Optimization Calculation of Vortex Type Granulation Devices: Application of Software Products and Computer Modeling

Artem Artyukhov[1[0000-0003-1112-6891]] and Jan Krmela[2[0000-0001-9767-9870]]

[1]Sumy State University, 2 Rymskogo-Korsakova Street, Sumy 40007, Ukraine
a.artyukhov@pohnp.sumdu.edu.ua
[2]Alexander Dubcek University of Trencin, 491/30 I. Krasku, Puchov 02001, Slovak Republic
jan.krmela@fpt.tnuni.sk

Abstract. The paper studies the hydrodynamic conditions of gas flow motion and vortex granulator workspace design optimization. A comprehensive approach for determination of the hydrodynamic characteristics of a vortex gas flow and their visualization is proposed. The mathematical approach, based on Reynolds equations for turbulent flows solution, is presented. The mathematical model equations solution with the definition of gas flow velocity components in any point on the radius and height of vortex granulator, is obtained. The obtained results form the basis of original algorithm for calculating of vortex granulator hydrodynamic calculation and its basic dimensions optimization selection.

Keywords: Software, Modeling, Vortex Granulator, Hydrodynamics, Optimization
Key Terms: Development, Software Engineering Process, Research

1 Introduction

Flows of single-phase and multiphase medium play a key role in the working process of many contemporary engineering devices. The design of these devices for the required operating parameters is impossible without a reliable prediction of the characteristics of these flows. Since many modern engineering devices are expensive and time consuming to manufacture, physical modeling with the experimental determination of the parameters of their work in different modes, as a rule, requires a lot of time and cost. In addition, because of limited possibilities of modern experimental sensors and measuring instruments, experimental observations do not provide a complete picture of the phenomenon being investigated. Because of nature of these environments, flow of liquids and gases occur often very in complex manner to form nonstationary effects, “dead” zones and vortex structures [1,2]. The situation is further complicated by the presence of heat transfer, in considering flows mixture of several substances, flows with free surfaces, weighted particles in stream, flows with cavitation, boiling, condensation, combustion, chemical reactions [3-7]. These factors lead to growing interest of mathematical modeling tools for flows of liquids and gases, which allow to

predict the flow characteristics and parameters of the devices at design stages and stages of manufacturing in the metal.
Software can adequately simulate the complex physical effects taking place in flows motion in vortex granulator, and perform calculation of flows within the reasonable time [8,9]. They provide user convenient tools of data preparation and analysis of calculations results, and are a powerful tool for accurately predict the characteristics of flow of hydraulic parts at design stage, saving the resources to conduct a physical experiment.
Methods CFD (Computational Fluid Dynamics) suggest calculation of flows of liquids and gases through the numerical solution of equations of Navier-Stokes and continuity, describing the most general case of this medium motion (for turbulent flows - Reynolds equations).
The purpose of work is creation of vortex granulator optimization calculation algorithm. The author's software and calculation data visualization using software for calculation flows hydrodynamics should be created on base of the suggested algorithm.
As a working hypothesis according to the possibility of controlling the trajectory of motion and the residence time of the dispersed phase in the working space of the granulator due to the creation of mechanisms of its directed movement. A joint solution of the fundamental equations of the hydrodynamics of flow motion and kinetics of changes in the temperature and humidity characteristics of the interacting flows, as well as the growth rate of the granules, will allow inventing a rational design of the working space, the optimal flow of coolant and its temperature and humidity characteristics in the vortex granulator. The calculation is carried out according to the criterion of optimization "minimum" hydrodynamic "residence time of the dispersed phase in the working space of the device." "Hydrodynamic" time should be equal to "kinetic" - the time during which the temperature and humidity characteristics of the dispersed phase must acquire a normative value.

2 Theoretical basics

Given that, in practice interest is usually deals with not instantaneous, but with the average in time velocity value, for mathematical description of turbulent swirling motion of gas flow Reynolds equation as modification of Navier-Stokes equations is used [10]

$$\frac{\partial}{\partial t}\left(\rho \overline{V_i}\right)+\frac{\partial}{\partial q_j}\left(\rho \overline{V_i V_j}\right)+\frac{\partial}{\partial q_j}\left(\rho \overline{V_i' V_j'}\right)=-\frac{\partial p}{\partial q_i}+\frac{\partial}{\partial q_j}\left[\mu\left(\frac{\partial \overline{V_i}}{\partial q_j}+\frac{\partial \overline{V_j}}{\partial q_i}\right)\right]+f_i \quad (1)$$

where $\overline{V}$ - average in time values of velocity; $\overline{V}'$ - components of velocity pulsations; μ - coefficient of turbulent viscosity; t - time; ρ - gas density; p - pressure; f_i – element, characterizing the mass forces effect; qj - coordinate axes (in the case of hydrodynamic modeling in granulator working volume as it is shown above, it is advisable to use curvilinear coordinate system), i, j - 1 ... 3; for cylindrical coordinate system (fig. 1) code "1" - axial direction (z), code "2" - radial direction (r), code "3" - circular direction (φ) (figs 1,2).

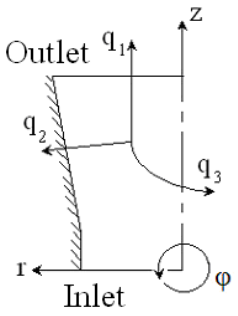


Fig. 1. Scheme of vortex granulator workspace and coordinate system.

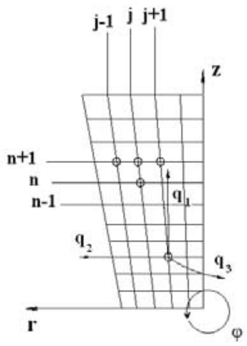


Fig. 2. Construction of calculation grid.

The Reynolds equations system is supplemented with flow continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial q_j}\left(\rho V_j\right) = 0. \tag{2}$$

The main advantage of description and problem solving hydrodynamics method, based on numerical solution of Reynolds complete equations - accuracy and versatility.

For Reynolds equations (1) solving Boussinesq hypothesis [10] is used. According to this hypothesis, the members with velocity pulsations $\left(\rho \overline{V_i' V_j'}\right)$ in equation (3) are associated with the averaged flow characteristics in such relation:

$$\rho \overline{V_i' V_j'} = -\mu\left(\frac{\partial \overline{V_i}}{\partial q_j} + \frac{\partial \overline{V_j}}{\partial q_i}\right) + \frac{2}{3}\rho \delta_{ij} k\,, \tag{3}$$

where $k = 0,5\left(\overline{V_j' V_j'}\right)$ – turbulence kinetic energy, $\delta_{ij} = 1$ when $i = j$, $\delta_i = 0$ when $i \neq j$.

The Reynolds system of equations is elliptic. It is used to calculate the trends in those cases where flow characteristics at arbitrary point area depend on the structure of flow both above and downstream, i.e. when the dominant direction of the fluid is absent or weakly expressed. Ellipticity system of equations means to address it is necessary to set the boundary conditions for all variables in all the borders of calculation area.

When axisymmetrical flow modeling equation of motion (1) and continuity of flow (2) is significantly simplified. For curved (cylindrical) coordinate system are as follows (with the introduction of equation (3) Reynolds number $Re = V_0 D/\nu$ where characteristic parameters D – diameter of input cross section calculation area; V_0 - average rate velocity in the input section; ν - kinematic viscosity):

– Reynolds equations projected on the axial direction q_1:

$$\frac{V_1}{H_1}\frac{\partial V_1}{\partial q_1} + \frac{V_2}{H_2}\frac{\partial V_1}{\partial q_2} - \frac{V_2^2}{H_1 H_2}\frac{\partial H_2}{\partial q_1} - \frac{V_3^2}{H_1 H_3}\frac{\partial H_3}{\partial q_1} + \frac{1}{H_2}\frac{\partial\left(\overline{V_1' V_2'}\right)}{\partial q_2} + \frac{\left(\overline{V_1' V_2'}\right)}{H_1^2 H_2 H_3}\frac{\partial\left(H_1^2 H_3\right)}{\partial q_2} +$$

$$+\frac{1}{H_1}\frac{\partial\left(\overline{V_1'V_1'}\right)}{\partial q_1}+\frac{\left(\overline{V_1'V_1'}\right)}{H_1^2H_2H_3}\frac{\partial\left(H_1H_2H_3\right)}{\partial q_1}-\frac{\left(\overline{V_2'V_2'}\right)}{H_1H_2}\frac{\partial H_2}{\partial q_1}-\frac{\left(\overline{V_3'V_3'}\right)}{H_1H_3}\frac{\partial H_3}{\partial q_1}=-\frac{1}{H_1}\frac{\partial p}{\partial q_1}+$$

$$+\frac{1}{\mathrm{Re}}\left(\frac{1}{H_1^2}\frac{\partial^2 V_1}{\partial q_1^2}+\frac{1}{H_2^2}\frac{\partial^2 V_1}{\partial q_2^2}+\frac{1}{H_1H_2H_3}\frac{\partial V_1}{\partial q_1}\frac{\partial(H_2H_3/H_1)}{\partial q_1}+\frac{1}{H_1H_2H_3}\frac{\partial V_1}{\partial q_2}\frac{\partial(H_1H_3/H_2)}{\partial q_2}+\right.$$

$$-\frac{2}{H_1H_2^2}\frac{\partial H_2}{\partial q_1}\frac{\partial V_2}{\partial q_2}+\frac{V_1}{H_1}\frac{\partial}{\partial q_1}\left(\frac{1}{H_1H_2H_3}\frac{\partial\left(H_2H_3\right)}{\partial q_1}\right)+ \qquad (4)$$

$$\left.+\frac{V_2}{H_1}\frac{\partial}{\partial q_1}\left(\frac{1}{H_1H_2H_3}\frac{\partial\left(H_1H_3\right)}{\partial q_2}\right)-\frac{V_2}{H_2H_3}\frac{\partial}{\partial q_2}\left(\frac{H_3}{H_1H_2}\frac{\partial H_2}{\partial q_1}\right)\right);$$

– Reynolds equations projected on the radial direction q_2:

$$\frac{V_1}{H_1}\frac{\partial V_2}{\partial q_1}+\frac{V_2}{H_2}\frac{\partial V_2}{\partial q_2}-\frac{V_1V_2}{H_1H_2}\frac{\partial H_2}{\partial q_1}-\frac{V_3^2}{H_2H_3}\frac{\partial H_3}{\partial q_2}+\frac{1}{H_1}\frac{\partial\left(\overline{V_1'V_2'}\right)}{\partial q_1}+\frac{\left(\overline{V_1'V_2'}\right)}{H_1H_2^2H_3}\frac{\partial\left(H_2^2H_3\right)}{\partial q_1}+$$

$$+\frac{1}{H_2}\frac{\partial\left(\overline{V_2'V_2'}\right)}{\partial q_2}+\frac{\left(\overline{V_2'V_2'}\right)}{H_1H_2^2H_3}\frac{\partial\left(H_1H_2H_3\right)}{\partial q_2}-\frac{\left(\overline{V_3'V_3'}\right)}{H_2H_3}\frac{\partial H_3}{\partial q_2}=-\frac{1}{H_2}\frac{\partial p}{\partial q_2}+$$

$$+\frac{1}{\mathrm{Re}}\left(\frac{1}{H_1^2}\frac{\partial^2 V_2}{\partial q_1^2}+\frac{1}{H_2^2}\frac{\partial^2 V_2}{\partial q_2^2}+\frac{1}{H_1H_2H_3}\frac{\partial V_2}{\partial q_1}\frac{\partial(H_2H_3/H_1)}{\partial q_1}+\frac{1}{H_1H_2H_3}\frac{\partial V_2}{\partial q_2}\frac{\partial(H_1H_3/H_2)}{\partial q_2}+\right.$$

$$\left.+\frac{2}{H_1H_2^2}\frac{\partial H_2}{\partial q_1}\frac{\partial V_1}{\partial q_2}+\frac{V_2}{H_2}\frac{\partial}{\partial q_2}\left(\frac{1}{H_1H_2H_3}\frac{\partial\left(H_1H_3\right)}{\partial q_2}\right)\right); \qquad (5)$$

– Reynolds equations projected on the circular direction q_3:

$$\frac{V_1}{H_1}\frac{\partial V_3}{\partial q_1}+\frac{V_2}{H_2}\frac{\partial V_3}{\partial q_2}+\frac{V_1V_3}{H_1H_3}\frac{\partial H_3}{\partial q_1}+\frac{V_2V_3}{H_2H_3}\frac{\partial H_3}{\partial q_2}+\frac{1}{H_2}\frac{\partial\left(\overline{V_2'V_3'}\right)}{\partial q_2}+\frac{\left(\overline{V_2'V_3'}\right)}{H_1H_2H_3^2}\frac{\partial\left(H_1H_3^2\right)}{\partial q_2}+$$

$$+\frac{1}{H_1}\frac{\partial\left(\overline{V_1'V_3'}\right)}{\partial q_1}+\frac{\left(\overline{V_1'V_3'}\right)}{H_1H_2H_3^2}\frac{\partial\left(H_2H_3^2\right)}{\partial q_1}=\frac{1}{\mathrm{Re}}\left(\frac{1}{H_1^2}\frac{\partial^2 V_3}{\partial q_1^2}+\frac{1}{H_2^2}\frac{\partial^2 V_3}{\partial q_2^2}+\right. \qquad (6)$$

$$\left.+\frac{1}{H_1H_2H_3}\frac{\partial V_3}{\partial q_1}\frac{\partial(H_2H_3/H_1)}{\partial q_1}+\frac{1}{H_1H_2H_3}\frac{\partial V_3}{\partial q_2}\frac{\partial(H_1H_3/H_2)}{\partial q_2}+\frac{V_3}{H_1H_2}\frac{\partial}{\partial q_2}\left(\frac{H_1}{H_2H_3}\frac{\partial H_3}{\partial q_2}\right)\right);$$

– continuity equation:

$$\frac{1}{H_1H_2H_3}\left(V_1\frac{\partial(H_2H_3)}{\partial q_1}+V_2\frac{\partial(H_3H_1)}{\partial q_2}\right)+\frac{1}{H_1}\frac{\partial V_1}{\partial q_1}+\frac{1}{H_2}\frac{\partial V_2}{\partial q_2}=0, \qquad (7)$$

where H_1, H_2, H_3 – Lamé coefficient [10].

Further simplification of system of equations (4) - (7) for simulating the vortex flow of gas phase in the workspace granulator is possible using the following assumptions [11-13]:
- expected the presence of dominant flow direction along which the axial component of gas flow velocity is everywhere positive and far exceeds the radial;
- gas flow velocity component in the axial direction varies considerably slower than in the radial;
- velocity and pressure values in every elementary volume of gas flow depend only on the conditions downstream and do not depend on the conditions upstream.
These assumptions allow to conduct analysis of components in equations (4) - (7) and discard those, that provide significant impact on the result of the calculation.
After accounting assumptions for axially symmetric gas flow equation (4) - (7) be written as

$$\frac{V_1}{H_1}\frac{\partial V_1}{\partial q_1}+\frac{V_2}{H_2}\frac{\partial V_1}{\partial q_2}-\frac{V_3^2}{H_1H_3}\frac{\partial H_3}{\partial q_1}+\frac{1}{H_2}\frac{\partial\left(\overline{V_1'V_2'}\right)}{\partial q_2}+\frac{\left(\overline{V_1'V_2'}\right)}{H_1^2H_2H_3}\frac{\partial\left(H_1^2H_3\right)}{\partial q_2}=$$

$$=-\frac{1}{H_1}\frac{\partial p}{\partial q_1}+\frac{1}{\mathrm{Re}}\left(\frac{1}{H_2^2}\frac{\partial^2 V_1}{\partial q_2^2}+\frac{1}{H_1H_2H_3}\frac{\partial V_1}{\partial q_2}\frac{\partial(H_1H_3/H_2)}{\partial q_2}\right); \tag{8}$$

$$\frac{\partial p_r}{\partial q_2}=\frac{V_3^2}{H_3}\frac{\partial H_3}{\partial q_2}\ ; \tag{9}$$

$$\frac{V_1}{H_1}\frac{\partial V_3}{\partial q_1}+\frac{V_2}{H_2}\frac{\partial V_3}{\partial q_2}+\frac{V_1V_3}{H_1H_3}\frac{\partial H_3}{\partial q_1}+\frac{V_2V_3}{H_2H_3}\frac{\partial H_3}{\partial q_2}+\frac{1}{H_2}\frac{\partial(\overline{V_2'V_3'})}{\partial q_2}+\frac{(\overline{V_2'V_3'})}{H_1H_2H_3^2}\frac{\partial(H_1H_3^2)}{\partial q_2}=$$

$$=\frac{1}{\mathrm{Re}}\left(\frac{1}{H_2^2}\frac{\partial^2 V_3}{\partial q_2^2}+\frac{1}{H_1H_2H_3}\frac{\partial V_3}{\partial q_2}\frac{\partial(H_1H_3/H_2)}{\partial q_2}+\frac{V_3}{H_1H_2}\frac{\partial}{\partial q_2}\left(\frac{H_1}{H_2H_3}\frac{\partial H_3}{\partial q_2}\right)\right); \tag{10}$$

$$\frac{1}{H_1H_2H_3}\left(V_1\frac{\partial(H_2H_3)}{\partial q_1}+V_2\frac{\partial(H_3H_1)}{\partial q_2}\right)+\frac{1}{H_1}\frac{\partial V_1}{\partial q_1}+\frac{1}{H_2}\frac{\partial V_2}{\partial q_2}=0\,. \tag{11}$$

This system of equations is closed equation sustainability costs:

$$\int_0^{Q_2} V_1H_2H_3dq_2=const\ , \tag{12}$$

where Q_2 - coordinate q_2 on the wall of working volume of vortex granulator.
Obtained system of equations (8) - (11) has a parabolic character, and its decision based on the method proposed by Patankar and Spalding [14] and realized in SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) procedure and its modifications.
Numerical solutions of mathematical models equations is performed in one marching passage from the working volume input cross section to output using finite volumes method with the elements of finite-element approach. Before calculating the estimated grid is constructed (fig. 2), and unknown values of velocity and pressure are found in the nodes of this grid.

3 Software description

The program «Conical channel»© is designed to calculate axial symmetric gas flows in channels, including the swirling flows in the diffuser [15,16].
Initial data for calculation are geometric configuration of channel properties and parameters of gas and parameters of flow in the input cross-section. The calculation objective is to determine the fields of velocity and pressure in full range of calculated area and, consequently, the determination of energy losses between the input and output cross sections of channel. The program displays the calculation data as graphic dependencies.
Program`s work starts with opening or creating new file of calculated area configuration. Example of calculation area configuration is shown in fig. 3.
After selecting the necessary parameter for calculation program builds estimated grid (fig. 2). For the analysis of motion velocity components it is necessary to define the nature of dependencies graphical components and match them within a comparative graph as it is shown in figs 4-6.

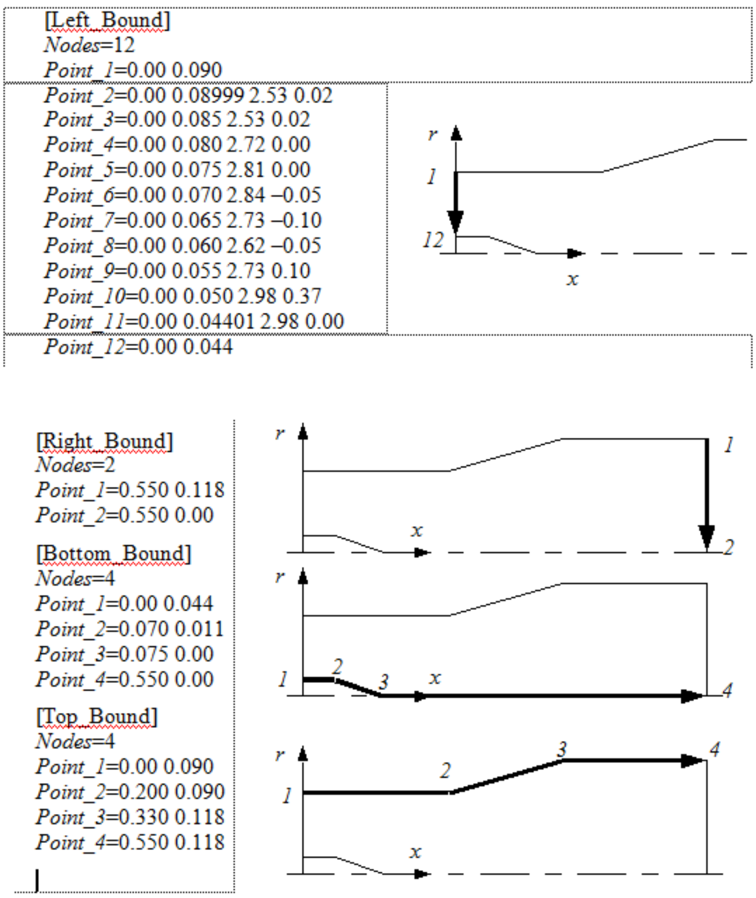


Fig. 3. Example of calculation area configuration.

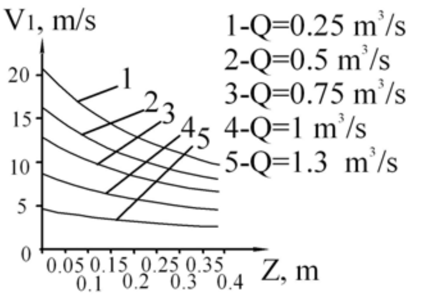


Fig.4. Calculated change of the longitudinal velocity of the gas flow.

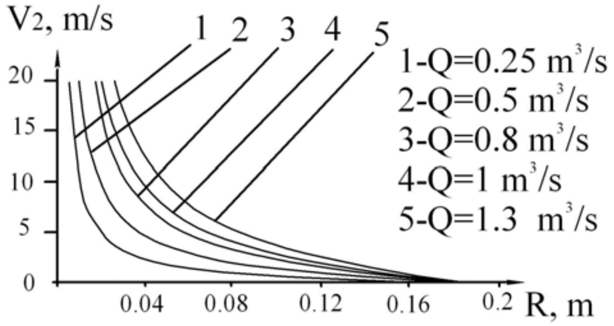


Fig.5. Calculated change of the radial velocity of the gas flow.

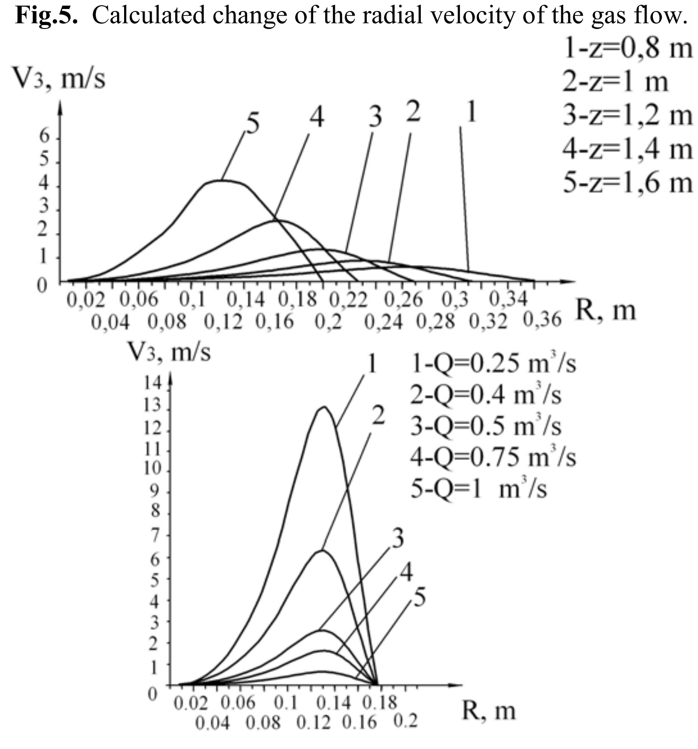


Fig.6. Calculated change of the circumferential velocity of the gas flow.

4 Visualization of results and discussion

For research results visualization in this study we have used complex ANSYS CFX [17], which allows to export obtained using «Conical channel»© results. The main results of visualization are shown in figs 7-11.

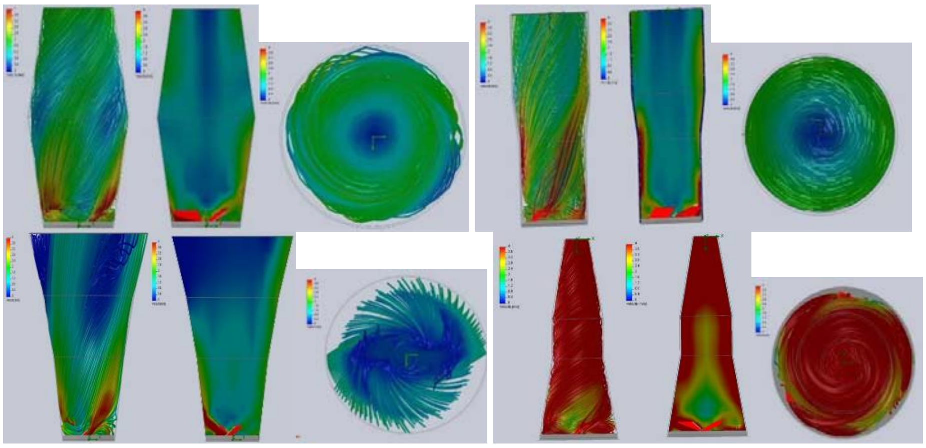


Fig.7. Filling the gas flow velocity field when installing of gas-distributing unit with blades and various configuration of granulator workspace with blades inclination angle α = 30 ° and their number n = 3.

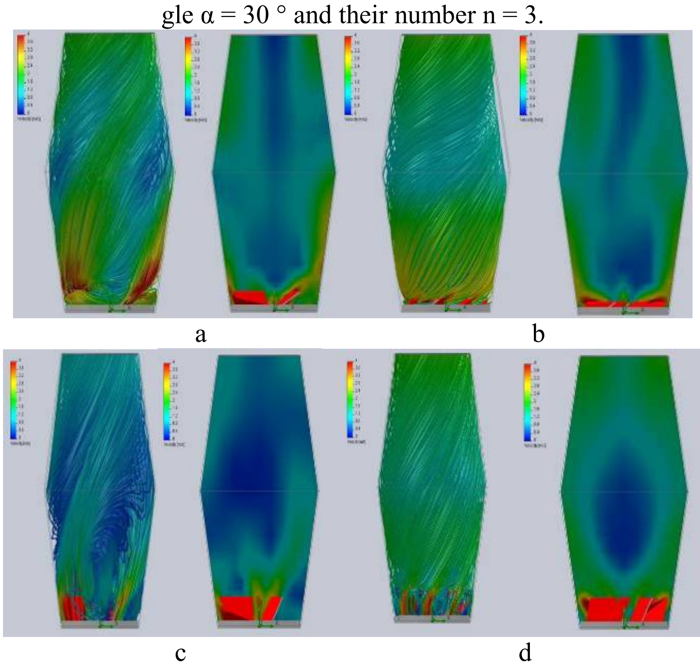
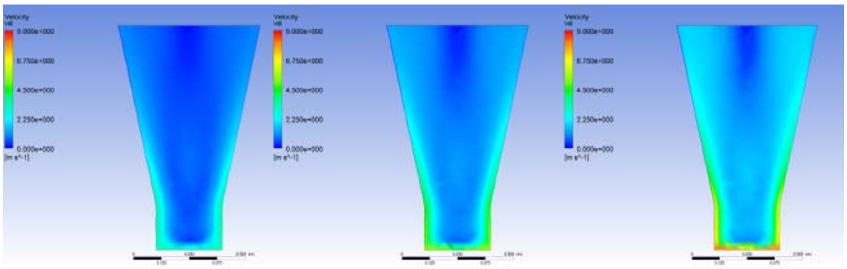


Fig. 8. Filling the gas flow velocity field when installing of gas-distributing unit with blades: a – α=30°, n=3; b – α=30°, n = 8; c – α =60°, n =3; d – α=60°, n=8.



a b c

Fig. 9. The impact of granulator workspace design and gas flow velocity components on the gas flow total velocity and gas movement trajectory (working space "diffuser" with cylindrical insertion in the lower part), d=300 mm; l_c=200 mm; L=1000 mm, φ=12°: a - V_r=V_z=1 m/s; V_φ =3 m/s; b - V_r=V_z=1 m/s; V_φ =5,2 m/s; c - V_r=V_z=1 m/s; V_φ =8 m/s.

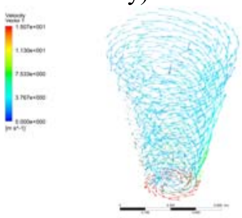
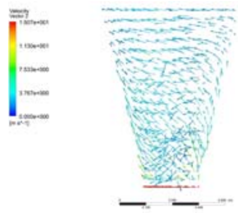
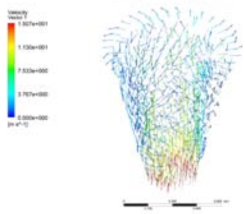
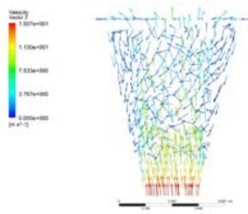
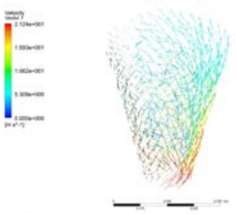
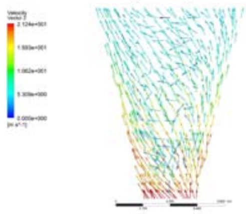
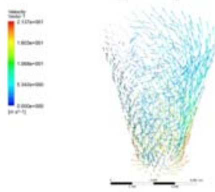
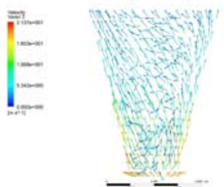
Values of velocities	The direction of gas flow motion (axonometry)	The direction of gas flow motion (space)
V_z=1 m/s; V_r=1 m/s; V_φ=15 m/s		
V_z=15 m/s; V_r=1 m/s; V_φ=1 m/s		
V_z=15 m/s; V_r=1 m/s; V_φ=15 m/s		
V_z=8 m/s; V_r=15 m/s; V_φ=8 m/s		

Fig.10. Gas flow movement vectors for different values of speed components.

V_z=1 m/s; V_r=1 m/s;
V_φ=15 m/s

Vz=8 m/s; Vr=1 m/s;
Vφ=15 m/s

Vz=15 m/s; Vr=1 m/s;
Vφ=15 m/s

V_z=8 m/s; V_r=15 m/s;
V_φ=8 m/s

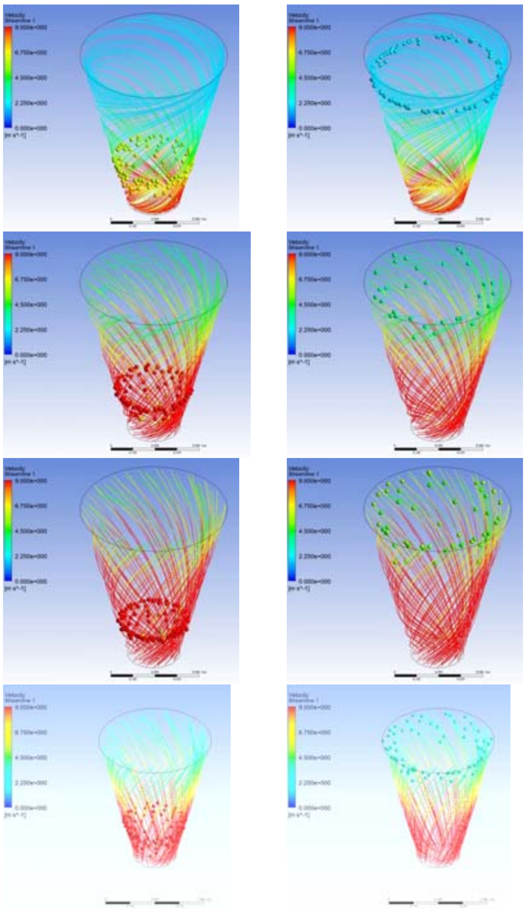


Fig.11. Gas flow movement trajectory for different values of speed components.

Analysis of graphic dependences of gas flow rate velocity under various conditions has identified monotonous nature of rate velocity reduction under all calculations conducting conditions.
Comparison of theoretical calculation for different cross sections of working space and different opening cone angles shows that the area of maximum circular speed for arbitrarily chosen section is r = 0,66-0,72 R.
Analysis of graphical dependencies shows the reduction zone of circular velocity growth by increasing the gas flow rate and narrowing the range of maximum speed. This velocity peak remains constant at geometric place in the working space of vortex granulator.
The value of circular velocity with increasing the gas flow rate increases faster. At the same time, with the increasing gas flow rate in workspace space of vortex granulator the angular velocity slow growth zone is growing. Thus, the vortex is moving toward solid wall and has a greater intensity.

Analysis of dependences of circular velocity changes under different conditions identified pattern of velocity distribution by the radius of device and its quality change according to the set of parameters.

Given the results of analysis of circular velocity peak of gas flow in cross section of device workspace for granular product from the melt (solution) device (or group of devices) for spraying is advisable to locate within the working space vortex granulator in specified range of current radius at random selected height and cone opening angle with the advice, received the results of experiment [2] (optimal height of location sprayer in defined to be h = 0,6-0,8H).

Continuously increasing the circular velocity of gas flow before reaching peak and reduction after passing its peak had obtained confirmation by experiment and defined range of gas distribution unit operation with maximum efficiency. In the area of minimum circular velocity the granules motion intensification and "dead" zones prevention, that is possible in the range up to r = 0,25R, is achieved by reasonable selection of gas-distributing unit with additional elements for flow swirling.

The value of gas flow radial velocity, received by the results of analytical solution, and experimental data have high degree of compliance. There is mutual rejection numerical value of speed and overall graphic image of diagrams of full speed radial component of gas flow has the same character. It is mentioned even radial velocity decreasing from the center (core) of gas flow to the periphery.

According to the analysis the influence of conical workspace opening angle on the possibility of reverse vortex in center of weighted layer and place a geometric location of individual elements weighted layer connection place and the transition region combined weighted layer connection was identified. With the increasing of cone opening angle (up to 10-13°) zone of reverse vortex has a constant value and is determined within r = (0,15-0,25) R. This situation is observed before h=(0,3-0,4) H. Recirculation zone is located in the inlet of diffuser.

In general in the following functional dependencies for each component of gas flow velocity it is observed is the same quality pattern. For rate and radial velocity components of gas flow for the initial conditions and changing set of geometrical and technological conditions does not cause such significant change of quantitative distribution value along the radius and height for both angular velocity component gas stream. Based on the analysis of hydrodynamic properties of gas flow due to certain variables the rational selection of geometry workspace vortex granulator becomes possible (opening angle α and height z).

Analysis of simulation using visualization software ANSYS CFX has showed:

- depending on gas flow velocity component value trajectory of its movement has a different configuration with the predominance of one or another direction;
- when the axial velocity component predominance the area of gas flow movement is narrowed;
- when velocity circular component predominance we observe an increasing zone of gas flow vortex motion in height;
- when the velocity radial component predominance gas flow movement to the wall of vortex granulator is made more intense;
- under certain conditions the intensity of gas flow initial twisting does not affect the trajectory of its movement, and affects only the value of gas flow resulting velocity;

- velocity radial component is characterized by maximum value on the axis of the device.

5 Conclusions

Simulation results allowed us to develop an algorithm for vortex granulator hydrodynamic calculating, which is represented on fig 12.

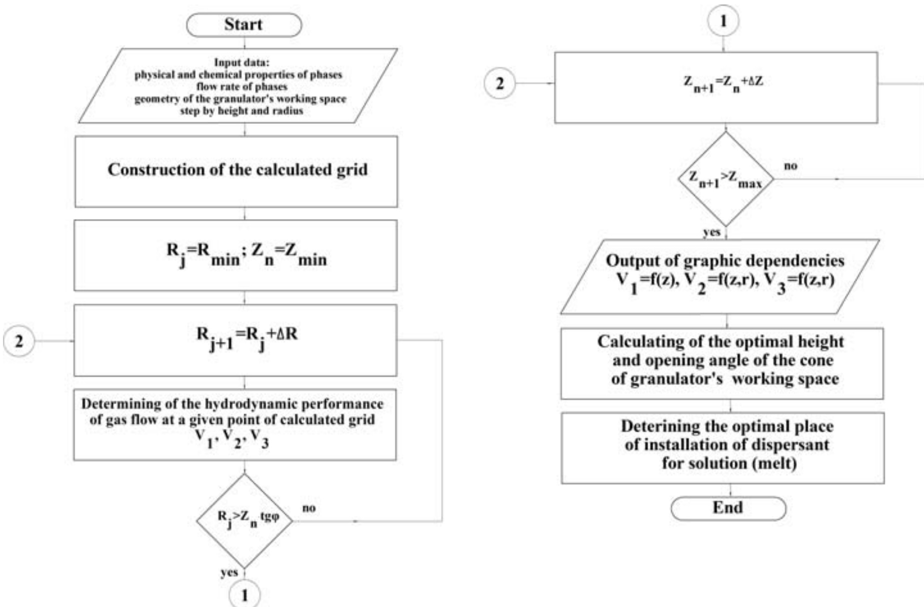
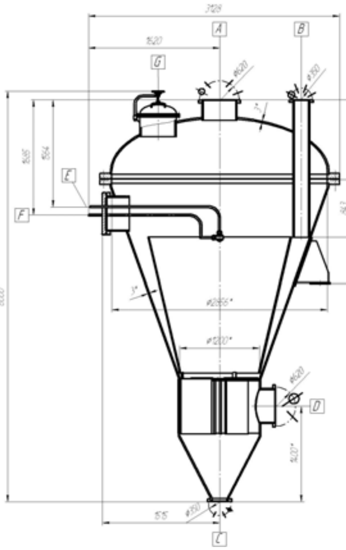


Fig. 12. An algorithm for vortex granulator hydrodynamic calculating

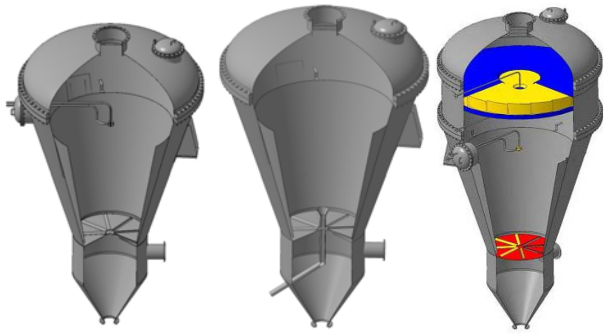
Example of granulator, designed based on hydrodynamic calculation (porous ammonium nitrate production, final product performance 3000 kg / day, commodity fraction - granules 2-3 mm) is shown in figs 13, 14.

The review of the modern software products (simulation modeling systems) used in the calculations for the chemical production plants (Aspen HYSYS®, PRO/II, GasCondOil, ChemCAD, DESIGN II, SIGMAFINE, gPROMS ModelBuilder, GIBBS and others) [18-25] shows that such software is mainly implemented for the technological calculation of the specified construction and under certain technological parameters of the chemical plants. The optimization calculation of the technological process requires a multiple initial provisioning; a quantity of such provisions for the optimization calculations may be numerous. The simulation software used for the hydrodynamic and heat-mass transfer processes in the chemical production (ANSYS Fluent, COSMOS FlowWorks, FlowVision, Flow-3D CFD, Ansys CFX, COMSOL Multiphysics and others) [26-31] enable to model only one construction variant of the installation and, thus, it reduces the optimization calculation performance. In practice, we use various models of the numerical solution of the classical equation of hydrodynamics and heat-mass transfer for turbulent flows.



Symbol	Function
A	Outlet of gas
B	Inlet of seeding agent
C	Outlet of granular product
D	Inlet of drying air
E	Air inlet for spraying of the liquid material
F	Inlet of melt
G	Hatch

Fig.13. The industrial design of vortex granulator.



a b c

Fig. 14. Vortex granulator designs: a – with spraying of the melt; b – with a previous wetting of granules and simple inner case; c – with separating device for exhaust gases cleaning

Creating a comprehensive algorithm for determining the hydrodynamic characteristics of vortex flows (the author's software product and Ansys CFX) allows us to achieve high accuracy results and choose the optimal granulator configuration following the optimization criterion. This approach is more effective than using only the software products which are mentioned above.

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7 References

1. Artyukhov, A.E., Sklabinskyi, V.I.: Experimental and industrial implementation of porous ammonium nitrate producing process in vortex granulators. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, 42-48 (2013).
2. Artyukhov, A.E., Fursa, A.S., Moskalenko, K.V.: Classification and separation of granules in vortex granulators. Chemical and Petroleum Engineering, 51, Nos 5–6, 311–318 (2015). https://doi.org/10.1007/s10556-015-0044-x
3. Shi, De-Pan, Luo, Zheng-Hong Guo, An-Yi.: Numerical Simulation of the Gas−Solid Flow in Fluidized-Bed Polymerization Reactors. Industrial & Engineering Chemistry Research, 49 (9), 4070–4079 (2010). https://doi.org/10.1021/ie901424g
4. Pandaba, P., Sukanta, K.D.: Numerical Simulation for Hydrodynamic Analysis and Pressure Drop Prediction in Horizontal Gas-Solid Flows. Particulate Science and Technology Volume, 32(1), 94-103 (2014). https://doi.org/10.1080/02726351.2013.829543
5. Feldmann, F., Hagemann, B., Ganzer, L., Panfilov, M.: Numerical simulation of hydrodynamic and gas mixing processes in underground hydrogen storages. Environmental Earth Sciences, 75, 1165-1172(2016). https://doi.org/10.1007/s12665-016-5948-z
6. Artyukhov, A.E.: Optimization of mass transfer separation elements of columnar equipment for natural gas preparation. Chemical and Petroleum Engineering, 49, Nos. 11-12, 736-740 (2014). https://doi.org/10.1007/s10556-014-9827-8
7. Prokopov, M.G., Levchenko, D.A., Artyukhov, A.E.: Investigation of liquid-steam stream compressor. Applied Mechanics and Materials, 630, 109-116 (2014). https://doi.org/10.4028/www.scientific.net/AMM.630.109
8. Tenneti, S., Subramaniam, S.: Particle-resolved direct numerical simulation for gas-solid flow model development. Annual Review of Fluid Mechanics, 46, 199-230 (2014). https://doi.org/10.1146/annurev-fluid-010313-141344
9. Yang, J., Wang, Q., Zeng, M., Nakayama, A.: Computational study of forced convective heat transfer in structured packed beds with spherical or ellipsoidal particles. Chemical Engineering Science, 65(2), 726-738 (2010). https://doi.org/10.1016/j.ces.2009.09.026
10. Sinaiski, E.G.: Hydromechanics: theory and fundamentals. Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA (2010).
11. Artyukhov, A.E., Fursa, A.S., Moskalenko, K.V.: Classification and separation of granules in vortex granulators. Chemical and Petroleum Engineering, 51, Nos 5–6, 311–318 (2015). https://doi.org/10.1007/ s10556-015-0044-x
12. Artyukhov, A.E., Sklabinskyi, V.I.: 3D Nanostructured Porous Layer of Ammonium Nitrate: Influence of the Moisturizing Method on the Layer's

Structure. Journal of Nano- and Electronic Physics, 8, No 4(1), 04051-1–04051-4(2016). https://doi.org/10.21272/jnep.8(4(1)).04051
13. Artyukhov, A.E., Sklabinskyi, V.I.: Investigation of the temperature field of coolant in the installations for obtaining 3D nanostructured porous surface layer on the granules of ammonium nitrate. Journal of Nano- and Electronic Physics, 9(1), 01015–101015-4 (2017). https://doi.org/10.21272/jnep.9(1).01015.
14. Patankar, S.V.: Numerical heat transfer and fluid flow. Washington, DC: Hemisphere Publishing Corp (1980).
15. Artyukhov, A., Sklabinskyi, V.: Theoretical analysis of granules movement hydrodynamics in the vortex granulators of ammonium nitrate and carbamide production. Chemistry & chemical technology, 9 No 2, 175-180 (2015). https://doi.org/10.23939/chcht09.02.175
16. Artyukhov, A., Sklabinskyi, V.: Hydrodynamics of gas flow in small-sized vortex granulators in the production of nitrogen fertilizers. Chemistry & Chemical Technology, 9 No 3, 337-342 (2015). https://doi.org/10.23939/chcht09.03.337
17. Computational Fluid Dynamics: ANSYS CFX and FLUENT CFD Software [Electronic resource]. Access mode: https://caeai.com/ansys-software-support/ansys-software/computational-fluid-dynamics-ansys-cfx-and-fluent-cfd-software.
18. Aspen HYSYS® [Electronic resource]. Access mode: http://www.aspentech.com/products/aspen-hysys/
19. SimSci PRO/II [Electronic resource]. Access mode: http://software.schneider-electric.com/products/simsci/design/pro-ii/
20. GasCondOil [Electronic resource]. Access mode: http://thermogas.kiev.ua/Products.htm
21. ChemCAD [Electronic resource]. Access mode: http://www.chemstations.com
22. DESIGN II [Electronic resource]. Access mode: https://www.winsim.com/design.html
23. SIGMAFINE [Electronic resource]. Access mode: https://sigmafine.pimsoftinc.com
24. gPROMS ModelBuilder [Electronic resource]. Access mode: https://www.psenterprise.com/products/gproms
25. GIBBS [Electronic resource]. Access mode: http://www.gibbsim.ru
26. ANSYS Fluent [Electronic resource]. Access mode: http://www.ansys.com/Products/Fluids/ANSYS-Fluent
27. COSMOS FlowWorks [Electronic resource]. Access mode: http://www.solidworks.com/sw/products/simulation/flow-simulation.htm
28. FlowVision [Electronic resource]. Access mode: http://tesis.com.ru
29. Flow-3D CFD [Electronic resource]. Access mode: https://www.flow3d.com
30. Ansys CFX [Electronic resource]. Access mode: http://www.ansys.com/products/fluids/ansys-cfx
31. COMSOL Multiphysics [Electronic resource]. Access mode: https://www.comsol.com