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STUDY OF THE INFLUENCE OF TRIBOLOGICAL AND ELECTRICAL PROPERTIES OF WINTER RAPE SEEDS ON THEIR EQUILIBRIUM ANGLE ON THE SEPARATING PLANE

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Abstract. In many cases, it is possible to obtain the high-quality seed material of difficult-to-separate seed mixtures of agricultural crops in the process of its post-harvest processing on electric separators, in which the working body is an inclined plane moving in an electric field. On such a plane, separation is carried out according to the set of tribological, physical-mechanical and electrical properties of the constituent components. The efficiency of electroseparation can be increased by thorough investigation of these properties both for crop seeds and for weed seeds or various types of injured grains.

It is found out that the universal criterion, on the basis of which it is possible to analyse the influence of tribological, physical-mechanical and electrical properties on the behaviour of the components of a difficult-to-separate seed mixture on the separating plane, is the angle of equilibrium of the seed on it.

The mathematical expression of the equilibrium angle is formulated, in which the shape, dimensions, roughness, material of the separating plane are represented by the friction angle φ, and the electrical properties of the seeds (electrical conductivity, dielectric permittivity, etc.) – by the multiplicity of the electric force k_o.

Due to the experimental studies of the equilibrium angles of winter rape seeds, as well as various types of injured seeds, it has been found out that shrunken, injured seeds, compared to high-quality ones, have larger values of the equilibrium angles, and this confirms the possibility of their separation on the inclined separating plane moving in the electric field.

Under the condition of choosing the optimal value of the speed V_n and the intensity of the electric field E, it is possible to achieve the maximum difference in the values of the $\Delta\alpha_p$ equilibrium angles for individual seeds, and at the same time to achieve an effective mode of operation of the separator. The equilibrium angle α_p of the components of the seed mixture has a decisive influence on the design parameters (dimensions) of the working body (plane) of the electric separator.

Keywords. Rapeseed, tribological properties, electrical properties, equilibrium angle, electric separator.

1. INTRODUCTION

Obtaining high yields of agricultural crops is impossible without the availability of a sufficient amount of high-quality seed material. Post-harvest processing, in particular separation, plays an important role in improving its yield qualities. It is possible to separate high-quality seeds from difficult-to-separate weed impurities or various types of injured seeds in case it is a success to detect significant differences in their tribological, dimensional, mass, aerodynamic, electrical properties, etc. However, the components of small-seeded mixtures, which are difficult to separate, have a significant similarity in geometric dimensions, mass and aerodynamic properties. Because of this, it is impractical to use these properties as a sign of divisibility in seed cleaning machines.

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The difference between crop and weed seeds, high-quality seeds and a certain kind of injured seeds can be detected and implemented in the separation processes based on a set of tribological and electrical properties. As the analysis of the conducted studies shows [1, 2], t is most effectively carried out in the process of electrical separation using a plane moving in an electric field as a working body. Therefore, conducting thorough studies of both tribological and electrical properties of seeds will contribute to the development of effective designs of machines for cleaning the seed material of agricultural crops from difficult-to-separate impurities of weeds and various kinds of injured or biologically inferior dead seeds.

A number of publications [3–6] are devoted to the problem of determining the tribological properties of seeds. In work [7], a device with an inclined adjustable friction plane was used to obtain statistical data on the values of seed friction coefficients. However, it does not provide sufficient accuracy and the measurement process is time-consuming. To eliminate these shortcomings, the device is proposed, in which the inclined surface is movable, and the angle of its inclination can be adjusted [8].

The use of the Jenikiego device significantly increases the accuracy of measurements of the coefficients of external and internal friction of seeds of agricultural crops [3, 9]. The procedure for their determination consists in establishing the force of movement of the studied type of the seed material under a defined vertical load on the studied friction surface. In this case, you can use surfaces of different materials and a certain area.

Comprehensive studies of the physical and mechanical properties of seeds [10–12] also provided for the determination of their friction coefficients. Experimental studies of determination of static and dynamic coefficients of external friction of seeds are presented in [13–15]. Some researchers have set themselves the following goals: experimental finding of coefficients of sliding friction of components of seed mixtures of agricultural crops, including impurities on various frictional surfaces [6, 16]; calculation of the coefficients of static friction due to the maximum angle of inclination of the friction plane at which the grain begins to move; detection of a correlation between friction coefficients with various biological characteristics, for example, laboratory germination, the degree of injury of seeds, their fragility [17]. At the same time, different types of installations were used to determine the angles of inclination of friction surfaces and coefficients of external friction.

Other researchers studied the electrical properties of the components of seed mixtures, in particular winter rapeseed [18–20]. They revealed a significant difference in the values of dielectric permittivityand the angle of dielectric loss in a wide frequency range of winter rapeseed and its difficult-to-separate weed – the seeds of Galium aparine. The identified regularities made it possible to establish the amount of the electric charge that can accumulate on the seed material in the process of electroseparation, and hence the strength of the electrical interaction between the seed and the separating surface.

The given data show that in order to obtain a synergistic effect – to obtain the greatest differences in the values of tribological and electrical properties between the seeds of crops and the seeds of weeds or various kinds of injured seeds, it is advisable to carry out theoretical and experimental determination of the specified groups of parameters of the components of difficult-to-separate seed mixtures. Their results will contribute to the discovery of new signs of divisibility and optimization of electrical separation parameters.

2. METHODS

The research was carried out on the experimental installation, the technological scheme of which is presented in Figure 1.

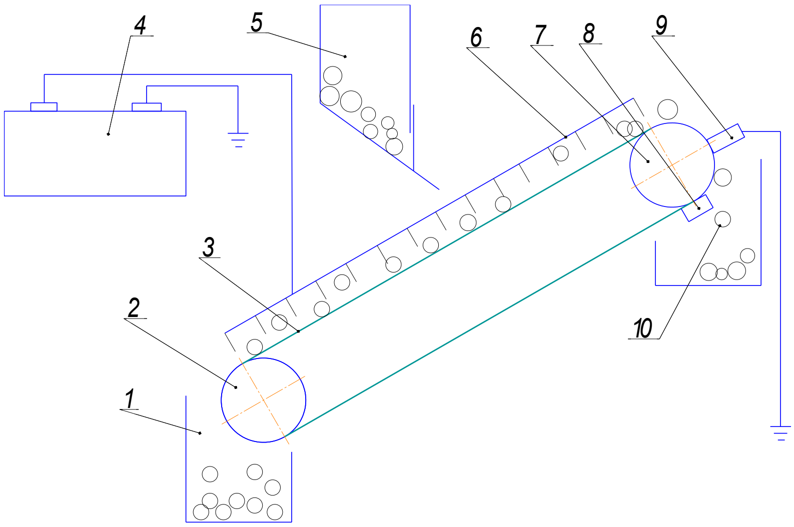


Figure 1. Technological scheme of the experimental installation (1 – receiver of conditioned seeds; 2 – driven roller; 3 – separating plane; 4 – high voltage power supply; 5 – hopper-feeder; 6 – coronating electrode; 7 – guide roller; 8 – cleaning brush; 9 – grounding; 10 – waste receiver).

During the research, winter rape seeds were used, which were conditionally divided into three types based on the surface condition (Figure 2).

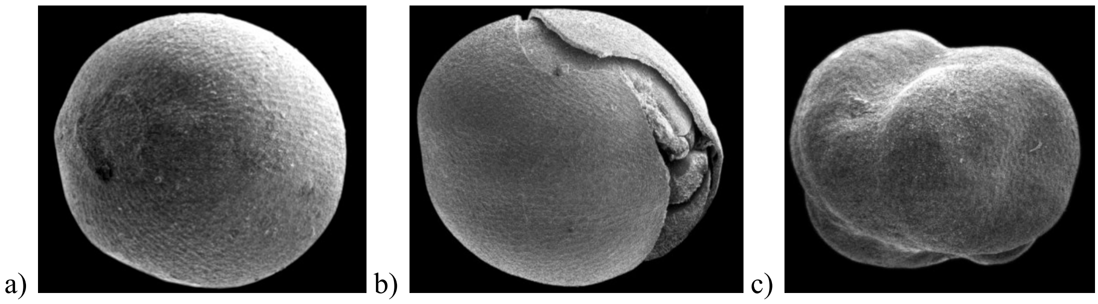


Figure 2. Types of studied winter rape seeds: a) high-quality – full, spherical in shape; b) shrunken – wrinkled, irregular in shape with incomplete endosperm; c) injured – with various types of shell cracks, a destroyed shell or core.

The measurement of the equilibrium angles was carried out according to the separate adjustable parameters, which were characterized by the specified values of the electric field intensity E and the movement velocity V_n of the separating plane. According to the research plan, they were carried out under the following conditions:

1 – the movement velocity V_n of the plane varied from 0.03 m/s to 0.15 m/s if $E=const$;

2 – the intensity of the electric field E varied from 0.7 to 3 kV/cm if $V_n=const$.

For each case, according to the given specified values of the mentioned conditions, the smallest angle of inclination α_{H} was found, which ensured the removal of all the seeds of the sample up the belt, and the largest angle α_{B}, due to which all the seeds rolled down it. The difference of these angles was the range of variation of the distribution of this sample. Dividing it by the number of classes n_i, we obtained the class interval:

$$i_\alpha = \frac{\alpha_{\text{B}} - \alpha_{\text{H}}}{n_i} \qquad (1)$$

This interval was rounded to a whole number. The number of classes n_i was determined for each component. One value of i_α was accepted for all experiments provided that the number of classes i_α was not less than 5.

Having stabilized in each experiment the values of the parameters characterizing the above-mentioned individual cases of research, first the angle $\alpha_H + i_\alpha$ was set and the seeds were released onto the belt. The seed that fell into the lower receiving hopper had an equilibrium angle equal to:

$$\alpha_P = \alpha_H + \frac{i_\alpha}{2} \tag{2}$$

The seeds found in the upper receiving hopper were again released onto the moving belt at the angle of inclination equal to $\alpha_H + 2i_\alpha$, repeating everything as in the previous experiment.

The seeds that had the maximum equilibrium angle took part in the last experiment of this series.

Graphical dependences of the equilibrium angles of the components of the rape seed mixture on the parameters of the separator were obtained taking into accountthe results of the research.

3. RESULTS AND DISCUSSION

In order to identify the differences in the behaviour of the components of the seed mixture on the separating plane moving in the electric field, it is proposed to investigate the integral indicator at the theoretical and experimental levels, which relates the influence of their tribological and electrical properties on these differences. Such an integral indicator is the angle of its equilibrium α_p, that is, the angle at which the seeds are on the plane at rest or move without acceleration.

The mathematical expression of the angle of equilibrium of the particles of the seed mixture is determined based on the analysis of the forces acting on them (Figure 3).

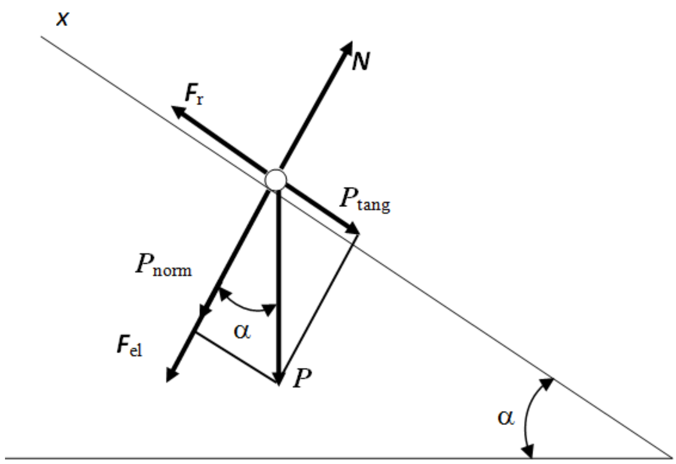


Figure 3. Scheme of the forces acting on the seed on an inclined moving plane: P, P_{norm}, P_{tang} – force of gravity and its normal and tangential components; F_{el} – electric force; F_r – resistance force; N – bond reaction; α – angle of inclination of the plane to the horizon.

A seed on the inclined plane will be in equilibrium if the forces acting on it are equal:

$$P_{tang} = F_r. \tag{3}$$

Let us expand the force of gravity P into the components P_{tang} andP_{norm}. In this case, the component P_{tang} is directed towards the greatest inclination of the plane, and P_{norm} – along the normal to the plane. Thus, we have:

$$P_{norm} = mg \cdot \cos\alpha\,; \tag{4}$$

$$P_{\tan g} = mg \cdot \sin\alpha. \tag{5}$$

Let us consider the case when, in addition to the gravitational field, we have a uniform force field above the plane. The force vector F_{el} of this field, regardless of the location of the plane in the space, acts along the normal to it.

$$F_{el} = k_o mg \ , \tag{6}$$

where, k_o – multiplicity of electric force.

The force P_{tang} acts on the particle on the plane and is the driving force for its movement along it, and the forces P_{norm}, $F_{ел}$ determine the reaction of the plane N to the particle. At the same time, it is acted upon by the resistance force F_r (friction force), which is always directed tangentially to the trajectory and in the direction opposite to the seed's relative movement velocity vector.

Taking into account the expressions (4), (5) and (6), the equation (3) will take the following form:

$$P_{tang} = f(P_{norm} + F_{el}) \tag{7}$$

In ideal conditions, it can be assumed that α_p is approximately equal to the friction angle of seed rolling φ.

Under such conditions, using (7), it is possible to obtain a mathematical expression of the angle of equilibrium of the seed on the plane moving in the electric field:

$$\alpha_p = \varphi + arcsin(k_o \cdot sin\varphi) \tag{8}$$

where, α_p is the angle of equilibrium of the seed in the electric field on the inclined moving plane, degrees;

φ – the angle of equilibrium of the seed on the inclined plane in the absence of the electric field, degrees.

Analyzing how the obtained expression (8) reflects the influence of the forces acting on the seeds, the following should be noted. The force of friction depends on the properties of the surface of the seed, its shape, size, roughness and material of the belt and is expressed in the equation (8) by the angle of friction φ.

The additional electric force is determined by the parameters of the electric field (intensity) and the electric properties of the seed (electrical conductivity, dielectric permittivity, etc.) and is expressed as a multiplicity of the electric force k_o. The parameters of the electric field can be adjusted, which in turn is a necessary condition for controlling the separation process and determining its optimal modes.

In order to identify the possibilities of separating injured and high-quality winter rape seeds on the inclined moving separating plane in the absence of the action of the electric field, experimental studies were conducted to determine the angles of equilibrium on it. Using the obtained data, the variation curves of the distribution of high-quality and injured rape seeds according to this indicator were constructed (Figure 4).

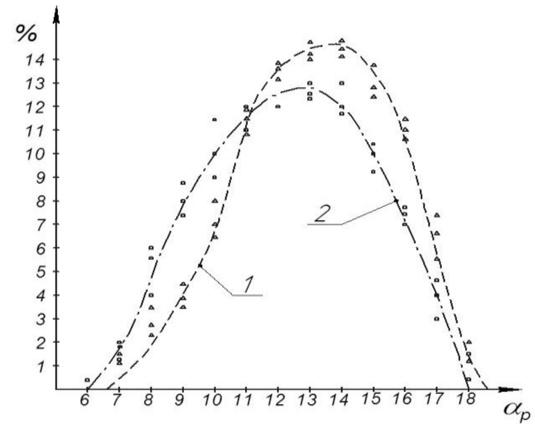
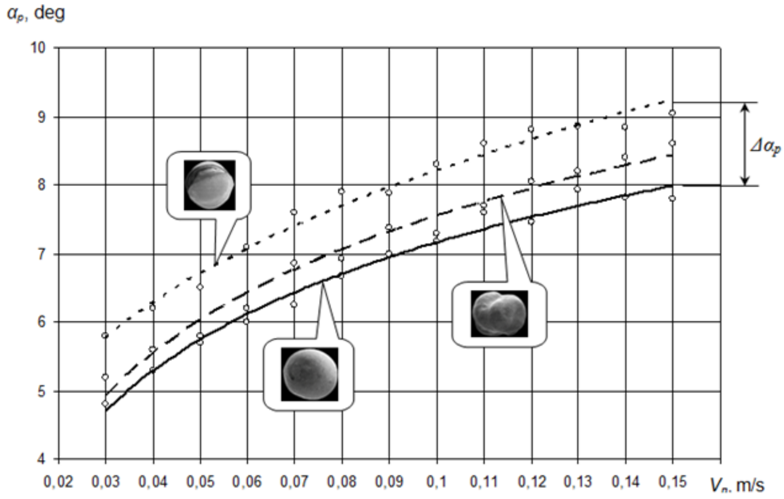


Figure 4. Variation curves of the distribution of rape seeds by the angle of equilibrium: 1 – injured seeds; 2 – high-quality seeds.

The analysis of the given variation curves proves an insignificant difference in the equilibrium angles for both high-quality and injured seeds, as well as low efficiency of their separation on the inclined moving separating plane.

In order to increase the difference $\Delta\alpha_p$ between high-quality and injured rape seeds, it is proposed to impose the electric field on this plane. Having determined the equilibrium angles of the studied components of the seed mixture under such conditions, graphical dependences of its values on the movement velocity of the belt(Figure 5) and the intensity of the electric field imposed on it (Figure 6) were constructed.

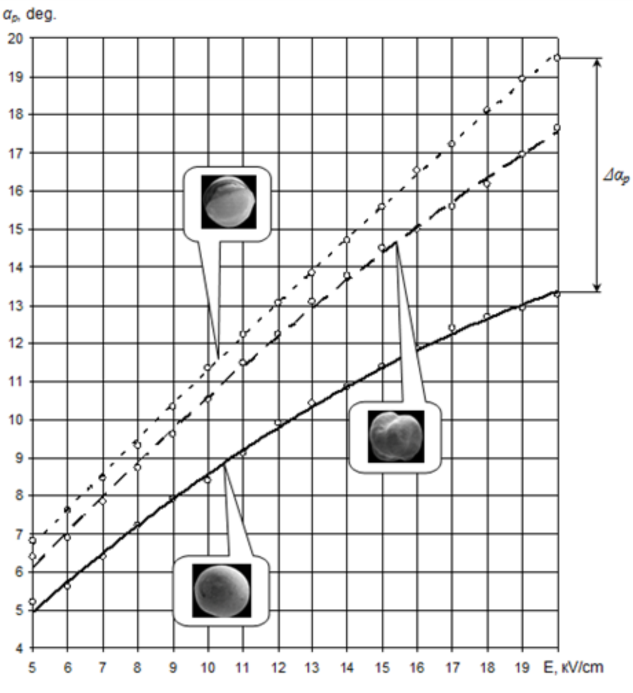


—— high-quality; ----- shrunken; ······ injured

Figure 5. Dependencies of the change in the equilibrium angle of winter rape seeds on the movement velocity of the belt V_n.

The obtained research results indicate that with an increase in the movement velocity of the belt V_n, the angle of equilibrium of the rape seeds α_p increases.

The value of the equilibrium angles of the studied seeds is significantly affected by the intensity of the electric field E. The value of the additional electric force F_{el}, which is perpendicularly applied to the separating plane, depends directly proportionally on it. As intensity increases, the angles of equilibrium of both high-quality, shrunken and injured seeds increase (Figure 6).



—— high-quality; ----- shrunken; ······ injured

Figure 6. Dependencies of the change in the equilibrium angle of winter rape seeds on the intensity of the electric field E.

Having analyzed Fig. 5 and 6, it should be noted that injured and shrunken seeds, compared to high-quality ones, have a larger equilibrium angle. If, in the absence of the electric field, the difference in the equilibrium angles of the components of the seed mixture does not exceed 3 degrees or 10%, then the presence of an additional electric force allows it to be increased to 7 degrees or 34–47%. The reason for this is the fact that the shrunken and injured seeds receive a greater charge and, under the condition of increasing the electric force, are more strongly pressed by it to the plane. It is for these reasons that their equilibrium angle, compared to others, is greater.

An increase in E allows to obtain the maximum value of the difference in the equilibrium angles $\Delta\alpha_p$ for the studied seeds, which is a necessary condition for their effective separation according to the set of tribological and electrical properties.

This conclusion is confirmed by the results of the experimental data on the operation of the electric separator, in which the working body is an inclined plane moving in the electric field. At different values of the parameters of its work, the dependences of the content of low-quality seeds K (the degree of their separation) in the received seed material on the angle of inclination of the separating plane to the horizon, its movement velocity, and the intensity of the electric field in the working zone of the separator were obtained (Figure 7).

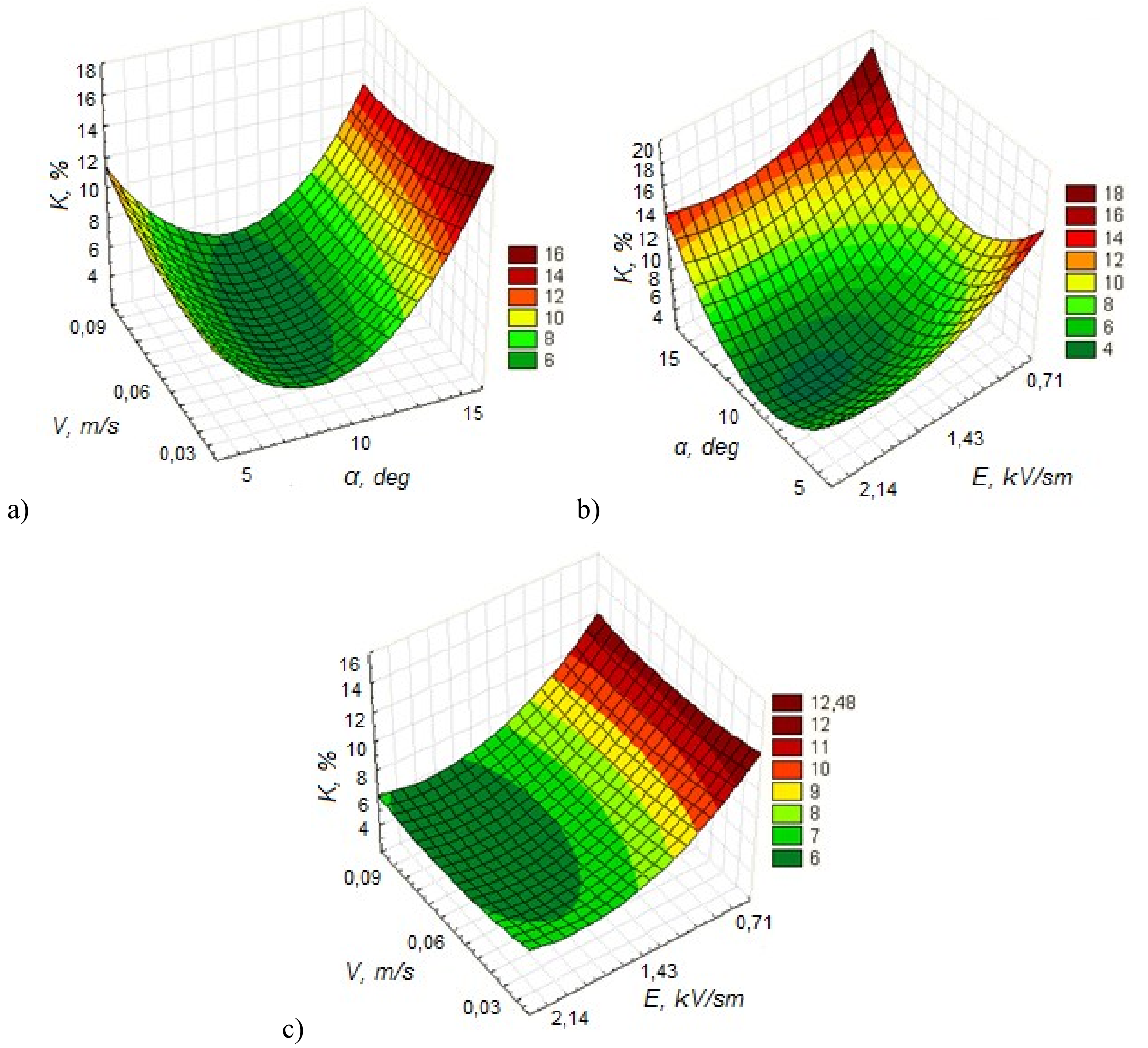


Figure 7. Dependencies of the content of low-quality K seeds (the degree of their separation) in the obtained seed material: a) $K=f(\alpha, V_n)$; b) $K=f(\alpha, E)$; c) $K=f(V_n, E)$.

Analyzing Figure **7**, we can see that the angle of inclination of the separating planeα and the intensity of the electric field E have the greatest influence on the degree of separation of low-quality seeds.

Experimental studies have shown that the smallest number of low-quality seeds (K=4%) in the separated seed material of winter rapeseed is ensured at the angle of inclination of the separating plane α=8.7 degrees, its movement movement velocity V_n=0.07 m/s and the intensity of the electric field E=2 kV/cm.

4. CONCLUSIONS

The following conclusions can be drawn on the basis of the conducted research:

– the universal criterion on the basis of which it is possible to analyze the influence of tribological and electrical properties on the behaviour of the components of the difficult-to-separate seed mixture of winter rape on the separating plane is the angle of equilibrium of the seed on it.

– the obtained mathematical expression of the given equilibrium angle takes into account the set of seed properties, in particular, the shape, dimensions, roughness, material of the separating plane that are represented by the friction angle φ, and the electrical properties of the seeds (electrical conductivity, dielectric permittivity, etc.) – by the multiplicity of the electric force k_o.

– due to the experimental studies of the angles of equilibrium of winter rape seeds, as well as various types of injured seeds, it has been found out that shrunken, injured seeds, compared to high-quality ones, have larger values of the angles of equilibrium, which confirms the possibility of their separation on the inclined separating plane moving in the electric field;

– it is possible to improve the quality of the seed material thanks to its processing on electric separators, in which the working body is the inclined plane moving in the electric field, and the separation takes place according to the set of tribological and electrical properties of its components.

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