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Results of Numerical Modelling of the Process of Separation of Seed Material of Small-Seeded Crops on a Cylindrical Cell Trier

Abstract. The relevance of this study is conditioned upon the need to increase the amount of high-quality seed material of small-seeded crops, which cannot be achieved without an important process of separation. The separation is based on technical and technological principles of separation of seed material, depending on the differences in physical and mechanical properties of individual components of seed material. Cylindrical triers are used to separate seeds according to their length. The purpose of the study was to find the theoretical regularities of changes in the technological parameters of separation of the seed material of small-seeded crops from the structural and mode parameters of a cylindrical seed trier by numerical modelling. The solution of the set problems was implemented in the STAR-CCM+ programme based on the finite element method. Considering the physical and mechanical properties of the seed material, as a result of the study, a visualisation of the separation process was obtained depending on the research factors: the rotation frequency of the trier cylinder, the diameter of the cylinder, and the number of seeds and impurities in the seed mixture. According to the simulation results, the dependence of the relative content of impurities ε on factors under study was obtained in the form of second-order regression equations. Using the Mathematica programme, a compromise problem was solved, which lies in minimising the multiplicative function of the research criteria, and the rational constructive and technological parameters of the trier separator were found. The material of this paper is intended for scientists, graduate students, designers of agricultural machinery, students, and specialists in agricultural production

Keywords: mechanisation, separators, seed material, separation process

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INTRODUCTION

At various stages of seed processing of small-seeded crops, a separation process is used, the basis of which is the technical and technological principles of seed separation, based on differences in the physical and mechanical properties of individual components, among which one should note the shape, size, mass, specific weight, surface condition, and other properties inherent in the main seed and impurities. Carefully selected seed cleaning equipment has a considerable impact on the quality of its separation.

To separate the seeds, which differ in length, seed cleaning machines, namely cylindrical triers, are used. Their working body is a cylinder with an inner shell surface and a collection hopper installed on the axial support of the cylinder. The principle of operation of the trier is based on the rotation of the cylinder, during which seeds with different geometric sizes fall into the cells [1]. Long seeds have low resistance at rest and are carried towards rotation of the cylinder and fall out of the shell at a certain angle. Short seeds have high resting resistance and fall out of the pods, but at a different angle. All the seeds must fall out of the pods, and this depends on the structural parameters of the equipment, which include the rotation frequency of the cylinder and its diameter.

The purpose of this study was to find the theoretical regularities of changes in the technological parameters of separation of seed material of small-seeded crops from the structural and operational parameters of the cylindrical cell trier by numerical modelling and establishing rational structural and technological parameters of the trier separator.

In connection with the growing needs for high-quality visualisation with the possibility for the viewer to immerse

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himself in a virtual environment, a preliminary feasibility study was performed, the purpose of which was to find the advantages and disadvantages associated with visualisation in a virtual environment of the CAVE type [2]. The study [3] described the development of a method for predicting events that occur when the diesel fuel flow hits the walls of the combustion chamber. A mathematical model of the films on the walls of the chamber formed as a result of spraying was constructed. The paper [4] investigated the experimental data on the distribution of solid particles in horizontal pipelines, which were modelled using computational fluid dynamics (CFD) and the discrete element method (DEM). In [5], using the STAR-CCM+ software package, conditions for increasing the efficiency of removing small particles from the cyclone were applied. The paper [6] describes an attempt to visualise the behaviour of the flow in various geometric conditions of the pipe. The authors obtained the values of pressure and velocity contours on various parts of the pipe in which water is the medium.

Models of ideal extrusion and mixing, diffusion, and combined models have become widespread among modern researchers [7; 8].

A scientific originality of this study lies in the use of numerical modelling to investigate the separation of seed material of small-seeded crops on a cylindrical trier.

MATERIALS AND METHODS

Based on the above-mentioned studies, it was proposed to solve the problems in the STAR-CCM+ programme, which is based on the finite element method.

The numerical modelling is performed using the following methods and approaches [9]: analysis of the structure of material flows, empirical method, approach of the mechanics of continuous media, statistical method, entropy-information method.

As a seed model, mustard seeds were accepted, the physical and mechanical properties of which were as follows: Poisson's ratio – 0.5; Young's modulus – 0.2 MPa; density – 700 kg/m^3; coefficient of rest friction – 0.8; normal recovery factor – 0.5; tangent coefficient of recovery – 0.5; the coefficient of rolling resistance – 0.3. The model of the mustard seed is a sphere. Therewith, the seeds can have an effective diameter within the $d_g \in [dgmax_{gmin}]$ range, where d_{gmin} 0.001 m is the minimum value of the effective seed diameter, m; d_{gmax}=0.003 m is the maximum value of the effective seed diameter, m.

The seed mixture was presented in the form of two components: seeds of the main crop and impurities [10].

The following physical and mechanical properties were adopted as a model of impurities in the seed mixture: Poisson's ratio – 0.5; Young's modulus – 0.2 MPa; density – 700 kg/m^3; coefficient of rest friction – 0.8; normal recovery factor – 0.5; tangent coefficient of recovery – 0.5; the coefficient of rolling resistance – 0.3. In this case, the effective diameter of impurities obeys the normal distribution. Therewith, impurities can have an effective diameter within the $d_g \in [dgmax_{gmin}]$ range, where d_{gmin}=0.002 m is the minimum value of the effective diameter of the impurity, m; d_{gmax}=0.004 m is the maximum value of the effective diameter of the admixture, m.

The properties of the environment were as follows: environment – air; dynamic viscosity – 1.85508·10-5 Pa·s; turbulent Prandtl number – 0.9; acceleration of free fall – 9.8 m/s^2; temperature – 293 K; pressure – 101,325 Pa. The calculation scheme of the cylindrical cell trier is presented in Figure 1.

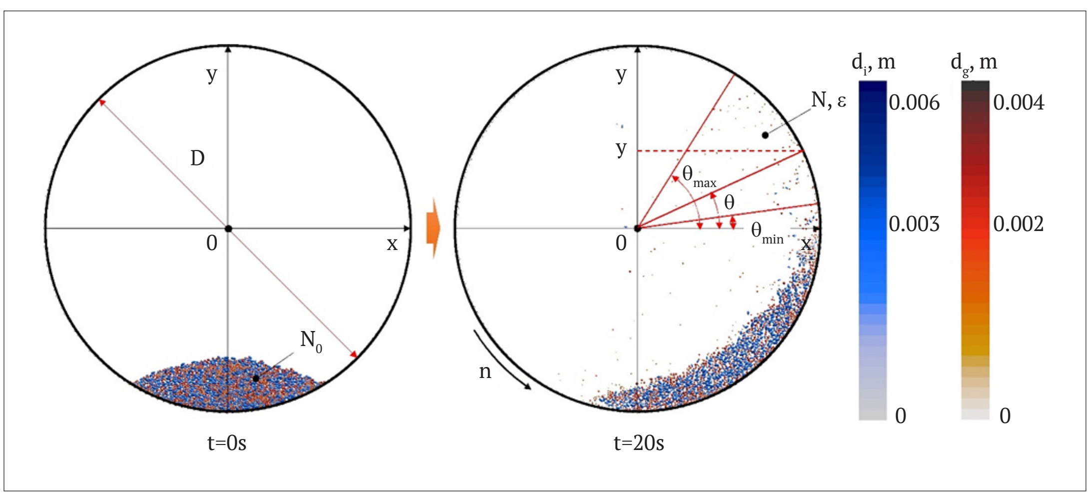

Figure 1. Calculation scheme of a cylindrical shell trier for numerical modelling in the STAR-CCM+ software package

Factors for numerical modelling are the diameter of the trier separator cylinder *D*, its rotation frequency *n* and the number of seeds in the seed mixture N_0 at the initial time. The levels of variation by factors are presented in Table 1. Numerical modelling was implemented using a fully factorial experiment. The total number of experiments was 5^3=125.

Table 1. Levels of variation by numerical modelling factors

Level	Factor		
	Trier cylinder diameter D, m (x_1)	Trier cylinder rotation frequency n, rpm (x_2)	The number of seeds and impurities in the seed mixture N_0, pcs (x_3)
-1.0	0.2	30.0	1,000
-0.5	0.3	37.5	2,000
0	0.4	45.0	3,000
+0.5	0.5	52.5	4,000
+1.0	0.6	60.0	5,000

The minimum θ_{min} and maximum θ_{max} values were determined from the list of values of the angle θ of seed exit from the pod.

The number of all components of the seed mixture N, which were within the minimum θ_{min} and maximum θ_{max} angles of rotation of the trier separator cylinder, was chosen as a performance criterion.

The criterion for evaluating the quality of the separation process was the relative content of impurities θ in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder.

As a result of data processing in the Mathematica software package, it was necessary to establish the dependence of the above-mentioned criteria of the separation process on research factors in the form of second-order regression equations.

Statistical processing of the obtained data in the Mathematica software package consisted in determining the Student's criterion [11] for each coefficient of the regression equation and comparing it with the table value. If the calculated value is less than the table value, then the coefficient of the regression equation is insignificant and can be ignored.

The obtained regression equation was checked for adequacy using the Fisher test [12] and the correlation coefficient [13-15].

RESULTS AND DISCUSSION

The dependence of the values of the minimum θ_{min} and the maximum θ_{max} values of the angles of seed exit from the cell of the trier cylinder on research factors, which was obtained using the Mathematica programme, has the following coded form:

$$\begin{aligned}\theta_{min} = 0{,}311838 - 0{,}0758691\, x_1 - 0{,}0252283 x_1^2 + \\ +0{,}246916 x_2 - 0{,}00964664\, x_1 x_2 + 0{,}0125726 x_2^2 + \\ + 0{,}104465\, x_3 - 0{,}00984237\, x_1 x_3 + \\ +0{,}081428\, x_2 x_3 + 0{,}0366488\, x_3^2 ,\end{aligned} \quad (1)$$

$$\begin{aligned}\theta_{max} = 0{,}989517 + 0{,}277431 x_1 - 0{,}0739117 x_1^2 + \\ +0{,}499129\, x_2 + 0{,}0953195 x_1 x_2 - 0{,}0359794\, x_2^2 - \\ - 0{,}00436025 x_3 + 0{,}00296865 x_1 x_3 - \\ -0{,}00305847 x_2 x_3 - 0{,}0160532 x_3^2 .\end{aligned} \quad (2)$$

Statistical processing of Equations (1) and (2) are presented in Tables 2 and 3, respectively.

Table 2. Results of statistical processing of Equation (1)

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	0.311838	0.00917538	33.9864	$4.14411 \cdot 10^{-43}$
a_{10}	-0.0758691	0.0046433	-16.3395	$1.0548 \cdot 10^{-24}$
a_{20}	0.246916	0.00536162	46.0524	$2.41186 \cdot 10^{-51}$
a_{30}	0.104465	0.00536162	19.4839	$7.70832 \cdot 10^{-29}$
a_{12}	-0.00964664	0.00656662	-1.46904	0.146645
a_{13}	-0.00984237	0.00656662	-1.49885	0.138754
a_{23}	0.081428	0.00758248	10.739	$4.843 \cdot 10^{-16}$
a_{11}	-0.0252283	0.00804243	-3.1369	0.00256524
a_{22}	0.0125726	0.00906279	1.38727	0.170097
a_{33}	0.0366488	0.00906279	4.04388	0.000141885

Table 3. Results of statistical processing of Equation (2)

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	0.989517	0.0229487	43.1186	$1.52231 \cdot 10^{-49}$
a_{10}	0.277431	0.0116135	23.8887	$6.77808 \cdot 10^{-34}$
a_{20}	0.499129	0.0134101	37.2205	$1.49665 \cdot 10^{-45}$
a_{30}	-0.00436025	0.0134101	-0.325148	0.746114
a_{12}	0.0953195	0.0164239	5.80371	$2.10038 \cdot 10^{-7}$
a_{13}	0.00296865	0.0164239	0.180752	0.857125
a_{23}	-0.00305847	0.0189647	-0.161272	0.872379
a_{11}	-0.0739117	0.0201151	-3.67444	0.000484351
a_{22}	-0.0359794	0.0226671	-1.58729	0.1173
a_{33}	-0.0160532	0.0226671	-0.708216	0.481343

Comparing the calculated Student's criterion with the tabular $t_{0.05}(125)=1.98$, insignificant regression coefficients were rejected. As a result, the Equations (1) and (2) are transformed as follows:

$$\theta_{min} = 0{,}311838 - 0{,}0758691x_1 - 0{,}0252283\,x_1^2 + 0{,}246916\,x_2 + 0{,}104465x_3 + 0{,}081428x_2x_3 + 0{,}0366488x_3^2, \quad (3)$$

$$\theta_{max} = 0{,}989517 + 0{,}277431\,x_1 - 0{,}0739117\,x_1^2 + 0{,}499129\,x_2 + 0{,}0953195\,x_1x_2 \quad (4)$$

By substituting the expressions for research factors into equations (3-4) instead of x_1–x_3 in an explicit form, one can obtain the dependence of the values of the minimum θ_{min} and the maximum θ_{max} of the values of the angles of seed exit from the cell of the trier cylinder on the research factors in a decoded form:

$$\theta_{min} = -0{,}0858955 + 0{,}12522\cdot D - 0{,}630707\cdot D^2 + 0{,}00831824\cdot n - 0{,}000124883\,N_0 + 2{,}71427\cdot 10^{-6}n\cdot N_0 + 9{,}1622\cdot 10^{-9}\cdot N_0^2, \quad (5)$$

$$\theta_{max} = -0{,}786462 + 1{,}43559\cdot D - 1{,}84779\cdot D^2 + 0{,}020566\cdot n + 0{,}0317732\cdot D\cdot n \quad (6)$$

Graphical interpretation of dependences (5-6) is presented in Figures 2-4.

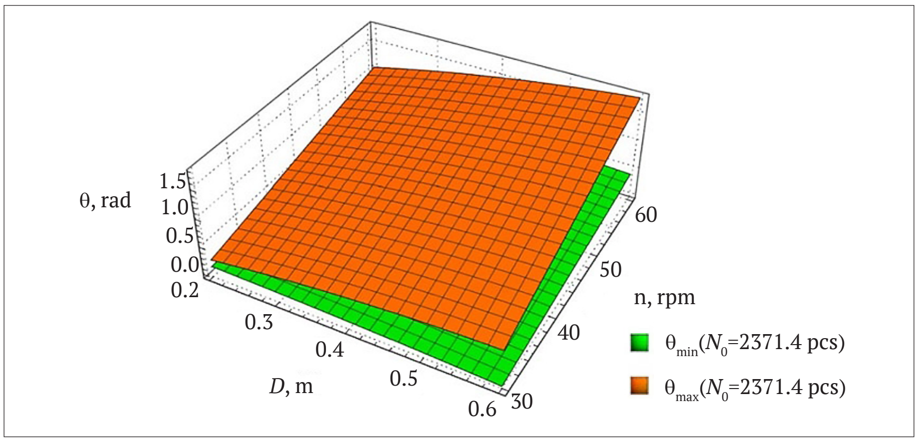

Figure 2. The dependence of the values of the minimum θ_{min} and the maximum θ_{max} values of the angles of seed exit from the cell of the trier cylinder on the diameter of the trier cylinder *D* and the rotation frequency of the trier cylinder *n*

Figure 2 demonstrates that with an increase in the rotation frequency of the cylinder and an increase in its diameter, the values of the angles of seed exit from the cell of the trier cylinder increase. The maximum seed exit angle is observed at the maximum rotation frequency of the cylinder, namely *n*=60 rpm and the maximum diameter *D*=0.6 m, and is θ_{max}=1.5 rad. The smallest value of the maximum seed exit angle is observed at the minimum rotation frequency of the cylinder, namely *n*=30 rpm and the smallest diameter *D*=0.2 m, and is θ_{max}=0.3–0.4 rad. Figure 2 shows that with an increase in the cylinder rotation frequency, the minimum seed departure angle θ_{min} increases, which is 0.4 rad at a cylinder rotation frequency *n*=60 rpm. At the minimum rotation frequency of the cylinder, namely *n*=30 rpm, the minimum seed exit angle θ_{min} is 0 rad. This is because at the minimum rotation frequency of the cylinder, the seed material practically does not move in the cylinder and does not reach the region θ_{min}.

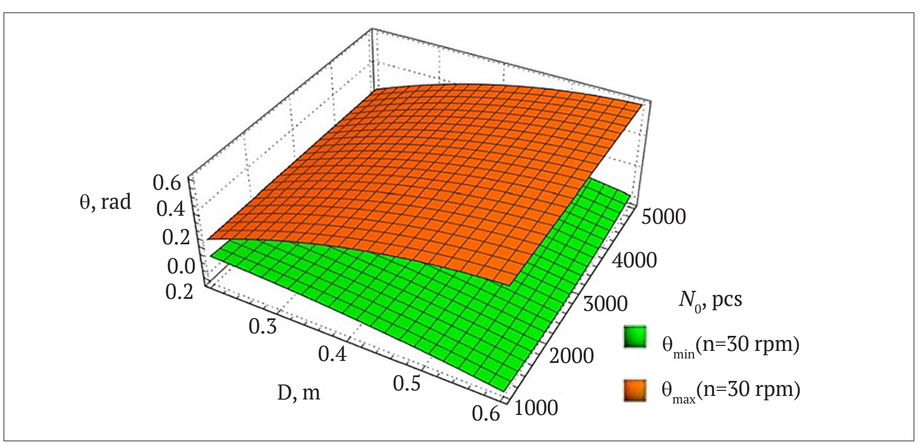

Figure 3. Dependence of the values of the minimum θ_{min} and maximum θ_{max} values of the angles of seed exit from the cell of the trier cylinder on the diameter of the trier cylinder *D* and the number of seeds and impurities in the seed mixture N_0

Figure 3 shows that as the diameter of the cylinder D decreases and the number of seeds in the mixture N increases, the value of the minimum seed exit angle θ_{min} increases. This is explained by the fact that at the minimum value of the diameter of the cylinder D, namely D=0.2 m, the seed material is practically not moved or is moved forming a thick layer of seed material, among which a dead layer is formed. On the contrary, the maximum angle of exit of the seed from the cell θ_{max} increases with an increase in the diameter of the cylinder D. This is explained by the fact that the seed material is better distributed on the inner surface of the cylinder and forms a thin layer that is easier to move when the trier cylinder rotates. The amount of seed material does not affect the maximum angle of exit of the seed from the cell θ_{max} at different values of the diameter of the cylinder D.

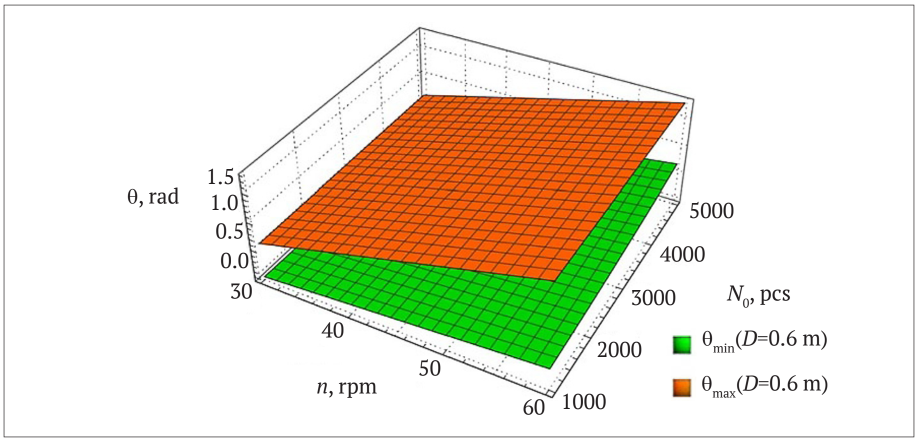

Figure 4. The dependence of the values of the minimum θ_{min} and the maximum θ_{max} values of the angles of seed exit from the cell of the trier cylinder on the rotation frequency of the trier cylinder n and the number of seeds and impurities in the seed mixture N_0

Figure 4 shows that the values of the minimum θ_{min} and maximum θ_{max} of the seed exit angles increase with an increase in the rotation frequency of the trier cylinder n. The values of the minimum seed exit angle θ_{min} increase with an increase in the rotation frequency of the trier cylinder n, and these values also depend on the number of seeds and impurities in the seed mixture N_0. Figure 4 demonstrates that with an increase in the amount of seed material, the minimum angle θ_{min} of seed exit from the pod increases. This is explained by the fact that at a higher rotation frequency of the trier cylinder n, more seed material is distributed over the inner surface of the trier cylinder in the direction of rotation of the cylinder, and the smaller the dead layer of seed material is formed.

The maximum angle of exit of the seed from the cell θ_{max} also increases with an increase in the rotation frequency of the trier cylinder n. The amount of seed material does not affect the maximum angle of exit of the seed from the cell θ_{max}.

Statistical analysis of Equations (5) and (6) in the variation range under study showed that the Pearson correlation coefficient is 0.82 and 0.85, respectively. In turn, Fisher's criterion was $F_{(7)}=2.27<F_t=2.49$ and $F_{(8)}=2.17<F_t=2.49$, respectively. This confirms the adequacy of the obtained models.

The dependence of the values of the number of all components of the seed mixture N that were within the minimum θ_{min} and maximum θ_{max} angles of rotation of the trier separator cylinder on the research factors, which was obtained using the Mathematica programme, has the following coded form:

$$N = 235{,}731 - 47{,}14\,x_1 + 47{,}74\,x_1^2 + 165{,}44x_2 + \\ +59{,}26x_1x_2 + 29{,}8667\,x_2^2 + 170{,}96x_3 - \\ -88{,}6x_1x_3 + 90{,}6133x_2x_3 - 2{,}20952\,x_3^2 \quad (7)$$

Statistical processing of Equation (7) is presented in Table 4.

Table 4. Results of statistical processing of Equation (9)

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	235.731	12.0203	19.6112	$5.36449\cdot10^{-29}$
a_{10}	-47.14	6.08299	-7.74948	$8.13362\cdot10^{-11}$
a_{20}	165.44	7.02403	23.5534	$1.54678\cdot10^{-33}$
a_{30}	170.96	7.02403	24.3393	$2.26924\cdot10^{-34}$
a_{12}	59.26	8.60264	6.88858	$2.72815\cdot10^{-9}$
a_{13}	-88.6	8.60264	-10.2992	$2.72282\cdot10^{-15}$
a_{23}	90.6133	9.93347	9.12202	$3.02192\cdot10^{-13}$
a_{11}	47.74	10.536	4.53111	0.000025749
a_{22}	29.8667	11.8728	2.51556	0.0143649
a_{33}	-2.20952	11.8728	-0.1861	0.852946

Comparing the calculated Student's criterion with the tabular $t_{0.05}(125)=1.98$, the insignificant regression coefficients were excluded. As a result, the Equation (7 is transformed as follows:

$$N = 235{,}731 - 47{,}14\,x_1 + 47{,}74x_1^2 + \\ +165{,}44x_2 + 59{,}26x_1\,x_2 + 29{,}8667\,x_2^2 + \\ +170{,}96x_3 - 88{,}6x_1x_3 + 90{,}6133\,x_2x_3 \quad (8)$$

By substituting into equation (10) instead of x_1–x_3 the expressions for research factors in an explicit form, one obtains the dependence of the values of the number of all components of the seed mixture *N* that were within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder on the research factors in a decoded form:

$$N = 534{,}531 - 1414{,}9\,D + 1193{,}5D^2 - \\ -17{,}88\,n + 19{,}753\,D\,n + 0{,}132741\,n^2 + \\ +0{,}03816\,N_0 - 0{,}2215\,D\,N_0 + 0{,}00302044\,n\,N_0 \quad (9)$$

The optimal values of the factors under the condition of the maximum amount of all components of the seed mixture (*N*=816 pcs) are *D*=0.2 m, n=60 rpm, N_0=5,000 pcs.

The graphical interpretation of the dependence (9) is presented in Figures 5-7.

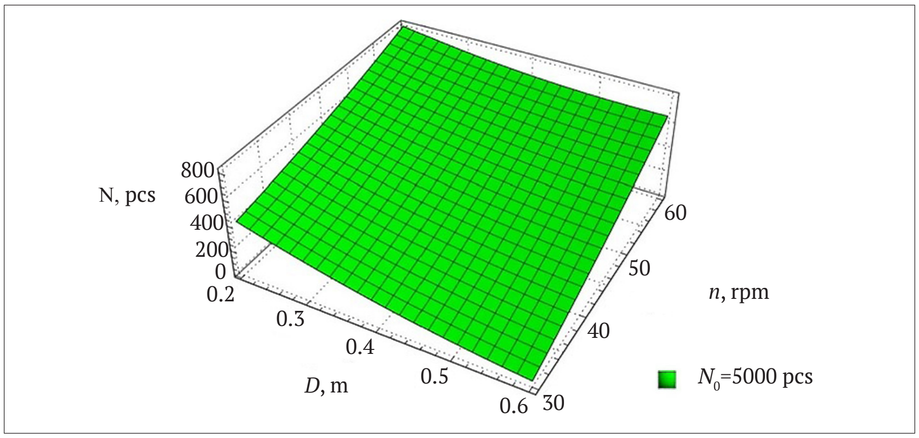

Figure 5. The dependence of the values of the number of all components of the seed mixture *N*, which were within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder on the diameter of the trier cylinder *D* and the rotation frequency of the trier cylinder *n*

Figure 5 shows that the values of the number of all components of the seed mixture *N* increase with a decrease in the diameter of the cylinder and an increase in the frequency of rotation of the cylinder *n*. With an increase in the rotation frequency of the cylinder, the seed will reach the cells more often and, accordingly, the seed will be more efficiently separated into the main crop and impurities. The diameter of the trier cylinder *D* is also important because with a larger diameter, less seed material reaches the area between the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder.

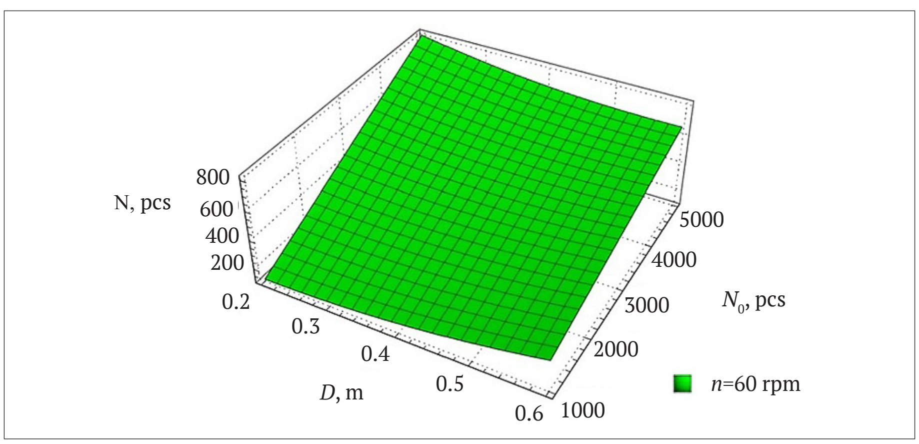

Figure 6. The dependence of the values of the number of all components of the seed mixture *N*, which were within the minimum θ_{min} and maximum θ_{max} rotation angles of the cylinder of the trier separator on the diameter of the cylinder of the trier *D* and the number of seeds and impurities in the seed mixture N_0

Figure 6 shows that the number of all components of the seed mixture *N*, which were within the minimum θ_{min} and maximum θ_{max} angles of rotation of the trier separator cylinder, increases with the increase in the total number of all components of the seed mass N_0. In addition, Figure 6 demonstrates that the number of all components of the seed mixture N, which were within the minimum θ_{min} and maximum θ_{max} angles of rotation of the cylinder of the trier separator, increases with an increase in the diameter of the cylinder D.

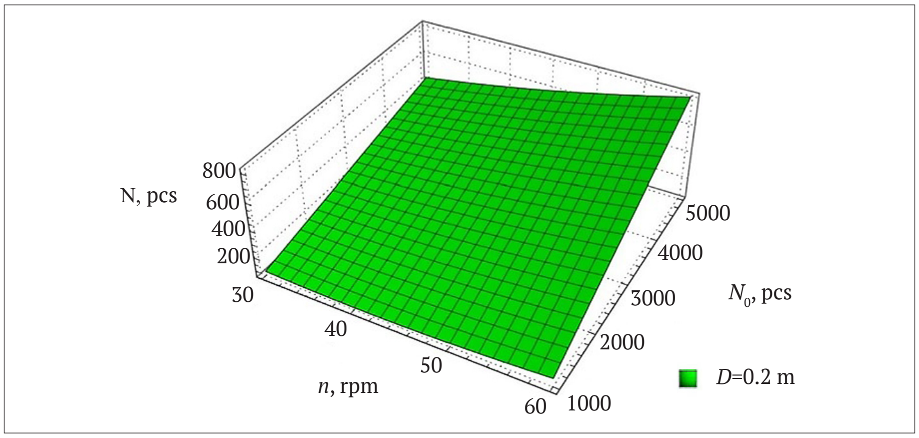

Figure 7. The dependence of the values of the number of all components of the seed mixture N, which were within the minimum θ_{min} and maximum θ_{max} angles of rotation of the cylinder of the trier separator, on the frequency of rotation of the cylinder of the trier n and the number of seeds and impurities in the seed mixture N_0

Figure 7 shows that the rotation frequency of the cylinder n at the minimum value N_0 (N_0=1,000 pcs) practically does not affect the value of the number of all components of the seed mixture N, which were within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder. As the values of N_0 and the cylinder rotation frequency n increase, the values of the amount of seed material N increase. The amount of seeds and impurities in the seed material N_0 affects the amount of seed material N that was within the minimum θ_{min} and maximum θ_{max}: the greater the amount of N_0, the greater the amount of material reached the required limits.

Statistical analysis of Equation (9) in the variation range under study showed that the Pearson correlation coefficient is 0.83 and 0.85, respectively. In turn, Fisher's criterion was $F_{(7)}=2.11<F_t=1.87$ and $F_{(8)}=2.17<F_t=2.49$, respectively. This confirms the adequacy of the obtained models.

The dependence of the relative content of impurities ε in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder, on the research factors, which was obtained using the Mathematica programme, has the following coded form:

$$\varepsilon = 11{,}9176 - 11{,}2438\,x_1 + 5{,}25111\,x_1^2 + \\ +1{,}25032\,x_2 + 0{,}95207\,x_1x_2 - 0{,}203757\,x_2^2 + \\ +2{,}28584\,x_3 + 0{,}593043\,x_1x_3 - 2{,}9289x_2x_3 + \\ +4{,}12055\,x_3^2 \quad (10)$$

Statistical processing of Equation (10) is presented in Table 5.

Table 5. Results of statistical processing of Equation (12)

Coefficient	Value	Error	Student's t-test	Probability
a_{00}	11.9176	0.866702	13.7505	$6.51748\cdot10^{-21}$
a_{10}	-11.2438	0.438604	-25.6353	$1.06553\cdot10^{-35}$
a_{20}	1.25032	0.506456	2.46876	0.0161966
a_{30}	2.28584	0.506456	4.51339	0.0000274407
a_{12}	0.95207	0.62028	1.5349	0.129661
a_{13}	0.593043	0.62028	0.956089	0.34257
a_{23}	-2.9289	0.716237	-4.08929	0.000121504
a_{11}	5.25111	0.759684	6.91222	$2.47842\cdot10^{-9}$
a_{22}	-0.203757	0.856067	-0.238015	0.812618
a_{33}	4.12055	0.856067	4.81335	$9.21338\cdot10^{-6}$

Comparing the calculated Student's criterion with the tabular $t_{0.05}(125)=1.98$, the insignificant regression coefficients were excluded. As a result, the Equation (10) is transformed as follows:

$$\varepsilon = 11{,}9176 - 11{,}2438x_1 + 5{,}25111\,x_1^2 + \\ +1{,}25032\,x_2 + 2{,}28584x_3 - \\ - 2{,}9289\,x_2x_3 + 4{,}12055\,x_3^2 \quad (11)$$

By substituting into Equation (11) instead of x_1–x_3 the expressions for research factors in explicit form, one obtains the dependence of the relative content of impurities ε in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder, on the research factors in decoded form:

$$\varepsilon = 44{,}321 - 161{,}241\,D + 131{,}278\,D^2 + \\ +0{,}376244\,n - 0{,}000644556\,N_0 - \\ -0{,}00009763\,n\,N_0 + 1{,}03014\cdot10^{-6}N_0^2 \quad (12)$$

The optimal values of the factors under the condition of the minimum relative content of impurities in the seed mixture (ε=3.02%) are *D*=0.6 m, *n*=30 rpm, N_0=1734 pcs.

A graphical interpretation of dependence (12) is presented in Figures 8-10.

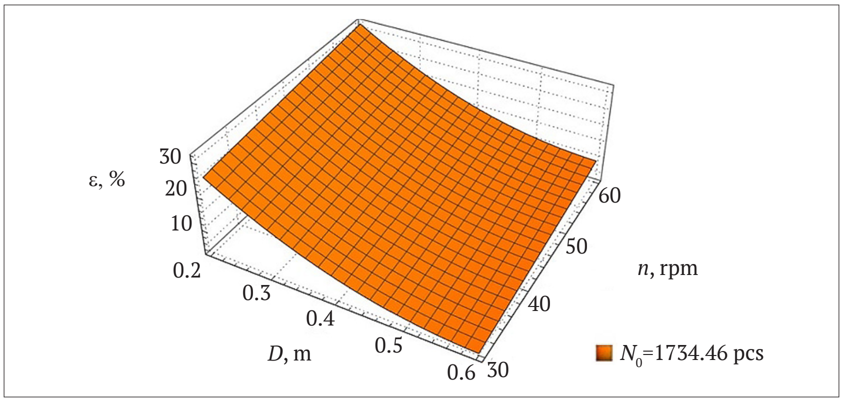

Figure 8. The dependence of the relative content of impurities ε in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder on the diameter of the trier cylinder *D* and the rotation frequency of the trier cylinder *n*

Figure 8 shows that as the cylinder diameter *D* decreases, the relative content of impurities ε in the seed mixture increases. This is explained by the fact that with a smaller diameter, the efficiency of separating seed material is considerably reduced. The speed of rotation of the cylinder n also affects the relative content of impurities in the seed material. When the values of the frequency n increase, the relative content of impurities ε increases.

Figure 9 demonstrates that the relative content of impurities ε in the seed mixture increases with a decrease in the diameter of the cylinder and an increase in the number of seeds and impurities in the seed mixture N_0. The maximum amount of seed material (N_0=4,000 pcs, N_0=5,000 pcs) is more rationally divided using a cylinder with a larger diameter, namely *D*=0.5-0.6 m.

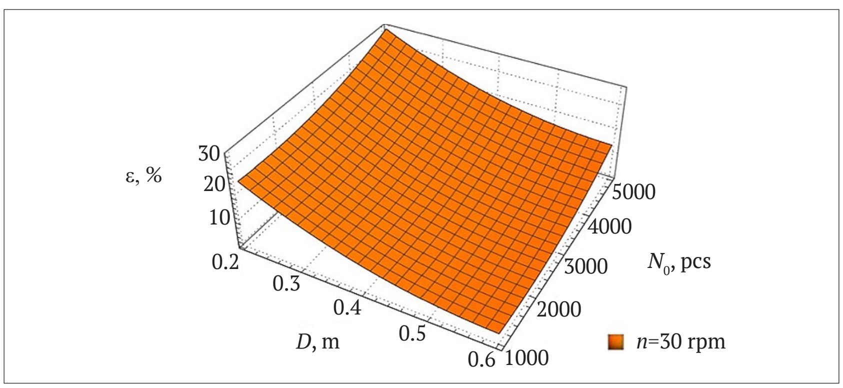

Figure 9. The dependence of the values of the relative content of impurities ε in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} angles of rotation of the cylinder of the trier separator on the diameter of the cylinder of the trier D and the number of seeds and impurities in the seed mixture N_0

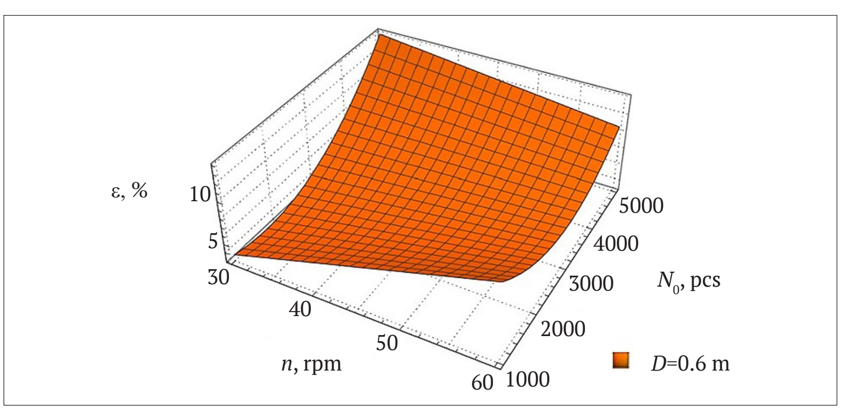

Figure 10. The dependence of the values of the relative content of impurities ε in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} rotation angles of the cylinder of the trier separator on the rotation frequency of the cylinder of the trier n and the number of seeds and impurities in the seed mixture N_0

Figure 10 shows that the largest values of the relative content of impurities ε occur in two cases: with the minimum value of the cylinder rotation frequency n=30 rpm and the maximum amount of seed mixture N_0=5,000 pcs, the relative content of impurities ε in the seed mixture is ε=13%; at the maximum value of the cylinder rotation frequency n=60 rpm and the minimum amount of seed mixture N_0=1,000 pcs, the relative content of impurities ε in the seed mixture is ε=12-14%.

Statistical analysis of equations (12) in the variation range under study showed that the Pearson correlation coefficient is 0.88 and 0.87, respectively. In turn, Fisher's criterion was $F_{(7)}=1.84<F_t=2.49$ and $F_{(8)}=1.98<F_t=2.49$, respectively. This confirms the adequacy of the obtained models.

Since the optimal values of factors according to individual research criteria do not coincide, the following compromise problem is to be solved:

$$\begin{cases} \varepsilon(D,n,N_0) \to min, \\ N(D,n,N_0) \to max. \end{cases} \quad (13)$$

Problem (13) will be solved by the method of scalar ranking by minimising the multiplicative function considering the importance coefficient of the private criterion:

$$\frac{\frac{N}{max(N)}}{\frac{\varepsilon}{max(\varepsilon)}} \to max$$

where *max* is the maximum function value.

Using the Mathematica programme, solving equation (14) together with (9) and (12) gives rational structural and technological parameters of the trier separator: D=0.58 m, n=46.8 rpm, N_0=2,722 pcs. With these parameters, the optimisation criteria were equal to N=251 units, ε=5.89%, θ_{min}=0.22 rad, θ_{min}=1.26 rad.

Similar, but this time practical studies [16], were conducted by a scientist from Denmark, who investigated the behaviour of seed material during separation in a cylindrical trier. The author obtained a linear dependence between the rotation frequency of the cylinder and the angle of fall of the seeds from the cylinder pods. As a result, the scientist obtained the optimal values of the diameters of the pods and the frequency of rotation of the cylinder, namely: for three mixtures of hemp and rice, the optimal ranges of the diameter of the pods were 6.5-7 mm, and the frequency of rotation from 36.71 rpm to 42.60 rpm; for the three mixtures of hemp and wheat, the optimal value of the cell diameter was 6.5 mm, and the optimal range of rotation frequency was from 36.71 rpm to 39.73 rpm.

CONCLUSIONS

As a result of the numerical simulation of the process of separation of seed material of small-seeded crops on a cylindrical seed trimmer in the Star CCM+ software package, the dependence of the values of the minimum θ_{min} and maximum θ_{max} of the angles of seed exit from the seed cylinder trimmer on the research factors was obtained in the form of second-order regression equations. The number of all components of the seed mixture N, which were within the minimum θ_{min} and maximum θ_{max} angles of rotation of the trier separator cylinder, was chosen as a performance criterion. According to the simulation results, the dependence of the number of all components of the seed mixture N on research factors was obtained in the form of second-order regression equations. The criterion for evaluating the quality of the separation process was the relative content of impurities ε in the seed mixture, which was within the minimum θ_{min} and maximum θ_{max} rotation angles of the trier separator cylinder. According to the simulation results, the dependence of the relative content of impurities ε on factors under study was obtained in the form of second-order regression equations. Solving the compromise problem using the scalar ranking method by minimising the multiplicative function considering the importance coefficient of the private criterion in the Mathematica software package, which is reduced to minimising the relative content of impurities ε and maximising the number of all components of the seed mixture N that were within the minimum θ_{min} and maximum θmax angles of rotation of the cylinder, the rational design and technological parameters of the trier separator were obtained: D=0.58 m, n=46.8 rpm, N_0=2,722 pcs. With these parameters, the optimisation criteria were equal to N=251 units, ε=5.89%, θ_{min}=0.22 rad, θ_{min}=1.26 rad. Considering the obtained parameters, the next stage of research is to conduct an experiment using a laboratory setup to confirm the simulation results and further improve the existing trier separator by developing a mechatronic system that allows controlling the parameters of the trier and obtaining the optimal sorting result at the output.

REFERENCES

[1] Aliiev, E., & Lupko, K. (2021). Prerequisites for the creation of a mechatronic system of indented cylinders for the separation of fine seeds. *Scientific Horizons*, 24(3), 75-86.

[2] Broas, P. (2001). Advantages and problems of CAVE-visualisation for design purposes. In M. Lehtonen (Ed.), *Virtual prototyping VTT research programme 1998-2000* (pp. 73-81). Otaniemi: Technical Research Centre of Finland.

[3] Bai, C. (1996). *Modelling of spray impingement processes*. (Doctoral thesis, University of London, London, Great Britain).

[4] Kubicki, D., & Lo, S. (2012). Slurry transport in a pipeline – comparison of CFD and DEM models. In *Ninth international conference on CFD in the minerals and process industries* (pp. 1-6). Melbourne: University of Melbourne.

[5] Han, S.W., Lee, W.J., & Lee, S.J. (2012). Study on the particle removal efficiency of multi inner stage cyclone by CFD simulation. *World Academy of Science, Engineering and Technology*, 6, 411-415.

[6] Satish, G., Ashok, K.K., Vara, P.V., & Pasha, S.M. (2013). Comparison of flow analysis of a sudden and gradual change of pipe diameter using fluent software. *International Journal of Research in Engineering and Technology*, 2, 41-45.

[7] Ivanets, V.N., Bakin, I.A., & Belousov, G.N. (2002). Entropy approach to the evaluation of the process of mixing bulk materials. *Storage and Processing of Agricultural Raw Materials*, 11, 16-18.

[8] Bakin, I.A., Belousov, G.N., & Sablinsky, A.I. (2001). Modeling of the mixing process by the entropy-information method. In *New technologies in scientific research in education: Materials of the All-Russian scientific-practical conference* (pp. 34-40). Yurga: Yurga Technological Institute.
[9] Iguchi, M., & Ilegbusi, O.J. (2014). *Basic transport phenomena in materials engineering*. Dordrecht: Springer.
[10] Shevchenko, I., Aliev, E. (2018). Research on the photoelectronic separator seed supply block for oil crops. *INMATEH-Agricultural Engineering*, 1(54), 129-138
[11] Grzhybovsky, A. (2008). The choice of a statistical criterion for testing hypotheses. *Human Ecology*, 11, 48-57.
[12] Mocny, F. (2019). Analysis of nonparametric and parametric criteria for testing statistical hypotheses. *Statistics of Ukraine*, 1, 13-23.
[13] Prishenko, O., Chernogor, T., & Buhkalo, S. (2019). Some features of correlation analysis. In *Information technology: Science, technology, technology, education, health* (pp. 320-322). Kharkiv: V. N. Karazin Kharkiv National University.
[14] Buhkalo, C., Iglin, S., Glavcheva, Y., & Miroshnichenko, N. (2018). Possibilities of determining the components of complex projects. *Bulletin of the National Technical University "KhPI"*, 40, 46-52.
[15] Dreyper, N. (2006). *Applied regression analysis*. Moscow: Finance and statistics.
[16] Buus, O.T. (2013). *Analysis of the indented cylinder by the use of computer* vision (Doctoral thesis, University of Southern Denmark, Aarhus, Denmark).

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

[1] Aliiev E., Lupko, K. Prerequisites for the creation of a mechatronic system of indented cylinders for the separation of fine seeds. *Scientific Horizons*. 2021. Vol. 24, No. 3. P. 75–86.
[2] Broas P. Advantages and problems of CAVE-visualisation for design purposes. *Virtual prototyping VTT research programme 1998–2000* / M. Lehtonen (Ed.). Otaniemi: Technical Research Centre of Finland, 2001. P. 73–81.
[3] Bai C. Modelling of spray impingement processes: Doctoral thesis, degree of doctor of philosophy. London: University of London, 1996. 449 p.
[4] Kubicki D., Lo S. Slurry transport in a pipeline – comparison of CFD and DEM models. *Ninth international conference on CFD in the minerals and process industries* (Melbourne, 10-12 December, 2012). Melbourne, 2012. P. 1–6.
[5] Han S.W., Lee W.J., Lee S.J. Study on the particle removal efficiency of multi inner stage cyclone by CFD simulation. *World Academy of Science, Engineering and Technology*. 2012. Vol. 6. P. 411–415.
[6] Satish G., Ashok K.K., Vara P.V., Pasha S.M. Comparison of flow analysis of a sudden and gradual changeof pipe diameter using fluent software. *International Journal of Research in Engineering and Technology*. 2013. Vol. 2. P. 41–45.
[7] Иванец В.Н., Бакин И.А., Белоусов Г.Н. Энтропийный поход к оценке процесса смешивания сипучих материалов. *Хранение и пераработка сельскохозяйственного сырья*. 2002. № 11. С. 16–18.
[8] Бакин И.А., Белоусов Г.Н., Саблинский А.И. Моделирование процесса смешивания энтропийно-информационным методом. *Новые технологи в научных исследованиях в образовании: материалы Всероссийской научно-практической конференции* (г. Юрга, 25 февраля 2001 г.). Юрга, 2001. С. 34–40.
[9] Iguchi M., Ilegbusi O.J. Basic transport phenomena in materials engineering. Dordrecht: Springer, 2014. 277 p.
[10] Shevchenko I., Aliev E. Research on the photoelectronic separator seed supply block for oil crops. *INMATEH-Agricultural Engineering*. 2018. Vol. 1, No. 54. С. 129–138.
[11] Гржибовский А.М. Выбор статистического критерия для проверки гипотез. *Экология человека*. 2008. Вып. 11. С. 48–57.
[12] Моцний Ф.В. Аналіз непараметричних і параметричних критеріїв перевірки статистичних гіпотез. *Статистика України*. 2019. № 1. С. 13–23.
[13] Пріщенко О.П., Черногор Т.Т., Бухкало С.І. Деякі особливості проведення кореляційного аналізу. *Інформаційні технології: наука, техніка, технології, освіта, здоров'я*: тези доповідей XXVII міжнар. наук.-практ. конференції (Харків, 15–17 травня 2019). Харків, 2019. С. 320–322.
[14] Бухкало С.І., Іглін С.П., Главчева Ю.М., Мірошниченко Н.М. Можливості визначення компонентів складових комплексних проектів. *Вісник НТУ «ХПІ»*. 2018. Вип. 1316, № 40. С. 46–52.
[15] Дрейпер Н. Прикладной регрессионный анализ. Москва: Финансы и статистика, 2006. 57с.
[16] Buus O.T. Analysis of the indented cylinder by the use of computer vision: Doctoral thesis, degree of doctor of philosophy. Aarhus: University of Southern Denmark, 2013. 169 p.

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Результати чисельного моделювання процесу сепарації насіннєвого матеріалу дрібнонасіннєвих культур на циліндричному чарунковому трієрі

Анотація. Актуальність дослідження зумовлена необхідністю збільшення кількості якісного насіннєвого матеріалу дрібнонасіннєвих культур, що неможливо досягти без важливого процесу сепарації. Сепарація заснована на техніко-технологічних принципах розділення насіннєвого матеріалу в залежності від відмінностей фізико-механічних властивостей окремих складових насіннєвого матеріалу. Для сепарації насіння за ознакою довжини призначені циліндричні трієри. Метою дослідження є визначення теоретичних закономірностей зміни технологічних параметрів процесу сепарації насіннєвого матеріалу дрібнонасіннєвих культур від конструктивно-режимних параметрів циліндричного чарункового трієра шляхом чисельного моделювання. Вирішення поставлених задач реалізовано в програмі STAR-CCM+ на базі методу кінцевих елементів. Враховуючи фізико-механічні властивості насіннєвого матеріалу, в результаті дослідження отримано візуалізацію процесу сепарації в залежності від факторів досліджень: частоти обертання циліндра трієра, діаметра циліндра та кількості насінин і домішок в насіннєвій суміші. За результатами моделювання отримано залежність у вигляді рівнянь регресії другого порядку відносного вмісту домішок ε від факторів досліджень. З використанням програми Mathematica вирішено компромісну задачу, яка полягає в мінімізації мультиплікативної функції критеріїв досліджень і визначені раціональні конструктивно-технологічні параметри трієрного сепаратора. Матеріал статті призначений для науковців, аспірантів, конструкторів сільськогосподарської техніки, студентів і фахівців сільськогосподарського виробництва

Ключові слова: механізація, сепаратори, насіннєвий матеріал, розділення