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The Influence of Corona Wind on the Convective Drying Course

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The convection drying belongs to very energy-consuming processes. Any agent, which can limit energy consumption, has large meaning. The agent being able to accelerate heat and mass process exchange in the convection drying appears to be an electric field. The influence of the electrostatic field is in the range of the main trend of the considerations, which is often neglected because of the difficulties to provide safety at industrial utilization and giving less spectacular effects at heat generation than the heat generation carried out in the alternating electric field.

The main problem described in the paper is the verification of the hypothesis stating that the ionic wind can increase convection drying process. The verification of the hypothesis on the possibility of influence on mass exchange kinetics during drying of solids was carried out on the basis of experimental tests. Thanks to the test stand, it was possible to influence on the wheat grain drying process.

Keywords: Electric Field, Corona Wind, Convective Drying.

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I. Introduction

The electric field can modify the speed of convective drying course because it generates accompanying phenomena in dried materials or changes the heat and mass transfer between the material and the drying medium. The convective drying process is widely used in agri-food industry (i.e. wheat grain drying) despite it has a very low efficiency.

The electrostrictive forces are one of the agents increasing heat transfer in liquids. This type of the research was carrying out in 1936 [1]. The experimental layout was related only to the natural convection between a thin wire and a metal cylinder. In 1983, Tarushkin pointed out at the potential possibility of using electrodynamics field acting on the internal grain structure [2]. He suggested that mechanical tension generated in strong electrostatic field cause structure microchanges which reduce moisture retention and minimise energy consumption in convective drying processes. He didn't carry out any research to prove this. The volume of electrostriction force can be calculated from formula [2]:

$$F_s = \frac{1}{2}\varepsilon_0 \int_V \mathrm{grad}(E^2 \frac{\partial \varepsilon}{\partial \tau}\tau)dV , \qquad (1)$$

where: F_s – electrostriction forces, N; τ – mass density, kg m^{-3}; $\partial\varepsilon/\partial\tau$ – partial change of specific inductive capacity that is caused by the deformation; V – volume, m^3; E – electric field intensity, V m^{-1}; ε_0 – permittivity of vacuum ($\varepsilon_0 = 8.8542\cdot10^{-12}$ F m^{-1}); ε – dielectric constant (relative dielectric permittivity).

In 1990, Baran created mathematical formulas describing the influence of electrical properties of grains and their shape on the volume of the electrostrictive forces [3]. He calculated that the volume of the electrostrictive forces was a few grades too low to cause macroscopic grain deformation. He carried out tests of grain drying the grain exposed to electrostatic field before the beginning of the drying process. As a result he stated that there were no effects changing the drying course. Because of the grains were not exposed to electric field during whole drying processes, nobody knows if there were any stresses in grain (in the form of remanence) or if they disappeared in the beginning of the drying process.

Basing on their earlier investigations, the authors of this paper put their attention to the corona wind role. In 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 (V_0), the partial discharge occurs in the space between electrodes. This partial discharge is limited by the space with the strongest electric field intensity. Free electrons and ions are generated in the space with the biggest 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 [4]:

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

where: F_c – ion-drag force, $F_c = 0$ for $V \leq V_0$, N; α – numerical factor dependent on the system geometry ($\alpha = 8/9$ 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.

The research of the heat and mass transfer process in the convective drying carried out in 1972 and 1995 confirmed the importance of the influence of the corona wind on heat and mass transfer at low air velocity [4, 5]. In 1972, Sadek, Fax and Hurwitz published the results of the research of the heat and mass transfer process in the convective drying of the sponge with water. The sponge was exposed on the flat, grounded electrode above which the wire matrix was put. In 1995, Wolny and Kaniuk published the results of the research of convective drying of ceramic substance and water vaporisation from surfaces were carried out in electric field in the presence of the corona wind.

The mentioned two groups of research were based on the direct acting of the corona wind on the water surface. This is completely different configuration than during convective grain drying where the water is compound inside a drying material.

II. Test stand

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

The main element of the test stand was the drying chamber (Fig. 1). The measurement capacitor was inside the drying chamber. The drying samples of wheat grains were placed on the lower electrode. The measurement capacitor was attached to the string of the balance. The electronic balance sent the information about the current mass of the dried sample to the computer. The electronic balance allowed for mass measurements of 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 %. The initial mass of each specimen was 100 g. Every time two series of drying were carried out. In one of them the sample was exposed to the electrostatic field and in the other not. Each drying process lasted 1.5 hour. The computer registered the loss of vaporised mass of water every 2 minutes.

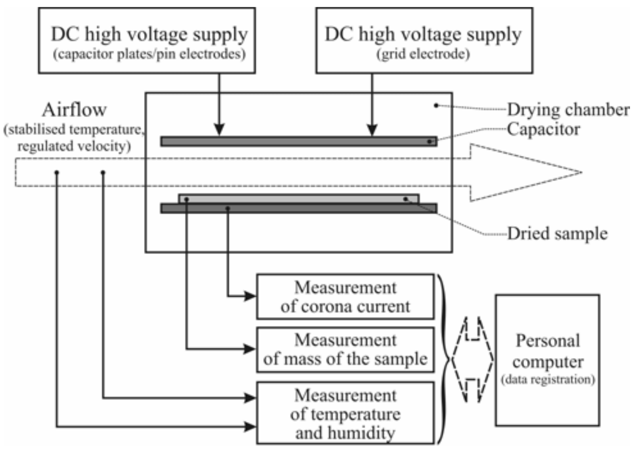

Fig. 1. Block diagram of the test stand.

During the experiments a few kinds of capacitors were used. The construction of capacitor allowed the generation of the corona wind. In presented cases the capacitor was equipped with:

- a flat electrodes with the conducted surfaces placed outside (Fig. 2 a),
- a flat lower electrode with the conducting surface placed inside, the upper electrode equipped with the pin matrix (Fig. 2 b);
- a flat lower electrode with the conducting surface placed inside, the upper electrode equipped with the pin matrix and the grid electrode for the corona current regulation (Fig. 2 c). This capacitor allows to generate corona wind with a controlled corona current at constant value the electric field intensity. The acting pin electrodes and grid electrodes allow to obtain electric field distribution on the surface of the dried sample close to the uniform. The electric field intensity value changes about 0.1 % [6].

The following series of the measurements were carried out:

- in the configuration of upper electrode equipped with pin matrix and with upper electrode equipped with

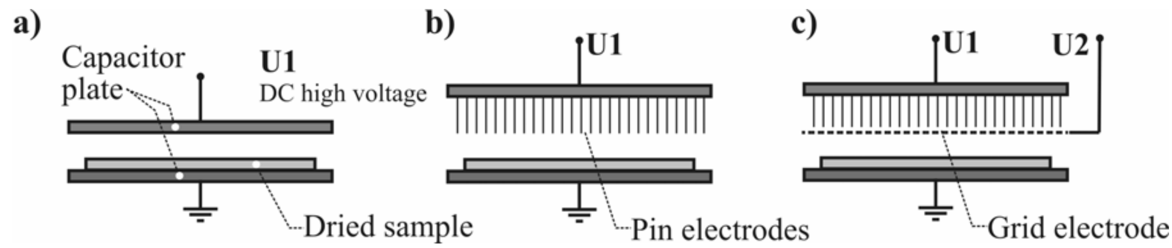

Fig. 2. Configurations of measurements capacitors: a) to generate the electrostrictive forces, b) to generate the corona wind, c) to generate the constant corona wind at the constant value of the corona current.

pin matrix and grid electrode;
- the air velocity was from 0.3 m s^{-1} to 1.4 m s^{-1};
- the range of mean field intensity was 0, 200, 300 and 400 kV m^{-1};
- the range of air temperature was – 303, 313 and 323 K.

III. Results

The following results have been found:
- In the flat capacitor - in which the corona wind was not generated (Fig. 2a), there was no measurable influence of the field on the drying process (Fig. 3). It means that in the given configuration, there is no mass transfer augmentation caused by electrostrictive forces.

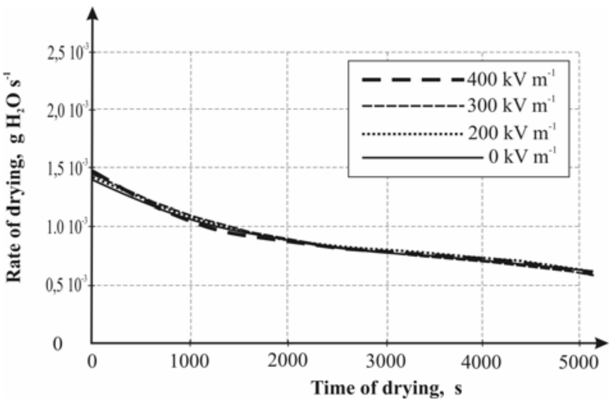

Fig. 3. Rate of drying of wheat grain at temperature 303 K in the flat capacitor (in which the corona wind was not generated).

- At high air velocity, the mass transfer augmentation does not exist. With the air velocity higher then 0.3 m s^{-1} it was impossible to register measurable changes of drying processes.

The drying process can be described using different groups of curves. The group of curves showing the rate of grain drying seems to be the best to describe the dynamic of the drying process. The presented groups of curves are selected from the whole measurement range and they up to the temperature 303 K. The other cases have similar courses.

Fig. 4 shows the rate of drying in the capacitor equipped with the pin matrix (Fig. 1 b). The mass transfer augmentation is observed every time. In the first moment, the rate of vaporisation could be higher nearly twice (~1.3 10^{-3} g s^{-1} at 0 kV m^{-1}, ~2.6 10^{-3} g s^{-1} at 400 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 the simple dependence between the electric field intensity and the acceleration of drying [7].

The analysis of the dependence between rate of grain drying and electric field intensity requires taking under considerations on the corona wind (attending the electric field). The ratio of the corona wind can be corona current density. In the configuration from Fig. 2bc, the 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 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 a measure of a 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 electrodes, is attracted to the earthed electrode. The energy obtained by electrons and ions can be exchanged during collisions with neutral gas molecules. The 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 influence of ionic wind at the higher air velocity (i.e.: 1.4 m s^{-1}) and why there was effect at air velocity 0.3 m s^{-1} when criteria Reynolds Number was 818÷916 [7].

In configuration with the controlled electric field intensity and the constant corona current (Fig. 2c) the rate of drying curves had different courses (Fig. 6). In the conditions with the constant corona current, the initial

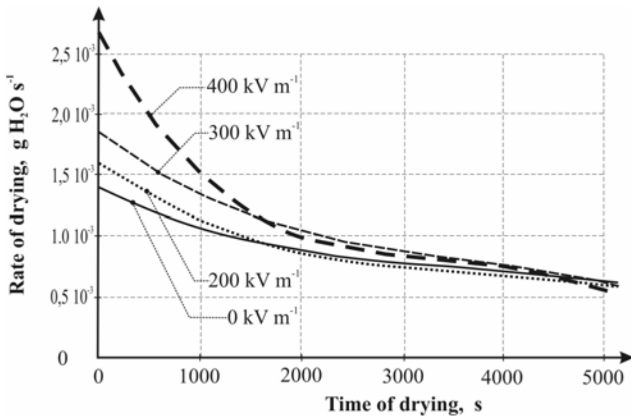

Fig. 4. Rate of drying of wheat grain at temperature 303 K with variable corona current.

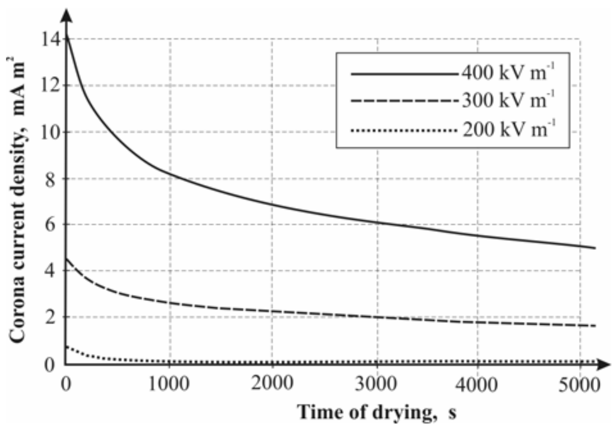

Fig. 5. Corona current density versus time of drying.

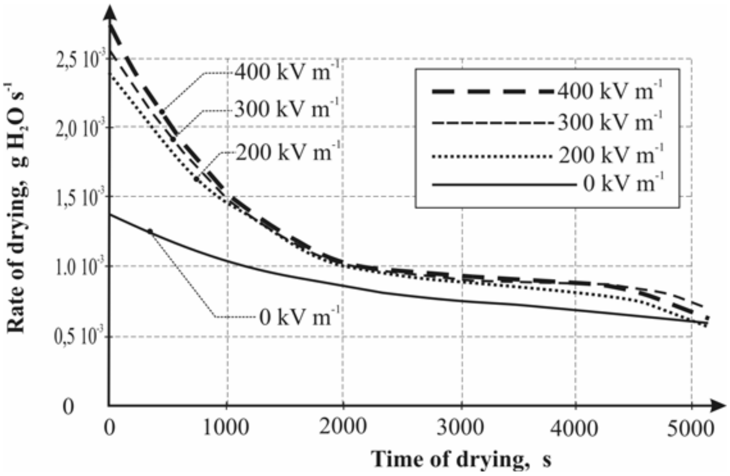

Fig. 6. Rate of drying of wheat grain at temperature 303 K with constant corona current.

rate of the removing water seemed to be more independent on the electric field intensity. The mass transfer was nearly the same, irrespective on the electric field intensity. The maintaining of the corona wind at the constant value let extend the electric influencing on the whole drying course. In both types of configurations, the augmentation of the removing water existed mainly in the beginning of drying [7].

IV. Conclusions

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

- The corona wind was most important factor, which could change convective drying course. In the case of a pin matrix the increased drying was observed.
- The initial rate of drying can be about 2 times the rate of convection drying without the electric field and corona wind (Fig. 4, 6).
- The rate of water vaporisation depended mainly on a corona current and not directly dependent on electric field intensity (Fig. 6).

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Вплив вітру сонячної корони на конвекційне сушіння

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Конвекційне сушіння відноситься до сильно енергетично поглинаючих процесів. Велике значення має будь-який агент, який може обмежити енергоспоживання. Агент, який здатний прискорити процеси обміну тепла маси при конвекційному сушінні проявляється електричною областю. Вплив електростатичної області, який є основною лінією у даній роботі, часто нехтується через свою складність, щоб надавати безпеку в індустріальній утилізації і безспектральні ефекти при генерації тепла, ніж коли генерація тепла виникає в альтернативній електричній області.

Головною проблемою, описаною в статті, є перевірка гіпотези, згідно якої іонний вітер може збільшити конвекцію процесу сушіння. Перевірка гіпотези про можливості впливу на кінетику масообміну протягом сушіння твердих тіл була виконана на основі експериментальних випробувань. Завдяки тестуванню, було можливим вплинути на пшеничне зерно при процесі сушіння.