Agric Res J **58** (5) : 867-873, *October* 2021
DOI No. 10.5958/2395-146X.2021.00124.1

MEASUREMENT OF MOISTURE CONTENT AND GAMMA RADIATION SHIELDING CHARACTERISTICS OF TREE SPECIES GROWN IN PUNJAB

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ABSTRACT

The present study deals with investigation of the moisture content and radiation shielding characteristics of 10 native and exotic tree species grown in Punjab State by using gamma scintillation detection method at oven dry state. The intensity of the emergent radiation was measured, when each of these tree species at a given moisture level was placed between a scintillation detector and a gamma source (^{137}Cs of energy 0.662 MeV and having strength of 1.0 microcurie). The obtained results show an appreciable evidence of radiation attenuation due to the variable chemical composition of the selected tree species and the dependence of the attenuation coefficient on density. The obtained mass attenuation coefficients at different moisture levels were plotted against the relative moisture content of tree species and it was observed that attenuation coefficient increases with decreasing moisture content, i.e., mass attenuation coefficient is least for completely wet sample and is highest for the oven dried sample. The obtained mass attenuation coefficient for selected trees of teak, babul, mango, shisham, chir pine, mulberry, oak, dek, safeda and poplar are in unit of cm²/kg: 128.5±9.3, 114.6 ± 4.2, 107.8 ± 6.4, 81.2 ± 8.2, 79.3 ± 5.9, 77.5 ± 8.8, 74.8 ± 6.5, 69.4 ± 9.2, 64.9 ± 7.0 and 64.1 ± 8.2, respectively.

Keywords: Half value layer, Mass attenuation coefficient, Moisture content, Scintillation detector

The gamma-ray spectroscopy is one of the most widely used radiation penetration techniques of all the non-destructive methods employed for testing in modern industry. The study of interaction of gamma radiations with the materials of common and industrial use, as well as of biological and commercial importance has become major area of interest in the field of radiation science. A proper characterization, evaluation of penetration and diffusion of gamma rays in the external and internal medium are necessary for a scientific study of interaction of radiation with matter. The mass attenuation coefficient which usually depends upon the energy of incident radiation and nature of the material (Kumaran and Bomberg *et al.,* 1985) provides a very important information for characterizing the penetration and diffusion of gamma radiation in any medium.

Gamma rays are electromagnetic waves of an extremely high frequency emitted by radioactive nuclei such as, ^{40}K, ^{232}Th and ^{238}U and their decay product (Auwal *et al.,* 2011) are major source of irradiation for human body; and have high penetrating power so that most of the substances can not absorb them effectively. Gamma rays are ionizing radiation and are thus biologically hazardous. They are produced by the decay of atomic nuclei via transition from a high energy state to a lower state known as gamma decay, but may also be produced by other processes. However, they are less ionizing than alpha or beta particles which are of course less penetrating. Shielding from gamma rays requires large amount of material mass, in contrast to alpha particles, which can be blocked by paper or skin, and beta particles which can be shielded by a thin foil. Gamma rays are better absorbed by materials with high atomic numbers and high density.

Besides numerous applications; these highly energetic and highly penetrating radiations can cause harmful effects to living cells/tissues/organs. On the one hand, highly absorbed doses can result in serious effect in nervous system damage, radiation sickness ,etc. On the other hand, low absorbed doses can cause elevated cancer risks. Hence, for efficient use of radiations, proper shielding from these radiations is needed. The most effective radiation protection is the use of shielding materials between the workers and the source. An efficient radiation shielding material is expected to have high gamma ray attenuation coefficient in order that a small thickness will produce significant reduction in intensity of the radiation. In general, the radiation shielding materials include lead, mercury and concrete. However, they have certain disadvantages viz. toxicity, strength, etc. In daily life, a large number of radiation centers (X-ray, CT scan etc.) uses wooden doors of different thickness made from different tree species.

In this paper, radiation shielding effectiveness of ten native and exotic tree species (namely teak, babul, mango, shisham, chir pine, mulberry, oak, dek,

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Date of receipt: 24.01.2020, Date of acceptance: 08.09.2020

safeda and poplar) grown in Punjab were investigated by using gamma scintillation detection method. The shielding effectiveness of any substance can be measured in terms of various parameters such as mass attenuation coefficient, linear attenuation coefficient, mean free path, effective atomic number, effective electron number, tenth value thickness, etc. The mass attenuation coefficient which measures the probability of interaction (absorption or scattering) with target is the most fundamental parameter among all these parameters (Singh *et al.,* 2007).

The moisture content is another important parameter to be determined for hygroscopic composite materials like wood as it affects the physical, mechanical and chemical properties of these materials. The internal stresses and dimensional stability of wood like materials get affected very badly due to variations in the moisture content in them which then create structural defects in these materials. The deformation and other defects of finished products reduce product quality and have the potential to damage a manufacturer's reputation.

Wood consists of a large number of small cells, which are generally tubular in shape. The cells in a living tree always contain water. It is in the form of 'free' water in the cell cavities, and 'bound' water in the cell walls, which are fully saturated. The amount of free or bound water contained in any wood sample can be expressed as its moisture content and contents varies from one wood type to another. Wood used indoors will eventually stabilize at 8 - 14% moisture content; outdoors at 12-18%. The moisture content of many wood samples has been estimated by various people using either of the following methods: oven drying method including microwave oven drying, electrical resistance method, dielectric method, by using a neutron moisture gauge by nuclear magnetic resonance (NMR), study of radio frequency signals to determine moisture content in wood (Dennis and Beall, 1977; Steele and Cooper, 2006) and by the measurement of electromotive force (emf) developed in between rotating discs (Negi, 1997). Generally, it is measured by the weight of water as a percentage of the oven dry weight of the wood fiber (a state where density becomes constant). The decay of wood can be controlled by controlling the water content in it. Water by itself does not harm the wood, but rather, wood with consistently high-water content enables fungal organisms to grow. Wood destroying fungus causes more damage to the structures than all the fires, floods and termites combined. Fungus occurs generally when the moisture content of wood exceeds 20 - 30 %, coupled with the optimal temperatures (32^{o} - 90^{o} F), an adequate supply of oxygen and a suitable source of energy and nutrients. The fungus secretes enzymes that break down the wood into usable food for it thereby reducing the strength of wood if this condition continues over a large period of time.

Radiation methods have also been used to determine moisture content and density of wood and other composite materials (Spolek and Plumb, 1981). The basic principle of radiation technique used to study composite hygroscopic materials is that penetration of the radiation (X-ray, beta ray or gamma ray) into the material is dependent on the material density, and how deep the radiation penetrates into the material. The effect of wood chemical composition on the mass attenuation coefficients was investigated by Lindgren (1991) and Macedo *et al.* (2002) and after studying the ratios 50/25/25, 25/25/50 and 10/10/80 for cellulose/hemicelluloses/lignin, it was found that the average value of the attenuation coefficient was 0.0876 cm^{-1} with a 0.4 percent coefficient of variation. They concluded that no significant changes were found in the mass attenuation coefficients because of composition changes.

MATERIALS AND METHODS

When gamma rays or X-rays of given intensity (I) are made to pass through the matter of given thickness, there is reduction in the intensity of the incident beam which is termed as attenuation. The Beer-Lambert Law which establishes the relationship between the attenuated intensity and incident intensity of the beam in terms of attenuation coefficient (μ) can be given as:

$$I = I_o e^{-\mu\rho t} \qquad (1)$$

where I_o is the radiation counts during a certain time duration without any absorber, I is the photon counts during the same time with a thickness t of absorber between the source of radiation and the detector, ρ is the density of the absorber, and μ is the mass attenuation coefficient. The mathematical rearrangement of equation (1) yields density as:

$$\rho = \frac{1}{\mu t} ln\left(\frac{I}{I_0}\right) \qquad (2)$$

The densities of selected wood samples were also obtained using the conventional method given as follow:

$$\rho = m/V \qquad (3)$$

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

The water content of the sample, after determining its density for state having moisture content m and for oven dry state, can be calculated from the following equation:

$$\text{water content} = \frac{\rho_m - \rho_o}{\rho_o} \times 100 \qquad (4)$$

where, is the density of the sample with the moisture content (m), is the density of oven dry state.

For calculating the mass attenuation coefficients of the selected samples, narrow beam transmission

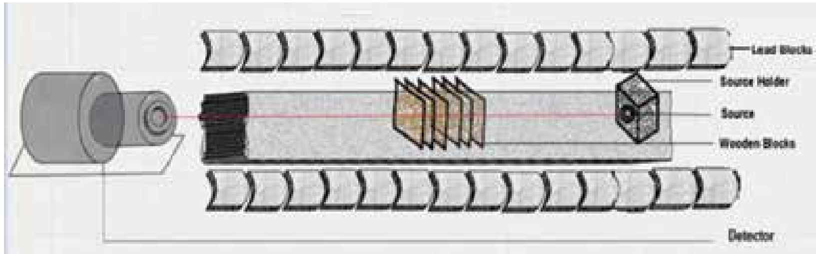

Fig. 1. Schematic diagram of the experimental setup.

geometry was used as depicted in Fig. 1. Photon beam of 662 keV from radioactive isotope ^{137}Cs having strength of 1.0 micro-curie, procured from BARC India was used in the present study. Transmitted pulse height spectra was recorded using compact sodium iodide (thallium activated) scintillation detector (1''×1'') procured from Nucleonix India; having resolution of 7.5 % at 662 keV coupled with single channel analyzer.

The detector and source were kept at the distance of 20.0 cm. To minimize the exposure of gamma rays to the radiation workers, the lead housing with sufficient thickness was used to keep the gamma ray source. The whole experimental setup was placed in the center of the room at the height of around 50 cm from the floor so as to minimize the contribution of scattered photons from the walls and floor. The calibration of experimental set up was done by passing 662 keV gamma rays through aluminum plates of different thickness. Fig. 2 shows the fitted plot of relative transmitted intensity versus thickness of aluminum plates. The obtained mass attenuation coefficient of aluminum using 662 keV gamma radiations was 64.74 ± 5.3 cm^2/kg which is in agreement with Hubbell and Seltzer (1995) values. The above procedure and result confirmed the validity of experimental setup and method adopted to obtain the mass attenuation coefficient of the selected tree species.

The tree species under study were taken from the fields of Punjab Agricultural University, Ludhiana. The details about species are listed in Table 1. Fresh samples were collected and immediately taken to the laboratory and kept at room temperature. The freshly procured wood samples were sliced into 15 pieces along the radial direction having dimensions of (8.2 x 8.1 x 1.1) cm with the help of microtome knife. The dimension and weight measurement of these slices were done by using Vernier caliper having accuracy of 0.1 mm and weighing them on Shimazu digital balance having an accuracy of 0.1 mg, respectively.

These wooden slices were dipped in water for period of 3/4 days so as to maximize their water content. Single channel analyzer of the gamma ray spectrometer, NaI(Tl) scintillation detector was set to accept 662 keV photopeak of ^{137}Cs. Zero absorber corresponded to only air in between the source and detector. Initially, one sample was kept and counts were noted, after this another sample was kept on its left, and the thickness and counts were again noted using

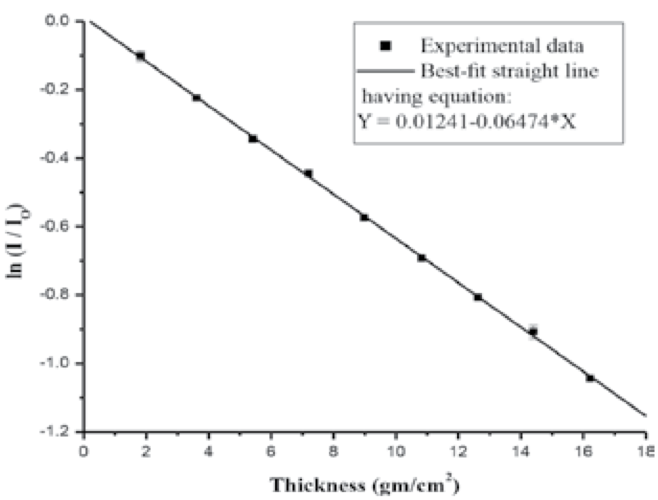

Fig. 2. The fitted curve of measured logarithmic relative transmission of 662 keV gamma photons versus *Aluminum* plates absorber thickness (gm/cm²).

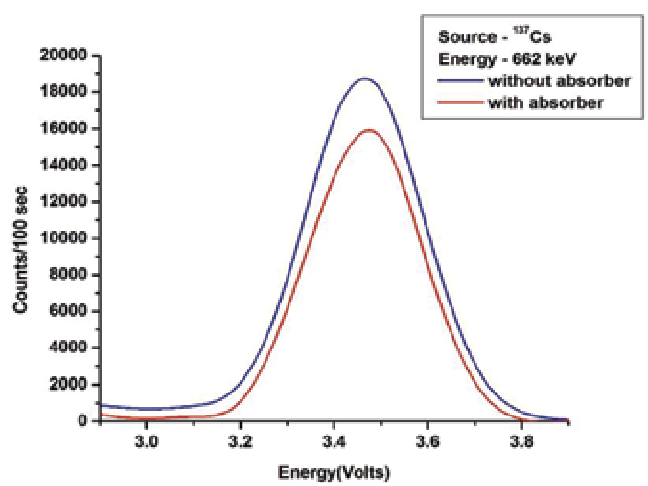

Fig. 3. Observed pulse-height distribution with and without absorber.

single channel analyzer. Then another sample was kept on its right and again thickness and counts were noted. This procedure was done till all 15 wood samples were placed between detector and source. Counts were recorded for 50 seconds for each absorber thickness and sufficient number of sets were taken so as to keep the statistical error below 1%. A typical observed pulse-height distribution with and without wood sample is shown in Fig. 3.

The samples were heated in an electric oven at (100-105°C) for about 2-4 hours. The intensity measurements were again done by varying the thickness to calculate the mass attenuation coefficient and moisture content of the wood samples. The above procedure was repeated for same durations till the samples attained their oven dried states (a state where weight becomes constant). The complete experiment was repeated 3-4 times for reproducibility of results for oven dry state and completely wet state of the samples.

RESULTS AND DISCUSSION

A semi-logarithmic plot of relative transmitted intensity versus thickness for fully wet and oven dry state (ODS) of teak wood is shown in Fig. 4. Similar fit behavior has been observed for all other samples. The mass attenuation coefficient of each wood sample at fully moisture state and other moisture levels was obtained by using least-squares fit analysis. The following equation was applied to the obtained data set for fresh and oven dry state:

$$I = I_0 a^x \quad (5)$$

where x is the absorber thickness (gm/cm^2), and I_0 and 'a' are the fitting constants. Using logarithmic, the above equation can be written as:

$$lnI = lnI_0 + xlna \quad (6)$$

Hence, the mass attenuation coefficient corresponds to negative slope of equation (6):

$$\mu \text{ (cm}^2\text{/kg)} = -1000 \, ln \, a \quad (7)$$

where factor 1000 appears as μ has been expressed as (cm^2 kg^{-1}). The obtained value of mass attenuation coefficient (μ) at different moisture level for selected tree species is listed in Table 2; and for oven dray state (ODS) is listed in Table 3, whereas, total error on mass attenuation coefficient (Δμ) is obtained by combining, error on statistics of counting, least squares fitting error of data, and error on measurement of thickness of wood sample, in quadrature. The fitted plot of the mass attenuation coefficient versus moisture content for *Teak* wood has been shown in Fig. 5. Solid line represents the least square fit to obtained values of mass attenuation coefficients at different moisture levels. The similar fit behavior was observed for all other selected tree species.

The negative slope from the Fig. 5 depicts that the mass attenuation coefficient increases with the decreasing moisture content of wood samples. Also, this can be observed from the Table 2 that mass attenuation coefficient for ODS is always higher than that for fully moisture state. This type of behavior can be explained on the basis of effective atomic number. The effective atomic number of water is 3.33 (according to weighted fraction method) and composition of wood is complex (Bradley *et al.,* 1991), the estimated effective atomic number of wood is between 4 to 5. So, with increase in the moisture level of the wood its effective atomic number will go down as compared to dry wood. The photon attenuation is directly proportional to the effective atomic number, hence with decreased effective atomic number the photon attenuation will decrease and consequently mass attenuation coefficient will decrease with increase in moisture level of wood. Also, the regression analysis has shown that the phenomena of attenuation is solely dependent on the thickness of wood sample at 1% level of significance (see column 5 of Table 2).

Table 1. List of tree species used in present study.

Common Name	Scientific Name	Family	Density (gm/cm^3)
Teak	*Tectona grandis*	Lamiaceae	0.91
Babul	*Vachellia nilotica*	Fabaceae	0.83
Mango	*Mangifera indica*	Anacardiaceae	0.77
Shisham	*Dalbergia sissoo*	Fabaceae	0.74
Chir pine	*Pinus roxburghii*	Pinaceae	0.70
Mulberry	*Morus alba*	Moraceae	0.68
Silver Oak	*Grevillea robusta*	Proteaceae	0.69
Dek	*Melia composita*	Meliaceae	0.59
Safeda	*Eucalyptus tereticornis*	Myrtaceae	0.50
Poplar	*Populus deltoides*	Salicaceae	0.44

Table 2. Mass attenuation coefficients (cm^2/kg) of used tree species as absorbers at different moisture level using 0.662 MeV from ^{137}Cs source.

S. No.	Name of Sample	Water Content (%)	[μ (cm^2/kg) ±SE]	Coff. of multiple determination (R^2)
1	Teak	106.84	40.9 ± 5.1	-0.997*
		85.53	52.2 ± 8.2	-0.997*
		55.87	71.4 ± 4.9	-0.992*
		37.28	75.1 ± 5.7	-0.999*
		23.46	88.8 ± 8.1	-0.995*
		7.49	117.7 ± 8.4	-0.996*
		ODS	128.5 ± 9.3	-0.992*
2	Babul	115.8	47.9 ± 1.9	0.999*
		86.8	64.7 ± 2.1	0.999*
		60.1	69.2 ± 5.1	0.999*
		48.5	79.0 ± 4.1	0.997*
		19.1	93.4 ± 3.1	0.994*
		ODS	114.6 ± 4.2	0.998*
3	Mango	129.81	44.1 ± 7.3	-1.000*
		90.37	63.4 ± 6.2	-1.000*
		47.26	79.0 ± 4.2	-1.000*
		24.38	88.4 ± 5.6	-1.000*
		10.3	90.6 ± 6.4	-1.000*
		ODS	107.8 ± 6.4	-1.000*
4	Shisham	64.48	63.2 ± 9.3	-0.999*
		42.14	67.2 ± 6.3	-0.999*
		34.01	69.8 ± 5.1	-1.000*
		20.82	73.5 ± 6.2	-0.998*
		15.66	74.5 ± 7.8	-0.999*
		5.63	79.7 ± 9.2	-0.997*
		4.21	80.9 ± 7.8	-0.998*
		ODS	81.2 ± 8.2	-0.998*
5	Chir pine	163.07	46.1 ± 3.5	-0.999*
		98.65	60.0 ± 6.5	-1.000*
		67.89	64.8 ± 2.7	-0.999*
		46.68	69.8 ± 9.2	-0.999*
		23.60	73.7 ± 4.4	-1.000*
		ODS	79.3 ± 5.9	-0.999*
6	Mulberry	137.9	42.9 ± 7.5	0.993*
		82.4	50.4 ± 4.7	0.999*
		54.1	58.9 ± 6.3	0.999*
		21.7	61.3 ± 6.7	0.999*
		ODS	77.5 ± 8.8	0.997*
7	Silver Oak	101.55	64.6 ± 6.8	-1.000*
		74.60	65.5 ± 8.4	-1.000*
		49.88	68.3 ± 6.3	-1.000*
		28.40	72.2 ± 6.8	-1.000*
		15.09	73.2 ± 6.2	-1.000*
		ODS	74.8 ± 6.5	-0.996*
8	Dek	85.6	58.3 ± 10.3	0.998*
		57.7	62.8 ± 9.9	0.996*
		28.7	64.3 ± 6.8	0.991*
		16.	67.1 ± 7.5	0.991*
		7.5	68.2 ± 7.4	0.992*
		ODS	69.4 ± 9.2	0.997*
9	Safeda	114.6	43.8 ± 7.2	-0.999*
		73.93	50.8 ± 7.9	-0.999*
		56.95	54.9 ± 6.3	-0.998*
		42.05	58.4 ± 6.8	-1.000*
		18.34	61.8 ± 6.1	-0.999*
		ODS	64.9 ± 7.0	-0.995*
10	Poplar	98.7	52.4 ± 6.7	0.998*
		61.7	55.1 ± 8.7	0.994*
		35.5	59.8 ± 4.8	0.996*
		18.6	60.2 ± 9.3	0.996*
		4.70	62.6 ± 9.7	0.999*
		ODS	64.1 ± 8.2	0.991*

(*) Regression is significant at level of significance $p < 0.0001$ where SE is the standard error in μ.

Table 3. Mass attenuation coefficients (cm²/kg) of tree species as absorbers at oven dry state (ODS) using 0.662 MeV gamma radiations from ^{137}Cs source.

Name of Sample	[μ (cm²/kg) ±SE]	Coff. of multiple determination (R^2)
Teak	128.5 ± 9.3	-0.992*
Babul	114.6 ± 4.2	0.998
Mango	107.8 ± 6.4	-1.000*
Shisham	81.2 ± 8.2	-0.998*
Chir pine	79.3 ± 5.9	-0.999*
Mulberry	77.5 ± 8.8	0.997
Silver Oak	74.8 ± 6.5	-0.996*
Dek	69.4 ± 9.2	0.997*
Safeda	64.9 ± 7.0	-0.995*
Poplar	64.3 ± 8.2	0.991*

As it is well known fact that attenuation coefficient depends upon the energy of incident photons and nature of absorbing material. However, the present study is based upon photon beam of 662 keV from radioactive isotope ^{137}Cs, hence attenuation coefficient solely depends upon the nature of absorbing wood. Generally, attenuation coefficient decreases with increase in energy as high energy photons are not easily attenuated as compared to low energy photons. The present study has helped us to determine the radiation hardness of different tree species. A close look at the Table 3 regarding mass attenuation coefficient at oven dry state revealed that mass attenuation coefficient is highest for Teak wood among selected species with value of 128.5 **±** 9.3 cm²/kg. The attenuation ability of the selected tree species in descending order is as: teak, babul, mango, shisham, chir pine, mulberry, oak, dek, safeda and poplar*;* and for energy of 662 keV obtained values of mass attenuation coefficient are in unit of cm²/kg: 128.5 **±** 9.3, 114.6 ± 4.2, 107.8 **± 6.4,** 81.2 ± 8.2, 79.3 ± 5.9, 77.5 ± 8.8, 74.8 **± 6.5,** 69.4 ± 9.2, 64.9 ± 7.0 and 64.1 ± 8.2, respectively. The half value layer was also calculated for selected tree species and listed in Table 4. The teak has lowest half value layer and poplar has highest. This implies that a very lesser thickness of teak is required compared to other selected tree species to attenuate the radiation of same energy. In summary, a wood with high attenuation coefficient has low half value layer and is a good absorber of radiation compare to a wood with low attenuation coefficient and high half value layer. From this study, it has been observed that the teak is the best absorber of radiation while the poplar is weak absorber of radiation among all selected tree species.

Thus, based upon present studies it could be concluded that attenuation coefficient, density and half value layer are characteristics that can be used for sorting the radiation shielding ability of the materials. The present study compared the shielding characteristics of ten native and exotic tree species grown in Punjab region by using gamma scintillation detection method at oven dry state. Measurements showed that the good absorber of radiation is the wood

Table 4. Calculated Half Value Layer for selected tree species.

Common Name	Scientific Name	Half Value Layer (cm)
Teak	*Tectona grandis*	5.97
Babul	*Vachellia nilotica*	7.37
Mango	Mangifera indica	8.35
Shisham	*Dalbergia sissoo*	11.18
Chir pine	Pinus roxburghii	12.60
Mulberry	Morus alba	13.86
Silver Oak	*Grevillea robusta*	13.59
Dek	*Melia composita*	17.33
Safeda	*Eucalyptus tereticornis*	21.66
Poplar	*Populus deltoides*	24.75

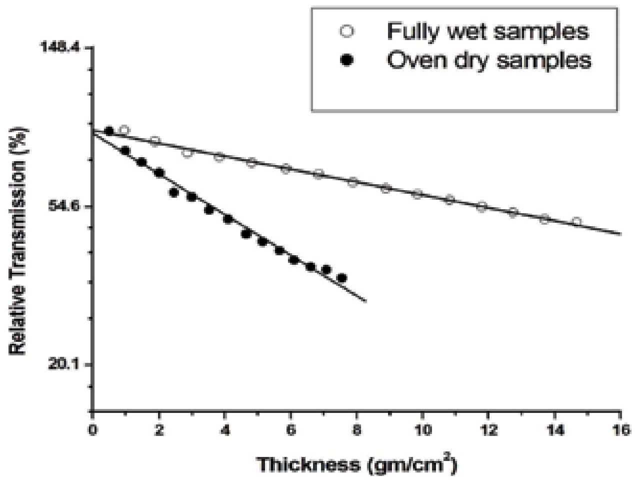

Fig. 4. Semi-logarithmic plot of relative transmission *vs.* thickness for completely wet and dry samples of teak wood samples.

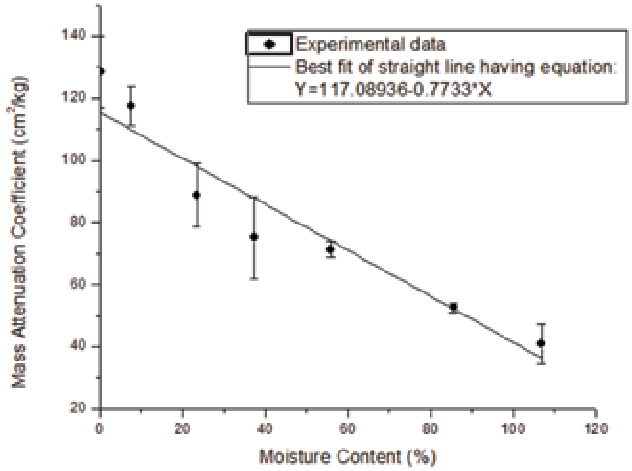

Fig. 5. Fitted plot of relative moisture content (%) versus mass attenuation coefficient (cm^2/Kg) for teak wood sample.

which has high attenuation coefficient, high density and low half value layer. Also, the technique of determining the water content of wood sample is simple, rapid and more accurate. Thus, these studies are useful tool to continuously monitor the water changes of plants and would be beneficial to the wood product manufacturers. It is recognized that further work can be carried out using other energies (standard radioisotopes or not available for the standard radioisotopes) such as Compton scattering of the primary beam followed by the procedure described above. The results of such measurements could be quantitatively understood by suitable Monte Carlo simulation of the above process for given experimental condition in real field practices.

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