The Effects of Electric Field Intensity and Pneumatic Pressure on the Dielectric Constant of Rye Kernels

Marek B. Horyński

Dept. of General Electrotechnology
Lublin Technical University
ul. Nadbystrzycka 38 A, 20-618 Lublin, Poland,
tel: +48 81 5381 300, fax: +48 81 5381 299
mhor@elektron.pol.lublin.pl

Keywords: *heterogeneous dielectrics, rye grain kernels, dielectric constant, pneumatic pressure, electrostatic field intensity, rye*

Abstract:

The paper presents a description of a test stand to determine the dependencies of rye grain dielectric constant on pressure and on electrostatic field intensity. The study showed that grain dielectric constant increases together with electrostatic field intensity and decreases when higher pressure is exerted. This change is more distinctive at higher moisture content of grain.

INTRODUCTION

The most important electrical parameters of grains are:
1. Resistivity;
2. Dielectric constant;
3. Loss tangent;
4. Grain orientation moment in homogeneous electrostatic field.

These parameters depend on factors such as kernel composition, moisture content, and temperature of the grain and the frequency of electric field.

Dielectric properties of biological materials can be applied to the determination of water content, drying, heating, quality detection, electrical treatment, and sorting and grading. Dielectric properties of grain seed are important because of their correlation with grain moisture content and because they influence the absorption energy at high frequency and microwave electromagnetic fields in dielectric heating applications.

These measurements let us examine the correlation between stresses of mechanical origin (pressure) and of electrical origin (field).The awareness of these correlations can be useful in the design of drying devices that utilise the effect of electrostatic field on grain.

MATERIALS AND METHODS

The equipment developed measures the dependence of dielectric constant of seeds on mechanical stresses and electrostatic field intensity. Because single grain kernels are small, the procedure was based on average grain mass.

1. Measurements were carried out on rye grain sample, average dimensions: length $l \approx 7.3$ mm, diameter $d \approx 2.7$ mm, measure of the roundness $B_w = d/l \approx 0.37$, the mass of grain sample 35 grams.
2. Before the measurements the grains were placed in an air washer to obtain established moisture content and temperature.
3. Dielectric constant values were determined by the measurement of capacitance of the capacitor in which the grain sample was placed.

The investigated sample is heterogeneous because of non-uniform structure of the grain and the random distribution of grain in the measuring capacitor. Both factors can influence the measurements. The following parameters (figure 1) describe the grain dimensions:

l – length,
d – diameter,
$B_w = d/l$ – measure of the roundness.

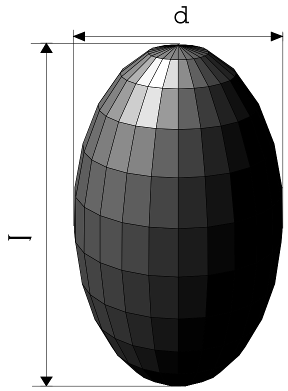

Figure 1. Spheroidal model of grain seed

The laboratory stand presented in figure 2 was constructed to measure dielectric constant vs. electrostatic field intensity and the influence of pressure and grain seed moisture.

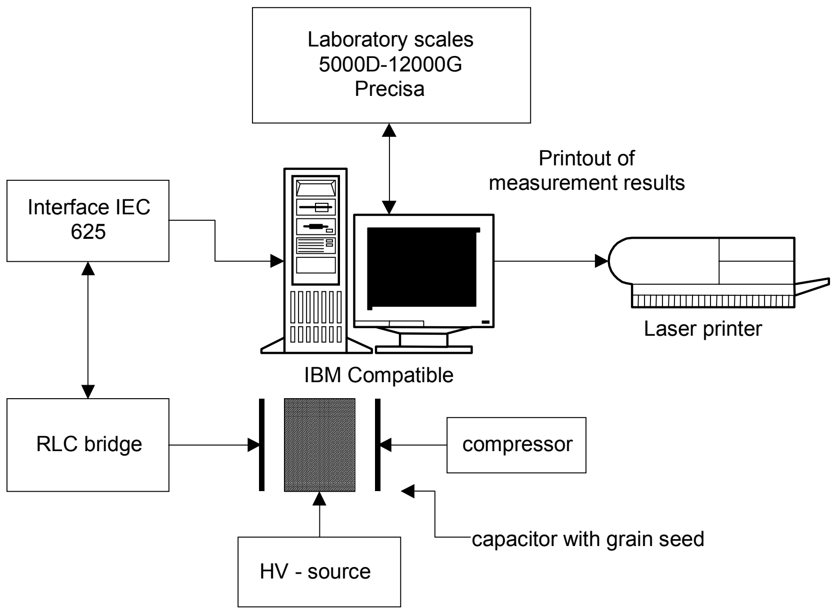

Figure 2. Laboratory stand

A compression chamber was constructed to generate mechanical stresses by introducing high pressure air into the grain sample. There is a cylindrical capacitor inside the compression chamber and the grain is placed in it. Figure 3 presents the layout of the chamber and the distribution of grain.

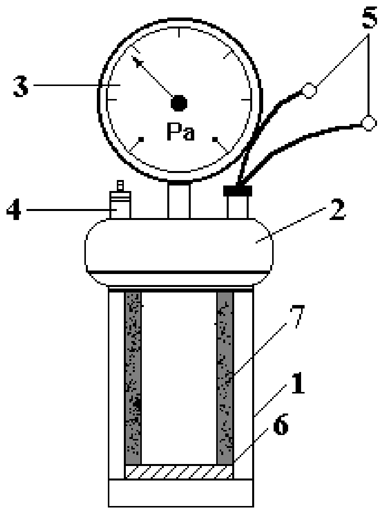

Figure 3. Diagram of the pressure vessel and the measuring capacitor: **1** - steel cylinder, **2** - cover, **3** - manometer, **4** - valve, **5** - capacitor leads, **6** - measuring capacitor, **7** - grains

A compressor chamber consists of a steel cylinder (1). It is covered with a lid screwed up from the top (2). The lid includes pressure gauge (3) and air inlet valve (4). The compressor [Donau RS/7] allows for the pressure up to 800 kPa. The compressor is equipped with a steam trap for moisture control and a pressure reducer to provide precision pressure adjustments. For the purpose of additional dehydration, there is a filter. The filter has two functions – traps the condensed water from the cylinder and dehydrates the air from the steam. Dielectric constant was measured by means of an automatic RLC bridge type E318. This bridge enables measurements at 1000 Hz, measured capacitance range 0.05 pF ÷ 200μF.
The electrostatic field is generated in a measuring chamber, which was a flat capacitor (figure 4) and was designed and constructed for the purpose of those tests. Tested dielectrics (grains) were placed in that field. The electrostatic filed intensity was determined from the formula: **E = U/d**, where **U** - voltage; **d** – distance between capacitor plates; this was changed in the supplier (HV source) through adjusted voltage output.

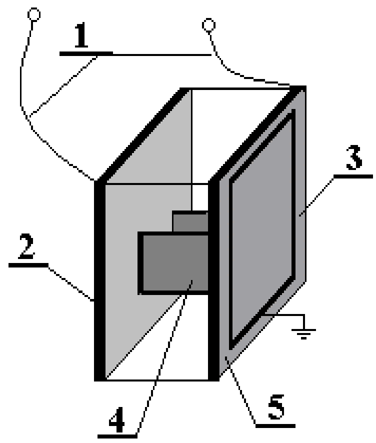

Figure 4.a. Flat capacitor: **1** - capacitor leads, **2,3** - capacitor plates, **4** - grain chamber, **5** – screen

The dielectric constant has been determined indirectly through measurements of capacitance of either the empty and grain filled chamber (1):

$$\varepsilon_{(z-p)} = \frac{C}{C_0}, \qquad (1)$$

where:

C - capacitance of the capacitor filled with grain, F,
C_0 - empty capacitor capacitance, F,
z – grain,
p – pressure,
z-p – grain – air mixture.

The change of dielectric constant by percent $\Delta\varepsilon$ is determined from:

$$\Delta\varepsilon = \frac{\varepsilon_p - \varepsilon_k}{\varepsilon_p} 100,\% \qquad (2)$$

where:

ε_p - dielectric constant of grain determined when there is no additional pressure applied to the kernels and the kernels and the chamber is at atmospheric pressure,
ε_k – dielectric constant of grain of k<u>th</u> pressure value.

RESULTS AND DISCUSSION

The percent changes of dielectric constant related to the initial value of rye grain vs. pressure and electrostatic field intensity are presented in figures 5 and 6.

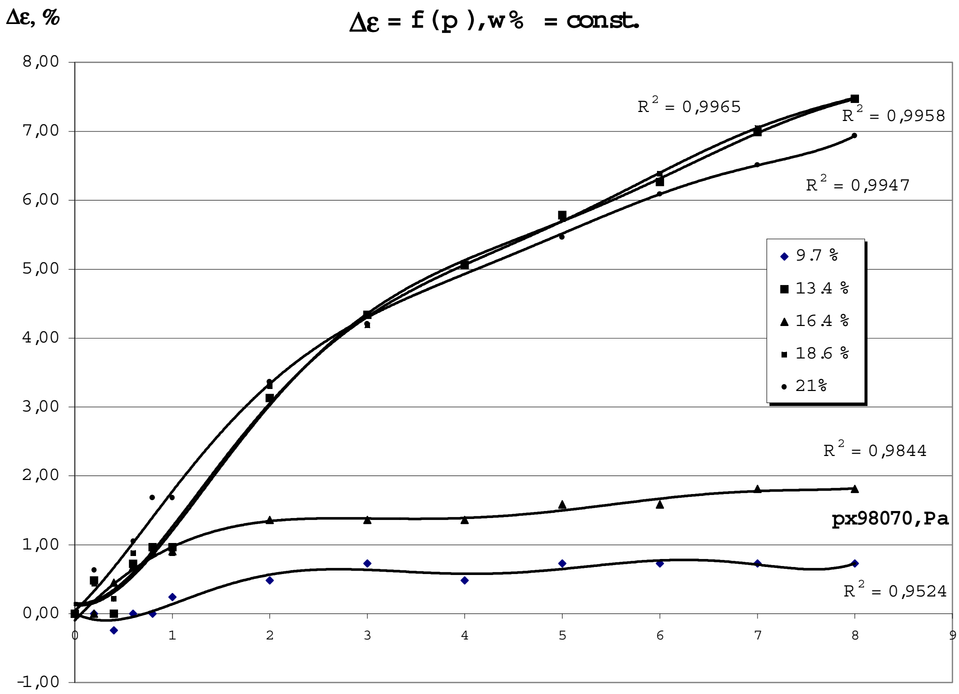

Figure 5. The percent changes of dielectric constant related to the initial value of rye grain vs. pressure at $w_{\%}$= const, (R – regression coefficient).

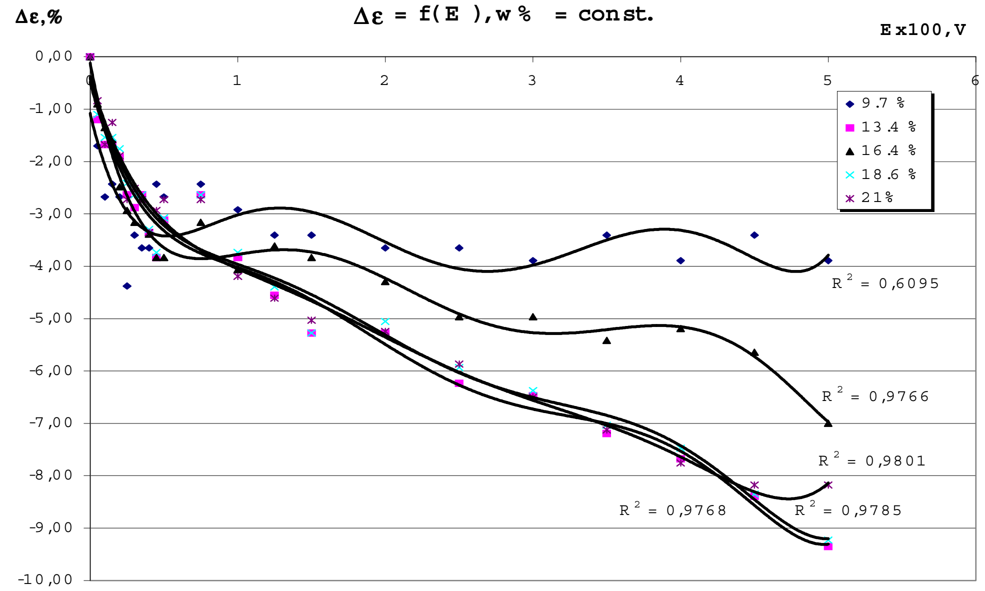

Figure 6. The percent changes of dielectric constant related to the initial value of rye grain vs. electrostatic field intensity at $w_{\%}$= const.

A correlation coefficient analysis was used to determine the relation between the influence of electrostatic field and pressure on grain dielectric constant. The equation of this correlation coefficient is (3):

$$\rho_{x,y} = \frac{Cov(X,Y)}{\sigma_x \sigma_y}, \qquad (3)$$

where: $-1 \leq \rho_{x,y} \leq 1$.

The covariance coefficient has the form (4):

$$Cov(X,Y) = \frac{1}{n} \sum_{j=1}^{n} (x_j - \mu_x)(y_j - \mu_y), \qquad (4)$$

where: *Cov(X,Y)* – covariance i.e. the mean of product of deviations of each pair of data; this makes possible to determine the dependence between the two sets of data,
x_j, y_j – j^th elements of the respectively compared data sets X and Y,
μ_x, μ_y – respective means of X and Y data sets,
σ_x, σ_y – standard deviation of X and Y data sets, respectively,
n – number of compared elements from X and Y data sets.

Positive values of correlation coefficient ρ indicate that the increase (drop) of dielectric constant under the influence of electrostatic field intensity is accompanied by the increase (drop) of dielectric constant under the influence of pressure. This proves the very strong relationship between them (the more intensive when value is closer to 1). In the case when the high increase of dielectric constant under the influence of one input is accompanied by the drop under the other input then the correlation between them is negative (correlation coefficient values are close to –1). When these values are close to zero it means that the inputs are not related (**Table 1**).

Table 1. Correlation coefficients ρ vs. pressure and electrostatic field intensity for rye of moisture content $w_{\%} = 9.7$ %

p(Pa) x98070	ε_p	**E(kV/m.) x100**	ε_E	ρ	**<p>(Pa) x98070**	**<E>(kV/m.) x100**
0	4.12	0.00	4.11	-0.397	0-8	0-1
0.2	4.12	0.05	4.18	-0.196	0-8	0.05-1.25
0.4	4.13	0.10	4.22	-0.001	0-8	0.1-1.5
0.6	4.12	0.15	4.21	0.187	0-8	0.15-2
0.8	4.12	0.20	4.22	0.128	0-8	0.2-2.5
1	4.11	0.25	4.29	0.015	0-8	0.25-3.0
2	4.10	0.30	4.25	-0.465	0-8	0.3-3.5
3	4.09	0.35	4.26	-0.693	0-8	0.35-4
4	4.10	0.40	4.26	-0.781	0-8	0.4-4.5
5	4.09	0.45	4.21	-0.834	0-8	0.45-5.0
6	4.09	0.50	4.22	-0.818	0.2-8	0.5-5.0
7	4.09	0.75	4.21	-0.865	0.4-8	0.5-4.5
8	4.09	1.00	4.23	-0.652	0.6-8	1-5
		1.25	4.25	-0.418	0.8-8	1.25-5
		1.50	4.25	-0.351	1-8	1.5-5
		2.00	4.26	0.128	2-8	2-5
		2.50	4.26	0.438	3-8	2.5-5
		3.00	4.27	0.453	4-8	3-5
		3.50	4.25	0.011	5-8	3.5-5
		4.00	4.27	0.966	6-8	4-5

CONCLUSIONS

The following conclusions can be found from the tests of dielectric constant of grain subjected to mechanical stresses and electrostatic field intensity:

1. Grain dielectric constant depends on mechanical stresses (figure 5).
2. Grain dielectric constant depends on electrostatic field intensity (figure 6).
3. The change of dielectric constant of grains depends on their humidity.
4. The influence of pressure and electrostatic field is more intensive for wetter grains.
5. Grain dielectric constant drops at the increase of compressive stresses (the more, the wetter grains are):
   $\Delta\varepsilon = 7.5$ % for grains of water content $w_{\%} = 18.6$ % at pressure of p = 784560 Pa.
6. Grain dielectric constant increases together with electrostatic field intensity $\Delta\varepsilon = -9.4$ % for grains of water content of $w_{\%} = 13.4$ % at E = 500 kV/m (minus means the increase of relative dielectric constant).
7. The changes of dielectric constant generated by mechanical stresses are strongly related to the changes inducted by electrostatic field in some ranges (see **Table 1**). This let us expect that the awareness of the influence of mechanical stresses on the grain dielectric constant can make possible to determine the electrostictive forces inducted by the field

References

1. HORYŃSKI M., PIETRZYK W., WALUSIAK S., 1994, Investigations of mechanical stress influence on grain dielectric permeability changes, -abstract- XXI C.I.G.R. World Congress and AgEng '94 Conference on Agricultural Engineering. Milan, Italy
2. HORYŃSKI M., PIETRZYK W., WALUSIAK S., 1996, Dependence of barley dielectric permeability on moisture and mechanical stresses, -abstract- International Conference on Rational Use of Renewable Energy Sources in Agriculture in connection with the Environmental Control, 2-7 June, Budapest, Hungary
3. HORYŃSKI M., PIETRZYK W., WALUSIAK S.,1996, Influence of electric field and moisture on barley dielectric permeability, -abstract- International Conference on Rational Use of Renewable Energy Sources in Agriculture in connection with the Environmental Control, 2-7 June, Budapest, Hungary.