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Study of Brazilian Woods Using Gamma-Ray Sources

Gilberto Carvalho and Leonardo Gondim de Andrade e Silva

Radiation Technology Centre, Nuclear and Energy Research Institute, National Nuclear Energy Commission (IPEN-CNEN/SP, São Paulo, 05508-000, Brazil

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Abstract: Due to the availability and particular features, wood was one of the first materials used by mankind with a wide variety of applications. It can be used as raw-material for paper and cellulose manufacturing; in industries such as chemical, naval, furniture, sports goods, toys, and musical instruments; in building construction and in the distribution of electric energy. Wood has been widely researched; therefore, wood researchers know that several aspects such as temperature, latitude, longitude, altitude, sunlight, soil, and rainfall index interfere as to the growth of trees. This behavior explains why the average of physical chemical properties is important in wood study.Most of the researchers consider density to be the most important wood property because of its straight relationship with the physical and mechanical properties in wood. There are three types of wood density: basic, apparent and green. The apparent density was used here at 12% of moisture content. In this study, four different types of wood were used: "Freijó", "Jequitibá", "Muiracatiara" and "Ipê". For wood density determination by non-conventional method, ^{241}Am, ^{133}Ba and ^{137}Cs gamma-ray sources, a NaI scintillation detector and a counter were used. The results demonstrated that this technique is quick and accurate. Considering the nuclear parameters obtained as half-value layers and linear absorption coefficients, ^{137}Cs demonstrated to be the best option to be used for inspection of the physical integrity of electric wooden poles and live trees for future works.

Key words: Brazilian woods, density, gamma-ray.

1. Introduction

Due to the availability and particular features, wood was one of the first materials to be used by mankind with a wide variety of direct and indirect uses. Currently it plays an important role as a source of domestic and industrial energy. Moreover, it can be used as raw material for paper and cellulose manufacturing, in industries such as, chemical, naval, furniture, sports goods, toys, and musical instruments; in building construction (houses, buildings, bridges), and to support the distribution of electricity [1].

1.1 Physical Properties of Wood

The main physical properties of wood are: density, moisture, shrinkage, thermal, electrical and sonic conductivity, hardness, resistance to fire fungi, insects and chemical attack. Furthermore, density, the main property of wood and also moisture, due to its direct and intense influence on density will be the focus of this work.

1.1.1 Moisture

After being sawn, the wood is air-dried, having the water content reduced by evaporation. The free water is the first to be removed. Theoretically, only after the removal of the entire capillary water, the water loss from the cell wall will start. This loss occurs up to the value of the saturation fiber point (SFP), which is around 28% of moisture. Many of the wood properties show no changes when the moisture content (MC) is above the SFP. Therefore, the free water has little effect on the wood, except the reduction of its own weight. Nevertheless, from and below this MC, some properties such as hardness, flexural and compression demonstrate significant changes in their values. The density, which is the physical property of interest in

Corresponding author: Gilberto Carvalho, Ph.D, research fields: gammagraphy and Brazilian woods. E-mail: gcarval@ipen.br.

this study, is also greatly affected by moisture [2]. After the material exposure to the air for losing water impregnation, it is reported that the wood is dry and the humidity ranges from 15%-17%. After reaching this level, the wood is a hygroscopic material, starting a constant moisture exchange with the environment. The MC tends to a dynamic equilibrium, defined as the equilibrium moisture content (EMC), which is dependent on temperature and relative moisture [3]. Environmental conditions differ according to different locations, and depend on many factors such as geographical location, sunlight, air currents and other factors (sometimes even in the same place). These variations will interfere with the EMC, and consequently with density.

1.1.2 Moisture Content

The moisture content of a wood is the relationship between the weight of the water in the wood and the weight of the wood in dry state, expressed as a percentage (%):

$$U = \frac{P_u - P_s}{P_s} \cdot 100\ (\%) \qquad (1)$$

where, U is the moisture content of the wood (%); P_u is the weight of wet wood (g); P_s is the weight of dry wood (g).

1.1.3 Density

The value of wood density indicates the total amount of cell wall support (fibers), transport (vessels) and storage (axial and longitudinal parenchyma), contained in a given volume of wood, including the percentage of extractives. Because of variations in the dimensions and proportions of various tissues of the wood, the density may vary from 0.13 to 1.40 g/cm^3 between species. However, the density of matter woody solid varies very little and can assume a value average of 1.50 g/cm^3 for all woods [4]. It is known that several factors interfere in the growth of trees: soil, climate (temperature and humidity), altitude, latitude, biological, geographical, edaphic and environmental factors. Therefore, when the properties of wood are referred, the reference consists on the average properties. This principle is also applied for density [5]. The density is the most important physical property for characterization of wood, being related to the amount of mass contained in the unit volume [6]. It is the most important parameter for assessing the quality of the wood because of its relationship with other properties of the material [7]. The apparent density (ρ_{ap}) corresponds to the density measured under the conditions of one atmospheric pressure, at 20 °C temperature and relative moisture 65% [8].

The aim of this study was to show the density of different kinds of Brazilian wood in order to obtain their absorption coefficient and half-thickness values using radioisotopic sources for future analysis of physical integrity of electric wooden poles and live trees.

2. Materials and Methods

2.1 Samples

2.1.1 Wood

It was used four different kinds of woods (Fig. 1) listed below with their common names and their scientific nomenclature:

- "Freijó" (*Cordiagoeldiana*) Huber-family Boraginaceae;
- "Jequitibá" (*Carinianalegalis*) (Mart.) Kuntze-family Lecythidaceae;
- "Muiracatiara" (*Astroniumlecointei*) Ducke-amily Anacadiaceae;

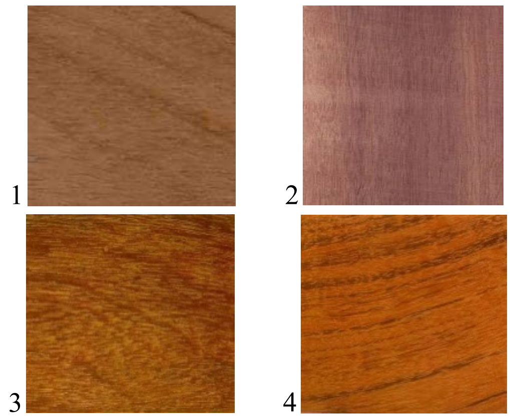

Fig. 1 Kind of woods.

- "Ipê" (*Tabebuiaserratifolia*) (Vahl.) Nichols-family Bignoniaceae.

The choice of these woods was based on the range of density values, from 0.55 to 0.60 g/cm^3 for "Freijó" and "Ipê", around 1.00 g/cm^3. The samples for testing moisture, about forty (40) of each species were prepared in accordance with Brazilian Standards NBR 7190 [9]. They were cut, planed and sanded in the woodwork at "Nuclear and Energy Research Institute (IPEN)". About fifteen samples of each species were selected considering the following characteristics: finish, uniformity of size and absence of defects. The dimensions used for oven testing (moisture content) were: 2 × 3 × 5 cm and 7 × 7 × A cm, where A varied from 14 to 21 mm of thickness. The tests were performed in an oven with forced ventilation and digital thermostat at a temperature of 103 ± 2 °C until completely dry (until the samples were completely dry). Using a digital scale, several regular weighing of samples were performed until a constant weight was reached.

2.1.2 Acrylic

The material used as a standard to calculate the densities of the woods was acrylic or polymethylmethacrylate (PMMA), a thermoplastic hard, clear and colorless, with a molecular form ($C_5O_2H_8$) and melting point between 130 and 140 ºC This material is quite stable at room temperature, without changing dimensions and mass density ranging from 1.15 to 1.19 g/cm^3. As the material has not been certified, it was used the same method to calculate the density of the wood, that is, the conventional method: mass/volume. The standard used has the dimensions of 70 × 70 × 191 mm and density of 1.164 g/cm^3.

2.2 Radioactive Sources

Gamma emitters were used to obtain the linear absorption coefficients and densities of woods. Table 1 presents the characteristics of the radioactive sources used.

(*) – Ionization constant [10]. The activities of the sources used were:

Americium 241 (^{241}Am) – 20.43mCi (7.6 × 10^{4}Bq) – 01/01/2002;

Barium 133 (^{133}Ba) - 20.14mCi (75.5 × 10^{4}Bq) – 01/01/2002;

Cesium 137 (^{137}Cs) – 228mCi (843.6 × 10^{4}Bq) - 09/04/2012.

3. Results and Discussion

3.1 Moisture

The values of moisture percentage from the oven test for fifteen samples of each kind of wood are shown in Table 2.

3.2 Density

3.2.1 Conventional Method

The same samples used in the oven test were measured using a digital caliper Digimess with resolution of 0 001 mm, and a Mitutoyodigital micrometer, resolution of 0.001 mm, five points for height and width, and twenty four points for thickness. Using the Eq. (2):

$$\rho = m/V \quad (2)$$

where, ρ is density (g/cm^3); m is mass (g); V is volume (cm^3).

The values found with their standard deviations are shown in Table 3.

To obtain the density at 12% moisture, there are two options: either we use the diagram of Kollmann, which can lead to errors in reading or a simplified equation, which was the option used for ease of handling [11]. The equation is as it follows:

Table 1 Characteristics of radioactive sources.

Isotope	Energy range (MeV)	Energy average (MeV)	GammaFactor* (R.m²/hCi)	Halflife (year)
^{241}Am	0.0119 to 0.0595	0.035	0.13	432.2
^{133}Ba	0.0310 to 0.3830	0.157	0.44	10.54
^{137}Cs	0.0322 to 0.6620	0.615	0.31	30.14

Table 2 Oven test: moisture percentage calculation.

Kind of wood	Moisture % (average)	Standard deviations
Freijó	12.635	0.061
Jequitibá	13.697	0.020
Muiracatiara	13.513	0.055
Ipê	13.248	0.087

Table 3 Average densities obtained by conventional method.

Kind of wood	Density (g/cm^3)	Standard deviations
Freijó	0.581	0.021
Jequitibá	0.760	0.016
Muiracatiara	0.874	0.001
Ipê	1.029	0.012

$$\rho_{12} = \rho_{U\%} \frac{(1+12/100)}{(1+U/100)} \quad (3)$$

where, ρ_{12} is the density in g/cm^3, the moisture content of 12%; $\rho_{U\%}$ is the density in g/cm^3, the moisture content U; Uis obtained in the oven tests.

The percentage differences between the densities of wood obtained at U% (oven test) and 12% were:

Freijó…………….(+)0.52%

Jequitibá…………(+)1.4%

Muiracatiara……..(+)1.39%

Ipê……………… .(+)0.18%

These results show small differences.

3.2.2 Nuclear Method

The results obtained from the oven test (moisture) for the two wood dimensions used were very similar. Due to this fact, samples with larger dimensions were chosen for the density tests using the nuclear method. The method is based on the absorption of radiation in accordance with Lambert-Beer law adapted as, in practice; we rarely work with monochromatic parallel beams.

The equation is:

$$I = I_0.e^{-\mu x} \quad (4)$$

where, I_0 is the intensity of the incident beam, that is, before interacting with the material; I is the intensity of the emergent beam, that is, after the interaction with the material; x is the material thickness (cm); μ is the linear absorption coefficient of the material (cm^{-1}).

By extension of concept, the intensity of the beams of radiation (I, I_0) may be substituted for counts (C, C_0) and thus can obtain the linear absorption coefficients of woods involved in the trials. In the same way, one can determine the intensity emerging by the calculation and also in practice by adding or subtracting respect to the bodies of the original tests and thus obtain the values of the half-thickness of the wood to be tested. Densities were determined subsequently by comparing the values obtained with a standard obtained with the acrylic.

The tests were performed using the radioactive sources, ^{241}Am, ^{133}Ba and ^{137}Cs (Fig. 2), an arrangement with a NaI scintillator 2''(Fig. 3) and a spectrometer. Novelec multichannel model SM 512 (Fig. 4), samples of 70 × 70 × A mm (15 of each species), thickness ranging from 14 to 21 mm. The values found for the apparent densities and linear absorption coefficients are shown in Table 5.

Comparing the values from both methods, conventional and nuclear, we found that the largest percentage differences were:

Freijó with ^{241}Am………. (-) 3.11%;

Jequitibá with ^{133}Ba…….. (-) 2.27%;

Table 4 Average densities obtained at 12% moisture.

Kind of wood	ρ_U (g/cm^3)	ρ_{12} (g/cm^3)
Freijó	0.581	0.578
Jequitibá	0.760	0.749
Muiracatiara	0.874	0.862
Ipê	1.029	1.017

Fig. 2 ^{241}Am (left) and ^{137}Cs (right) sources.

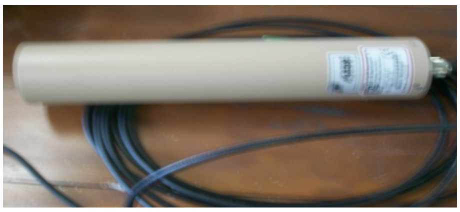

Fig. 3 NaI scintillator of 2", Ludlum, model 44-10.

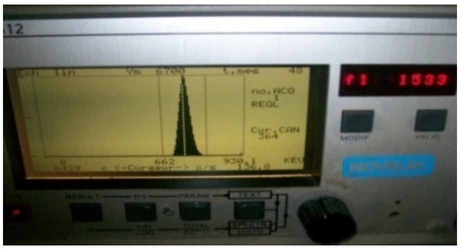

Fig. 4 SpectrometerNovelec model SM512, showing the peak of energy (^{137}Cs).

Muiracatiara with ^{133}Ba…… (-) 3.98%;

Ipê with ^{137}Cs…………….... (-) 3.25%;

which representssmall differences.

To obtain the values of the half-value layers (HVL), the Lambert-Beer Eq. (4) was used, by considering the intensity of the beam after attenuation in the material equal to half of the initial gamma beam (incident). Thus, the Lambert-Beer equation, after substituting $I = I_0/2$ and applied to two members, napierian logarithm is:

$$X_{1/2} = 0.69314/\mu \qquad (5)$$

$X_{1/2}$ is the value of the half-thickness or half-value layer (cm); μ is the linear absorption coefficient (cm^{-1}) as previously presented.

The results from the calculations are shown in Table 6.

4. Conclusions

(1) Oven test. The results from the oven test had their values close to moisture content of 12%. That fact demonstrates that the tests were conducted properly, because the standard deviations are not significant;

(2) Linear absorption coefficient. Data that could delimit the results obtained in this study were not found in the literature. The values found in the tests, which allowed the calculation of densities, compared with the standard acrylic, lead us to conclude that they are very good, considering the density values obtained experimentally;

(3) Calculation of apparent density using conventional and nuclear methods based on the results from the several tests with radiation, it can be concluded that the values found are consistent with those obtained using the conventional method, not exceeding 3.93%, using ^{133}Ba for "Muiracatiara", with

Table 5 Densities and linear absorption coefficients for 3 sources.

Kind of wood	ρ_U (g/cm^3)	ρ_{12} (g/cm^3)	μ_U (cm^{-1})	μ_{12} (cm^{-1})
		^{241}Am (59.5 keV)		
Freijó	0.599	0.596	0.10540	0.10482
Jequitibá	0.769	0.758	0.13401	0.13207
Muiracatiara	0.875	0.863	0.15532	0.15318
Ipê	1.051	1.039	0.18586	0.18381
		^{133}Ba (356 keV)		
Freijó	0.577	0.574	0.05678	0.05646
Jequitibá	0.778	0.766	0.07608	0.07408
Muiracatiara	0.841	0.829	0.08395	0.08279
Ipê	1.039	1.019	0.10287	0.10175
		^{137}Cs (662 keV)		
Freijó	0.583	0.580	0.04518	0.04492
Jequitibá	0.759	0.748	0.05886	0.05801
Muiracatiara	0.872	0.860	0.06753	0.06660
Ipê	0.996	0.985	0.08039	0.07950

Table 6 Half value layers of kinds of wood, in mm, related to energies of gamma emitters.

Kind of wood	^{241}Am (mm)	^{133}Ba (mm)	^{137}Cs (mm)
Freijó	66.1	122.8	154.3
Jequitibá	52.5	93.6	119.5
Muiracatiara	45.1	83.7	104.1
Ipê	37.7	68.1	87.2

insignificant errors. Although, these results qualify the nuclear technique, it is necessary to refine the technique with the use of sources with higher activities, larger collimation and higher radiological protection;

(4) Half value layers, taking into account the obtained values for the absorption coefficients, which proved to be correct, the values of half-layers are perfectly acceptable, since a fixed parameter (or ln2 = 0.69314) and linear absorption coefficients obtained experimentally are taken into consideration for these calculations.

Due to the satisfactory results, we intend to perform the testing with a larger number of woods in order to establish:

- Database of linear and mass absorption coefficients, half-value layers, maximum sensitivity method and limits of thickness;
- Use of the parameters obtained, especially with ^{137}Cs, to verify the integrity of wooden poles and standing trees (live trees). The radioisotope ^{137}Cs is cited like the best because: (a) long half-life; (b) more adequate to detector Ludlum; (c) high energy, allowing test samples with higher thickness; (d) ease of obtaining sources in desired activities.

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