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Study of the Process of Purifying Grain from Light Impurities and Dust

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Abstract. *The study's aim is wheat grain cleaning from light impurities and dust and the development of a statistical model and identification of the main kinetic dependencies during the cleaning process. For the study, an experimental method of grain cleaning and processing of experimental studies on grain cleaning using the Matlab software package was used. The obtained regression equations results made it possible to estimate the value of the cleaning coefficient depending on the technological parameters of the cleaning process (from the height of the chamber, the thickness of the incoming grain layer and air velocity). Rational process modes were chosen due to the factors under study which have an ambiguous effect on the cleaning coefficient (air velocity and thickness of the incoming grain layer, chamber height). As a result of optimizing the grain cleaning process, rational values of the chamber height, air velocity and thickness of the incoming grain layer were determined, which ensure the maximum values of the cleaning coefficient. The main design difference of the proposed installation is perforated shutters for airflow input and dust-air mixture output, which are installed along with the height of the pneumatic chamber with a certain angle of inclination, which ensures uniform distribution of the airflow around the entire perimeter. The volume of the chamber contributes to better entrainment of light impurities and dust. The scope is relevant for the primary processing of freshly harvested grain and the grain processing industry.*

Keywords: *grain mixtures, cleaning, light impurities cleaning coefficient, blinds, mathematical model, pneumatic system, grain cleaning machine.*

Introduction

Ensuring the safety of the quality of the freshly harvested grain, at the stages of its post-harvest processing (cleaning, drying), is especially important during the period of grain harvesting.

The process of cleaning grain is carried out on machines with pneumatic systems. The process of separating grain from large impurities (spikelet, straw residues, etc.) and light impurities (husks, small weed seeds, etc.) in pneumatic systems of grain pre-cleaning machines occurs by airflow [1-3]. However, as the main working element modern grain cleaning machines for preliminary cleaning of grain heaps with a pneumatic system do not fully meet requirements in terms of their performance.

In the research works [8], the use of preliminary stratification of a granular mixture with an increase in the concentration of light impurities in the upper layer of the mixture was considered. In this work, mathematical models are obtained for determining the trajectory of the particles under discussion, considering the previous separation of mixtures, and the corresponding dependencies are established. As a part of the study, the influence of the initial coordination of the introduction of particles of light impurities, their sizes, and densities, as well as the technological and design parameters of the air separator operation are taken into account.

Another study [4] presents data on the cleaning of the grain mixture with the consistent use of airflow during aspiration and multi-tiered placement of sorting grates in grate mills. The authors proposed to increase the proportion of sorting grids in mills to 70...80% and the airflow velocity in the pre-filter cleaning channel to 8.0 m/s to improve air-sieve seed-cleaning machines.

Different study [10] related to a multivariate analysis was performed to establish the regularities of the process of pneumatic separation of a straw heap by three pneumatic channels with a variation in the kinematic parameters of pneumatic separators. The effect on the separation process of the probabilistic characteristics of the supply of a heterogeneous heap, the distribution of airflow velocities over the width of the pneumatic separators and the probability densities of the speeds of the heap components hovering are estimated. The process of heap pneumoseparation at each section of the pneumochannel is considered and shared components of the heap components and their percentages in each isolated fraction are shown. The possibility of pneumoseparation of the crushed straw heap into specified fractions at given productivity of 0.6-0.7 kg/m·s has been revealed. It has been established that with the rational functioning of the pneumatic separator, the straw content in the business fraction is 97.03%.

Other work was carried out [14] on the calculation of technological parameters and separation efficiency of a universal grain cleaning machine, where based on the developed models, the technological parameters of the universal grain cleaning machine were calculated for the operating modes for preliminary, primary, and secondary cleaning of grain.

The study [15] regarding the prospects of the processes of separating the seed grain mass into fractions are substantiated. The relationship between the effective coefficient of dynamic viscosity and the density of particles in the discrete and continuous phases and the volume concentration of particles of the discrete phase in the obtained mechanical-mathematical model of separation of the grain mass in a pseudo-boiling layer according to its density was established. In this case, the porosity of the fluidized layer, the longitudinal and transverse angles of inclination of the base surface to the horizontal plane, the amplitude and frequency of oscillations of particles of the continuous phase were considered, the angle of the vibration direction relative to the perpendicular to the base surface. The simulation results in rational values of the amplitude and frequency of vibrations of the working surface of the pneumatic sorting table, as well as the angles of inclination of the working surface were obtained.

The authors also analyze the simulated process of separating grain impurities from the fraction of light sludge in the zone of the suction window fan [1]. The resulting mathematical model adequately describes the process of fractionation of light waste in the sedimentary zone of the suction chamber in the diametrical window of the fan.

In the other different research works [4-8], the authors used the well-known equations of theoretical mechanics for the acting forces in the horizontal and vertical planes, which are mathematically flawless. Their further calculations of certain dynamics of the process are revealed. The relationship between the mathematical model and experimental studies is shown. Experimental data are confirmed by theoretical studies of mathematical description and modelling in the form of a polydisperse two-phase flow, taking into account concentration, inertia, relaxation time, and drag coefficient. But the increase in productivity and throughput reduces the functioning of the installation. The authors had difficulties with the simultaneous regulation of the fan speed, overpressure, airflow, and grain flow supply [8].

The development of a more advanced grain flow separation technology and its implementation are hampered by several factors: a variety of grain crops and methods for its separation; the complexity of the process of interaction of particles of separated materials with the airflow and the working bodies of the machine; insufficient development of the theoretical foundations of separation by airflow and methods to justify the choice of operating modes of machines [9-11].

Therefore, the aim of this work was to study and search for rational modes of grain cleaning from light impurities and dust to improve the cleaning efficiency and develop a statistical model for grain cleaning.

To achieve this goal, it was necessary to justify the choice of rational regimes for the process of cleaning grain from light impurities and dust.

Materials and methods

The study of the process of cleaning grain from light impurities and dust was carried out on an experimental setup (Figure 1), which consists of body 1; perforated dampers for the airflow inlet 2 and the dust-air mixture outlet 3; a valve for regulating and establishing the thickness of the incoming grain 4; inclined grate for loosening grain 5; receiving bin for initial grain 6; cyclone for separating dust from air 7; valve for adjusting and setting the height of the chamber 8; cleaned grain bunker 9; cargo valve 10; anemometer testo 416 (serial number 03621531, Germany, measuring range 0.6-40 m/s) 11; airspeed damper 12; fan 13; bag filter 14; dust collector 15; valve 16.

The main distinguishing features of the proposed [12] design of a device for cleaning grain from impurities:

- a device for cleaning grain from dust includes a working area between two louvred pipes, louvered pipes for removing the dusty air mixture are connected to a common aspiration system;
- blinds, which are formed louvre nozzles, are made perforated;
- above the working area of the air chamber there is a guide grid that serves to feed the incoming layer of grain into the working area;
- shutters for airflow inlet and air mixture outlet are located in parallel and at a certain angle of inclination, and the gap (step) between the shutters for input and output along the height of the device is constant.

The working length of the suction louvre pipes 3 is regulated by changing the height of gate 8. The thickness of the incoming grain layer is regulated by valve 4 located under hopper 6.

The original grain from the receiving hopper 6 enters the pneumatic chamber, where it is subjected to intensive action of the airflow sucked in by the fan of the aspiration system. Air enters the working area through perforated louvres 3 to enter the airflow. Due

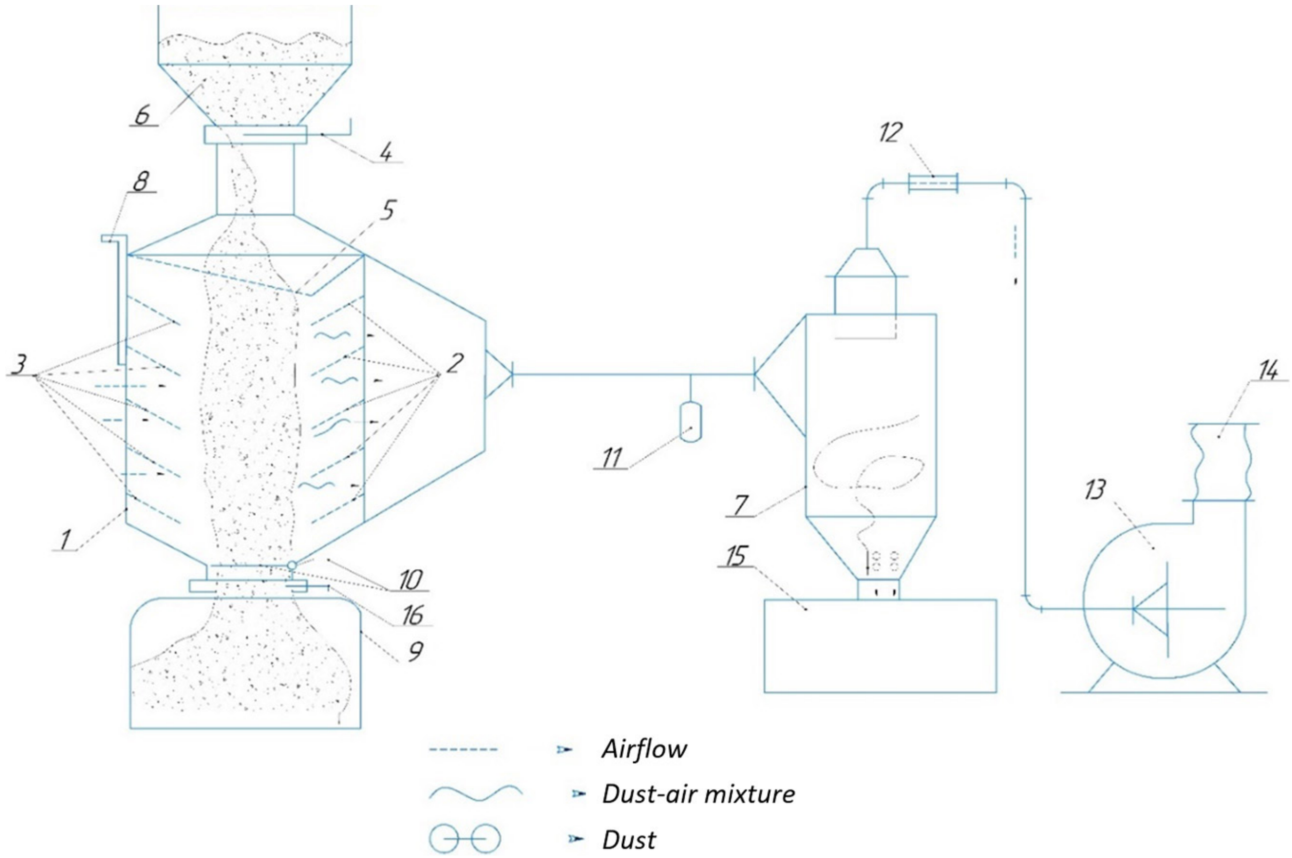

Figure 1 – Experimental installation for cleaning from light impurities and dust: 1 – pneumatic chamber body; 2 – perforated blinds for removing the dust-air mixture; 3 – perforated blinds for airflow entry; 4 – gate valve for regulating and receiving an incoming consumer; 5 – inclined grate for loosening the consumer; 6 – receiving hopper for the initial consumer; 7 – cyclone for separating dust from the air; 8 – gate valve for regulating and holding the chamber; 9 – bunker for cleaning the executive body; 10 – cargo valve; 11 – anemometer; 12 – gate for airspeed control; 13 – fan; 14 – bag filter; 15 – dust collector; 16 – gate valve

to the loosened state of the grain, air easily penetrates the intergranular space of the incoming grain layer. The perforation in shutters 2 and 3 reduces the aerodynamic resistance of the shutters themselves and ensures uniform distribution of the airflow in the chamber. Dust together with air (air mixture) is sent to the aspiration system through the louvre pipes to remove the dust-air mixture. The cleaned grain is sent down to cyclone 7.

A special device was made (Figure 2), which is a vertical cylinder 4 with a diameter of 80 mm, divided in height by a porous partition 3 made of belting and a metal sieve. On top of the cylinder, in the outlet of the outlet air duct, a bag filter 5 made of special material is installed. Inside the filter, there are sieves with a hole size of 250 microns to retain light impurities [16].

The maximum dust removal in this installation is ensured at a filtration rate $\upsilon = 2.5$ m/s, a purge time $\tau = 30$ s, and a grain layer height in the cylinder $H = 40$ mm. The assumed air filtration rate of 2.5 m/s is ensured by the location of valve 3 installed at the fan outlets.

The sequence of experiments: wheat with a total weight of 1640 kg, to be cleaned, was mixed in a special auger mixer, and passed through the conveyor 7 until a homogeneous mass was obtained. In five places, a sample with a total weight of at least 5 kg was taken from the total mass of grain using a special sampler. A certain mass of grain from the sample taken was placed in a cylinder so that its height did not exceed 40 mm, and blown through the porous partition with a fan for 30 s. Then, the mass of dust isolated from the grain sample was determined by the weight gain of the filter. At each purge, the weight of the sample of grain was strictly considered. For the calculation, the average values of the mass of the ejected dust were taken after each blowing of the grain sample.

Before the start of the experiment, the dust content of the initial grain was determined. The sequence of experiments: wheat with a total weight of 320 kg, to be cleaned, was mixed in a special auger mixer, and passed through a conveyor until a homogeneous mass was obtained. In five places, a sample with a total weight of at least 5 kg was taken from the total mass of grain using a special sampler. A certain mass of grain from the sample taken was placed in a cylinder so that its height did not exceed 40 mm, and blown through the porous partition with

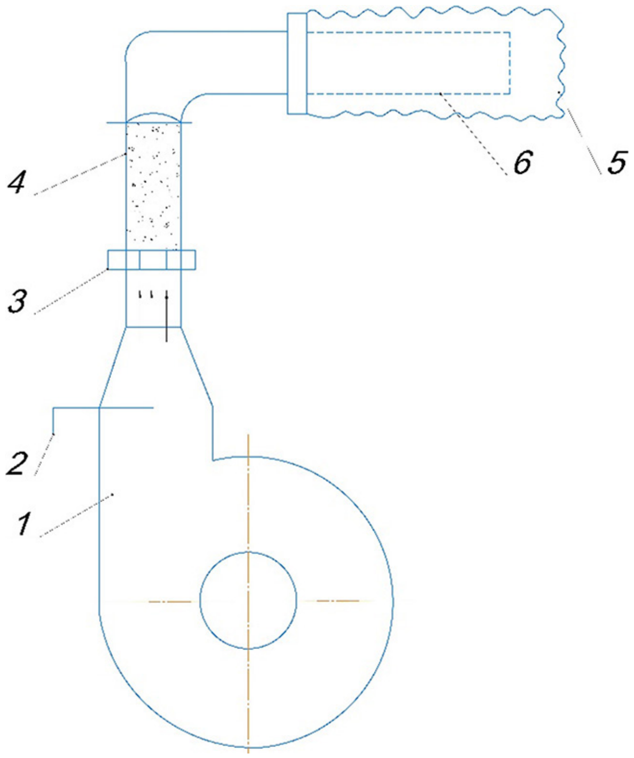

Figure 2 – Device for cleaning grain from dust: 1 – blower fan, 2 – valve, 3 – porous partition, 4 – cylinder, 5 – bag filter, 6 – sieve

a fan for 30 s. Then, the mass of dust isolated from the grain sample was determined by the weight gain of the filter. At each purge, the weight of the sample of grain was strictly considered. For the calculation, the average values of the mass of the ejected dust were taken after each blowing of the grain sample.

Results and discussion

To obtain a mathematical model of the process of cleaning grain from dust and light impurities, which is a regression equation, a second-order rotatable plan (Box plan) was used, when the number of factors x is 3, and the number of experiments is more than 20, the number of experiments at the zero point was 6 and the number coefficients of the equation equals to 10.

As a mathematical apparatus, we use mathematical and statistical methods, the resulting system of regression equations, the relationship which models the most preferred optimality criterion with the rest.

The cleaning coefficient (y) is the main criterion for the process of cleaning grain from dust and light impurities, and it is influenced by the following factors: the thickness of the incoming grain layer (h, mm), airspeed (υ, m/s) and chamber height (H, mm), the above factors determine specific production conditions. Therefore, it is advisable to adjust the system of regression equations following these factors.

The regression equation looks like:

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 +$$
$$+ b_{13}x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2.$$

Coding intervals and levels of variation of input factors for cleaning grain from dust and light impurities are presented in Table 1.

The experiment planning matrix is presented in Table 2.

Studies have been carried out to identify the best value of the coefficient of the process of cleaning from dust and light impurities based on the parameters of regression analysis. Optimization of the cleaning process from dust and light impurities is shown in Figure 3.

On figure 3 the efficiency of cleaning grain from impurities decreases with a decrease in the air supply rate. However, with an increase in the air supply rate to the grain mass, with an increase in the thickness of the grain mass layer, it improves to 40 mm, with an increase in thickness above this value, the efficiency decreases. The best efficiency value with a grain layer thickness of 40 mm and an air velocity of 3.841 m/s was 0.95.

It is easy to see that the planning matrix is orthogonal with linearly independent column vectors; therefore, the diagonality of the matrix and the system of equations is normal, and hence the mutual independence of the estimates of the coefficients of the regression equation. Then the regression equation for cleaning grain from impurities with the best efficiency coefficient y has the form:

$$y = 0,841383494 + (-0,0301x_1) + 0,07566x_2 +$$
$$+0,02424x_3 + 0,0025x_1x_2 + 0,0025x_3 - 0,0025x_2x_3 -$$
$$-0,03786x_1^2 - 0,02375x_2^2 - 0,02022x_3^2.$$

Thus, the optimum parameters for cleaning grain from impurities fall at the point where the thickness of the incoming grain layer is 40 mm and the height of the chamber is 600 mm, with an air supply of 3.841

Table 1 – Coding of intervals and levels of variation of input factors

Factors		Levels of variation					Variation intervals
natural	coding	–1,68	–1	0	+1	+1,68	
δ, mm, thickness of the incoming grain layer	x_1	23,18	30	40	50	56,82	10
υ, m/s, air speed	x_2	2,159	2,5	3,0	3,5	3,841	0,5
H, mm, camera height	x_3	430	500	600	700	768,2	100

Table 2 – Matrix of rotatable planning of experimental studies of the process of cleaning grain from dust and light impurities

№	Coding			Natural			Experimental
	x_1	x_2	x_3	δ, mm, thickness of the incoming grain layer	υ, m/s, air speed	H, mm, camera height	y
1	–	–	–	30	2,5	500	0,67
2	–	–	+	30	2,5	700	0,72
3	–	+	–	30	3,5	500	0,82
4	–	+	+	30	3,5	700	0,85
5	+	–	–	50	2,5	500	0,60
6	+	–	+	50	2,5	700	0,65
7	+	+	–	50	3,5	500	0,75
8	+	+	+	50	3,5	700	0,80
9	–1,68	0	0	23,18	3,0	600	0,82
10	+1,68	0	0	56,82	3,0	600	0,73
11	0	–1,68	0	40	2,159	600	0,68
12	0	+1,68	0	40	3,841	600	0,95
13	0	0	–1,68	40	3,0	430	0,78
14	0	0	+1,68	40	3,0	768,2	0,87
15	0	0	0	40	3,0	600	0,85
16	0	0	0	40	3,0	600	0,84
17	0	0	0	40	3,0	600	0,85
18	0	0	0	40	3,0	600	0,83
19	0	0	0	40	3,0	600	0,84
20	0	0	0	40	3,0	600	0,82

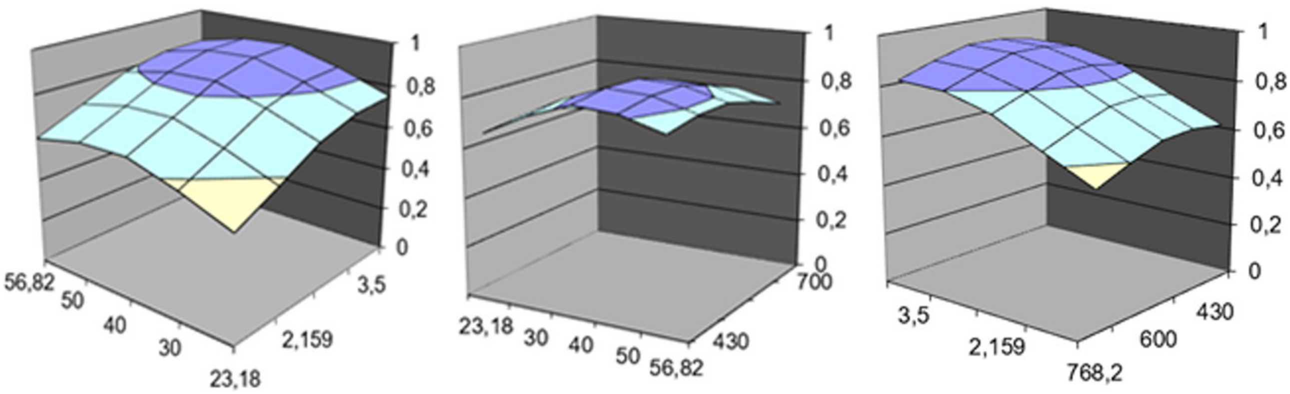

Figure 3 – a – dependence of the thickness of the grain layer inflow and air velocity;
b – dependence of the thickness of the grain layer inflow and the height of the chamber;
c – dependence of air velocity and chamber height

m/s, at this point the efficiency coefficient is 0.95.

The calculated value of the Fisher criterion $F_p = 4.913587$.

Tabular value of the Fisher criterion $F_t = 5.05$.

with degrees of freedom $f_1 = 5$.

with degrees of freedom $f_2 = 5$.

Conclusion

Experimental studies have been carried out on the purification of consumables from light impurities and dust processed using the proposed installation. A regression equation has been obtained for calculating the cleaning coefficient depending on the parameters of the technological cleaning processes (on the suction value, airflow). As a result of the process of extracting dust, significant values of suction capacity, air velocity and consumption of the consumed substance, the maximum values of the cleaning coefficient were revealed.

Thus, the optimal parameters for controlling the flow from impurities depend on the thickness, where the thickness of the consumed volume is 40 mm, and the thickness of the chamber is 600 mm, with an air supply of 3.841 m/s, while the factor of efficiency is 0.95.

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Дәнді жеңіл қоспалардан және шаңнан тазалау процесін зерттеу

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***Аңдатпа.** Зерттеу объектісі – астықты жеңіл қоспалардан және бидай дәнінің шаңынан тазарту процесі. Жұмыстың мақсаты – статистикалық үлгіні жасау және бидай дәнін тазарту процесінің негізгі кинетикалық тәуелділіктерін анықтау. Ұсынылған қондырғының негізгі құрылымдық айырмашылығы – ауа ағынын енгізу және шаң-ауа қоспасын шығару үшін перфорацияланған жалюздерді қолдану, олар ауа ағынын камераның бүкіл көлеміне біркелкі таралуын қамтамасыз ететін және жеңіл қоспалар мен шаңның жақсы шығарылуына ықпал ететін белгілі бір көлбеу бұрышы бар ауа камерасының биіктігі бойынша орнатылады. Зерттеу жүр-*

гізу үшін астықты тазартудың эксперименттік әдісі және Matlab бағдарламалық жасақтамасының көмегімен астықты тазарту бойынша эксперименттік зерттеулерді өңдеу қолданылды. Алынған регрессиялық теңдеулер тазарту процесінің технологиялық параметрлеріне (камераның биіктігіне, кіретін астық қабатының қалыңдығына және ауа жылдамдығына) байланысты тазарту коэффициентінің шамасын бағалауға мүмкіндік берді. Зерттелетін факторлар (ауа жылдамдығы және кіретін астық қабатының қалыңдығы, камераның биіктігі) тазарту коэффициентіне әр түрлі әсер ететіндігін ескере отырып, процестің ұтымды жағдайларын таңдау жүргізілді. Астықты тазарту процесін оңтайландыру нәтижесінде тазарту коэффициентінің максималды мәндерін қамтамасыз ететін камераның биіктігінің, ауа жылдамдығының және кіретін астық қабатының қалыңдығының ұтымды мәндері анықталды. Жаңа жиналған астықты бастапқы өңдеуге арналған токтар және астықты қайта өңдеу өнеркәсібі кәсіпорындары қолдану саласы болып табылады.

Кілт сөздер: *дән қоспалары, тазалау, жеңіл қоспалар, тазалау коэффициенті, жалюздер, математикалық модель, пневматикалық жүйе, дән тазалау машинасы.*

Исследование процесса очистки зерна от легких примесей и пыли

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Аннотация. *Предметом исследования является процесс очистки от легких примесей и пыли зерна пшеницы. Цель работы – разработка статистической модели и выявление основных кинетических зависимостей процесса очистки зерна. Основным конструктивным отличием предлагаемой установки перфорированных жалюзи для ввода воздушного потока и вывода пылевоздушной смеси по высоте пневмокамеры с определенным углом наклона, который обеспечивает равномерное распределение воздушного потока по всему объему камеры и способствует лучшему уносу легких примесей и пыли. Для проведения исследований использовался экспериментальный метод очистки зерна и обработка экспериментальных исследований по очистке зерна – с помощью программного комплекса Matlab. Полученные регрессионные уравнения позволили оценить величину коэффициента очистки в зависимости от технологических параметров процесса очистки (от высоты камеры, толщины поступающего слоя зерна и скорости воздуха). Учитывая, что исследуемые факторы (скорость воздуха и толщина поступающего слоя зерна, высота камеры) неоднозначно влияют на коэффициент очистки, был проведен выбор рациональных условий процесса. В результате оптимизации процесса очистки зерна были определены рациональные значения высоты камеры, скорости воздуха и толщины поступающего слоя зерна, обеспечивающие максимальные значения коэффициента очистки. Областью применения являются тока для первичной обработки свежеубранного зерна и предприятия зерноперерабатывающей промышленности.*

Ключевые слова: *зерновые смеси, очистка, легкие примеси, коэффициент очистки, жалюзи, математическая модель, пневматическая система, зерноочистительная машина.*

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