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DIELECTRIC DETERMINATION OF MOISTURE OF WOOD USING TIME DOMAIN REFLECTOMETRY*

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A b s t r a c t. The usefulness of time domain reflectometry, TDR, for wood moisture was examined. TDR was applied to determine the dependent on moisture relative dielectric constant, ε, of wood. The relationship between volumetric moisture, θ, and relative dielectric constant was investigated for pine, beech and oak. Obtained results showed a linear relationship $\sqrt{\varepsilon}\ (\theta)$, with intercept, *itc*, and slope, *slp*, varying from one species to another, dependent on porosity, η. Fitting a regression line to $itc(\eta)$ and to $slp(\eta)$ produced a η-sensitive conversion equation accounting for porosity.

Fitting a regression line to the aggregated species $\theta_{TDR}(\theta)$ data set, resulted in a 1:1 line with $R = 0.9962$ and $SD = 0.019$. Thus, it was concluded that TDR could be a convenient technique to estimate volumetric moisture of wood with no specific calibration needed.

K e y w o r d s: time domain reflectometry, TDR, wood moisture determination

INTRODUCTION

Electrical monitoring of the wood drying process is a basic need in the wood industry. Common moisture meters for wood are of the conductance-type. Conductance-type meters use the relation between the wood electrical conductivity, σ, as influenced by moisture, θ. Calibration of the method rests in determining θ versus σ conversion equation. The meters are simple and cheap, however their application is troublesome because $\sigma(\theta)$ changes from one species to another. Therefore, when working with different woods, the conductance-based readings of wood moisture need frequent recalibration, which makes the method inconvenient.

Since TDR proved as a method for dielectric properties of matter [2], its applicability was examined to measure soil moisture [1,3,10] and also for other porous agriculture materials, like grain, plant tissue, plant seeds [5] and cereals grain [7].

TDR operates at electrical field frequencies ranging from 0.5 to 5 GHz, where the contribution of parasite conductance current to the whole polarization current can be neglected [6]. Therefore, because TDR has proven its applicability for electroconductive materials, such as soil and because the solid matter of the soil, as well as solid matter of plant tissue, do not differ remarkably regarding their relative dielectric constants, ranging for both from 2 to 5 [4,8], it

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was assumed that TDR should be applicable also for determining the moisture of wood.

MATERIALS AND METHODS

The study investigated woods of pine, beech and oak, having different bulk densitiy, porosity and salinity. Chosen characteristics of the investigated samples are listed in Table 1.

Table 1. Chosen properties of the investigated woods

Species	Porosity cm^3cm^{-3}	Bulk density $g\ cm^{-3}$	Solid mater density $g\ cm^{-3}$	Acidity water extract (pH)	$ecE_{5:1}$ dSm^{-1}
Pine	0.681	0.398	1.25	5.60	0.10
Beech	0.659	0.757	2.22	5.69	0.27
Oak	0.197	0.653	0.813	3.94	0.15

$ecE_{5:1}$ is electrical conductivity of water extract obtained from mixture of 1 part of wood and 5 parts of water by mass.

The investigated wood was cut into rectangular blocks of 70 x 90 x 10 mm. Each block was provided with two pilot holes of 2 mm in diameter and separated by 16 mm, drilled in its center perpendicular to the 70 x 90 wall. 20 such blocks of each investigated wood were prepared. 10 blocks were oven dried and the remaining 10 were saturated with water under pressure of 20 mm Hg.

To determine relative dielectric constant of wood time domain reflectometry, TDR, technique was applied [3,9]. The sensor (Fig. 1) was consisted of two, 10 cm long, parallel stainless steel rods of 2 mm in diameter and separated by 16 mm. A Hewlett-Packard HP54120B sampling oscilloscope with a Hewlett-Packard HP 54121A TDR sampling head was used as the TDR measuring unit.

The dry and wet blocks, taken in a given optional ratio, were piled up to form a single, aggregated block of 70 x 90 x 100 mm having the pilot holes aligned, as shown in Fig. 2.

The TDR sensor rods were threaded through the whole, sandwich-like, sample and the resultant dielectric constant of the sample was measured using TDR. Resultant (weighted average) volumetric moisture, θ, of the sample was then

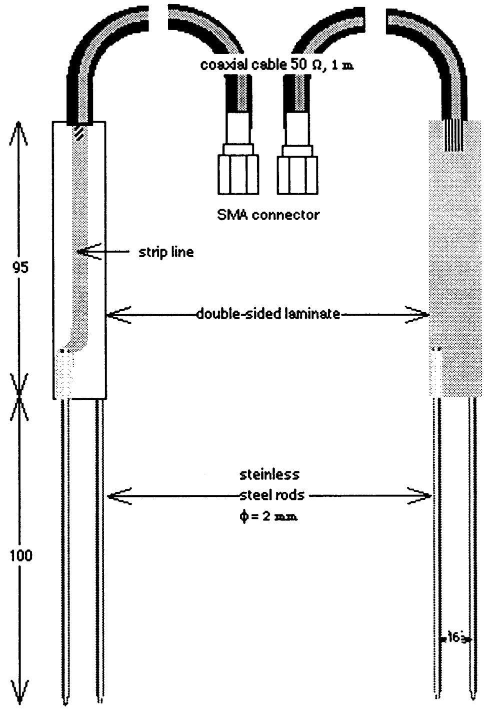

Fig. 1. Details of the sensor used.

calculated from dry-to-wet ratio of the used blocks, according to:

$$\theta = \eta\ N_s / N \qquad (1)$$

where η is porosity of wood (assumed to be equal to the saturation moisture), N_s - number of saturated blocks, N - number of all blocks constituting the sample.

The dry-to-wet ratio of the blocks was then changed and the procedure repeated.

RESULTS AND DISCUSSION

Obtained $\sqrt{\varepsilon}(\theta)$ relations for the investigated woods are shown in Fig. 3. The regression lines differ with intercept and slope. It had been found, that intercept, *itc*, as well as slope, *slp*, were correlated to porosity, η, of the samples, η, according to:

$$itc = 1.80 - 0.47\eta;\ R = 0.7187 \qquad (2)$$

$$slp = 12.2 - 9.60\eta;\ R = 0.9995. \qquad (3)$$

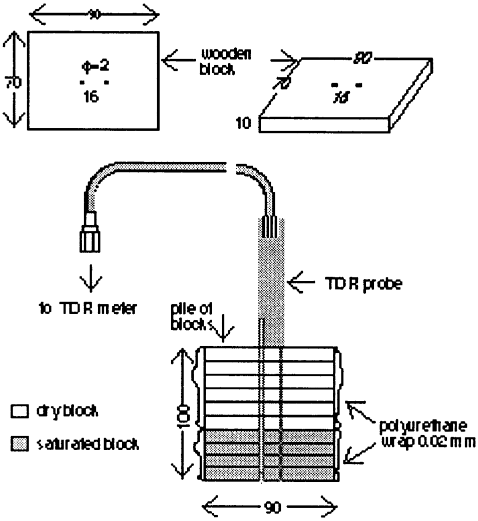

Fig. 2. Principle of obtaining samples of wood having different moisture.

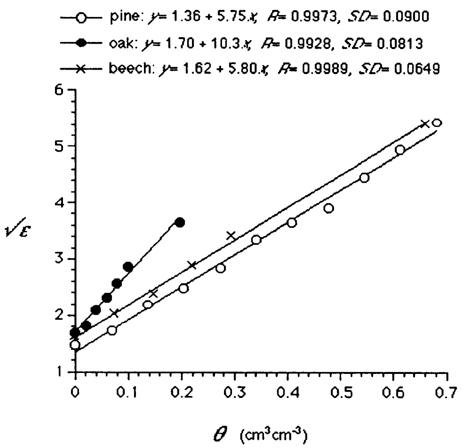

Fig. 3. Relative dielectric constant, ε, versus volumetric moisture, θ, of wood.

Because:

$$\sqrt{\varepsilon} = itc + slp\theta \tag{4}$$

therefore, by substituting for *itc* and *slp* from Eqs (2) and (3) respectively, a conversion formula that accounts for porosity was derived:

$$\theta = \frac{\sqrt{\varepsilon} - 1.80 + 0.47\eta}{12.2 - 9.60\eta}. \tag{5}$$

Fitting a regression line to aggregated, comprising all species together $\theta_{TDR}(\theta)$ data set, resulted in a 1:1 line as shown in Fig. 4.

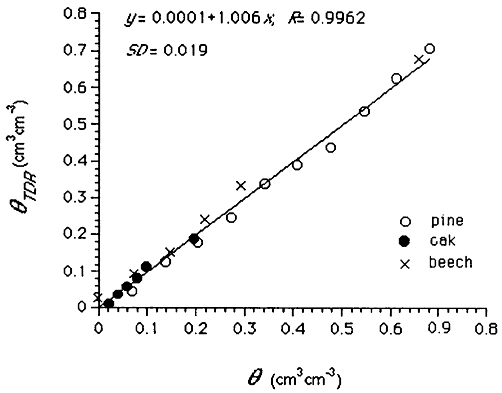

Fig. 4. Comparison of volumetric moisture of wood determined using TDR, θ_{TDR}, with that determined gravimetrically, θ, using the oven-drying method. SD is standard deviation.

From the above it appears that TDR can be a convenient technique for measuring the volumetric moisture of wood, with no specific calibration needed. When using a surface TDR moisture probe the pilot holes are unnecessary.

CONCLUSION

1. Linearity of the $\sqrt{\varepsilon}(\theta)$ relationship makes TDR equally sensitive over the full range of changes of moisture of wood.

2. TDR suits the dielectric determination of wood moisture, especially in automated, microprocessor-controlled, data aquisition systems.

3. Using TDR no wood-specific calibration is needed if porosity is accounted for.

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