Stepan KOVALYSHYN[1], Viktor DADAK[1], Vadym PTASHNYK[1], Oleksiy SHVETS[1], Deta ŁUCZYCKA[2], Tomasz DRÓŻDŻ[3], Paweł KIEŁBASA[3], Marcin WESOŁOWSKI[4]

Lviv National Agrarian University[1]
Wrocław University of Environmental and Life Sciences, The Faculty of Life Sciences and Technology[2]
University of Agriculture in Krakow, Faculty of Production and Power Engineering[3]
Warsaw University of Technology, Faculty of Electrical Engineering[4]

doi:10.15199/48.2020.01.15

The Study of Electrical Properties of Components of a Winter Rape Seed Mixture

***Abstract**. Having conducted the investigation of electrical properties on the example of winter rape (Brassika napus oleifera diennis metzg) and its difficult-to-separate weed – cleavers (Galium aparine), we revealed a significant difference in their dielectric permittivity and the angle of dielectric loss in the wide frequency range. The revealed regularities allowed us to determine the value of the electric charge that can accumulate on the seed material in the separation process, and thus the strength of the electrical interaction between seed and separation surface.*

Streszczenie.** W artykule przedstawiono badania wybranych właściwości elektrycznych, które można wykorzystać do separacji nasion roślin produkcyjnych (Brassika napus oleifera diennis metzg) od nasion roślin niepożądanych (Galium aparine), których parametry geometryczne i masowe są bardzo zbliżone. Odnotowano różnice w przenikalności dielektrycznej oraz oszacowano wartość ładunku elektrycznego, który może gromadzić się w materiale. (**Identyfikacja właściwości elektrycznych różnicujących mieszaninę nasion rzepaku ozimego).

Keywords: seed, dielectric permittivity, electric charge, electric separation.
Słowa kluczowe: in the case of foreign Authors in this line the Editor inserts Polish translation of keywords.

Introduction

The seed industry of plant growing has strategic importance in providing agricultural manufacturing with seeds of high quality. In many countries worldwide, it has great importance, since a sufficient quantity of high-quality sowing material with high yields, which does not contain any kind of damaged or biologically defective non-viable seed, directly impact production of one or another crop and the growth of yield produced by manufacturers. The above arguments are confirmed by research results done by numerous scientists [1-10].

In the structure of sowing cultures an important place is allocated to oilseeds, especially winter rape. In Ukraine, its cultivating area occupies about 10% [11]. Obtaining of sufficient quantity of high-quality seed material of this culture for the needs of commodity producers is quite a difficult task. One of the reasons for this is that a significant percentage of seeds are damaged during harvesting and after-harvesting [12].

Another reason is that in the process of producing this culture there are weeds, especially cleavers, which seeds, by most physical and mechanical properties, practically do not differ from the seeds of the main culture.

This is confirmed by the data [13], according to which the approximate length of the winter rape seed is between 1.89–2.3 mm and cleavers' length – 1.95–2.4 mm, the height – 1.95–2.5 mm and 1.58–2.42 mm respectively, the width – 2.1–2.5 mm and 1.9–2.7 mm. The coefficient of friction of winter rape seeds on the steel is 0.81, and cleavers is 0.85.

It is practically impossible to separate all sorts of damaged seeds and seeds of difficult-to-separate impurities from winter seed rape with the use of existing seed cleaning machines that perform separation according to shape, surface condition or geometric dimensions of the separating mixture components [14].

It is possible to create more perfect separating machines or fundamentally new ones by using the principle of superposition of forces of different physical nature [15, 16]. Due to this, separation proceeds not only by the physical and mechanical properties of the seed mixture components, but also by the internal biochemical properties. This effect can be achieved by using additional electric fields while separating [17-20].

There is a close connection between physical-mechanical, biological and electrical properties of seeds [21]. Therefore, for increasing the efficiency of separation of weeds impurities or various kinds of damaged and biologically defective seeds from crop seed mixtures, it is advisable to use electrical separation methods that make use of the difference in electrical conductivity and dielectric permittivity of the components of the mixture, their ability to accumulate and give an electric charge, etc. Due to the information on electrical properties of the components of seed mixtures, one can turn to the substantiation of the design and parameters of machines for seeds separation, which use an electric field as an additional working organ. A number of researchers have indicated this in their studies, in particular [22-24]. However, as shown in [25], the electrical properties of seeds of most small-seeded crops and their difficult-to-separate weeds have not yet been clarified.

The aim of this article is to determine the possibility of separating small-seed mixtures in separators using the electric field as an additional working body and substantiating the optimal parameters of the work of these separators on the example of winter rapeseed and its weed – cleavers by studying their basic electrophysical parameters: dielectric permeability and angle of dielectric losses.

Material and methods

In the course of research on determination of electrical properties of the components of small-seeded mixtures, specimens of winter rape seeds (*Brassika napus oleifera diennis metzg*) and its weed – cleavers (*Galium aparine*), that have undergone primary and secondary treatment, were used. Microphotographs of the studied seeds, which were taken by means of a digital microscope SIGETA Forward 10-500x5,0 Mpx LCD, are shown in Fig. 1a and 1b.

The research program envisaged the determination of basic electrophysical parameters of seeds – electrical resistance, dielectric permittivity and dielectric loss coefficient.

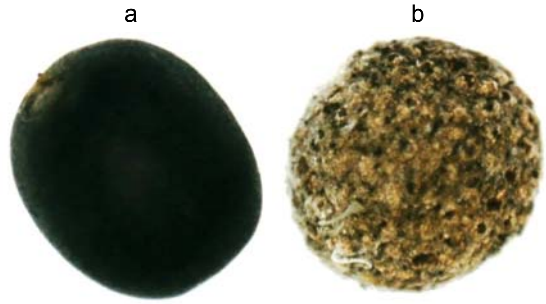

Fig. 1 Microphotography of seeds of winter rape (a) and its difficult-to-separate weed – cleavers (b)

Since the variation of seed moisture results in significant changes in its electrophysical parameters, the moisture values were pre-determined separately for each component of the mixture by the Mettler Toledo HG 63 analyzer and maintained at the level of 7–8 % during the course of impedance spectroscopy of the investigated components of the winter rape seed mixture.

The material of biological origin owing to its specificity (heterogeneity, shape, porous structure, chemical composition) requires the development of new and adaptation of existing measurement methods. Today, there are no standardized methods for measuring electrophysical parameters of heterogeneous dielectric materials with nonlinear polarization, but most researchers [26-28] use standard methods of experimental studies of high-resistance insulating materials at low voltage.

To study the basic electrophysical parameters of seeds of winter rape and cleavers, the method of indirect measurement in a wide frequency range has been applied. In this method, the electrodes of a measuring cell are considered as plates of a flat capacitor filled with the investigated dielectric material [28].

To measure electrophysical properties of the seeds, the investigated samples of winter rape and weed-cleavers were alternately placed in a collapsible capacitor cell with flat copper electrodes (Fig. 2). Before each measurement, the capacitor cell was emptied, cleaned and re-filled with seeds again. The measuring cell was connected by a two-electrode circuit (without a blocking electrode), which allowed it to be used at frequencies above 10 kHz, provided that superficial scattering can be neglected [27].

The main problem of measuring the resistance of alternating current is the correct interpretation of the obtained results. Since the equivalent electrical circuit of the samples under investigation is unknown, the capacitance and resistance values determined at a certain fixed frequency may not correspond to its actual parameters. Therefore, it is necessary to conduct measurements in a wide frequency range and, in the future, to select the frequency region where the measured values correspond to the actual volume resistance of the sample. It should be taken into account that in polycrystalline materials, the total resistance of samples consists of the volume resistance of grains and the resistance of the grain boundaries derived by the capacity of these boundaries.

The complete resistance of the investigated material and the capacity of the measuring cell were determined by means of the ATLAS 0441 HIA device in the AC frequency range from 1 kHz to 10 MHz at a temperature of 20 ºC and relative air humidity of 60 %.

The relative instrumental error of the method does not exceed 1 %. However, when working with high-resistance materials, the value of the useful signal is often commensurate with the magnitude of parasitic capacitance and galvanic currents, so all measurements were made with a threefold repetition.

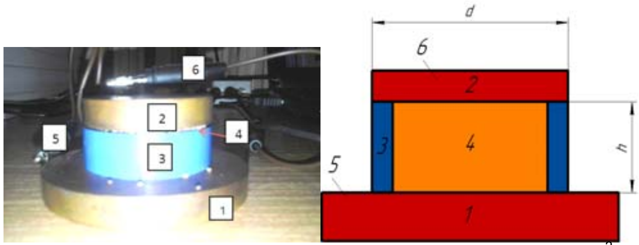

Fig. 2 Collapsible capacitor cell with flat electrodes $d = 6\cdot10^{-2}$ m, $h = 1.5\cdot10^{-2}$ m (a) – general view; (b) – constructional scheme
1 – lower electrode, 2 – upper electrode, 3 – bracket, 4 – investigated material, 5 and 6 – connectors

Results and discussion

To assess the possibility of separation of small-seeded mixtures in electric separators, in which an electric field of corona discharge is applied as an additional force factor, the dielectric permittivity ε and the dielectric loss factor $tg\ \delta$ of the investigated winter rape seeds and their main impurity – cleavers were studied.

The dielectric permittivity allows us to estimate the change in the electrostatic interaction of charges in a vacuum and in the investigated medium. To determine the relative permittivity of the investigated seeds ε the formula of a flat capacitor (1) is used:

(1) $$\varepsilon = \frac{d}{\varepsilon_0 S} C,$$

where: ε_0 – electric constant, $F\cdot m^{-1}$; C – capacity of the investigated material, F; S – surface area of the electrode, m^2; d – interelectrode distance, m.

Another important parameter characterizing the electrical properties of seeds is the coefficient of dielectric loss $tg\ \delta$. For its calculation, the ratio (2) is used:

(2) $$tg\delta = \frac{1}{2\pi fCR},$$

where: f – current frequency, Hz; R – resistance of the investigated material.

The dielectric loss coefficient is a dimensionless magnitude that expresses real losses in dielectrics.

The results of the experimental determination of frequency dependence of dielectric permittivity of the studied seeds are presented in Figs. 3–4, shows the frequency dependence of the tangent of the dielectric loss angle. As we can see from Fig. 3 the dielectric permittivity of the investigated specimens differs substantially throughout the frequency range, and this difference increases with a decrease in frequency and reaches 25 %. The dielectric loss tangent (Fig. 4) also varies depending on the frequency of perturbing oscillations and indirectly indicates the specific frequency dependence of the RC product. The obtained results affirm that it is possible to separate the seeds of cleavers from the seeds of winter rape in electric separators, where as an additional force influence the electric field is used.

The study of the dielectric permittivity and the dielectric loss of the corn seeds in the range of 1-100 MHz, presented in the work [29], also confirms a significant dependence of the dielectric permittivity of the seed material on its viability and other biological peculiarities. The value of the angle of dielectric loss will undergo more significant changes compared to the dielectric permittivity, but the frequency range will be somewhat reduced.

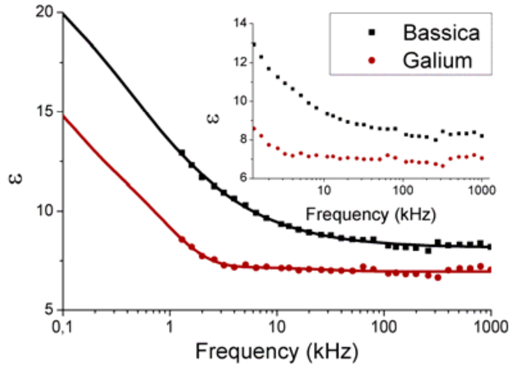

Fig. 3. Frequency dependence of dielectric permittivity of investigated samples of rapeseed and cleavers: the results of experimental measurements – insertion, the results of extrapolation – the main figure.

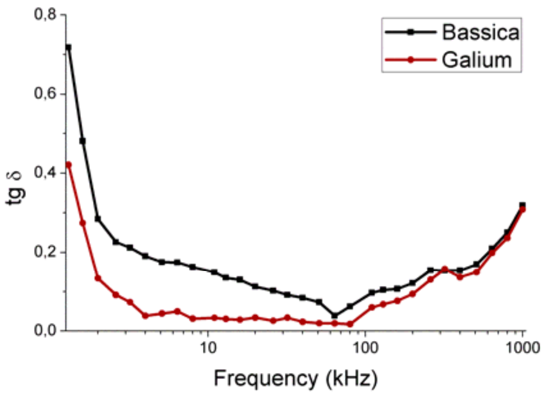

Fig. 4. Frequency dependence of the tangent of the dielectric loss angle of rape and cleavers seeds samples.

In practice, the best results of electric separation of various dielectric materials are observed under the conditions when their charging takes place by friction to surfaces of special materials or ionization in a corona discharge field [30, 31].

One of the key factors that determines the effectiveness of seed separation in an electric field of corona discharge is the maximum value of the accumulated charge and the charge/discharge rate of seeds. In contrast to electrically conductive materials, which, as a result of partial electrons scattering, retain only a small part of the accumulated charge. Dielectrics in similar conditions keep much greater charges. According to the data [32], the shape of the particle and its contact area with the working separating surface influence the value of the accumulated charge significantly. So in the seed of rounded shape the accumulated charge is much greater than in the seeds of the ellipsoid shape, in which the charge remains only at the points of contact with the separating surface. The charge/discharge rate also varies considerably depending on the type of material and the conditions of the process.

The greatest charge that can accumulate in a dielectric particle in an electric field can be estimated by the Mohr formula:

(3) $$Q_{max} = 4\pi\varepsilon_0 a^2 E\left[\frac{c^2}{a^2} + \frac{2}{\frac{3}{\varepsilon - 1} + \frac{3N}{4\pi}}\right],$$

where: Q_{max} – maximum accumulated charge, C; E – intensity of the electric field of corona discharge, Vm^{-1}; a – particle radius, m; c – half-axle of rotation, m; N – depolarization factor.

Taking into account that for seed samples of spherical shape the ratio $\frac{c}{a} = 1$, and the depolarization factor $N = \frac{4}{3}$, the expression (3) can be represented in the form of the Potenie formula:

(4) $$Q_{max} = 4\pi\varepsilon_0 a^2 E\left[1 + 2\frac{2(\varepsilon - 1)}{(\varepsilon + 2)}\right].$$

The extrapolation of the experimental curves $\varepsilon(f)$ to the point 0 Hz (insertion of Fig. 3) allowed to determine the values of the dielectric permittivity of rape ($\varepsilon = 19.9$) and cleavers ($\varepsilon = 14.8$) in DC and, based on the expression (4), to estimate the value of the maximum possible accumulated charge. Extrapolation results are also shown in Fig. 3.

During corona charging and subsequent discharging of seeds on a grounded electrode, their charges $Q(t)$ vary over time according to the exponential law, depending on the transition resistance and the capacity of the seed-electrode system

(5) $$Q(t) = Q_{\max} e^{-\frac{2t}{RC}},$$

the values of which can be determined by extrapolating the results presented in Fig. 4. The results of the analysis of the function (5) for rape seeds and cleavers are shown in Fig. 5.

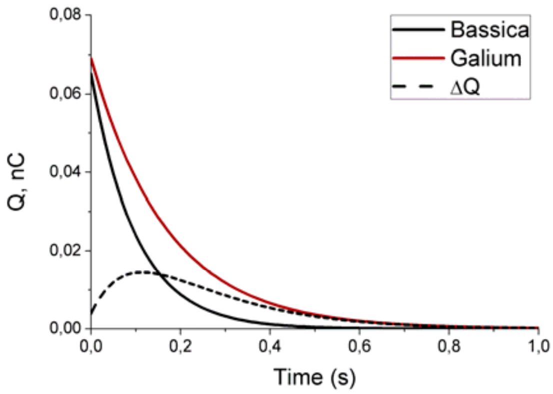

Fig. 5. Kinetics of investigated seeds discharging process: $E = 300$ kV·m^{-1}, $a = 1\cdot 10^{-3}$ m

As we can see from Fig. 5 the difference in the values of the residual charge is a function of time and in the given conditions significantly affects the value of the electrical interaction between the charged seeds and the electric separation surface, and the magnitude of this interaction reaches its maximum at a time $t = 0.1\ s$ and practically disappears after $t = 0.6\ s$.

To determine the magnitude of the electrostatic interaction between the spherical seed and the plane surface of the electrode, in the role of which the separator conveyor belt is, we use the mirror image method. When reflecting on the boundary of two dielectrics, the field in the medium in which the charged seeds are located is determined by the charge Q_1, and the field from the side of the belt of the separator conveyor, by charge Q_2:

(6) $$Q_1 = Q_{max},$$

(7) $$Q_2 = -Q_{max}.$$

To calculate the interaction force directly, you can use the ratio:

(8) $$F = \frac{|Q_1 Q_2|}{4\pi\varepsilon_0\varepsilon_2 r^3}\vec{r},$$

where: $\vec{r}$ – vector radius; r – distance between charges; $\varepsilon_2 = 1.0006$ – relative dielectric air permittivity.

To apply the (8), it is necessary to formulate a number of assumptions, in particular:

the seed has an ideal spherical shape;

the charge of the seed is concentrated in its geometric center.

Then, on the basis of (5-8), we can formulate the expression for calculating the dependence of the interaction force of charged seeds with a surface, which graphic representation is shown in Fig. 6.

a)

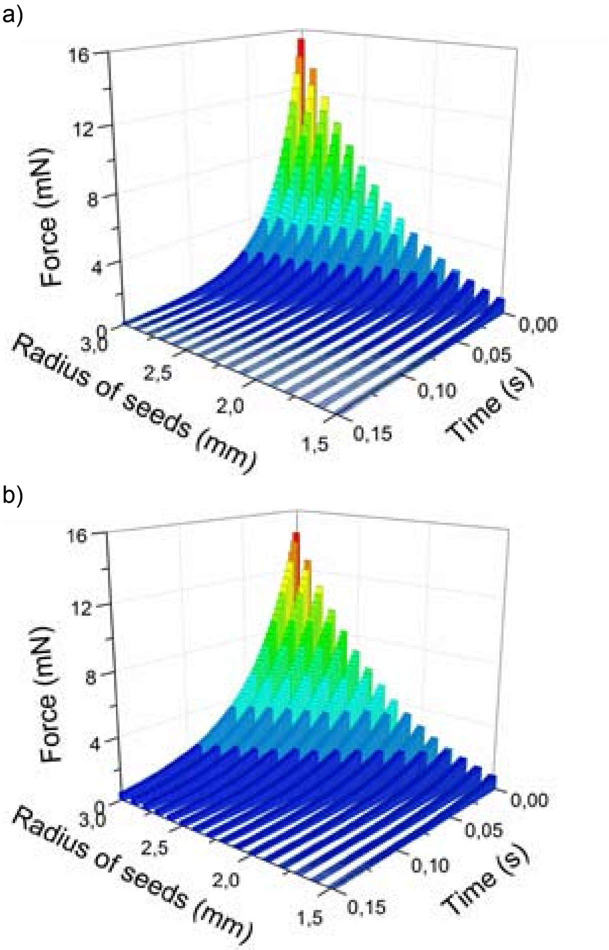

Fig. 6. Power characteristics of electrostatic interaction of charged seeds with separation surface
(a) – winter rape, (b) – cleavers

Presented in formulas (5-8) dependences and their graphical representations, shown in Figs. 3 - 6, give an opportunity to state the following. For the studied seeds, the maximum value of the accumulated charge and the rate of discharge mainly depends on their dielectric permittivity. Since for the investigated samples of seeds of winter rape and cleavers the value of dielectric permittivity differs essentially in the entire frequency range, it can be affirmed that the magnitude of their accumulated charge, and, as a consequence, the strength of their interaction with the separation surface will be different. This is one of the main conditions for efficient separation of some seeds from others in the process of electric separation.

The obtained results on determination of electrical properties of seeds give grounds to pre-substantiate the parameters of electric separation. In particular, the dependence of Q(t), depicted in Fig. 5, allows to determine the optimal duration of stay of components of investigated mixtures on the separation surface. Comparison of the strengths of interaction of the studied seeds with the surface of electric separation (Fig. 6) allows us to optimize the parameters of the electric field of the corona discharge.

Conclusions

1. Having examined the dielectric permittivity of seeds of winter rape and cleavers, a significant difference between the obtained values of the dielectric permittivity in the whole investigated frequency range from 1 kHz to 1 MHz was established. This difference increases with decreasing alternating current frequency. And DC values of the dielectric permittivity of winter rape is ε = 19.9, and cleavers ε = 14.8.

2. The tangent of the angle of dielectric loss also varies with the frequency of the disturbing vibrations. At the high frequency approximate to 1 MHz, the difference in the values of tangent of the angle of dielectric loss has not been found, but with decreasing frequency of the current to 1-10 kHz, a difference of values of the angle of dielectric loss at the level of 45-83 % has been recorded.

3. Extrapolation of the obtained values of the dielectric permittivity of winter rape and its main impurity – cleavers allowed us to estimate the maximum possible charge that is accumulated by seeds during their stay on the electroconductive surface. It is shown that during the corona charging and further discharging of seeds on the grounded electrode, their charge $Q(t)$ varies with time according to the exponential law. The difference of values of residual charge significantly influences the magnitude of the electric interaction between the charged seeds and electroseparation surface, and the magnitude of this interaction reaches its maximum at time t = 0.1 s and almost disappears in t = 0.6 s.

4. The obtained results on determination of electrical properties of seeds of small-seeded mixtures give grounds to assert about the possibility of their effective separation in the process of electric separation. The analysis of electrical and physical properties of these seeds enables to pre-substantiate the parameters of the electric separation, in particular, the optimal duration of their stay on the separation surface and the parameters of the electric field of the corona discharge in the working zone of the electric separator.

__Authors__: prof., PhD Stepan Kovalyshyn, Lviv National Agrarian University, Vol. Velykogo str., 1, 80381 Dubliany, Ukraine E-mail: stkovalyshyn@gmail.com; PhD Viktor Dadak, Lviv National Agrarian University, Vol. Velykogo str., 1, 80381 Dubliany, Ukraine E-mail: dadakv@i.ua; PhD Vadym Ptashnyk, Lviv National Agrarian University, Vol. Velykogo str., 1, 80381 Dubliany, Ukraine E-mail: ptashnykproject@gmail.com; PhD Oleksiy Shvets, Lviv National Agrarian University, Vol. Velykogo str., 1, 80381 Dubliany, Ukraine E-mail: opshvets@yahoo.com, dr hab. inż. Deta Łuczycka, Wroclaw University of Environmental and Life Sciences, The Faculty of Life Sciences and Technology, ul. J. Chelmonskiego 37/41, 51-630 Wrocław, E-mail: deta.luczycka@upwr.edu.pl; dr inż. Tomasz Dróżdż, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Mickiewicza Av. 21, 31-120 Krakow, E-mail: Tomasz.Drozdz@office.urk.edu.pl; dr hab. inż. Paweł Kiełbasa, University of Agriculture in Krakow, Faculty of Production and Power Engineering, Mickiewicza Av. 21, 31-120 Krakow, E-mail: pawel.kielbasa@urk.edu.pl.

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