Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 33, No. 1, February, 2023, pp. 39-46
Journal homepage: http://iieta.org/journals/rcma

Characterization of Adansonia Digitata (Baobab Wood) Bio-Oil and Biochar Produced Using a Fixed-Bed Tubular Reactor

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https://doi.org/10.18280/rcma.330106

Received: 1 October 2022
Accepted: 16 November 2022

Keywords:
Adansonia digitata, biochar, biomass, bio-oil, pyrolysis

ABSTRACT

The investigation of the characterization of Adansonia digitata biomass from pyrolysis in a fixed-bed tubular carbon steel reactor at temperatures of 400°C to 700°C. Firstly, proximate, ultimate, and heating value analyses of the raw biomass were obtained prior to experimental runs via the fast pyrolysis process; thereafter, the quality of the bio-oil and biochar yields for bioenergy and industrial applications was investigated using the following analyses: higher heating values (HHV), lower heating values (LHV), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FT-IR). Optimum bio-oil (52.70 wt%) and bio-char (40 wt%) yields were obtained at temperatures of 500 and 400°C, respectively. GC-MS analysis of the yielded biooil revealed a higher percentage of oleic acid, phenol, methanol, and ketone among the fuel compositions, whereas the bio-oil chemical composition includes carbon (70.99%), hydrogen (13.40%), nitrogen (0.54%), oxygen (15.01%), and sulfur (0.06%), flash (81) and pour points (-7) for bio-oil with HHV (30.75 MJ/kg) and LHV (27). The results obtained demonstrated that the properties of products can serve as a waste management strategy, sorbent, soil enhancer, and biofuel industry application.

1. INTRODUCTION

Renewable energy is considered an attractive and reliable energy source that is abundantly available globally [1]. Today's research on renewable energy has made it possible to harness energy from it in numerous forms that have been confirmed to be safe for the environment and less expensive [2, 3]. The use of renewable energy has increased in comparison to other forms of energy available on Earth due to their devastating effects; one such example is hydrocarbons (fossil fuel), which is one of the most commonly consumed energies daily and has a negative impact on the earth and all of its beings in it, such as increasing global warming, pollution, climate change, and ozone depletion, among others [4, 5]. However, Kan et al. [6] reported that renewable energy has been more biomass-based because it presently contributes about 13% of the world's energy supply. Its composition includes 38–50% of cellulose, 23–32% of hemicellulose, 15–25% of lignin, and different segments (i.e., inorganic species and extractives) with a total percentage of 5–13% in biomass [7, 8]. The pros of the use of biomass as a source of fuel are numerous and include: vast availability; fuel yield optimization; various energy forms that can be harnessed from it; cheapness in terms of raw material cost; etc. Furthermore, since biofuels are obtained from biomass, they fundamentally reduce the harmful emission of gases, for example, SOx, and NOx [9]. The advantage of utilizing biomass is precisely its renewable nature and its capacity to re-use the greenhouse gas (CO_2) that is released to the surrounding environment [10, 11]. Also, the biofuels obtained are applicable to the bioenergy and industrial sectors [12]. Energy generation from a higher percentage of biomass is required to serve as an alternative to fossil fuels while minimizing environmental impact during the conversion process of biomass to gaseous fuels, solid fuels, heat, electricity, liquids, and other products and chemicals [13]. The use of wood for producing electricity and heat has attracted serious interest in parts of the world due to its endogenously accessible, affordable, and renewable fuel. The fast growth in the availability of woody biomass and the current improvement in technologies possessing more efficiency and effectiveness with low levels of emission will enable woody biomass to have a more attractive advantage as a fuel alternative.

Biomass is said to have been providing energy for mankind for a very long epoch in history; hence, many literary works have termed it a major source of energy. Energy in biomass can be found in materials like vegetable oils, wood, straw, and agricultural waste. Bioenergy is renewable energy gained from organic materials such as animals or plants. Biomass is a very significant source of energy production, supplied by agriculture and other waste materials. The production of transport fuel, electricity, and even heat has been achievable

with most of these technologies (anaerobic digestion, pyrolysis, combustion, gasification, and hydrolysis) through the use of biomass materials [14]. This technology has the potential to aid in the resolution of environmental issues; most of these conversion processes are thermo- and biochemical ones that involve the thermal destruction of biomass into fuel char, gases, and liquids in the absence of oxygen. It is often seen to mean anhydrous, signifying that there is no water [15]. The process of thermochemical conversion is highly established, and it's a technology that was originally developed for the processing of chemical and petroleum products; therefore, the application of agricultural biomass in this procedure makes it challenging as a result of complex issues such as oxygen, sulfur, nitrogen, moisture, and other metal contents [16]. However, thermochemical processes include; pyrolysis, carbonization, torrefaction, liquefaction, and gasification, which are reliable in the conversion of biomass into bio-oil, charcoal, syn-gas, etc. [17]. As a result of the current energy crisis in Nigeria, there have been vast efforts in the research and development of the various thermochemical conversion methods of biomass into different forms of fuels in a bid to ensure the availability of sustainable energies [18]. Thermochemical conversion is one of the most effective methods of biomass conversion into biofuels [19]. It deals with the decomposition of biomass under controlled heating or oxidation at a high temperature above 150℃ to produce biofuels such as solid, liquid, and gaseous fuels, etc.

The conversion of biomass to bioenergy or fuel requires different conversion processes, such as the thermal process and the biochemical process. Guedes et al. [20] analysis of the various biomass conversion processes highlighted the two processes' advantages and shortcomings. The thermochemical processes (gasification, torrefaction, and pyrolysis) require the combustion of the biomass to harness heat and power. Gasification is a promising method in the conversion of biomass into fuel, but some other factors limit its affordability, such as, the produced gas is expensive to store or transport, which therefore, demands instant use of the fuel. The thermal degradation of biomass via the pyrolysis method has gained popularity because it is efficient, has a low operational cost, reduces feedstock transportation from the point of production to the consumption destination, and is capable of producing liquid, solid, and gaseous fuel in the absence of oxygen, unlike torrefaction, which yields mainly solid fuel [21]. Also, Goodman [22] reported that pyrolysis favors high production of bio-oil at a yield of about 70%, and with the high presence of complex organic compounds such as aromatic hydrocarbons, ether, alcohol, organic acids, sugars, phenols, etc., it can be utilized for chemical production. Pyrolysis is classified as fast, intermediate, and slow pyrolysis. Also, fast pyrolysis among the pyrolysis methods has been mentioned to ensure maximum bio-oil yield [23]. Fast pyrolysis is a direct thermochemical technique. During this process, the feed material is heated at an increased temperature range of 300-800℃ at a faster heating rate of 10-200℃/s with a short solid resistance time of 0.5-10 sec and with a fine particle size less than 1 mm in the feedstock without oxygen [24]. Due to the high heating involved in fast pyrolysis, the biomass particle sizes are often small, which affects the type of bio-oil generated.

Pyrolytic products could be utilized as feedstock for manufacturing or chemical facilities, or they could be used as fuels after or before initial upgrading. Additionally, the items promote a cleaner environment while still having a high economic worth. In the study by Barik [25], a fixed bed reactor was used to perform fast pyrolysis on microalgae, maize cobs, and rice husk at temperatures between 300 and 700℃. The temperature range for maximum yields for bio-char was 300 to 350℃, bio-oil was 350 to 450℃; and non-condensable gas was 450 and 650℃. In the empirical study conducted by [26] on the quick pyrolysis-based breakdown of sawdust, with the variable factors kept constant and the temperature range in the reactor was optimized from 450 to 540℃ in order to examine the relationship between the yields of the products. The type and size of the goods were found to be greatly influenced by temperature, according to the results. According to Chowdhury et al. [27], the percentage of the biomass's proximate analysis, ultimate analysis and the heating values physicochemical characteristics has a significant impact on pyrolysis yields. Bonfim and De-Paula [28] stated that one of the cons involved in the conversion of biomass into various fuels is the Ash content which has been noted to be harmful and contaminate the environment such as water sources, respiratory issues, also reduction infertility of the earth soil [29]. Junna et al. [30] investigated the parametric study of flash pyrolysis of Jatropha oil cake using nitrogen (N_2) in an electrically heated fluidized bed reactor. Results showed that the pyrolysis oil had a calorific value of 19.66 MJ/kg and could be upgraded to a higher quality bio-fuel or serve as a source of low-grade fuel directly. An investigation of the effects of the pyrolysis residence time and temperature on various biochar yields were carried out by Piloto-Rodríguez et al. [31], it was observed that an increase in residence time at about 8 hours at 300℃ reduce the yield of biochar generated while the residence time had little effects on the biochar yield at 600℃, instead, it led to a change in the surface and internal structure of the biochar. With this, there has been a call for more research on understanding the thermal conversion behavior of various biomass before utilization, by investigating the degradation process will lead to optimization of the biomass properties and hence, improve on the yields while reducing the negative side involve in the biomass thermo-conversion process.

The bio-oil yield from the pyrolysis process possessed a high percentage of oxygen, low percentage of carbon and oxygen contents in comparison with fossil fuel [32], wealthy functional groups and dark-brown organic liquid with a burly bitter smell [33]. This method is industrially achievable and at a low cost. However, most of the bio-oil yields are usually inferior due to their high moisture content, high corrosive and viscous nature as well as low heating value, and thermal instability. This study focused on the extraction of both liquid and solid biofuel from *Adansonia digitata* (baobab wood) using fast pyrolysis technique. The solid fuel, biochar and the liquid fuel, biooil were then characterized using SEM, FT-IR and GC-MS techniques to analyze the properties of the yielded biofuels.

2. MATERIALS AND METHODS

2.1 Materials

The biomass sample used in this analysis was collected from the trunk of Baobao wood [*Adansonia digitata* (*AD*)] waste processing facility in Ota, Southern Nigeria. Using distilled water, the contaminants contained in the wood sample was removed before being sun-dried for three days then milled

to fine particle sizes sieved to a uniform particle size of 0.5 mm (500) as indicated in the studies of Nomanbhay et al. [34]. All the processes were carried out in the mechanical central workshop at Bells University of Technology, Ota, Nigeria. The proximate and elemental analysis of the biomass was carriedout on the processed dried samples, precisely measured and stored at room temperature in sealed containers. Correlation equations were then utilized to determine the presence of HHV.

2.2 Pyrolysis setup and experimental procedure

The pyrolysis set-up comprised of a tubular fixed-bed insulated reactor, gas collector, condenser, ice bath, PID temperature controller, inert gas flow system, and electric heater of 4 kW capacities (Figure 1). The biomass sample was fed into the fixed-bed reactor, covered, and properly fastened for a run at a pre-set furnace temperature range of 400, 500, 600, and 700℃ with constant heating rate (12.5℃/min), residence time (25 min) and nitrogen flowrate (125 mL/min) to maintain inert environment. The bio-water mixture which was automatically separated into bio-oil and water were generated by passing the gas through a condenser. The weight of product yield was determined (bio-oil and bio-biochar) by obtaining the mass balance (bio-gas). By running the gas through a condenser, a bio-water combination was created that automatically separated into bio-oil and water. Bio-oil and bio-char were used to calculate the weight of the product yield, while bio-gas was used to calculate the mass balance [35, 36]. The resulting bio-oil was then kept in a refrigerated space of 20℃.

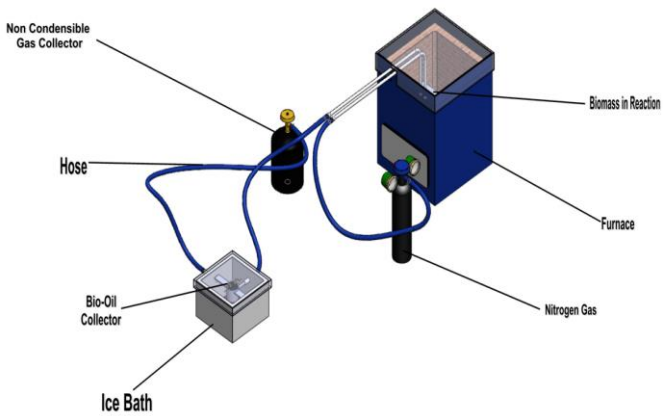

Figure 1. Pyrolysis setup

2.3 Biomass and bio-oil characterization

2.3.1 Elemental composition of sample

The elemental composition C, H, N, O, and S of the biomass and bio-oil was determined using Eltra elemental analyzer in line with ASTM D5373 and ASTM D4239-11 standard, while the proximate analysis (MC, FC, VM, Ash) was obtained using ASTM E872-82 and ASTM D1102-84.34 standard.

2.3.2 Heating values of bio-oil

Using ASTM D2015-00 standard, bomb calorimeter was relied upon in determining the higher heating value (HHV) of the biomass yields. Where, a crucible with about 2 g of biomass sample was placed in a metallic bomb with a high-pressure oxygen atmosphere at the present temperature (25℃). The bomb calorimeter was then used to present the results. Also, Eq. (1) was used to derive the lower heating value (LHV) as proposed by Goodman et al. [22].

$$HV\ (MJ/kg) = HHV - (0.218 \times H) \quad (1)$$

where, H=weight% of hydrogen obtained via ultimate analysis.

2.3.3 GC/MS analysis

The analysis of the GC/MS was carried out using Shimadzu gas chromatograph analyzer (Model QP2010). The analyzer operation was carried out in an atmosphere filled with helium (He) with a 1.5 ml min^{-1} flow rate, having 40 and 700 m/z mass scanning range.

2.3.4 SEM and FTIR analysis of bio-char

Geometry and surface morphology of bio-char was determined using FEI Nova Nanolab 200 scanning electron microscope. Scanning Electron Microscope-Energy Dispersive X-ray spectroscopy (SEM-EDX) and Fourier-transform infrared spectroscopy (FT-IR) was used for classification of chemical compounds, detect functional groups, and characterize covalent bonding.

3. RESULTS AND DISCUSSION

3.1 Physio-chemical properties

Proximate and ultimate analysis results of the biomass sample, *Adansonia digitata* (baobab wood) is presented in Table 1. The results obtained from ultimate analysis shows that the elemental compositions of Carbon, Hydrogen, Nitrogen, Oxygen and sulfur are 47.53, 5.78, 1.57, 44.15%, and 0.97 wt% respectively. The proximate analysis results showed Moisture content (8.04 wt%), volatile matter (71.20 wt%), Fixed carbon (19.41 wt%), and ash content (1.35 wt%). The high volatile matter (72.20 wt%) present in the biomass influenced the yield of bio-oil due to their ability to produce high devolatilization and burn gases in the reactor [13, 16].

Table 1. Proximate and ultimate analysis of *Adansonia digitata (AD)* raw sample

Ultimate Analysis		Proximate Analysis	
component	**composition (wt%)**	**component**	**composition (wt%)**
C	47.53	MC	8.04
H	5.78	VM	72.20
N	1.57	FC	19.41
O	44.15	Ash	0.35
S	0.97		
HHV (MJ/kg)	16.27	LHV (MJ/kg)	15.60

**key; MC; VM; FC; LHV; HHV stands for Moisture content; Volatile Mater; Fixed carbon; lower heating value; higher heating value respectively.

The low ash content (1.35 wt%) which is the amount of impurities left after the biomass is burned makes the biomass more suitable for pyrolysis process as a high ash content increase the slag formation, harmful deposit, risk of fouling and corrosion in the reactor during pyrolysis process. Hence, leading to extensive equipment maintenance [37]. Also, the low ash content at 1.35 wt% at 500℃ during the pyrolysis process indicates a significant bio-oil yield, as the low percentage of ash content reduce the catalytically cracking of the bio-oil into NCG [38, 39]. The wood samples had a larger

proportion of fixed carbon (19.41 wt%) than the fixed carbon in wood residues (11–15 wt%), indicating that they contained more energy and had a higher heating value of 16.27 MJ/kg [4, 37]. The low ash content falls within the range of 1.08 wt% and 1.93 wt% reported by [37, 40] and moisture content value of 8.70 wt% obtained from the results are appropriate for wood fuels. NOx and SOX gas generation is restricted by the low sulfur content (0.97 wt%) and nitrogen concentration (1.57 wt%). the reduction of environmental contamination [41]. The high Carbon and Hydrogen contents shows a good hydrocarbons content that would be released during pyrolysis process.

Table 2 presents the chemical compositions and bio-oil yields properties. From the chemical analysis, the major constituents include; Carbon (70.99 wt%), Hydrogen (13.40 wt%), Nitrogen (0.54 wt%), Oxygen (15.01 wt%), and sulfur (<0.06 wt%). The low Sulfur and Nitrogen contents indicate that the fuel is environmentally friendly due to its low emission of SO_x and NO_x gases that can be utilized by plants for photosynthesis [41]. HHV (30.75 MJ/kg) and LHV (27.83 MJ/kg) are in agreement with the report [4, 15, 39]. These values are lower than the heating value of fossil fuel due to the present of moisture content in the raw biomass prior to experimentation [38]. The flash (81) and pour points (-7) of the bio-oil are within the flammability when compared with that of diesel with a flash point (75) and pour points (-2), which are very similar. Furthermore, lower flash points are suitable for the bio-oil's flammability and volatility qualities, while pour point indicates the temperature at which a bio-oil ceases to flow due to the formation of wax crystals that increase its viscosity. The biooil's pH, density, Viscosity, and API gravity values are in agreement with the results on bio-oils from biomass reported by Singh et al. [10]. Bio-oil yield pH value (4.9) compared to that of diesel (5.5-8.0) shows that the bio-oil lacks behind while density at 40°C (0.98 g/cm^3) showed close comparison with those of fuel oil (0.910 g/cm^3), furnace oil (0.92 g/cm^3), and heavy fuel oil (0.989 g/cm^3). The increase in HHV (37.75 MJ/kg) in the bio-oil yield baobab wood was attributed to their high carbon (51.99 wt%) and hydrogen contents (6.9 wt%) relative to the amount of oxygen contents as obtained during ultimate analysis [4, 42].

Table 2. Bio-oil fuel properties at 500°C

Properties	Diesel	Heavy fuel oil	Bio-oil
Flash point	75	-	81
Pour point	-2	-	-7
pH			4.90
Density (g/ml)@40°C	0.78	0.94	0.98
Viscosity (cst (mm^2/s)@ 40°C	1.8 -4.1	180	4.56
API gravity	45.0 -46.0	40	19.18
Bio-oil Elemental Analysis (db. wt%)			
C	-	-	51.99
H	-	-	6.90
N	-	-	0.54
O	-	-	40.51
S	-	-	0.06
HHV (MJ/kg)	45.0 -46.0	40	30.75
LHV (MJ/kg)			27.83

3.2 Influence of temperature on biomass yields

The influence of temperature on *Adansonia digitata (AD)* products yield was recorded within the temperature range of 400 to 700°C as presented in Figure 2. Results showed that temperature had a direct influence on the bio-oil yield, increment in temperature resulted to the increase in bio-oil and gas yield, this can be attributed to the availability of additional energy to disintegrate the biomass bonds [20]. At the initial stage, the biochar yield increased at temperature range <400°C, while the bio-oil products decreased due to incomplete pyrolysis process at low temperature. Hence, leading to high yield of biochar and low production of bio-oil. For the influence of the temperature on the yielded char, it was observed that char yields decreased with a value of 40 wt.% to 24.80 wt.% as the temperature continues to rise. Continuous pyrolysis process led to an increase in bio-oil yield from 47.20 wt.% at 400°C. to 52.70 wt.% at 500°C and decreases further as 50.80wt.% and 45.60 wt.% at 600 and 700°C respectively due to secondary cracking reaction of high-molecular hydrocarbon [43]. For gas yield, increase in temperature from 400°C to 700°C resulted to increase in non-condensble gases yield from 12.60wt.% to 29.60 wt.% which could be attributed to secondary cracking which decreased bio-oil yield and enhance the yield of NCG. This result is in strong agreement with the report of [44].

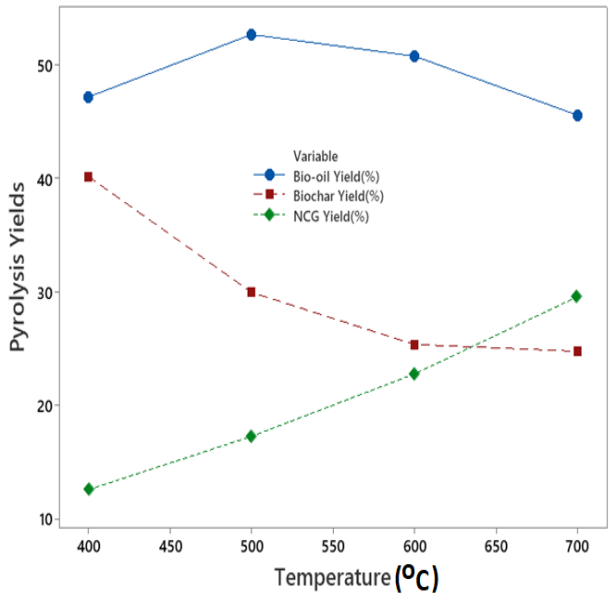

Figure 2. Product yield distribution

3.3 Bio-oil chemical analysis

GC-MS analysis is significant in identifying the presence of about thirty compounds which consisted of 98.8% of the volatile extract in the bio-oil yields. The Terpenoids and most abundant components, *trans*-2-furanmethanol (5%), palmitic acid (5.8%), 9-octadecenal (10%), *cis*-10-pentadecen-1-ol (12.5%), *trans*-2-octadecadecen-1-ol (15%), oleic acid (22%) and other compounds (39.7%) made up the extract as presented in Table 3. The chemical contents present in the fuel makes the biofuel an important raw feedstock in industries such as pharmaceutical and likewise dye industries. Also, the biodiesel is suitable for power generation via internal combustion engines due to the confirmed presence of compounds like; ketone, oleic/fatty acids, esters, phenolic and alcohol compounds. These chemical compositions of the biomass agree with the pyrolysis results reported on woody biomass by Oyebanji et al. [36].

Table 3. Chemical composition of *Adansonia digitata (AD)* at 500

Compounds	Retention Index	Percentage Composition	MF	MW
Tetramethylmethane	434	0.4	C_5H_{12}	72
2-methylfuran	642	0.9	C_5H_6O	82
trans-2-octadecadecen-1-ol	2061	15.00	$C_{18}H_{36}O$	268
oleic acid	2175	22.00	$C_{18}H_{34}O_2$	282
3-methylfuran	643	0.8	C_5H_6O	82
Trimethylnitromethane	716	0.5	$C_4H_9NO_2$	103
2-pentynal	724	1.4	C_5H_6O	82
palmitic acid	1968	5.8	$C_{16}H_{32}O_2$	256
Dimethylvinylmethanol	600	0.5	$C_5H_{10}O$	86
4-ethyl-1,3-dioxolane	738	0.5	$C_5H_{10}O_2$	102
vinyl butyrate	775	0.5	$C_6H_{10}O_2$	114
1-hydroxy-2-butanone	798	1.0	$C_4H_8O_2$	88
cis-3-octene	823	1.0	C_8H_{16}	112
trans-3-octene	824	1.5	C_8H_{16}	112
2-methoxymethyltetrahydrofuran	825	0.5	$C_6H_{12}O$	116
2,4-pentadienoic acid	873	1.0	$C_5H_6O_2$	98
trans-2-furanmethanol	885	5.0	$C_5H_6O_2$	98
5-methyl-3-methylene-5-hexen-2-one	887	1.5	$C_8H_{12}O$	124
tetrahydro-2-furanmethanol	892	0.5	$C_5H_{10}O_2$	
Corylone	972	1	$C_6H_8O_2$	112
Butylglyoxylate	973	0.5	$C_6H_{10}O_3$	130
3-hydroxy-6-methylpyridazine	975	1	$C_5H_6N_2O$	110
3-methyl-1,2-cyclopentanedione	1003	0.5	C_6H_8O	112
methyl-1-cyclohexenyl ketone	1027	5.5	$C_8H_{12}O$	124
methyl 2-butyl-2-cyclopropene-1-carboxylate	1057	1	$C_9H_{14}O_2$	154
o-guaiacol	1090	2	$C_7H_8O_2$	124
Syringol	1279	0.7	$C_5H_8N_2$	96
2,4-dimethoxyphenol	1279	1.5	$C_8H_{10}O_3$	154
3-nonynoic acid	1290	0.7	$C_9H_{14}O_2$	154
1-methyl-3-nitro-2(1H)-pyridinone	1376	1	$C_6H_6N_2O_3$	154
pelargic acid	1272	1	$C_9H_{18}O_2$	158
cis-10-pentadecen-1-ol	1763	12.5	$C_{15}H_{30}O$	226
n-pentadecanoic acid	1869	2	$C_{15}H_{30}O_2$	242
9-octadecenal	2007	10	$C_{18}H_{34}O$	266
Percentage Total		**98.8**	1.5	

3.4 Biochar analyses

Characteristics of biochar are represented in Table 4; ash content of biochar and biomass were 1.60 and 0.35 wt% at 500 respectively. The biomass ash content was lower than bio-char ash content because of the volatilization of organic matter during pyrolysis while non-volatile ashes remained completely in biomass particles. The average HHV of 27.50 MJ/kg and average LHV of 25.49 MJ/kg obtained from the results are reasonable properties of biomass [29]. Bio-char morphologies are presented in Figure 3 with SEM micrographs magnifications of 5000x, 6000x, and 8000x respectively. The cloudy and cloggy formation was noticed in biochar micrographs was attributed to rapid heat transfer process within the biochar pore during pyrolysis process The present of pores with difference sizes and shape within the biochar surfaces is attributed to the emission of volatile matter during pyrolysis process. Hence, the biochars are applicable as catalyst for energy generation such as dry methane reforming to produce clean fuels e.g., syngas and hydrogen [45].

This shows that the pyrolysis temperature did not lead to total collapse or destruction of the cell walls of the biochars. Also, there are whitish deposits on the surfaces of the biochars. These deposits are the inorganic materials such as potassium that were volatilized during pyrolysis [44].

Figure 4 presents FTIR analysis of the biochar yields, in the analysis, ten peaks were attained; peak at 3850.60 – 3368 cm^{-1} depicts O–H stretching carboxylic group; a band at 2919 – 2356.62 cm^{-1} can be attributed to C–H stretching vibration of methylene, methyl and methoxy groups; a peak at 1709.38 cm^{-1} indicates conjugated C=C phenyl rings; peak at 1605.10 cm^{-1} corresponds to C–O stretch, secondary alcohol; peak at 1443 cm^{-1} corresponded to C–H in-plane bends; peak at 1373.54 cm^{-1} revealing of C–H variable alkenes groups; peak at 1034 cm^{-1} revealing of C–O secondary alcohol stretch and peak at 722.27 cm^{-1} indicate the presence of silica The existence of any functional groups like; methyl, methylene, methoxy was not noticed, phenyl, alkenes groups, and alcohol suggest that all the biochar could be used as fuel to generate energy [36]. It can be concluded that ***Adansonia digitata*** bio-char obtained could be utilized in various area such as; a fuel either mixed or not mixed, pollutant adsorbent, soil quality enhancer etc. [43, 46]. This study provide a sustainable material that is viable in energy generation [47-50].

Table 4. ***Adansonia digitata (AD)*** bio-char yields proximate and ultimate analysis at **500**℃

Ultimate Analysis		Proximate Analysis	
Constituent (s)	**Composition (%)**	**Constituent (s)**	**Composition (%)**
C	60.30	Moisture Content	8.60
H	24.21	Volatile matter	14.22
N	0.27	Fixed Carbon	75.47
O	15.20	Ash	1.60

S	0.02		
HHV (MJ/kg)	32.51	LHV (MJ/kg)	27.23

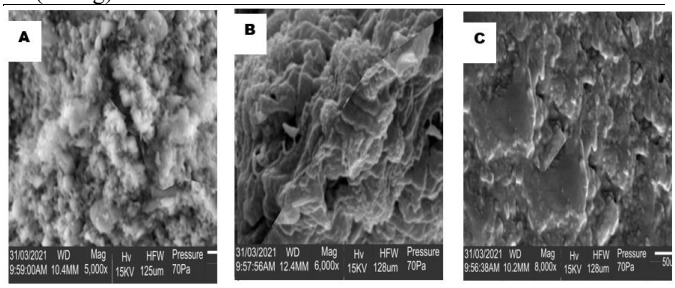

Figure 3. SEM of ***Adansonia digitata (AD)*** at 5000x, 6000x, 8000x respectively

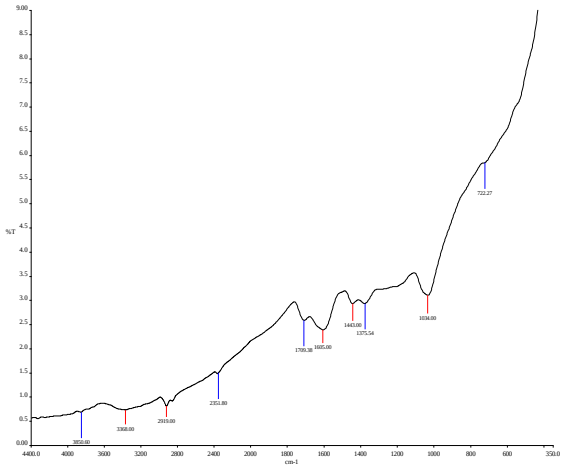

Figure 4. Biomass *Adansonia digitata* Fourier Transform Infrared (FTIR) spectra showing the bio-char yields

4. CONCLUSION

The pyrolysis analysis of biomass from *Adansonia digitata* wood was investigated. The characterization of the biochar and biooil yielded within the temperature range of 400 to 700°C showed reliable experimental values that were comparable to those of other woody biomass materials' liquid and solid products. An optimum biochar (40 wt%), bio-oil (52.7 wt%), and NCG (29.6 wt%) yield were attained at 400, 500, and 700°C, respectively. Results from GC-MS analysis, proximate analysis, ultimate analysis, and evaluations of the fuel properties were also obtained. The high heating value (37.75 MJ/kg) of the bio-oil was attributed to its high carbon (51.99 wt%) and hydrogen (6.9 wt%) contents. Hence, the bio-oil is useful as fuel due to its high density (0.98 g/cm^3). Likewise, the flash (81) and pour points (-7) of the bio-oil are within the range of flammability when compared with those of diesel oil, whose flash and pour points are 75 and -2, respectively. The results of the GC-MS analysis established the existence of some compounds such as aromatic hydrocarbons, nitrogenous base compounds; fatty acids, and phenolic compounds. With the observation of these compounds in the biomass, it indicates the usability of the biofuel yields as biodiesel for combustion and can also serve as a chemical source for industrial use, although more improvement of the fuel properties would be of good advantage towards renewable energy applications. The presence of pores with different sizes and shapes within the biochar surfaces is attributed to the emission of volatile matter during the pyrolysis process. Hence, the biochars are applicable as catalysts for energy generation, such as dry methane reforming to produce clean fuels such as syngas and hydrogen.

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