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NUMERICAL SIMULATION OF THE PROCESS OF PRELIMINARY SEPARATION OF THE SEED MIXTURE ON THE SCREW FEEDER OF THE VIBRO-FRICTION SEPARATOR

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The separation process is the most important stage in the preparation of seed material of small-seeded oil crops. It is based on technical-technological principles of separation of seed material, the basis of which is the difference in the physical and mechanical properties of individual components. Such properties include shape, size, mass, specific gravity, surface condition and other properties that characterize the main seed of the crop and impurities.

Since the seed mixture is a polydisperse medium in its physical essence, the theoretical studies were carried out using numerical simulation software packages that contain models of discrete elements.

The goal is to carry out a numerical simulation of the process of preliminary separation of the seed mixture on a screw feeder and to substantiate its rational design parameters.

To carry out numerical simulation of the process of separation of the seed mixture on the vibro-friction separator, the improved physical and mathematical apparatus (1)–(12) of the movement of the particle of the seed mixture component, which is included in the model of the Simcenter Star-CCM+ software package, was used.

As a result of the numerical simulation of the process of preliminary separation of the seed mixture on the screw feeder, a visualization of the process of movement of their main components (seeds of the main crop, weed seeds and plant impurities) from the accepted research factors (step of the turn of the screw plate) was obtained H_f*, angle of inclination of the screw plate* α_f*, the radius of the seed injection point* r_f*, angle of rotation of the screw plate* θ_f*).*

According to the results of the calculation, the regression equations of the second order of the dependence of the radius were obtained r_θ *from the origin of the coordinates to the point of intersection of the trajectory of the components with a line that is at a certain angle* θ_f *rotation of the screw plate, from research factors. As an evaluation criterion, the condition of expanding the distribution zone of the components of the mixture is adopted, which consists in the fact that the radius for the seeds of the main crop* $r_н$ *should be the largest, and the radius for plant impurities* $r_д$ *should be the smallest. By solving the mathematically given condition by the method of function ranking and unification into a single criterion, rational design parameters of the screw feeder of the vibro-friction separator were obtained:* $H_f = 0{,}192$ *m,* $\alpha_f = 14{,}7$ *°,* $r_f = 0{,}014$ *m,* $\theta_f = 96{,}2$ *°.*

Keywords: *seed, mixture, components, separator, feeder, fractions, parameters, screw, efficiency, modeling.*

Eq. 20. Fig. 10. Table 3. Ref. 19.

1. Problem formulation

The separation process is the most important stage in the preparation of seed material of small-seeded oil crops. It is based on technical-technological principles of separation of seed material, the basis of which is the difference in the physical and mechanical properties of individual components. Such properties include shape, size, mass, specific gravity, surface condition and other properties that characterize the main seed of the crop and impurities.

Many years of experience indicate the effectiveness of using vibro-friction separators in technological lines of post-harvest processing of seed material of agricultural crops. The working body of such separators are friction surfaces (decks), mounted in blocks of 5–40 surfaces, which are installed on the frame of the separators with the appropriate angle of transverse and longitudinal inclination. The separation of components of loose materials on the working friction surfaces of such separators is performed according to a complex of physical and mechanical properties: shape, elasticity and frictional properties [1, 2].

2. Analysis of recent research and publications

Their main drawback is the significant dependence of the efficiency of separation on the quality of the supply of the source material to the working surfaces. This is due to the fact that the main condition for the successful separation of seed mixtures is movement along the working surfaces in a monolayer, when each seed contacts the surface and reveals its inherent properties. With point loading of the seed mixture, which is implemented in modern designs of vibro-friction separators, it can enter the surface of the working bodies in several layers, and then the separation begins only after the mass is dispersed to the level of a monolayer. By this time, the seeds interact with each other, their mutual capture and deviation from the proper trajectories of movement, which reduces the efficiency of the separation process.

This drawback is eliminated in [3, 4], where the dosing of the material and its direction to each working surface is carried out with preliminary separation according to technological features, for example, according to the shape of its components, in such a way that the rounded components go to the lower part of the working surfaces, to the upper - flat, and of intermediate shape - to the middle part. But it is not yet clear what effect the design parameters of the screw feeder of the vibro-friction separator have on the process of preliminary separation of the seed mixture.

This makes it necessary to study the technological process of the preliminary separation of the seed mixture based on the mathematical model of the movement of particles along the screw surface of the feeder.

Since the seed mixture is a polydisperse medium in its physical essence, it is more efficient to carry out further theoretical research using numerical simulation software packages that contain models of discrete elements. This is confirmed by research [5–11].

The analysis of existing software packages made it possible to choose Simcenter Star-CCM+ (Siemens AG) as the working environment, which contains the largest toolkit for the discrete element method (DEM) and interaction with a continuous solid environment using computational fluid dynamics (CFD) methods [12–14].

Statistical processing of the obtained data and regression equations involved the use of the Wolfram Cloud software package, which is designed for engineering mathematical calculations [15, 16].

3. The purpose of the article

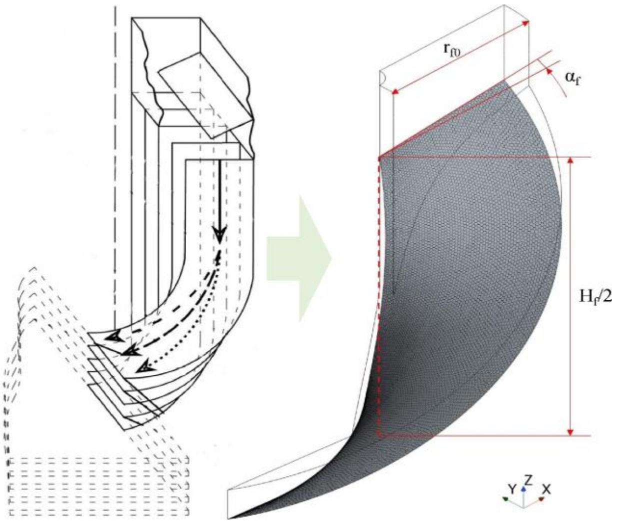
Carry out a numerical simulation of the process of preliminary separation of the seed mixture on a screw feeder and justify its rational design parameters.

4. Results of the researches

The proposed screw feeder of the vibro-friction separator includes a housing in which the guide screw plates are installed (Fig. 1, a). Screw plates are built by rotating a segment (length – r_{f0}), which is located at an angle α_f to the horizon The pitch of the spiral plate – H_f, however, only half of the turn is used for the model (Fig. 1, b).

In fig. 1 (b) a 3D model of the grid of the guide screw plate of the feeder of the vibro-friction separator is constructed. The grid is built on the basis of models: generator of polyhedral cells and generator of surface grid. The value of the basic cell size is 0.001 m. Other grid parameters in Simcenter Star-CCM+ are set by default. The grid has a mixed character: there are elements of structured and unstructured grids.

For further theoretical calculations, the rape seed mixture was chosen as the object. The analysis of the composition of the rapeseed mixture showed the presence of three groups of main components: the main crop (rapeseed seeds), plant impurities (particles of stems, leaves, etc.) and hard-to-separate weed seeds (marsupials, pikulnik, etc.). The shape of the presented components was approximated in the form of a cluster of spherical particles (Fig. 2), on which the method of discrete elements is based.



a *b*

Fig. 1. Structural and technological scheme (a) and 3D model (b) of the screw feeder of the vibro-friction separator

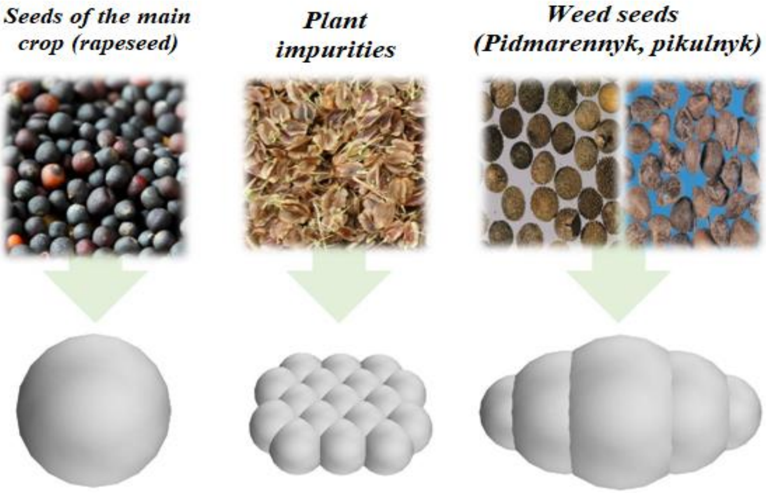


Fig. 2. Approximation of the shape of the components of the seed mixture in the form of a cluster of spherical particles

The following are selected as physical models in Simcenter Star-CCM+. For the external environment (air) is an ideal gas that can move according to the model of a separate flow. Physical and mechanical properties of air: dynamic viscosity – $1{,}85508 \cdot 10^{-5}$ Pass; molar mass – 28,96 g/mol.

For seed mixture components – Lagrangian multiphase, discrete element method, drag force, constant density, Hertz-Mindlin interaction model. The physical and mechanical properties of the components of the seed mixture are shown in Table 1. The gravity vector with coordinates was chosen as reference values [0,0; 0,0; -9,81] m/s^2.

Table 1

Average values of physical and mechanical properties of seed mixture components

Property	Seeds of the main crop (rapeseed)	Vegetable impurities	Weed seeds (podmarennik, pikulnik)
Effective diameter, mm	1,45±0,32	1,53±0,41	1,15±0,26
Actual density, kg/m^3	1150±140	530±120	950±130
Young's modulus, MPa	7,8±1,2	3,6±0,9	4,9±1,0
Poisson's ratio	0,17±0,03	0,24±0,06	0,15±0,03
The coefficient of rest friction of the particle against the wall	0,30±0,04	0,28±0,04	0,32±0,04
Recovery factor	0,59±0,10	0,11±0,04	0,26±0,11
Rolling resistance coefficient	0,130±0,018	0,320±0,084	0,230±0,032
The coefficient of friction between particles at rest	0,39±0,06	0,41±0,06	0,45±0,07

The modeling process is non-stationary and implicit. The time step is 0.001 s. The number of iterations in one time interval is 5. The Courant number for particle motion was in the range of 0.05–0.35.

Let's consider the physical-mathematical device of the movement of a particle of a seed mixture component, which is included in the model of the Simcenter Star-CCM+ software package. The equations of motion of a rounded uniform particle in a fixed coordinate system have the form (Fig. 3):

$$m\dot{\overline{\upsilon}}_p = \overline{F}_g + \overline{N} + \overline{F}_a + \overline{F}_{contact} \qquad (1)$$

where m – mass of the component, kg; $\overline{\upsilon}_p$ – component speed, m/s:

$$\overline{\upsilon}_p = \dot{\overline{r}} - \dot{\overline{a}} \qquad (2)$$

where $\overline{F}_g$ – gravity, H:

$$\overline{F}_g = \Omega_p \rho_p \overline{g}, \qquad (3)$$

where ρ_p – real density of the component, kg/m^3; Ω_p – volume of the component, m^3; $\overline{g}$ – acceleration of free fall, m/s^2; $\overline{N}$ – cnormal reaction force of the support, H; $\overline{F}_a$ – the viscous drag force of the component in air, H;

$$\overline{F}_a = \frac{1}{2}\pi D_p^2 \rho_a f_M(\mathrm{Re})\left(\overline{\upsilon}_a - \overline{\upsilon}_p\right)\left|\overline{\upsilon}_a - \overline{\upsilon}_p\right|, \qquad (4)$$

where $\overline{\upsilon}_a$ – air velocity vector, m/s; ρ_a – air density, kg/m3; D_p – effective seed diameter, m/s;

$$D_p = \left(\frac{3\Omega_p}{4\pi}\right)^{1/3}, \qquad (5)$$

where $f_M(\mathrm{Re})$ – coefficient of viscous drag; $\overline{F}_{contact}$ – force of contact interaction of the component with the wall, according to the Hertz-Mindlin spring-damper contact model [17–19], H;

$$\overline{F}_{contact} = -K_n\overline{d}_n - N_n\overline{V}_n + \frac{\left|K_n\overline{d}_n\right| C_{fs}\overline{d}_t}{\left|\overline{d}_t\right|}, \qquad (6)$$

where K_n – normal coefficient of stiffness of the elastic component of the component and the wall, kg/s^2; N_n – normal damping coefficient of the damping component and the wall, kg/s; C_{fs} – statistical coefficient of friction between the component and the wall; N_t – tangential damping coefficient of the damping component, components and walls kg/s; d_n, d_t, – virtual overlap of components and walls in the normal and tangential directions, m.

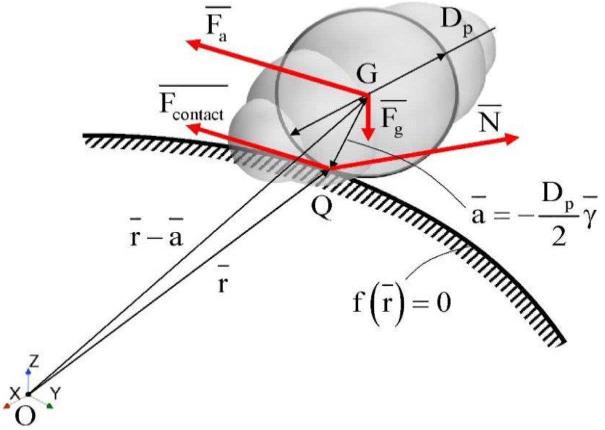


Fig. 3. Scheme of the forces acting on the component of the mixture when it moves along the surface

In turn, the law of conservation of angular momentum has the form:

$$I\dot{\overline{\omega}} = \overline{a} \times \left(\overline{N} + \overline{F}_{contact}\right), \qquad (7)$$

where $\overline{\omega}$ – angular velocity vector, rad/s; I – moment of inertia of the mixture component, kg/m^2;

$\bar{a}$ – vector from the center of mass to the point of contact, m:

$$\bar{a} = -\frac{D_p}{2}\bar{\gamma}, \tag{8}$$

where $\bar{\gamma}$ – unit vector normal to the surface:

$$\bar{\gamma} = \frac{\bar{\nabla} f\left(\bar{r}\right)}{\left|\bar{\nabla} f\left(\bar{r}\right)\right|}; \tag{9}$$

where $f\left(\bar{r}\right)$ – surface equation.

The condition of no slippage (the speed of the contact point is zero):

$$\overline{\upsilon_p} + \bar{\omega} \times \bar{a} = 0, \tag{10}$$

$$\dot{\bar{r}} + \frac{D_p}{2}\dot{\bar{\gamma}} = \frac{D_p}{2}\bar{\omega} \times \bar{\gamma}, \tag{11}$$

Considering (1), (4) and (8), equation (7) can be represented as

$$I\dot{\bar{\omega}} = \frac{mD_p^2}{4}\bar{\gamma} \times \left(\dot{\bar{\omega}} \times \bar{\gamma} + \bar{\omega} \times \dot{\bar{\gamma}}\right) + \frac{D_p}{2}\bar{\gamma} \times \left(\frac{1}{2}\pi D_p^2 \rho_a f_M\left(\mathrm{Re}\right)\left(\overline{\upsilon_a} - \overline{\upsilon_p}\right)\left|\overline{\upsilon_a} - \overline{\upsilon_p}\right| + \overline{F_g}\right), \tag{12}$$

As a result, we get a system of six equations (1) and (12), which describes the dynamics of the kinetic moment vector relative to the point of contact and the force. This system of equations is solved in Simcenter Star-CCM+, taking into account that the initial and boundary conditions of the equation in the current iteration are the solution of the system of equations in the previous iteration.

Modeling was carried out in two stages. The first stage consisted in modeling the trajectory of the movement of individual particles of the components of the seed mixture when changing the geometric parameters of the screw feeder of the vibro-friction separator. The modeling scheme and levels of variation by research factors are shown in fig. 4 and in Table 2, respectively. According to the results of numerical modeling, the trajectory of the movement of the components of the seed mixture in the horizontal plane until the moment of collision with the side wall was determined. The research was conducted according to the full-factor plan (5 factors, 5 levels) with a total of 625 experiments.

Figure 4 demonstrates that the seeds of the main crop, due to their spherical shape, move along a larger trajectory than the weed seeds and the components of plant impurities. This observation confirms the principle of operation of the screw feeder of the vibro-friction separator.

In fig. 5 shows a visualization of the numerical simulation of the process of seed movement of the main crop for different locations of the seed injection point (for different r_f). An increase in the radius of the seed injection point leads to an increase in the radius of curvature of the seed movement trajectory of the main crop. This causes the early reflection of the seed from the side wall and a change in the trajectory of movement. At the same time, further movement of seeds along the side wall is observed.

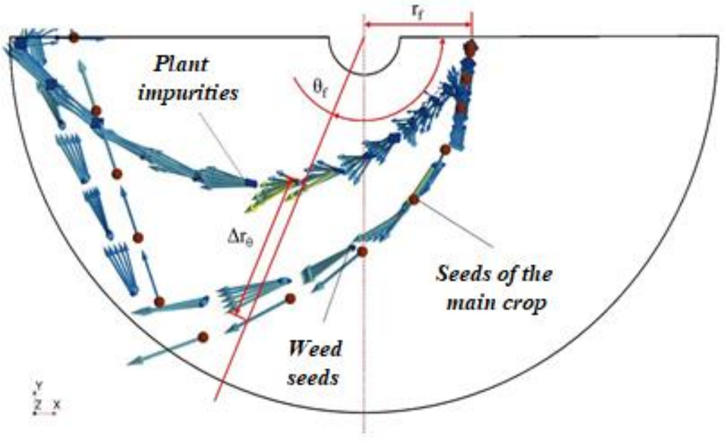


Fig. 4. Scheme of numerical simulation of the movement of individual particles of the components of the seed mixture

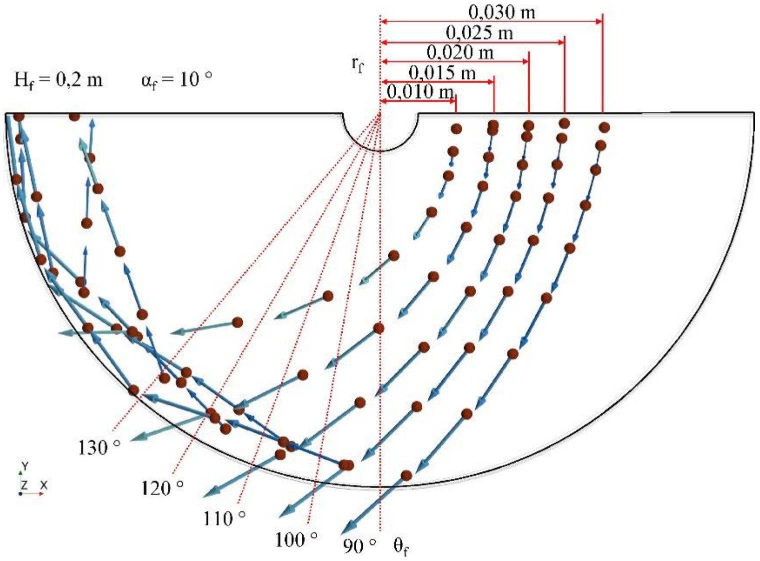


Fig. 5. Visualization of the process of moving seeds of the main crop for different locations of the seed injection point (for different r_f)

Table 2

Levels of variation by research factors

Level	The pitch of the spiral plate H_f, m	Angle of inclination of the screw plate α_f, °	The radius of the seed injection point r_f, m	Angle of rotation of the screw plate θ_f, °
Code	x_1	x_3	x_4	x_5
– 1,0	0,10	5	0,010	90
– 0,5	0,15	10	0,015	100
0	0,20	15	0,020	110
+ 0,5	0,25	20	0,025	120
+ 1,0	0,30	25	0,030	130
Δ	0,05	5	0,005	10

In fig. 6 shows a visualization of the numerical simulation of the process of moving seeds of the main crop for different angles of inclination of the screw plate α_f. An increase in the angle of inclination leads to a decrease in the radius of curvature of the trajectory of the movement of the seeds of the main crop. This causes later reflection of the seed from the side wall. At a large angle of inclination (> 25 °) movement of seeds without reflection from the side wall is observed.

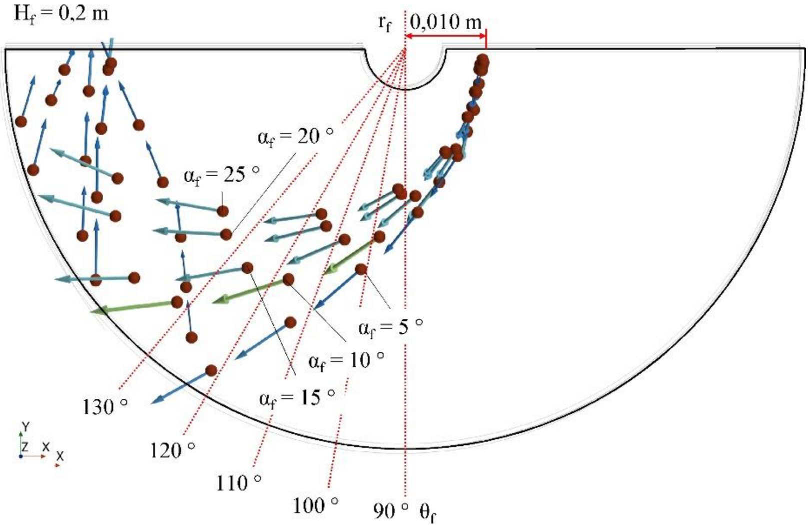


Fig. 6. Visualization of the process of moving seeds of the main crop for different angles of inclination of the screw plate α_f

In fig. 7 shows a visualization of the numerical simulation of the process of moving the seeds of the main crop for different pitches of the spiral plate H_f. An increase in the pitch of the coil leads to a decrease in the radius of curvature of the trajectory of the movement of the seeds of the main crop. This causes later reflection of the seed from the side wall.

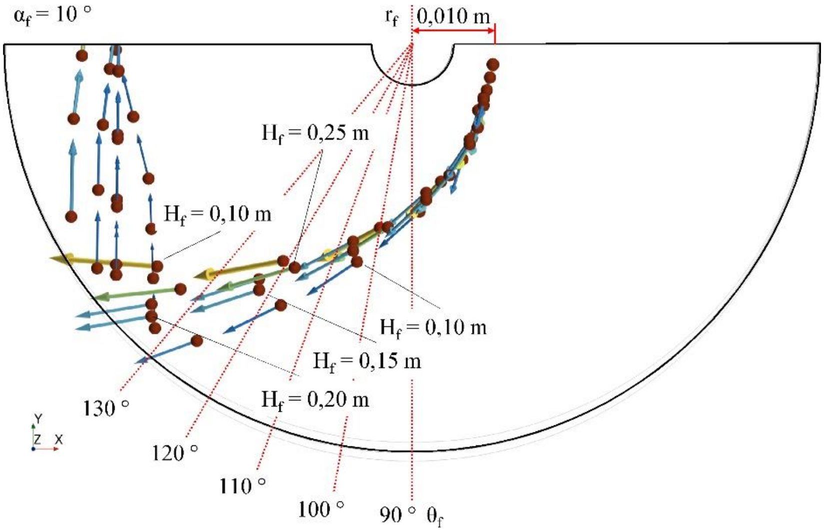


Fig. 7. Visualization of the process of moving the seeds of the main crop for different turns of the screw plate H_f

Similarly, fig. 5–6 the movement of plant impurities and weed seeds is observed. Therefore, we will calculate the radius of the point of intersection of the trajectory of the components with a line that is at a certain angle θ_f rotation of the screw plate, from research factors. Calculation of dependencies in the form of coded second-order regression equations was performed in the Wolfram Cloud software package:

– for seeds of the main crop:

$$r_н = 44{,}929 - 0{,}67504\,x_1 + 0{,}0518857\,x_1^2 + 1{,}5616\,x_2 + 0{,}18832\,x_1 x_2 - \\ - 1{,}06514\,x_2^2 + 7{,}22416\,x_3 + 0{,}8344\,x_1 x_3 + 0{,}01216\,x_2 x_3 - 5{,}69349\,x_3^2 + \\ + 2{,}18832\,x_4 + 0{,}24592\,x_1 x_4 - 0{,}01648\,x_2 x_4 - 2{,}56688\,x_3 x_4 + 0{,}56845\,x_4^2; \quad (13)$$

– for weed seeds:

$$r_б = 44{,}46 - 0{,}80528\,x_1 + 0{,}0573714\,x_1^2 + 1{,}86864\,x_2 + 0{,}2288\,x_1 x_2 - \\ - 1{,}28891\,x_2^2 + 8{,}67872\,x_3 + 1{,}00624\,x_1 x_3 + 0{,}01184\,x_2 x_3 - 6{,}7968\,x_3^2 + + 2{,}61312\,x_4 + \\ 0{,}29312\,x_1 x_4 + 0{,}0096\,x_2 x_4 - 3{,}10944\,x_3 x_4 + 0{,}678857\,x_4^2; \quad (14)$$

– for plant impurities:

$$r_д = 42{,}7261 - 1{,}12192\,x_1 + 0{,}133943\,x_1^2 + 2{,}63952\,x_2 + 0{,}31088\,x_1 x_2 - \\ 1{,}49783\,x_2^2 + 12{,}1786\,x_3 + 1{,}39936\,x_1 x_3 + 0{,}00704\,x_2 x_3 - 9{,}61874\,x_3^2 + 3{,}6992\,x_4 + 0{,}432\,x_1 \\ x_4 - 0{,}01216\,x_2 x_4 - 4{,}35184\,x_3 x_4 + 0{,}956343\,x_4^2. \quad (15)$$

The statistical processing of the obtained regression equations (13)–(15) is shown in the table. 3. For 625 experiments and a 95% confidence probability, the tabular Student coefficient (t-statistic) is 1.96.

Table 3

Statistical treatment of regression equations (13)–(15)

Coef.	(13)			(14)			(15)		
	Standard Error	t-statistic	P-Value	Standard Error	t-statistic	P-Value	Standard Error	t-statistic	P-Value
a_{00}	0,0183	2450,9	0	0,0184	2414,4	0	0,0173	2468,3	0
a_{10}	0,0100	-67,4	0	0,0100	-80,1	0	0,0094	-118,7	0
a_{20}	0,0100	156,0	0,	0,0100	185,9	0	0,0094	279,4	0
a_{30}	0,0100	722,0	0,	0,0100	863,5	0	0,0094	1289,1	0
a_{40}	0,0100	218,7	0,	0,0100	260,0	0	0,0094	391,5	0
a_{12}	0,0141	13,3	0	0,0142	16,1	0	0,0133	23,2	0
a_{13}	0,0141	58,9	0	0,0142	70,8	0	0,0133	104,7	0
a_{14}	0,0141	17,3	0	0,0142	20,6	0	0,0133	32,3	0
a_{23}	0,0141	0,85	0,390	0,0142	0,8	0,405	0,0133	0,52	0,598

Coef.	(13)			(14)			(15)		
	Standard Error	t-statistic	P-Value	Standard Error	t-statistic	P-Value	Standard Error	t-statistic	P-Value
a_{24}	0,0141	-1,16	0,244	0,0142	0,67	0,499	0,0133	-0,91	0,363
a_{34}	0,0141	-181,4	0	0,0142	-218,7	0	0,0133	-325,7	0
a_{11}	0,0169	3,06	0,002	0,0169	3,3	0,007	0,0159	8,38	0
a_{22}	0,0169	-62,9	0	0,0169	-75,8	0	0,0159	-93,7	0
a_{33}	0,0169	-336,6	0	0,0169	-400,1	0	0,0159	-602,3	0
a_{44}	0,0169	33,6	0	0,0169	39,9	0	0,0159	59,8	0

Excluding non-significant regression coefficients, that is, those in which the calculated Student coefficient (t-statistic) is less than the table one, and decoding equations (13)–(15), we finally have:

- for seeds of the main crop:

$$\begin{gathered} r_{\text{н}} = -\,11{,}9426 + 0{,}438039\,\alpha_f - 0{,}010651\,\alpha_f^2 - 41{,}8642\,H_f + 0{,}1883\,\alpha_f H_f + \\ + 5{,}18857\,H_f^2 + 0{,}0288606\,of + 0{,}12296\,H_f\,\theta_f + 0{,}00142114\,\theta_f^2 + \\ + 4244{,}71\,r_f + 834{,}4\,H_f\,r_f - 12{,}8344\,\theta_f\,r_f - 56934{,}9\,r_f^2; \end{gathered} \tag{16}$$

– for weed seeds:

$$\begin{gathered} r_{\text{б}} = -\,24{,}0525 + 0{,}527778\,\alpha_f - 0{,}0128891\,\alpha_f^2 - 50{,}0261\,H_f + 0{,}2288\,\alpha_f H_f + \\ + 5{,}73714\,H_f^2 + 0{,}0389166\,\theta_f + 0{,}14656\,H_f\,\theta_f + 0{,}00169714\,\theta_f^2 + \\ + 5095{,}54\,r_f + 1006{,}24\,H_f\,r_f - 15{,}5472\,\theta_f\,r_f - 67968,\,r_f^2; \end{gathered} \tag{17}$$

– for plant impurities:

$$\begin{gathered} r_{\text{д}} = -\,52{,}6602 + 0{,}65112\,\alpha_f - 0{,}014978\,\alpha_f^2 - 72{,}9873\,H_f + 0{,}31088\,\alpha_f H_f + \\ + 13{,}3943\,H_f^2 + 0{,}0509554\,\theta_f + 0{,}216\,H_f\,\theta_f + 0{,}00239086\,\theta_f^2 + 7178{,}99\,r_f + \\ + 1399{,}36\,H_f\,r_f - 21{,}7592\,\theta_f\,r_f - 96187{,}4\,r_f^2. \end{gathered} \tag{18}$$

The graphic visualization of dependencies (16)–(18) is shown in Fig. 8–9.

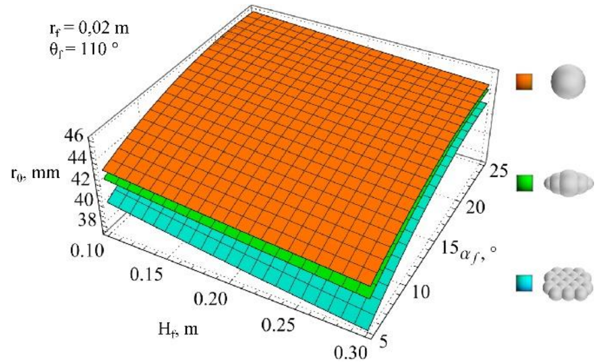


Fig. 8. Dependence of the radius r_θ from the pitch of the turn of the screw plate H_f and the angle of inclination of the screw plate α_f

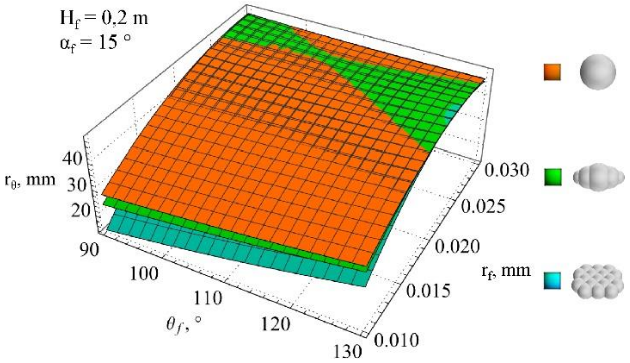


Fig. 9. Dependence of the radius r_θ from the radius of the seed injection point r_f and the angle of rotation of the screw plate θ_f

Analysis of fig. 8–9 shows that with an increase in the pitch of the spiral plate H_f the radius r for all components of the mixture decreases. In turn, increasing the angle of inclination of the screw plate α_f, the radius of the seed injection point r_f and the rotation angle of the screw plate θf leads to an increase in the radius r_θ. At the same time, the highest growth rate is observed for plant impurities, and the lowest for seeds of the main crop. This is due to the fact that the seeds of the main crop have the shape of a ball and when moving, the rotational movement, which is the same as plant impurities, prevails.

As an assessment criterion, the condition that the radius for the seeds of the main crop is accepted $r_{\text{н}}$ should be the largest, and the radius for plant impurities $r_{\text{д}}$ should be the smallest. This condition leads to the expansion of the zone of distribution of the components of the mixture. Mathematically, it can be written as follows:

$$\begin{cases} r_{\text{н}}\left(H_f, \alpha_f, r_f, \theta_f\right) \to \max, \\ r_{\text{д}}\left(H_f, \alpha_f, r_f, \theta_f\right) \to \min. \end{cases} \tag{19}$$

Expression (2.19) can be transformed by ranking the function and combining it into a single criterion:

$$K = \frac{r_{\text{н}}\left(H_f,\alpha_f,r_f,\theta_f\right) - \min\left[r_{\text{н}}\left(H_f,\alpha_f,r_f,\theta_f\right)\right]}{\max\left[r_{\text{н}}\left(H_f,\alpha_f,r_f,\theta_f\right)\right] - \min\left[r_{\text{н}}\left(H_f,\alpha_f,r_f,\theta_f\right)\right]} \times$$
$$\times \frac{\max\left[r_{\text{д}}\left(H_f,\alpha_f,r_f,\theta_f\right)\right] - r_{\text{д}}\left(H_f,\alpha_f,r_f,\theta_f\right)}{\max\left[r_{\text{д}}\left(H_f,\alpha_f,r_f,\theta_f\right)\right] - \min\left[r_{\text{д}}\left(H_f,\alpha_f,r_f,\theta_f\right)\right]} \rightarrow \max. \qquad (20)$$

The dependence graph of the optimization criterion is shown in Fig. 10.

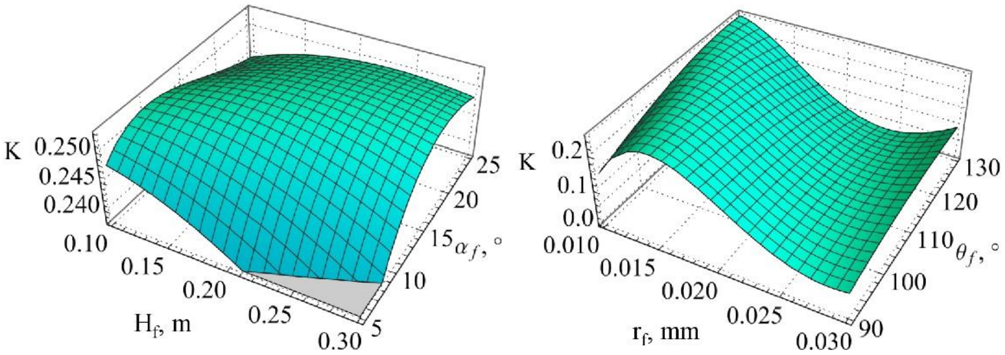


Fig. 10. Dependence of the optimization criterion K on research factors

Solving equation (20) in the Wolfram Cloud software package, we obtain the following rational values of the design parameters of the screw feeder of the vibro-friction separator: H_f = 0,192 m, α_f = 14,7 °, r_f = 0,014 m, θ_f = 96,2 °.

5. Conclusions

For the numerical simulation of the process of separation of the seed mixture on the vibro-friction separator, the improved physical and mathematical apparatus (1)–(12) of the particle movement of the seed mixture component, which is included in the model of the Simcenter Star-CCM+ software package, was used.

As a result of the numerical simulation of the process of preliminary separation of the seed mixture on the screw feeder, a visualization of the process of movement of their main components (seeds of the main crop, weed seeds and plant impurities) from the accepted research factors (step of the turn of the screw plate) was obtained H_f, angle of inclination of the screw plate α_f, the radius of the seed injection point r_f, angle of rotation of the screw plate θ_f).

According to the results of the calculation, the regression equations of the second order of the dependence of the radius were obtained r_θ from the origin of the coordinates to the point of intersection of the trajectory of the components with a line that is at a certain angle θ_f rotation of the screw plate, from research factors. As an evaluation criterion, the condition of expanding the distribution zone of the components of the mixture is adopted, which consists in the fact that the radius for the seeds of the main crop $r_{\text{н}}$ should be the largest, and the radius for plant impurities $r_{\text{д}}$ should be the smallest. By solving the mathematically given condition by the method of function ranking and unification into a single criterion, rational design parameters of the screw feeder of the vibro-friction separator were obtained: H_f = 0,192 m, α_f = 14,7 °, r_f = 0,014 m, θ_f = 96,2 °.

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ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ПРОЦЕСУ ПОПЕРЕДНЬОЇ СЕПАРАЦІЇ НАСІННЄВОЇ СУМІШІ НА ГВИНТОВОМУ ЖИВИЛЬНИКУ ВІБРОФРИКЦІЙНОГО СЕПАРАТОРА

Процес сепарації є найважливішим етапом підготовки насіннєвого матеріалу дрібнонасіннєвих олійних культур. Він заснований на техніко-технологічних принципах розділення насіннєвого матеріалу, основою яких є відмінність фізико-механічних властивостей окремих компонентів. До таких властивостей належать форма, розмір, маса, питома вага, стан поверхні та інші властивості, що характеризують основне насіння культури та домішки.

Так як насіннєва суміш є по фізичній сутності полідисперсним середовищем, то теоретичні дослідження проведені з використанням програмних пакетів чисельного моделювання, які містять моделі дискретних елементів.

Метою є проведення чисельного моделювання процесу попередньої сепарації насіннєвої суміші на гвинтовому живильнику і обґрунтувати його раціональні конструктивні параметри.

Для проведення чисельного моделювання процесу сепарації насіннєвої суміші на віброфрикційному сепараторі використано удосконалений фізико-математичний апарат (1)–(12) руху частинки компонента насіннєвої суміші, який закладено в моделі програмного пакету Simcenter Star-CCM+.

В результаті чисельного моделювання процесу попередньої сепарації насіннєвої суміші на гвинтовому живильнику отримано візуалізацію процесу переміщення їх основних компонентів (насіння основної культури, насіння бур'янів і рослинних домішок) від прийнятих факторів досліджень (крок витка гвинтової пластини H_f, кут нахилу гвинтової пластини α_f, радіус точки інжекції насіння r_f, кут повороту гвинтової пластини θ_f).

За результатними розрахунку отримані рівняння регресії другого порядку залежності радіусу r_θ від початку координат до точки перетину траєкторії руху компонентів із лінією, яка знаходиться під певним кутом θ_f повороту гвинтової пластини, від факторів дослідження. В якості критерію оцінки прийнята умова розширення зони розподілу компонентів суміші, яка полягає в тому, що радіус для насіння основної культури $r_н$ повинен бути найбільшим, а радіус для рослинних домішок $r_д$ повинен бути найменшим. Вирішуючи математично задану умову методом ранжування функції і об'єднання у єдиний критерій отримані раціональні конструктивні параметри гвинтового живильника віброфрикційного сепаратора: $H_f = 0{,}192$ м, $\alpha_f = 14{,}7$ °, $r_f = 0{,}014$ м, $\theta_f = 96{,}2$ °.

Ключові слова: *насіння, суміш, компоненти, сепаратор, живильник, фракції, параметри, гвинт, ефективність, моделювання.*

Ф. 20. Рис. 10. Табл. 3. Літ. 19.

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