

# Performance and Evaluation of the Heating Value of Wood Biomass for Use in Steam Thermal Power Plant

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**Abstract** - Wood biomass is a potential alternatives source of energy for electricity generation if well Harnessed. This is due to its prospect in the production of fuel having high calorific value that can be used to drive a steam turbine in the production of electricity. This study shows the Performance and evaluation of the heating values of wood biomass for use in steam thermal power plant. Biomass (wood wastes) from six tropical species, Iroko (*Melicia Exclsa*), Omo (*Cordial Platythyrta*), Obeche (*Tripochiton Scleroxylon*), Afara (*Terminal Superb*), Ayin (*Anogeissuseleio Carpus*), Abura (*Mirangya Cilita*) collected from twelve(12) sawmills in Akure metropolis Ondo state in south west Nigeria, were used as a feedstock. The proximate and ultimate analyses were performed to access the energy characteristics of the collected wood samples according to the procedure of American Society Standard Test Material (ASTM) for ultimate and proximate analysis ASTM E870-82. A computer program (MATLAB) was developed to determine the calorific value, volume of air, consumption of water and steam require in powering a 1.0 MW-h steam thermal power plant (Model). The results from laboratory experiments and energy calculations from the model revealed that the six wood species used in this study contain relatively low moisture content and ash content, high proportion of volatile matter and high calorific value, low level of sulphur as well as a sufficient high value of thermal energy potential. The boiler efficiency, mass of air, volume of air, steam consumption of the six samples of wood at different air fuel ratio were determined. Furthermore the model required 7.985 kg/h of wood waste, 13.206 kg/h mass of water, 1.86 factor of evaporation and 7.1 kg/h of steam consumption. The volume and mass of air require is 58.297 m<sup>3</sup>/h and 318.813 kg/h respectively.

**Keywords:** Wood Biomass, Steam, Calorific value, Thermal Power, Energy Potential.

## I. INTRODUCTION

Energy demand, supply, and pricing have enormous impact on the socio-economic development, the living standards and overall quality of life of the population of a nation, Mohamad and Anuge, (2016). The form of energy that is very crucial for human existence is electrical energy as it tends to form the heart of any meaningful growth in any country. Throughout the world electricity is the most widely used and desirable form of energy Oyedepo (2012). It is the bedrock, indispensable driving force and essential ingredient as well as a basic requirement for socio-economic growth and development Oyedepo et al.(2015). Be it entertainment, recreation, agriculture, commerce, industry, transport, education, communication, health, architecture and many others Unachukwu et al., (2015).

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 demand of the population (which is approximately two hundred million people). This is based on the fact that the available megawatt-hour is not enough to cater for the teeming populace CEC (2002). However, Nigeria is endowed with abundance of renewable and non-renewable energy resources including Hydro, wind, solar energy etc. A proper leverage on this abundance of energy resources will enable proper development which is antigen to the development of any nation. On the other hand even though Nigeria is endowed with massive reserves of hydro energy, petroleum and gas, most of the country's citizens do not have access to uninterrupted supplies of electricity Ubani, (2013). Electricity outage is one of the main challenges confronting the residential, commercial and industrial sectors of Nigeria's economy. And all attempts at addressing this problem have not yielded the desired results Nwachukwu et al., (2014). Energy sufficiency and security is a key to development and prosperity since it provides essential inputs for socio-economic development at regional, national and sub-national levels; thereby providing vital services that improve the quality of life Singh and Sookh, (2004). The

access to affordable energy is an essential component of achieving the Millennium Development Goals and UN Sustainable Development Goals for Nigeria, Amigun et al., (2011).

Today, every country draws its energy needs from a variety of sources. Energy sources therefore, have to be explored and developed to enhance industrial breakthrough, national security and financial stability of the nation. Biomass is one of these sources. Biomass 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. It is available in varying forms throughout the developing World. Ohimain (2011). Osafehinti and Ayodeji (2018) observed that among various source of biomass which comprises palm kernel shells, municipal wastes, wood and its waste is a very cheap source of fuel when properly harnessed.

In Nigeria, about 11 million hectares of forest and 5.5 million hectares of other wooded land are available; according to the Food and Agriculture Organization (FAO) (2016), Logging activities in the forests and wood processing at the various wood processing industries generate a huge volume of wood wastes annually across cities in the country. For example, about 294,798 tonnes of wood waste is generated yearly in the city of Lagos Kehinde et al (2014). Aina, (2016), estimated that about 2288 m<sup>3</sup> of wood wastes are generated daily in Abeokuta, while Dosunmu and Ajayi (2002) reported that 5.2 million tonnes of wood wastes are generated from the Nigerian sawmills per year. These quantities of wood could be harnessed to generate electricity, heat and transport fuels by using several technologies available such as direct combustion, gasification and pyrolysis Armau (2013). In 2015, about 46% of renewable energy consumed in European Union (EU) came from solid biomass Bourguignon, (2015), in 2013, solid biomass accounted for 3% of the electricity produced in the EU and 15% of the heat produced in the industrial sectors. The use of woody biomass for energy generation can offset fuels such as coal, gasoline, natural gas and oil Basker et al (2012). Such practice can enhance economic development, foster new industries and encourage green economy as well as energy independence.

This work focuses on the Evaluation of the heating values of wood biomass for use in steam thermal power plant. The study intends to access the energy content of the selected wood, moisture content and their various calorific values for effective and efficient electrical energy generation.

Therefore, this study assessed the performance and evaluation of the heating value of wood biomass for use in steam thermal power plant, which include proximate and ultimate analysis of six species of wood, develop a model for determining the calorific values of wood and estimating the mass of air and water consumption at different air fuel ratio.

## II. MATERIALS AND METHODS

The materials and method used for the study are as follows:

### 2.1 Materials

Wood biomass from six tropical species were collected from sawmills and wood markets across Akure metropolis in Ondo States in south western part of Nigeria. The wood species (wood samples), were: Obeche (*Triplochiton sclerxylon*), Iroko (*Milicia excelsa*), Afara (*Terminallia superba*), Ayin (*Anogeissus leiocarpus*), Abura (*Mitragyna Ciliata*), Omo (*Cordia Millenii*).

### 2.2 Methods

Wood processing activities were physically observed for 5 day/week at the various sawmills and wood markets visited for eight (8) consecutive weeks to collect each of the samples of wood (sawdust and pellet). The sample collected were sun dried to reduce moisture content and to prevent degradation. Experiments were carried out on each sample to determine their moisture content as well as their proximate and ultimate analyses. The experiments were conducted according to the procedure of the America Society Standard Test Method (ASTM) for ultimate and proximate analysis (ASTM E870-82(2013)). A model was developed with Matlab computer language for estimating the heating values of selected wood sample (including any kinds) and computing quantities of fuel samples (wood biomass), water and steam required to generate 1.0 MW-h of electrical energy.

#### 2.2.1 Estimation of the volume wood (waste/ pellet)

The volume of weekly milled wood (VWW) base on six working days was given by equation 1.

$$v_{ww} = 6 * 0.8164NLD$$

$$V_{WW} = 4.898NLD \quad (1)$$

Where:

NLD = Number of lumber per day

### 2.2.2 Proximate and Ultimate Analyses

The proximate analysis determine the physiochemical properties of the biomass like moisture content, fixed carbon, volatile matter and ash content, while ultimate analysis determine the elemental composition of carbon, hydrogen, oxygen and sulphur.

The following equation were used to determine the parameters

#### 2.2.2.1 Moisture Content

Moisture content (MC) is given below

$$MC = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \quad (2)$$

#### 2.2.2.2 Ash content (AC)

$$AC = \frac{M}{M_s} \times 100\% \quad (3)$$

$M$  = Mass of the Ash

$M_s$  = mass of the sun dried sample

#### 2.2.2.3 Volatile Matter Content

The volatile matter (VM) is given below

$$VM = \frac{W-Z}{W} \times 100 \quad (4)$$

$W$  = Weight of sun dried pellets

$Z$  = Weight of dried wood pellet

#### 2.2.2.4 Fixed Carbon Content

Fixed carbon (FC) is given below

$$FC\% = 100 - MC - VM - AC\% \quad (5)$$

#### 2.2.2.5 Mathematical model to determine the calorific value of various woods

$$C_{v,s}(\text{in kJ/kg}) = 33440.C + 115300.H + 9279.S - 2440.H_2O \quad (6)$$

Where: C is the carbon content (%);

H is the hydrogen content (%); S is the sulphur content (%); and  $H_2O$  is the water content (%)

### 2.3 Determination of the turbine internal efficiency

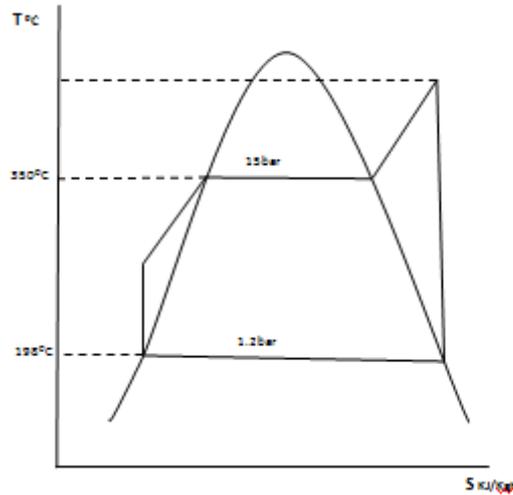


Figure 1: shows the T-S diagram of 1.0 MW-h waste wood steam thermal power plant (WWSTPS)

Table 3.1 showing Conditions of steam at inlet temperature (350°C)

The internal efficiency of the turbine was evaluated using equation 7 and 8 as given by Chattopadhyay, (2004)

$$\eta_t = \frac{h - h_2}{h - h_{f2}} \quad (7)$$

Pressure(bar)	V(m <sup>3</sup> /kg)	h <sub>f</sub> (kJ/kg)	h <sub>fg2</sub> (kJ/kg)	S <sub>f2</sub> (kJ/kgK)	S <sub>fg</sub> (kJ/kgK)	T <sub>sat</sub> (°C)
15 bar	278.5	844.7	1945.2	6.978	4.1261	198.3
1.2 bar		439.7	2244.1	1.3609	5.937	
15 bar and 350°C		h*=3147.5		s*=7.102		

The adiabatic enthalpy drop

$$(\Delta h) = h - h_2 \quad (8)$$

### 2.4 Determination of the work done

Impulse steam turbine was considered because it is a single state process. Turbine and pump are the two work utilizing components involved in the energy generation. The turbine work done (W<sub>exp</sub>) according to Nag (2008) is the product of the adiabatic enthalpy drop and the stage internal efficiency. It is expressed in equation 9:

$$W_{exp} = \Delta h \cdot \eta_t \quad (9)$$

### 2.5 Mass of Fuel Charged to the Boiler

Actual mass of fuel charged to the boiler is

Addition of mass of fuel to unburnt mass of fuel

$$M_{fa} = m_f + m_{fu}$$

$$M_{fa} = (1 + \sigma_f)m_f \quad (10)$$

Where M<sub>fa</sub> is actual mass of fuel, m<sub>f</sub> mass of fuel, m<sub>fu</sub> mass of unburnt fuel, σ<sub>f</sub> is fraction of unburnt fuel,

## 2.6 Determination of Factor of evaporation ( $F_{ev}$ )

The factor of evaporation is given by equation (11)

$$F_{ev} = \frac{H_f + L_v + C_p \Delta t - H_{fw}}{H_w} \quad (11)$$

Where:  $H_f$  is enthalpy of steam,  $L_v$  is latent heat of vapourization,

$C_p$  is specific heat capacity of steam,  $\Delta t$  is temperature difference,  $H_{fw}$  is enthalpy of feed water, at ambient temperature  $H_w$  is enthalpy of water at boiling temperature

## 2.7 Mass of Water Required

$$MR_q = F_{ev} \cdot M_{st} \quad (12)$$

Where:  $F_{ev}$  is factor of evaporation,  $M_{st}$  is mass of steam

Boiler efficiency which is the ratio of the heat load of the generated steam to the heat supplied by the fuel (wood) over the same period as expressed in the equation 13 by Nag (2008) as:

$$\text{Boiler efficiency} = \frac{\text{heat output}}{\text{heat input}}$$

$$\eta_b = \frac{M_{st} \cdot \Delta h}{m_f (1 + \phi) C_v} \quad (13)$$

Where

$\eta_b$  is boiler efficiency,  $M_{st}$  is mass of steam,  $\Delta h$  is adiabatic drop in the boiler,  $\phi$  is air fuel ratio,  $C_v$  is calorific value,

## 2.8 Air required in the system

$$\text{Air fuel ratio} = \frac{\text{mass of air}}{\text{mass of fuel}}$$

$$M_a = m_f \cdot \phi \quad (14)$$

$$M_{ac} = (1 + \phi) m_f \quad (15)$$

Where,  $M_{ac}$  is actual mass of air,  $m_f$  mass of fuel,  $\phi$  is air fuel ratio,  $M_a$  is mass of air

## 2.9 Volume of air ( $v_a$ )

$$\text{volume of air} = \frac{\text{mass of air}}{\text{density of air}}$$

$$v_a = \frac{m_a}{\rho_a} \quad (16)$$

$$v_a = \frac{(1 + \phi) m_f}{\rho_a} \quad (17)$$

## 2.10 Determination of thermal power potential of the plant

$$\text{power} = \frac{\rho_{wd} \cdot V_d \cdot C_v \cdot \Delta t_{int}}{3600} \quad (18)$$

Where:  $VdW$  is the volume of daily milled wood waste ( $m^3$ ),  $\rho_{wd}$  is the density of the wood species ( $kg/m^3$ ) and  $CV$  is the calorific value (Mj/Kg),  $\eta_{int}$  is turbine efficiency.

### III. RESULTS AND DISCUSSION

#### Proximate Analysis

The result of the proximate analysis of the various sample are presented in table 3.1

#### Proximate Analysis of Selected Wood Biomass Material

Table 3.1 proximate analysis of the selected wood biomass

Types of wood	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed carbon (%)
Abura	7.1	1.68	77.48	13.77
Iroko	8.9	4.64	82.44	3.96
Afara	3.52	1.95	82.17	12.36
Omo	6.4	1.07	85.57	6.96
Ayin	15.2	0.71	80.62	4.0
Obeche	2.3	2.71	82.73	11.94

Table 3.1 shows that the percentage moisture content range from 2.3 % to 15.2 % and Ayin had the highest with 15.2% while that of the Obeche had the least 2.3 % follow by Afara with 3.52 %. The results agreed with the finding of Ogunsola *et al* (2018) that the moisture content ranges from 2.0 to 16.02 %. This shows that Obeche is the one with the highest durability value in terms of their storage. The relatively low moisture content favours thermo-chemical conversion, since high moisture content reduces the efficiency of the system and also reduces the energy available from wood wastes during combustion as heat would be required to vaporize the water Yang *et al* (2005) The percentage volatile matter of the samples ranges from 77.48 to 85.57%, this results agreed with the findings of Akihito *et al* (2017), Ogunsola *et al* (2018). Who reported that the volatile matter of wood ranges from 71.01 to 87.70%, with Omo having the highest value and Abura with the least value. The volatile matter strongly influences combustion behaviour of solid fuel. Loo (2008).

The Ash content of the sample ranges from 0.71% ( Ayin) to 4.64% ( Iroko). The result agreed with the findings of Akinola and Fapetu (2015) ranges from 0.78 to 4.89%. The high Ash content for Iroko indicates that it has a high mineral matter. All other Ash content obtained in this study was lower than 4 %. This indicates that slagging (an incombustible by products) might not occur in other species of wood samples except for that of Iroko are used as biomass fuel. This low ash content is a desirable factor for energy generation and this aligns with the finding of Loo and koppejan (2008) that the higher the ash content in a fuel the lower its heating value.

The fixed carbon content of the wood sample varied from 3.96 % Iroko to 13.77 % of Abura. The result agreed with the findings of Ogunsola *et al* (2018) that the fixed carbon content ranges from 3.89 to 17.75 %. The high fixed carbon contents indicate that biomass will require a long combustable time. The results shown from table 3.1 indicates that these wood samples will have ease of burning and stable flame during combustion as well as high heating value.

Table 3.2 Ultimate analysis of the wood selected samples

Wood type	Hydrogen content(% vol)	Carbon content (% vol)	Oxygen content (% vol)	Sulphur content (% vol)
Abura	5.03	45.27	41.00	0.02
Iroko	5.34	26.56	46.72	0.03
Afara	5.56	57.00	35.86	0.05
Omo	3.10	48.21	42.22	0.02
Ayin	4.03	38.14	44.50	0.04

Obeche	4.32	32.24	36.15	0.03
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The results obtained from the six pellets sample are shown in table 3.2 indicate that the value of Hydrogen range from 3.10% (Omo) to 5.56% (Afara). This shows that the species has a good heating values having fall below 6%. The carbon content ranges from 26.56% Iroko to 57% for Afara. The oxygen content varied from 35.86% for Afara to 46.72% (Iroko), and finally the sulphur content ranges between 0.02 (Omo) to 0.05 (Afara). The results agreed with the findings of Ogunsola *et al* (2018). The high carbon content is expected to increase the calorific value of the fuel. The figure also reveals high percentage of hydrogen and oxygen; depict high energy potential of the wood samples. the results, agreed with the finding of Akhator *et al* (2017) who reported an oxygen content and hydrogen content of 5.1 to 5.59% and 35.8 to 39.11% and sulphur content from 0.03 to 0.06%. Carbon, hydrogen and oxygen are the major components of biomass feedstock and the reactants required during combustion process. It can be seen from the figure that the wood species contain low level of sulphur as required by the DIN51731 and as affirmed by Akhator *et al* (2017).

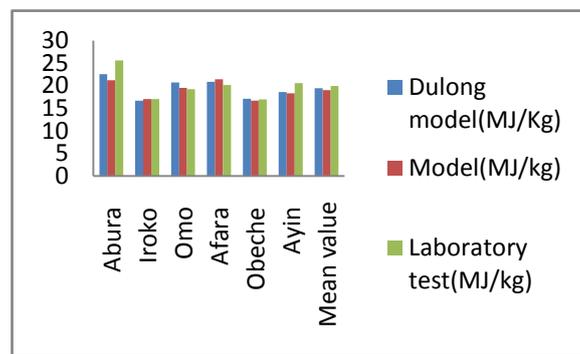


Figure 3.1 Comparison of the GCV experimental with the design model and Dulong Berthelot model

The mean calorific value of 19.04 MJ/kg and 19.98 MJ/kg from both the laboratory analysis, and the model, both agreed with the findings of Nag (2011) and Rajput (1997) and that of Dulong model which ranges from 15.8 MJ/kg to 26 MJ/kg. The result indicate good energy contents and also agreed with that of Akhator *et al*(2017) and Ogunsola *et al*(2018). Who reported that the calorific values of wood ranges between 17.5 MJ/kg to 26.2 MJ/kg and those calorific values of wood does not vary much from one species to another.

Table 3.3: The summary of the average volume of wood wastes and log generated on a daily basis for the 12 sawmills visited in Akure for this study

S/N	Name of Sawmill	Average number of log per day (Ft <sup>3</sup> )	Average number of log per week (Ft <sup>3</sup> )	Average number of lumber produced per day (Ft <sup>3</sup> )	Average number of lumber per week (Ft <sup>3</sup> )	Average volume of waste generated per day (m <sup>3</sup> )	Average waste generated per week (m <sup>3</sup> )
1	Babatunde F.A	5	15	288	2016	55.71	334.26
2	Alahaji Disu	3	8	432	3456	36.5	219.0
3	Aswara plc	4	8	144	720	51.1	306.6
4	Osbondu	5	10	288	2880	81.2	487.2
5	Bosan	4	11	504	6048	58.9	353.4
6	Adekoya	3	13	576	8084	62.9	377.4
7	Bolaji	3	9	436	5232	92.8	556.8
8	Tony S	5	15	720	4320	64.8	388.8
9	Owadasha	4	9	360	3240	75.8	454.8
10	Mukola	4	10	648	1788	68.2	409.2
11	Ifeoluwa	3	9	298	2317	67.3	403.8
12	Ajibade	3	12	331	3120	65.3	391.8
	<b>Total</b>	<b>42</b>	<b>129</b>	<b>5025</b>	<b>43221</b>	<b>790.51</b>	<b>4743.06</b>
	<b>Mean</b>	<b>3.5</b>	<b>10.75</b>	<b>418.75</b>	<b>3601.75</b>	<b>65.88</b>	<b>395.255</b>

The table shows the total of 461.3 m<sup>2</sup> of daily log, and a total of 2767.8 m<sup>2</sup> per week. a total volume of 790.51 m<sup>3</sup> per day and 4743.06m<sup>3</sup> weekly.

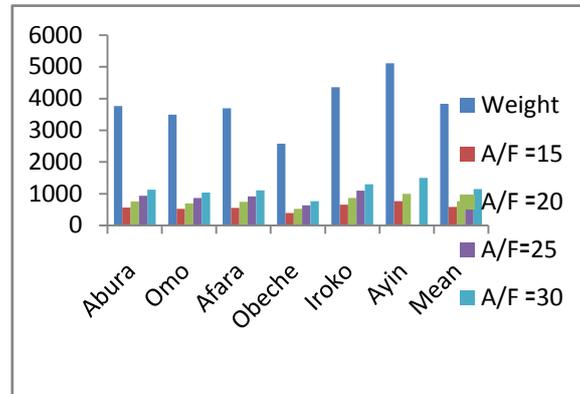


Figure 3.2: Mass of Air at different Air fuel Ratio

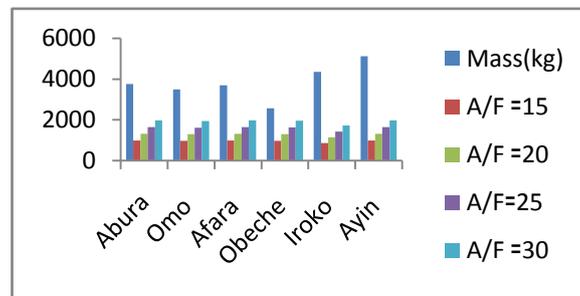


Figure 3.3 Volume of air at different air fuel ratio

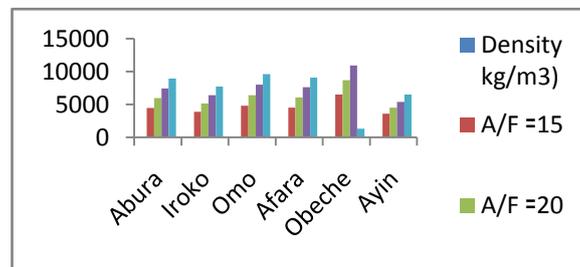


Figure 3.4 steam consumption using each wood species at different air fuel ratio

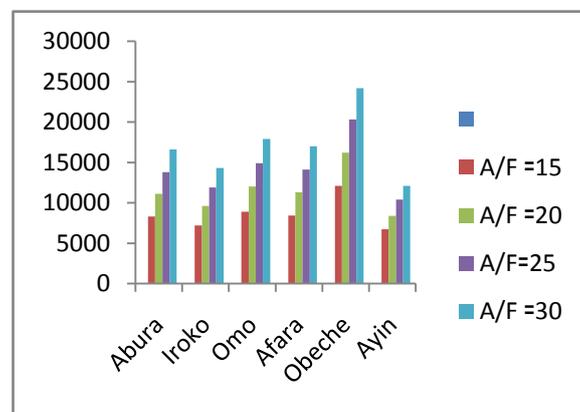


Figure 3.5 rate of water require by each specie at different air fuel ratio

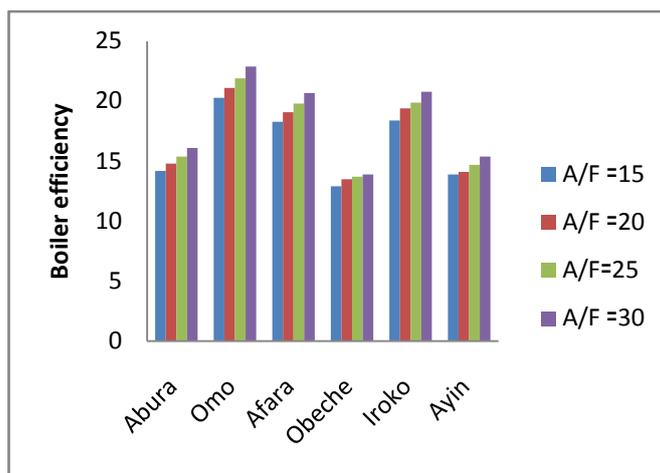


Figure 3.6 Boiler efficiency at different air fuel ratio

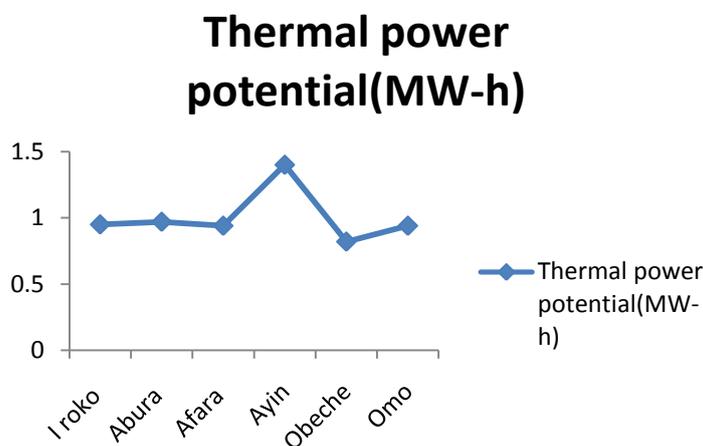


Figure 3.7 Thermal power potential of wood sample

Figure 3.2 to 3.7 shows the mass of air, volume of air, boiler efficiency, water requirement, steam consumption and thermal potential of the six sample of wood at different air fuel ratio. The results shows that as the air fuel ratio increases the mass of air, volume of air, steam consumption, water requirement and the performance of the boiler also increases. The result also shows that Obeche performance is the least 12.2% at 15:1 to 13.9% at 30:1 and the highest is omo with 20.3 to 22.9 at 15:1 and 30:1 respectively. Also the mass of fuel affect the boiler efficiency, the higher the quantity of wood charged into the furnace the higher the performance of the boiler. This result agrees with the findings of Damilola *et al* (2021) which ranges between 16 to 26.5. Furthermore the cost of design is higher with high Air fuel ratio according to Damiloloa *et al* (2021). Figure 3.8 shows that, Ayin has the highest thermal power potential and Obeche has the least. From their mean performance the selected wood sample has a good power generating potential, however due to their economic value, cost and availability, afara wood is more suitable for power generation due to its availability, having shown to have good calorific value and good thermal potential.

### 3.5 Summary of results of the different stages of the thermal plant model

S/N	PARAMETERS	EQUATION	CALCULATED VALUES
1	Adiabatic enthalpy drop of turbine	$\Delta h = h_1 - h_2$	585.2 KJ/KG

2	Work done by turbine	$W_{exp} = \Delta h \cdot \eta_{int}$	379 KJ
3	Dryness factor	$h_2 = h_{f2} + x \cdot h_{fg2}$	0.946
4	Rate of Steam consumption	$M_{st} = \frac{2685.6}{W_{exp}}$	7.1 Kg/h
5	Factor of evaporation	$F_{ev} = \frac{H_f + L_v + C_p \Delta t - H_{fw}}{H_w}$	1.86
6	Mass of water required	$M_{Rq} = F_{ev} \times M_{st}$	13.206 Kg/h
7	Mass of fuel charged	$M_{fa} = (1 + \sigma f) m_f$	5.304 T/h
8	Mass of air require	$M_{ac} = (1 + \phi) m_f$	318.813 kg/h
9	Volume of air require	$v_a = \frac{(1 + \phi) m_f}{\rho_a}$	58.297 m <sup>3</sup> /h
10	Power potential of wood sample	$power = \frac{\rho_{wd} * V_d * CV * \eta_{int}}{3600}$	1.00 MW-h

#### IV. CONCLUSION

This study assesses the performance and evaluation of the heating value of wood biomass for use in steam power plant. The volume of wood waste per wood specie has been identified and the heating value of the fuels identified. A model for determining the calorific value of wood has been developed using their proximate and ultimate analyses result. The study revealed that, the wood species had a calorific value ranging from 16.96 to 25.5 MJ /kg and a thermal potential ranging from 0.82 to 1.4 MW-h.

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

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**Citation of this Article:**

P. Egbaelu, E. I Bello, O. Z Ayodeji, “Performance and Evaluation of the Heating Value of Wood Biomass for Use in Steam Thermal Power Plant” Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 5, Issue 12, pp 73-83, December 2021. Article DOI <https://doi.org/10.47001/IRJIET/2021.512015>

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