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THEORETICAL RESEARCH OF SEPARATION PROCESS GRAIN MIXTURES

S. P. Stepanenko[1], B. I. Kotov[2]

[1]National Scientific Center "Institute of Mechanization and Electrification of Agriculture". Ukraine.
[2]Podolsky State Agricultural and Technical University. Ukraine.

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Corresponding authors: stepanenko_s@ukr.net

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Abstract. Theoretical researches of the technological process of pneumoviral separation of grain mixtures on the pneumatic flow center separators of new generation grains, aimed at increasing the efficiency and quality of the phased separation of grain mixtures. The analysis of the results of the well-known studies presented in the scientific and technical literature on the issues of pneumatic and centrifugal and pneumatic separation of grain mixtures was carried out by analytical and deductive methods, on the basis of which the parameters of the investigated operations of the technological process of the motion of the grain mixture in the pneumoviral separating device were substantiated by theoretical methods. The theoretical researches of the technological process of pneumoviral separation of grain mixtures have been made, which makes it possible to determine the structural-kinematic and technological parameters of the grain-cleaning air-solenoid pneumatic-centrifugal unit with productivity from 25-50 t / h on primary purification of wheat grain with the provision of qualitative indicators in accordance with DSTU 3768: 2010 and seed quality of seeds respectively РН-1-3 ДСТУ 2240-93 at productivity from 10-20 t / h. It is established that the application of the process of pneumatic separation of cereal mixtures when used in the construction of a pneumatic centrifugal separator has the potential to increase its productivity by 1,5-2 times compared with the performance of known industrial separators and on its basis create a new generation of universal centrifugal centrifugal separators with productivity of 50, 100 and 200 t / h

Key words: theoretical dependence, grain mix, dosage, separation, distribution, efficiency, productivity, quality.

Introduction

Extremely widespread in Ukraine and in other countries of the world, there are air-grate grain separators with gravitational working bodies such as flat oscillating, cylindrical rotating sieve and vertical or inclined pneumatic separation channels, which are characterized by limited severity of separation, which greatly complicates the creation on their basis of high-performance separators for cleaning and sorting grain materials.

The prospect of the development and application of modern high-tech technical equipment in agricultural production [1-5] and the prospect of a comprehensive solution to the problem of post-harvest processing and preservation of grain in Ukrainian farms [1, 3, 6] is the creation of modern refrigeration and drying-storage complexes that provide direct-flow processing of crops with bringing to the norms of basic conditions in accordance with DSTU on concrete grain crops, which, in turn, requires the creation of high-performance universal grain separators (machines for primary cleaning of grain) with productivity from 25 - 200 t / h.

Formulation of problem

Scientific researches of the motion of grain mixtures using centrifugal forces of inertia as the most effective ones allowed the creation and introduction into production of universal grain separators with productivity from 15 to 100 t / h [12-15], which became the basis for mastering the machine-building production of the family of universal vibrocentric separators of the type BCS.

In the indicated separators, the integration of working bodies and the joint use of air and grid separating devices in the form of autonomous grain cleaning units are used. The design and technological scheme of the pneumatic separating device was developed on the basis of conducted scientific research [1-6], which does not allow to increase the productivity of the machine with the necessary quality of primary cleaning of grain.

In connection with the foregoing, the problem of the development of technical means and the theoretical and mechano-technological substantiation of the technological process of pneumoviral separation in the machines of primary purification of the new generation of grain is relevant, and its solution will provide such a new, higher level.

Analysis of recent research results

In the known universal grain separators of the type BCS used pneumatic centrifugal devices [1-6, 10, 11], while the separation process does not allow to provide significant increase in the efficiency and quality of separation [5, 6]. The authors [7, 8, 9] note that the increase in productivity at non-changing quality indices is directly or indirectly related to the design features of dosing devices, rotary scatterers and the organization of air separation channels.

The research of [10, 11, 12] of the disk grain distributor for a pneumatic system with a vertical ring aspiration channel (an analogue of the grain cleaning unit BCC) achieved some increase in the efficiency of grain purification by a vibration centrifugal separator, by developing a pneumatic separating channel with a vertical annular aspiration channel separated by partitions [13, 14] . Increased productivity with this development has not been achieved.

Studies [7, 15-17], aimed at increasing the separation efficiency in pneumatic centrifugal devices, achieved some improvement in the quality of separation of grain mixtures. However, the results of these studies did not confirm the feasibility of using the proposed designs of air-cooled devices on centrifugal separators.

As a result of the research, the design and technological scheme of the grain separator has been developed, which provides an increase in the separation efficiency due to the following factors: the combination of the rotational spreader and the bounding walls of the circular air-separating channel with vortex upward airflow [15, 16], the design of the dosing device and its co-positioning relative to the rotational grain mixer spreader [16], use of vortex upward airflow [5], use of new design of rotational spreader [5].

Purpose of research

Theoretical studies of the technological process of pneumoviral separation of grain mixtures on the new generation of grain centrifugal separators of grain mills, aimed at increasing the efficiency and quality of phased separation of grain mixtures.

Results of research

Using mechano-mathematical methods [6, 10, 12, 18, 20, 22], developments and studies [2-7, 16-21] have been carried out, which allowed to substantiate the design and technological scheme of the grain-cleaning module of the universal grain separator of the new generation and to substantiate the pneumoviral the method and design of a device for separating cereal mixtures, which provides the necessary controlled loading (productivity) of the module and the uniform distribution of the grain mixture in the pneumatic air flow due to the new design of the rotary spreader.

As a result of the research [5, 6, 7] the design of the pneumoviral device was created, the principal scheme of which is presented in Fig. 1. The essence of the technological process is as follows: the grain mixture through the loading grain lines 1 when the squirrels of the dispensing device 2 are opened by gravity on the center of the rotational spreader 3, which is fixed to the shaft 7 of the rotor of the separator rotating with the optimum (for the lattice system) speed ω.

The rotary scatterer 3 supplies the grain mixture with a uniform layer of a given thickness, which is determined by the amount of its flow through the window of the dispensing device 2, into the air separation channel limited by the outer wall 4. The air in the window of the louver 5 and the conical 6 walls is in the direction of rotation of the rotary spreader 3 of the cereal mixture , which creates an air rising vortex flow.

As a result of the interaction of the particles of the grain mixture with the air flow, the mixture is divided: the lungs are carried out beyond the air channel, and heavy (full grain of the main crop) is reflected from the wall of the 4 pneumatic channels and is directed to the surface of the louvre cone 5, which performs a dual function: the foundation of the pneumoviral flow air and aerodynamic transport of heavy fractions to the center.

The linear velocity of the grain mixture and the angles of the direction of its introduction into the pneumoviral channel relative to the axes of the cylindrical coordinate system 0ρθz are determined by calculations when solving the system of differential equations [5].

The separation of the air flow of the grain mixture on the light and heavy fraction is carried out by means of the interaction of particles of this mixture introduced into the air stream with velocity v and air flow, the intensity of which is determined by adjusting the aspiration system, and its direction is measured experimentally: the measurement of the angle of incidence is measured by dynamic pressure tubes to the axis of the cylindrical coordinate system 0ρθz, which allows you to calculate the components of the air velocity vBR, vBES, and vBz in the direction of the coordinates, determine the air resistance forces the environment of the particles of the cereal mixture in the direction of the indicated axes of coordinates, using the known formula $R = mk_n v^2$, where k_n- particle coefficient of sailing.

In the general case, the Navier-Stokes equation [5, 7, 9] is used to describe the flow of air in the working zone of the vortex chamber. In accordance with the Prandtlian hypothesis [9, 12, 18, 22] the voltages in the turbulent flow are equal:

$$\tau_{xy} = \rho\varepsilon dV/dy \quad (1)$$

where ε – coefficient of kinematic viscosity of air flow, which depends on the trajectory of shear l [5, 9, 22] $\varepsilon = l^2 dV/dy$.

Taking into account the dependence on the displacement trajectory and velocity [9]:

$$\varepsilon = l^2 \partial/\partial r(V_\varphi/r) \quad (2)$$

where $l = f(r)$, r – the value of the radius of the vortex chamber at the time t, m;

V_φ – circular air velocity, m/s.

In this case, the coefficient of the kinematic viscosity of the air flow is replaced by the turbulent viscosity coefficient e. With this approach, it is possible to obtain an analytical solution of these equations in the following form [9, 18]:

$$V_\varphi = \frac{V_{\varphi_1}R_1 - V_{\varphi_2}R_2}{R_1^{Re+2} - R_2^{Re+2}} r^{Re+1} + \frac{V_{\varphi_2}R_2R_1^{Re+2} - V_{\varphi_1}R_1R_2^{Re+2}}{R_1^{Re+2} - R_2^{Re+2}} r^{-1} \quad (3)$$

where V_{φ_1}, V_{φ_2} – Circular velocity of air, respectively, in radii R_1, R_2, m/s;

R_1 – the radius of the arrangement of tangential cracks for introducing airflow on the conical portion of the vortex chamber, m;

R_2 – the radius of the aspiration channel for removing the airflow from the vortex chamber, m;

Re – number of Reynolds.

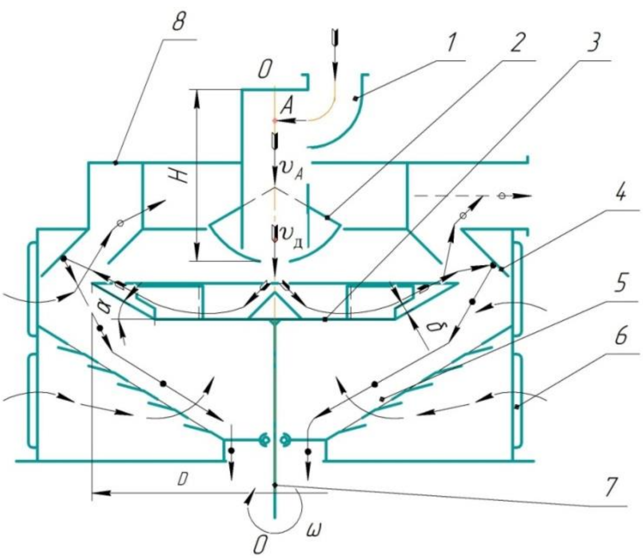

Fig. 1. Principal scheme of pneumoviral device [15, 16]: 1 – loading grain lines; 2 – dosing device; 3 – rotary spreader of grain mixture; 4 – the wall of the air channel; 5 – louver cone; 6 – louver cylindrical wall; 7 – separator rotor shaft; 8 – is a casing

Theoretical studies are aimed at determining the analytical dependence, in which, when taking into account the boundary conditions for air flow only at the entrance to the vortex chamber, one can obtain the basic geometric dimensions of this vortex chamber and determine the values of the velocity of the vortex upward air flow and the particles of the grain mixture at any distance per radius of the vortex chamber:

$$\begin{cases} V_r\frac{\partial V_r}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_r}{\partial \varphi} + V_z\frac{\partial V_z}{\partial z} - \frac{V_\varphi^2}{r} = -\frac{1}{\rho}\frac{\partial P}{\partial r} + \\ +\varepsilon\left(\frac{\partial^2 V_r}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 V_r}{\partial \varphi^2} + \frac{\partial^2 V_r}{\partial z^2} + \frac{1}{r}\frac{\partial V_r}{\partial r} - \frac{2}{r^2}\frac{\partial V_\varphi}{\partial \varphi} - \frac{V_r}{r^2}\right) \\ V_r\frac{\partial V_\varphi}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_\varphi}{\partial \varphi} + V_z\frac{\partial V_z}{\partial z} + \frac{V_rV_\varphi}{r} = -\frac{1}{\rho r}\frac{\partial P}{\partial \varphi} + \\ +\varepsilon\left(\frac{\partial^2 V_\varphi}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 V_\varphi}{\partial \varphi^2} + \frac{\partial^2 V_\varphi}{\partial z^2} + \frac{1}{r}\frac{\partial V_\varphi}{\partial r} + \frac{2}{r^2}\frac{\partial V_r}{\partial \varphi} - \frac{V_\varphi}{r^2}\right), \\ V_r\frac{\partial V_z}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_z}{\partial \varphi} + V_z\frac{\partial V_z}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial r} + \\ +\varepsilon\left(\frac{\partial^2 V_z}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 V_z}{\partial \varphi^2} + \frac{\partial^2 V_z}{\partial z^2} + \frac{1}{r}\frac{\partial V_z}{\partial r}\right) \\ \frac{\partial V_r}{\partial r} + \frac{1}{r}\frac{\partial V_\varphi}{\partial \varphi} + \frac{\partial V_z}{\partial z} + \frac{V_r}{r} = 0 \end{cases} \quad (4)$$

where V_r – radial air velocity, m/s;

V_φ – circular air velocity, m/s;

V_z – axial air velocity, m/s;

P – full pressure in the vortex chamber, Pa;

ε – coefficient of viscosity of the turbulent flow;

ρ – grain mix density, kg/m^3.

To do this, we assume that the flow of air in the vortex chamber is asymmetric, for the solution of this problem we use the Navier-Stokes equation in a cylindrical coordinate system (4).

Assuming that the vortex airflow in the chamber is asymmetric, and its motion becomes flat, then mathematical assumptions can be written as follows:

$$\frac{\partial}{\partial \varphi} = 0;\ \frac{\partial}{\partial z} = 0;\ V_z = 0.$$

Under these conditions, the Navier-Stokes equation system (4) is written as:

$$\begin{cases} V_r(r)\left(\frac{d}{dr}V_\varphi(r)\right) + \frac{V_r(r)V_\varphi(r)}{r} = \\ = \varepsilon\left(\frac{d}{dr}\left(\frac{d}{dr}V_\varphi(r)\right) + \frac{\frac{d}{dr}V_\varphi(r)}{r} - \frac{V_\varphi}{r^2}\right) \\ V_r\left(\frac{d}{dr}V_r(r)\right) - \frac{V_\varphi(r)^2}{r} = \frac{\frac{d}{dr}P(r)}{\rho} \\ \frac{d}{dr}V_r(r) + \frac{V_r(r)}{r} = 0 \end{cases} \quad (5)$$

From the third equation of the system (5), the radial component of the air velocity depends only on the radius, and also this equation is a differential equation in the complete derivatives, therefore its solution becomes the following form:

$$V_r(r) = \frac{C_1}{r} \quad (6)$$

Permanent integration of : C_1 is possible to determine from the condition if, on radius R_1, we know the value of the radial component of the air flow.

The value of this speed will be written as follows:

$$V_{r1} = \frac{Q_g}{2\pi R_1 H} \quad (7)$$

where Q_g – volumetric flow rate of air;

H – height of the vortex chamber, m

Consequently, constant integration is determined from the relation:

$$C_1 = V_{r1}R_1 \quad (8)$$

and the equation for determining the radial component of the air flow velocity will take the following form:

$$V_r = \frac{V_{r1}R_1}{r} \quad (9)$$

After the transformations from the first equation of system (5) one can obtain the theoretical dependence by which the quantity of the air velocity in the radius of the vortex chamber is determined quantitatively. This equation is a differential equation of the second degree with constant coefficients, but some simplifications have led to the dependence on one variable, which is the radius of the vortex chamber. Twice about integrating this differential equation, we obtain an analytic dependence in which there are two constant integrals:

$$V_\varphi(r) = \frac{C_2}{r} + C_3 r^{\left(\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)} \quad (10)$$

If the first derivative from the received dependence of the velocity of the air flow at a radius near a point with radius R_1 is 0, the analytical expression for this derivative has the form:

$$\frac{d}{dr}V_\varphi(r) = -\frac{C_2}{r^2} + \frac{C_3 r^{\left(\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)}(V_{r1}R_1+\varepsilon)}{\varepsilon r} \quad (11)$$

then the second condition that will determine the second constant integration, will be the equality of the velocity component of the air flow rate, the velocity of air flow from the input tangential cracks located on the radius R_1.

$$V_{r1} = \frac{Q_g}{h_{щ} n_{щ} H} \quad (12)$$

where $h_{щ}$ – width of tangential gap, m;

$n_{щ}$ – number of tangential cracks, pcs.

After the substitution, we obtain a system of two equations with two unknowns:

$$\begin{cases} 0 = -\frac{C_2}{R_1^2} + \frac{C_3 R_1^{\left(\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)}(V_{r1}+\varepsilon)}{R_1 \varepsilon} \\ V_{\varphi 1} = \frac{C_2}{R_1} + C_3 R_1^{\left(\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)} \end{cases} \quad (13)$$

The solution of this system of equations (13) is the analytic equations for constant integration:

$$\begin{cases} C_2 = \frac{V_{\varphi 1} R_1 (V_{r1} R_1 + \varepsilon)}{2\varepsilon + V_{r1} R_1} \\ C_3 = \frac{\varepsilon V_{\varphi 1} R_1^{\left(-\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)}}{2\varepsilon + V_{r1} R_1} \end{cases} \quad (14)$$

Consequently, we obtained an analytical expression by which we can quantitatively determine the value of the velocity of the airflow along the radius of the vortex chamber. To do this, you must specify the boundary conditions. In our case, such conditions are quantitative data of the velocity of the airflow within a radius equal to the radius of the arrangement of the tangential cracks for introducing air into the vortex aspiration chamber. After adding the values of the constants obtained as a result of the solution of the differential equation, the dependence for determining the velocity velocity of the vortex airflow along the radius of the vortex chamber will be as follows:

$$V_{\varphi}(r) = \frac{V_{\varphi 1} R_1 (V_{r1} R_1 + \varepsilon)}{(2\varepsilon + V_{r1} R_1) r} + \frac{\varepsilon V_{\varphi 1} R_1^{\left(-\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)} r^{\left(\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)}}{2\varepsilon + V_{r1} R_1}. \quad (15)$$

To solve this mathematical dependence (15) and to facilitate its analysis, we will write this expression in the following form:

$$V_{\varphi}(r) = \frac{1}{(2\varepsilon + V_{r1} R_1) r} \left(V_{\varphi 1} \left(R_1^2 V_{r1} + R_1 \varepsilon + \varepsilon R_1^{\left(-\frac{V_{r1}R_1+\varepsilon}{\varepsilon}\right)} r^{\left(\frac{V_{r1}R_1+2\varepsilon}{\varepsilon}\right)} \right) \right). \quad (16)$$

The analysis of the equations of the system (4-16) shows that the parasitic coefficient and the coefficient of kinematic viscosity, which is different for particles with different characteristics, is of paramount importance in the nature of the motion of the grain mixture particles in all directions of the vortex stream. In the radial direction, the movement of particles of the grain mixture is slowing down, and in the tangential direction it is accelerated, which provides the movement of heavy particles along the curvilinear trajectories with the approach to the axis of the vortex stream while simultaneously slowing down their fall. For light particles it promotes accelerated removal of them from the separation zone beyond the separating channel.

Compare the obtained dependence (16) with the results of calculations, for example, the ideal flow of air. It is known that in order to determine the velocity in a perfect airflow (without taking into account the viscosity), it is possible to obtain dependence on the conservation law of the moment of the number of rotational motion, which has the following known expression:

$$m_i \frac{d}{dt}\left(r V_{\varphi}\right) = 0 \quad (17)$$

where m_i – mass i – th volume of air.

Considering this mathematical dependence on the condition, that $m_i \neq 0$ and $dt \neq 0$, we obtain the following condition:

$$d\left(r V_{\varphi}\right) = 0 \quad (18)$$

Considering this equation, taking into account that the value r is a variable, we obtain a differential equation of the form:

$$V_{\varphi}(r) + r\left(\frac{d}{dr} V_{\varphi}(r)\right) = 0 \quad (19)$$

the solution of which will be as follows:

$$V_{\varphi}(r) = \frac{C_1}{r} \quad (20)$$

The constant integration of C_1 can be determined from the boundary conditions at the entrance to the vortex aspiration chamber. That is, when $r = R_1$, we assume that the velocity will be determined and exactly $V_{\varphi} = V_{\varphi 1}$. Consequently, under such conditions, constant integration will be determined by the following dependence:

$$C_1 = V_{\varphi 1} R_1. \quad (21)$$

Consequently, the analytical equation for determining the velocity in the ideal flow of air (without taking into account the viscosity) will take the following form:

$$V_{\varphi}(r) = \frac{V_{\varphi 1} R_1}{r}. \quad (22)$$

Let's consider in our example how the dependences (16) differ in determining the velocity of the viscous vortex airflow and the dependence (22), which determines the value of the velocity of the ideal airflow.

In these research, we take a vortex aspiration chamber with a radius of location of the tangential cracks $R_1 = 0{,}5\ m$, the value of the radial component of the full air flow velocity on the given radius $V_{r1} = 5\ m/s$,, the value of the velocity component at the same radius of the vortex chamber $V_{\varphi 1} = 17\ m/s$. We restrict the area along the radius of the vortex aspiration chamber, the radius of the aspiration canal to remove contaminated air from the vortex chamber, $R_2 = 0{,}15\ m$.

In Figure 2. Graphic dependencies are presented that clearly compare the calculations of the velocity of the ideal air flow and the viscous vortex air flow within the limits of the above dimensions of the vortex chamber and the specified boundary conditions.

Analyzing the obtained graphic dependences, we arrive at the conclusion that there is a significant decrease in the value of the velocity of the viscous vortex airflow relative to the velocity of the ideal airflow. This discrepancy is also confirmed by other investigators [23] for diverting the designs of aspiration chambers.

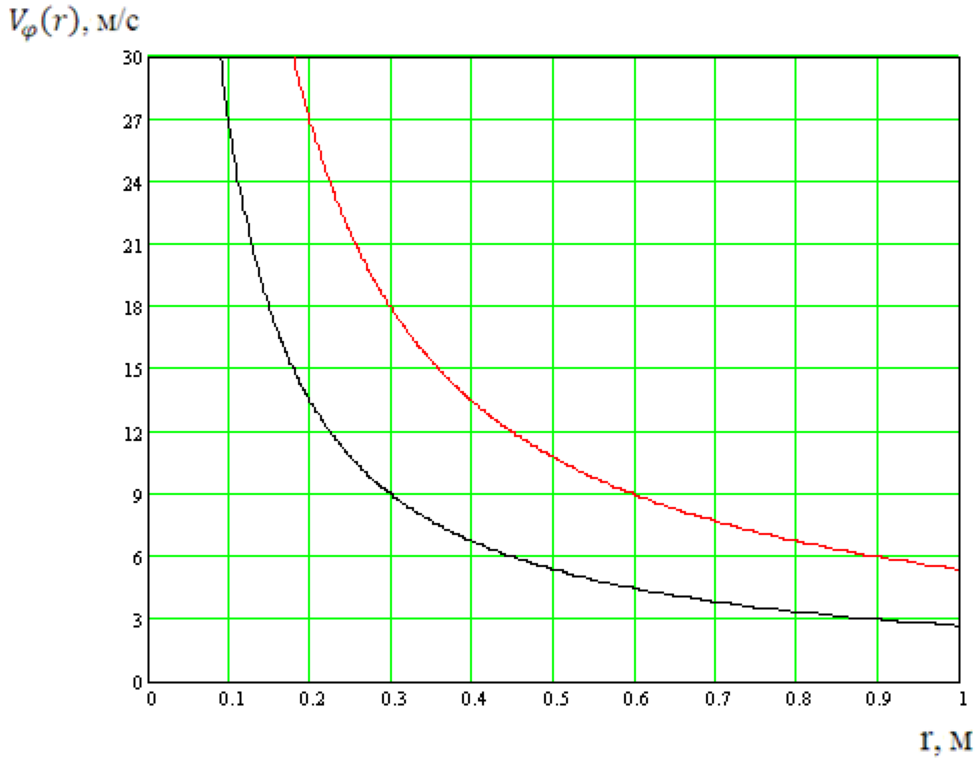

Fig. 2. Graphic dependencies of the velocity of the airflow along the radius of the vortex aspiration chamber (the upper line is for an ideal air flow; the bottom line is for a viscous vortex air stream).

Conclusions

1. The conducted research confirm the possibility intensification of the separation of the grain mixture in the pneumatic separating device, and theoretical reserch and mechano-technological substantiation of operations allow to determine the technological, kinematic and structural elements of such devices.

2. Taking into account the constructional possibilities of extending the perimeter of the pipeline and the intensification of its technological process, it is possible to create a grain-cleaning air-rack pneumatic center-flow block (module) with a high degree of unification and using the modular principle of constructing a separator structure with productivity up to 200 t / h. The analysis of the operations of the pneumoviral device shows his dear opportunities, which involves reducing of grain and seeds.

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ТЕОРЕТИЧНЕ ДОСЛІДЖЕННЯ ПРОЦЕСУ РОЗПОДІЛУ ЗЕРНОВИХ СУМІШЕЙ

С. П. Степаненко, Б. І. Котов

Анотація. У роботі наведені результати теоретичного дослідження взаємодії часток компонентів зернового матеріалу при противоточной подачі матеріалу в повітряний потік і при змінних епюрах швидкості потоку вздовж осей координат. Встановлено, що використання змінної швидкості збільшує величину розщеплення траєкторій руху і ефективність розділення. Аналізуючи отримані результати математичного моделювання балістики частинок компонентів зернового матеріалу можна визначити, що збільшення величини розщеплення (розгалуження) траєкторій руху частинок при використанні змінної швидкості повітряного потоку за координатами. Збільшення величини розщеплення траєкторій однозначно характеризує збільшення ефективності поділу компонентів зернового матеріалу на фракції по аеродинамічним властивостям, які як відомо щільно корелюють з якісними показниками зернового матеріалу. Отримані результати досліджень процесу інерційного фракціонування свідчать про реальну можливість підвищення ефективності поділу матеріалу на фракції по аеродинамічних властивостях. Ефект епюри швидкості повітря в повітряному каналі може бути використано для управління процесами поділу матеріалу на фракції.

Ключові слова: теоретична залежність, зернова суміш, дозування, виділення, розподілу, ефективність, продуктивність, якість.

ТЕОРЕТИЧЕСКОЕ ИССЛЕДОВАНИЕ ПРОЦЕССА РАЗДЕЛЕНИЯ ЗЕРНОВЫХ СМЕСЕЙ

С. П. Степаненко, Б. И. Котов

Аннотация. В работе приведены результаты теоретического исследования взаимодействия частиц компонентов зернового материала при противоточной подаче материала в воздушный поток и при переменных эпюрах скорости потока вдоль осей координат. Установлено, что использование переменной скорости увеличивает величину расщепления траекторий движения и эффективность разделения. Анализируя полученные результаты математического моделирования баллистики частиц компонентов зернового материала можно определить, что увеличение величины расщепления (ветвления) траекторий движения частиц при использовании переменной скорости воздушного потока по координатам. Увеличение величины расщепления траекторий однозначно характеризует увеличение эффективности разделения компонентов зернового материала на фракции по аэродинамическим свойствам, которые как известно плотно коррелируют с качественными показателями зернового материала.

Полученные результаты исследований процесса инерционного фракционирования свидетельствуют о реальной возможности повышения эффективности разделения материала на фракции по аэродинамическим свойствам. Эффект эпюры скорости воздуха в воздушном канале может быть использовано для управления процессами разделения материала на фракции.

Ключевые слова: теоретическая зависимость, зерновая смесь, дозировка, выделения, распределения, эффективность, производительность, качество.

S. P. Stepanenko ORCID 0000-0002-9307-2796.
B. I. Kotov ORCID 0000-0003-2369-7288.