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Vitalii Koshulko, Assoc. Prof., PhD tech. sci., **Ihor Kudriavtsev,** PhD student
Dnipro State Agrarian and Economic University, Dnipro, Ukraine
e-mail: vitaliykoshulko@gmail.com

Justification of the design of an aerodynamic separator for cleaning sunflower seed mixture waste

The aim of the research is to substantiate the structural and technological scheme of an aerodynamic separator for cleaning waste from sunflower seed mixtures, ensuring the separation of elongated particles based on their specific weight and morphometric characteristics. This is achieved by modifying the formation of pseudo-fluidized layers and the sequence of applying the principles of pseudo-fluidized flow generation. A method for separating bulk mixtures in a two-stage environment has been proposed. It includes the gravitational feeding of particles, increasing vibro-inertial impact, pseudo-fluidized medium generation, and the removal of dense fractions. The second stage involves separation through the sequential application of vibro-inertial and pneumatic methods of pseudo-fluidized medium generation, the use of a suspended layer, and the creation of a low-concentration layer. The structural and technological scheme of a column-type separator has been substantiated. Numerical modeling of the separation process of seed waste components in the rarefaction chamber allowed for the determination of motion trajectories and component distribution. The obtained dependencies include the distance between the peaks of husk and fine particle distributions (Δy) as a function of the effective diameter (D_p), feed rate (V_a), and the curvature radius of the upper edge of the chamber (R). The optimal factor values are: for D_p = 0.005 m → V_a = 3.21 m/s, R = 0.055 m; for D_p = 0.010 m → V_a = 3.35 m/s, R = 0.056 m; for D_p = 0.015 m → V_a = 3.49 m/s, R = 0.054 m. The average distance between distribution peaks is Δy = 0.443 m. Based on modeling and validated parameters, an experimental prototype of the column-type aerodynamic separator was developed and implemented in production at LLC «NVO Sorting Machines».
waste, sunflower, separation, cleaning, seeds, husk, modeling, method, parameters, properties, efficiency

Problem setting. Seed waste and debris are a promising raw material for processing, as they contain 30–50% of grain or oilseed impurities suitable for further use [1]. The extraction of this valuable raw material is possible only through mechanical sorting of waste using specialized equipment [2].

The aerodynamic method used to separate the sunflower seed mixture into husks, kernels, and other impurities is a key stage in processing at oil extraction plants [3]. However, one of the main challenges of this process is the incomplete separation of husks from kernels. This not only leads to the loss of food resources but also deteriorates the quality of subsequent processing stages. Therefore, research on optimizing the separation process of sunflower seed mixture waste is an extremely relevant task.

Analysis of the latest studies and publications. Currently, the most common equipment for cleaning sunflower seed mixture waste is the gravitational aerodynamic separator. This equipment is characterized by economic efficiency, simplicity of design, and ease of maintenance [4–6], and it can also be used for cleaning and sorting many other types of agricultural products [7–8].

Separators are usually designed as vertical separation channels through which an upward airflow passes, carrying particles fed from below or from the side [7]. It is believed that the way the seed mixture is fed can affect the airflow velocity, disrupt its stability, and hinder the complete separation of particles [7]. Research on this process has been conducted in various directions, using trial-and-error methods, such as modifying the design of the separation channel [8], adjusting the airflow velocity [9], and fine-tuning the mixture feed parameters [10].

A known method for separating bulk mixtures in a fluid medium also exists [11]. This method involves the gravitational feeding of mixture particles, the aerodynamic monotonically increasing influence on them at an acute angle to the vertical with a cascade of expanding turbulent air jets, and the extraction of finished fractions. The lower plane of the jets, due to the Coanda effect and positive feedback with the air in the inter-jet space, induces self-oscillating motion across the entire width, followed by an aperiodic force impact on the upper plane of the lower jet. The use of flat jets in the separation process undoubtedly improves the quality of fractionation of the bulk mixture by specific weight. However, this method is ineffective for separating bulk mixtures composed of particles whose length is several times greater than their width (e.g., meadow bluegrass seeds, pasture ryegrass, awnless brome, oats, damaged sunflower seeds and husks, sorting sunflower husks, and grain cleaning waste to extract oilseed and grain impurities, sorting grain waste to remove grain impurities, etc.). It cannot perform trieur functions, as "broken" seeds have the same specific weight as whole ones. Additionally, the method is unable to remove oilseed and grain impurities larger than 200 μm, which are carried away as aspiration waste. Since this separation method cannot affect the seeds in any other way due to the design and interaction of its components, its functional capabilities limit its applicability, which is a technological drawback.

From the state of the art, an analog is known—a column-type aerodynamic separator for fine cleaning of seed materials [12]. It includes a loading unit consisting of a loading hopper and a vibrating feeder, a pneumatic separation unit with an air flow source capable of adjusting the airflow intensity in the separation zone, and a pneumatic separation channel with an inlet for contaminated seed materials, an outlet for the useful fraction, and an outlet for waste. It also has a settling chamber with a conical hopper for directing waste into a screw trap and a vent, as well as collectors for the useful fraction and waste. The vibrating feeder is additionally equipped with an electronic oscillation control device, and the lower part of the pneumatic separation channel features an air distributor, while the upper part includes a rarefaction chamber with a baffle and an outlet for air and dust.

From the essence of this technical solution, it is clear that the column-type pneumatic separator-sorter is designed for cleaning and sorting agricultural products with a low percentage of debris and dust, as well as for sorting grain mixtures with contamination levels exceeding the technical standards for grain. To effectively remove grain/oilseed impurities from waste and processing byproducts, the separator must be equipped with a significantly large settling chamber. The chamber's size must be several times larger to ensure the effective sedimentation of aspirated impurities and lightweight debris. This substantially increases the overall dimensions and material consumption of the separator-sorter, requiring considerable construction volume for its use. Thus, a drawback of the known device is its large size and material intensity, as well as the need for a greater building volume for operation.

The results of the analysis indicate that airflow velocity, feed intensity, and the direction of mixture introduction significantly influence separation quality. Moreover, optimal operating parameters vary depending on material characteristics.

Despite the improvements achieved in the operation of aerodynamic separators, the process of cleaning sunflower seed mixture waste requires further study. Therefore, the development of design solutions to improve fine-cleaning machines for these waste products remains a relevant task in agro-engineering.

Setting objectives. The aim of the research is to substantiate the structural and technological design of an aerodynamic separator for cleaning sunflower seed mixture waste. This separator will ensure the separation of elongated particles based on both their specific weight and morphometric characteristics (the size of the separated mixture components) by altering the conditions of vibro-inertial and vibro-pneumatic effects on the raw material. This is achieved through a sequential two-stage pseudo-fluidized layer by modifying the principle of pseudo-fluidized layer formation and the sequence of applying the principles of pseudo-fluidized flow generation.

Presentation of the main material. The stated objective is achieved through a method of separating a bulk mixture in a two-stage fluidized medium. This method involves the gravitational feeding of mixture particles, an increasing vibro-inertial effect on them, the generation of a pseudo-fluidized medium, and the removal of dense fractions. According to the utility model, an additional second stage is included, in which separation occurs in a two-stage fluidized medium with the sequential application of vibro-inertial and pneumatic methods for generating pseudo-fluidized layers. A suspended pseudo-fluidized layer is used, and a pseudo-fluidized layer of low concentration is created.

In the first stage, a pseudo-fluidized layer is formed through vibro-inertial influence, where the grain mixture is stratified based on density, and the coarse dense fraction is removed. In the second stage, the pseudo-fluidized layer is maintained in a suspended state by the pneumatic influence of an air flow. The dense mass of the pseudo-fluidized layer transitions to a low-concentration pseudo-fluidized state, allowing dense mixture particles ranging in size from over 200 μm to less than 1.0 mm to settle into the lower layers and be removed.

A distinguishing feature of the proposed method for separating a bulk mixture in a two-stage fluidized medium is the sequential use of vibro-inertial and pneumatic methods for generating pseudo-fluidized layers, the use of a suspended pseudo-fluidized layer in the second stage, and the creation of a low-concentration pseudo-fluidized layer in the second stage. This allows for the additional extraction of grain or oil impurities larger than the particles removed by aspiration but smaller than those removed by the pneumatic sorting method (0.2–1.0 mm).

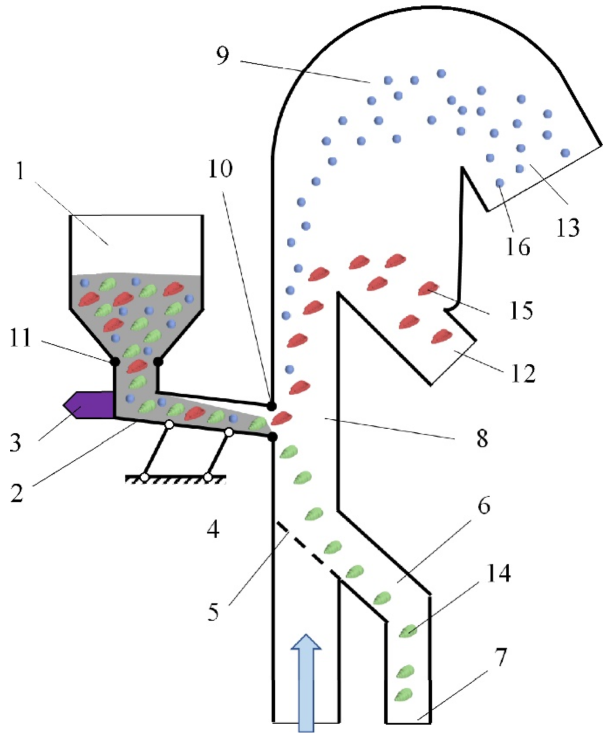
The technical result of the utility model is the ability to modify the method of generating a pseudo-fluidized layer and create a low-concentration pseudo-fluidized layer, as well as to use a sequential fluidized medium approach to alter the nature of grain mixture sorting and improve sorting quality. This significantly expands the functional capabilities of the proposed technology and, consequently, its range of applications.

Thus, the set of essential features of the proposed technical solution collectively ensures the achievement of the stated goal as defined in the problem statement.

To clarify the problem, attention should be paid to the properties of the mixture being sorted. For example, in the case of sunflower oilseed raw material, the mixture consists of oil impurities with a fractional composition specified in DSTU 7011-2009 [13] (damaged by pests, sprouted, immature, frost-affected, fully or partially dehulled, mechanically damaged, or damaged by phytophagous bugs, with sizes smaller than the primary grain). The mixture also includes fragments of grain of various sizes, but oil impurities share a common characteristic – density. The pseudo-fluidized layer's property in implementing density-based sorting has its limitations. Sunflower husks and waste predominantly consist of elongated particles with branched structures.

During the generation of the pseudo-fluidized layer, mixture particles interlock, compact, and form conglomerates – localized densifications that increase the internal resistance of the mixture, the shear resistance index, and the uncertainty of the natural slope angle. Conglomerates hinder the stratification (layering) of the mixture, particularly for small particles. According to experimental studies conducted using the DSTU 7123:2009 methodology [14], the mass fraction of fat and extractive substances in absolutely dry matter is nearly 10% due to a dense fraction sized 0.2–1.0 mm that remains in the mixture and is not sorted out. This represents almost half of the raw material that could be used in production.

To explain the proposed method, it is first appropriate to consider the design of the device that implements it. The further explanation is illustrated in the diagram, which shows the schematic of the device for implementing the proposed method of separating a bulk mixture in a two-stage fluidized medium (Fig. 1).



1 – hopper; 2 – vibrating chute; 3 – vibrator; 4 – loading window; 5 – airflow stabilizer; 6 – discharge window for dense fraction; 7 – discharge pipe for dense large fraction (kernel); 8 – sorting channel; 9 – fluidization chamber; 10 – flexible insert for vibrating chute; 11 – flexible insert for hopper; 12 – discharge pipe for dense small fraction (husk); 13 – discharge pipe for aspiration waste (dust, fine particles); 14 – dense large fraction (kernel); 15 – dense small fraction (husk); 16 – aspiration waste (dust, fine particles)

Figure 1 – Diagram of the device for implementing the proposed method of separation of bulk mixture in a two-stage flowing medium

Source: developed by the authors

The proposed method of separation of bulk mixture in a two-stage flowing medium is carried out as follows. First, the gravitational feeding of the bulk material mixture from the hopper 1 into the vibrating chute 2 is performed. The mixture of bulk material, for example, the waste from primary or secondary sunflower seed cleaning, or, for instance, sunflower husk, contains a dense fraction with sizes close to the size of sunflower seed kernels, crushed kernel fragments, underdeveloped seeds, pressed seeds, i.e., material commonly referred to as oil admixture. The vibrating chute 2 is connected to the hopper 1 via a flexible insert 11, and to the sorting channel 8 via a flexible insert 10, which do not hinder the movement of the vibrating chute 2 relative to other components of the device. The vibrator 3 generates oscillations in the vibrating chute 2 with the required frequency and amplitude, and the inclination of the vibrating chute in the direction of the loading window 4 is selected depending on the characteristics of the bulk mixture.

In the vibrating chute 2, the mixture transitions to a pseudo-fluidized state, for which a vibro-inertial excitation method is used. The denser particles occupy the lower layer and are mixed towards the window 4. Denser smaller particles require significant time in the pseudo-fluidized environment for stratification and, as a result, do not reach the lower layer before being unloaded into the unloading window 4. The smallest dense particles do not undergo stratification at all due to the high internal resistance of the mixture.

The stratified mixture, in a pseudo-fluidized state, is loaded through the window 4 into the sorting channel 8, where the lower layer of the dense fraction descends onto the air flow stabilizer 5, which is inclined towards the dense fraction unloading window 6. Under the influence of gravity and aerodynamic forces, the dense fraction is unloaded into window 6. The upper layer of the mixture, which enters the sorting channel 8, remains in a pseudo-fluidized state using pneumatic methods. In this state, the upper layer of the mixture does not descend but stays suspended, with the mixture "dissolving" in a much larger volume of the sorting channel 8 than in the vibrating chute 3. As a result, the pseudo-fluidized layer achieves a low concentration of particles. At low concentration, the particles are far apart, allowing stratification of the smaller dense components of the mixture. In the pseudo-fluidized suspended layer, the smaller particles of the dense fraction are able to descend onto the air flow stabilizer 5, and are then removed through the unloading window 6 into the dense fraction unloading pipe 7.

The portion of the mixture free from both large and small dense fractions rises upwards in the sorting channel 8 due to the aerodynamic interaction between the air flow and the mixture, reaching the rarefaction chamber 9. In the rarefaction chamber, the fine dense fraction (husk) and aspirated waste (dust, small particles) are separated and enter the respective pipes 12 and 13. After that, the fractions are diverted to their respective hoppers.

A significant difference between the proposed technical solution and previously known ones is the complete change in the conditions of influence on the mixture that is in a pseudo-fluidized state. This distinction allows for the additional extraction of individual fractions from the bulk mixture, regardless of their shape and size, expanding the scope of the method's application and significantly improving the technological efficiency of sorting equipment. No known separation methods can possess these properties, as they do not include the full range of essential features present in the proposed technical solution.

The proposed utility model has been tested in practice. The method is used in the design of sorting machines in the SS-001...SS-018 model range. The separation method does not include operations or processes that could not be reproduced with the current stage of scientific and technological development, particularly in the field of agricultural engineering, which means that it is industrially applicable. No similar separation methods for bulk mixtures in a flowing medium with the indicated distinguishing features and advantages have been found in known patent documentation or scientific and technical sources. Therefore, the proposed technical solution meets the novelty criterion and is considered eligible for legal protection.

The technical advantages of the proposed technological solution include the ability to change the stratification pattern of the dense mixture, which can now extract small oil admixtures from the mixture, significantly expanding the functional capabilities of the claimed machinery, and, consequently, the scope of its application.

After describing the proposed method of separation of bulk mixtures in a flowing medium, it should be clear to experts in this field that all the above-described features are illustrative, not limiting, and presented by this example. Numerous possible modifications of the method, such as the number of pseudo-fluidization methods in the sorting machine cascade, and separation modes, can vary depending on the state and type of the raw material undergoing separation, and, of course, lie within the scope of one of the conventional and natural approaches in this field of knowledge and are considered within the scope of the proposed technical solution.

The core of the proposed utility model lies in the fact that the separation is carried out in a two-stage flowing medium with sequential use of vibro-inertial and pneumatic methods for generating pseudo-fluidized environments, using a suspended pseudo-fluidized layer in the second stage of the method, and creating a low-concentration pseudo-fluidized layer in the second stage, which enables the additional extraction of seed or oil admixture particles larger than the aspirated waste particles but smaller than the pneumatic sorting method's ability to remove particles in the range of 0.2–1.0 mm. This approach improves the quality of separating the bulk mixture into individual fractions, and this factor provides the proposed method with the aforementioned advantages. Changing the proposed principle to another would naturally limit the range of these advantages, and it would no longer be considered a new technical solution in this field of knowledge, as similar methods would not require any creative effort from designers and engineers and could not be considered as results of their creative activity or new intellectual property objects eligible for protection.

To substantiate the regime parameters of the aerodynamic separator of the column type depending on the composition of the contaminated sunflower seed mixture, numerical simulation has been conducted. The simulation scheme is shown in Fig. 2.

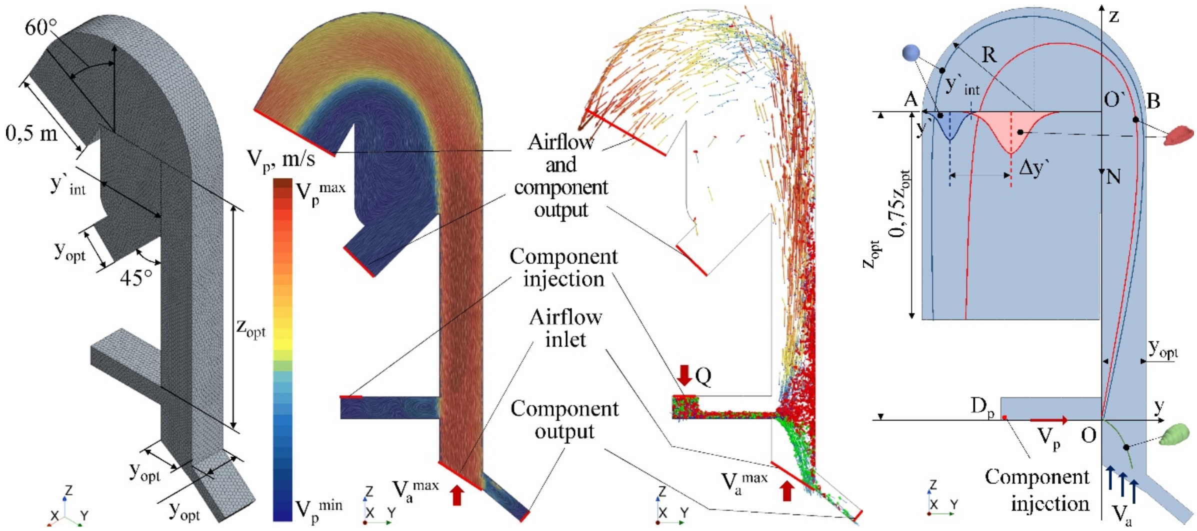


Figure 2 – The scheme of modeling the separation of components from the sunflower seed mixture waste in the pneumatic separation channel

Source: developed by the authors

It is assumed that the seed mixture has been pre-calibrated on sieves, and the effective diameter of the components is in the range from 0.009 m to 0.013 m.

The factors of numerical modeling of the movement of the components of sunflower seed mixture waste in the pneumatic separation channel and the vacuum chamber include the effective diameter of the components D_p (0.005–0.025 m), the air flow velocity V_a (5–15 m/s), and the radius of curvature of the upper edge of the vacuum chamber R (0.4–0.6 m).

As a result of numerical modeling of the separation process of sunflower seed mixture waste in the vacuum chamber, the distribution of mixture components (sunflower husk and fine particles) along the line AB (Figure 2) has been constructed, as shown in Figure 3.

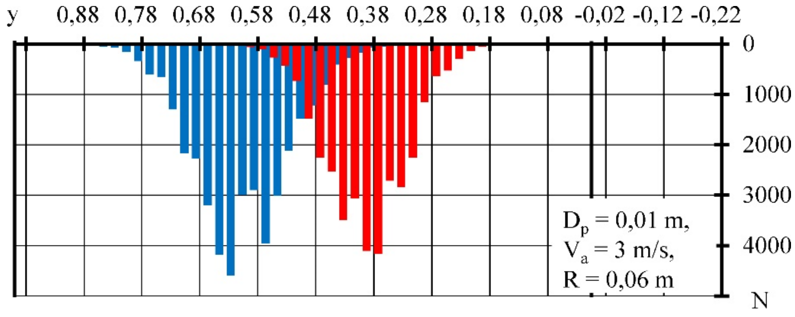


Figure 3 – An example of the distribution of sunflower seed mixture waste components in the vacuum chamber for the corresponding combination of research factors
Source: developed by the authors

The condition for the qualitative separation of sunflower husks and fine particles in the vacuum chamber is the maximization of the distance Δy`. As a result of data optimization in the Wolfram Cloud software package, the optimal values of the research factors were obtained: for D_p = 0.005 m → V_a = 3.21 m/s, R = 0.055 m; for D_p = 0.010 m → V_a = 3.35 m/s, R = 0.056 m; for D_p = 0.015 m → V_a = 3.49 m/s, R = 0.054 m.

In this case, the average distance between the distribution peaks of sunflower husks and fine particles is Δy` = 0.443 m.

Taking into account the results of numerical modeling and the justified design and technological parameters of the column-type aerodynamic separator, an experimental research prototype was created, the general view of which is shown in Fig. 4. This separator has been implemented in production at LLC Research and Production Association «Sorting Machines» [15].

Figure 4 – General view of the experimental research prototype of the column-type aerodynamic separator SS-012 (LLC «RPA Sorting Machines»).
Source: developed by the authors

Conclusions. A method for separating a bulk mixture in a two-stage fluidized medium is proposed. The method involves the gravitational feeding of mixture particles, increasing vibro-inertial impact on them, generating a pseudo-fluidized medium, and discharging dense fractions. Additionally, the method includes a second stage, in which separation is performed in a two-stage fluidized medium using successive vibro-inertial and pneumatic methods for generating pseudo-fluidized environments. A suspended pseudo-fluidized layer is utilized, and a low-concentration pseudo-fluidized layer is created. Based on this method, a structurally and technologically justified scheme of a column-type separator has been developed.

As a result of numerical modeling of the separation process of seed mixture waste components in the rarefaction chamber, the trajectories and distributions of its components were obtained. The dependencies of the distance between the peaks of the distributions of sunflower husks and fine particles (Δy) in the rarefaction chamber on the effective diameter (D_p), the feed velocity of the components (V_a), and the curvature radius of the upper edge of the rarefaction chamber (R) were determined. Considering the condition of maximizing Δy, the optimal values of the research factors were obtained: for D_p = 0.005 m → V_a = 3.21 m/s, R = 0.055 m; for D_p = 0.010 m → V_a = 3.35 m/s, R = 0.056 m; for D_p = 0.015 m → V_a = 3.49 m/s, R = 0.054 m. The average distance between the peaks of the distributions of sunflower husks and fine particles was found to be Δy` = 0.443 m.

Based on the results of numerical modeling and the justified structural and technological parameters of the column-type aerodynamic separator, an experimental research prototype was developed and implemented in production by LLC «RPA Sorting Machines».

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В.С. Кошулько, доц., канд. техн. наук, **І.М. Кудрявцев,** здобувач вищої освіти на третьому рівні
Дніпровський державний аграрно-економічний університет, Дніпро, Україна

Обґрунтування конструкції аеродинамічного сепаратора для очищення відходів насіннєвої суміші соняшника

Метою досліджень є обґрунтування конструктивно-технологічної схеми аеродинамічного сепаратора для очищення відходів насіннєвої суміші соняшника, який забезпечує розділення подовжених часток за питомою вагою та морфометричними характеристиками. Це досягається шляхом зміни формування псевдорозріджених шарів і послідовності використання принципів генерації псевдорозрідженого текучого середовища.

Запропоновано спосіб сепарації сипучої суміші у двостадійному середовищі, що включає гравітаційну подачу частинок, зростаючий віброінерційний вплив, генерацію псевдорозрідженого середовища та відвід щільних фракцій. Друга стадія включає сепарацію із послідовним застосуванням віброінерційного та пневматичного способів генерації псевдорозріджених середовищ, використання завислого шару і створення шару низької концентрації. Обґрунтовано конструктивно-технологічну схему сепаратора колонного типу. Чисельне моделювання процесу сепарації компонентів насіннєвих відходів у камері розрідження дозволило визначити траєкторії руху та розподіл компонентів. Отримані залежності відстані між піками розподілів лушпиння та дрібних частинок (Δy) від ефективного діаметра (D_p), швидкості подачі (V_a) і радіуса кривизни верхньої грані камери (R). Раціональні значення факторів: для D_p = 0,005 м → V_a = 3,21 м/с, R = 0,055 м; для V_a = 0,010 м → V_a = 3,35 м/с, R = 0,056 м; для D_p = 0,015 м → V_a = 3,49 м/с, R = 0,054 м. Середнє значення відстані між піками розподілів Δy = 0,443 м.

На основі моделювання та обґрунтованих параметрів створено експериментальний зразок аеродинамічного сепаратора колонного типу, який впроваджено у виробництво ТОВ «НВО «Сортувальні машини».

корм, пресування, стиснення, чисельне моделювання, лабораторні дослідження, змішування, тиск, параметри, фізико-механічні властивості, ефективність

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