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THEORETICAL STUDY OF SORTING SMALL SEEDS ON A TRIBOELECTRIC DEVICE

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Abdukodir Rosaboev[1], Bakhodir Tagayev[1], Nematjon Akramov[1], Davlat Dinikulov[2].

([1]Scientific Research Institute of Agricultural Mechanization, Tashkent, Uzbekistan. [2]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan)

Abstract

The article presents information about the design, operating principle of a triboelectric device for sorting small seeds, and the results of theoretical studies on their sorting, using bell pepper as an example. The results of theoretical studies showed that bell pepper seeds, depending on the ratio of the acting forces and, accordingly, their mass, detach from the surface of the rotating charged working element of the triboelectric device at various rotation angles. The latter allows, by correctly establishing the coordinate of the separating plane's location axis, to qualitatively separate the sorted seeds based on their mass into various fractions, i.e., sowing and technical fractions. In this case, if bell pepper seeds with a mass of less than 4.5 mg are considered low-quality and unsuitable for sowing, it is sufficient to create an induced electric field strength of 4 10^5 V/m on the surface of the rotating working body of the triboelectric device for their sorting.

Introduction. It is known that currently in agricultural production, there are no devices for sorting small seeds to improve their sowing qualities. Therefore, subsidiary, small-scale farms and farm enterprises are forced to sow small crop seeds without preliminary sorting. This leads to an increase in the consumption rate of small seeds, as well as the additional expenditure of 100-120 man-hours/ha of manual labor to thresh the excess plants [1].

It is known from literature sources that high-quality, biologically homogeneous, and full-fledged sowing seeds of agricultural crops with high laboratory-field germination and potential yield are the key to a future harvest. To obtain high-quality, biologically homogeneous, and full-fledged sowing seeds of agricultural crops with high laboratory-field germination and potential yields, it is necessary to sort them according to all their most important and physical-mechanical properties [2, 3, 4, 5]. Such a requirement is met by sorting crop seeds in an electric field [6, 7, 8]. Because the electric field acts on them directed electrical force taking into account all physical-mechanical properties. As a result, in the electric field seeds are sorted by all important physical-mechanical properties, i.e. by mass, geometric size, density, electrical resistance, dielectric permeability, etc. Considering the above, we proposed sorting small seeds using the triboelectric method [9, 10, 11].

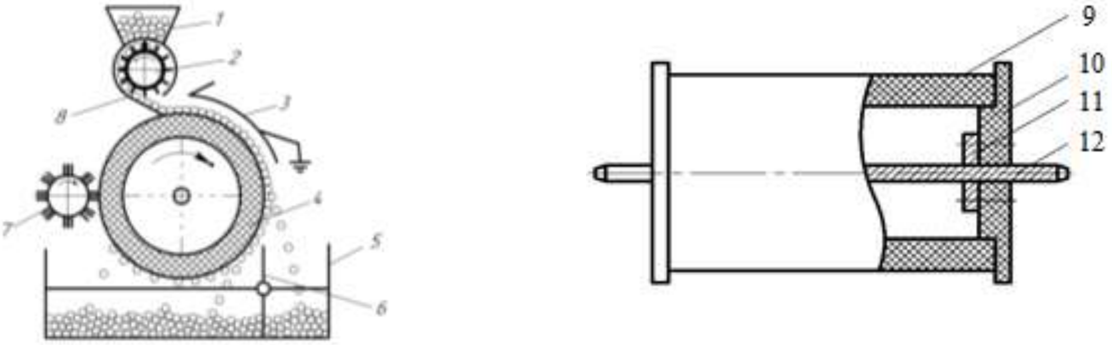
The essence of the proposed method lies in the fact that when two dielectric rotating bodies, i.e., a polyethylene tube and a dielectric brush, are rubbed against each other, a high-voltage electric field is induced on the surface of the working body. Seeds, falling on the surface of a rotating charged working element, are polarized and attracted to it by the resulting electrical force. The magnitude of the electrical force attracting the seeds to the working element's surface varies depending on their physical and mechanical properties. In this regard, depending on the ratio of the acting forces, small seeds are torn off from the surface of the rotating charged working element at different angles of rotation and fall into the corresponding fractions of the receiving bin, i.e. into the sowing or technical fractions. To substantiate the possibility of sorting fine seeds using the proposed method, an experimental sample of a triboelectric device was manufactured, and theoretical and experimental studies were conducted to sort them to obtain full-fledged sowing seeds.

Experimental research. A theoretical study of the technological process of sorting small seeds using a triboelectric device and substantiation of the angles of their separation from the surface of a rotating charged working element and the magnitude of the induced electric field strength.

A theoretical study of the technological process of sorting small seeds on a triboelectric device was carried out using the laws and rules of theoretical mechanics and electrical engineering based on mathematical analysis. Based on the results of theoretical studies, a graph was constructed of the change in the angles of separation of bell pepper seeds from their mass at different values of the induced electric field strength, and by analyzing the curves of the dependencies, a conclusion was made about the possibility of sorting small seeds on a triboelectric device.

Research results. Based on the analysis of previous studies on sorting small seeds in the electric field and taking into account the advances of science and production, a technological scheme and working organ of a triboelectric device for their sorting has been developed in recent years.

Figure 1 shows the process diagram and working part of the proposed triboelectric device for sorting small seeds.



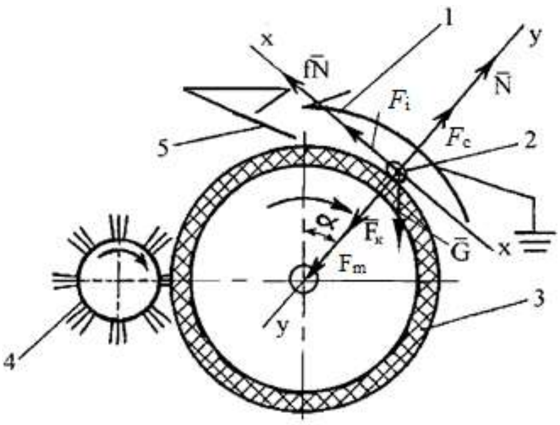
a) b)

1-loading hopper; 2-feeder; 3-grounded electrode; 4-working organ; 5-receiving hopper; 6-dividing plane; 7-brushing brush; 8-roller board; 9-polyethylene tube; 10-side discs; 11 flanks; 12 shaft

FIGURE 1. Process diagram (a) and working part (b) of the Triboelectric device

The triboelectric device consists of a loading hopper 1, a feeder 2, a grounded electrode 3, a working element 4, a receiving hopper 5, a dividing plane 6, a rubbing brush 7 and a sliding board 8. The working element 4 is made from a polyethylene pipe 9 and is secured to the shaft 12 using side disks 10 made from a dielectric material and flanges 11.

The device operates as follows. When connected to the power grid, the gear motor rotates the feeder 2, the working element 4, and the rubbing brush 7 via a chain drive. The friction of the rubbing brush 7 and the polyethylene pipe 9 generates a high-voltage electric field on the surface of the working element 4. At this point, the small seeds being sorted are fed from the loading hopper 1 in an even layer, via the feeder 2 and the chute board 8, onto the surface of the rotating, charged working element 4. Seeds, upon impact with the surface of the working element 4, are polarized and attracted to it by the resulting electrical force. In addition to the electrical force, the seeds are subject to the mirror-image force, centrifugal force, gravity, inertia, reaction, and friction. Depending on the ratio of the acting forces and, consequently, their physical and mechanical properties, they are separated from the surface of the working element 4 at various rotation angles and fall into the corresponding fractions of the receiving bin 5, i.e., the seed or technical fractions. Seeds and other light impurities adhering to the surface of the working element 4 are removed using the rubbing brush 7. Figure 2 shows a diagram of the forces acting on small seeds when they hit the surface of a rotating charged working element of a triboelectric device.



1 – grounded electrode; 2 – seeds; 3 – working element; 4 – rubbing brush; 5 – loading hopper

FIGURE 2. Diagram of forces acting on small seeds

As follows from Figure 2, the following forces act on the seeds that fall on the surface of the rotating charged working element of the triboelectric device:

1. The electric field force F_K arising under the action of an induced electric field on a charged seed [12, 13]

$$F_K = E \cdot Q = \frac{\varepsilon_0 E^2 ab\Phi_3}{4}\left(1 + 2\frac{\varepsilon_s - 1}{\varepsilon_s + 2}\right), \qquad (1)$$

where, E - is the induced electric field strength, V/m;

Q- is the charge acquired by the seeds, Cl;

ε_0= 8,85·10^{-12} F/m – Dielectric constant;

a, b – respectively, the large and small axis of the seed, m;

ε_s – relative dielectric permeability of semen;

Φ_3 – seed shape factor [14].

2. Electric force of the mirror representation F_m, arising from the interaction of a charged semen with a charged working organ [15, 16]

$$F_m = \frac{Q^2}{r_{ekv}^2} = \frac{\varepsilon_0 E^2 ab\Phi_3}{16\pi}\left(1 + 2\frac{\varepsilon_s - 1}{\varepsilon_s + 2}\right)^2, \qquad (2)$$

where, $r_{ekv}=(1/2)\sqrt{ab\Phi_3}$– the equivalent seed radius is equal to the ellipsoid surface, m.

3. Centrifugal force F_c

$$F_c = \frac{mV_s^2}{R}, \qquad (3)$$

where, m – mass of seeds, kg;

V_s – seed linear speed, m/s;

R – working parts radius, m.

4. Gravity force G

$$G=mg, \qquad (4)$$

where, g – acceleration of free fall, m/s^2.

5. Force of inertia F_i

$F_i = \frac{mdV_s}{dt}$. (5)

6. Force of reaction of working organ to seeds N.

7. Friction force F_f

$F_f = fN$, (6)

where f – is the coefficient of friction of the seed over the surface of the working member in motion.

From the diagram of forces acting on the seeds, it can be seen that the force of the electric field F_K and the electric force of the mirror display F_m press the seeds to the surface of the rotating charged working member, the centrifugal force F_c repels it, the gravity G in the first quadrant presses the seeds to it, in the second quadrant retreats from it. In this regard, depending on the ratio of the acting forces and, accordingly, the physical and mechanical properties of small seeds, it is possible to substantiate the angles of their detachment from the surface of the rotating charged working element and some operating modes of the triboelectric device.

From Figure 2, it follows that the separation of seeds from the surface of the working organ occurs when the condition N=0 is met, when

$F_K + F_m + G\cos a - F_c = 0$. (7)

By adding together in expression (7) the forces F_K, F_m, G and F_c of their values and carrying out some transformations, we obtain the following expression for determining the angle of separation of the small seeds from the surface of the rotating working part of the triboelectric device

$$\alpha = arccos\left[\frac{V_s^2}{gR} - \frac{\varepsilon_0 E^2 ab\Phi_3 L}{mg}\right], \quad (8)$$

where α is the angle of separation of the seed from the working surface, °.

Here,

$$L = \frac{1}{4}\left(1 + 2\frac{\varepsilon_s - 1}{\varepsilon_s + 2}\right) + \frac{1}{16\pi}\left(1 + 2\frac{\varepsilon_s - 1}{\varepsilon_s + 2}\right)^2. \quad (9)$$

From expression (8) it follows that, with constant design parameters and operating mode of the triboelectric device, the angle of seed separation depends on the square of the electric field strength (E) and the physical and mechanical properties (a; b; Φ_3; ε_s; m) of the seeds themselves. By changing the magnitude of the voltage of the induced electric field, it is possible to change the angle of separation of the seeds from the surface of the rotating charged working member of the triboelectric device according to their physical-mechanical properties over a wide range. The voltage of the induced electric field can be the main regulating factor when sorting small seeds on a triboelectric device.

Using formula (8) we calculate to justify the angles of separation of small seeds of different mass from the surface of rotating charged working part of triboelectric device at the following parameter values, on example of seeds of bell pepper : $V_s=V_b$=0,81 m/s; g=9,81 m/s²; R_b=0,155 m; E=3·10⁵; 4·10⁵ и 5·10⁵ V/m; a= 4,30·10⁻³ m; b=3,54·10⁻³ m; Φ_3=1,13; ε_s=7,0 и L=0,65.

Figure 3 shows the curve changes of the angles of separation of the seeds of the Bulgarian pepper from the surface of the working part according to their mass at different magnitude of the tension of the induced electric field.

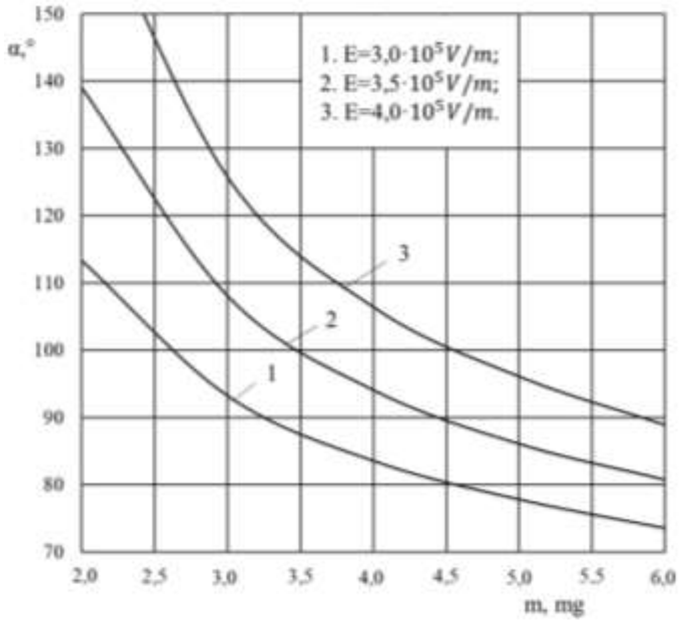


FIGURE 3. Curves of change in the angle of detachment (α) of bell pepper seeds from the surface of the working body depending on their mass (m) at different magnitudes of the electric field strength (E)

The dependence curves show that with a change in the mass of bell pepper seeds, the angle of their detachment from the surface of the working organ changes. For example, if the tear-off angle of bell pepper seeds with a mass of 3.0 mg is 103°03´, then the tear-off angle of bell pepper seeds with a mass of 6.0 mg is 84°09´ (Fig. 3, curve 2), i.e., with an increase in the seed mass, the tear-off angle from the surface of the triboelectric device's working body decreases. This is explained by the fact that with an increase in the mass of bell pepper seeds, the magnitude of the electric force of their pressure on the surface of the working organ decreases. In this regard, seeds of different masses and, accordingly, differing in physical and mechanical properties, detach from the surface of the working organ at different rotation angles. The latter allows, by correctly establishing the coordinate of the location axis of the separating plane, to qualitatively separate the sorted bell pepper seeds into various fractions, i.e., into sowing or technical fractions. From Figure 3, it is also evident that with a change in the magnitude of the induced electric field strength, the angle of rupture of bell pepper seeds of the same mass changes. For example, if at an electric field strength of 3·10⁵V/m the separation angle of 3.0 mg seeds is 86°30' (Fig. 3, curve 1), then at 5·10⁵ V/m it is 126°32' (Fig. 3, curve 3), i.e., with an increase in the magnitude of the applied electric field strength, the separation angle of the same mass seeds from the surface of the working body increases. This is explained by the fact that as the induced electric field strength increases, the electric force pressing the seeds against the surface of the working element increases, and, consequently, the angles at which they are released from it. Therefore, by varying the induced electric field strength, the angles at which small seeds are released from the surface of the rotating charged working element of the triboelectric device can be varied over a wide range.

An analysis of the dependence curves in Figure 3 shows that if bell pepper seeds weighing less than 4.5 mg are considered low-quality and unsuitable for sowing, then to sort them on the surface of the rotating charged working element of the triboelectric device, it is sufficient to create an induced electric field strength of $4 \cdot 10^5$ V/m. Increasing or decreasing the induced electric field strength from this value leads to a deterioration in the technological efficiency of their sorting.

Experimental studies of bell pepper seed sorting using a triboelectric device confirmed the results of theoretical studies. Using a triboelectric device with a working element diameter of 310 mm, a rotational speed of 50 min^{-1}, and an induced electric field strength of $4 \cdot 10^5$ V/m, high-quality, biologically uniform, and viable seeds with high laboratory and field germination rates, as well as potential yield, were obtained.

CONCLUSION

With the design parameters and operating mode of the triboelectric device constant, and the induced electric field strength remaining the same, the angle at which small seeds are lifted off the rotating working element changes as their physical and mechanical properties change, i.e., the mass of the small seeds. This allows for the accurate separation of bell pepper seeds into seed and industrial fractions by correctly positioning the separating plane.

In this case, with a change in the magnitude of the applied electric field strength, the angle of detachment of seeds of the same mass changes. In this regard, with a change in the magnitude of the induced electric field strength, it is possible to change the angle of detachment of bell pepper seeds from the surface of the rotating charged working body within wide limits, i.e., the induced electric field strength can serve as the main regulating factor when sorting small seeds on a triboelectric device.

If bell pepper seeds weighing less than 4.5 mg are considered low-quality and unsuitable for sowing, it is sufficient to create an induced electric field strength within $4 \cdot 10^5$ V/m to sort them on the surface of the rotating charged working element of the triboelectric device.

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