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Characteristics Study of Wood Wastes from Sawmills

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Authors' contributions

This work was carried out in collaboration between the two authors. Author OPF initiated the study and supervised it. Author AOA carried out the laboratory works of the study, wrote the proposal and the first draft of the manuscript. The results and discussions were jointly done.

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ABSTRACT

The availability of energy in wood wastes is evaluated in this work. Biomass from seven tropical wood species; Obeche (*Triplochiton scleroxylon*); Iroko (*Melicia excelsa*); Danta (*Nesogordonia papaverifera*); Mahogany (*Khaya ivorensis*); Omo (*Cordia platythyrsa*); Mansonia (*Mansonia altissima*) and Afara (*Terminalia superba*) retrieved from sawmills across Akure and its environment in South West Nigeria were pyrolysed in a fixed-bed batch thermal reactor. Laboratory experiments revealed that the wood wastes possess energy that can be converted for use in other forms such as fuels and chemicals. The volume of the three products of pyrolysis – char, pyro-oil and pyro-gas were evaluated for every kilogram of wood biomass pyrolysed. Wood off-cuts prepared into 50 x 20 x 20 mm were used, and it was found that wood has an average energy content of 21.7544 MJ/kg, made up of 8.52 MJ (39.15%) in the char, 8.76 MJ (40.26%) in the liquor, and 4.48 MJ (20.59%) in the pyro-gas; low ash content of 4.15% and electricity equivalent of 6.06 kWh, made up of 2.37 kWh (39.12%) in the char, 2.44 kWh (40.26%) in the liquor, and 1.25 kWh (20.62%) in the gas.

Keywords: Energy; wood waste; fuels; ash content; pyrolysis.

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1. INTRODUCTION

Energy; the ability to do work is essential to mankind as he make use of it in his daily life. It is one of the indispensable factors for continuous development and economic growth [1]. The demand of energy is increasing rapidly in the developing countries due to automation, industrialization and urbanization [2]. The growing population and technological developments have shown that the present sources of energy in use are not adequate. The world population has increased at an explosive rate from 1.65 billion to just over 6 billion people in the 20th century, and continues to increase [3]. There is therefore an urgent need to develop alternative energy sources. Wood, being the most common form of biomass is considered to be of benefit in this regard [4].

Biomass is the renewable, biodegradable or combustible organic matter generated through life processes, which are dependent upon solar energy and its utilization is a rapidly growing sector of renewables. Worldwide, biomass is the fourth most – used fuel after oil, coal and natural gas [5-7]. Though, most biomass usage in the developing world is in thermal applications, especially for cooking, the sector is increasingly modernizing to provide efficient secondary energy forms such as fuels and electricity [7].

The socio – economic development, standard of living, as well as the quality of life of any country largely and primarily depend on the availability and supply of energy. The availability and supply of energy came under great pressure because of increasing demands of the ever-increasing global population. This eventually leads to the problem of energy crisis. This is especially true for developing countries like Nigeria [1]. All the major sectors – industrial, commercial, transportation and residential – have been designed for and have grown on an unrestrained access to cheap energy, which in this content refers to‘ affordable and unfailing energy supply’. But energy from fossil fuels and other non-renewable sources has become so expensive quickly that our patterns of consumption have had little time to adapt. The recent happenings in the energy sector of Nigeria are a pointer in this direction [8].

The high cost of fossil fuels and the exhaustible possibilities of their sources may warrant the use of alternative fuels sourced from renewable sources. Renewable energy resources are in general, more evenly dispersed over the earth’s surface than fossil fuels. Hence they increase the scope for local, regional or national energy self-sufficiency. Fuels from such sources may be undiluted or mixed with fossil fuels when applied [9-11].

At present, the main conventional source of energy used all over the world is the fossil fuel. Fossil fuels are non-renewable and hence their deposits will eventually be exhausted. Therefore, alternative energy sources must be exploited to their full potential. Solar energy, nuclear energy, energy from tides, wind energy and hydroelectric energy are some of the alternative resources. However, one of the major renewable alternative sources is the bio-energy obtained from woody biomass [7,12,13].

There abounds wood wastes all over the place, especially in sawmills and wood-based industries and can be converted to bio-oil, charcoal, pyro-acids and pyro-gas. Bio-oil or pyro-oil can substitute for fuel oil or diesel in many static applications including boilers, furnaces, engines and turbines for electricity generation. There are also a wide range of chemicals that can be derived including food flavourings, resins, agro-chemicals, fertilizers and emission control agents [14,15].

The objective of this paper therefore is to perform a characteristics study of wood wastes from sawmills that include calorific value, specific gravity and moisture content, in order to determine the quantity of energy lost during the conversion process.

2. MATERIALS AND METHODS

2.1 Materials

Biomass from seven tropical wood species were retrieved from sawmills across Akure and its environment in South West Nigeria. The wood species were: Obeche (*Triplochiton scleroxylon*); Iroko (*Melicia excelsa*); Danta (*Nesogordonia papaverifera*); Mahogany (*Khaya ivorensis*); Omo (*Cordia platythyrsa*); Mansonia (*Mansonia altissima*); and Afara (*Terminalia superba*) [16]. The actual volume converted to planks and the volumes of wastes (sawdust and slabs) were determined from the volume of wood processed in these sawmills.

2.2 Method

The woods collected were prepared into 50 x 20 x 20 mm sizes and oven dried to 18% Moisture Content at 100ºC for 24 hours per batch. The dried samples were kept in polythene bags to prevent them from excessive humidity.

Samples were withdrawn and tested for Volatile Matter, Ash Content, Fixed Carbon, Heating Values, Moisture Content and Specific Gravity. The tests were conducted using the American Society for Testing and Materials Standards ASTM C566 and ASTM D1102. Known densities of the wood species were used to calculate the mass of the wastes and hence the energy content of the wastes. Known equations were used in the determination of the various parameters.

2.2.1 Bomb calorimeter test

Objective: To determine the calorific value of wood wastes.

Test Procedure: The apparatus used were a ballistic calorimeter, oxygen gas and galvanometer.

Oven-dried specimens of each sample were well ground and re-dried to a constant weight. 0.25 g of each specimen was loaded into the calorimeter crucible and this was assembled as specified in Manual CB – 370. The crucible containing the sample was placed on the support pillar at the base of the bomb and a 50 mm long cotton thread was inserted between the firing wire coil and the centre of the test specimens in the crucible. This was to initiate the burning of the specimen. The sealing bomb was positioned in its groove. The knurled locking ring of the calorimeter is then raised and the bomb lowered onto the ring and the body rotated until the thread fully engaged the thread on the ring.

The sealing ring was then tightly screwed on and the thermocouple plugged into position throughout the top of the bomb. Oxygen was passed into the interior of the bomb from a cylinder, through the top valve on the calorimeter to a pressure of about 25 bar. The indicator on the galvanometer was adjusted to zero and this was left stable for about 30 seconds to check the stability of the ambient temperature within the bomb. Pressing the switch button and releasing it immediately ignited the bomb content. The maximum temperature rise indicated on the galvanometer was noted. The procedure was carried out for both the calibration samples of benzoic acid and for each specimen from the test samples.

2.2.1.1 Heating values

The heating value was obtained using the following equation:

$$H.V. = \frac{Q_s - Q_{ws}}{m} C \quad (1)$$

where

H.V. = Heating Value(kJ)
Q_s = Galvanometer Reading with sample (ºC)
Q_{ws} = Galvanometer Reading without sample (ºC)
C = Calibration Constant
M = Mass of sample(g)

2.2.2 Proximate and ultimate analysis

Proximate analysis determines physiochemical parameters like moisture, volatile matter, fixed carbon and ash content in the biomass, while ultimate analysis, also known as elemental analysis of ions, determines the percentage of carbon, hydrogen, Nitrogen and organic sulphur with oxygen present in the biomass.

The following equations were used to determine the parameters.

2.2.2.1 Volatile matter

$$\%\,V.M. = \frac{M_{sp} - M_{fd}}{M_{sp}} \times 100 \quad (2)$$

where

V. M. = Volatile Matter (%)
M_{sp} = Initial Mass of sample (g)
M_{fd} = Mass of sample (g) after 10 minutes at 900ºC

2.2.2.2 Ash content

$$\%Ash = \frac{M_{AR}}{M_S} \quad (3)$$

where

M_{AR} = Mass of Ash Residue (g)
M_s = Mass of Sample (g)

2.2.2.3 Fixed carbon

$$\% F.C. = 100 - (\%V.M. + \%Ash) \quad (4)$$

2.2.2.4 Specific gravity

$$S.G. = \frac{W_{ws}}{W_{vw}} \quad (5)$$

where

W_{ws} = Weight of Wood sample (g)
W_{vw} = Weight of equal volume of water (g)

2.2.3 Energy content

This is the actual amount of energy present in the sample. It was calculated using the following equation:

$$E.C. = \rho \times v \times H.V\ (kJ) \quad (6)$$

Where

E.C. = Energy Content(MJ)
ρ = density of wood sample (kg/m^3)
v = volume of wood processed (m^3)
H.V = Heating Value of wood sample (kJ)

Using the mean heating value of the wood samples, the energy contents of the products were calculated for the varying reactor temperatures. The wood samples used consist of a mixture of the seven wood species (1 kg mixture of Iroko, Mahoghany, Omo, Mansonia, Afara, Danta, and Obeche).

From energy units, the energy contents were converted to electricity units, using a conversion factor given by [17]. The conversion factor used is as given below:

1 kWh = 3.6 MJ; and1 MJ = 0.278 kWh.

2.3 Thermal Reactor

A fixed-bed batch thermal reactorthat consists of an electrically fired furnace chamber was used for the pyrolysis. The furnace wall is made of laterite material obtained from Akure. The pyrolysis plant is shown in Fig. 1.

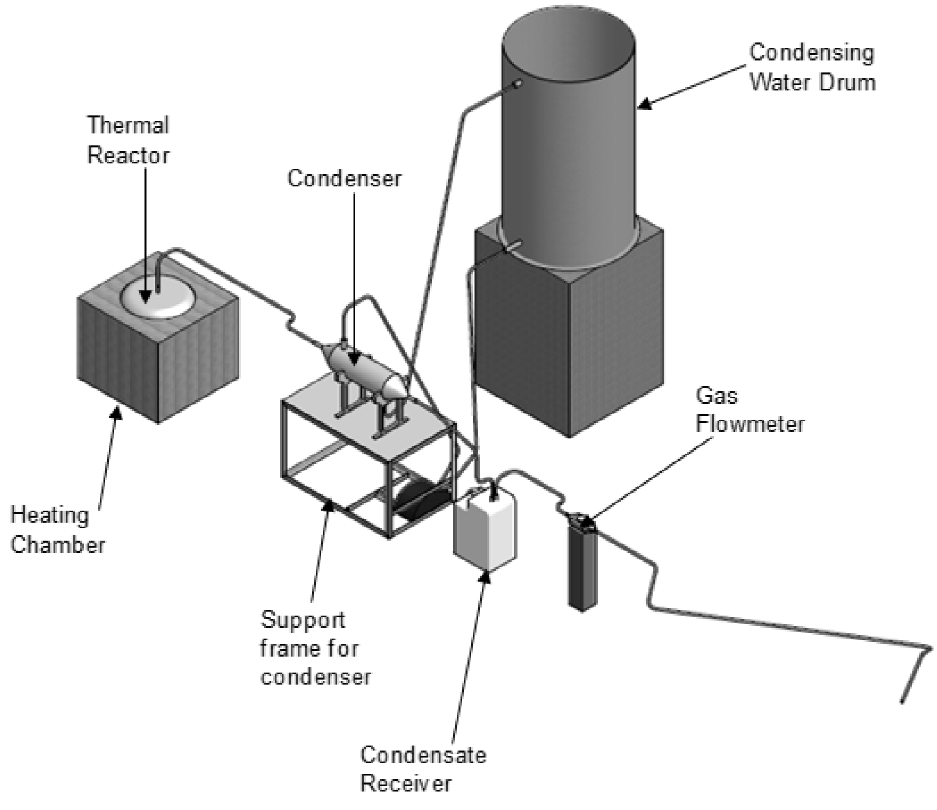

Fig. 1. Fixed-bed batch pyrolysis plant

3. RESULTS AND DISCUSSION

The results obtained are presented in Tables 1 to 6.

Table 1. Proximate analysis of wood samples

Wood species	Volatile matter %	Ash content %	Fixed carbon %
Iroko	71.18	3.68	25.14
Mahoghany	77.14	3.42	9.44
Omo	81.67	1.65	16.68
Mansonia	81.44	2.92	15.64
Afara	90.68	0.78	8.54
Danta	84.32	4.89	10.79
Obeche	90.07	1.74	8.19
Mean	**82.36**	**4.15**	**13.49**
Standard deviation	**±6.39**	**±1.31**	**±5.69**

Table 1 shows an average volatile matter to be 82.36% and a low ash content of 4.15% (a desirable factor for fuel woods). This indicates that the quantity of hydrocarbons in the wood samples was high, and hence would have high energy content. The relatively high fixed carbon would be expected to increase the heating value. The result agreed with [17], that the share of volatile matters is wood is typically high; constituting about 80% of the energy originating in the combustion of volatiles.

Ash content is the amount of solid wastes after complete burning process of a fuel. High ash content of a fuel generally reduces heating value. Therefore, the low ash content of the wood samples was desirable.

Table 2. Heating values of wood samples

Wood species	Heating value, MJ/kg
Iroko	22.88
Mahoghany	20.33
Omo	22.11
Mansonia	19.06
Afara	24.17
Danta	23.09
Obeche	20.65
Mean heating value	**21.75 MJ/kg**
Standard deviation	**±1.67**

Findings from the study gave a mean heating value of 21.75 MJ/kg±1.67, which is good energy content (Table 2). The result agrees with literature findings of Cheremisinoff [18]; that the heating values of different wood species do not vary greatly from one species to the other, the average value being 18.7 – 21.9 MJ/kg.

A mean value of 17.59%±3.78 moisture content was obtained from the results, which is a reasonable moisture level for the wood fuels (Table 3). This agrees with [19] who concluded that the moisture content of air-dried biomass depends on the relative humidity and that it varies from 10-26%. High moisture content has big effect on the heating value of woods during combustion, as heat would be expended to vapourize it.

Table 3. Percentage moisture content and specific gravity of wood samples

Wood specie	% Moisture content (air dried)	Specific gravity (oven dried)
Iroko	12.51	0.69
Mahoghany	16.92	0.68
Omo	15.68	0.86
Mansonia	17.77	0.81
Afara	23.43	0.83
Danta	14.26	0.43
Obeche	22.59	0.75
Mean	**17.59**	**0.72**
Standard deviation	**±3.78**	**±0.14**

The heat per unit volume of wood depends on its specific gravity, and is the weight of material per unit of volume expressed on an oven-dry-weight base [20]. The average value of 0.72±0.14 pre-supposes that the potential energy of the wood samples were high.

Table 4 shows the results of the chemical analysis of the wood samples, with higher carbon contents than other elements. High carbon content is expected to increase the heating value of the wood. The mean value of 50.03%±0.92 agreed with literature that puts the carbon content of wood at between 45 – 50% [15].

The result in Table 5 implied that one kilogram of wood contained 21.76 MJ made up of 8.52 MJ in char, 8.76 MJ in the liquor, and 4.48 MJ in the gas produced during pyrolysis.

The result in Table 6 shows that for every kilogram of wood pyrolysed, an electricity equivalent of 6.06 kWh is contained. This is made up of 2.37 kWh in the char, 2.44 kWh in the liquor, and 1.25 kWh in the gas produced. This result agrees with the result of the Sustainable Energy Development Office (SEDO) of Western Australia that the energy content of wood is 16.2 MJ/kg which is equivalent to 4.5 kWh/kg [21].

Table 4. Ultimate analysis of wood samples

Wood specie/ parameter	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
Iroko	50.20	5.28	0.03	0.01	44.80
Mahoghany	49.27	5.62	0.02	0.01	44.60
Omo	50.42	5.48	0.03	0.01	44.06
Mansonia	51.39	5.42	0.03	0.01	42.18
Afara	48.44	5.72	0.03	0.01	44.40
Danta	49.68	5.60	0.03	0.01	44.68
Obeche	50.82	5.18	0.02	0.01	43.97
Mean	**50.03**	**5.47**	**0.027**	**0.01**	**44.10**
Standard deviation	**±0.92**	**±0.18**	**±0.01**	**0.00**	**±0.83**

Table 5. Energy content of products (MJ) at varying temperatures for 1 kg mixture ofIroko, mahoghany, omo, mansonia, afara, danta and obeche

Parameter	Reactor temperature (ºC)	Char (MJ)	Oil (MJ)	Gas (MJ)
1 kg mixture ofIroko, mahoghany, omo, mansonia, afara, danta and obeche	200	13.49	7.40	0.87
	300	12.18	8.27	1.31
	400	9.57	10.22	1.96
	500	8.27	10.66	2.83
	600	6.09	9.57	6.09
	700	5.66	7.83	8.27
	800	4.35	7.40	10.01
Mean	**500**	**8.52**	**8.76**	**4.48**

Table 6. Electricity power equivalents of products (kWh/kg) for 1 kg mixture ofIroko, mahoghany, omo, mansonia, afara, danta and obeche

Parameter	Reactor temperature (ºC)	Char (kWh/kg)	Oil (kWh/kg)	Gas (kWh/kg)
1 kg mixture ofiroko, mahoghany, omo, mansonia, afara, danta and obeche	200	3.75	2.06	0.24
	300	3.39	2.30	0.36
	400	2.66	2.84	0.54
	500	2.30	2.96	0.79
	600	1.69	2.66	1.69
	700	1.57	2.18	2.30
	800	1.21	2.06	2.78
Mean	**500**	**2.37**	**2.44**	**1.25**

4. CONCLUSION

The volume of wood waste per wood variety in selected sawmills had been identified and the heating values of the fuels determined. The energy content of a mixture of the selected wood species (Iroko, Mahoghany, Omo, Mansonia, Afara, Danta and Obeche) was determined. It was inferred that the mean heating value of the wood samples used is 21.75 MJ/kg for every kilogram of the feedstock with a deviation of ±1.67. For every kilogram of wood pyrolysed, the energy content is 21.76 MJ, made up of 8.52 MJ (39.15%) in the char, 8.76 MJ (40.26%) in the liquor, and 4.48 MJ (20.59%) in the pyro-gas; andin every kilogram of wood pyrolysed, electricity power equivalent of 6.06 kWh is contained. This consists of 2.37 kWh (39.12%) in the char, 2.44 kWh (40.26%) in the liquor, and 1.25 kWh (20.62%) in the gas.

It can thus be concluded that large and significant energy contents are stocked in wood wastes and can be converted to use as an alternative source of energy either for heating or for electricity generation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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