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PRELIMINARY STUDIES OF BRAZILIAN WOOD USING DIFFERENT RADIOISOTOPIC SOURCES

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ABSTRACT

Due to 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 instrument; 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 with the growth of trees. This behavior explains why average physical-chemical properties are important when wood is studied. The majority of researchers consider density to be the most important wood property because of its straight relationship with the physical and mechanical properties of 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: "freijo", "jequitibá", "muiracatiara" and "ipê". For wood density determination by non-conventional method, Am-241, Ba-133 and Cs-137 radioisotopic sources; a NaI scintillation detector and a counter were used. The results demonstrated this technique to be quick and accurate. By considering the nuclear parameters obtained as half value layers and linear absorption coefficients, Cs-137 radioisotopic source 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.

1. INTRODUCTION

Due to 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 instrument; in building construction (houses, buildings, bridges), and to support the distribution of electricity[1].

For this study, four different types of trees were selected.

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. Out of these, 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 starts. This loss occurs up to the value of the saturation fibers point (SFP), which is around 28% 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 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 (%).

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

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 known that several factors interfere with 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 of 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 the other material properties [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 wood was to study 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 the physical integrity of electric wooden poles and live trees.

2. MATERIALS AND METHODS

2.1. Samples

2.1.1. Wood

We used four different kinds of woods (Figure 1) listed below with their common names and their scientific nomenclature:

1- “Freijó”*(Cordia goeldiana) Huber-Boraginaceae*
2- “Jequitibá” (*Cariniana legalis*) (Mart.) Kuntze-Lecythidaceae
3- “Muiracatiara” (*Astronium Lecointei*) Ducke-family Anacadiaceae
4- “Ipe” (*Tabebuia serratifolia*) (Vahl.) Nichols - Family Bignoniaceae

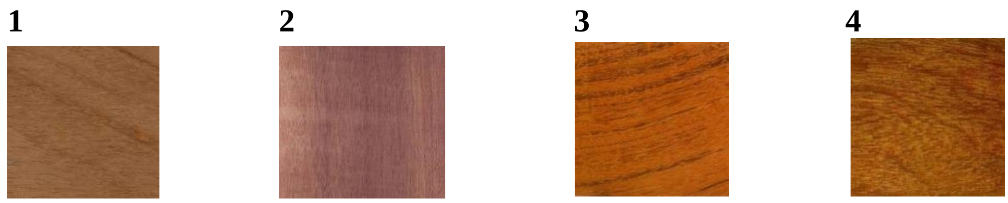

Figure 1: Kind of woods.

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 ”ipe”, around 1.00g/cm^3. The samples for testing moisture, about forty (40) of each species were prepared in accordance with the Brazilian Standard NBR 7190 [9]. They were cut, planed and sanded in the woodwork at “Instituto de Pesquisas Energéticas e Nucleares (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: 2x3x5cm and 7x7xA, where A had 14 to 21mm of thicknesses. 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 140ºC. 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, the same method to calculate the density of the wood, that is, the conventional method: mass / volume was used. The standard used has the dimensions of 70x70x191mm 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.

Table 1: Characteristics of radioactive sources

Radioisotope (name/symbol)	Range of energies (MeV)	Energy (average) (MeV)	Gamma Factor* (R/h.Ci a 1m)	Half life (year)
Amerício (Am-241)	0.0119 a 0.0595	0.035	0.13	432.2
Bário (Ba-133)	0.0310 a 0.3830	0.157	0.44	10.54
Césio (Cs-137)	0.0322 a 0.6620	0.615	0.31	30.14

(*) – Ionization constant [10]. The activities of the sources used were:
Americium 241 (Am-241) – 20.43mCi (7.6 x10^{4}Bq) – 01/01/2002;
Barium (Ba-133) - 20.14mCi (75.5 x10^{4}Bq) – 01/01/2002;
Cesium 137 (Cs-137) - 228mCi (843.6 x 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.

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

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 Mitutoyo digital micrometer, resolution of 0.001 mm., five points for height and width, and twenty four points for thickness. Using the equation (2):

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

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.

Table 3: Densities obtained by conventional method

Kind of wood	Density (average) (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

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 follows:

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

where:

ρ_{12} is the density in g/cm3, the moisture content of 12%;
$\rho_{U\%}$ is the density in g/cm3, the moisture content U%;
U% is obtained in the tests of moisture oven.

Table 4: Densities obtained at 12% moisture

Kind of wood	Density (average) U% moisture content (g/cm^3)	Density (average) 12% moisture content (g/cm^3)
Freijó	0.581	0.578
Jequitibá	0.760	0.749
Muiracatiara	0.874	0.862
Ipê	1.029	1.017

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 were slight 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 Beer-Lambert law adapted as, in practice, we rarely work with monochromatic parallel beams.

The equation is:

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

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 counts may be substituted for (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 test originals 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, Am-241, Ba-133 and Cs-137 (Figure 2), an arrangement with a NaI scintillator 2 "(Figure 3) and a spectrometer. Novelec multichannel model SM 512 (Figure 4), samples of 70x70xAmm (15 of each species), thickness ranging from 14 to 21mm. The values found for the apparent densities and linear absorption coefficients are shown in Tables 5, 6 and 7.

Figure 2: Models of radioactive sources used (Am-241-left; Cs-137-right).

Figure 3: NaI scintillator of 2", **Ludlum, model 44-10.**

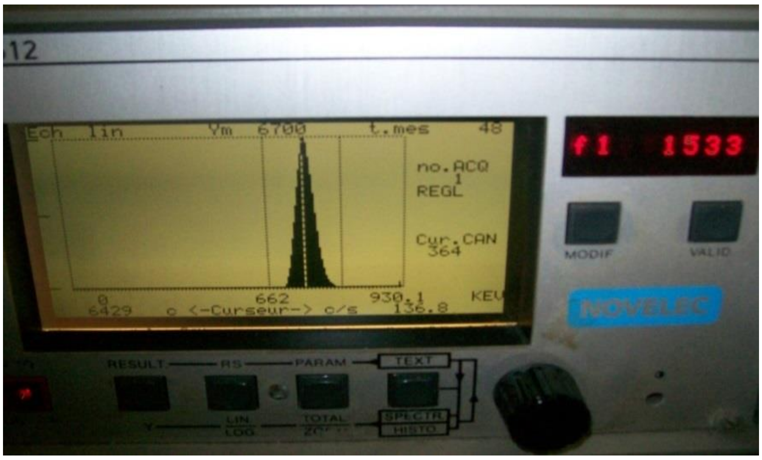

Figure 4: Spectrometer Novelec model SM512, showing the peak of energy (Cs-137).

Table 5: Densities and linear absorption coefficients – Am-241 (59.5 keV)

Kind of wood	Density U% moisture content (g/cm^3)	Density 12% moisture content (g/cm^3)	Linear absorption coefficient (cm^{-1})	Linear absorption coefficient (cm^{-1})
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

Table 6: Densities and linear absorption coefficients – Ba-133 (356 keV)

Kind of wood	Density U% moisture content (g/cm^3)	Density 12% moisture content (g/cm^3)	Linear absorption coefficient (cm^{-1})	Linear absorption coefficient (cm^{-1})
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

Table 7: Densities and linear absorption coefficients – Cs-137 (662 keV)

Kind of wood	Density U% moisture content (g/cm^3)	Density 12% moisture content (g/cm^3)	Linear absorption coefficient (cm^{-1})	Linear absorption coefficient (cm^{-1})
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

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

Freijó with Am-241 (-) 3.11%;
Jequitibá with Ba-133 (-) 2.27%
Muiracatiara with Ba-133 (-) 3.98%;
Ipe with Cs-137 (-) 3.25%;
which represent slight differences.

To obtain the values of the half-value layers (HVL), the Lambert-Beer equation (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 $I = I_0 /2$ for equation (4) 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 (cm);

μ is the linear absorption coefficient (cm^{-1}) as previously presented.

The results from the calculations are shown in Table 8.

Table 8: Half value layers of kinds of wood, in mm, related to energies of gamma emitters

Kind of wood	Am-241 (mm)	Ba-133 (mm)	Cs-137 (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

4. CONCLUSIONS

a- 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.

b- Linear absorption coefficients. 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, leads us to conclude that they are very good, considering the density values obtained experimentally.

c- Calculation of apparent density using convention nal 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 Ba-133 for "muiracatiara", with 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.

d- Half value layers. Taking into account the obtained values for the absorption coefficients, which proved to be correct, the values of the half-layers are perfectly acceptable, since a fixed parameter (or ln 2 = 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:
1- database of linear and mass absorption coefficients, half-value layers, maximum sensitivity method and limits of thickness;
2- the use of the parameters obtained, especially with Cs-137, to verify the integrity of wooden poles and standing trees (live trees). The radioisotope Cs-137 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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