Research paper

Comparative testing of two alternating current methods for determining wood moisture content in kiln conditions

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Tamme, H., Kask, R., Muiste, P., Tamme, V. 2021. Comparative testing of two alternating current methods for determining wood moisture content in kiln conditions. – Forestry Studies | Metsanduslikud Uurimused 74, 72–87 ISSN 1406-9954. Journal homepage: <http://mi.emu.ee/forestry.studies>

Abstract. Research into the possibility of applying the electric impedance spectrometry (EIS) method and the dielectric capacitance method (DECM) simultaneously above fibre saturation point (FSP) and in harsh kiln conditions has been relatively scarce. In the framework of this research, tests were carried out on the operational reliability of the measuring capacitor (MEC) prototype used for calibrating the DECM in the harsh internal climate (50°C and 98% RH) of the kiln. Condensation of water vapor on MEC plates, leakage of MEC insulators and the emergence of static electric charges on MEC plates were studied. Quantitative ranges were found for MEC performance-disrupting effects on the parasitic capacities induced by each effect. The DECM was found to be less reliable than the EIS method for application in harsh kiln conditions. Secondly, under the same test conditions and for the same wood species (birch), the possibilities of the DECM method and the EIS method were comparatively modeled with the predetermined Rozema quality criterion of $\pm 1.75\%$ MC for predicting the moisture content (MC) of birch wood above FSP. It was found that, under the same test conditions, the DECM method proved more accurate than the EIS method for predicting birch wood MC above FSP. Based on the tests, it was concluded that DECM can be used in practice by applying a non-destructive method to reliably determine the average moisture content of a wood batch immediately prior to commencing the wood-drying process.

Key words: dielectric capacitance method, electric impedance spectroscopy, wood drying.

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Introduction

In drying wood, it is necessary to monitor the moisture content of the wood in order to control the drying process. It is particularly important to reliably determine the average moisture content (MC) of fresh-

ly sawn wood prior to commencing the wood-drying process in order to use a simulation program to assess the drying time, energy consumption, risk of cracks developing during the drying process and other changes in wood quality (Salin, 1990; Tamme, 2016).

DOI: 10.2478/fsmu-2021-0005

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In practice, the direct current (DC) electric resistance method (Stamm, 1927; Tamme *et al.*, 2012; Uwizeyimana *et al.*, 2020) for determining and monitoring wood moisture content is widely used, as it is an inexpensive and reliable method for use both at room temperature and in harsh kiln conditions (Gann, 2021; Scanntronik, 2021; Brookhuis, 2021; BES Bollmann, 2021; etc.). However, the main disadvantage of the DC resistance method is that the MC readings obtained by this method are not reliable above FSP (ca. more than 30% MC) (ASTM D4444-08, 2008; Tamme, 2016). The alternating current (AC) resistance method has proven approximately 14% more accurate than the DC method (Casans Berga *et al.*, 2019). The EIS method has been used for determining wood MC gradient (Tiitta *et al.*, 1999). The EIS method was used to monitor wood drying in combination with the acoustic emission (AE) method (Tiitta *et al.*, 2010). Another widely utilized method for determining wood MC is the dielectric capacitance method (DECM) (James *et al.*, 1985). This high-frequency capacitance method has also been called the microwave method. Previous research (Moschler, 2004) used the high-frequency (4–6 GHz) capacitance method to determine the average MC of wood in a kiln, leading to the development of a corresponding prototype calibrated into a moisture meter. In the case of the capacitance method, the prevailing geometry of the measuring capacitor (MEC) is a design with carefully electrically insulated flat parallel plates (Moschler, 2004; Tamme *et al.*, 2019). The advantage of the various technical applications of plate capacitor geometry is the simple calculation formula for electric capacitance (Zuleta, 2005):

$$C = \varepsilon \varepsilon_0 A / d \quad (1)$$

Where C is the capacitance of a parallel plate capacitor, A is the area of one plate in square meters, and d is the distance between the plates in meters. The constant

ε_0 is the permittivity of vacuum, and ε is the dielectric constant or relative dielectric permittivity. The dielectric constant ε depends on the moisture content of the wood placed between the MEC plates. According to formula (1), the electric capacitance C is proportional to the dielectric constant ε , hence the specific name of the method for determining the moisture content of wood – the dielectric capacitance method. For comparison: absolute dry (oven-dry) wood $\varepsilon = 4$, and water $\varepsilon = 80$ (Welling, 2010).

A flat ring capacitor for measuring wood MC below FSP (e.g., Brookhuis, (2020), FMW moisture indicator, 3.5 MHz operating frequency measured with an oscilloscope) and a flat slit capacitor (9.375 GHz operating frequency) for measuring wood MC both below FSP and above FSP have also been used (Johansson *et al.*, 2003).

The objective of our research was to test the MEC prototype developed for the paper in harsh conditions similar to those of a kiln in order to assess risks to the reliability of the MEC. The second objective was to use regression analysis to identify the possibilities of the DECM and EIS methods to establish the predetermined accuracy and to make a reliable determination of wood MC above FSP within the EIS operating frequency range of 1 Mz–10 Hz.

Material and Methods

The relationship between electric capacitance, the wood impedance modulus and average moisture content above and below FSP (FSP is agreed at 30% wood moisture content) was explored using a clear birch board with a thickness of 35 mm, width of 150 mm and length of 470 mm.

The moisture content of the birch wood specimen was varied by means of a specially developed laboratory drying schedule (Tamme *et al.*, 2013). The drying schedule ensured that during the first drying phase (at constant speed), the drying curve decreased linearly and moisture gradients

in the specimen were minimal.

The average MC of wood was determined by weighing the specimen at various randomly selected times using a precision weight with a resolution of 0.1 g. After weighing the specimen at the same average MC, other necessary measurements were also carried out as quickly as possible, such as measurements of the wood electric capacitance and wood impedance. In the final stage of the tests, the dry weight of the specimen was determined by drying it at 103°C. The actual moisture content of the specimen (relative to its dry weight) at the moment of weighing was identified according to ISO 3130:1975 (1975) standard.

An improved version of the parallel plate MEC was developed to determine the electric capacitance of wood at different moisture levels above FSP, compared to that used in our previous paper (Tamme *et al.*, 2019); its circuit diagram is shown in Figure 1(a) and the MEC with the measured specimen is shown in the photograph in Figure 1(b).

The cubic measure between the MEC plates was chosen at about 10% larger than the cubic measure of the specimen. This difference between the cubic measures ensured the necessary slack (tolerance zone) for the specimen when it was replaced between the plates after each weighing. The MEC allowed for the possibility of separate and combined heating of the insulators and plates in the form of a film of water vapor in the climate chamber to study condensation on MEC structural elements and to remove static electric charges of triboelectric origin (Tamme *et al.*, 2019) in the system. Additionally, the developed parallel plate measuring capacitor prototype was tested in conditions similar to kiln climate in the FEUTRON climate chamber (Feutron Klimasimulation GmbH, 2021). The tests were conducted at a temperature of 50°C and at a maximum relative air humidity (RH) of 98%. The purpose of the tests was to check the reliability of the measuring capacitor in the harsh kiln climate and to eliminate the

Figure 1. (a) Circuit diagram of the measuring capacitor (MEC) and (b) photograph of the MEC prototype with the tested birch wood specimen. 1 – signal connector, 2 – capacitor plate, 3 – wood specimen, 4 – capacitor insulator, FRA – frequency response analyzer, 5 – triboelectric charge collector, 6 – film insulator, 7 – heating cable, 8 – heat insulator.

occurrence of water vapor saturation and condensation of humidity on the measuring capacitor plates and insulators.

According to literature (Moschler, 2004), the microwave measuring capacitor prototype with parallel plates was tested at room temperature and at temperatures of 40°C and 60°C. Moschler (2004) contains no data on the relative humidity in the chamber during the tests, which is an important climate parameter. The measurements of electric capacitance present-

ed in this paper were carried out using the LCR55 (Wavetek Meterman, 2021) capacitance meter (CAM). The LCR55 capacitance meter has an operating frequency of 1,000 Hz as measured with an oscilloscope.

Wood impedance was measured using stainless steel insulated pin electrodes made by the company Gann (Gann 2021), which were nailed into the wood across the grain at a spacing of 30 mm (Brookhuis Micro-Electronics, 2009). The nails were driven to a depth of 1/3 of the thickness of the wooden material (Welling, 2010), which is about 12 mm from the board surface for a 35 mm board thickness. After each impedance measurement, the electrodes were nailed into the next randomly selected location on the board and at the same depth from the surface of the board. The impedance modulus of the measured AC complex electric resistance was calculated on the basis of impedance spectrometry (EIS) measurement data using EIS standard formulas (Krause, 2003; Tammé *et al.*, 2019). Each time, the impedance modulus was determined when the EIS spectrum phase angle had a minimum (ca. 4 to 5 degrees) value. An AUTOLAB PGSTAT 408N impedance analyser with NOVA 1.8 software was used (Metrohm Autolab, 2021).

Interference with the reliability of the measuring capacitor in conditions similar to harsh kiln climate (that is, imitated in a laboratory climate chamber) was also recorded using impedance spectra and processed with the NOVA 1.8 software using the circle-fit analysis tool. To do so, frequency scanning between 1 MHz and 10 Hz and the electric sine wave amplitude of 50 mV were applied.

The possible effect of static electricity on the measurements taken by the measuring capacitor was first investigated indirectly using Keithley's model 6517B with an electrometer (Keithley, 2004) and then directly for potentials safe for the instrument (up to 0.9 V) using LCR55 (Tammé *et al.*, 2019).

Statistical processing of the test results was based on the principles of a metrology standard ISO 3534-1:1993 (1993) and carried out with software R (R Core Team, 2010), MS Excel and NOVA 1.8. In the case of Student t-distribution and linear regression for the single measurement, the upper and lower tolerance lines (confidence limits) of the regression line are presented in MS Excel at 95% confidence level as follows (Kiviste, 1999):

$$\text{Intercept } b_0 \text{ lower} = b_0 - TINV(\alpha; n - 2) * s_{b_0} \quad (2)$$

$$\text{Intercept } b_0 \text{ upper} = b_0 + TINV(\alpha; n - 2) * s_{b_0} \quad (3)$$

$$\text{Slope } b_1 \text{ lower} = b_1 - TINV(\alpha; n - 2) * s_{b_1} \quad (4)$$

$$\text{Slope } b_1 \text{ upper} = b_1 + TINV(\alpha; n - 2) * s_{b_1} \quad (5)$$

Where s_{b_0} and s_{b_1} are the standard errors of the regression line intercept and slope (Kiviste, 1999).

The following formulas were used to estimate the standard error (SE) and the average root-mean-square error (RMSE) of the regression model:

$$SE = \sqrt{\frac{1}{(n-2)} \sum_{i=1}^n (y_i - \hat{y})^2} \quad (6)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y})^2} \quad (7)$$

Where y_i = the estimated values and $\hat{y}$ = the actual values.

The non-parametric Kolmogorov-Smirnov test and the Shapiro-Wilk test (Tamme *et al.*, 2014) were used in the R software environment to estimate the reliability of the regression models.

Results and Discussion

Changes in electric parameters caused by water vapor condensation were measured using the LCR55 and the EIS method.

Effect of water vapor condensation on MEC plates

Figure 2. The dependence of MEC useful capacitance and parasitic capacitance caused by water vapor condensation on MEC plates on the actual average moisture content of wood in the same coordinate grid. The upper curve in the figure represents parasitic capacitance, and the lower, useful capacitance.

Figure 3. Increment of parasitic capacitance due to condensation of water vapor on MEC plates at varying wood moisture levels.

The parasitic capacitance of condensation observed on MEC plates (indicated as C_{parasite} in Table 1) and the useful capacitance are shown on the same axis in Figure 2, depending on the average moisture content of wood. The EIS method allowed the development dynamics of the condensation process to be monitored (Figure 4, a) and b)) and the quantitative parameters for the electric capacitance C_{parasite} to be calculated.

Figure 3 shows the relative time increments of the parasitic capacitance of condensation on the MEC plates at different wood average moisture levels recorded using the capacitance meter (CAM) LCR55. Both the EIS method and the LCR55 show a similar magnitude for the parasitic capacitance on the MEC plates ($C_{\text{parasite}} = 660$ pF and $C_{\text{parasite}} = 800$ pF, respectively). Based on Figure 3, it may be concluded that the higher the average MC of wood, the greater the value of parasitic capacitance due to water vapor condensation. Parasitic capacitance of approximately 5 times the useful capacitance may completely obscure the correct useful capacitance measurements under conditions favourable for water vapor condensation.

Leakage effect of MEC insulators

The leakage effect of the insulators is characterized by the occurrence of parallel resistance of the condensed water film on the insulators in addition to parasitic capacitance, which shunts the resistance of the insulators. The MEC insulator resistance in normal operation is approximately 10 giga-ohms or greater. The circle-fit analysis found that in the initial phase of leakage, the parallel resistance of a leaking insulator is $R_p = 61$ kOhm and its parasitic capacitance is $C_s = 163$ pF, whereas $R_p = 0.78$ kOhm and $C_s = 681$ pF in the final phase of the leakage.

MEC static charge effect

Figure 5 shows the dynamics of electrostatic charge formation when placing the birch

Figure 4. Impedance spectra of leakage of MEC insulators: (a) Start phase of the leakage and (b) End phase of developed leakage.

wood specimen between and removing it from the MEC plates. This procedure was repeated 15 times. A measurement interval of 0.1 seconds was used. In Figure 5, one maximum of impulse voltage generated by static charge corresponds to each cycle of placement and removal of the specimen between the MEC plates. Maximum values (or peaks) with negative potential were predominantly recorded. Because the potential was measured from the electrostatic charge removal system (see Figure 1), the wood itself was oppositely charged; that is, predominantly positive. The potential of electrostatic charges generally decreases when the movement of the specimen in relation to the MEC ceases. However, this

Figure 5. Dynamics of the potential for static electric charges of triboelectric origin when the birch wood specimen is placed between and then removed from the MEC plates.

is not always the case, as Figure 5 shows an exceptional peak where the potential remains high (ca. 10 V) for a considerable time (ca. 30 seconds). The triboelectric potential peak may exceed the CAM LCR55 safe input voltage (up to 0.9V) by about 10 times.

MEC temperature effect

In previous research (Moschler, 2004), the electric capacitance of the measured wood was found to increase slightly with the increase in wood temperature. The same tendency was confirmed in our previous paper (Tamme *et al.*, 2019). In this current study, the measured increase in electric capacitance of MEC with oven-dry wood was from room temperature of 23°C to 105°C: 121 pF to 124 pF. Thus, the effect of temperature on the electric capacitance of oven-dry wood is negligible (only 3 pF) and may be disregarded in a rough approximation. The minor effect of temperature on the capacitance method is also highlighted in industry guidelines (Welling, 2010). On the basis of the above, it was concluded

that due to its low temperature sensitivity, the DECM could be used in practice immediately prior to the start of the wood-drying process by a non-destructive method to reliably determine the average moisture content of the wood batch for the wood drying simulation program.

In addition, an important trend that emerged during testing must be pointed out: namely, condensation effects that obscure the useful capacitance of MEC predominate when the air RH in the climate chamber is higher than 60%, but electrostatic charges occur often on the MEC when the air RH in the climate chamber is lower than 60%.

To summarize, the various physical characteristics and effects influencing the electric capacitance of the MEC are presented in Table 1. Based on the data in the bottom row of Table 1 (useful capacitance), it can be concluded that the DECM in the range below FSP (0–30% MC) is about 8 times more sensitive per percent of MC compared to the range above FSP (30%–105% MC).

Table 1. The main physical reliability characteristics of the dielectric capacitance method (DECM) in kiln climate and the corresponding capacitance meter (CAM) response.

Effect, parameter, figure no.	Effect range	CAM response
Condensation of water vapor on MEC plates, Fig. 2, 3	$C_{\text{parasite}} = 340 \text{ to } 845 \text{ pF}$ $C_{\text{parasite}} = 681 \text{ pF}$, determined using EIS method	CAM reading recorded ca. 5x and moderately increasing**
Leakage of MEC insulators, Fig. 4	$C_{\text{parasite}} = 163 \text{ to } 681 \text{ pF}$ $R_{\text{parallel}} = 61 \text{ to } 0.778 \text{ k}\Omega$	Floating of CAM reading
Triboelectric charges on MEC plates, Fig. 5	$U_{\text{static}} = -10.5 \text{ to } 4.29 \text{ V}$	Floating of CAM reading, CAM spoilage risk
Useful MEC capacitance, * below FSP (0.% to 30%) Useful MEC capacitance, above FSP (30% to 105%)	$C_{\text{useful}} = 121 \text{ to } 205 \text{ pF}$ $MC = 0 \% \text{ to } 30\%$ $C_{\text{useful}} = 205 \text{ to } 231 \text{ pF}$ $MC = 30\% \text{ to } 105\%$	CAM reading stable and reliable

* Useful MEC capacitance depends on the moisture content of wood and the thickness of the wood material according to the MEC, formula 1. Wood moisture content is related to the dielectric constant ϵ in formula 1.

** "Moderately increasing" means that it is possible to manually retrieve a CAM numerical reading, but it slowly increases as the water vapor condensation progresses (see Figure 3).

Useful capacitance of MEC and dielectric capacitance modelling

Useful capacitance is defined as the measured capacitance of MEC with wood, which excludes interfering effects, such as condensation on MEC plates, leakage of MEC insulators and the presence of static charges on MEC plates. Our previous paper (Tamme *et al.*, 2019) indicated that useful capacitance also depends significantly on the selected CAM operating frequency, while being higher in the low frequency range. However, low frequencies proved more sensitive to the effect of water vapor condensation.

For useful capacitance only, it would be reasonable to establish a statistically reliable correlation (generally a linear regression model) between the actual (i.e., determined by weighing) average moisture content of wood and the moisture content predicted by the capacitance method or, in other words, to statistically model the capacitance method. The methodology for modelling the EIS method does not differ from modelling the capacitance method.

Comparatively, the results of modelling the capacitance method and the EIS method are presented in Table 2 and Figures 6, 7, 8, 9, 10, 11.

Formulas in Table 2 and Figure 11, which connect various methods, are presented according to the needs of the wood drying practice. The model RMSE or SE, the p-value and the coefficient of determination R^2 mainly attract theoretical interest. Wood drying practitioners are primarily interested in two issues based on the modelling results: whether a single measurement fall on the 95% confidence level within the desired measurement precision range, and if not, how many repeated measurements are required in the series of measurements in order to achieve the desired prescribed precision. A series of measurements is defined as a certain number (k) of measurements repeated and arithmetically averaged at close moments in time under the same testing conditions (Brookhuis, 2020; Laaneots & Mathiesen, 2006). The Rozema quality criterion was used to define the prescribed measurement accuracy, according to which the standard uncertainty of the wood moisture meter reading must be less than or equal to 3.5% MC (Rozema, 2010). The individual measurement tolerance interval calculated on the Student t-distribution assumption based on formulas 2, 3, 4 and 5 should represent extended uncertainty in metrology

Table 2. Modelling results of the dielectric capacitance method (DECM) and electric impedance spectrometry (EIS) method. In regression models, the independent x -variable is the actual MC (%), and the dependent y -variable is the predicted MC (%). The predicted single measurement tolerance bands on the 95% confidence level, y_{upper} and y_{lower} , are calculated using formulas 2, 3, 4 and 5. The SE is calculated according to formula 6. The tolerance interval (TI) is calculated using the formula $TI = y_{upper} - y_{lower}$. N is the number of measurements repeated under the same test conditions and k is the number of measurements averaged per series of measurements (i.e., the averaging period). For models with a series of measurements (k), the identification type shall be “multiple”.

N obs., k -period	Method type, Fig. no.	Equations for predicting single measurement tolerance bands and TI	R^2	p-value and tests*	SE
$N = 63$	DECM (above FSP), Fig. 6	$y_{upper} = 1.0131x + 5.9063$ $y_{lower} = 0.9406x + 0.8399$ $TI = 0.0728x + 5.075$	0.97	<0.01 K-S	4.88
$N = 42$	DECM (below FSP), Fig. 7	$y_{upper} = 1.0135x + 0.2792$ $y_{lower} = 0.9788x - 0.1954$ $TI = 0.0348x + 0.4746$	0.99	<0.01 K-S S-W	0.61
$N = 63$ $k = 16$	DECM (above FSP) (multiple), Fig. 8	$y_{upper} = 1.006x + 0.44$ $y_{lower} = 0.9929x - 0.4163$ $TI = 0.0124x + 0.8775$	0.99	<0.01 K-S S-W	0.46
$N = 63$	EIS (above FSP), Fig. 9	$y_{upper} = 0.9448x + 11.196$ $y_{lower} = 0.787x + 2.41$ $TI = 0.1622x + 8.135$	0.87	<0.01 K-S	5.01
$N = 63$ $k = 16$	EIS (above FSP) (multiple), Fig. 10	$y_{upper} = 1.0134x + 1.728$ $y_{lower} = 0.968x - 0.84$ $TI = 0.0365x + 2.836$	0.99	<0.01 K-S	0.867

* Kolmogorov-Smirnov (K-S) test and Shapiro-Wilk normality (S-W) test

Figure 6. DECM modelling at wood moisture levels above FSP.

Figure 7. DECM modelling at wood moisture levels below FSP.

Figure 8. DECM modelling at wood moisture levels above FSP, multiple ($k=16$) model.

Figure 9. EIS modelling at wood moisture levels above FSP.

Figure 10. EIS modelling at wood moisture levels above FSP, multiple ($k=16$) model.

Figure 11. Comparison of the tolerance intervals (TI) predicted for single measurements of different models (using formulas in Table 2) and with the Rozema quality criterion at wood moisture levels above FSP. Corresponding graphs of the predicted TI are given from top to bottom as follows: EIS, DECM, EIS multiple, Rozema quality criterion (dashed line, parallel to x-axis), and DECM multiple.

terms (Laaneots & Mathiesen, 2006). Thus, equating the Rozema 3.5% MC quality criterion with the tolerance interval in this study actually makes the Rozema criterion somewhat more stringent. In Figure 11, the Rozema criterion is marked with a dashed line parallel to the x-axis.

In Moschler's paper (2004) it was found that the actual MC point of 28.60% of the high frequency capacitance method (4.5 to 6.0 GHz) is estimated to have a predicted expanded uncertainty of $\pm 3.62\%$; thus, the corresponding tolerance interval for this point is 7.24% MC. In comparison, a tolerance interval of 7.26% MC calculated for the same actual MC point of 28.60% was found in this study for the low-frequency capacitance method (see Table 2, second row), using the relevant formulas. Therefore, the consistency of repeated (reproduced) measurements in different laboratories and under different test conditions is surprisingly good. In another paper (Johansson *et al.*, 2003), an RMSEE of 12.52% MC was found for the high-frequency (9.375 GHz) capacitance method for above FSP, and of 0.74% MC for below FSP. This

study found SE values that were very close to the RMSEE, as is shown in Table 2 (see formulas 6 and 7): above FSP SE it was 4.88% MC and below FSP SE it was 0.61% MC. Thus, below FSP the numerical data are comparable, but above the FSP range, the low-frequency capacitance method used in this study provides results that are twice as good as those achieved with the model residual error.

In our research, comparable experiments for the dielectric capacitance and EIS method were conducted under the same test conditions and for the same tree species (birch). In addition, 16 arithmetic averages in a single series of measurements were modelled in the MC range above FSP. The compared results are presented in Figures 6, 7, 8, 9 and 10 and in Table 2. Figure 11 shows that there is a tendency for the tolerance interval (TI) of a single measurement to increase in proportion to the increase of the actual MC, though the increment is different for each model. The results of the modelling summarized in Figure 11 also show that in the actual MC range (30–150%), the Rozema quality

criterion cannot be met either by a single measurement performed with the capacitance method or by a single measurement performed with the EIS method. Using a series of 16 measurements, only the capacitance method can meet the Rozema quality criterion in the actual MC range above FSP (30–150%), whereas the EIS method fails to do so. However, according to Table 2 (row 5), the SE of the EIS method is lower than the Rozema quality criterion ($SE = 0.867$). Consequently, by increasing the number of measurements (k) to more than 16, it is likely that the Rozema quality criterion can also be met in the case of the EIS method. The wood moisture meter with the recently patented electric charging effect (polarization-type) may prove promising for use in the harsh climatic conditions of a kiln (Tamme *et al.*, 2020). The patented polarization-type wood moisture meter has basically the same reliability as a conventional resistance-type moisture meter given how it is calibrated, but could meet the Rozema quality criterion with just one measurement based on the modelling results (that is, without the series of 16 repeated measurements) (Tamme *et al.*, 2021).

The reliability of the regression models in Table 2 was verified by the Kolmogorov-Smirnov and Shapiro-Wilk non-parametric test of regression residuals in the program R environment, in accordance with the methodology used in a previous paper (Tamme *et al.*, 2014). All the models given in Table 2 passed the Kolmogorov-Smirnov test (marked as “K-S” in the table). The DECM (below FSP) and the DECM (above FSP, multiple) passed the more stringent Shapiro-Wilk normality test (marked as “S-W” in Table 2).

Conclusions

The DECM was found to be less reliable than the EIS method for use in harsh kiln climate. The dielectric capacitance method will require more development in the fu-

ture so that it can be reliably (i.e., without the risk of parasitic capacitance and static charges) used in harsh kiln conditions. However, testing of the DECM and the EIS method under the same test conditions and comparing the modelled test results according to the Rozema quality criterion showed that the dielectric capacitance method exhibits higher accuracy in the MC range above FSP. The DECM of low sensitivity to temperature may prove promising in practice, if the purpose is to quickly and reliably determine prior to the start of the drying process the average moisture content of a wood batch for the wood drying simulation program using a non-destructive method.

Acknowledgements. This work was supported by the Environmental Investment Centre of Estonia (Grant No. 16200).

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Puidu niiskussisalduse määramise kahe vahelduvvoolu meetodi katsetamine puidukuivati tingimustes

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Kokkuvõte

Selles artiklis uuriti kahte erinevat vahelduvvoolu meetodit puidu niiskussisalduse määramiseks. Dielektrilise mahtuvusmeetodi (lühidalt *mahtuvusmeetod*) korral asetatakse puit, mille niiskussisaldust määratakse, omavahel, ja ühtlasi uuritavast puidust elektriliselt isoleeritud metallplaatide vahele. Moodustub nn. mõõtekondensaator, milles puit täidab dielektriku rolli. Plaatide vahelise elektrimahtuvuse mõõtmiseks rakendatakse plaatidele vahelduvpinge. Puidu niiskussisaldus muudab dielektriku (antud juhul puidu) elektrilisi omadusi, ning seetõttu muutub ka mõõtekondensaatori elektrimahtuvus, mis mõõdetakse ja seostatakse mõõtemudelil ehk kalibreerimismudelil puidu niiskussisaldusega. Teise vahelduvvoolu meetodi, elektrilise impedantsi spektromeetria meetodi korral antakse vahelduvpinge otseselt puitu sisestatud roostevabast terasest või süsinikkiust nõoelektroodidele, ja mõõdetakse puidu elektrilist kogutakistust (impedantsi), seejärel koostatakse vastav mõõtemudel puidu niiskussisalduse määramiseks.

Elektrilise impedantsi spektromeetria ja mahtuvusmeetodi kasutamise võimalusi on üheaegselt üle kiu küllastuspunkti

puidu niiskussisaldustel ja puidukuivati karmides kliimatingimustes suhteliselt vähe uuritud. Selle uurimuse raames tehti mahtuvusmeetodi kalibreerimiseks kasutatud mõõtekondensaatori prototüübi töökindluse katsetused puidukuivati karmi sisekliima (50°C ja 98% RH) tingimustes. Uuriti veeauru kondenseerumist mõõtekondensaatori plaatidel, plaatide isolatorite lekkimist ja staatiliste elektrilaengute tekkimist plaatidel. Mõõtekondensaatori töökindlust häirivate efektide jaoks leiti iga efekti poolt esile kutsutud parasiitmahtuvustele kvantitatiivsed vahemikud. Leiti, et mahtuvusmeetod on puidukuivati karmides kliimatingimustes kasutamiseks vähem töökindel kui elektrilise impedantsi meetod. Samuti modelleeriti võrdlevalt samades katsetingimustes ja sama puuliigi (kask) korral mahtuvusmeetodi ja elektrilise impedantsimeetodi võimalusi etteantud Rozema kvaliteedikriteeriumiga $\pm 1.75\%$ kasepuidu niiskussisalduse ennustamiseks üle puidu kiu küllastuspunkti niiskussisaldustel. Samades katsetingimustes osutus kasepuidu niiskussisalduse ennustamisel üle kiu küllastuspunkti puidu niiskussisalduste piirkonnas mahtuvusmeetod täpsemaks kui elektrilise impedantsi meetod.

Received August 23, 2021, accepted October 04, 2021