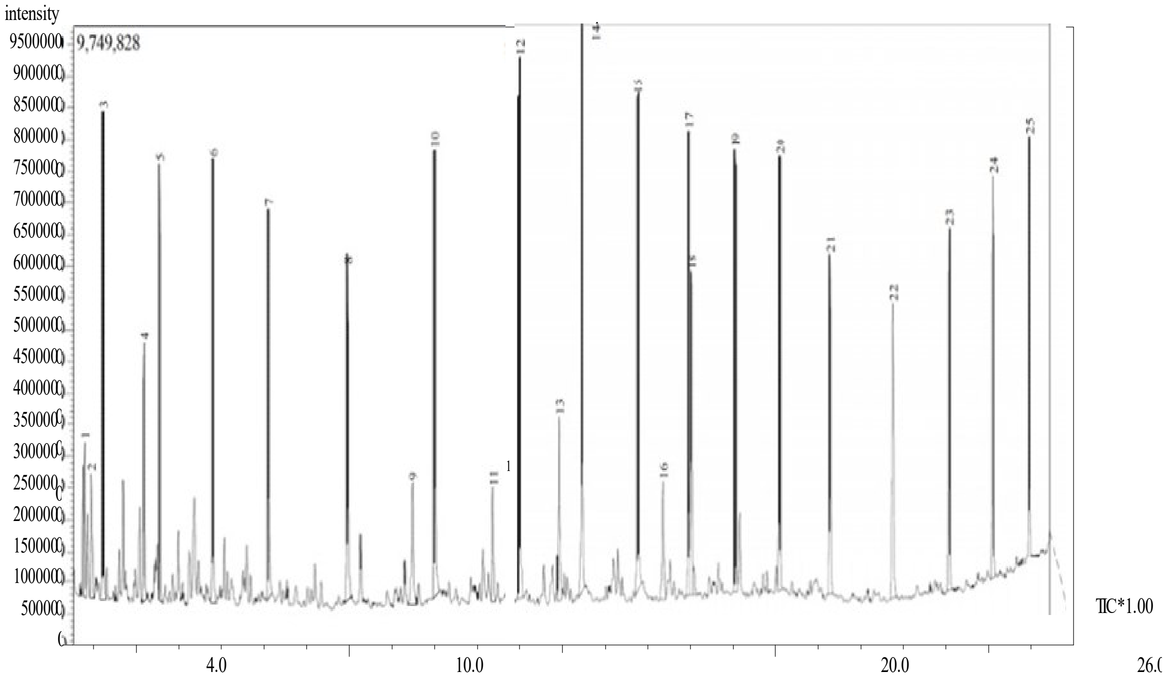

Figure 4. GC-MS of bio-oil produced at 600°C

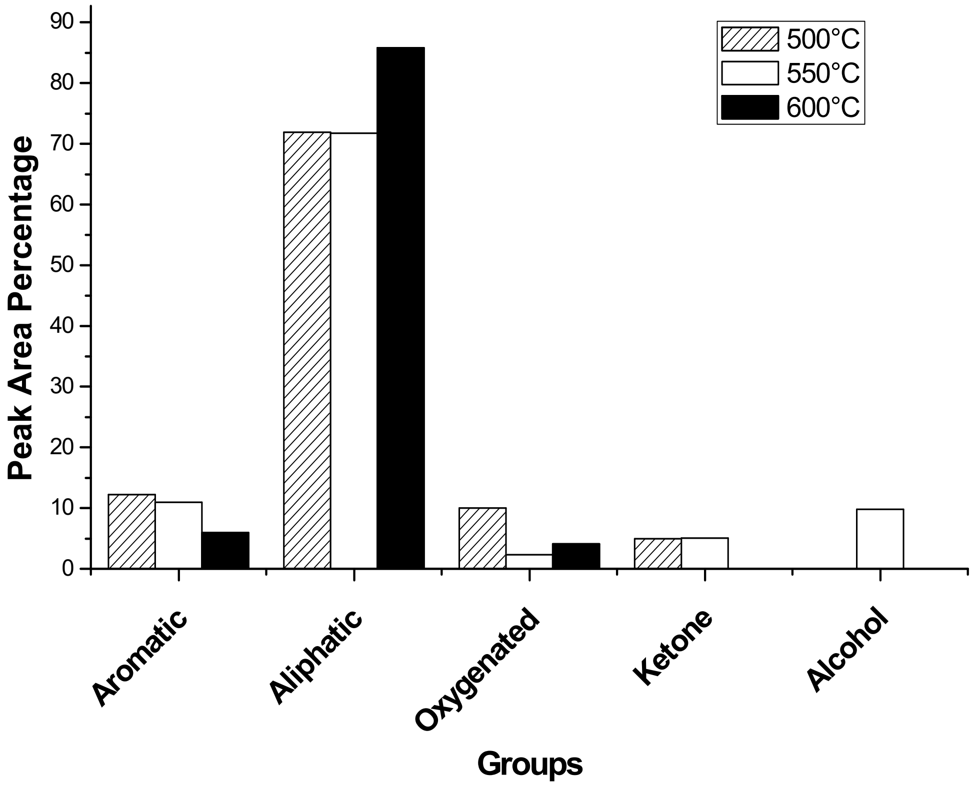

Figure 5. Compounds identified in bio-oil based on peak area percentage