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Experimental Determination of Volume Masses of Some Tropical Timbers Function of Their Moisture and the Temperature: Case Study of IROKO (*ChloraphoraExcelsa*), SAPELLI (*EntandrophragmaCylindricum*), SIPO (*Entandrophragma Utile)*, BUBINGA (*GuibourliaLessmannii*), AZOBE (*LophiraAlata)*, EBONY (*DiospyrosCrassiflora*)

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Abstract: ***This research studies density of tropical timbers' species Iroko (ChloraphoraExcelsa), Sapelli (Entandrophragma Cylindricum), Sipo (Entandrophragma Utile), Bubinga (GuibourliaLessmannii), Azobé (LophiraAlata) and Ebony (Diospyros Crassiflora), depending of their moisture rate and high surrounding atmospheric temperatures (50°C, 60°C, 70°C) by successive weighting. Results present two timber's categories (light-weighted and weighted). The correlations providing density when considering their moisture rate and ambient temperature are established at first approximation. Such correlations ease digital simulation and modelling of the drying process. The results are adequate. The moisture rate and the surrounding temperature influence the porosity of these species and that of the density, as well. The porosity of each species at the anhydrous is determined.***

Keywords: Tropical woods, Density, Moisture content, temperature, Iroko, Sapellie, Sipo, Bubinga,Azobe, Ebony

1. Introduction

Timber is a porous medium with an interconnected network of vessels and pores within which water flows by several mechanisms (Kiaeret al.2013; Monkam 2007;Nsouandélé, et al 2011). Hence the volume mass of timber cannot be expressed explicitly as that of other materials. It depends on the species in regard with the variation of the rate of chemical elements (cellulose, hemicellulose, lignite, water and air) which constitute them. These elements make complex the determination of the densityof tropical timbers.

The physics' literature upon determination of volume masses of tropical timbers remains poor. Some estimations and correlations of this with the moisture rate have passed analytical and experimental studies, as those carried by researchers from CIRAD-Forêt, who determine densityof dried tropical timbers (Gérard et al 1998; Merakeb 2006). B. Bonoma et al. studied the influence of the moisture and the temperature over the porosity and the densityof some tropical timbers(Ayous, Lotofa, etc). They determine volume masses and porosity of anhydrous tropical timber species at high temperatures. They show that for high temperatures ($T \geq 80°C$), densityincreases only with the moisture rate and the temperature. However, results from the literature's review are obtained under the hypothesis that volume masses of tropical timbers have mean values assumed constants by considering a treshole variable numbers of statistical tests. Hence these results suffer from an inherent insufficiency (Simo 2014).

The aim of this study is to improve researches carried out by the CIRAD-foret and B. Bonoma et al. the volume mass is determined by considering some insufficiencies like:

- The variation of the moisture rate in timber and the surrounding temperature;
- The variation of the porosity of tropical timbers;
- The definition of mathematical correlations of the densityfor each species studied.

This involves sampling in the heart of the tree (core or Aubier, low, middle or high level of the bunch). This work provides also physical significance to parameters found through our correlations in order to state a general relationship between volume masses of tropical timbers with moisture rate (porosity) and ambient temperature (Zelinka et al 2016). These correlations are requirements for the modelling and the digital simulation of the drying of timber(Nsouandélé et al 2011;Monkamet al 2013).

This study is valuable and must be carried out when building with wood. The study focus on six timber species classified into two groups:

- Heavy timbers (Azobé and Ebony) commonly used in civil engineering (buildings, bridges, railways) and in ebony mancraft.
- Heavy-light timbers (Iroko, Bubinga, Sapelli, Sipo) commonly used in external and internal carpentry.

The study starts with the presentation of the model, followed by the experimental protocol. It ends with discussion of results and a conclusion indeed.

2. Mathematical Model

By definition the following volume masses are distinguished:

The anhydrous volume mass of timber given by:

$$\rho_0 = \frac{M_0}{V_0} \tag{1}$$

M_0 and V_0 are the mass and the volume of the dried wood in Kgand in m^3, respectively.

The wet volume mass:
By analogy to the density in the dried state, the wet density is considered for the mass and volume of a timber with a non-neglected moisture rate H.

$$\rho_H = \frac{M_H}{V_H} \tag{2}$$

M_H and V_H the mass and volume of a sample at a moisture rate H.

The computation of the volume mass requires the moisture rate of the sample, which is determined by the ratio of the mass of water on the mass of an anhydrous timber according to the following relation

$$H = \frac{M_H - M_0}{M_0} \times 100 \tag{3}$$

M_H is sample's mass at the moisture rate H, M_0 is the anhydrous sample's mass.

The porosity of a species is the ratio of the pores volume on the sample's volume. When using an anhydrous timber, the porosity p (%) is equated by:

$$p = 100(1 - \frac{\rho_o}{\gamma_s}) \tag{4}$$

Where ρ_o (kg/m^3) and γ_s (kg/m^3) are respectively the volume masses of the anhydrous sample and an assumed non porous timber. γ_s is constant for every species and is equal to 1500 kg/m^3.

The volume withdrawal R_H(%) is a mean of quantifying the variation of the volume from the anhydrous to the wet state H. it is obtained by:

$$R_H = 100\left(\frac{V_H - V_o}{V_o}\right) \tag{5}$$

The equations 2, 3 and 5 above, enable to obtain equation (6):

$$\rho_H = \rho_0 \frac{(H+100)}{(R_H+100)} \tag{6}$$

3. Experimental Protocol

We used the weighting method to determine the volume mass (Bonomaet al 2005; Nsouandéléet al 2010;Simo 2014). All these samples come from the core of woodof timber pieces extracted from mature trees (more than 80 years old) from the Centre region, Cameroon. Samples of 35x30x20 mm (length, width, and thickness) dimensions have been cut from the same piece along the axial, radial and tangential directions, respectively. This is in accordance with the French standards NFB 51-005 (Monkam et al 2013) which recommends the use of cubic samples of 20 mm thick (radial).

The L.420S$^+$ electronic weight from Sarterius GMBH with 0,001g precision have been used for each weighting.

The 17x22x37 cm Memmert made dryer was used to keep samples at the desired temperature. It maximum temperature is 220°C with a 2°C precision, the power 900W, the input voltage is 220V. Dimensions of samples are measured with a tenth Vernier.

Four samples per specie cut on a same piece were used, in accordance with E. Agoua et al.(2001)who recommends at least two samples cut at about 450mm of each end of the piece of timber.

Three samples per specie were used for measurements at 50°C, 60°C and 70°C, and the fourth for the determination of the anhydrous volume masses. These are obtained by setting the dryer at 105°C until masses stabilize (become constants).

Assuming the anhydrous mass, the samples are weighted and measured every thirty minutes out of the dryer. The process is followed for several temperature drops 50°C, 60°C and 70°C until the lowest the choice of temperatures (50°C, 60°C and 70°C) is based on the high temperatures and extreme use of wooden structures.

The volume mass is hence computed with relation (2) and the moisture rate of timber with relation (3) while the anhydrous porosity is deducted from relation (4).

4. Results and Discussion

The figures 1,2 and 3show the different experimental volume masses of studied timber species with mean relative error of 8% depending on extreme temperature close to atmospheric values 50°C,60°C and70°C.For each temperature we get two groups:

- The first group is characterised by species (Azobé, Ebony) that form the group of heavy timbers. Their masses vary very less with values greater or equal to 1000 kg/m^3. These species have a strong and more complex texture.
- The second group of species (Iroko, Sapelli, and Sipo) is the group of light-heavy timbers. The water content from these is greater than that of heavy timbers. Volume masses of these timbers are less than 1000 kg/m^3.

The Bubinga behaves as an intermediate species, depending on its moisture rate.Its volume mass is sometimes greater or less than 1000 kg/m^3.

The variation of the volume mass with the wet of the timber is more important above the saturation point of the fibres (migration of free water), and weak below it because of the low variation of masses (extraction of confined water) and the high volume variation due to important outspreads. Migrations and outspreads of water from timber increase with temperatures.

Our results suggest that the volume masses increase with the moisture rate on a linear pattern, according to the literature (Monkam et al 2007; Gérard et al 1998), hence the correlation.

However ambient conditions, the Iroko, Sapelli and Sipo have close values. This result correlates the experimental results standards published by the Centre of International Cooperation in Agricultural Research for Development (CIRAD) (Gérard et al 1998). The same results are obtained with all the temperatures and all the timbers species (figures 1, 2, 3)

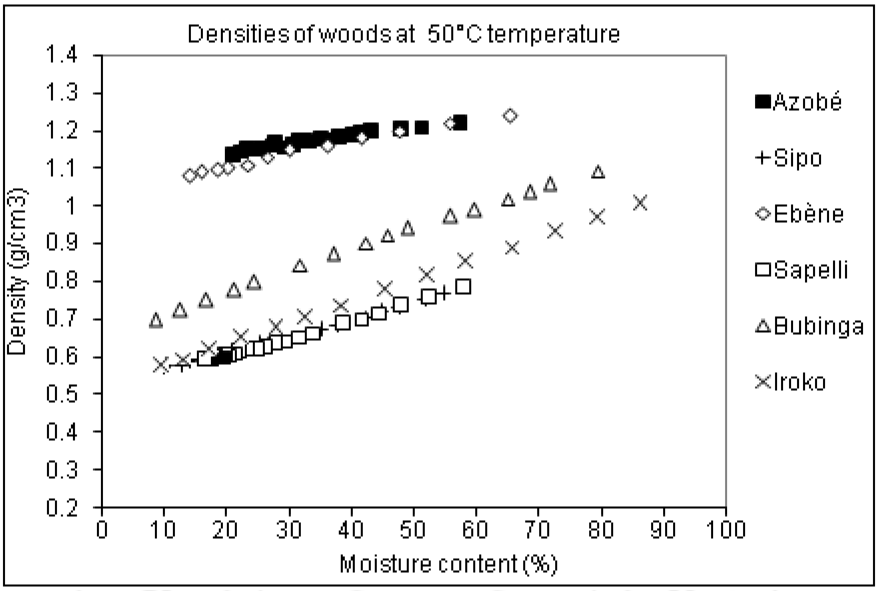

Figure 1: Density at 50°C temperature

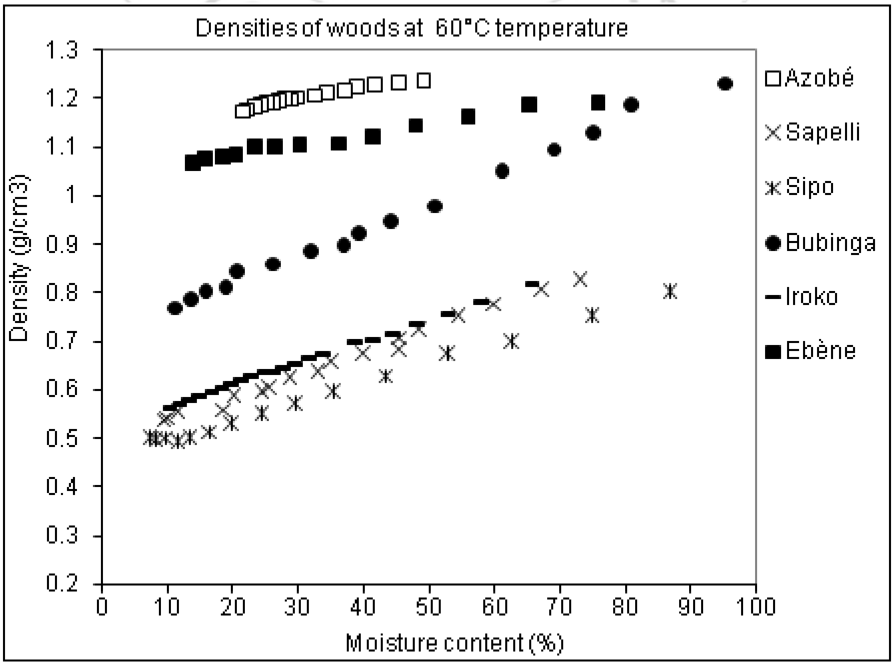

Figure 2: Density at 60°C temperature

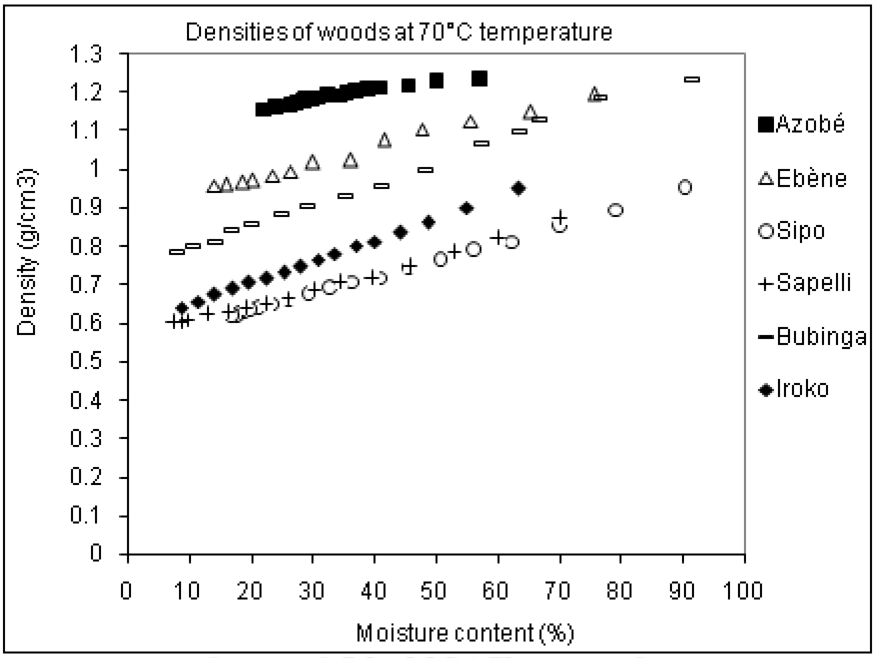

Figure 3: Density at70°C temperature

The figures 4, 5 and 6 show the linear regressions of the volume masses of tropical timbers considered in this work depending on the moisture rate or wet at different temperatures. The influence of the temperature is obvious on charts, and the slopes differ with the species. The consideration of peculiar texture t relevant to each species leads to the study of porosity and the integration of the temperature in the linear regression. To correlate experimental points, a relation that considers both the influence of the temperature and the moisture rate is required(Zelinka et al 2008). This relation was used by Ngohe-Ekam (1992) to the estimation of the thermal conductivity of tropical timbers.

The influence of temperature is not explicit in the figures and the regression slopes differ by wood, which grants a particular texture to each timber and leads to the study of the porosity of the wood and the influence of temperature in the linear regression.

$$\rho(T,H)=a+bT+cH+dHT \quad (6)$$

Where $\rho_H(T)=A+BH$ (7)

With $A=a+bT$ et $B=c+dT$ (8)

T is the temperature in (°C), H is the moisture or water rate in (%)

The a, b, c and d are coefficients to be determined from experimental values. These are determined so that by minimizing the spread ofexperimental curves from theoretical curves. The relation (9) enables to determine the relative incertitude necessary for the evaluation of the deviation between experiments and corresponding correlations.

$$E(\%)=\frac{100}{N}\sum_{i=1}^{N}\frac{|\rho_{thi}-\rho_{exi}|}{\rho_{exi}} \quad (9)$$

Where ρ_{th} and ρ_{ex} arevolume masses obtained through correlation and experimentation, respectively; and N is the number of experimental points per piece of timber.

This study shows that anhydrous volume mass is related to the temperature and given by the relation (10).

$$\rho_H(T,0)=a+bT \quad (10)$$

Where $\rho_0(T,0)=A=\rho_0$

The resulting a, b, c, dcoefficients per species, porosities (p), anhydrous volume masses $\rho_0=\rho(T,0)$ and standards $\rho_{15}=\rho(T,15\%)$ per timber and per temperature are given in table 1.

The anhydrous volume masses and standards obtained fit results from literature (Gérard et al 1998) and improve information on tropical timbers.

The porosity results in table 1 show that porosity decreases with the density of the timber. Porosity classes are defined by timber classes: light-weight [45% à 70%[and weight [20% à 45%[timbers.Timber is abundant and insecticides (pores) lower in heavy timber. The thread is tangled, the irregular and often interlocked. This defines them as timbers dedicated to concrete constructions (civil engineering) (Gérard et al 1998). Light-weight timbers are more used for in-/outdoor carpentry (equipment, decorations, roofs, floors, etc.). The a, b, c, d coefficients are function of the species and also of the part of the tree considered (Aubier, Duramen).

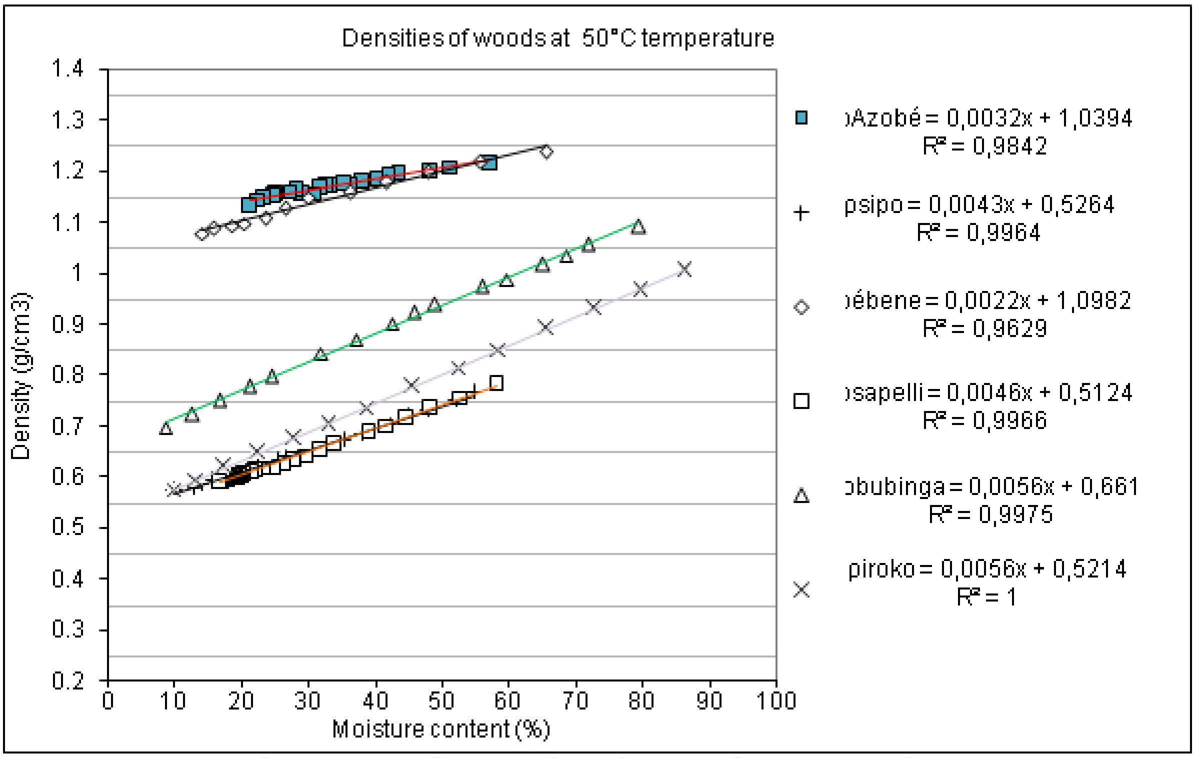

Figure 4: Regression lines of densityat 50°C

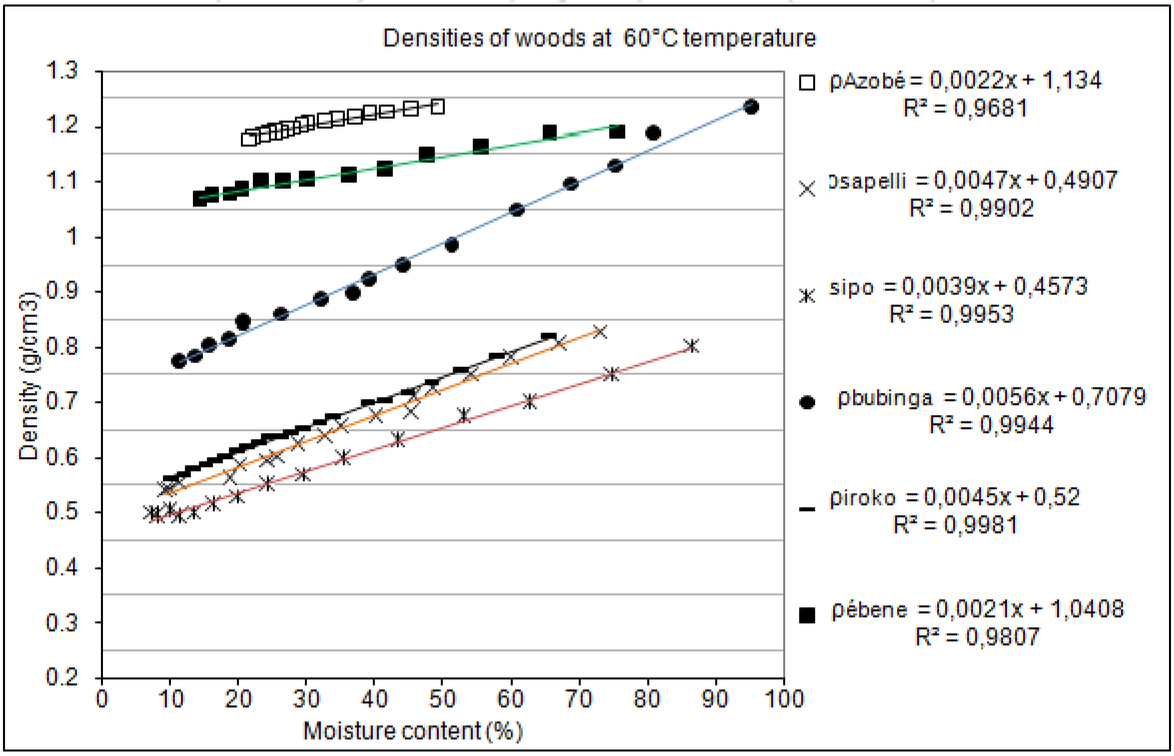

Figure 5: Regression lines of density at 60°C

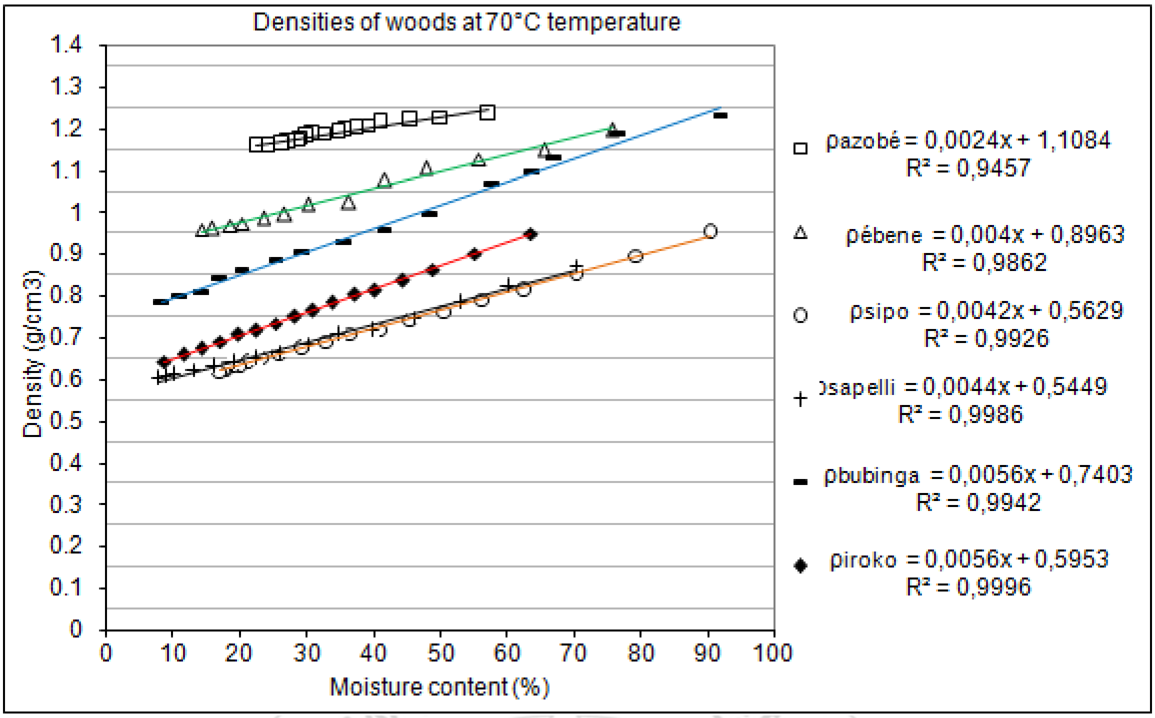

Figure 6: Regression lines of densityat 70°C

The a,b,c,d coefficients are reals and require a physical interpretation. They are function of the species and also of the part of the tree considered (Aubier, Duramen) for the study. The coefficient is a purely anhydrous value corresponding to the 0°C temperature and a zero moisture rate. It is merely not possible to get this value experimentally.The coefficients b, c, d are first order approximation of volume masses function of the moisture rate and the temperature. They enable to foster the coefficient a in order to find real physical values. These correlations improve the models and bring them close to practical results.

Table 1: Value of volume masses of some tropical timbers function of their moisture and the temperature

Woods	T(°C)	B (kg/m^3 %)	A(kg/m^3)	p (%)	ρ_0 (kg/m^3)	ρ_{15} (kg/m^3)	E (%)
Sipo	60°C	3,917	453,742	63,90	453,742	454,329	1,243
	70°C	4,236	562,957	62,76	562,957	563,592	2,047
	50°C	4,341	526,398	64,38	526,398	527,049	1,335
Sapelli	60°C	4,740	490,684	64,69	490,684	491,395	0,987
	70°C	4,465	544,895	60,36	544,895	545,564	1,148
	50°C	4,656	512,634	65,36	512,634	513,332	1,163
Iroko	60°C	4,553	520,121	69,73	520,121	520,803	2,165
	70°C	5,684	595,362	61,82	595,362	596,214	2,324
	50°C	5,663	552,151	63,92	552,151	553,000	2,127
Azobé	60°C	2,217	1134,70	33,35	1134,7	1135,032	3,315
	70°C	2,468	1108,04	26,40	1108,04	1108,410	2,359
	50°C	3,233	1039,47	33,86	1039,47	1039,954	1,972
Bubinga	60°C	5,671	707,963	47,35	707,963	708,813	2,993
	70°C	5,643	740,75	48,68	740,75	741,596	2,546
	50°C	5,667	661,895	48,27	661,895	662,745	2,043
Ebony	60°C	2, 105	1040,208	34,45	1040,208	1040,523	2,472
	70°C	4,108	896,370	37,46	896,37	896,986	2,336
	50°C	2,287	1098,224	37,58	1098,224	1098,567	3,987

5. Conclusion

In this paper, an experimental determination of volume masses of heavy (Azobé, Ebony) and light-heavy (Sipo, Sapelli Iroko and Bubinga) tropical timbers is achieved by weighting. This study enable to set correlations improved by real numbers a, b, c, d that express the first order approximations of volume masses depending on the moisture rate of samples and the ambient temperature. These correlations ease the numerical simulation and modelling of the drying process, the sorption isotherms and the use of these timbers. They are in accordance with experimental results with owing the errors found. This study shows that the volume mass increases with the moisture rate and it is influenced by the ambient temperature and the old of the tree and the part of the tree considered (sap-wood, core-wood).

The study provides volume masses of eleven tropical timbers from Cameroon.

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