

The Influence of Electric Field on the Energy Consumption of Convective Drying Processes

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***Abstract.** The electric field can change the speed of convective drying because it generates accompanying phenomena in dried materials or changes the heat and mass transfer between the material and the drying medium.*

These accompanying phenomena are generated in the material by electrostriction forces. These forces can cause deformations inside grains through the compression or tension of particular layers. Heat and mass transfer in drying air is intensified by ionic wind.

This paper presents the test results of convective drying of wheat in the electrostatic field and in the presence of ionic wind. The intensified drying processes are illustrated by the curves of drying.

***Keywords.** Convective drying, air drying, energy consumption, electrostriction forces.*

INTRODUCTION

Agri-food processes face problems of rational use of energy especially the ones that are commonly used because of its high energy consumption. It seems necessary to reduce the energy consumption of convection drying. Any agent, that could change the speed of drying and reduce energy consumption, is very important. The reduced energy demand can be achieved by an equivalent drying method or by adding new agents which could change the speed of drying. The electric field could be that agent increasing the speed of mass and heat transfer during the convection drying processes.

Senftleben (1936) presented his research on the influence of electric and magnetic field on thermal conductivity of gases. He pointed that there were no influence of magnetic field on thermal conductivity in the sodium steam or it was not possible to register this influence and the thermal conductivity of gas increased with the square of electric field intensity.

During the experiment described by Sadek et al. (1972), the drying material was put in the electric field. In this field the corona wind was generated. The ions generated near pin electrodes collided with gas ions and they exchanged their energy. The ion drag force, acting normal to a grounded electrode could be described by the formula (1).

Formula 1 shows that the influence depends on the electrical parameters (voltage, drying material dielectric permittivity) and geometric parameters (area of the electrodes, spacing between electrodes).

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

The Sadek's tests showed that the electric field can influence the convection drying. During the Sadek's tests the corona wind was the factor intensifying heat and mass transfer.

The practical meaning of convective heat and mass transfer is the convective drying of a solid body surface. Material humidity is changed inside the solid body because of heat conduction. The analysis of the convective heat and mass transfer requires the analysis of phenomena inside the drying material.

When dielectric material is exposed to electrostatic field, two kinds of forces can appear:

- ponderomotive forces that tend to move the dielectric,
- electrostriction forces that cause the deformation of its internal structure.

The electrostriction forces can make deformation inside the dielectric by stressing or stretching its particular layers. This deformation can reflect in the ability of moisture retention during drying. The deformation causes the change of the dielectric mass density. This causes changes of dielectric permittivity. The volume of electrostriction force can be calculated from another, formula presented by Tarushkin (1983) and Baran (1989):

$$\bar{F}_s = \frac{1}{2} \varepsilon_0 \int_V \text{grad} \left(E^2 \frac{\partial \varepsilon_r}{\partial \tau} \tau \right) dV_V. \quad (2)$$

In case the of electrostriction forces the influence does not depend directly on geometric parameters configuration. The influence mainly depends on electrical parameters such as electric field intensity or drying material dielectric permittivity.

The paper presents the experimental results. They can help to answer the question what kind of factors associated with the electric field can intensify the heat and mass transfer during wheat grain drying processes.

THE EXPERIMENT COURSE

The main elements of the test stand were a drying chamber and a measurement capacitor. The dried samples of *Roma* wheat grains were placed on the lower electrode of the capacitor. The measurement capacitor was attached to the string of the electronic balance. The electronic balance allows for mass measurements of 0.1% accuracy. The electronic balance sends the

information about the current mass of the dried sample to the computer serial port. The electrodes in the measurement capacitor were connected to the adjusted DC high voltage supply. The maximal voltage was 12 kV. The fan-heater was placed in the inlet of the chamber.

During the experiments three kinds of capacitors were used (Fig. 1). In particular versions the capacitor was equipped with:

- the flat electrodes with the conducted surfaces placed outside (Fig. 1 a),
- the flat lower electrode with the conducted surface placed inside and the upper electrode equipped with a pin matrix (Fig. 1 b),
- the flat lower electrode with the conducted surface placed inside, the upper electrode equipped with pin matrix and the grid electrode for the corona current adjustment (Fig. 1 c).

The drying sample was artificially moistened up to 20 %. 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 was not. Each drying process lasted 1.5 hour. The computer registered the loss of vapourised mass of water every two minutes.

The following series of measurements were carried out:

- the range of drying air velocity was from 0.3 to 1.4 m s⁻¹,
- the range of field intensity was 0, 200, 300 and 400 kV m⁻¹,
- the range of air temperature was - 303, 313 and 323 K.

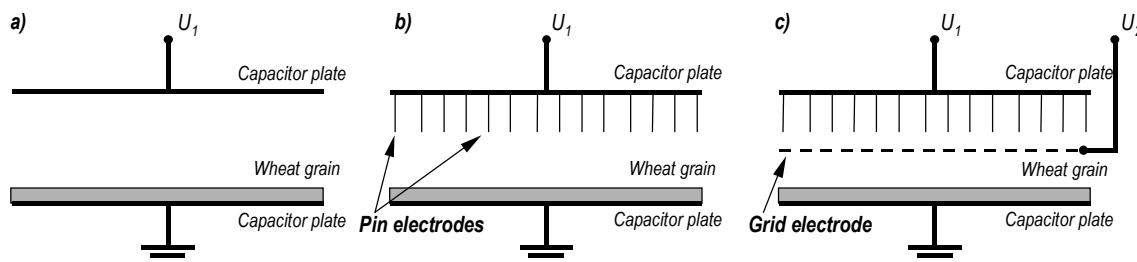


Figure 1. Configurations of measurements capacitors: a) to generate electrostrictive forces, b) to generate corona wind, c) to generate constant corona wind at constant value of the corona current.

THE RESULTS

The preliminary tests let us find the following results:

1. There was no measurable influence of the field on the drying process in the flat capacitor, in which the corona wind was not generated. It means that in the given configuration, there is no mass transfer augmentation caused by electrostrictive forces.
2. There is no mass transfer augmentation in each type of capacitor, at high air velocity ($v > 0.3$ m s⁻¹).

3. The mass transfer augmentation was observed every time in the capacitor equipped with the pin matrix, in which the corona wind was generated (at air velocity of 0.3 m s^{-1}).

On the basis of received results the experiments focused on the type of capacitor and on the range of air velocity that could guarantee the drying speed increase. The configuration allowing for corona wind generation has been used. For every combination of the electric field intensity and the temperature the following graphs have been plotted: the one of the water removed versus time of drying, the other one of the rates of removing water during drying and the drying curves.

The exemplary group of drying curves for the application of electric field intensity at temperature 303 K is presented in Fig. 2. The results illustrate the drying in configuration with the capacitor with the changing value of corona current (Fig. 1 b). There is no visible effect influence of electric field of the intensity 200 kV m^{-1} in Fig. 2. The influence of corona current of the intensity 200 kV m^{-1} is statistically negligible at 303 K. The influence grows together with the temperature. It seems from the drying curves that the increase of the electric field intensity and the corona current increased the speed of drying. It is possible to get the water content equal to $0.180 \text{ g H}_2\text{O/g d.m.}$ after 1.5 hour of drying at electric field of 400 kV m^{-1} intensity. The comparative sample has a water content equal to $0.193 \text{ g H}_2\text{O/g d.m.}$ after the same time of drying. It points out the possibility of influence of ionic wind on the drying processes.

Figure 3 illustrates the drying course of *Roma* wheat in the capacitor of configuration of the constant corona current. The value of corona current is constant during the whole drying process. This value equals the initial value of the corona current from the capacitor configuration without the grid electrode.

The constant value of the corona current enables additional intensification of a drying process. The curves in Fig. 3 show that in new conditions, the field with the intensity of 200 kV m^{-1} causes augmentation of water removing. The same situation occurs at higher electric field intensity.

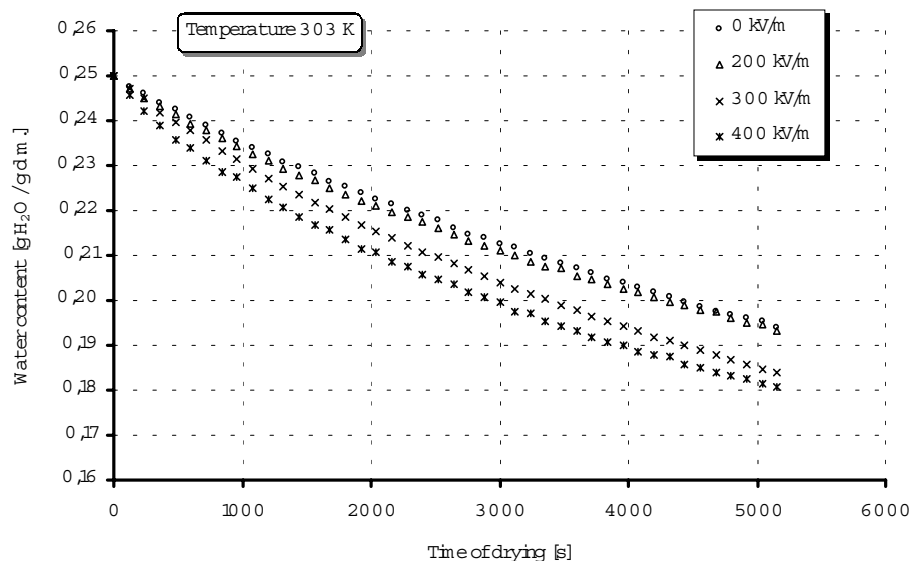


Figure 2. Drying curves of *Roma* wheat at temperature 303 K with the variable corona current.

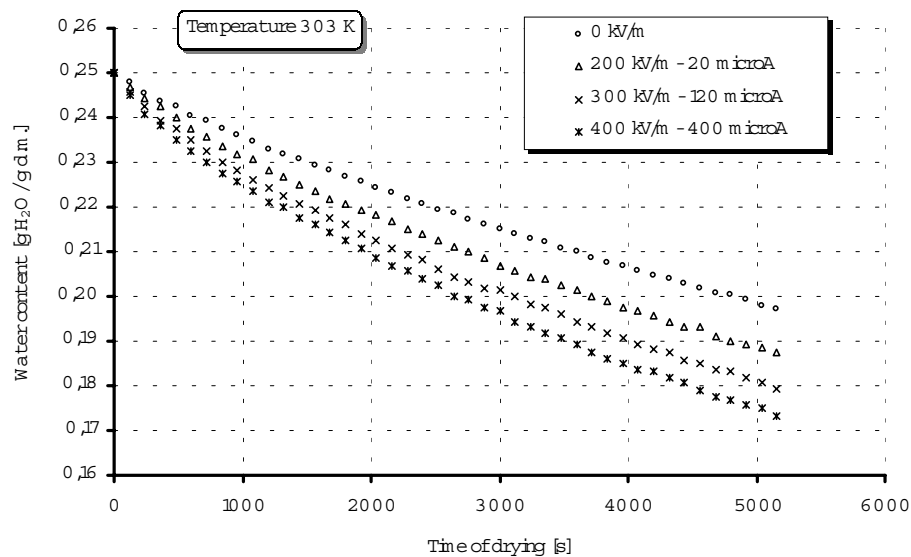


Figure 3. Drying curves of *Roma* wheat at temperature 303 K with the constant corona current (the value corona current equals the initial value of the corona current).

The constant corona current allows the increase of drying speed. The final water content of the drying sample was 0.180 g H₂O/g d.m. (Fig. 2) after the drying with the electric field at intensity 400 kV m⁻¹ and the variable value of corona current. The same field with intensity and the constant value of corona current enables the final water content of the drying sample equals to 0.173 g H₂O/g d.m. (Fig. 3) at the same time.

The energy saving ratio factor $q\%$ has been determined to compare the visible (on the drying curves) changes of drying kinetics. Two assumptions have been established:

- the quantity of energy given to samples was the same in each process,
- the quantity of energy dissipated between the electrodes of the capacitor by the corona current is incomparatively smaller than the energy given by heated air.

The ratio factor $q\%$, introduced by Pietrzyk and Krakowiak (1991), makes possible to compare the energy delivered by convection in two kinds of drying processes. The energy saving ratio factor $q\%$ is:

$$q\% = \left(\frac{u - u_2}{u - u_1} - 1 \right) \cdot 100. \quad (3)$$

The values of the energy saving ratio factor $q\%$, based on the detailed results from the particular drying tests with the variable value corona current are presented in Table 1.

Table 1. The convection energy saving ratio factor $q\%$

Temperature [K]	Electric field intensity [kV m^{-1}]		
	200	300	400
303	3,57 %	21,76 %	30,54 %
313	5,95 %	16,08 %	16,99 %
323	26,15 %	16,21 %	37,26 %

CONCLUSIONS

The objective of this paper is to answer to the question what kind of factors associated with the electric field can intensify the heat and mass transfer during wheat grain drying. The possible two factors are the corona wind (described by Sadek et al., 1972) and/or ponderomotive forces (described by Baran, 1989; Horynski, 1989; Pietrzyk and Krakowiak, 1991; and Tarushkin, 1983).

The conclusion reached on the basis of measurements is that the electrostatic field, inducing only electrostrictive forces (without the free charges), does not affect the speed of mass transfer in drying samples. This way, the Tarushkin's hypothesis (1983) of the possible energy consumption changes by means of electrostrictive forces, has not been proved. It seems that the deformation inside the dielectric caused by the electrostriction forces is too small to reflect in the ability of moisture retention during drying.

The electric field generating the corona wind changes the drying conditions. The main factor changing the convection drying course in the electric field is the corona wind. The energy saving ratio factor $q\%$ has dropped to the value of 37% in the tested range. The more detail research can verify existing electrical field influence extremes. Thanks to this research, it will be possible to prove or rule out their another reason for existence.

The maximal experimental values of the energy saving ratio factor $q\%$ are high. These high values have been reached in laminar flow regime. During industrial grain drying higher air

velocities are used. This is the reason why the described method of intensification of drying can not be used in standard industrial convection grain drying. The additional limitation of using electric field with the corona wind is possibility of disruptive discharge occurring. The disruptive discharge may result in grain firing.

The results do not exclude the use of electric field with the corona wind during plant incombustible material drying. The other research will be focused on different incombustible material, which can be dried in laminar flow regimes.

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NOMENCLATURE

A - area of the flat electrode, m^2 ;

E - electric field intensity, $V\ m^{-1}$;

F_c - ion-drag force, $F_c=0$ for $V \leq V_0$, N;

F_s - electrostriction forces, N;

$q\%$ - energy saving ratio factor, %;

s - spacing between electrodes, m;

u - moisture content before drying, $kG\ H_2O\ (kG\ d.\ m.)^{-1}$;

u_1 - moisture content in a specimen not exposed to electric field during drying process, $kG\ H_2O\ (kG\ d.\ m.)^{-1}$;

u_2 - moisture content in a specimen exposed to electric field during drying process, $kG\ H_2O\ (kG\ d.\ m.)^{-1}$;

v - air velocity, m s^{-1} ;

V - electrode voltage (V_0 - threshold voltage below which the ionic current is insignificant), V;

V_V - volume, m^3 ;

α - numerical factor dependent on the system geometry ($\alpha=8/9$ for parallel electrodes);

ε - dielectric permittivity, F m^{-1} ;

ε_0 - permittivity of vacuum ($\varepsilon_0 = 8.8542 \cdot 10^{-12} \text{ F m}^{-1}$);

$\partial\varepsilon_r/\partial\tau$ - partial change of specific inductive capacity that is caused by the deformation;

τ - mass density, kg m^{-3} .