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SOFTWARE FOR CALCULATION OF VORTEX TYPE GRANULATION DEVICES

ABSTRACT

The article deals with considering the features of original software for calculation of hydrodynamic conditions and kinetic characteristics of granulation process in multistage vortex devices for multi-layer granules and granules modification. In the base of software Vortex Granulator©, Classification in vortex flow© and Multistage Vortex Granulator© original mathematical model for calculating the flow rate of gas and granules classification and separation processes in vortex granulator, granules warming kinetics and removing moisture from the granules was put in. Software was designed on JavaFx platform. Vortex Granulator©, Classification in vortex flow© and Multistage Vortex Granulator© allow to conduct optimization calculation of vortex granulator according the criterion of minimum required residence time of granules in device`s workspace. The article also provides estimates of hydrodynamic characteristics of gas flow movement using software product ANSYS CFX based on author's mathematical model.

KEYWORDS

Vortex granulator; software; hydrodynamics; thermodynamics; kinetics.

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ПРОГРАММНОЕ ОБЕСПЕЧЕНИЕ ДЛЯ РАСЧЁТА ГРАНУЛЯЦИОННЫХ УСТРОЙСТВ ВИХРЕВОГО ТИПА

АННОТАЦИЯ

Статья посвящена описанию возможностей оригинального программного обеспечения для расчёта гидродинамических условий и кинетических характеристик процесса гранулирования в многосекционных вихревых аппаратах для получения многослойных гранул и модификации гранул. В основу программных продуктов Vortex Granulator©, Classification in vortex flow© и Multistage Vortex Granulator© положена оригинальная математическая модель расчёта скорости газового потока и гранул, процессов классификации и сепарации гранул в вихревом грануляторе, кинетики прогрева гранулы и удаления влаги из гранулы. Программные продукты созданы на платформе JavaFx. Vortex Granulator©, Classification in vortex flow© и Multistage Vortex Granulator© позволяют проводить оптимизационный расчёт вихревого гранулятора по критерию минимально необходимого времени пребывания гранул в рабочем пространстве аппарата. В статье также представлены расчеты гидродинамических характеристик движения газового потока с применением программного продукта ANSYS CFX на основе авторской математической модели.

КЛЮЧЕВЫЕ СЛОВА

Вихревой гранулятор, программное обеспечение, гидродинамика, термодинамика, кинетика.

INTRODUCTION

Currently searching for new ways of fluid bed granulation is carried out. They should have a high specific performance to ensure rational energy consumption and be environmentally friendly [1]. New class of granulating equipment, that was created by above-stated requirements, are granulators of vortex type [2]. In [3-11] the theoretical basis of the calculation and experimental results, which should be in base of Vortex granulators engineering calculation methods, are presented. An urgent problem is the creation of software for implementation of technique. Existing analogues [12,13] can’t carry out calculation with sufficient accuracy, because they are based on classical algorithms for calculating fluidized bed devices

[14,15]. These algorithms are not applicable for calculating of vortex granulators due to fundamental differences in organization of movement of dispersed material flow and fluidizing agent. Additional interest deals also with use of advanced products for the calculation of fluid flow and heat and mass transfer (eg ANSYS SFX, Flow Vision, etc.) on the basis of export in their platform original mathematical models.

The purpose of the work is creation of original software systems for engineering and optimization calculation of vortex type granulation equipment and application of author mathematical models for calculation of granulator`s characteristics using the advanced software products.

The practical significance is that software systems will be used in calculating of multi stages vortex granulators for production of multilayer fertilizers, granules with pore structure, modified granules.

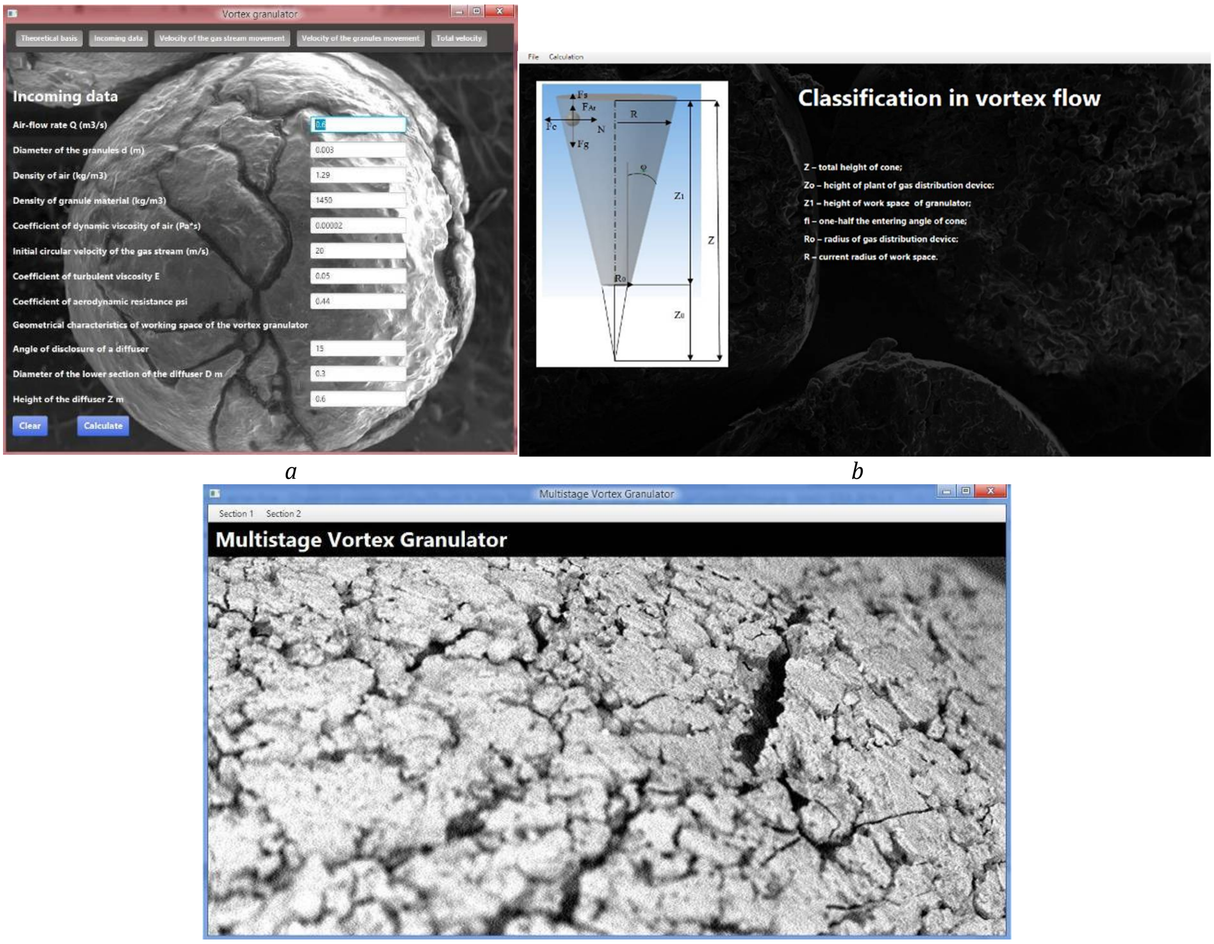
METHODOLOGY

In this work the software for calculation of hydrodynamic and kinetic characteristics of granulation process in vortex devices - Vortex Granulator©, Classification in vortex flow© and Multistage Vortex Granulator©. Programs were written in Java that allows you to quickly calculate the values from given formulas, as well as a set of tools for developing client interface and visualization of obtained values in the form of plots. The Java language provides the application work in different operating systems.

Platform for RIA (Rich Internet Application) development has been selected JavaFX, which allows to build a unified application with rich graphical user interface. JavaFX provides a set of tools with which developers can rapidly create applications for desktops, mobile devices, etc.

In the base of software Vortex Granulator© (program interface is presented on fig.1 a) there is a system of the Navier-Stokes equations and equations of flow continuity (single stream) and system of differential equations of movement of granules in cylindrical coordinate system [3,4,7].

In the base of software Classification in vortex flow© (program interface is presented on fig.1 b, in this article the program was used to calculate the kinetics of granules heating and dehydration) there is a system of differential equations of granules warming kinetics and kinetics of removing moisture from the granules [9,10].



Incoming data

Air-flow rate Q (m3/s) 0.6
Diameter of the granules d (m) 0.003
Density of air (kg/m3) 1.29
Density of granule material (kg/m3) 1450
Coefficient of dynamic viscosity of air (Pa*s) 0.00002
Initial circular velocity of the gas stream (m/s) 20
Coefficient of turbulent viscosity E 0.05
Coefficient of aerodynamic resistance psi 0.44
Geometrical characteristics of working space of the vortex granulator
Angle of disclosure of a diffuser 15
Diameter of the lower section of the diffuser D m 0.3
Height of the diffuser Z m 0.6

a

Classification in vortex flow

Z – total height of cone;
Zo – height of plant of gas distribution device;
Z1 – height of work space of granulator;
fi – one-half the entering angle of cone;
Ro – radius of gas distribution device;
R – current radius of work space.

b

Multistage Vortex Granulator

c

Fig. 1. Interface of programs Vortex Granulator© (a), Classification in vortex flow© (b) and Multistage Vortex Granulator© (c)

In the base of software product Multistage Vortex Granulator© (program interface presented on fig.1 c) there is mathematical model of flow`s main properties technological calculation of devise`s size engineering calculation [8,16].

All software products allow to export the calculations results in excel files. The results of these calculations are presented in main part of the article.

The object of research is vortex granulator, schematic diagram of which is shown in fig. 2.

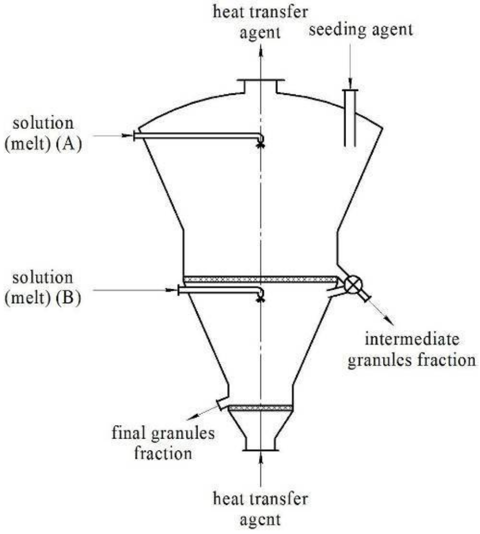


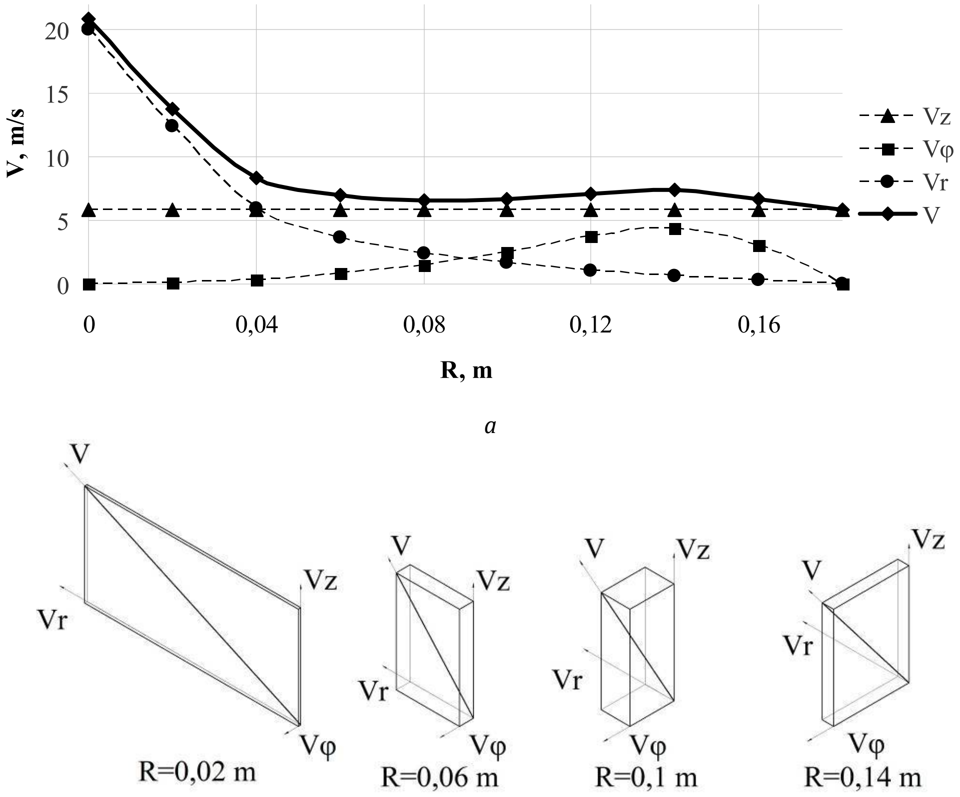
Fig. 2. Schematic diagram of multistage vortex granulator

In the paper following notations were made:
V_Z – expenditure (axial, vertical) component of movement speed of gas flow, m / s;
V_r – radial component of movement speed of gas flow, m / s;
V_φ – peripheral component of movement speed of gas flow, m / s;
V – total speed of gas flow, 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;
L – total height of conical housing of vortex granulator, m (mm);
l_c – height of top and / or bottom cylindrical insert of vortex granulator housing, m (mm);
Q – gas flow rate, m^3 / s.
t_{fa} – temperature of fluidizing agent, ° C;
t_g – temperature of granules, ° C;
t_{fb} – average temperature of fluidized bed, ° C;
d – granule`s diameter, m (mm);
τ – granules drying time, s;
G_{sa} – seeding agent amount, kg / h;
C – moisture removal value, kg / s · square meters;
U_{in} – initial moisture content in material, kg moisture / kg material;
U_{fin} – final moisture content in material, kg moisture / kg material.

The main objectives of this research are:
- determination of speed components of gas stream movement;
- definition of granules warm-up time to target temperature and humidity;
- definition of technological performance indicators of vortex granulator (required amount of seeding agent, optimal average temperature of fluidized bed, granules optimum drying time).

RESULTS AND DISCUSSION

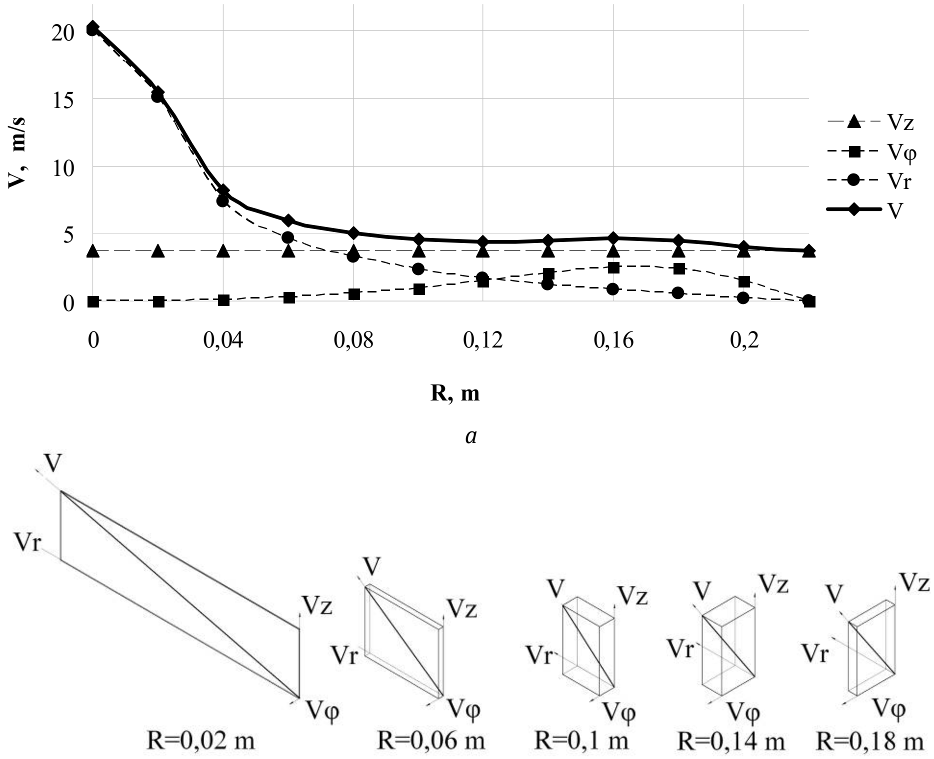
In figs 3-5 the results of calculation components of gas flow speed, gas flow total speed and the direction vector total speed at different height of granulator`s workspace using software «Vortex Granulator»© are shown.



a

b

Fig. 3. Calculation of gas stream total speed (a) and direction of gas stream speed vector (b) at Q=0,63 m³/s, φ=13°, z=0,8 m

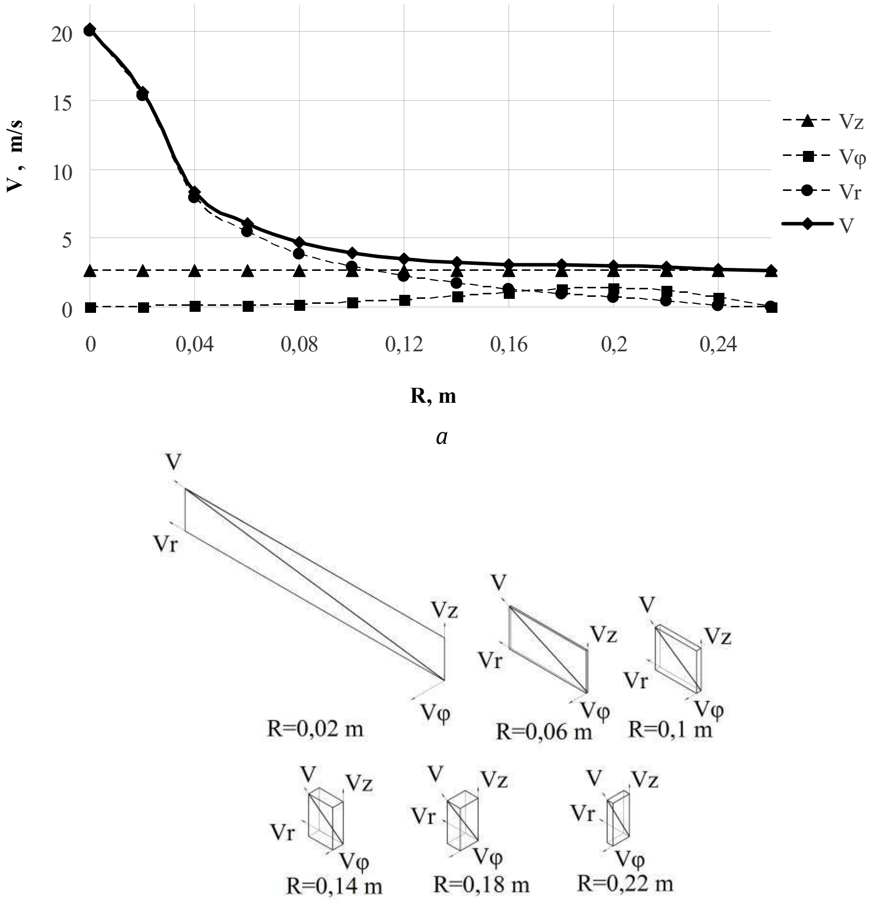


a

b

Fig. 4. Calculation of gas stream total speed (a) and direction of gas stream speed vector (b) at Q=0,63 m³/s, φ=13°, z=1 m

The analysis of figs 3-5 show that at different granulator heights total speed of gas stream and its vector depends on various components of speed. In the immediate vicinity of gas distribution unit gas moves mainly on spiral trajectory, at the top of granulator – in upward movement regime. Over device radius physical picture of movement is follows: from the center and till the value (0,5-0,6) R gas actively moves in radial direction, in the range (0,6-0,9) R along with active movement in radial direction there is intense gas flow barnacle, in the range radiuses device > 0,9R intensity radial movement is significantly reduced and the gas gets spiral movement with a gradual movement in the height of device.



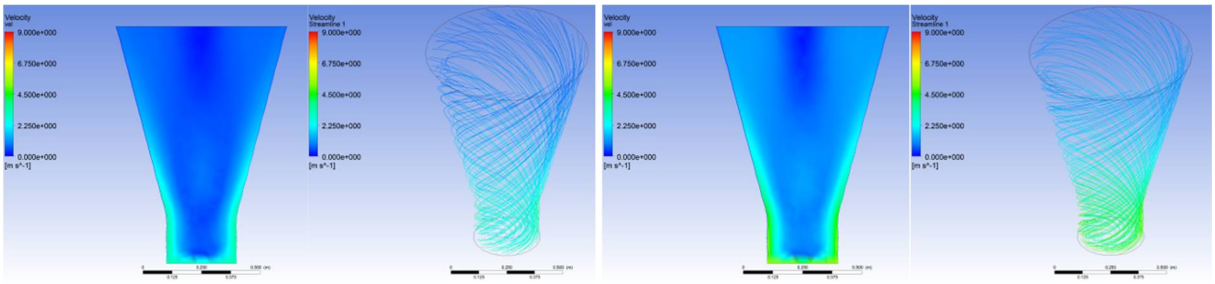
a

b

Fig. 5. Calculation of gas stream total speed (a) and direction of gas stream speed vector (b) at Q=0,63 m³/s, φ=13°, z=1,2 m

The results of calculations of gas flow total speed and the direction of its movement allow further to simulate the optimal conditions for classification granules on fractions in the vortex granulator working space, make a diversion aimed seeding agent, select the appropriate location of dispersant and determine the conditions of drops solution or melt deformation.

For the visualization of calculation results and construction of speed field of gas flow in workspace different configurations vortex granulator author mathematical model [3,4] was exported to software ANSYS CFX. The calculation results of speed fields of gas flow in vortex granulator workspace, its individual sections at different heights and gas flow trajectory are presented on figs 6-9.



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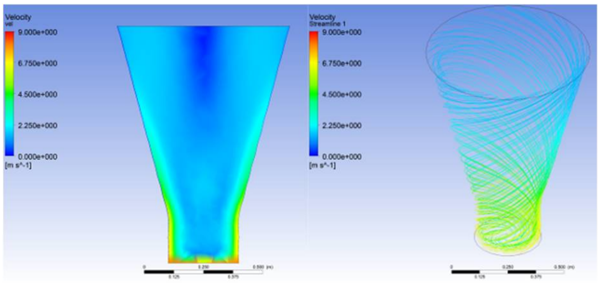
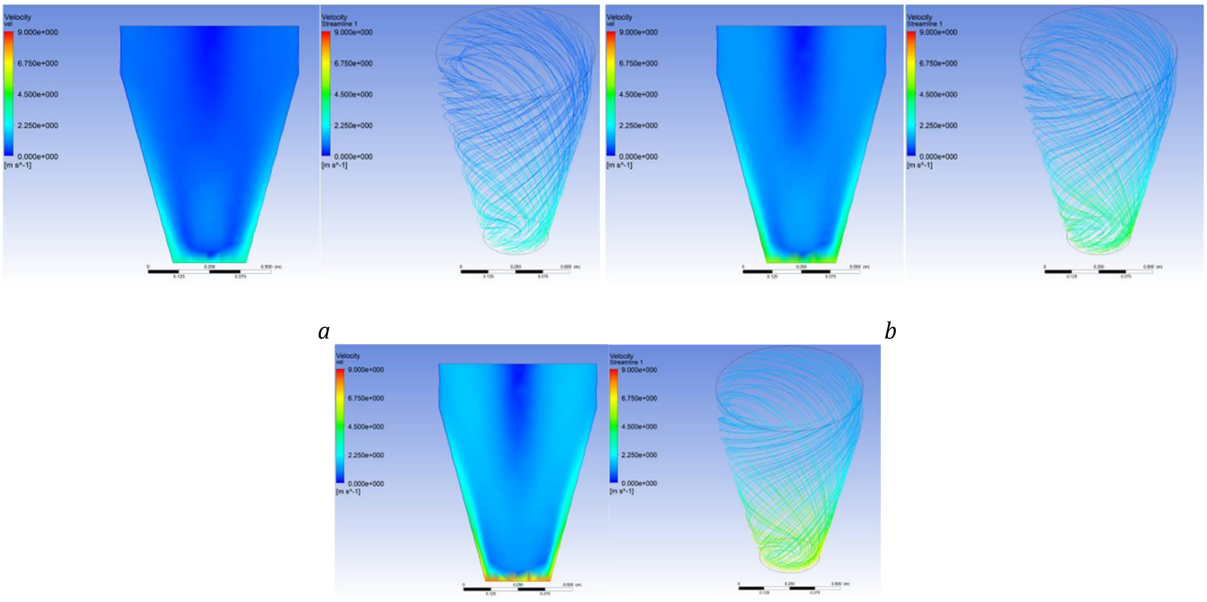


c

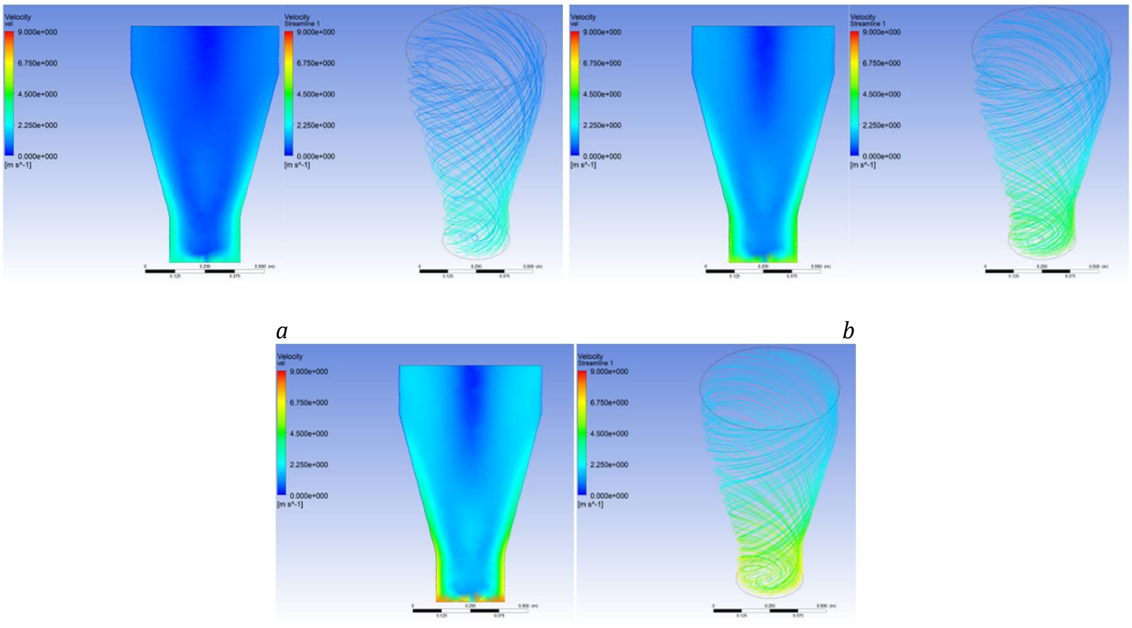
Fig. 6. The impact of granulator`s workspace design and granule's speed components of gas stream on gas flow total speed and gas flow trajectory (workspace "cone" with cylindrical insert in lower part, D=300 mm; l_c=200 mm; L=1000 mm, φ=15°): a – V_r=V_z=1 m/s; $V_φ$ =3 m/s; b – V_r=V_z=1 m/s; $V_φ$=5,2 m/s; c – V_r=V_z=1 m/s; $V_φ$ =8 m/s



a *b*

c

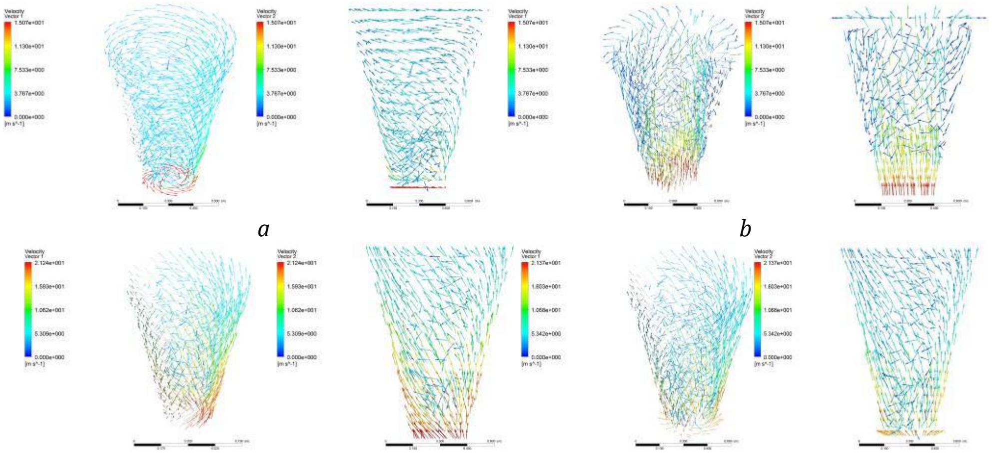
Fig. 7. The impact of granulator`s workspace design and granule's speed components of gas stream on gas flow total speed and gas flow trajectory (workspace "cone" with cylindrical insert in upper part, D=300 mm; l_c=200 mm; L=1000 mm, φ=15°): a –V_r=V_z=1 m/s; $V_φ$ =3 m/s; b – V_r=V_z=1 m/s; $V_φ$=5,2 m/s; c – V_r=V_z=1 m/s; $V_φ$ =8 m/s



a *b*

c

Fig. 8. The impact of granulator`s workspace design and granule's speed components of gas stream on gas flow and gas flow trajectory total speed (workspace "cone" with cylindrical insert in lower and upper parts, D=300 mm; l_c=200 mm; L=1000 mm, φ=15°): 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



a

b

c

d

Fig. 9. The impact speed components of gas stream on gas flow trajectory (workspace "cone" with cylindrical insert in lower part): a – V_z=1 m/s; V_r=1 m/s; V_φ=15 m/s; b – V_z=15 m/s; V_r=1 m/s; V_φ=1 m/s; c – V_z=15 m/s; V_r=1 m/s; V_φ=15 m/s; d – V_z=8 m/s; V_r=15 m/s; V_φ=8 m/s

Analysis of simulation results, that are presented on figs 6-9, shows that:

- according to gas flow speed component value it has a different configuration of predominance of some movement direction;
- if an axial speed component is prevailing, the area of gas flow movement is narrowed;
- if an angular speed component is prevailing, there is an increasing of gas flow vortex monument zone in height;
- if the radial speed component is prevailing, gas flow movement to the vortex granulator wall is more intensive;
- in certain conditions the intensity of initial gas flow does not affect to its movement trajectory, and affects only to the value of resulting gas flow speed;
- axial speed component is gradually decreased with gas flow movement in height of granulator (this is associated with the increasing granulator cross-sectional area);
- circular speed component is characterized by maximum value in outcome place from gas distribution device;
- radial velocity component is characterized by maximum value on device`s axis.

In figs 10-12 the results of calculation of temperature change kinetics granules radius in certain time period and granule`s temperature in given time range using software Classification in vortex flow © are presented. Granules with different diameter are heated with varying intensity, which gives rise to define the granules warming time in polydispersed system at the level of maximum heating time for granule with largest diameter. Given the fact that, as it was shown by experimental results, in the vortex granulator`s bottom part distribution of wet granules on size is unclear, uniform heating of entire polydispersed system is possible only in case of specified above time observance.

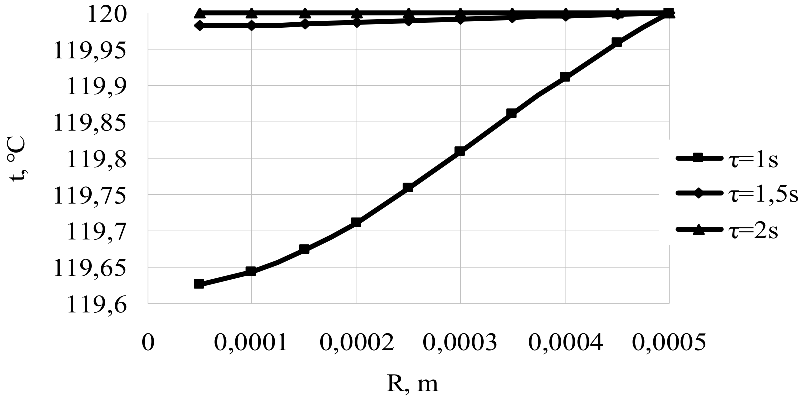


Fig. 10. Heating kinetics of ammonium nitrate granule with radius at t_{fa} =120°C t_g=30°C, d=1 mm

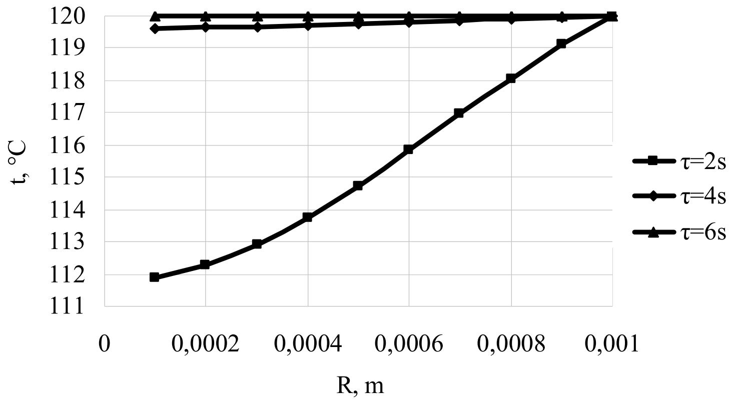


Fig. 11. Heating kinetics of ammonium nitrate granule with radius at t_{fa} =120°C t_g=30°C, d=2 mm

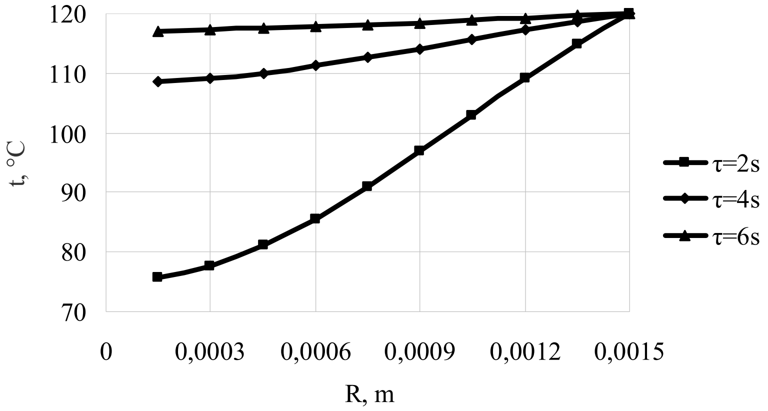
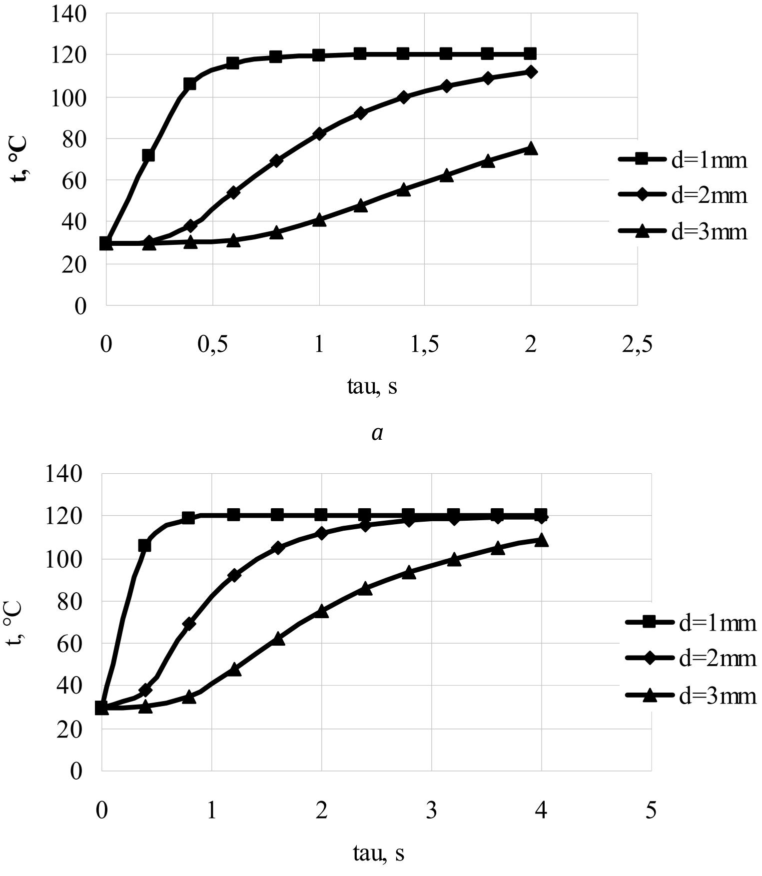


Fig. 12. Heating kinetics of ammonium nitrate granule with radius at t_{fa} =120°C t_g=30°C, d=3 mm



a

b

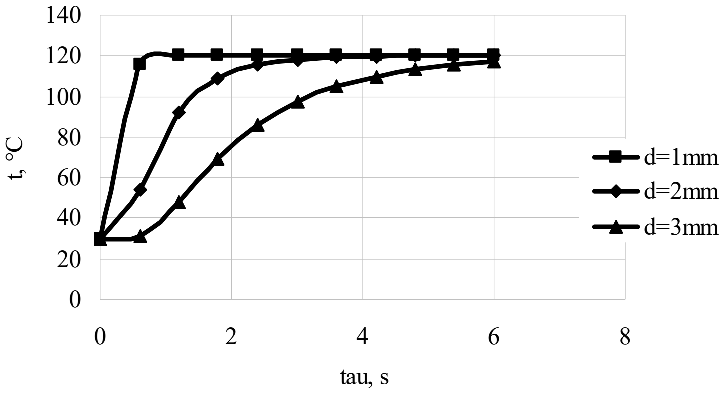


Fig. 13. Heating kinetics of ammonium nitrate granule with radius at t_{fa} =120°C t_g=30°C: a – τ=2 s; b – τ=4 s; c – τ=6 s.

The presented calculations are valid for heating with constant temperature and do not include the effect of granules temperature (such as with the introduction seeding agent) and liquid phase (wetting agent), which are introduced into the device to replace the coolant temperature.

Thus granule will warm up with heating agent to some specified temperature, and only then intense moisture removal will begin. This factor increases the overall necessary granules residence time in device. Calculations according mentioned above mathematical model showed that for the full heating of granules with d = 2 mm from 20 °C to 120 °C in flow of heating agent with temperature up to 120° it is necessary 8 seconds. If we will hold step calculation given the fact that the heating agent during introduction of granules and their humidification is cooled, then the gradual granules heating to 120 °C will take time period in 3-3.5 times higher than in previous case.

In figs 14,15 kinetics of changing relative weight of ammonium nitrate granules of different diameters at different moisture conditions and requirements for moisture content in final product is shown.

It should be noted, that in the first period of drying with constant speed in zone of intense vortex movement up to 60% of required moisture are removed.

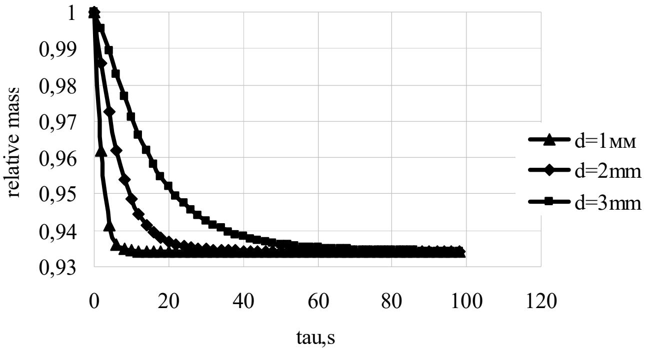


Fig. 14. Kinetics of relative weight of ammonium nitrate granules change at t_{fa} =100°C, U_{in} =0,01 kg moisture / kg of material, U_{fin} =0,003 kg moisture / kg material

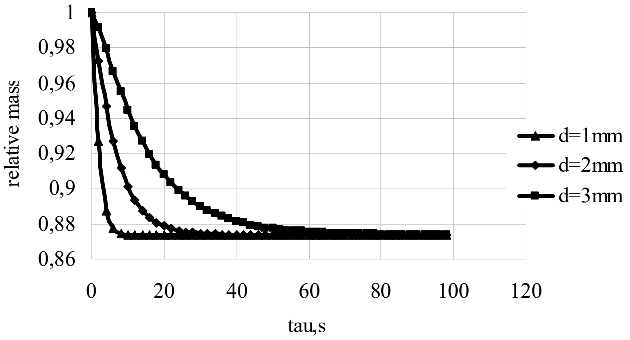


Fig. 15. Kinetics of relative weight of ammonium nitrate granules change at t_{fa} =100°C, U_{in} =0,02 kg moisture / kg of material, U_{fin}=0,001 kg moisture / kg material

In figs 16-19 the results of calculation of technological characteristics of granulation process in two-section vortex granulator using the software Multistage Vortex Granulator© are presented.

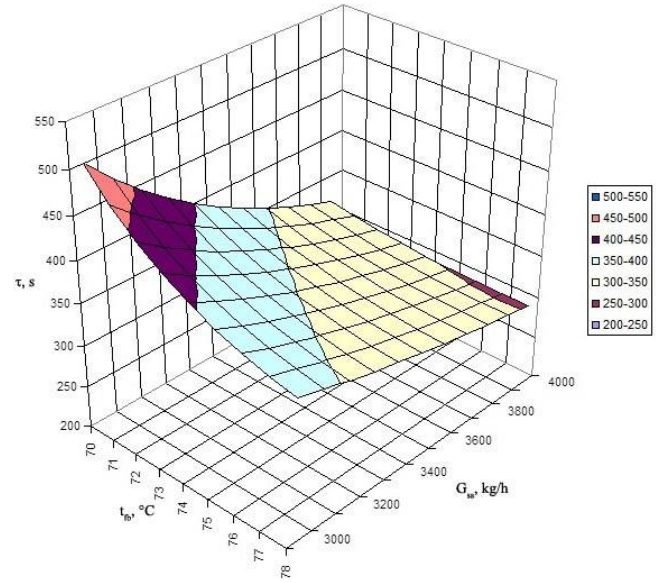


Fig. 16. The dependence of drying time from the G_{sa} and t_{fb}

Analysis of figs. 16-19 showed such granules formation patterns:

1. The drying time is reduced by increasing of retour amount and layer temperature, and retour consumption increasing more effectively reduces the residence time in 2 times. Seeding agent surface is area for crystallization process in a constant pulp consumption, increased layer temperature intensifies the crystallization on retour surface;

2. With the increasing of retour consumption lattice area is increasing, and layer temperature increasing leads to decrease of this area. Increasing the temperature increases the rate of moisture removal speed from the pulp, increasing of retour consumption leads to increasing of layer weight, so it is necessary lattice with larger area;

3. Increasing the lattice square reduces moisture removal.

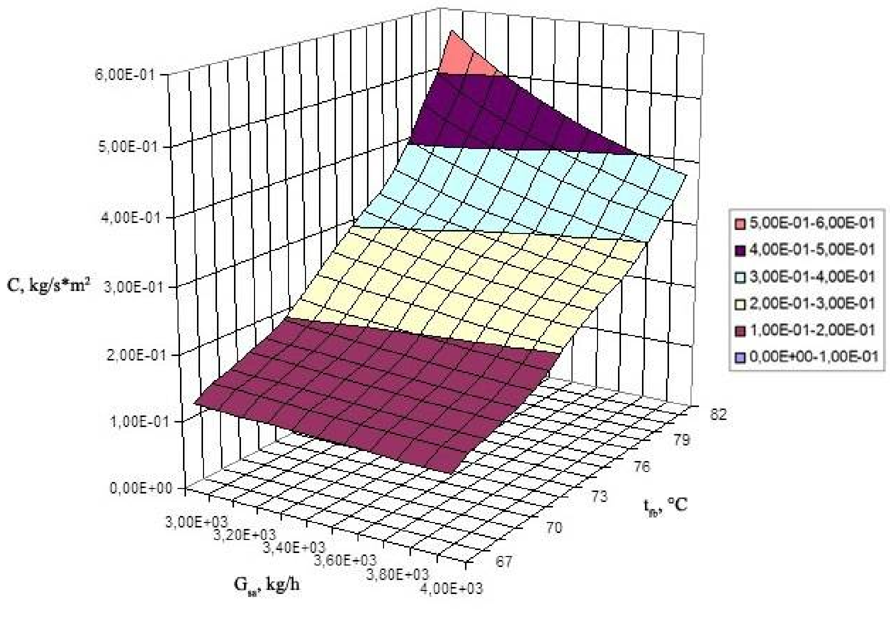


Fig. 17. The dependence of moisture removal in the lower chamber and quantity retour upon to layer temperature

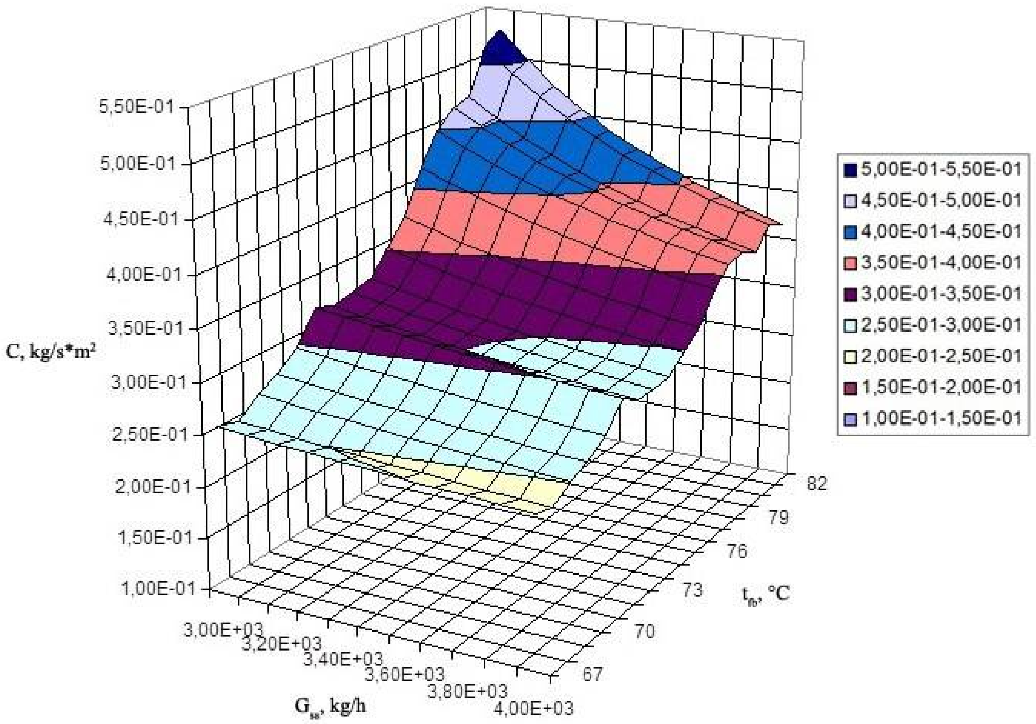


Fig. 18. Dependence of moisture removal in the upper chamber from layer temperature and retour amount

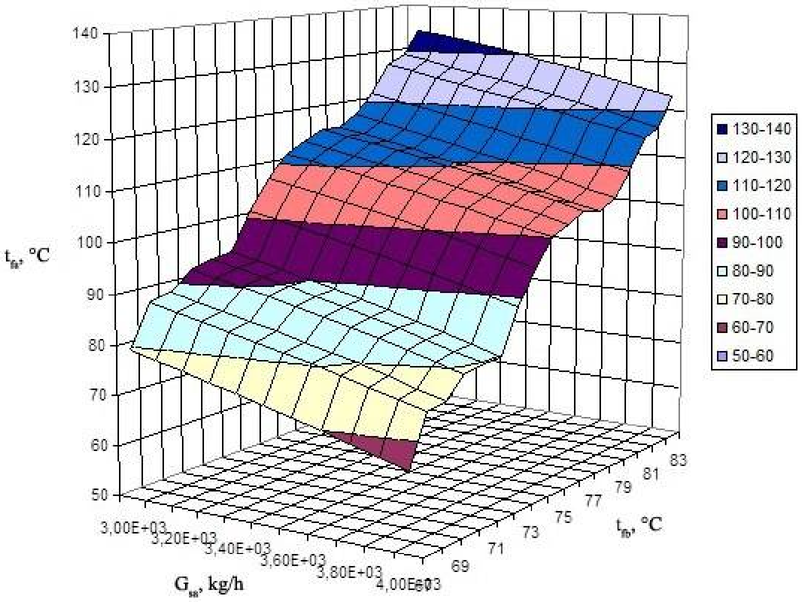


Fig. 19. Dependence of temperature of drying agent in the upper chamber from the layer temperature and retour amount

CONCLUSION

Optimization calculation results allow to find the optimal conditions for granulation process as in one chamber as well as in the multi-vortex type granulation devices. The main optimization criterion in this case is to provide the minimum required residence time of granules in granulator to complete formation of structure while maintaining the core strength.

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 No. 29950 Ukraine, IPC (2006) B01J2/16; No. 82754 Ukraine, IPC (2006) B01J2/16; No. 90798 Ukraine IPC (2009) B01J2/16 B01J8/08 B01J8/18; patent No.99023 Ukraine IPC (2012.01) B01J2/16 etc.) and author`s software products (certificates of authorship No 62692, 65140, 67472). The authors thank *researchers of department Processes and Equipment of Chemical and Petroleum Refinery Department, Sumy State University, for their valuable comments during the article preparation.*

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