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Influence of corona wind on the convective wheat grain drying course**

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Abstract. The convective drying process is widely used despite its very low efficiency. For this reason there are studies searching for a better drying method or agents, which can increase process efficiency. The electric field and accompanying phenomena seem to be the agents that can change the convective drying course.

This paper presents test results on convective drying of wheat grain in the electric field and in the ionic (corona) wind. These phenomena accompanying an electric field, can generate electrostriction forces in the drying material (it can cause deformations inside grain) or change heat and mass transfer between the grain surface and the drying medium (the ionic wind).

The present study was carried out using an experimental test stand. The test stand allows to generate corona wind with a controlled corona current at constant values of the electric field intensity. Air velocity and temperature were fully stabilised, too. The measurement and recording processes were automated using a personal computer. Comparison between various drying courses recorded, allow to find an electric agent changing convection drying course.

Keywords: electric field, corona wind, convective drying

INTRODUCTION

Phenomena accompanying an electric field can change convective drying in different ways. They can change an internal structure of the dried material or/and heat and mass transfer between the grain surface and the drying air.

In 1983, Tarushkin pointed out a possibility of internal structure changes caused by an electric field. The internal structure changes can be caused electrostrictive forces, which tend to deform the internal structure. Electrostrictive forces can produce deformation inside the dried dielectric by stressing or stretching its particular layers. Deformation causes a change in mass density. Level of electrostriction forces depends mainly on the density of the drying material mass and electric field intensity. This kind of deformation can be reflected in the ability of moisture retention during drying (Tarushkin, 1983). The author of this hypothesis did not carry out any research on the practical application of this type of drying.

It is possible to calculate the volume of the electrostrictive forces by means of mathematical formulas created later on the basis of electrical grain properties and their shape (Baran, 1990; Mohsenin, 1984). Calculations show that the volume of electrostrictive forces is a few grades too low to cause macroscopic grain deformation but this does not exclude their influence on drying process. The author of mathematical formulas describing the volume of electrostrictive forces carried out drying tests. Dried grain was exposed to an electrostatic field before the beginning of the convection drying process. In conclusion, he stated that there were no effects on decreasing consumption of drying energy. It is not known whether there were any stresses in the grain (in the form of remanence) or whether they disappeared in the beginning of the drying process. It seems that this is the reason why the experiment did not show any changes in the grain ability for moisture retention.

During investigations (Pietrzyk and Krakowiak, 1991) carried out by another group of researchers, grain was dried in a drum drier and the dried grain was exposed to an electrostatic field for a whole drying process. The results of these experiments demonstrated a decrease in the ability to retain moisture in the grain exposed to an electric field during the whole period of drying. The researchers did not give as to which agent has changed the drying course: electrostrictive forces (internal structure changes) or corona wind (change of heat and mass transfer in the drying air).

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Basing on the above investigations, the authors of this paper directed attention to the role of corona wind. In a heterogenic electric field, the threshold voltage (the threshold voltage means the voltage which initiates electric discharge) is smaller than the breakdown voltage. If voltage applied to the electrodes is between the threshold voltage and the breakdown voltage, partial discharge occurs in the space between electrodes. This partial discharge is limited by the space with the highest electric field intensity. Free electrons and ions are generated in the space with the highest electric field intensity. This kind of discharge is called a corona discharge. Coulomb forces propel the generated ions towards the opposite electrode. The ions collide with other gas molecules. The result of this is a corona wind. The additional ion-drag force, increasing heat transfer, acting normally to the grounded electrode is (Sadek *et al.*, 1972):

$$F_c \cong \alpha \varepsilon A \left(\frac{V - V_0}{s} \right)^2 \quad \text{for } V > V_0 , \qquad (1)$$

where: F_c - ion-drag force, $F_c = 0$ for $V \le V_0$, N; α - numerical factor dependent on the system geometry (α=8/9 for parallel electrodes), ε - dielectric permittivity, F m^{-1}; A - area of the flat electrode, m^2; s - spacing between electrodes, m; V - electrode voltage (V_0 - threshold voltage below which ionic current is insignificant), V.

Basing on the earlier research and the test stand allowing to generate corona wind with a controlled corona current at a constant value of the electric field intensity, the present authors carried out grain drying tests. The objective of the test was to find an answer which corona wind is an agent changing the drying course.

TEST STAND AND PROCEDURE

During the experiments, a few kinds of capacitors were used. In the case of a pin matrix, the increased drying was observed. Construction of a capacitor allowed for the generation of corona wind. In the presented cases, the capacitor was equipped with:

- a flat lower electrode with the conducting surface placed inside, the upper electrode equipped with a pin matrix (Fig. 1a);
- a flat lower electrode with the conducting surface placed inside, the upper electrode equipped with a pin matrix and the grid electrode for the corona current regulation (Fig. 1 b). This capacitor allows to generate corona wind with a controlled corona current at a constant value of the electric field intensity.

Figure 2 shows simulated distribution of electric field intensity on the surface of the dried specimen for the mean electric field intensity 400 kV m^{-1}. This figure shows that the acting pin electrodes and grid electrodes allow to obtain electric field distribution on the surface of the dried sample close to uniform. The electric field intensity value changes by about 0.1 %.

The measurement capacitor was inside the drying chamber (Fig. 3). The drying samples of Roma wheat grain were placed on the lower electrode. The sample of wheat grain was formed at a single level. The longest grain axes were parallel to the electrode. The measurement capacitor was attached to the string of the balance. The electronic balance (type: Precisa 5000D -12000G, manufactured by "Oerlikon" AG, Switzerland) sent the information about the current mass of the dried sample to the computer. The electronic balance allowed for mass measurements with 0.1 % accuracy. The supply was DC high voltage (maximal voltage was 12 kV). The fan-heater was placed in the inlet of the chamber. The drying sample was artificially moistened up to 20 % (0.25 kg H_2O kg d.m.$^{-1}$). The moistening process was carried out in the climatic chamber and it lasted about 72 h.

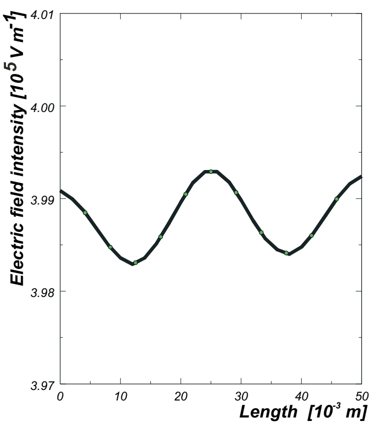

Fig. 2. Electric field intensity distribution on the surface of a dried sample in the capacitor to generate the corona wind at a constant value of the corona current.

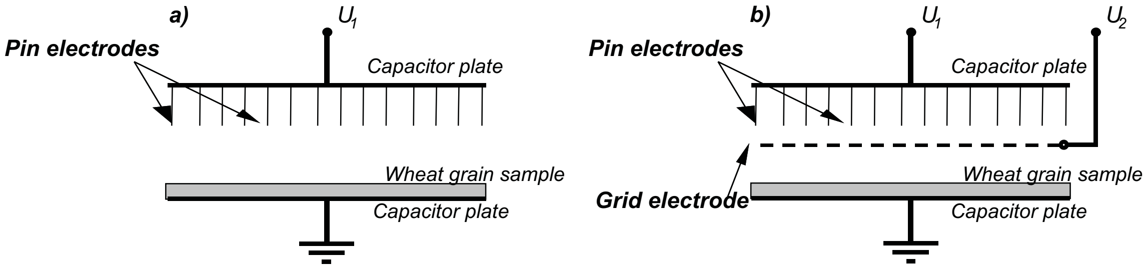

Fig. 1. Measurement capacitors: to generate the corona wind (a) and to generate the corona wind at a constant value of the corona current (b).

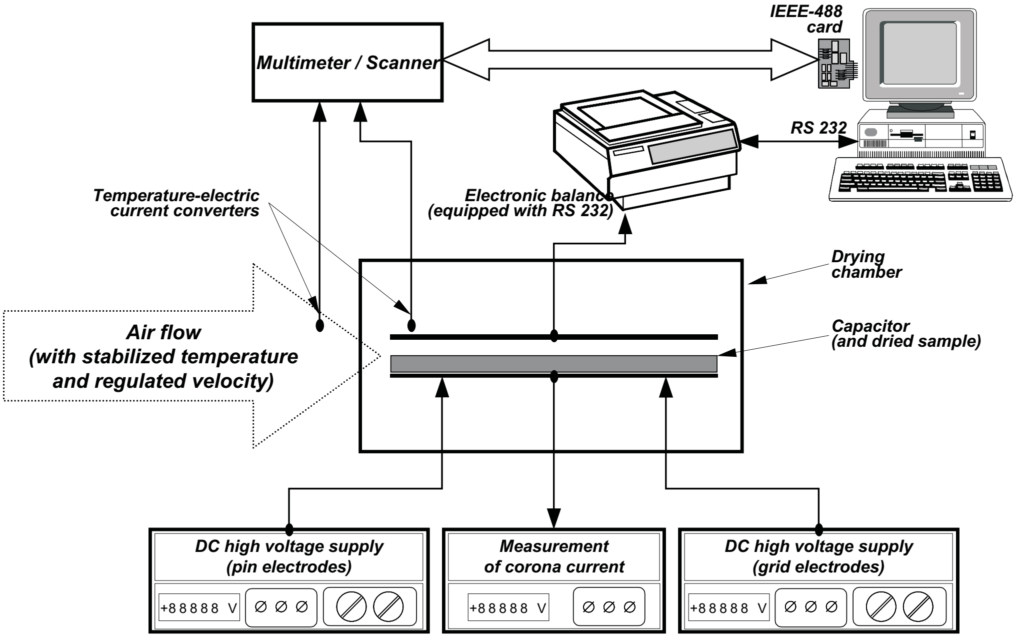

Fig. 3. Block diagram of the test stand.

The initial mass of each specimen was 100 g. Two series of drying were carried out each time. In one of them, the sample was exposed to the electrostatic field and in the other it was not. Each drying process lasted 1.5 h. The PC registered loss of vaporised mass of water every 2 min.

The following series of the measurements were carried out:

- in the configuration with the upper electrode equipped with a pin matrix and with the upper electrode equipped with a pin matrix and grid electrode,
- air velocity was 0.3 m s^{-1},
- range of mean field intensity was 0, 200, 300 and 400 kV m^{-1},
- range of air temperature was - 303, 313 and 323 K.

RESULTS

The drying process can be described using different groups of curves. The first group can be plotted directly on the basis of the registered vaporised water. The second group of curves consists of typical drying curves (moisture content in time), which are used in the drying technology. The third group of curves shows the rate of grain drying. This third group of curves seems to be the best to describe dynamics of the drying process. The presented groups of curves are selected from the whole measurement range and up to the temperature of 303 K. Other cases have similar courses.

Figure 4 shows the rate of drying in the capacitor equipped with a pin matrix (Fig. 1 a). The mass transfer augmentation is observed every time. In the first moment, the rate of vaporisation could be almost twice higher (~1.4 10^{-3} g s^{-1} at 0 kV m^{-1}, ~2.7 10^{-3} g s^{-1} at 0 kV m^{-1}). The drying augmentation effect decreases together with the drying time and the grain moisture decrease. Thus, it is impossible to talk about a simple dependence between the electric field intensity and acceleration of drying.

Analysis of the dependence between the rate of grain drying and electric field intensity requires taking under consideration corona wind (attending the electric field). The ratio of the corona wind can be corona current density. In the configuration from Fig. 1a, corona current density was calculated on the basis the lower electrode area. The value of the corona current came from the registered high voltage current. The value of the current density changes from 850

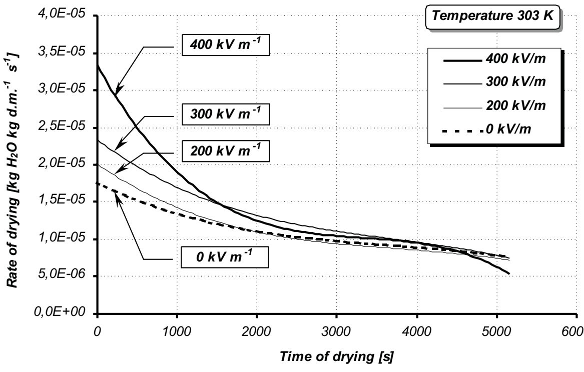

Fig. 4. Rate of drying of Roma wheat at a temperature of 303 K with a variable corona current.

μA m^{-2} at 200 kV m^{-1} through 5130 μA m^{-2} at 300 kV m^{-1} to 14700 μA m^{-2} at 400 kV m^{-1} (Fig. 5). It must be stressed, that the values are connected only with the initial part of the drying process. After some time, these values were decreasing. It means that the acceleration of water vaporisation was caused by the corona wind.

The corona current (or corona current density) can be the measure of partial discharge. This partial discharge occurs between the upper electrode of the capacitor and the drying sample. The cloud of positive ions, generated in the space between the electrodes, is attracted to the zero electrode. The effect of ion generation is shown in Fig. 6a, and the influence of moving ions on the drying surface (i.e., on the liquid surface) is shown in Fig. 6b.

The energy obtained by the electrons and ions, can be exchanged during collisions with neutral gas molecules. Introduction of moving ions to the drying air flow causes disturbances in the laminar layer. The airflow becomes more turbulent. The turbulence increases heat and mass exchange and changing speed of drying. The described mechanism shows why there was no effect of the influence of ionic wind at higher air velocity (i.e., 1.4 m s^{-1}).

In the configuration with controlled electric field intensity and constant corona current (Fig. 1b), drying curves had different courses (Fig. 7). In the conditions with a constant corona current, the initial rate of the removing water seemed to be more independent from the electric field intensity. The mass transfer was nearly the same, irrespective of the electric field intensity. Maintaining of the corona wind at a constant value, allowed to extend the influence of electricity on the whole drying course. In both types of configurations, augmentation of water removal existed mainly in the beginning of drying.

Analyzing the drying process in Fig. 8, one can see that during the experiment, the rate of drying and the water content both decrease. This kind of curve means that the drying process takes place in the second phase of the solid body drying.

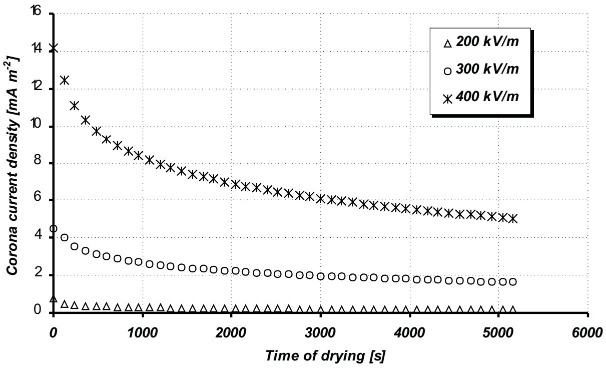

Fig. 5. Corona current density versus time of drying.

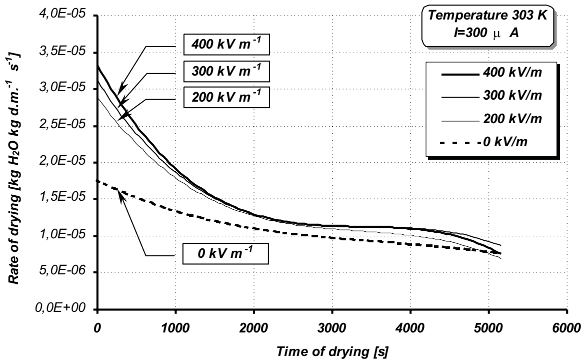

Fig. 7. Rate of drying of Roma wheat at a temperature of 303 K with constant corona current.

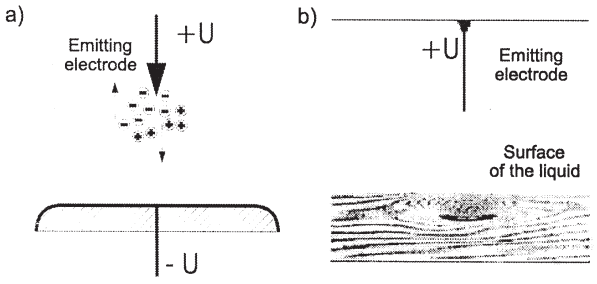

Fig. 6. Volumetric charge in the space between electrodes (a) and ionic wind acting on the surface of the liquid (b) (Wolny and Kaniuk, 1995).

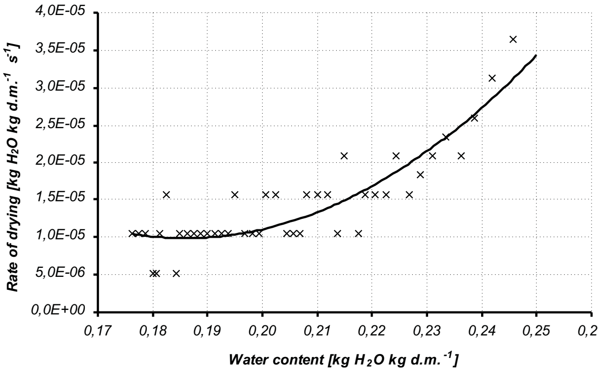

Fig. 8. Rate of drying of Roma wheat at a temperature of 303 K with constant corona current versus water content (400 kV m^{-1}).

CONCLUSIONS

On the basis of our measurements, the following can be concluded:

- In the group of measurements in which corona wind occurs, drying process was accelerated. The initial rate of drying can be about twice the rate of convection drying without the electric field and corona wind.

- The rate of water vaporisation depended mainly on the corona current and did not directly depend on the electric field intensity.

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