Needle electrodes for the measurement of DC and AC conductivity of potato

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Introduction

Electrical conductivy, as an easy measurable parameter of solid foods, is often used for different purposes. For example, in [1] the ac conductivity was exploited for studying the ohmic heating. Ohmic heating rates are critically dependent on the electrical conductivities of the foods being processed. The paper reports experiments to determine the changes in electrical conductivity which occur during ohmic heating of some common foods. A number of effects which occur during conventional heating, such as starch transition, melting of fats and cell structure changes, are shown to affect the electrical conductivity. Authors [2] used a constant voltage power supply in a static ohmic heating device. Conductivities of vegetable samples were increased by soaking them in salt solutions, while soaking in water resulted in reduced conductivity due to leaching of electrolytes. Conductivities under ohmic heating conditions increased linearly with temperature. When field strengths were decreased, the conductivity-temperature curve gradually became nonlinear, and under conventional heating conditions, a sharp transition was observed. Another examples of using electrical conductivities are described, for example, in [3, 4, 5, 6, 7].

Material and Methods

To measure the electrical conductivity of the food samples, some arrangement of electrodes must be used [8]. The most simple electrode system consists of two electrodes. Its disadvantage is the measuring the sum of the volume and surface currents which can not be separated in this case. But, if the dimensions of the electrodes and the sample are suitable chosen, the surface current is small and can be ignored. Of course, such arrangement is only for measurements where high precision is not required.

The basic arrangement represents two parallel electrodes with the area S and distance d between them. If the sample fills the all volume between the electrodes, the sample resistance is

$$R = \frac{1}{s}\frac{d}{S} \,, \tag{1}$$

where s is the conductivity of the sample material. Measuring the resistance by a suitable method, the conductivity can be determined. A contact between the sample and electrodes must be reliable during the measurement regardless of changing the sample dimensions as result of drying or heating. Therefore, the pressing force must be applied and is usually generated by a spring or by weight.

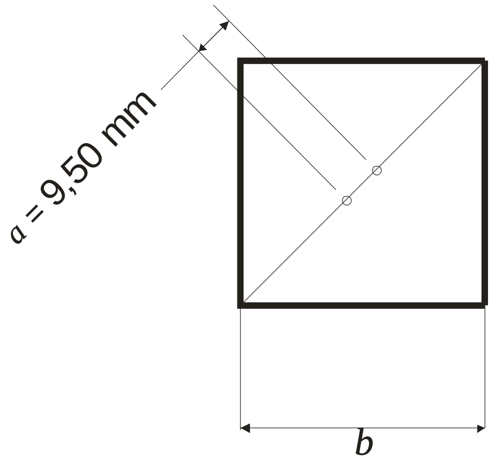

Fig. 1 Square shape of the sample with two electrodes in the center

In our research, we used two parallel electrodes made of Cu wire ∅1.3 mm with the distance a = 9.5 mm between them, as showed in Fig. 1.

In a literature, e.g. in [9], we can find a formula for a capacity between two parallel electrodes made of cylindrical wire. The formula can be transformed in to a resistance between the same electrodes using analogy between electrostatic field and current field. Putting $C \leftrightarrow 1/R$ and $e_0 \leftrightarrow s$ we obtain

$$R = \frac{1}{s}\frac{1}{p\,t\ln\dfrac{r}{a-r}} \quad , \tag{2}$$

where r is the radius of the electrodes, a is the distance between them and t is a thickness of the sample.

The formula (2) was derived at a condition, where the electrodes are located on the infinite plate, i.e. $b \to \infty$, see Fig. 1. A current field is symbolized by current filaments. The further from the electrodes the current filaments are the weaker is electric current in the filaments. The main part of the total current is transported by the shortest filaments which are close to the electrodes. If one wants to neglect the influence of the limited dimensions of the sample on the resistance R, the sample must be much larger than the distance between electrodes, i.e. $b >> a$. If not, a correction coefficient must be used.

Results and Discussion

According to our experience, an advantage of the needle electrode arrangement is

1. free escape of the water vapor from the all surface of the sample,
2. the electrodes are pressed by the sample material during drying, therefore the electrical contact is good without external pressing force.

To find a limit where neglecting the size of the sample is possible, we measured the resistance R as a function of the side of the square sample. In order to avoid electrolysis on the electrodes, we used AC voltage 27 V, 50 Hz. A simple volt-ampere method was exploited using two multimeters HM 8012 (Hameg, Germany) and transformer 230/27 V. The sample was stepwise cut to make its size lesser and lesser and the current was measured at the every size. The results are shown in Fig. 2. It can be seen that resistance becomes to be a constant if b > 33 mm. Therefore, for a ratio $b/a > 3.5$ the sample can be considered as infinite. In such case, we can use Eq. (2) for calculating the conductivity s of the sample material directly.

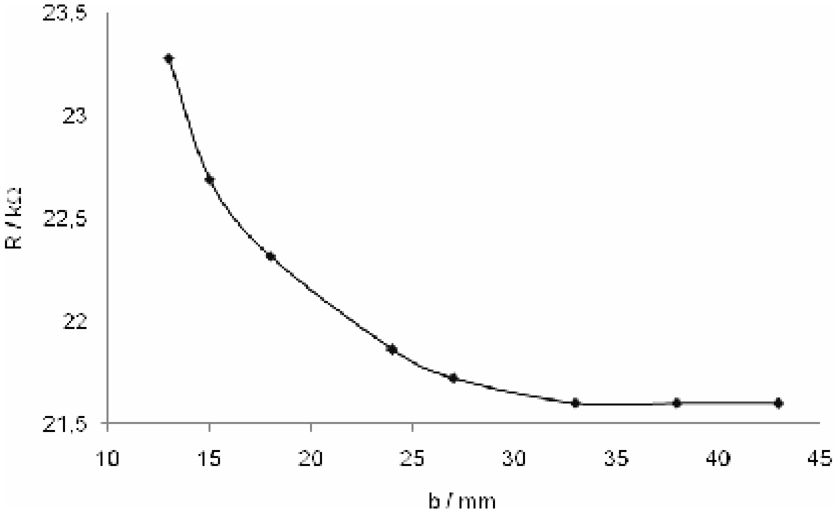

Fig. 2 Relationship between the resistance R and the side of the square

Acknowledgement

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