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Thermal characterization of local tropical woods in view of their valorization

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Abstract
This research paper presents the thermal characteristics of some local woods. Bioenergy is a term that refers to energy got from the degradation of wood, under heat, during combustion processes. Plants convert the solar energy in the process of food manufacture, called photosynthesis. Bioenergy is directly used to produce heat or electricity. Exploitation of Cameroon's forest for wood work produces a lot of wood waste that could be valorized for the production of electricity, for cooking, to ensure thermal comfort in buildings and as biofuels for heating purposes. To this effect, we proceeded with the classification of local woods from the energy point of view; done through the knowledge of their thermal properties. These properties, amongst others, include moisture content obtained by dehydration of the samples in an oven, specific heat capacity obtained through the method of mixtures, the higher heating value obtained by burning the samples in a calorimetric bomb. The results of the analyses of data got include the following: moisture content(%) of wood gave the following, *Triplochiton scleroxylon* (Ayous) 11.32, *Cyclicodiscus gabunensis* (Okan) 12.54, *Entandrophragma cylindricum* (Sapeli) 16.41, *Erythrophleum suaveolens* (Tali) 20 ; while the specific heat capacities (J/kg.K) gave the following, *Triplochiton scleroxylon* 2532.31 ; *Cyclicodiscus gabunensis* 1474.53 ; *Entandrophragma cylindricum* 1578.82 ; *Erythrophleum suaveolens* 1920.24 and the higher heating values (kJ/kg), then gave, *Triplochiton scleroxylon* 16821.92 ; *Cylicodiscusgabunensis*16678.12; *Entandrophragma cylindricum* 15997,36. The correlation between the higher heating value and the moisture content is established. When the moisture content increases the higher heating value decreases.

1. Introduction

Wood is an ancient and a natural material found in many different localities. It is used as a biofuel in cooking food, in heating the environment and in building material [1-8]. Recently bioenergy is used as a fuel in transport [9], in some regions, wood provides good thermal comfort for buildings [10]. South Cameroon, especially the east region, is covered by millions of hectares of dense forest. A good portion of this forest resource is exploited by industries concerned with forest management. These industries transform only about 30% to 40% of the wood harvested, at the primary level, hence living about 1.8 million of wood remains in the form of sawdust, small woods particles being burnt in open air [11]. Studies show that biomass (wood, charcoal, and sawdust) represents 77% of the energy balances in Cameroon. 95% of this biomass is used in cooking at homes, where 80% of these homes uses three stones fireplace [11]. The world's population keeps on increasing, today it is 7.4 billion [12]. This increase leads to a high demand in energy and unfortunately fossil fuels are limited over time while at the same time the Kyoto protocol calls for reduction in greenhouse gasses [13]. It is therefore necessary to shift attention towards green energy (biofuels) [14]. According to one analyses on Cameroonian wood remains, the following conclusions were made on the availability of each wood remain in the forest; sawdust, 16%, slabs, crumbs and sapwood, 25%; remains from trimming, 13%; broken heartwood, 10%. This gave a total of 64% of wood remains in the forest [15]. Thermo gravimetric analyses and modelisation of the kinetics of three Cameroonians biomass had been found, as a means to know their energy values [16]. Over exploitation of forest resources is a call for concern and is attributed to lack of sustainable management of these resources, which on the other hand is due to the unknown values of energy of this forest wood. The main objective of this article is to contribute to the development and exploitation of national energy resources for its energy supply in cooking, heating and electricity. Thermal characterization of the chosen wood species is thus carried out to find their energy values as well as their specific heat capacities. Two methods exist for the determination of the specific heat capacity; the mixture method and DSC (Differential Scanning Calorimetric) [17]. Remond *et al.* [18] affirms that the specific heat capacity is a function of the moisture content of the material concerned. Two types of humidity exist; humidity on oven dried basis and humidity on air dried basis. Humidity on air dried basis is the ratio of the water found in the wood to the total mass of the wood [19]. On the other hand, humidity on oven dried basis is the ratio of the mass of water found in the wood to the mass of the dried wood sample. Studies on wood energy generally use humidity on air dried basis. Several methods are enumerated for the determination of humidity [19]: the dehydration method in an oven and the dielectric method. The energy content of wood is calculated through the elementary composition (percentage of carbon and of hydrogen in wood) and the method of combustion in the calorimetric bomb according to the standards; NF M 03-005 of 1990. This work is structured in the following manner: firstly, we describe the materials used as wood species and as equipment. Secondly we discuss the methods used in the determination of specific heat capacity, moisture content and heating values. Thirdly, the work continues with the presentation of results and discussions and ends with a conclusion and perspectives.

Nomenclature

Symbols	*Designations*	*Units*
C:	*Heat capacity of the calorimeter*	*J/K*
C_{p}:	*the specific heat capacity of material*	*J/kg.K*
C_{e}:	*the specific heat of water*	*J/kg.K*
θ_{eq}:	*Equilibrium temperature*	*°C*
θ_{i}:	*Initial water temperature*	*°C*
θ_{wo}:	*Initial material temperature*	*°C*
$m1$:	*Mass of cool water*	*g*
$m2$:	*Mass of hot water*	*g*
m_h:	*Mass before drying of wood sample*	*g*
m_a:	*Anhydrous mass of wood sample*	*g*

2. Material and Methods

2.1. Material

2.1.1. Samples

The goal of this work is realized with the use of the following wood samples: *Triplochiton scleroxylon* (Ayous) with family name STRECULIACEAE, *Erythrophleum suaveolens* (Tali) with family ERYTHROXYLACEAE, *Cylicodiscus gabunensis* (Okan) with family FABACEAE-MIMOSOIDEAE and *Entandrophragma cylindricum* (Sapelli) with family MELIACEAE, all taken from the east region of Cameroon. Figure 1 shows the various samples used in this research work.

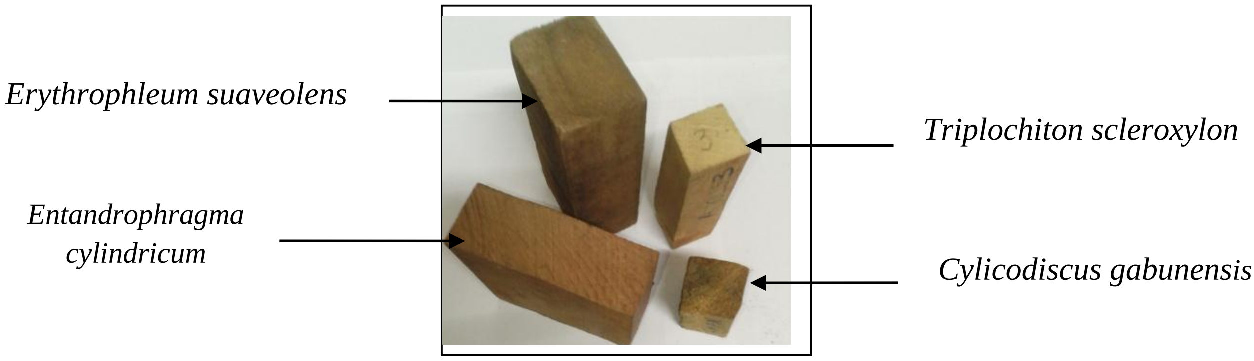

Figure 1: Wood sample.

2.1.2. Equipment

The equipment used in this research are presented in figure 2 and they include: a balance with 0.01g precision use to measure the mass of each sample, an oven marked Binder adjusted to 105°C for dehydration of the wood samples, a temperature sensor denoted Omega Engineering with serial number S/N: 525111,with 0,1°C as precision of measure , the Dewar flask calorimeter with a supply voltage of 12V max and heat capacity C less than 30 J/K use to obtain the equilibrium temperature between the sample, water and the calorimeter. The calorimetric bomb used to determine the Higher Heating Values of the burnt materials, a computer with characteristics M540, 4GB RAM, 2.53GHZ processor, 64 bits use to save data.

Figure 2: Equipments used

2.2. Methods

The methodology used for the characterization of the samples is as follows:

- The determination of the specific heat capacities of the samples by the mixture method after the calibration of the calorimeter and the determination of the moisture content of the samples;
- The determination of the heating values according to NF M 03-005 of 1990 of combustion of samples in a calorimetric;
- The specific heat capacity of a material is a function of its moisture content [20]. The determination of the moisture content is done through several methods, amongst which is the method of dehydration in an oven used in the realization of this research work.

2.2.1. Determination of moisture content

There are variations in the modes of dehydration of wood samples. The various ways of dehydration include, amongst others; using micro-waves, infrared radiation or using an oven. In this research an oven was used to dehydrate wood samples at a temperature of 100°C+/-5°C for 24 hours. The dehydrated wood was then weighed and the formula in equation (1) was used to obtain the moisture content of each wood sample [21].

$$\mathrm{H\%} = \frac{\mathrm{m_a}}{\mathrm{m_h}} * 100 \quad (1)$$

2.2.2. Determination of the specific heat capacity

The mixture method use for the determination of the specific heat capacity of materials is a method that involves thermal transfer from a body, whose specific heat we want to measure, to cool water at room temperature. In the case where thermal transfer involved is from hot water to a body whose $\boldsymbol{c_p}$ we want to know then the thermal energy ceded by water is as follows [21,22]:

$$\mathrm{Q} = \mathrm{mc_e}\Delta\theta \quad (2)$$

In the case where thermal losses of the system are neglected, we can consider that the energy absorbed by the body is exactly equal to the energy supplied by water. Hence:

$$\mathrm{Q_{wo}} + \mathrm{Q_w} + \mathrm{Q_{ca}} = 0 \quad (3)$$

Where $\mathrm{Q_{wo}}$ is the energy absorbed by the body, $\mathrm{Q_w}$ is the energy ceded by water and $\mathrm{Q_{ca}}$ the energy absorbed by the calorimeter. For the calibration of the calorimeter the following results:

$$m1c_e(\theta_{eq} - \theta_i) + C(\theta_{eq} - \theta_i) + m2c_e(\theta_{eq} - \theta_c) = 0 \quad (4)$$

And if the mass of hot and cool water are the same equation (4) gives

$$\mathbf{C} = \mathbf{m}\boldsymbol{c}_{\mathbf{e}}(2\boldsymbol{\theta}_{\mathbf{eq}} - \boldsymbol{\theta}_{\mathbf{i}} - \boldsymbol{\theta}_{\mathbf{c}})/(\boldsymbol{\theta}_{\mathbf{i}} - \boldsymbol{\theta}_{\mathbf{eq}}) \quad (5)$$

For the determination of Cp we have:

$$\mathrm{m1}c_{\mathrm{e}}(\theta_{\mathrm{eq}} - \theta_{\mathrm{i}}) + \mathrm{C}(\theta_{\mathrm{eq}} - \theta_{\mathrm{i}}) + \mathrm{m2c_p}(\theta_{\mathrm{eq}} - \theta_{\mathrm{wo}}) = 0 \quad (6)$$

Hence giving:

$$\boldsymbol{c_p} = \frac{(\mathbf{m1}\boldsymbol{c}_{\mathbf{e}} + \mathbf{C})(\boldsymbol{\theta_{eq}} - \boldsymbol{\theta_i})}{\boldsymbol{m2}(\boldsymbol{\theta_{wo}} - \boldsymbol{\theta_{eq}})} \quad (7)$$

2.2.3. The heating values of the wood samples

The heating value of each wood sample was determined after burning known quantities of it in a calorimetric bomb. The calorimeter bomb used contained excess pressurized air. This procedure was defined according to NF M 03-005 standard of 1990.The heating values were then calculated from the variation of temperature observed during combustion process [19].

3. Results and discussion

Results of the following are available; heat capacity of the calorimeter, values of specific heat as a function of moisture content, and then heating values of the different wood samples.

3.1. Specific heat capacity of the samples

- **Moisture content**

The table below contains results of different masses of samples before and after drying in an oven. The temperature of the oven was maintained constant for all samples as temperature and moisture content affects the quality of biomass during drying and storage [18,23].

Table1: Masses of dry wood

Wood samples	Mass before drying (g)	Anhydrous mass (g)
Cylicodiscus gabunensis (Okan)	35	30.61
Triplochiton scleroxylon (Ayous)	35	31.03
Erythrophleum suaveolens (Tali)	35	28.00
Entandrophragma cylindricum (Sapeli)	35	29.25

Table 1 presents different masses of different samples before and after drying in an oven. From the dehydration results we obtain the moisture content as shown on the following figure.

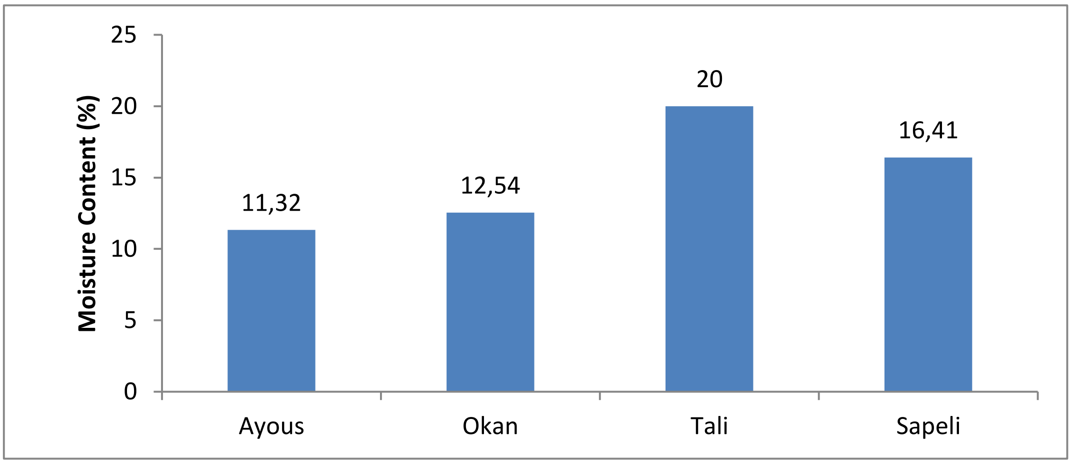

Figure3: moisture content of wood samples

Figure 3 shows the moisture content of the wood samples. It results from this results that two white wood samples (*Triplochiton scleroxylon* (Ayous), *Cylicodiscus gabunensis* (Okan)) have a moisture content relatively low with respect to samples of red wood (*Entandrophragma cylindricum* (Sapeli), *Erythrophleum suaveolens* (Tali)). It is also noted that amongst white wood, *Triplochiton scleroxylon* (Ayous) has moisture content slightly lower than *Cylicodiscus gabunensis* (Okan). Also *Entandrophragma cylindricum* (Sapeli) has a value of moisture content lower than its counterpart *Erythrophleum suaveolens* (Tali), a red wood species. To be in conformity with works of others [2], samples of red wood in relation to their moisture content must have heating values lower than those of white woods. It then result that the following wood samples can be valorized for heating purposes as their moisture contents are less than or equal to 20%: *Triplochiton scleroxylon, Cylicodiscus gabunensis, Entandrophragma cylindricum, Erythrophleum suaveolen* [24].

- **Heat capacity**
- Calibration of the calorimeter

Table 2 is termed the calibration parameter of the calorimeter' for validating the experimental procedure.

Table 2: *Calibration parameter to all experiment*

N°	Mass of cool water(g)	Mass of hot water (g)	T (°C) of cool water	T (°C) of hot water	Equilibrium T (°C)	C (J/K) of calorimeter	Relative error
1	200	200	22	81	52	28.82	1.1
2	200	200	22	81	52	28.82	1.1
3	200	200	22	81	53	29.85	2.3

The table presents the heat capacities of the calorimeter in three repeated experiment. The average value of these heat capacities represents the value of the heat capacity of the calorimeter which is ***29.16J/K.*** This value is in concordance with the value given in the guide sheet of the calorimeter used in the Technical Support [25], which should be less than 30 J/K.

- **Specific heat capacities of wood samples**

The temperature variations of each wood sample in water are recorded for duration of one hour. The temperature was registered after every two minutes. The temperature variation of each wood is shown in table 3.

Table 3: Temperature of different samples of wood.

Time (s)	Wood samples											
	Ayous			Okan			Tali			Sapeli		
	T1 (°C	T2 (°C)	T3 (°C)	T1 (°C)	T2 (°C)	T3 (°C)	T1 (°C)	T2 (°C)	T3 (°C)	T1 (°C)	T2 (°C)	T3 (°C)
0	70	70	70	70	70	70	70	70	70	70	70	70
120	69	68	69	69	69	69	69	69	69	69	69	69
240	67	67	68	68	68	69	68	68	68	68	69	68
360	67	67	67	68	67	68	68	68	68	68	68	68
480	66	66	67	68	67	68	67	67	67	67	68	67
600	65	65	66	67	67	68	67	67	67	67	68	67
720	65	65	66	67	66	67	67	66	66	67	67	67
840	64	64	65	66	66	67	66	66	66	66	67	66
960	64	64	65	66	66	66	66	66	65	66	67	66
1080	63	64	64	66	65	66	66	65	65	65	66	66
1200	63	63	64	66	65	66	65	65	65	65	66	65
1320	63	63	64	65	64	65	65	64	64	64	66	65
1440	62	63	63	65	64	65	64	64	64	64	65	64
1560	62	62	63	64	64	65	64	64	64	64	65	64
1680	62	62	63	64	64	64	64	63	63	64	65	64
1800	61	62	63	64	63	64	63	63	63	63	64	63
1920	61	61	62	63	63	64	63	63	63	63	64	63
2040	61	61	62	63	63	63	63	63	62	63	64	63
2160	60	61	62	63	62	63	63	62	62	62	63	63
2280	60	61	61	63	62	63	62	62	62	62	63	62
2400	60	60	61	62	62	63	62	62	62	62	63	62
2520	59	60	61	62	62	62	62	61	61	62	62	62

2640	59	59	61	62	61	62	62	61	61	61	62	62
2760	59	59	61	61	61	61	61	61	61	61	62	61
2880	59	59	60	61	61	61	61	61	60	61	62	61
3000	58	59	60	61	61	61	61	60	60	61	61	61
3120	58	59	59	61	61	61	61	60	60	60	61	60
3240	58	58	59	61	61	61	60	60	59	60	61	60
3360	58	58	59	61	61	60	60	59	59	59	61	60
3480	57	58	59	60	59	60	59	59	59	59	60	59
3600	57	58	59	59	59	60	59	59	59	59	60	59

- **Cooling curves of the wood samples**

Each wood sample was introduced in a calorimetric flash and the following curves were obtained.

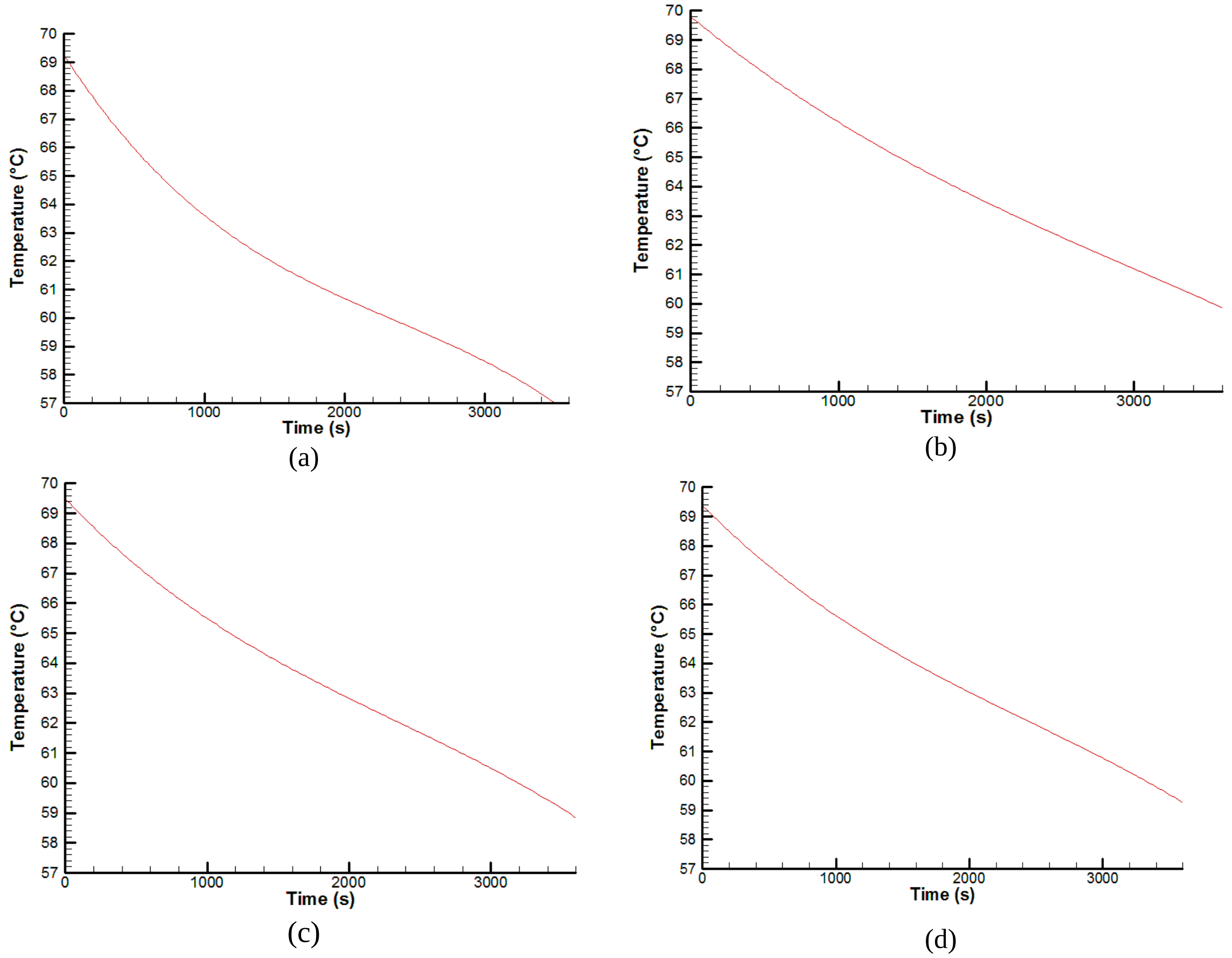

Figure 4: cooling curves of an ensemble of water and wood sample after thermal equilibrium

In figure 4, each cooling curve is obtained after introducing each wood sample in hot water. Figure 4 a, b, c, d represents the cooling curve of ayous, okan, sapeli and tali respectively. The vertical axis represents variation in temperature while the horizontal axis represents time. The angle formed at the summit gives information on the rate of cooling; the greater the angle the lower the rate of cooling and this varies from one species to another. An equilibrium temperature between water and each wood sample was reached. The equilibrium temperatures of the different wood samples associated with their respective specific heat capacities are presented in table4, for the various repeated experiment.

Table 4: Equilibrium temperatures and specific heat capacities of some wood samples

Samples	Experiment N°	Mass of sample (g)	Mass of water (g)	initial T (°C) of the sample	T (°C) of hot water	**Equilibrim T (°C)**	**Cp of samples (J/kg.K)**	Relative error (%)
Tali	1			24		**69.42**	**1834.11**	4.48
	2	11.52	388.70	26	70	**69.4**	**1985.67**	-3.40
	3			25		**69.4**	**1940.95**	-1.07
Okan	1			24		**69.4**	**1898.2**	-22.06
	2	11.52	388.70	24	70	**69.4**	**1898.2**	-22.06
	3			24		**69.8**	**627.2**	44.12
Sapeli	1			24		**69.4**	**1898.2**	0.00
	2	11.52	388.70	24	70	**69.6**	**1259.91**	20.19
	3			24		**69.4**	**1578.35**	0.00
Ayous	1			22		**69.2**	**2434.41**	7.92
	2	11.52	388.70	24	70	**69.4**	**1898.20**	28.20
	3			25		**69**	**3264.32**	23.46

Table 4 presents equilibrium temperatures of each wood sample with water and with the calorimeter. It also presents the specific heat capacity of the considered wood samples. For each sample, the mean of the specific heat capacities got from repeated experiment is considered as the value of the specific heat capacity of the sample. The specific heat capacity of each wood sample are presented as follows: *Triplochiton scleroxylon* (Ayous) =2 532.85J/kg.K; *Erythrophleum suaveolens* (Tali) = 1920.24 J/kg.K; *Entandrophragma cylindricum* (Sapelli) = 1578.82J/kg.K; *Cylicodiscus gabunensis* (Okan) = 1474.53J/kg.K. These specific heats are a function of their respective equilibrium temperatures. These values are in correspondence with the work of [17] on energy valorization of sub-particles from sawmills.

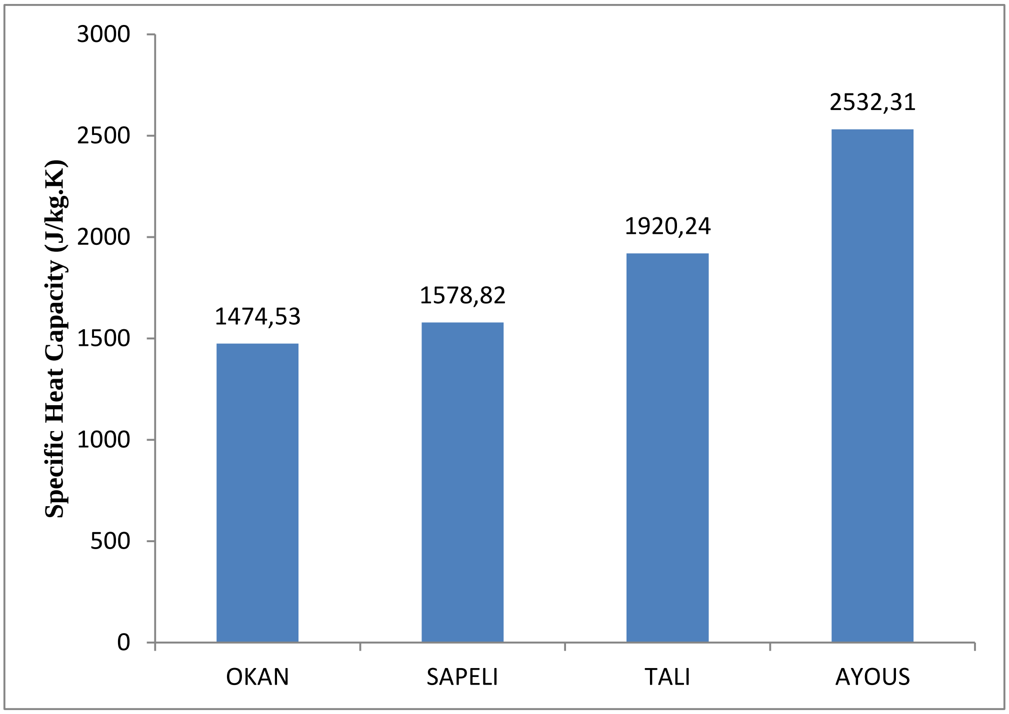

Figure 5: Specific heat capacity of each wood sample

From our experiment on the determination of the specific heat of some local woods such as *Triplochiton scleroxylon* (Ayous), *Entandrophragma cylindricum* (Sapeli), *Erythrophleum suaveolens* (Tali), okan, it comes out clearly that Ayous has the highest specific heat capacity of 2532.31 J/kg.K and that *Cylicodiscus gabunensis* (Okan) has the smallest, of 1474.53 J/kg.K as figure 5 shows. A material with a high specific heat capacity can withhold an enormous amount of energy but on its side needs to be supplied much energy before it releases its own energy [26-28]. Since materials with high Specific heat capacity can store much energy during hot hours and release it during cool hours, they are therefore suitable in regions where there is a significant variation between temperatures of the day and that of the night in order to establish thermal comfort. On the contrary, materials with less specific heat capacity will be suitable in regions with little variations between temperatures of the day and that of the nights. According to our findings *Triplochiton scleroxylon* and *Erythrophleum suaveolens* can be valorized in regions where there is a significant variation between temperatures of the day and that of the night meanwhile *Cylicodiscus gabunensis* and *Entandrophragma cylindricum*can be valorized in regions where there is an insignificant variation between temperatures of the day and that of the night.

3.2. Heating values

In order to determine the heating values, the samples are first dehydrated in an oven at a temperature of 105°C.

Table 5: Mass of the samples used for the determination of heating values

Samples	Anhydrous mass (g)
Cylicodiscus gabunensis (Okan)	30,61
Triplochiton scleroxylon (Ayous)	31.03
Entandrophragma cylindricum (Sapeli)	29.25

Table 5 presents masses of samples after drying in an oven. At first the choice of the mass of each sample had been 35g and because in one way or the other they had been used there was therefore need for dehydration.

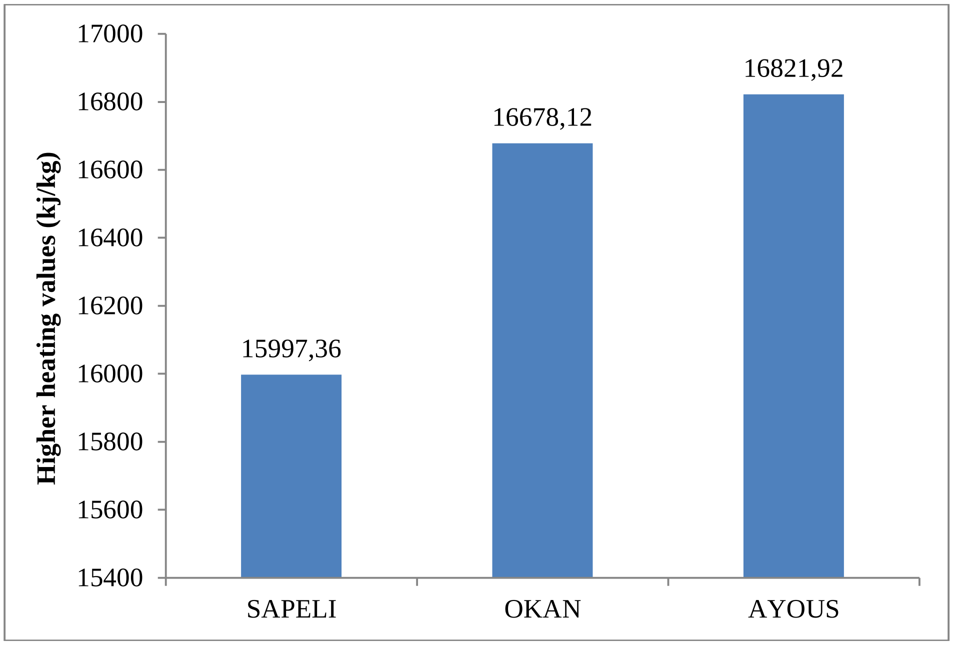

Figure 6: Higher heating values of some wood samples

From the chart in figure 6, the results of the energy content of the wood samples are presentedin increasing order as: *Entandrophragma cylindricum* (Sapelli), *Cylicodiscus gabunensis* (Okan) and *Triplochiton scleroxylon* (Ayous). These values are in accord with other studies [16] which found values of heating values of kernel palm endocarp at 121.2 kJ/mol, movingui at 158.8kJ/mol, and padcouk at 172.5kJ/mol. [22] in his studies showed that the average value of heating value of wood is about 18500kJ/kg. From the results of the heating values, the choice of the biomass or the remnants to be valorized in the case of our studies should be *Triplochiton scleroxylon* followed by *Cylicodiscus gabunensis* since their energy content is high and is closer to the average value found by [22] for wood samples.

3.3. The correlation between characteristics: Moisture content and higher heating values.

Figure 7 shows the variation of the moisture contents and the higher heating values for the following wood samples: *Entandrophragma cylindricum*, *Cylicodiscus gabunensis*, *Triplochiton scleroxylon*. The results show that the higher heating value increases as the moisture content decreases. These results are in accordance with the works of [18;19] which showed the dependence between the higher heating value and moisture content.

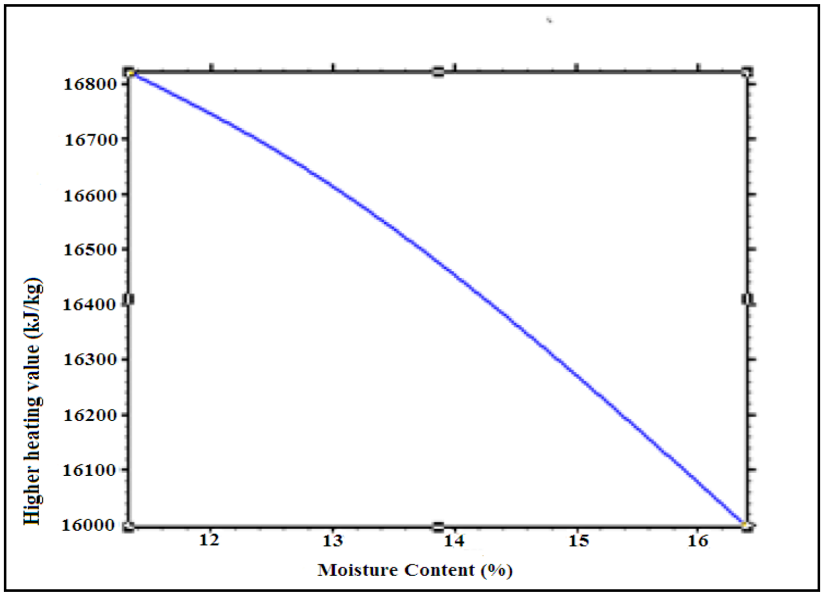

Figure 7: Heating values of samples as a function of moisture content.

4. Conclusion

This piece of work had been experimentally based on the thermal characterization of local woods. The energy content of these local woods were determined and served as a database on which decision can be made concerning valorization of the species studied in this work. In order to meet up with the target of this work; the dehydration method was used for the determination of the moisture content of material on air dry basis, the mixture method was used to determine the specific heat capacity and combustion in the calorimetric bomb for the determination of heating values. Results of the heating values showed that *Triplochiton scleroxylon* (Ayous) and *Cylicodiscus gabunensis* (Okan) have a high heating value compared to *Entandrophragma cylindricum* (Sapelli). From the results of the heating values, the choice of the biomass or the remnants to be valorized in the case of our studies should therefore be *Triplochiton scleroxylon* followed by *Cylicodiscus gabunensis.Triplochiton scleroxylon* (Ayous) has the highest specific heat capacity, compared to *Erythrophleum suaveolens* (Tali), and *Cylicodiscus gabunensis* (Okan). *Triplochiton scleroxylon* (Ayous) should therefore have the highest thermal storage capacity from the list followed by *Erythrophleum suaveolens*, since the specific heat capacity is directly linked to thermal storage capacity. *Triplochiton scleroxylon* and *Erythrophleum suaveolens* can be valorized in regions with significant variation in temperatures since they have a higher specific capacity while *Cylicodiscus gabunensis* and *Entandrophragma cylindricum* should be valorized in regions with insignificant variation in temperatures since they have a lower specific capacity.This work also confirms the dependence of higher heating value on moisture content. More studies are to be made on; density, porosity and on the percentage of ash in order to increase the information needed, so far as Valorization of wood is concerned. Meanwhile work continues on the usage and valorization of local materials.

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