Physical Characteristics Study of Roots (Wood) as Fuel Application

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***Abstract*—The depletion of fossil fuel has increased due to increasing demand of its usage. Forestry biomass is currently seen as the potential source of energy as it is being used to produce biofuel as one of the substitute for fossil fuels. The physical characterization study of forestry biomass is essential in order to identify its efficiency as fossil fuel substitute. This study presents the physical characterization of the chosen forestry biomass, roots (wood) as fuel application by undergoing several analyses such as proximate analysis, Thermogravimetric Analysis (TGA), Fourier Transform Infrared (FTIR) Analysis and heating value. The proximate analysis results indicated that root (woods) contains 4.79% moisture, 51.92% volatile matter, 4.72% ash and 38.57% fixed carbon; respectively. The study on the thermogravimetric behaviour of the roots (wood) indicates that the thermal decomposition of biomass sample decomposed at temperature above 250°C. The presence of functional group of aliphatic, aldehyde, aromatic and alkane represented for FTIR analysis. Hence, roots (wood) are potential biomass feedstock as fuel source as energy value of proposed study was achieved efficiently.**

Keywords—Biomass, Biofuel, Proximate and Thermogravimetric Analysis, FTIR, Heating Value

I. INTRODUCTION

Fossil fuels have been the main source of energy globally in which more than 81% of the world's primary energy depends on it [1]. Fossil fuel was among the resources that plays a significant role in this world. However, the production of fossil fuels gave a great impact on the environment globally.

Climate change which has been a global issue is one of the impacts of fossil fuel production. The burning of fossil fuel increases the carbon dioxide level in our atmosphere [2]. According to Ghani et al., (2013), the amount of carbon dioxide (CO_2) released to the atmosphere has risen more than 3% per annum since year 2000. This rise in emission of carbon dioxide (CO_2) has driven the search for alternative sources which can replace fossil fuels, renewable and reduced the impact on the environment [3].

Alternative sources such as forestry and agricultural wastes were the potential of the most important replacement for fossil fuels in developing countries [4]. First generation of feedstock for the production biofuels were food corps such as sugarcane and corn, while the second generation of feedstock includes agricultural, forestry and municipal waste. Production of biofuels has moved towards second generation feedstocks because the feedstocks were abundantly available locally in most countries [3].

Referring to Ghani et al., (2013) and Olanders & Steenari, (1995), the research study on the physical characterization of wood and straw by using rubber-wood-sawdust and ashes was conducted which has led us to evaluate the roots (wood) physical characteristics.

The efficiency of roots (wood) as a substitute for fossil fuels can be measured by conducting physical characterization analysis which includes proximate analysis, TGA, FTIR analysis and heating value determination. Proximate analysis presents the moisture content, volatile matter, fixed carbon and ash content of the roots (wood) biomass. TGA presents the thermal decomposition of roots (wood) during slow pyrolysis while FTIR presents the functional groups contain in the biomass. The determination of heating value refers to the amount of energy liberated when the fuel is completely burnt. Each parameter contributes significantly towards the heating value of the roots (wood) biomass.

II. METHODOLOGY

Experimental phase includes sample preparation, proximate analysis, TGA, FTIR analysis and calorific value. All the analysis conducted were according to ASTM methods.

A. Sample preparation

In this experimental study, roots (wood) sample was air-dried then grinded and sieved using cutting mill model SM 2000 (Retsch, Germany) to produce powder of <1mm. The sieved biomass was stored in air-tight containers at room temperatures before proceeding to the analysis.

B. Proximate analysis

Proximate analysis involves the determination of moisture content, volatile matter, ash content and fixed carbon content in the roots (wood) samples. The analysis is conducted three times to get the average readings.

The moisture content was measured in percentage using oven-dry method in accordance to ASTM D3173/D3137M (2017) [5] in a universal oven model UFE500 (Memmert, Germany) at 110°C for 30 minutes using approximately 3 g of the roots (wood) sample. After drying, the sample was stored in the desiccator until it reached room temperature before being weighed again. Closed weighing jar was used for all weighing.

The moisture content, (MC) was calculated using the formula below:

$$MC, \% = (X-Y)/Y \times 100\% \quad (1.1)$$

Where,

X – Initial mass, g
Y- Mass after oven-drying, g

Volatile matter, (V) was determined using the 1g of the oven-dried sample which is placed in a crucible. The crucible is placed into the furnace and heated at 950°C ± 50°C for 7 minutes. The percentage of volatile matter was determined according to ASTM D3175 (2017) [6] and calculated as below:

$$V = [(A-B)/A \times 100\%] - MC \qquad (1.2)$$

Where,
A – Weight of sample used, g
B – Weight of sample after heating, g
MC – Moisture content, %

According to ASTM D1102-84 (2013) [7] the ash content was determined by burning 1g of the oven-dried sample in a crucible inside the furnace. The sample is heated gradually until the temperature reached 575°C ± 25°C. The percent of ash content is calculated as follows:

$$Ash, \% = (X-Y)/Z \times 100\% \qquad (1.3)$$

Where,
X - Weight of container and residue, g
Y- Weight of empty container, g
Z- Weight of ash analysis sample, g

Hence, the percentage of fixed carbon was performed according to ASTM E777-17a (2017) [8]. It is obtained from the subtraction of 100% with the summation of moisture content, ash content and volatile matter. The calculation is as follows:

$$Fixed\ carbon, \% = 100\% - (A + B + C), \% \qquad (1.4)$$

Where,
A- Moisture content, %
B- Ash content, %
C- Volatile matter, %

C. Thermogravimetric analysis

Thermogravimetric analysis (TGA) was conducted using Thermogravimetric Analyser (Mettler Toledo, Switzerland). The sample is weighted into a crucible at approximately 10-20 mg. The roots (wood) sample was heated at temperature of 30°C to 600°C.

D. Fourier Transform Infrared analysis

Fourier Transform Infrared Spectroscopy was conducted using Fourier Transform Infra-Red (FT-IR), (Perkin Elmer, USA).

E. Heating value determination

The calorific value is determined by using calorimetric bomb (IKA C5000 Control, Germany). It was conducted according to the ASTM D5865 (2013) [9]. 1g of dried roots (wood) sample was weighed and placed in a crucible and into the stainless steel container. The bomb was filled with 30 bar of pure oxygen with purity above 99.5%. The sample was ignited and burned for 15 minutes using the ignition device. The samples were tested three times to get an average value.

III. RESULTS AND DISCUSSION

A. Proximate Analysis

The proximate analysis obtained presents the value of moisture content, volatile matter, ash content and fixed carbon in the roots (wood) sample. The results were tabulated in Table 1.

Table 1: Proximate Analysis of Roots (wood).

Properties	**Values, wt%**
Moisture	4.19
Volatile Matter	51.92
Ash	4.72
Fixed Carbon	38.57

The comparison for the proximate analysis with previous study was presented in Table 2.

Table 2: Comparison of Proximate Analysis of Forestry biomass.

Properties	**This study**	[10]	[10]	[2]
Moisture	4.19	5.67	6.00	-
Volatile Matter	51.92	84.00	74.33	51.39
Ash	4.72	1.00	4.67	22.69
Fixed Carbon	38.57	9.33	15.00	14.29

Comparison with previous study shows that the roots (wood) have the lowest moisture content. Low moisture content will influence the thermal treatment by increasing its calorific value and enhance ignition which results in shorter reaction time [11].

According to Ganesh (2006), the typical volatile matter for biomass should be in the range of 60% to 90%. The value obtained in present study is out of ranged due to the high contains of fixed carbon in roots (wood) which reduces the reactivity of the roots (wood) during combustion. Ash content was found to be 4.72% and this value is acceptable as it is below than 5% which contributes to the heating value of the roots (wood) and reduce dust emission during combustion [12].

B. Thermogravimetric Analysis (TGA)

The thermal behaviour of roots (wood) sample undergo slow pyrolysis using nitrogen gas at a heating rate of 10°C min^{-1} as shown in Figure 1.

The thermal degradation involves three phases which were evaporation and moisture loss of the sample, main devolatilization, and continuous slight devolatilization [13]. This was shown in phase I at temperature between 100 to 200°C, the moisture inside the sample evaporates and a small change of weight of the sample was observed. In phase II, the main devolatilization at temperature 250 to 400°C involves the decomposition of organic materials mainly hemicellulose, cellulose and lignin. According to Strezov et al., (2012), the decomposition of hemicellulose, cellulose and lignin typically occurs at temperature range of 190 to 320°C, 280 to 400°C and 320 to 450°C; respectively. The fast decomposition of these organic materials contributes to the weight loss of the sample in phase II. In phase III, the increased of temperature causes sample to become more stable and decomposition occurs slower as compared to phase II. Cellulose was converted to non-condensable gas and condensable organic vapours and aerosols once the temperature approached 400°C [14].

While, the DTG curve shown in Figure 2, where large fluctuation occurred during the decomposition of the biomass. At the temperature of 200°C, the rate of thermal degradation increased and it was identified as the DTG maximum peak [15].

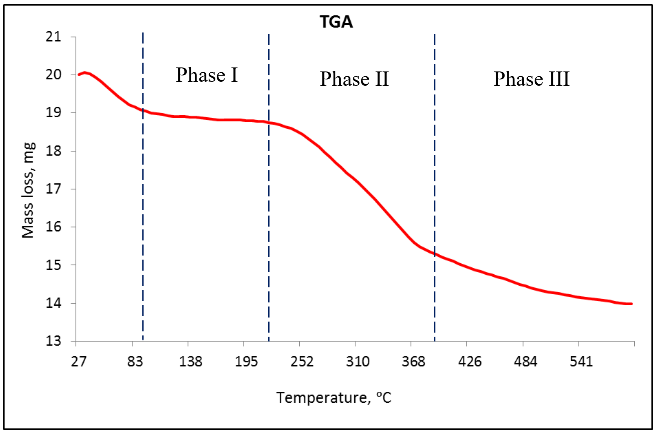

Fig. 1: Thermogravimetric (TGA) of the pyrolysis of roots (wood) at constant heating rate(10 min^{-1}) with N_2 gas.

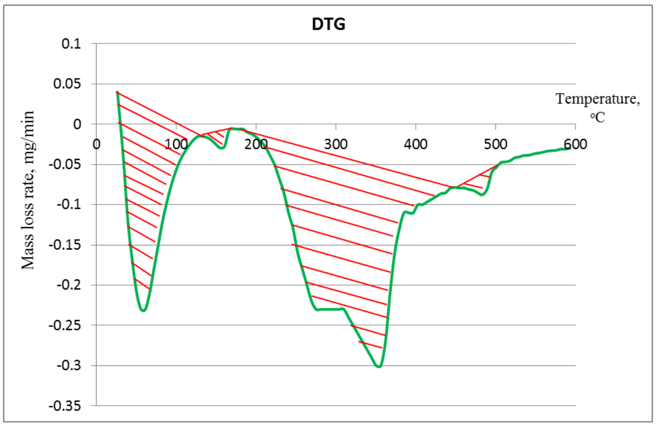

Fig. 2: Derivative Thermogravimetry of the pyrolysis of roots (wood) at constant heating rate (10 °C min^{-1}) with N_2 gas.

C. Fourier Transform Infrared Analysis (FTIR)

Figure 3 shows the results of FTIR for the roots (wood) sample that was analyzed.

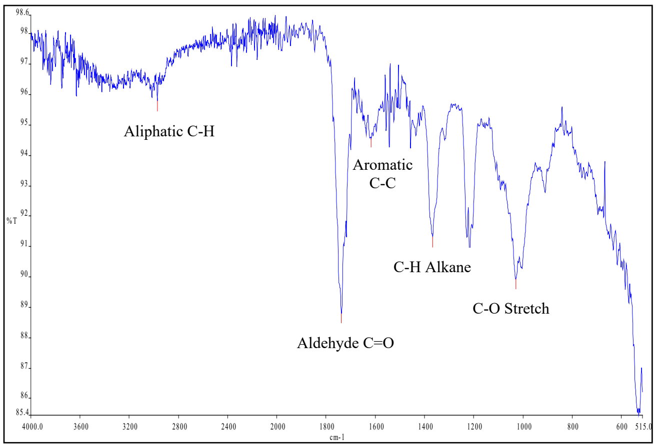

Fig. 3: FTIR spectra of roots (wood) sample.

Meanwhile, in Table 3 shows the list of functional groups contained in the roots (wood) sample with their respective wavelength. The bands between 2870 and 2990 cm^{-1} with the peak of 2970 cm^{-1} attributes to the presence of aliphatic C-H stretching [15]. The band with peak 1737 cm^{-1} was attributed to the presence of aldehyde C=O stretches. Hence, the bands between 1400 and 1600 cm^{-1} with two peaks which were 1619 cm^{-1} and 1542 cm^{-1} shows the presence of aromatic C-C bending. There was also a band between 1350 and 1450 cm^{-1} with the peak of 1366 cm^{-1} which indicates the presence of C-H alkanes functional group [16].

Table 3: Evaluation of FTIR spectra [16].

Functional Group	Characteristic Absorption (cm^{-1})
Aliphatic C-H Stretch	2990-2870
Aldehyde C=O Stretch	1690-1740 (s)
Aromatic C-C Bending	1500-1700 (m,m)
C-H Alkanes	1350-1645
C-O Stretch	1000-1300 (s)

D. Calorific Value

The heating value of roots (wood) obtained from calorimetric analysis of this study was shown in Table 4.

Table 4: Heating values of roots (wood) from calorimetric analysis.

	Reading 1	Reading 2	Reading 3
Heating Value (J/g)	28411	28415	28406

The average heating value obtained from the three readings was 28411 J/g. Based on the comparison in Table 5, the heating value of roots (wood) from this study was at the highest value. The high calorific value signifies that high amount of energy produced in combustion process. As mentioned by Antwi-Boasiako & Acheampong, (2016), the forestry biomass with high calorific value was favourable as fuel materials because of its low moisture content.

Table 5: Comparison of the calorimetric analysis.

Sample	Heating Value, J/g	Source
Roots (wood)	28411	This study
Forestry Waste	16000-20000	[10]
Different types of wood	17600-20700	[17]
Pine wood	24490	[14]

IV. CONCLUSION

In this study, the proximate analysis for roots (wood) shows that the moisture content in the biomass sample was 4.79% with moderate volatile matter and high fixed carbon. The decomposition organic materials in the roots (wood) occur at temperature 200°C to 450°C. The FTIR results shows the presence of aliphatic C-H stretch, aldehyde C=O stretch, aromatic C-C bending, C-H alkanes and C-O stretch. The calorific value of roots (wood) was found to be high which was suitable as fuel substitute to generate energy.

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