IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Wood fuel analysis of some selected wood species within Ibadan

To cite this article: O.E. Ogunsola *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **173** 012043

Wood fuel analysis of some selected wood species within Ibadan

O.E. Ogunsola[1], O. Adeleke[1] and A.T. Aruna[2]

[1]Department of Physics, University of Ibadan, Ibadan, Nigeria.
[2]Nigerian Institute of Science Laboratory Technology, Samonda, Ibadan, Nigeria.

seyiogunsola22@gmail.com

Abstract. Wood waste (saw dust) from sawmills if well harnessed is a potential alternative source of energy for electricity production. This is due to its prospects in the production of fuel such as biogas (methane, carbon dioxide and other trace gases) having high calorific value that can be used to drive a gas turbine in the production of electricity. However, since the electrical energy generated mainly through the hydro power generating stations along with the other power plants including the conventional coal and gas currently in existence in the country is not meeting the energy demand of Nigerians, it is therefore necessary to introduce additional sources of alternative energy in order to be able to augment these existing energy sources, and wood waste is the proposed alternative source of fuel energy used in this study. The fuel properties and characterization of six different wood waste samples (Iroko (Milicia excelsa), Masonia (Masonia altissima), Afara (Terminalia superba), Arere (Annona senegalensis), Ayin (Anogeissus leiocarpus) and Obeche (Triplochiton scleroxylon)) obtained from sawmills located within Bodija, Sango and Idi Ayunre areas of Ibadan were determined by following the procedure of the American Society Standard Test Method (ASTM E870-82(2013)) for the analysis of wood fuels. The result of characterization of the wood samples showed a range of values for the gross calorific values (20.14MJ/Kg to 22.30MJ/Kg), volatile matter (74.22% to 82.62%) and ash content (0.605% to 5.03%). The overall ratings of the fuel properties of the six wood samples in terms of their average ranking were obtained as 3.25 (Iroko), 3.13 (Masonia), 3.25 (Afara), 2.0 (Arere), 2.6 (Ayin) and 1.75 (Obeche) which suggests that wood waste from Obeche has the best fuel property because of its least rating while that of Afara and Iroko were the worst.
Keywords: Wood waste, fuel properties, alternative energy source, overall ratings.

1. Introduction

Nigeria is endowed with abundance of renewable and non-renewable energy resources including hydro, wind and solar energy. However, the present dependence of the Nigerian government on hydro and fossil fuel resources (petroleum, coal and gas) to generate electricity is not enough to meet the energy demands of the populace because of its unavailability to the majority of them. The increase in the demand for electricity in Nigeria had also resulted in the interest in other alternative sources of energy including wood wastes (biomass) by various researchers. Biomass is the primary source of energy for nearly 50% of the World‘s population [1] and wood biomass is a major renewable energy source in the developing world, representing a significant proportion of the rural energy supply. Biomass is defined as organic material, available on renewable basis, which are produced directly or indirectly from living organisms without contamination from other substances or effluents. It is a non-

fossilized and biodegradable organic material that originated from plant, animals and micro-organisms which could be residues/waste from forestry and agricultural product including the waste from the municipalities. Biomass is available in varying forms throughout the developing world. It can come from densely forested areas of the world or sparsely vegetated arid regions as well as farmlands and garbage collection centers. Worldwide, biomass is the fourth largest energy resource after coal, oil, and natural gas estimated at about 10% of global primary energy [2]. Biomass broadly falls into four types based on primary source which are wood and agricultural products, municipal solid waste, landfill gas and biogas, and alcohol fuels and so on. Biomass has high input but variable moisture content and is made up of carbon, oxygen, nitrogen, sulphur and inorganic elements [3].

Plant biomass is the largest potential source of biomass when compared to others. Most of these potentials lie in wood processing by-products referred to as wood shavings such as sawdust [4]. UNFCC [5] reported in 2005 that biomass generally has high moisture content and is made up of carbon, hydrogen, oxygen, nitrogen, sulphur and inorganic elements. The uncontrollable release of global warming gases to the atmosphere mainly from fossil fuel resource with harmful effect to damaging the ozone layer has made it very necessary to search for a technology with various methods to developing an alternative energy production in which sawdust from agricultural and forestry biomass is examined as the alternative energy source [6]. The combustion of agricultural biomass from sawdust (and other biomass) ranges from the utilization of wood stove in domestic application to industrial power plant applications which also generate greenhouse gases [7]. However, this biogas which is harmful to the ozone layer can be converted into useful valuable gaseous and liquid resource through the process called gasification [8].

Wood pellets are actually manufactured from waste products from other wood processing industries and sawmills. Although man rely on sawmill waste and forest harvest residuals for the bulk of their fibre supply, this sawdust could also be used to generate electrical power through a power plant that uses wood pellets as fuel. This kind of power plant which produces steam that runs a turbine to produce electricity is known as the biomass power plant or biopower plant.

2. Materials and Methods

The quantity (i.e. volume) of the daily amount of saw dust (wood waste) generated from the various wood species: Iroko (Milicia excelsa), Masonia (Masonia altissima), Afara (Terminalia superba), Arere (Annona senegalensis), Ayin (Anogeissus leiocarpus) and Obeche (Triplochiton scleroxylon) [9] obtained at the plank markets in Bodija (BM), Sango (SM) and Idi Ayunre (IM) areas of Ibadan land (Fig. 1) were estimated. Also, wood pellets were produced from the wood wastes (biomass) obtained from the various wood species, through the procedures of drying, milling, pelletizing, and cooling. The analyses of these wood species were determined by following the procedure of the American Society Standard Test Method [10] for the analysis of wood fuels. The thermal properties of the wood pellets obtained from the various wood species were carried out in order to determine their moisture content, ash content, volatile matter content, and fixed carbon content. The elementary analysis of these wood pellets was carried out in order to determine which of the elemental composition of Carbon, Hydrogen, Oxygen, Sulphur and Nitrogen is available in them. The fuel characteristics of these various wood species including their gross calorific values were determined from their wood pellets and compared with the values obtained using the Dulong-Berthelot model.

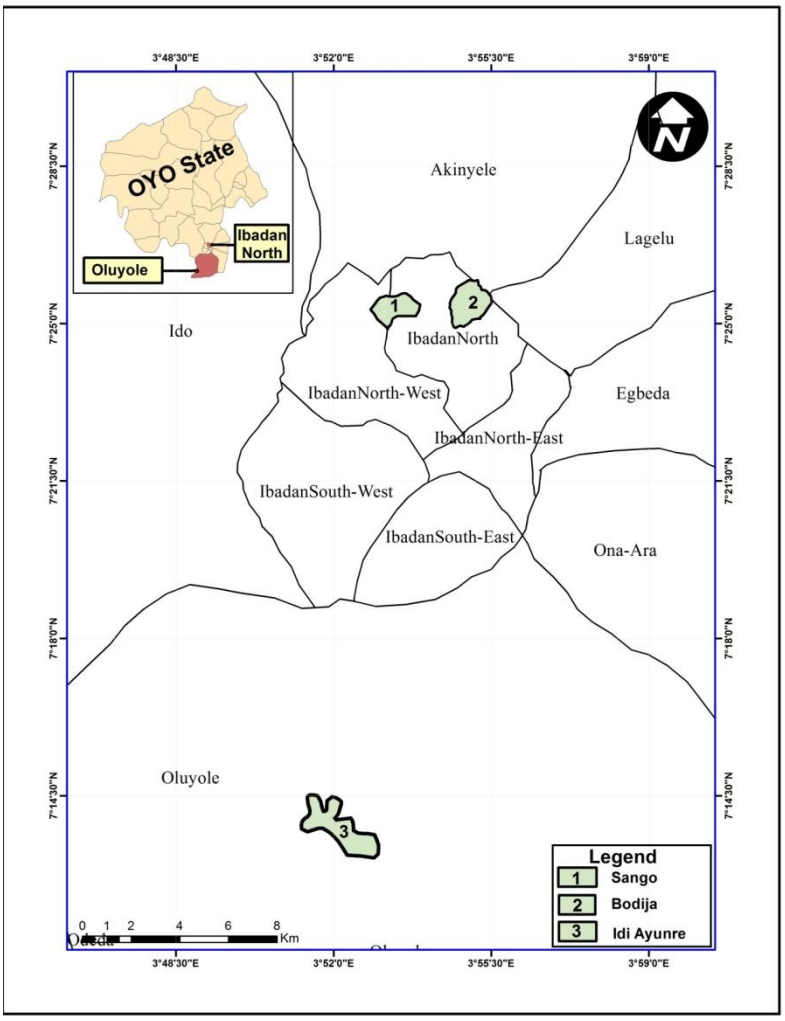

Fig. 1: Map of Oyo state showing plank market locations in Ibadan land

2.1 Estimation of Volume Waste

The process of milling a lumber (log) into planks generates a lot of wood waste which is a biomass that can be used for electricity generation. Similarly, the process of milling planks also generates waste on the average from a lumber (log of wood) and approximately 45-55% of the log will not be part of the final wood product [11]. It was estimated that the total volume of planks per truck (V_{PT}) in Bodija, Sango and Idi Ayunre markets where the survey was conducted is obtained as:

$$V_{PT} = 400V_P \tag{1}$$

This was based on the fact that each truck delivers 400 logs per truck.

The estimated volume of plank (V_P) from a piece of plank is (12x12x1) (inches^3) = (144 inches^3), and this is equivalent to 3.658m^3. Also the total daily plank volume (V_{DT}) offloaded was estimated as:

$$V_{DT} = N_{LD}V_P \tag{2}$$

where,

N_{LD}= Number of lumber per day

V_P = Volume of Plank.

Therefore,

$$V_{DT} = N_{LD} \times 3.658m^3 \tag{3}$$

Also, from the survey carried out, it was estimated that the volume of wood milled daily was 55% of the total 100% wood species supplied to millers at the various sawmills considered in this work. Out of this 55% volume of the daily milled wood, 34% of it accounted for the daily milled wood waste (V_{DW}) produced i.e.

$$V_{DW} = 34\% \times 55\% V_{DT} \tag{4}$$

$\therefore$ Daily milled wood waste,

$$V_{DW} = 0.187 V_{DT} \tag{5}$$

Thus,

$$V_{DW} = 0.187 V_{DT} = 0.187 \times N_{LD} \times 3.658 \tag{6}$$

$$\Rightarrow V_{DW} = 0.684 N_{LD} \tag{7}$$

Thus, the volume of weekly milled wood waste (V_{WW}) based on the six (6) working days the millers usually work in a week is:

$$V_{WW} = 6 \times V_{DW} \tag{8}$$

$$\Rightarrow V_{WW} = 6 \times 0.684 N_{LD} \tag{9}$$

$$\therefore V_{WW} = 2.74 N_{LD} \tag{10}$$

Then the total Volume of weekly milled wood waste (V_{WW}) is modeled as:

$$V_{WW} = 2.74 N_{LD} \tag{11}$$

2.2 Biomass Analysis

Biomass is a key resource for renewable energy generation [12]. This analysis was carried out by making use of the following techniques:

2.2.1 Proximate Analysis The proximate analysis of the biomass materials was determined by heating approximately 2g of the sun-dried mass of each wood species with particle size of 420μm using an electric furnace at a temperature of 500 ˚C for four (4) hours. It was cooled thereafter in a desiccator and weighed in order to determine the ash content of the samples. The percentage of volatile matter of the biomass was also determined.

2.2.1.1 Estimation of Moisture Content The moisture content of a biomass material (wood waste) which is directly related to a fuel's calorific value is obtained by first determining its initial weight before sun-drying it. After sun-drying, the samples were continually reweighed until a constant weight was attained (i.e. the final dry weight). The moisture content (MC) was obtained as:

$$MC = \frac{Initialweight - Finalweight \times 100\%}{Finalweight} \tag{12}$$

2.2.1.2 *Ash Content Determination* The ash content which is a measure of the mineral content and other inorganic matter in a biomass is used in conjunction with other procedures to determine the total composite of the biomass sample [13]. The ash content (AC) is calculated as:

$$AC = \frac{M}{M_s} \times 100\% \tag{13}$$

where, M is the mass of the ash and M_s is the mass of the sun-dried sample

2.2.1.3 Volatile Matter Content The percentage volatile matter of the biomass materials (wood shavings) was calculated by using 2 g each of the sundried biomass materials (wood shavings) with particle size of 425 μm placed in a porcelain crucible. Each sample was first sun-dried and then kept in a furnace at a temperature of 500˚C for 10 min and weighed after cooling in a desiccator. The volatile matter (VM) was then calculated as follows:

$$VM = \frac{X - Y}{X} \times 100\% \tag{14}$$

where,
X = weight of the sun-dried sample
Y = weight of the sample after 10 min in the furnace at 500˚C.

2.2.1.4 Fixed Carbon The fixed carbon is the solid combustible residue that remains after a coal particle is heated and the volatile matter is expelled. The fixed carbon content of a coal is determined by subtracting the percentages of moisture, volatile matter, and ash from a sample [14]. It is also the solid residue, other than ash, obtained by destructive distillation of a coal, determined by definite prescribed methods [15].
Fixed carbon (FC) can be expressed as:

$$FC(\%) = 100 - \%MC - \%AC - \%VM \tag{15}$$

2.2.2 Ultimate Analysis The ultimate analysis is the elementary analysis performed on the biomass in order to determine the elemental composition of carbon, hydrogen, oxygen, sulfur and nitrogen present in it. It also includes the amount of carbon monoxide, methane and carbon dioxide present in the synthesis gas obtained from the gasification of the biomass. It was this synthesis gas that when cleaned could be used to generate electricity. The energy output actually depends on the types of wood species used as fuel.

2.3 Fuel Characteristics
Fuel characteristics include the estimation of the calorific values which indicates the amount of heat obtained from the complete combustion with oxygen in a standard calorimeter

2.3.1 Estimation of Gross Calorific Value The gross calorific value of the samples of biomass materials was determined using an adiabatic bomb calorimeter. About 0.2 g each of these samples was burnt using the bomb calorimeter until complete combustion was obtained. The differences between the maximum and the minimum temperatures obtained for each of these samples were used to compute the gross calorific values of the biomass materials (wood waste) given as:

$$Q = \frac{(C_{Water} + C_{Cal})(T_2 - T_1)}{W_t} \times 100 \tag{16}$$

where,
Q = Calorific value of species (kJ/kg)
C_{water} = Heat capacity of water
C_{cal} = Heat capacity of the bomb calorimeter
$T_2 - T_1$ = Rise in temperature
W_t = Weight of the biomass material sample (kg)

2.3.2 *Dulong-Berthelot Model* The Dulong-Berthelot model which was originally developed for coal but modified by [16] was utilized in determining the heating value of biomass. This modified form is expressed as:

$$GCV = 349.1C + 1178.3H + 100.5S - 103.4O - 15.1N - 21.1ASH(kJ/kg) \quad (17)$$

where, C, H, S, O, N and ASH were the percentages of carbon, hydrogen, sulfur, oxygen, nitrogen and ash obtained from ultimate analysis.

2.4 *Bulk Density of the various Wood Species*

The density of biomass (wood shavings) plays a very important role in the determination of its fuel value and the denser a wood is, the more heat per volume it contained. The bulk densities of the various wood species are determined from their sun-dried masses using the expression:

Bulk density of wood (kg/m^3) = Mass of Specimen / Volume of Specimen (18)

3. Results and Discussion

The analysis of the six different types of wood species (Iroko (Milicia excelsa), Masonia (Masonia altissima), Afara (Terminalia superba), Arere (Annona senegalensis), Ayin (Anogeissus leiocarpus) and Obeche (Triplochiton scleroxylon)) obtained from sawmills located within Bodija, Sango and Idi Ayunre areas of Ibadan were carried out using laboratory investigations

3.1 *Volume of Wood Waste generated at the plank markets*

Table 1 is the result of the summary of the average volume of wood wastes generated on daily basis for the three plank markets considered in Ibadan for this study. Bodija being the largest of these plank markets has the largest average number of truck delivering lumber to the market and the highest average volume of waste generated on daily basis 957.6m^3. The total volume of wood waste generated by these three plank markets on daily basis is 1607.4m^3.

Table 1: Summary of the average volume of wood waste generated daily at plank markets in Bodija, Sango and Idi Ayunre areas of Ibadan

AVERAGE TRUCK NUMBER	IBADAN NORTH LG		OLUYOLE LG	TOTAL
	Bodija	Sango	Idi Ayunre	
AVERAGE TRUCK NUMBER PER WEEK (NT)	21	3.25	11	35.25
AVERAGE LUMBER PER WEEK (N_L)	8,400	1,300	4,400	14,100
AVERAGE LUMBER PER DAY (N_{LD})	1400	217	733	2350

AVERAGE WASTE VOLUME GENERATED DAILY (m^3)	957.6	148.4	501.4	1607.4

3.2 *Proximate Analysis*

The result of the proximate analysis of the various wood species obtained for this study (Table 2) showed that the percentage moisture content of Ayin was the highest, while that of Obeche was the least (Fig. 2). This indicates that Obeche will give the highest fuel calorific value (i.e. best fuel property) amongst the other wood species considered in this work. Also, it will be the one with the highest durability value in terms of their being stored. The ash content of the various wood species varied from 0.61% for Ayin to 5.03% for Afara (Fig. 3). The high ash content of Afara indicates that it has high mineral matter. The ash content of all the various wood species used in this study was lower than 6%, with Afara and Iroko having values of 4.6% and 5.0% respectively. All the other species had an ash content of less than 4%, a value at which slagging of ash (i.e. an incombustible by product) usually occurs for biomass fuels (wood shavings). Hence, it is likely that when sawdust of species like Masonia, Arere, Ayin and Obeche are used as fuel, slagging would not occur. On the contrary, slagging might occur when wood species like Afara and Iroko are used as biomass fuel. The volatile matter of the various six wood species used in this study varied from 74.22% Afara to 82.60% Obeche, with Obeche having the highest value and Afara the least (Fig. 4). The volatile matter of all other wood species was greater than 78% with the exception of Afara. The volatile matter content of a biomass material when high indicates that during the process of combustion, most of it will volatize and burn as gas. The fixed mass for these wood species varied from 3.97% (Iroko) to 17.75% (Afara) (Fig. 5). The high fixed carbon content indicates that the biomass will require a long combustion time. The fixed carbon which actually gives a rough estimate of the heating value of a fuel acts as the main heat generator during the burning of a biomass. Hence, the higher the content of carbon of the biomass fuel the more likely that the species would have higher heating value.

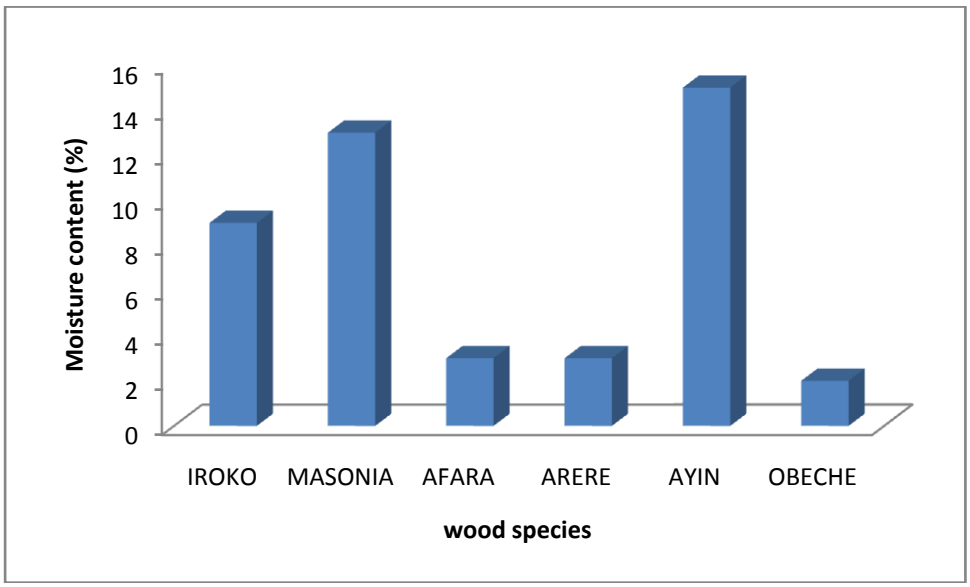

Fig.2: Percentage moisture content for the various wood species

Table 2: Proximate Analysis of data for selected wood waste biomass materials

Local Government	Saw Mill Location	Types of wood species	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)
Ibadan North	Bodija SM1	Iroko	9.0	4.62	82.41	3.97
Ibadan North	Bodija SM2	Masonia	13.0	2.01	80.93	4.06
Ibadan North	Sango SM3	Afara	3.0	5.03	74.22	17.75
Ibadan North	Sango SM4	Arere	3.0	2.75	78.54	15.71
Oluyole	Idi Ayunre SM5	Ayin	15.0	0.61	80.50	3.89
Oluyole	Idi Ayunre SM6	Obeche	2.0	3.51	82.60	11.89

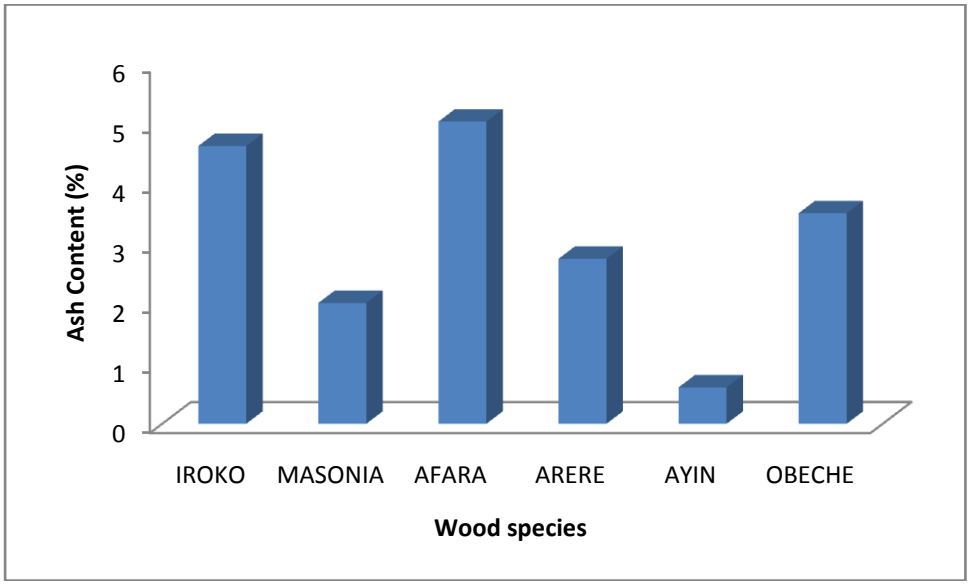

Fig.3: Percentage ash content for the various wood species

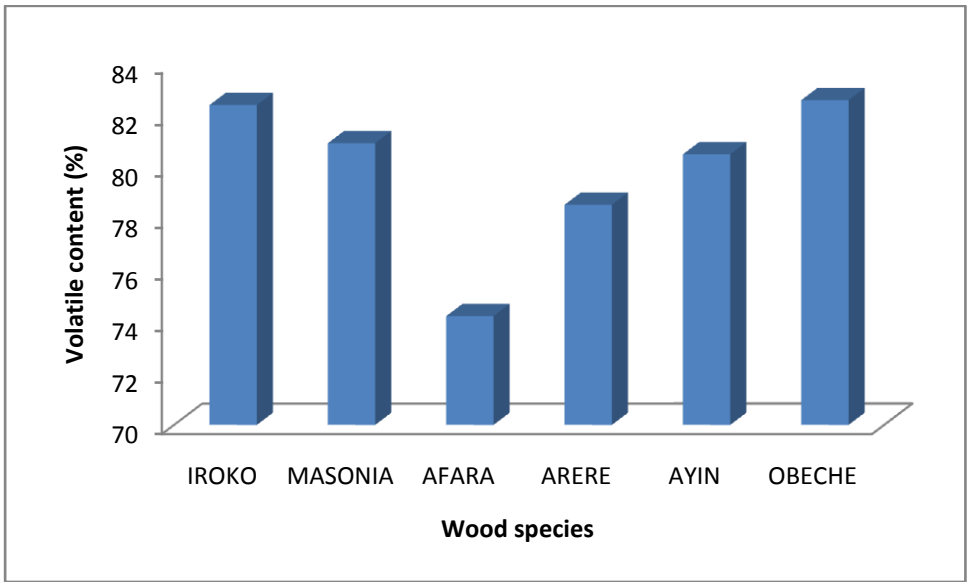

Fig. 4: Percentage volatile matter for the various wood species

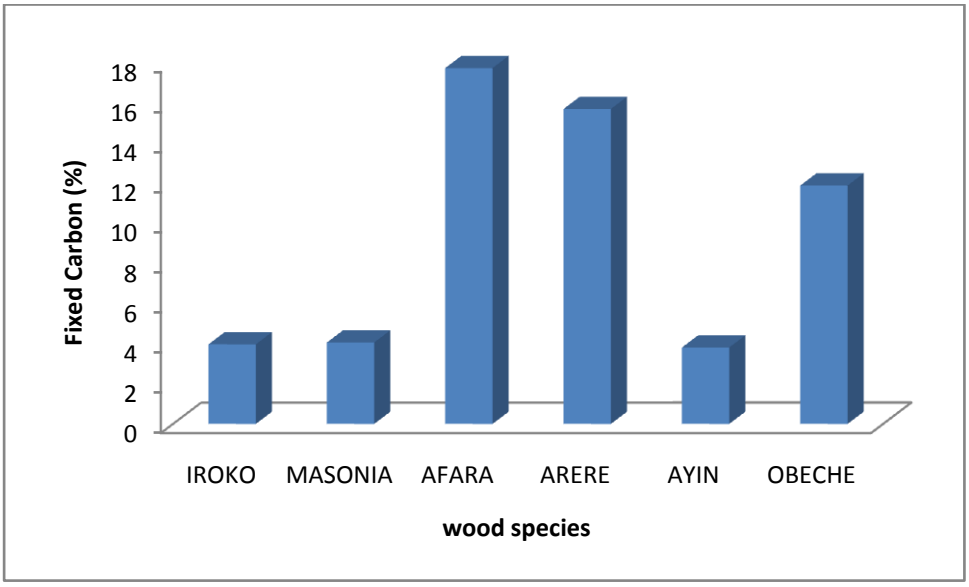

Fig.5: Percentage fixed carbon for the various wood species

3.3 *Ultimate Analysis*

The result of the ultimate analysis (Table 3) for the various wood species considered in this study shows that the values of Hydrogen content in the biomass materials ranged from 3.82% for Afara to 5.24% for Iroko (Fig. 6). With the exception of Iroko having 5.24%, the other wood species used in the study were below the expected range of 5% to 6% for a dry biomass matter with a good heating value. Methane content of the wood specie used ranged from 7.50% for Afara to 8.90% for Arere (Fig. 7), while the carbon dioxide content of the wood species ranged from 29.44% for Arere to 38.21% for Iroko (Fig. 8). The carbon monoxide content also ranged from 22.42% for Arere to 26.44% for Iroko (Fig. 9).

Table 3: Ultimate Analysis of data for selected wood waste biomass materials

Local Government	Saw Mill Location	Types of wood species	H_2 (% vol)	CH_4 (% vol)	CO_2 (% vol)	CO (% vol)
Ibadan North	Bodija SM1	Iroko	5.24	8.02	38.21	26.44
Ibadan North	Bodija SM2	Masonia	4.03	7.59	37.22	25.32
Ibadan North	Sango SM3	Afara	3.82	7.50	36.41	23.12
Ibadan North	Sango SM4	Arere	3.85	8.90	29.44	22.42
Oluyole	Idi Ayunre SM5	Ayin	4.08	8.63	31.43	23.42
Oluyole	Idi Ayunre SM6	Obeche	3.85	8.90	29.44	22.42

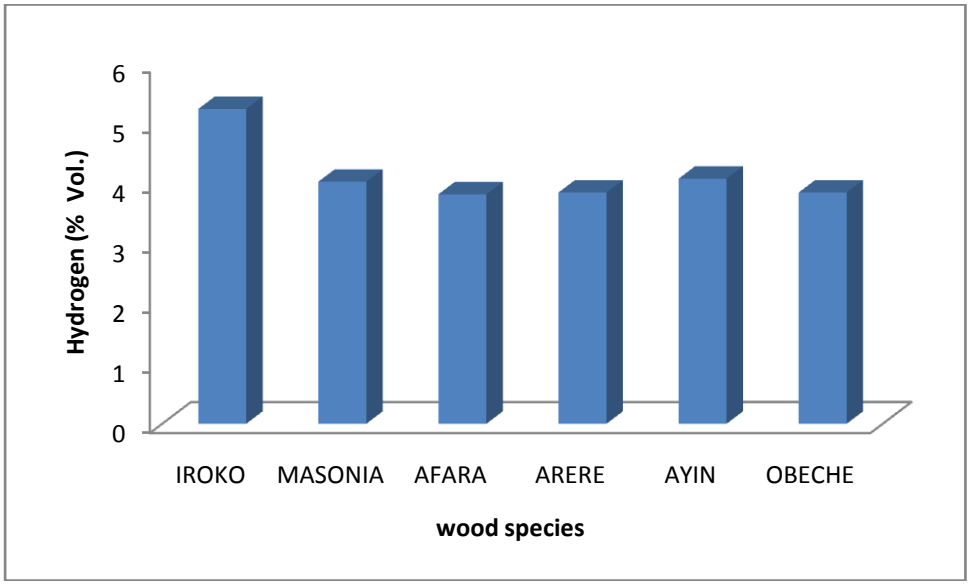

Fig. 6: Percentage volume of hydrogen for the various wood species

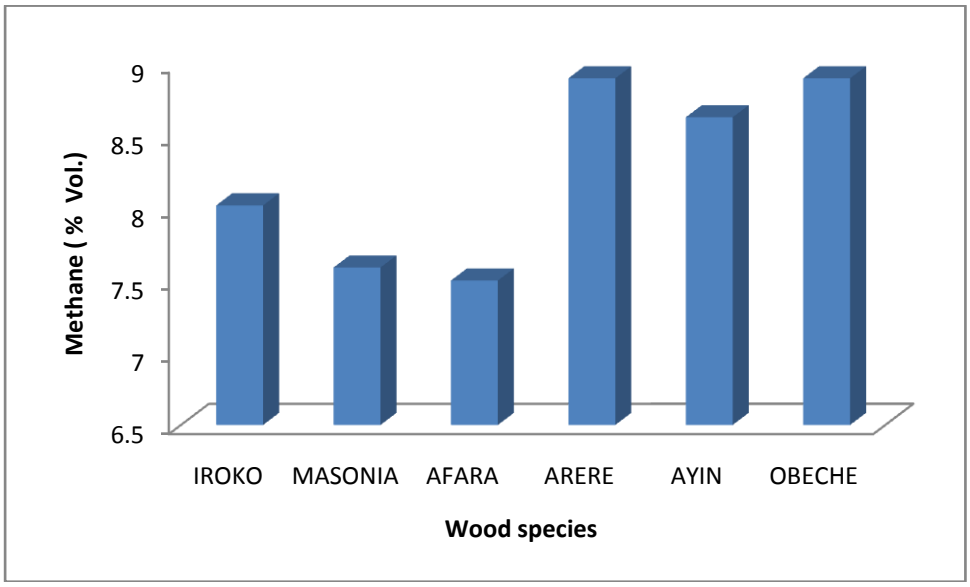

Fig. 7: Percentage volume of methane for the various wood species

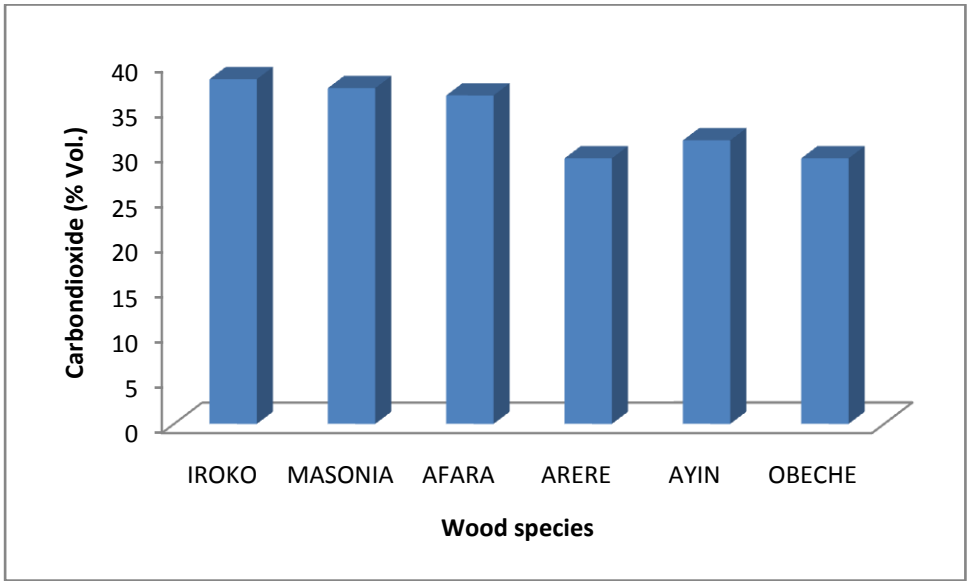

Fig. 8: Percentage volume of carbon dioxide for the various wood species

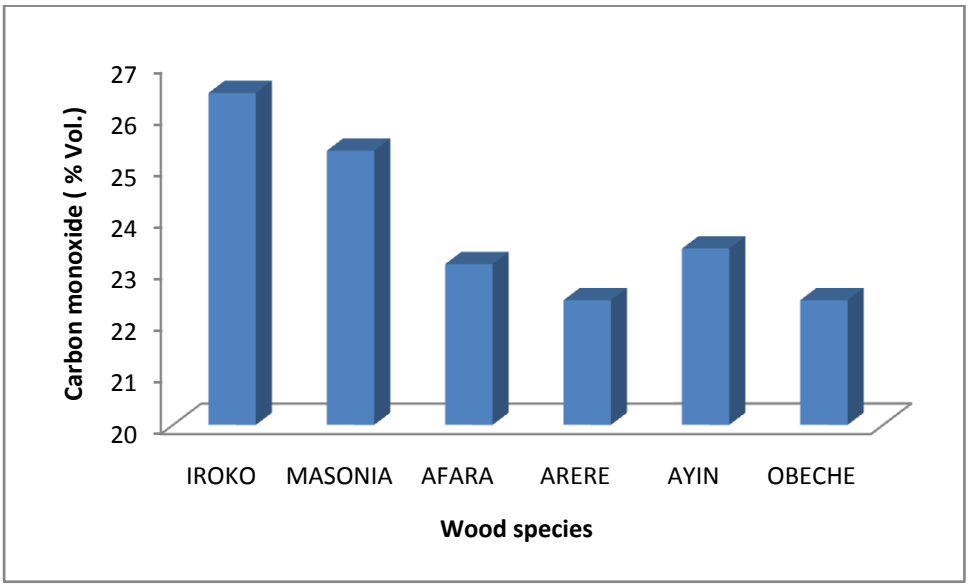

Fig. 9: Percentage volume of carbon monoxide for the various wood species

3.4 Fuel Properties

Table 4 shows the ranking of the fuel properties for the six wood species considered. The fuel properties were assigned values between 0-1, 1-2, 2-3, 3-4, 4-5, with 1 as the best and 5 as the worst. Significant variation was noticed in the fuel properties of these six different wood species with Obeche (1.75) having the least value, while Afara (3.25) had the highest value. This suggests that wood waste from Obeche has the best fuel properties, while the wood waste form Afara has the worst wood fuel properties. Thus, it must be noted that the lower rating values has the best wood species in terms of the fuel properties while the higher ratings has the worst wood species in terms of fuel properties (Fig. 10).

Table 4: Ranking of fuel Properties for the wood species

Properties	Iroko	Masonia	Afara	Arere	Ayin	Obeche
Wood density (Kg/m^3)	5	4	3	2	0	2
Gross Calorific Value (MJ/Kg)	5	5	3	1	2	1
Volatile Matter (%)	4	3	5	4	1	4
Ash Content (%)	5	2	3	1	4	1
Hydrogen (% Vol.)	0	3	5	2	3	2
Methane (% Vol.)	4	3	4	1	2	1
Carbon Dioxide (% Vol.)	2	0	1	2	5	0
Carbon Monoxide (% Vol.)	1	5	2	3	4	3
Fuel rating	3.25	3.13	3.25	2.00	2.63	1.75

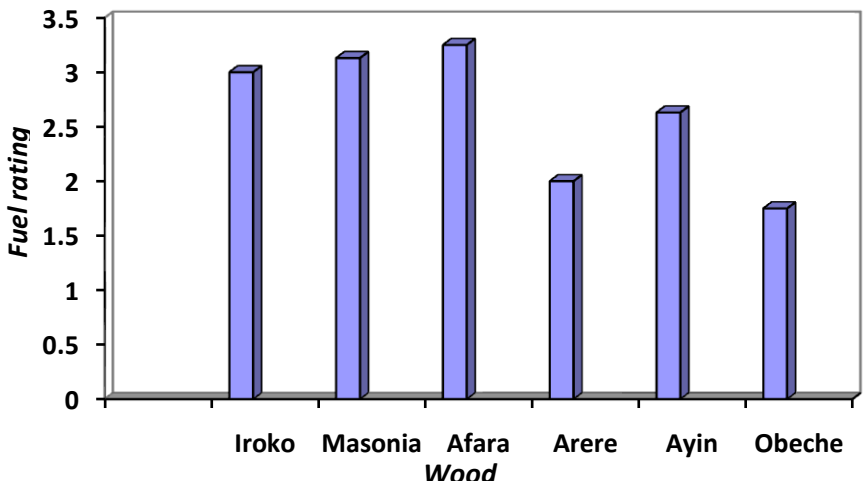

Figure 10: Fuel properties of wood species from six sawmills market in Bodija, Sango and Idi Ayunre areas of Ibadan with its rating

3.5 Gross Caloric Value of the Samples

The result of the gross calorific value of the six various wood waste species used (Table 5) shows that the least gross calorific value of 20.14 MJ/kg was obtained for Obeche, while the highest value of 22.30 MJ/kg was obtained for Ayin (Fig. 11). Comparison of the experimental value of GCV with the estimated Dulong-Berthelot model is as shown in Table 6. These values are consistent with those obtained from experiment only that they are lower due to the absent of components like sulphur and nitrogen in saw dust which reduces the calorific value (Fig. 12). This is also important because it shows that the saw dust obtained from the biomass from these wood species produces less ozone depletion greenhouse gases. However, it must be noted that despite that Arere was ranked fifth in the rating of the calorific value of the wood species but the overall rating value indicated that it has the second best fuel properties. Hence, it shows that calorific value should not be the only factor to be considered in determining the suitability of a biomass material for fuel briquettes.

Table 5: Gross Calorific Values for selected wood waste biomass materials

Types of wood species	Iroko	Masonia	Afara	Arere	Ayin	Obeche
Gross calorific value (MJ/kg)	20.20	21.50	20.68	22.15	22.30	20.14

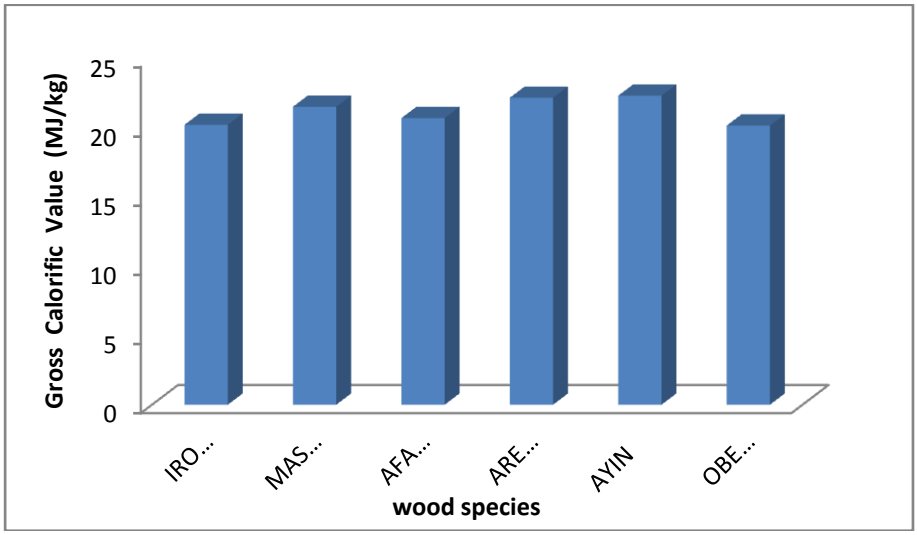

Fig. 11: Gross calorific value against the various wood species

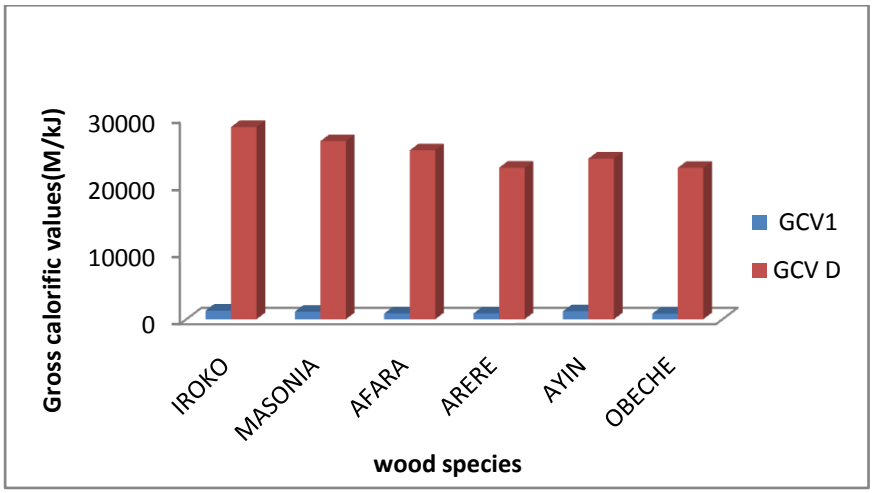

Fig. 12: Comparison of GCV experimental (GCV1) with Estimated Dulong-Berthelot model (GCVD)

Table 6: Comparison of GCV experimental with Estimated Dulong-Berthelot model

Wood waste species	Gross Calorific value Experimental	Gross Calorific Value Dulong-Berthelot model
IROKO	1289.42	28646.04
MASONIA	1135.00	26528.84
AFARA	865.47	25176.88
ARERE	874.04	22582.83
AYIN	1191.17	23942.82
OBECHE	848.43	22566.81

3.6 Bulk Density of the various Wood Species

Table 7 shows the densities of six various wood species used for this study. The densities of the various wood species range from 403.12 kg/m^3 for Iroko to 754.11 kg/m^3 for Ayin (Fig. 13). This result therefore suggests that Ayin is more likely to have a higher energy per unit volume than the other wood species considered in this study, because it will burn for a longer period of time than the other wood species. Woods with higher densities are also likely to produce briquettes with higher densities.

Table 7: Wood density value for selected wood waste biomass materials

Types of wood species	Iroko	Masonia	Afara	Arere	Ayin	Obeche
Wood density (kg/m^3)	403.12	440.52	562.74	560.05	754.11	734.69

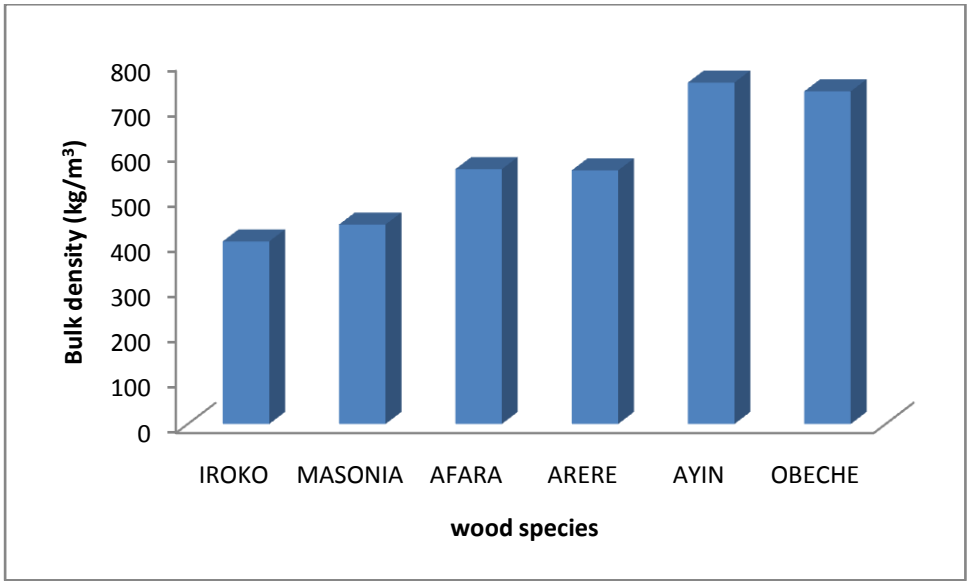

Fig.13: Bulk density of the various wood species

4. Conclusion

Wood biomass which is a major renewable energy source of energy in the developing world represents a significant proportion of the rural energy supply, and its potential lies in the residual waste usually referred to as wood shavings (sawdust). It is from these wastes that electrical power could be generated in a power plant that uses wood pellets as fuel. The estimated volume of wood milled daily from the various sawmills considered in this work was 55% of the total 100% wood species supplied to millers. Out of this 55% volume of the daily milled wood, 34% of it accounted for the daily milled wood waste. It was determined that the total volume of wood waste generated by the three plank markets in Ibadan on a daily basis amounts to 1607.4 m^3. The analysis of the six different types of wood species (Iroko, Masonia, Afara , Arere, Ayin and Obeche) obtained from the sawmills located within Bodija, Sango and Idi Ayunre areas of Ibadan were through laboratory investigations. This includes the utilization of both the proximate and ultimate analysis, and the estimation of the calorific values in the determination of their fuel characteristics.

The result of the proximate analysis of the various wood species obtained for this study showed that the percentage moisture content of Ayin was the highest, while that of Obeche was the least. This is an indication that Obeche will give the highest fuel calorific value (i.e. best fuel property) amongst the other wood species of wood considered in this work. Also, amongst these various wood species; Afara has the highest ash content which is an indication of high mineral matter. The volatile matter of Obeche being the highest and that of Afara the least indicates that during combustion process most of Obeche would not volatize, but would completely be burnt when utilized in cooking, while that of Afara would be otherwise. However, Afara has the highest fixed mass amongst these wood species with Iroko being the least. This high fixed carbon content indicates that the biomass will require a long combustion time. The result of the ultimate analysis shows that Iroko has the highest Hydrogen content, while Afara was the least. The methane content of Arere was the highest, while that of Afara was the least. Also, the carbon dioxide content of Iroko was the highest, while that of Arere was the least. Similarly, just as in the carbon dioxide content for the biomass, the carbon monoxide content of Iroko was the highest, while Arere was the least.

The fuel characteristics of these wood species showed that Afara has the highest value, while Obeche was the least. This suggests that wood waste from Obeche has the best fuel properties, while that of Afara was the worst. From the result of the gross calorific value (GCV), Ayin has the highest value, while Obeche had the least value. The comparison of the experimental value of the GCV with the estimated Dulong-Berthelot model showed consistency with those obtained from experiment, but of lower values due to the absent of components like sulphur and nitrogen in the saw dust obtained from these various wood species. This is an indication that saw dust obtained from these wood species produces less ozone depletion greenhouse gases.

The result of the bulk densities shows that Ayin has the highest value, while Iroko had the least value. This suggests that Ayin is more likely to have a higher energy per unit volume than the other species of wood used in this study, because it will burn for a longer period of time than the other species of wood. In summary, it can be concluded that amongst the six wood species studied in this work Obeche has the best fuel properties with both Arere and Afara being the worst.

References

[1] Karekezi S. and Kithyom, W. (2006). Bioenergy and Agriculture: Promises and Challenges. Bioenergy and the Poor. In: 2020 Vision for Food, Agriculture, and the Environment. International Food Policy Research Institute, Washington DC, USA

[2] Ladanai, S. and Vinterback, J. (2009). Global Potential of Sustainable Biomass for Energy. SLU, Institutionen for energy och teknik, Swedish University of Agricultural Sciences, Department of Energy and Technology, Report 013, ISSN 1654-9406, Uppsala

[3] Muhammad, M.B. (2016). Effect of Gasification operating Parameters on Quality of Syngas produced using sawdust feedstock. A dissertation submitted to the school of postgraduate studies Ahmadu Bello University, Zaria. In partial fulfillment of the requirement for the award of Master of Science Degree in Chemical Engineering. Accessed April 18, 2018 from kubanni.abu.edu.ng/jspui/bitstream/123456789/8068/…/

[4] Probsten, H.V; and Kicks, C.A. (1982). Briquetting Agricultural Waste as an Energy Source. Journal of Environmental Science, Computer Research & Technology (IJERT), Vol. 2 Issue 2.

[5] UNFCC (2005). Clarifications of Definition of Biomass and consideration of changes in Carbon Pools due to a CDM Project Activity. Accessed 18 April, 2018 from https://cdm.unfcc.int/Reference/Guidclarif/ar/methAR_guid07_v01.pdf

[6] Bergerson, J. and Keith, D. (2006). Life Cycle Assessment of oil sands Technologies Alberta Energy Futures Project Institute for Sustainable Energy, Environment and Economy (ISEE), University of Calgary.

[7] Christus, J.S., Joseph, S.S. and Thyagarajan, K. (2014). Performance Studies on Downdraft Gasifier with Biomass Energy Sources Available in Villages. Amercan Journal of Applied Science, 11(4), 611-622. DOI:10.3844/ajassp.2014.611.622.

[8] Reed, T.B., and Das, A.I. (1988). Hand book of Downdraft Gasifier Engine System. Solar Technical Information Program, Solar Energy Rresearch Institute (SERI) Colarado.
Basu, P. (2010). Biomass Gasification and Pyrolysis: Practical Design and Theory. Academic Press/ Elsevier, USA, 376pp.

[9] Hickey, M. and King, C. (2001). *The Cambridge Illustrated Glossary of Botanical Terms*. Cambridge University Press, UK. Accessed April 18, 2018 from http://en.wikipedia.org/wiki/Municipal_solid_waste

[10] ASTM E 870-82(2013), Standard Test Methods for Analysis of Wood Fuels, ASTM International, West Conshohocken, PA, 2013, www.astm.org

[11] Berberet, A., Ory, T., Poulos, V. and H. Powell. (2010). Milling the Future Sustainable Forestry and Sawmill Operations in Northern Winsconsin, Geography 565 Undergraduate Major Colloquim, 59pp.

[12] Biomass Analytical / Solid fuel Analysis. (2018). Assessed March 1, 2018 from www.laborec.be/ENG/Services/biomass-analysis/

[13] Sluiter, A., Hames, B. Ruiz, R., Scarlata, C., Sluiter, J. and D. Templeton. (2008). Determination of Ash in Biomass. Laboratory Analytical Procedure (LAP) National Renewable Energy Laboratory Technical Report NREL/FP-510-42622

[14] Encyclopedia Brittanica (2018) Fixed Carbon- Coal. Accessed April 25, 2018 from http://www.brittanica.com/topic/fixed-carbon

[15] ASTM (1981). Coal Resource Classification System of the U.S. Geological Survey. Accessed 26 March, 2018 from https://pubs.gov/circ/1983/0891/report.pdf
Wood, G.H., Kehn, T.M., Carter, M.D., Culberston, M.D (1983) Coal Resource Classification System of the U.S. Geological Survey-Geological Suvey Circular 891. Accessed 26 March, 2018 from https://pubs.usgs.gov/circ/1983/0891/report.pdf

[16] Channiwala, S.A. and Parikh, P.P. (2002). A unified correlation for estimating HHV of solid, liquid and gaseous fuels. Fuel, vol 81(8), pp. 1051-1063