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APPLICATION SOFTWARE PRODUCTS FOR CALCULATION TRAJECTORIES OF GRANULES MOVEMENT IN VORTEX GRANULATOR*

ABSTRACT

The article deals with the implementation of computer program for calculating the basic characteristics of granule movement in vortex granulator: speed and trajectory. For the calculation software programs Vortex Granulator© and Classification in vortex flow© were applied, as well as software package ANSYS CFX. Software allow to automatize the calculation simultaneously on multiple criteria optimization and visualization of calculation results in the form of plots or three-dimensional images. Calculation results are the base for the optimal choice of dispersant location and optimal sizes of the working chamber of the granulator.

KEYWORDS

Vortex granulator; software; trajectory; classification; calculation.

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ПРИМЕНЕНИЕ ПРОГРАММНЫХ ПРОДУКТОВ ДЛЯ РАСЧЁТА ТРАЕКТОРИЙ ДВИЖЕНИЯ ГРАНУЛ В ВИХРЕВОМ ГРАНУЛЯТОРЕ

АННОТАЦИЯ

Статья посвящена программной реализации расчёта основных характеристик движения гранул в вихревом грануляторе: скорости и траектории движения. Для проведения расчёта применены авторские программные продукты Vortex Granulator© и Classification in vortex flow©, а также программный комплекс ANSYS CFX. Программные продукты позволяют автоматизировать расчёт одновременно по нескольким критериям оптимизации и визуализировать результаты расчёта в виде графических зависимостей или трёхмерных изображений. Результаты расчёта являются основой для оптимального выбора места расположения диспергатора и оптимальных размеров рабочей камеры гранулятора.

КЛЮЧЕВЫЕ СЛОВА

Вихревой гранулятор, программное обеспечение, траектория, классификация, расчёт.

INTRODUCTION

Application of swirling flows technology during granulation in devices with fluidized bed disperse phase is one of the most promising methods for heat and mass transfer processes intensifying [1,2].

Due to lack of knowledge of hydrodynamic characteristics of flows movement when granulation in vortex fluidized bed some difficulties in design of vortex granulators occur. Vortex granulators in most cases are patented by industrial enterprises, which can conduct experimental research. The theoretical basis for calculation of such devices is limited to basic knowledge of fluid dynamics and heat and mass transfer in fluidized bed granulation. Calculations of vortex granulators are based on known algorithms for classical fluidized bed apparatus, for example, by methods [3].

Currently scientists of Sumy State University continues to work on theoretical description and experimental study of hydrodynamics of vortex flows movement and granulation process kinetics in devices with dispersed phase curling. In series of papers [4-12] the results of a theoretical description and experimental studies of movement hydrodynamics of single-phase and two-phase flows, processes of classification and separation of granules, modes of vortex fluidized bed, environmental aspects of vortex granulators introduction, etc were shown. In aggregate the results of these studies allow to create a

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methodology of vortex granulators engineering calculation.

The main stages of granulating calculation process in vortex machines we need to allocate blocks determining the hydrodynamic characteristics of granule motion (full speed and speed components), calculating the granules trajectories and granules classification process calculating. These characteristics allow to make optimal selection of dispersant location places, as well as to design the optimal granulator workspace configuration (when provided that the classification of granules to desired number of fractions).

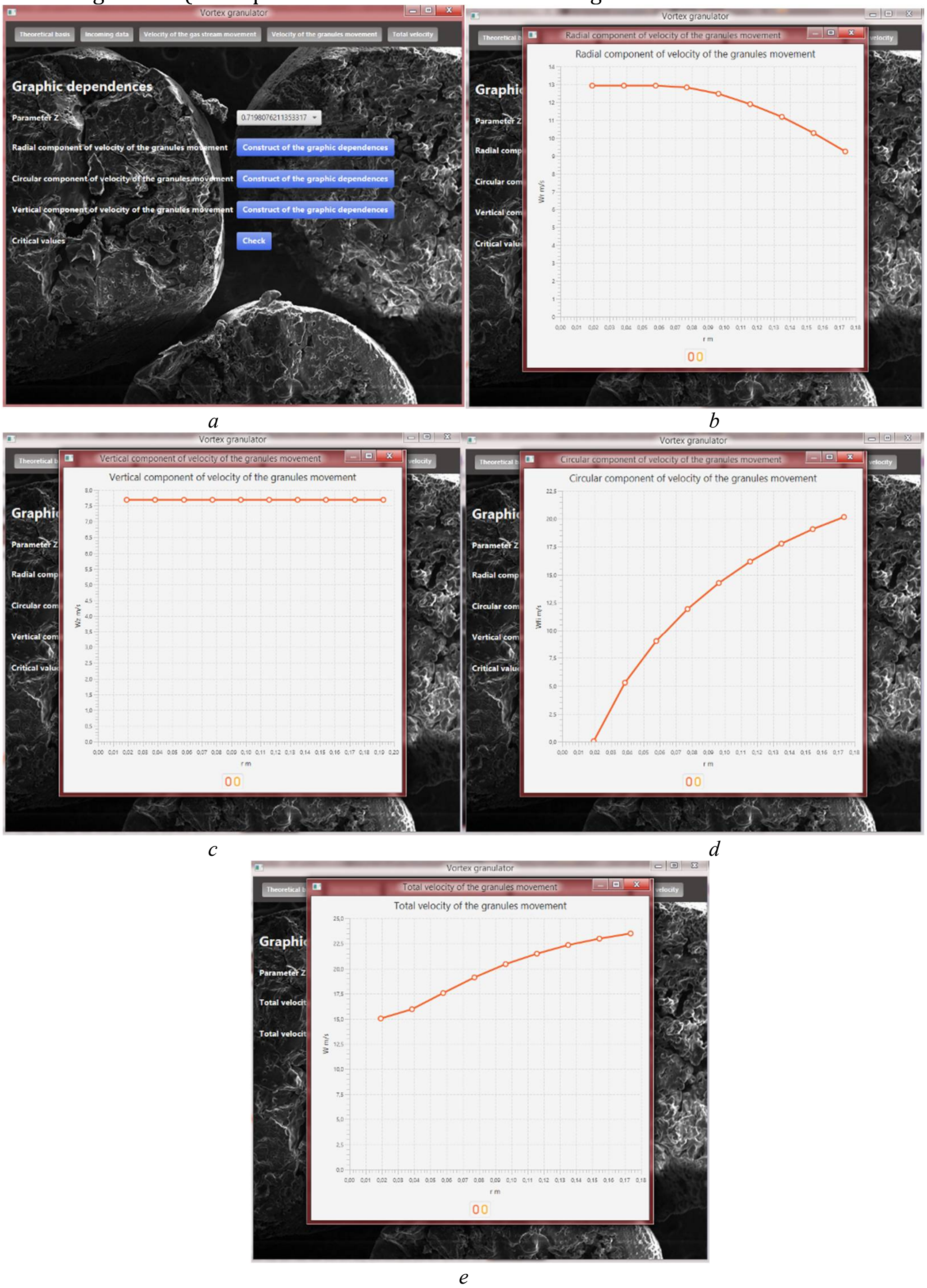


Fig. 1. Software Product Vortex Granulator©: a - window of plots creation of constituting granules components speed; b - radial component of granules speed movement; c - vertical component of granules speed movement; d - peripheral component of granules speed movement; e - total velocity of granules speed movement

Granulator with constant cross-sectional area do not provide the full process of classification and separation of non-tradables granules fraction in the granulator`s volume. This is because in the workspace vortex granulator consistency remains upward gas flow rate that corresponds to granules speed (or granules factions within a narrow range). To carry out granules classifications processes in device with a constant cross-sectional area if possible with the gas introduction to unit with several streams with different injection site altitude mark. This classification method is quite energy intensive and doesn`t get widespread application.

Much more effective method of classification is the use of solid phase devices with variable cross-sectional workspace area [13]. The creation in device volume fields of gas stream speed components of granulator height it is created different hydrodynamic conditions for granules movement. In the device height the distribution of the granules at different diameter (in case of classified granules from one material) or different mass (in terms of creating granules porous structure or multilayer granules) is done (Figure 1). This can not only get the product with given quality, but also while carrying out separation and granulation change the granulation terms.

METHODOLOGY

Software product Vortex Granulator© (program interface is presented on fig.1, this article presents the unit for calculating the granule`s hydrodynamic characteristics) is based on Navier-Stokes equations system and flow continuity equation (single stream) and system of differential equations of granules movement in cylindrical coordinate system [4,5].Software Classification in vortex flow© (program interface is presented in fig. 2, in this article the program used to calculate the distribution of granules in the height of granulators working space) is based on mathematical model of classification and separation of granules in vortex granulator [8].

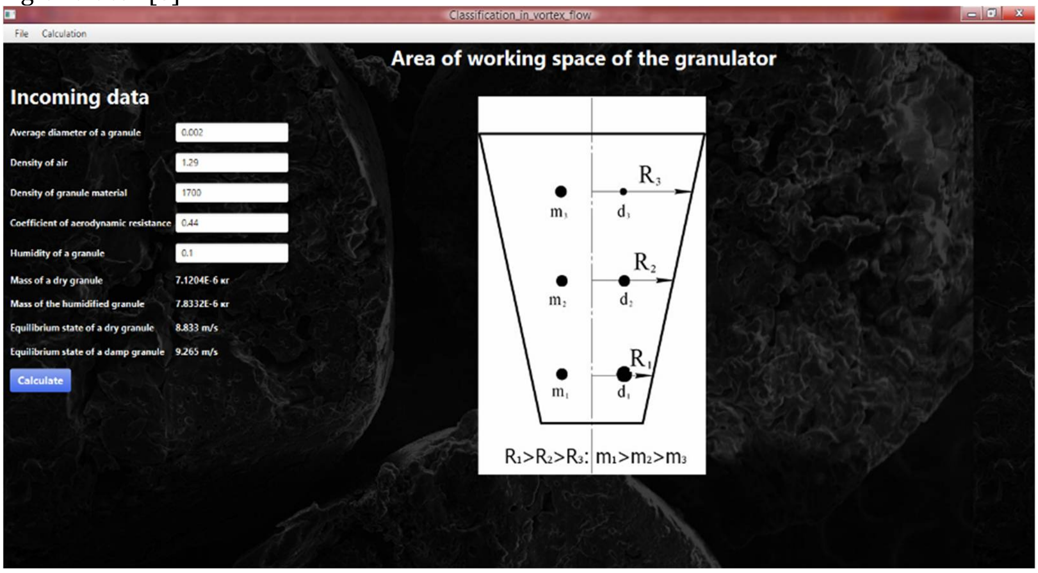


Fig. 2. Software Product Classification in vortex flow©

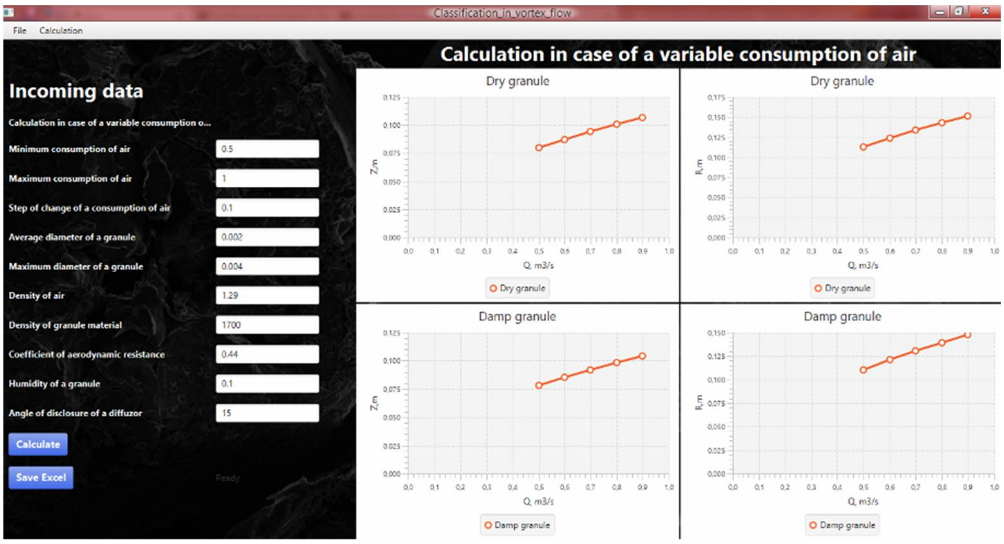


Fig. 3. Calculation of vortex granulator workspace geometry at variable air consumption

In software product Vortex Granulator © Granuly.java class are presented that displays a graph of speed components (vertical, radial and circumferential) of gas flow and granules. Class Traektory.java displays overall speed and trajectory of granules movement. Class Functional.java retains the program input values and includes methods of forming solutions and data to display graphic dependencies.

The main class of program Classification in vortex flow© is Main.java class that is responsible for displaying the main menu and connection other classes to it.

Program has two calculation areas to determine the optimum size of vortex granulator working space:

1. The gas flow speed (fig.2).
2. The workspace geometry:

• calculation with variable air expenditure - are displayed depending on the height of working space and the radius of cross section of air flow to dry and wet granules (fig.3);

• calculation at diffuser disclosure opening angle - are displayed depending on the height of working space from the diffuser opening angle for dry and wet granules (fig.4);

• calculation of granules distribution on fractions in granulator working space - shows the distribution of granules with different diameters at the height of working space vortex granulator (fig 5.).

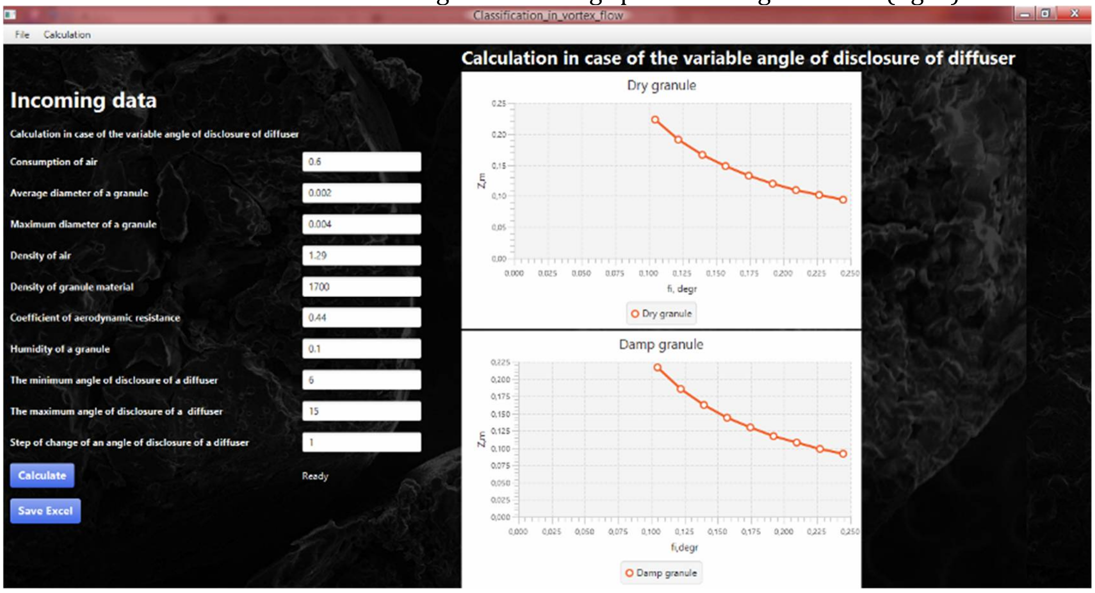


Fig. 4. Calculation of vortex granulator workspace geometry at variable diffuser opening angle

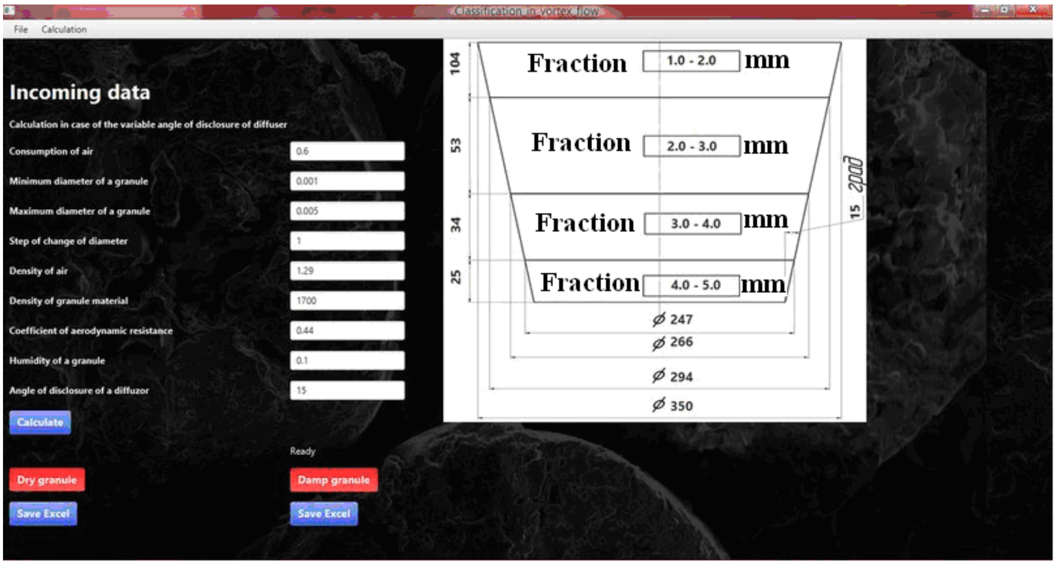


Fig. 5. The calculation of granules distribution on fractions in granulator`s working space

In solving the equations of mathematical model [4,5,8] numerical methods for solving differential equations were used. To do this we divide granulator`s conical housing the into a number of cylindrical sections as it is shown in fig.6.

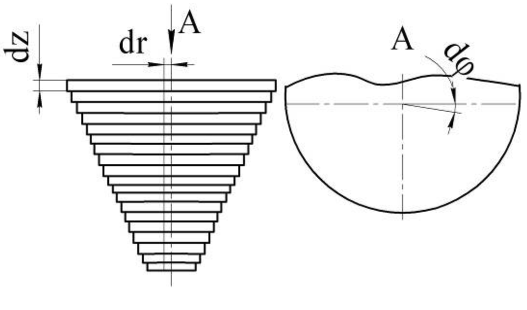


Fig.6. Calculation chart to determine the hydrodynamic characteristics of granules movement

In the paper following notations were made:

W_Z – expenditure (axial, vertical) component of movement speed of granule, m / s;

W_r – radial component of movement speed of granule, m / s;

W_φ – circumferential component of speed movement of granule, m / s;

V_φ – circumferential component of gas flow speed movement before contact with the granules, m / s;

V'_φ – primary circumferential component of gas flow speed movement after contact with the granules, m / s;

$V_{\varphi 1}$ – circumferential component of gas flow speed movement after contact with the granules, m / s;

W– total speed of granules, m / s;

Z – current height of vortex granulator working space, m (mm);

R – current range of vortex granulator working space, m (mm);

φ – half of opening angle of conical housing of vortex granulator, hail;

Q_g – gas flow rate, m^3 / s (m^3 / hr.).

Q_d – dispersed phase flow rate (performance of finished product), m^3 / s (cubic meters / hr.).

d – granule diameter, m (mm);

ψ – relative content of the dispersed phase in the working space of the vortex granulator, m^3 / m^3;

U – moisture of granules, % mass.

The main objectives of this research are:

- Study of granules impact on changing the speed of circumferential component of gas flow speed;
- Determining components of granules speed, granules full speed movement, its vector direction and general movement trajectory;
- Calculation of granules classification process.

RESULTS AND DISCUSSION

Investigation of granules effect on change gas flow circumferential speed component

The flow of continuous phase, which flow is modeled with system Navier-Stokes equations and flow continuity equation gives the angular momentum of discrete particles. In the case of liquid phase appearing in the working volume of device it is pulled into rotary motion by gas stream energy. This entry dispersed phase to continuous cause significant change in the value component of gas flow circumferential speed V_φ.

Fig.7 illustrates the results of calculation of speed value when $Q_d = 1,74$ m^3 / h, (granulator power for granular material, ammonium nitrate, 3000 kg / h, flow rate of gas flow from the material balance of power respectively Q_d) and comparing it with the initial value of speed angular component of gas flow. The projected decrease of angular speed component is more intensive in central zone with reduction to granulator`s periphery.

Comparative characteristics of gas stream angular speed component values after contact with granules with different load for granules is presented in fig.8. Similar calculations are possible to different values of parameter ψ, which determines the capacity of granulator for granular product. For each type as separate devices that are characterized by different values of speed $V_{\varphi 1}$, based on these calculations, range of ratios of loads on phases Q_d/Q_g of sustainable granulator work are defined.

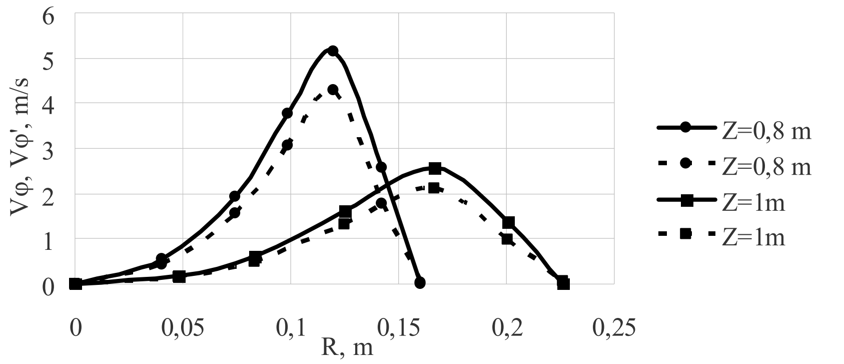


Fig. 7. Impact of granules to change the angular component of gas stream speed (Solid line shows the value of V_φ dotted - V'_φ)

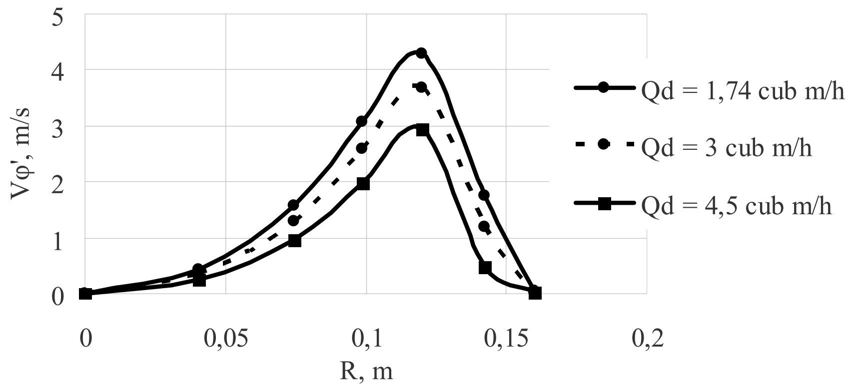
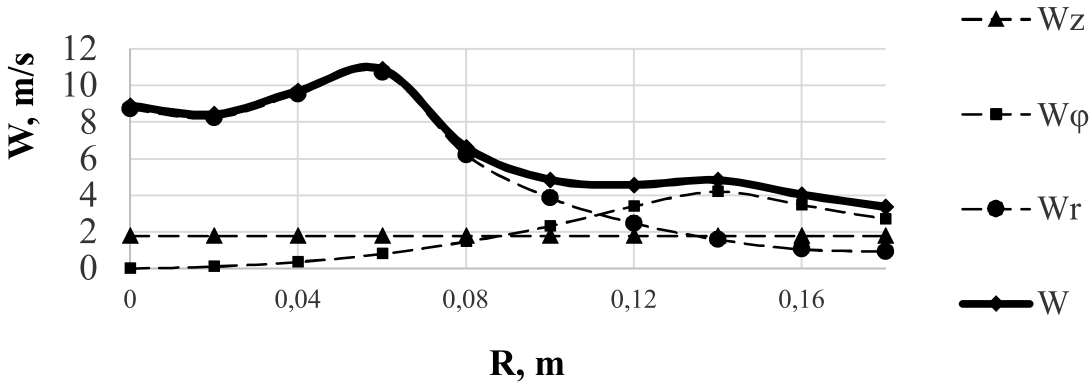


Fig. 8. Comparative characteristics of speed angular component of gas stream values after contact with granules with different load for dispersed phase



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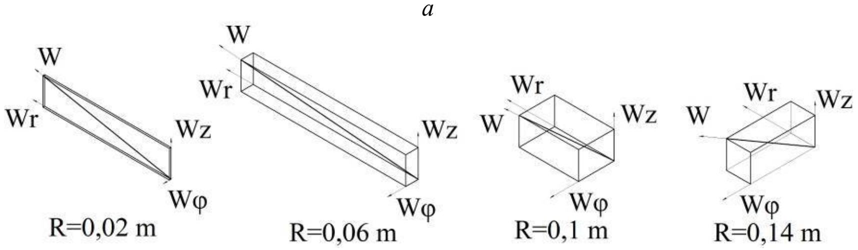

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Fig. 9. Calculation of granules total speed (a) and direction of granules speed vector (b) at Q = 0,63 m³ / s, φ = 13 °, z = 0,8 m

In mode of advanced weighted vortex layer granules movement trajectory in the working space of vortex granulator has characteristic spiral trajectory, formed progressively as granulator start function in working mode.

Dispersed phase moves along similar trajectory with gas flow, but at a slower rate: for the same period of time it cross the way smaller than the dispersion due to the fact that the height granulator in each section varies its value forces, acting on granule. As granules movements up by drying it loses part of its mass (thus decreasing the force of gravity acting on granule), cross section granulator increases, which tends to reduce aerodynamic drag force, gas flow twist is also reduced, which reduces the centrifugal force. Given the very complex hydrodynamic situation, calculation of granules trajectory is based on solving differential equations of movement in each direction.

Granules movement trajectory causes time its stay in vortex granulator workspace. This time should be sufficient to make the process of crystallization in all granule`s layers and no more to avoid the granules core destruction [13].

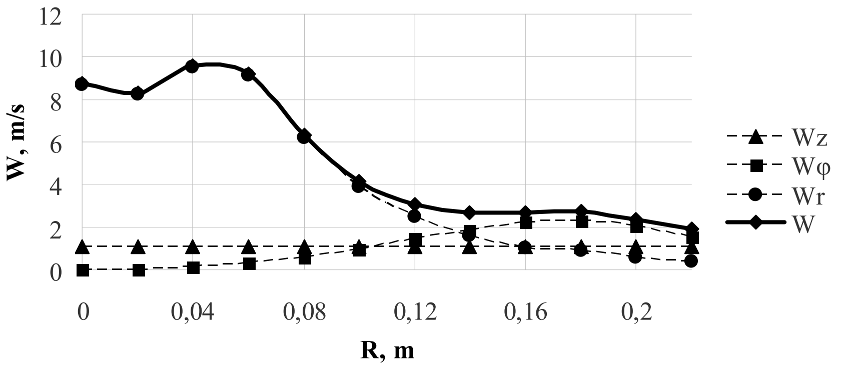
The calculation is carried out for cylindrical sections and the calculation results at one section is the original data to calculate the next section in the direction of granules movement.

The flow of granules in vortex granulator workspace is complex spatial structure, the configuration of which is affected by device constructive system design and granules properties. The solution of differential equations of movement allows to predict the granule`s location at a given time.

Determination of granules speed movement components, granules full speed movement, its direction vector and overall movement trajectory.

The results of calculation of granules total speed and determination of direction of speed vector and its change in height of device are shown in figs 9-11. The analysis shows that in height of device granules movement total speed is decreasing by reducing of expenditure and radial component.

The degree of granules spin is almost equal to degree of gas flow spin that suggests the angular gas flow speed component as determining to directed and uniform granules vortex movement. Concerning the regard preferred direction of granules speed vector, analysis results based on above mentioned figures allow to say that the zone of granules pronounced vortex movement, combined vortex and ascending movement and granules upward movement can expand or contract depending on initial spin of gas flow.



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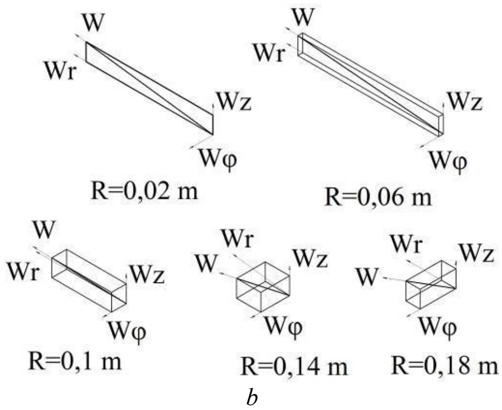

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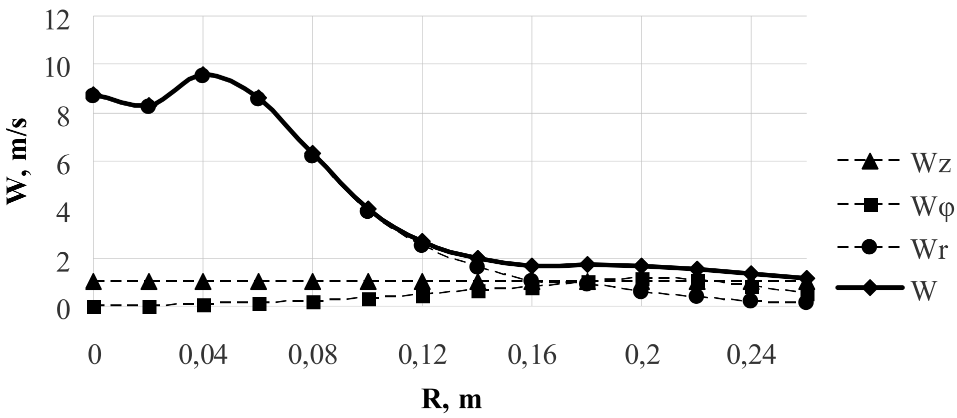
Fig. 10. Calculation of granules total speed (a) and direction of granules speed vector (b) at Q = 0,63 m^3 / s, φ = 13 °, z = 1 m



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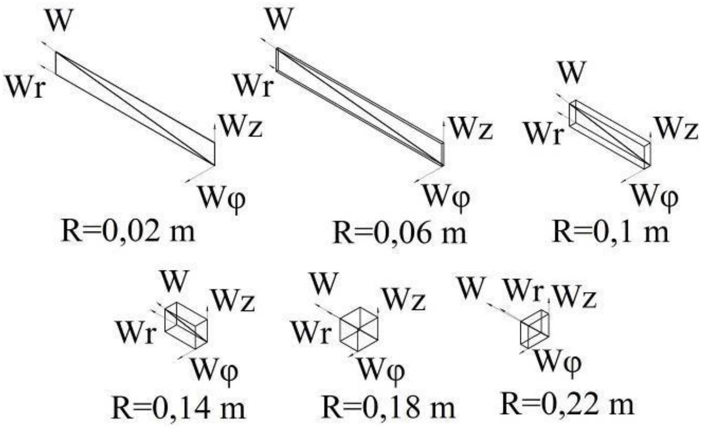

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Fig. 11. Calculation of granules total speed (a) and direction of granules speed vector (b) at Q = 0,63 m³ / s, φ = 13 °, z = 1,2 m

Using of granules movement differential equations in cylindrical coordinates and numerical solution method of Runge-Kutt using copyright software Vortex Granulator© trajectory depending on the design of the vortex granulator, granules properties and the cost of gas flow were obtained. All trajectories have spiral form with different geometrical characteristics.

Analysis of results calculation showed that with the granules movement from the center to wall full speed vector changes in direction depending on the preferences of particular component. At the initial time granule moves from the axis of device perpendicular to it due to the predominance of speed radial component. As we approach the half radius of vortex granulator granule begins to be drawn into the vortex motion due to the predominance of speed angular component. Near the wall of granulator granule moves along a spiral path of gradually moving vertically by increasing expenditure component impact its speed; does not change the trajectory to reach the upper section of vortex granulator.

Analysis of trajectories showed that:

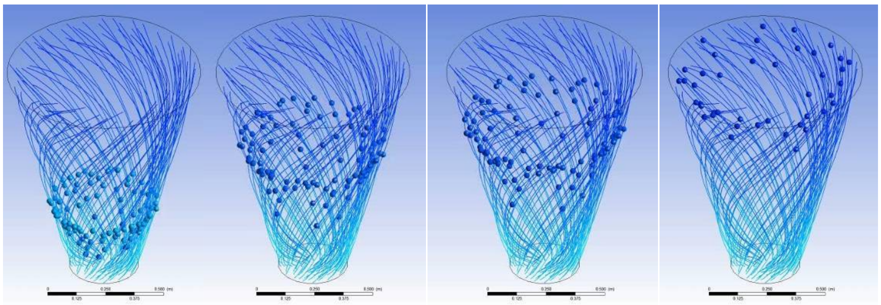
- Increasing the gas flow consumption and cone angle of opening vortex granulator workspace leads to reduction of spiral turns, increasing their step and reducing the time of granules spent in vortex granulator workspace;

- Increasing the value of initial gas flow spin (defined angle blades eddy and their number) and the diameter of granules change the trajectory of its movement by increasing the number of spiral turns, reducing their step, increasing the diameter of spiral upper section and increasing the granules time spent in vortex granulator workspace.

Granules are moving along the vortex granulator walls and actually do not stay in its central zone. This is the direction vector of action full speed of their movement from the center to the periphery due to the predominance of radial component of granules movement to two thirds of device radius. Closer to the walls of the granulator performance radial component decreases and the granules begin to get involved in rotary motion with vertical movement.

By rational selection of cone opening angle, angle of inclination of blades eddy and their number, gas flow consumption we can control granules movement to delay at certain section of vortex granulator.

Figs 12, 13 present the calculated granules trajectory at different components of its speed components. Trajectories were built using the author's mathematical model of granules movement with software system ANSYS CFX.



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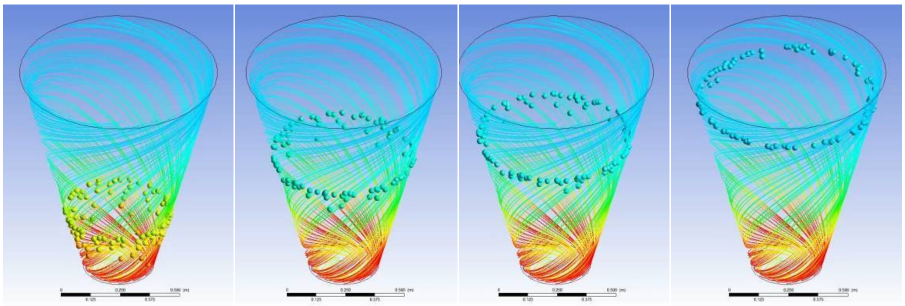

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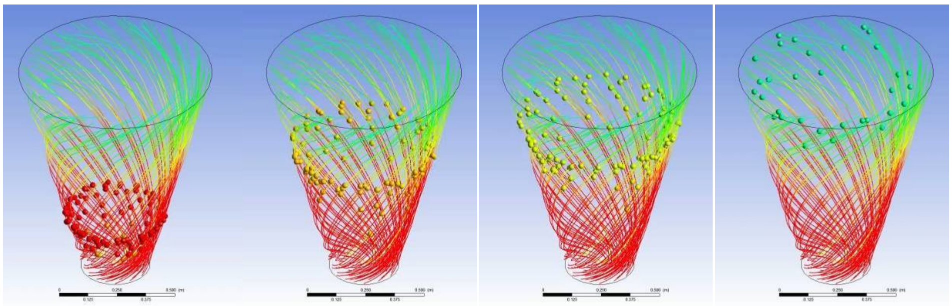
Fig. 12. Granules movement trajectories: a – W_z=1 m/s; W_r=1 m/s; W_φ=1 m/s; b – W_z=1 m/s; W_r=1 m/s; W_φ=15 m/s



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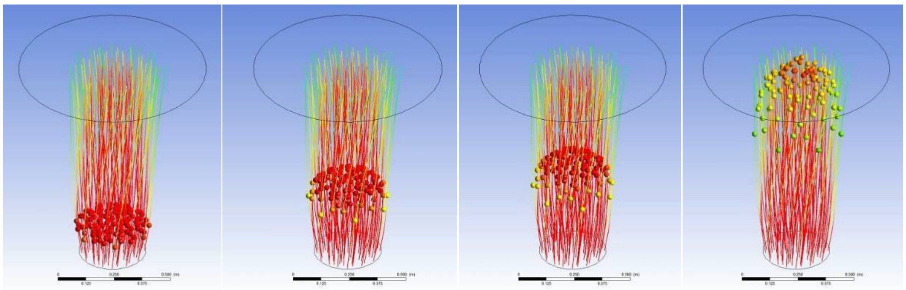

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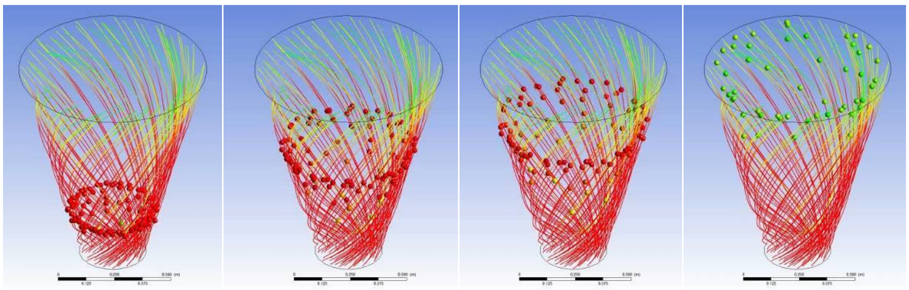

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Fig. 13. Granules movement trajectories: a – Wz = 8 m / s; Wr = 1 m / s; Wφ = 15 m / s; b – Wz = 15 m / s; Wr = 1 m / s; Wφ = 1 m / s; c – Wz = 15 m / s; Wr = 1 m / s; Wφ = 15 m / s

Calculation of granules classification process

Calculation results in Classification in vortex flow© are shown in figs 14-16.

Directed drainage of small granules in space with internal seeding agent circulation is provided by abrupt change in cross-sectional area after the gas output from the inner cone. By reducing the aerodynamic resistance force small granules begin to fall down through the cross-section between annular space, passing all of its height and in the inferior cross section are taken up by ejected gas flow.

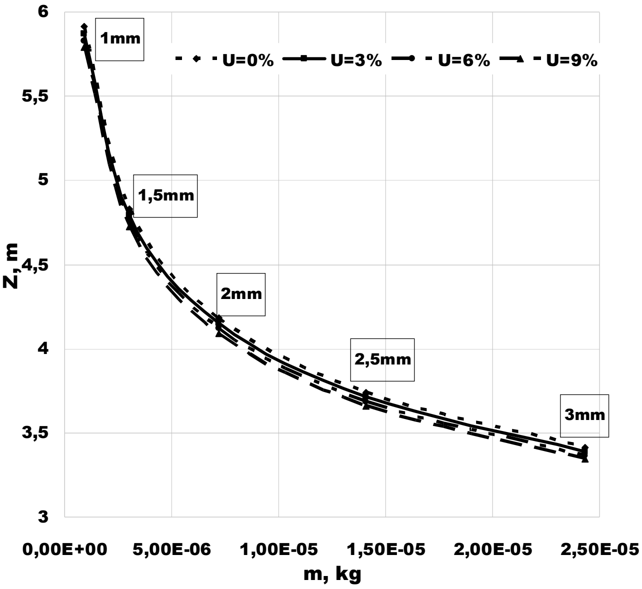

Fig. 14. Classification of granules by weight depending on moisture content at Q = 1 m³/s, φ=14°

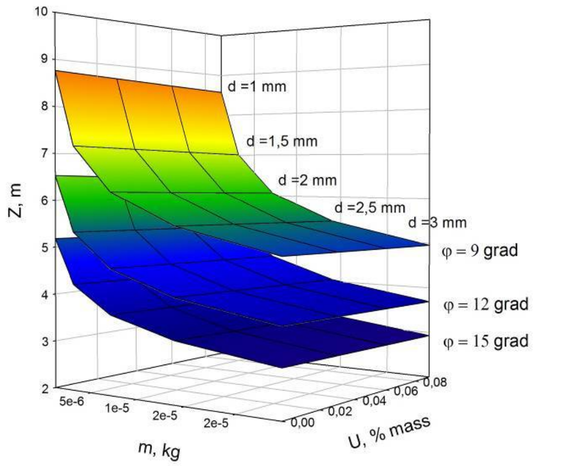

Fig. 15. Classification of granules by weight depending on moisture content and angle of opening vortex granulator cone at Q = 1 m³/s

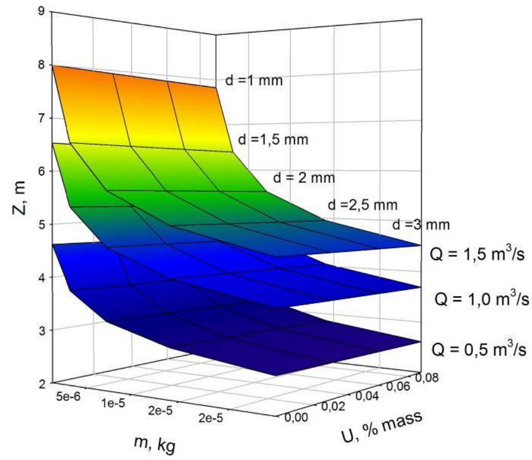

Fig. 16. Classification of granules by weight depending on moisture content and heat transfer agent consumption at angle of opening vortex granulator cone φ=12.

Separation of small grains is important to ensure their integrity. With intensive gas flow swirling fine granules after output from the inner cone are discarded to outer housing wall, bump against him and destroyed. Given that small fraction is heated in suspended layer in its core additional stresses, that reduce strength, are appeared.

At small angles of opening cone polydispersed system consists of separate layers:

- one above the other from large (heavy) fraction in lower section to small (light) in upper section without crossing each other layers. This option is possible with wide cut polydispersed system;

- one above the other from large (heavy) fraction in lower section to small (light) in upper section of the section layers separate factions together This variant is observed in narrow fractional composition of polydispersed system.

The calculation results to estimate the size of the granules that are outside the workspace granulator (above section, in which granules commodity faction minimum size are moving). These granules are separated in the top of space, and then go from the granulation area with gases.

The results of experimental studies [14] confirm the presence of specific areas of gas flow distribution in vortex granulator workspace based on observed granules trajectories.

CONCLUSION

Given algorithm for calculation of hydrodynamic characteristics of vortex granulating equipment allows to predict the behavior of a drop (pellets) from its departure from the dispersion device (nozzle, melt granulator) until the end of crystallization.

The results of analytical solution of mathematical model equations using software products Vortex Granulator© and Classification in vortex flow© allow to design granulator which along with granulation will make possible implementation classification and internal seeding agent circulation process.

This work was carried out under the project «Improving the efficiency of granulators and dryers with active hydrodynamic regimes for obtaining, modification and encapsulation of fertilizers», state registration No. 0116U006812. While preparing the article it was used information about the original designs of vortex granulators (patents Nos 99023 Ukraine IPC (2012.01) B01J2/16, Ukraine IPC 110992 B01J 2/00, B01J 2/16, 111406 Ukraine IPC B01J 2/04, B01J 2/16 etc.) and author`s software products (certificates of authorship No 65140, 67472). The authors thank researchers of department "Processes and equipment of chemical and refining industries", Sumy State University for their valuable comments during the article preparation.

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