Electrical impedance measurement of green Scots pine

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Abstract

Electrical impedance spectroscopy method is based on the measurement of electrical response at multiple frequencies. The measurement technique was studied in relation to the moisture content and density of green Scots pine sapwood and heartwood. For heartwood, resin acid content was also used as a reference parameter. Small samples were measured in green moisture state. The through-transmission measurements were conducted at frequency range from 1 Hz to 10 MHz. Parallel samples from the same tree were used in measurements in tangential and longitudinal directions. The moisture content range of sapwood pieces was 87 – 169 % (dry basis). For heartwood pieces the range was 23 – 44 %.

The measurements were conducted firstly with plastic sheet between the sample and electrodes. The plastic sheet acted as a dielectric layer, and in addition it protected the samples from drying during the measurement. Secondly, the measurements were made without the plastic cover to compare the results. At low frequencies, the electrical impedance responses measured with and without plastic cover differed greatly. At higher frequencies the responses approached each other. For heartwood specimens, there were significant correlations between impedance modulus and moisture content (e.g. r = -0.65, p < 0.001, N = 42 at 10 kHz) and density (e.g. r = -0.34, p < 0.05, N = 42, at 2.5 MHz). The impedance phase angle correlated with resin acid content at low frequencies (e.g. r = -0.46, p < 0.01 at 100 Hz).

1 Introduction

Electrical impedance spectroscopy (EIS) is a technique, in which alternating electric field at different frequencies is induced into a specimen, and the complex electric response is measured. Impedance modulus $|Z|$ and phase angle ϕ can be further calculated from the complex impedance.

Physical and chemical properties of wood affect its EIS response. Moisture content (MC) of wood is the dominant factor and in addition, for example, density and grain angle affect the measurement. Below fibre saturation point (FSP) electrical impedance decreases as a function of MC, but above FSP the effect of MC on EIS response is reduced.

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The extractive content of wood has shown to have effect on certain dielectric properties, especially when measured in transverse direction (Vermaas 1974). It has been hypothesised that nonwater-soluble and water-soluble extractives may have opposite effects on conductivity of wood (Skaar 1988).

In this study, the heartwood and sapwood of Scots pine were studied in green moisture state. The goal of the study was to evaluate the possibilities to determine pine characteristics, e.g. MC, density and extractive content, already in forest before transportation to industry. These properties are of interest both for timber producers and for woodchip consumers. In addition, the effect of a dielectric layer between sample and electrodes on the results was studied.

2 Materials and methods

The trees felled for the samples represented the whole range of total heartwood phenolics in the stand, and the sampling is described in (Harju & Venäläinen 2006). Handling of the tree discs, cutting of them and the determination of resin acid content (RAC) is presented in more detail in (Tomppo *et al*. 2009). Parallel samples were used for the tangential and longitudinal impedance measurements. Between the felling and cutting of the samples, the tree disks were stored in a freezer, as well as between the cutting and measurement. The sample thickness was about 3 mm, and the other dimensions varied depending on the tree size.

The electrical impedance measurements were made as through-transmission measurements at frequencies from 1 Hz to 10 MHz without the plastic covers and from 100 Hz to 10 MHz with the plastic covers. Solartron impedance analyser 1260A together with a dielectric interface 1296A was used for the measurements. Samples were measured in sample holder 12962A, with electrode diameter of 10 mm. First, the samples were measured with plastic covers and then without them. A single measurement took about 1 min 40 s. There was some variation in the thickness of the samples, and thus, the measurements were normalised with corresponding empty cell measurements. The parameters measured in longitudinal direction are hereafter referred with || as subscript and those in tangential direction with $\perp$ as subscript.

a) b)

Figure 1. A crosscut sample before separating the heartwood and sapwood (a). The circle (b) represents the size of the electrode (∅ 10 mm) compared to the specimen (from pith to bark about 95 mm).

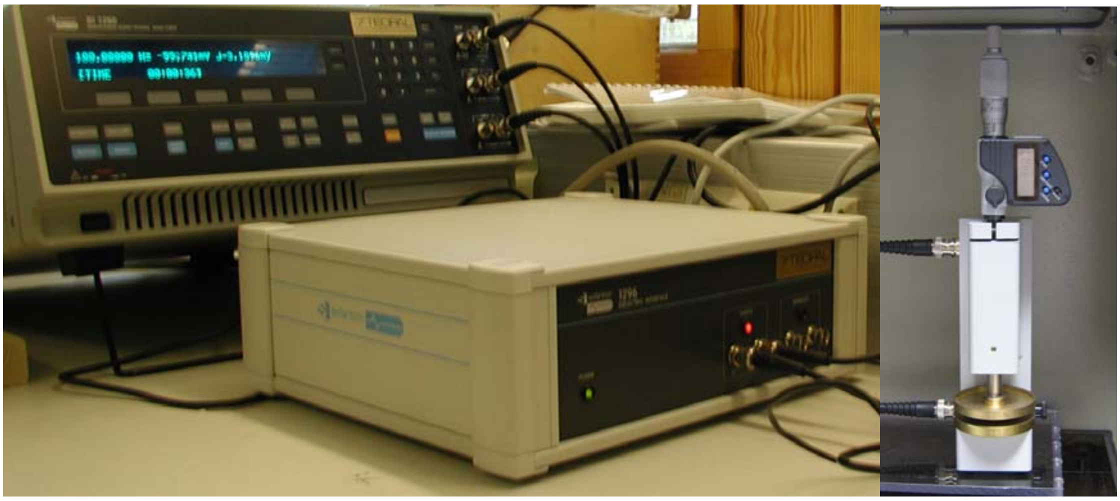

Figure 2. The impedance analyser with the dielectric interface (a) and the sample holder (b).

3 Results

In the sample sets, there were certain specimens that were considered as outliers. Therefore the sample number in each analysis is always indicated. The determined reference values are presented in Table 1. Examples for the impedance modulus and phase angle as a function of frequency are presented in Figure 3.

The average MC for heartwood was 31 %, and for sapwood 120 and 135 % for longitudinal and radial cuts, respectively. There was no correlation between heartwood RAC and MC, and very weak correlation for RAC and ρ ($r = 0.25$, $p < 0.05$, $N = 77$).

Table 1. Moisture content (MC) in green conditions and oven-dry density (ρ) of the heartwood and sapwood and resin acid content (RAC) for the heartwood. L refers to longitudinal cut and R to radial cut.

			Mean	Range	N
MC (%)	Heartwood	L	31	23 – 44	42
		R	31	24 – 43	41
	Sapwood	L	120	87 – 151	39
		R	135	109 – 169	41
ρ (kg/m3)	Heartwood	L	322	257 – 386	42
		R	356	256 – 422	42
	Sapwood	L	441	343 – 521	42
		R	473	332 – 643	42
RAC (mg/g)	Heartwood		49.0	4.1 – 160.2	39

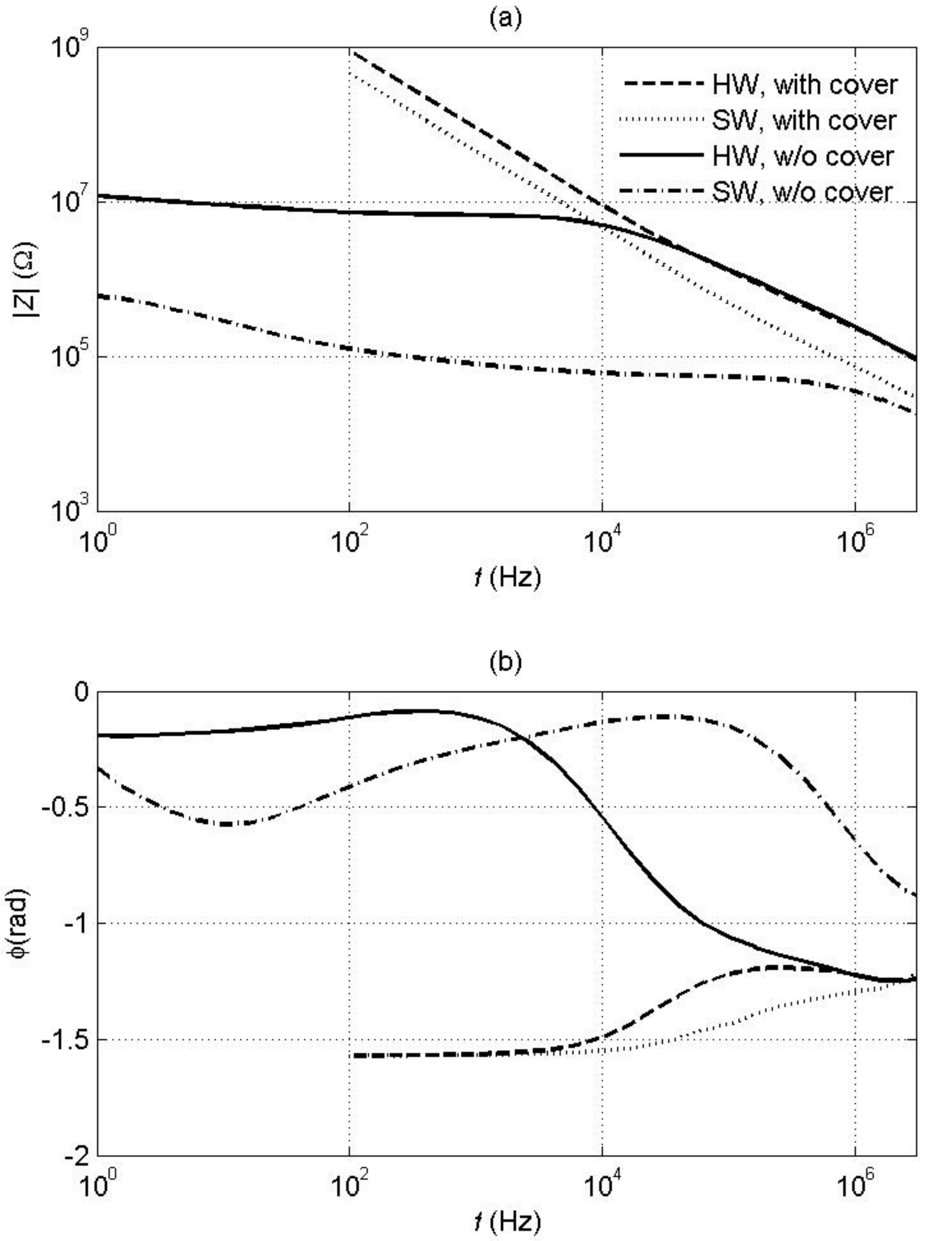

Figure 3. Impedance spectra for heartwood and sapwood parts of the sample in Figure 1. Measurements both with and without cover. MC for the heartwood sample was 32 % and for sapwood 103 %.

For heartwood pieces, there were significant correlations between |*Z*| and MC (Figure 4a); throughout the frequency range for measurement without plastic covers, and at high frequencies for measurements with plastic covers. For example for $|Z_{||}|$, r was -0.65 ($p < 0.001$, $N = 41$) at 10 kHz without the plastic covers. The results were similar in both measurement directions. Throughout the frequency range, the correlations were stronger for the measurements without covers. For phase angle $\phi_{||}$ and $\phi_{\perp}$, there were significant correlations (*p*

< 0.05) with MC for heartwood (Figure 4b), but not for sapwood. For sapwood pieces, the strongest correlation between $|Z_{\perp}|$ and MC was r = 0.35 (p < 0.05, N = 40, f = 16 kHz) for measurement with the plastic covers. For other measurements, i.e. without plastic covers or with plastic covers in longitudinal direction, there were no significant correlations.

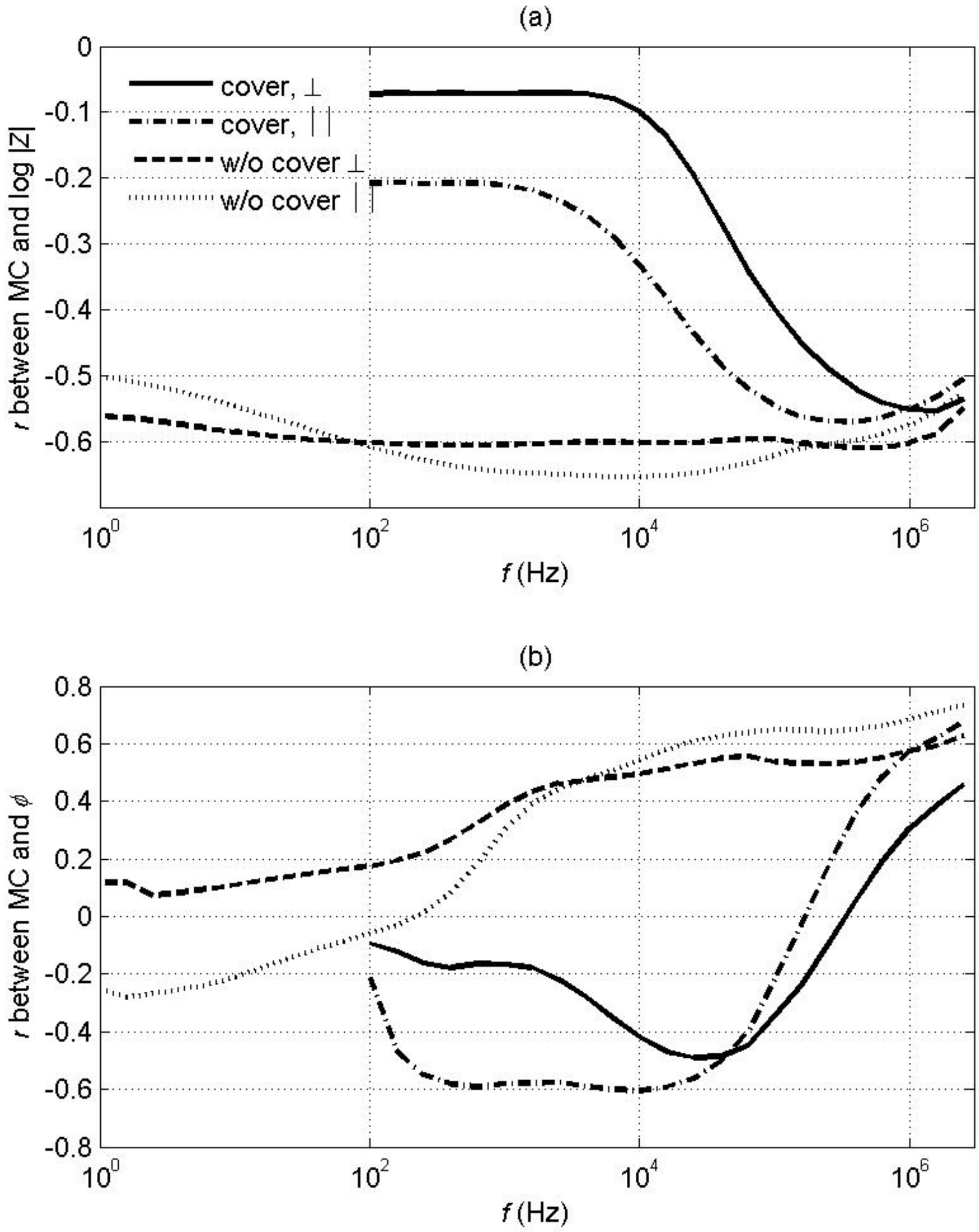

Figure 4.(a) The correlation coefficient r between MC and log $|Z|$ for heartwood specimens. (b) The correlation coefficient r between MC and ϕ for heartwood specimens. N = 37 – 42, and correlations are significant at 5 % level around r = 0.35.

For heartwood, there were significant correlations between $|Z_{||}|$ and ρ at high frequencies; r = -0.32 (p < 0.05, N = 41, f = 2.5 MHz) without plastic covers and

r = -0.41 (p < 0.01, N = 42, f = 2.5 MHz) with plastic covers. For sapwood, there was correlation between $|Z_{||}|$ and ρ when the measurements were made through the plastic covers. Correlation was significant from 100 Hz to 10 MHz; for example at 100 kHz r was -0.36 (p < 0.05, N = 42). For other sapwood measurements the correlations with ρ were not significant.

The phase angle of the tangential measurement of heartwood correlated significantly with RAC at frequencies from 1 Hz to 400 Hz (Figure 5, Figure 6). At 100 Hz the correlation was r = -0.46 (p < 0.01, N = 36).

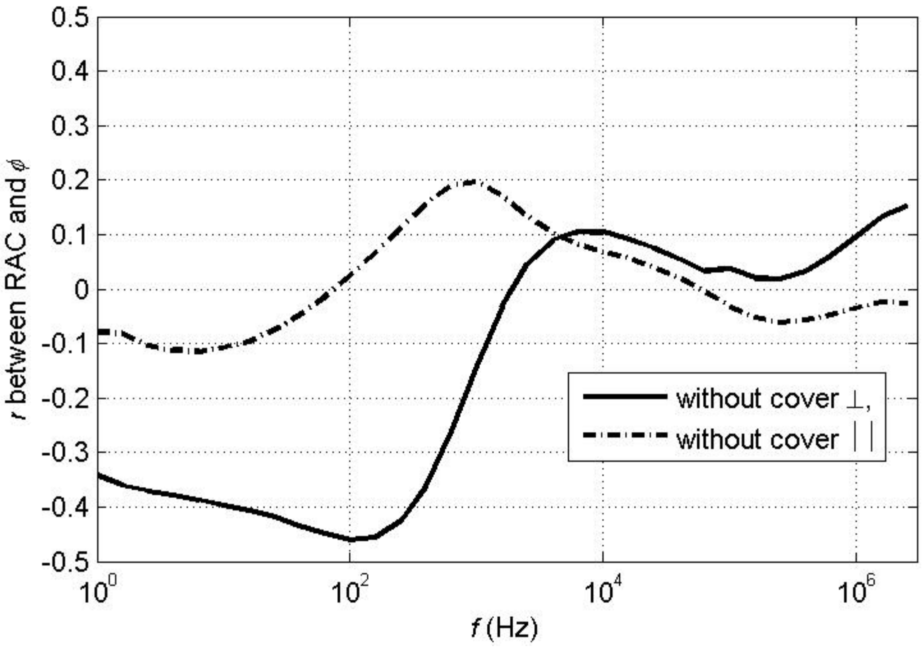

Figure 5. Correlation between heartwood RAC and ϕ. N = 36 for tangential measurement and 38 for longitudinal measurement.

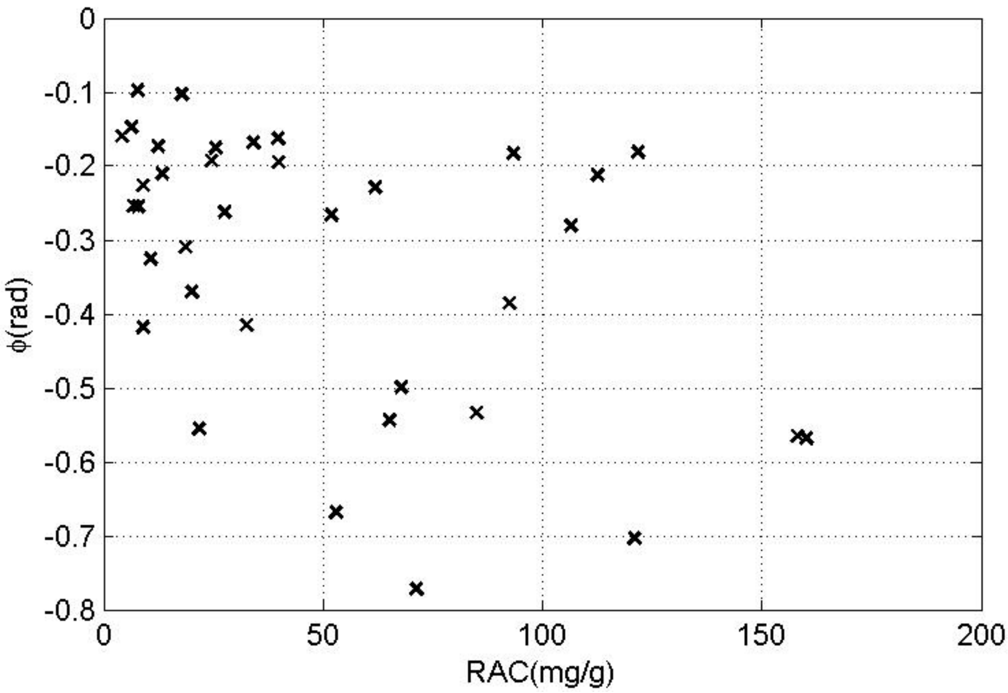

Figure 6. The phase angle $\phi_{\perp}$ at 100 Hz as a function of RAC. Correlation r = -0.46, $p < 0.01$, N = 36.

4 Discussion

There was a strong relation between MC and |*Z*| for heartwood but not for sapwood, which is explained by the lower MC range of heartwood compared to that of sapwood. For heartwood density, the correlation was better when the measurement was made through plastic covers. Otherwise, the correlations between dielectric parameters and EIS parameters for heartwood were stronger without the dielectric layer.

There was a significant correlation between RAC and impedance phase angle $\phi_{\perp}$ at frequencies from 1 Hz to 400 Hz. At this frequency range there was no significant correlation between ϕ and MC. According to the results, the measurement of green wood should be made in transverse direction in order to estimate the RAC of green wood.

The variation in extractive content can be considerable within tree, and for example pinosylvin content is increased close to the heartwood/sapwood border (Bergström *et al*. 1999). Thus, in further studies, a sample should be first measured with EIS and then extracted to get more precise reference values. In addition other measurement set-ups should be tested, because the through-transmission measurement is practical only for small laboratory scale samples.

The potential of EIS for extractive content estimation, or classification of trees accordingly, should be further studied.

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