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Dielectric properties of hops – an effect of bulk density

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Abstract

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Continuous detection of basic physical properties of freshly picked and cleaned wet hop cones would be very helpful for better control and automation of harvesting processes. That is why the main aim of this article was to determine the effects of bulk density changes on dielectric properties of freshly picked hop cones. Relative permittivity and loss factor were measured using a newly developed capacitance measuring device. A strong linear correlation between fresh hops relative permittivity and bulk density was found. This finding could be used e.g. for consequent hop drying process control. Significant differences between tested hop varieties were observed for both relative permittivity and loss factor measurements. These differences cannot be explained only by a slightly different moisture content of the measured varieties and ambient temperature changes. Measured material loss factor was only slightly affected by bulk density changes. However, relative permittivity was affected by bulk density changes significantly. These facts could be used for other properties of wet hop cones estimation.

Keywords: fresh hop cones; relative permittivity; loss factor; capacitance sensor

According to the information from the Food and Agriculture Organization of the United Nations (FAO 2016), the total quantity of hops harvested worldwide in 2014 was about 140,000 tonnes from an area of about 86,000 ha (http://faostat.fao.org), while both numbers are gradually increasing.

Hops are harvested at about 80% moisture content (wet basis) and are quickly dried to less than 12% moisture for storage (Thompson et al. 1985; Hofmann et al. 2013). According to Krofta et al. (2007), the optimum moisture content of dry hops is 8 to 12%. In the Czech Republic, the need for a continuous drier appeared when machine picking was introduced. At present, belt driers are preferred (Rybáček 1991). Rybáček (1991) also highlighted that technological factors involved in hop drying include hops layer thickness, the drying time interval and the speed of passage of the hops through different segments of the drier. Mejzr and Hanousek (2007) focused on the determination of drying parameters in hop belt drier and their optimization. Nowadays, the overall capacity of hop drying technologies in the Czech Republic exceeds its need. Therefore, modernisation and automation of existing drying technologies is preferred (Rybka et al. 2016).

Continuous detection of basic physical properties of wet hops entering the drier would be very helpful for better control and automation of a drying process. In this context, Nelson (2010) stated that the influence of dielectric properties on electric fields provides a means for sensing certain other properties of materials by nondestructive electrical measurements, which may be correlated with the dielectric properties.

Dielectric properties of agricultural materials depend on the amount of water, on the frequency of

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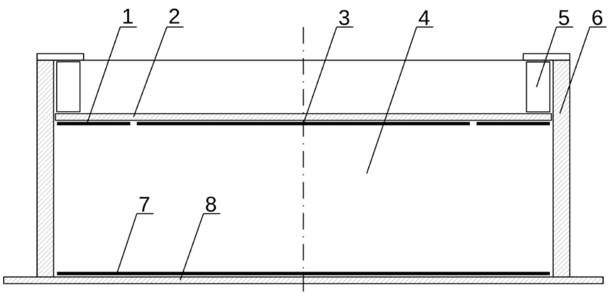

Fig. 1. Drawing of a novel device for the measurements of freshly picked and cleaned hop cones relative permittivity and loss factor in relation to material bulk density

1 – driven guard electrode, 2 – movable upper plate, 3 – upper measuring electrode, 4 – space for the tested material, 5 – cylindrical gauge, 6 – tubular frame, 7 – bottom measuring electrode, 8 – bottom PVC plate

the applied alternating electric field, on the temperature of the material and on the density, composition and structure of the material. In particulate materials, the bulk density also plays an important role (Nelson 2015). In our previous work (Kumhála et al. 2016) a non-destructive capacitance throughput sensor was successfully integrated in the PT-30 stationary hop-picking machine with the aim of a picking process control. The throughput of uncompressed loose-fill hops on a conveyor belt was determined with accuracy by this sensor. Nevertheless, wet hops entering the drier can be partly compressed.

Hence, the main aim of this article is to determine the effects of wet hops bulk density changes on dielectric properties of hops. Knowledge of these effects is essential for correct detection of wet hops basic physical properties or chemical composition by non-destructive methods.

MATERIALS AND METHODS

All experiments were carried out during four days of the 2015 harvesting season in the Hop Research Institute Co., Ltd., Saaz, farm Stekník (CR). Measurements were made in the hall where the stationary hop-picking machine is placed. Measurement days, tested hop varieties and ambient air temperatures are provided in Table 1.

For the purpose of hop material objective characteristics testing, at least three samples were taken from each measured variety and the moisture content of wet hop material was determined using the ASABE Standard S358.2 (2008) as an average from those samples.

It was decided to measure relative permittivity and loss factor of the fresh hop materials (cleaned hop cones transported away from hop-picking machine), both in relation to material bulk density. A special measurement device was newly developed for this purpose. The drawing of this device is shown in Fig. 1.

This measuring device works as a parallel plate capacitor with circular shape. Main body of the capacitor is made as a PVC tubular frame with an internal diameter of 350 mm and a height of 140 mm. The bottom of the tubular frame is made from a PVC plate. Bottom measuring electrode (plate made from steel sheet 1.5 mm thick with the diameter of 340 mm) is glued to the upper part of the bottom PVC plate. Another upper PVC circular plate is inserted in the upper part of the tubular frame. The upper PVC plate can move freely inside the tubular frame. At the bottom part of the upper PVC plate, two electrodes are glued. The upper measuring electrode with the diameter of 260 mm is in the centre and the shielding, driven guard electrode with annular shape (inner diameter of 270 mm, outer diameter of 340 mm) is on the outer periphery of the upper PVC plate. The upper electrodes are also made of steel sheet 1.5 mm thick. The distance of the upper PVC plate from the tubular frame top edge is adjustable by means of three cylindrical gauges with different length. The whole construction is placed on a wooden frame. The photography of this novel measuring device can be seen in Fig. 2.

Dielectric measurements were performed using a precision LCR meter 8110G (GW Instek, China). The electrical capacitance of the measuring capaci-

Table 1. Dates of measurement days, tested hop varieties and ambient air temperatures

Date	Hop variety	Ambient air temperature (°C)
August 26, 2015	ZPC (Saaz)	28
September 2, 2015	Premiant	23
September 8, 2015	Agnus	19
September 16, 2015	Sládek	27

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Fig. 2. A view of the design of a new capacitive device for the measurements of freshly picked and cleaned hop cones relative permittivity and loss factor in relation to material bulk density

tor and the loss factor at 1 V voltage and frequencies of 1 kHz, 10 kHz, 100 kHz and 1 MHz were measured using this device. Changes in material bulk density were simulated by incremental pressing of freshly picked and cleaned hop cones.

At the start of each particular measurement, hop cones were sprinkled in the tubular frame of the capacitor filling all its volume. Then, hop cones were slightly pressed by flipping the PVC plate with upper electrodes. In this initial state, the distance between upper and bottom measuring electrodes was 135 mm. This state corresponded only with minor compression of the sample (about 4%), which, however, was necessary to insure the contact between the electrodes. In subsequent measurement steps, each sample was gradually compressed by adding cylindrical gauges with the lengths of 20, 30, 40, 50, 60 and 70 mm. Bulk density ρ (kg/m^3) was then calculated using the formula:

$$\rho = 4m/d^2\pi h \qquad (1)$$

where: m – weight of the sample (kg); d – inner diameter of the measuring capacitor (m); h – distance between bottom and upper capacitor measuring plates (m)

Relative permittivity ε_r (F/m) was calculated using the formula:

$$\varepsilon_r = \frac{4C \times h}{\varepsilon_r d_e^2 \pi} \qquad (2)$$

where: C – measured electric capacity of the capacitor (F); $\varepsilon_0 = 8.85 \times 10^{-12}$ (F/m); d_e – diameter of upper measuring electrode (m)

For the purpose of data evaluation, the programming language Python 2.7 was used together with supporting libraries (NumPy 1.8.2 and Matplotlib 1.3.1).

RESULTS AND DISCUSSION

Measured moisture contents of all tested samples are provided in Table 2. As it can be seen in this table, material moisture content values ranged from 72.9 to 77.7%. However, for individual varieties, moisture contents varied of 2.1% in maximum.

Graphs in Fig. 3 show the relationship between relative permittivity and bulk density. Each of the four graphs in Fig. 3 displays the results obtained for one of the tested hop variety. Linear dependence was chosen to describe the type of this relationship. The coefficients of determination exceeded the value of 0.95 in most cases. Only in the variety Premiant, evaluation obtained coefficients of determination ranged from 0.88 to 0.92. It can be stated that very good linear relationship between relative permittivity and bulk density was found, regardless the measuring frequency used. This finding could be used for fresh hop cones physical properties measurements e.g. for drying process control purposes. The observed variation was very probably caused mainly by slightly different moisture contents of samples (Table 2) and ambient temperature (Table 1). In the case of evaluating one sample only, the calculated coefficients of determination reached values more than 0.98 including the Premiant variety. Nevertheless, it is necessary to note here that the relationship between relative permittivity and bulk density is generally nonlinear

Table 2. Moisture contents (%) of the tested samples

Hop variety	Sample 1	Sample 2	Sample 3
ZPC (Saaz)	75.7	76.1	76.6
Premiant	75.6	75.6	77.7
Agnus	72.9	73.0	74.2
Sládek	77.3	77.4	76.4

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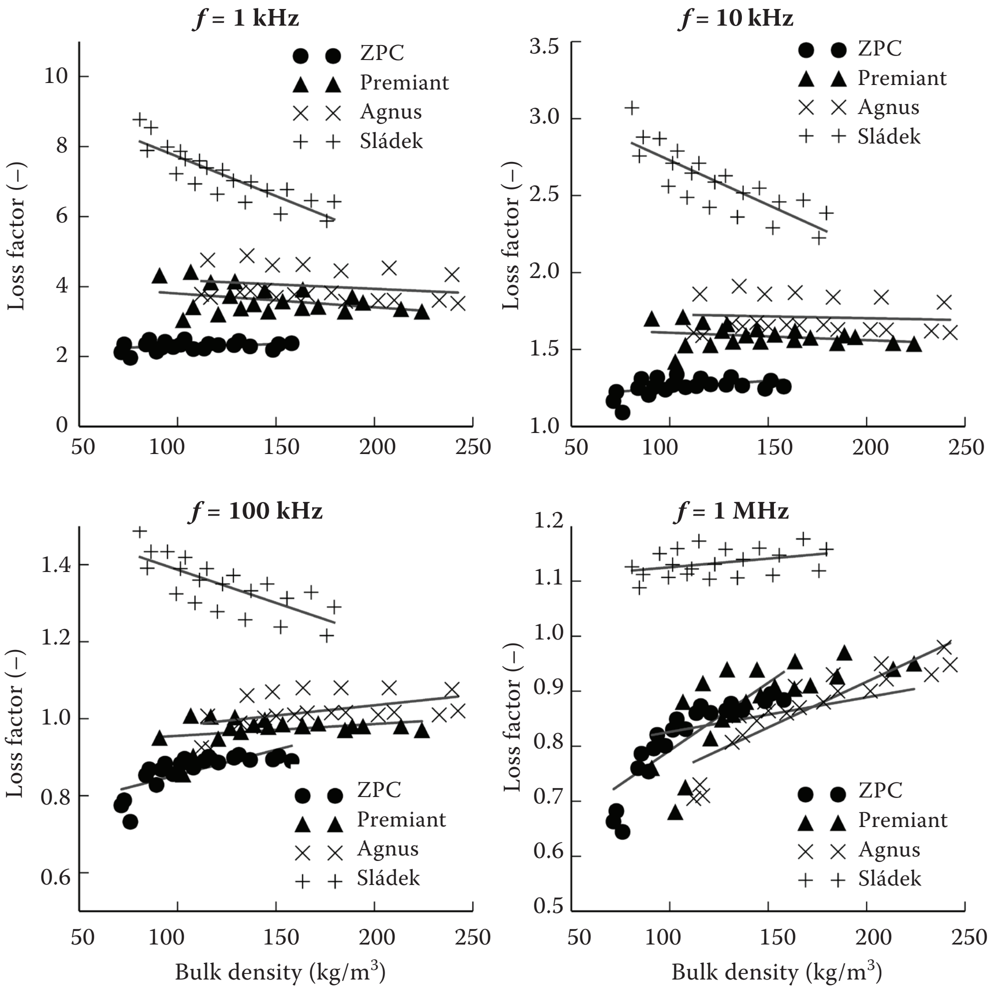

Fig. 3. The dependence of relative permittivity on freshly picked and cleaned hop cones bulk density for 1 kHz, 10 kHz, 100 kHz and 1 MHz frequencies. Coefficients of determination for varieties at 1 kHz frequency are as follows: 0.98, 0.92, 0.98, 0.98; at 10 kHz: 0.98, 0.89, 0.98, 0.95; at 100 kHz frequency: 0.99, 0.88, 0.98, 0.97; at 1 MHz: 0.99, 0.88, 0.99, 0.97 for varieties ZPC, Premiant, Agnus and Sládek, respectively

for the materials such as hop cones (Nelson, Trabelsi 2012). The observed dependencies charted in graphs in Fig. 3 are linear very probably because a relatively short interval of changes in bulk density was investigated during our measurements.

In accordance with the known behaviour of plant materials, measured relative permittivity decreased with increasing frequency. Relative permittivity in the range from 500 to 2,300 was observed at 1 kHz measuring frequency while the range observed at 1 MHz was from 20 to 110. However, it should be added that relative permittivity at frequencies from 1 to 10 kHz can be affected (increased) by electrode polarization effect (Oh et al. 2007).

The differences between the results for different tested varieties are also clear from the graphs in Fig. 3. These differences can be explained by different moisture contents and ambient temperature of the measured material; however, these facts themselves are probably not enough to explain such big differences observed between varieties. Also another factors, such as material structure or chemical composition, affected this behaviour with high probability (Nelson 2015).

The relationship between loss factor and bulk density of freshly picked and cleaned hop cones can be seen in Fig. 4. It is clear from Fig. 4 that in comparison with relative permittivity, the loss factor was much less affected by a change of bulk density. Relative permittivity increased from 4 to 7 times at doubling bulk density. In contrary, the change of loss factor at doubling bulk density was usually by about 20% only. Nevertheless, the differences between the observed hop varieties are also clear from Fig. 4.

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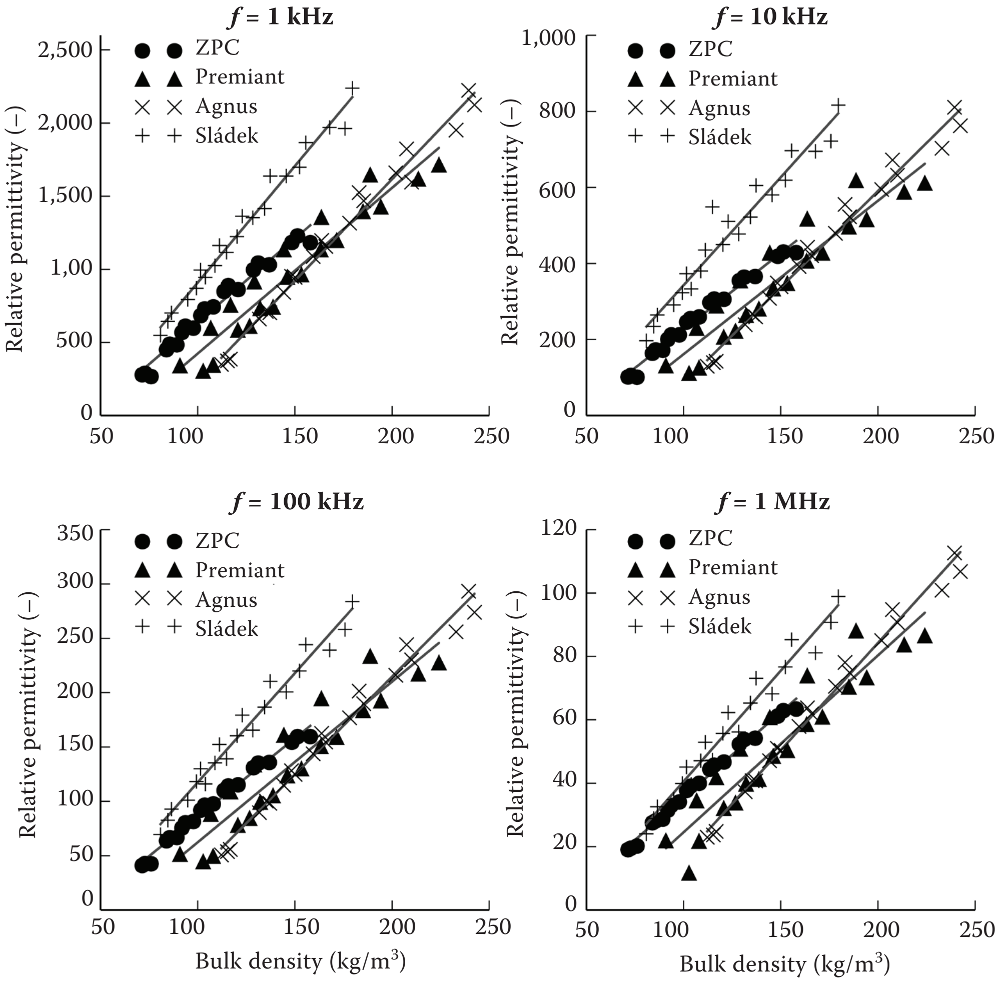

Fig. 4. The dependence of loss factor on freshly picked and cleaned hop cones bulk density for 1 kHz, 10 kHz, 100 kHz and 1 MHz frequencies. Coefficients of determination for varieties at 1 kHz frequency are as follows: 0.07, 0.15, 0.05, 0.77; at 10 kHz: 0.19, 0.07, 0.01, 0.68; at 100 kHz frequency: 0.53, 0.11, 0.23, 0.56; at 1 MHz: 0.74, 0.03, 0.78, 0.14 for varieties ZPC, Premiant, Agnus and Sládek, respectively.

The Sládek variety showed different behaviour compared to the other three varieties, independently of the measuring frequency. Measured values of loss factor were double for this variety in comparison with the others. This fact can be partly explained by different material moisture content, which resulted from 76.4 to 77.4 for this variety, whereas moisture contents for the ZPC and Premiant varieties were determined from 75.6% to 76.6% (in one case even 77.7%). Again, it is clear that the changes in material moisture content are not enough to explain the mentioned difference. In addition, more or less similar behaviour was observed in the case of the ZPC variety. Lower values of loss factor were measured for this variety and its behaviour was not correlated to the moisture content. Nevertheless, this deviation was not observed at the 1 MHz measuring frequency.

CONCLUSION

A very good linear relationship between relative permittivity and freshly picked and cleaned hop cones bulk density was confirmed by our measurements in the range of bulk densities from 70 to 250 kg/m^3. Coefficients of determination exceeded the value of 0.88 in all observed cases. Significant differences between the tested varieties were observed for both the relative permittivity and loss factor measurement. These differences may be affected by material moisture content and ambient

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temperature changes only partially. The composition of the measured material also very probably plays a significant role (especially in the case of loss factor). Measured material loss factor was only slightly affected by bulk density changes. However, measured relative permittivity was affected by bulk density changes significantly. This fact could be used for non-destructive measurements of different hop cones structural or chemical composition characteristics.

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