Research of the hydrodynamic and thermodynamic modes of vortex granulator's operation for obtaining of porous ammonium nitrate

Artem Artyukhov, Volodymyr Vedmedera, Oleksandr Kremnyev

Processes and Equipment of Chemical and Petroleum-Refineries Department, Sumy State University, UKRAINE, Sumy, Rymskogo-Korsakova street 2, E-mail: artemijar@yandex.ua

Abstract* – *The work purpose – studying of regularities of distribution of the humidified granules of porous ammonium nitrate in working space of the vortex granulator and thermodynamic conditions of processing of granules in a vortex gas flow. We carried out analysis of the influence of the velocity components of the gas stream on a trajectory of its movement in the working space of the vortex granulator. Features of distribution of granules on device height are investigated. The analysis of results of measurement of temperature fields in the vortex granulator (single-phase and two-phase flow) is submitted. Received results of researches will allow to develop mechanisms to control the movement of granules in the working space of the vortex granulating equipment and kinetics of removal of moisture from them.

Key words – porous ammonium nitrate, vortex granulator, hydro- and thermodynamics

I. Introduction

Currently search of new ways of receiving the granulated products with special characteristics, in particular, of porous ammonium nitrate for needs of the mining industry is conducted.

Receiving porous ammonium nitrate is carried out by the following methods:

1. Addition into the melt (solution) the pore-forming and modification additives.
2. Thermal treatment of granules.
3. Humidifying and drying of granules.

Each of these ways provides necessary absorbing and retentivity of granules in relation to diesel oil; thus ecological indicators of granules decrease (method 1), there is loss their durabilities (method 2), the scheme of production (method 3) becomes complicated.

It is necessary to have in basis porous ammonium nitrate from the granule which is evenly distributed on structure porosity which provides not only high ability to absorb oil, but also possesses high retentivity, thus keeping strength properties for receiving qualitative industrial explosive substances.

The perspective direction of development of chemical industry in this sector is creation of technological schemes of granulation with implementation of small-size vortex devices. When using vortex flows there is possibility of flight control of drop (granule) for providing conditions of lack of drop deformation in flight also the process of its secondary crushing.

Optimum hydrodynamic characteristics of continuous and disperse phases have to be matched for this purpose, trajectories of their movement should be calculated; the received results are compared with thermodynamic conditions of formation of granules of porous structure.

Advantages of way of receiving granules of porous structure in vortex flow:

– reduction of staying time of granules in the device volume and preservation of their strength characteristics;
– reduction of heat treatment cycles of granules;
– combination in one device of stages of moistening and drying of granules;
– possibility of classification of granules by the sizes;
– reduced equipment size.

The task of the work - studying of regularities of distribution of the humidified granules in working space of the vortex granulator and thermodynamic processing conditions of granules in vortex gas flow.

The procedure for conducting investigations:

– studying of process of granules classification by the sizes in working space of the vortex granulator;
– studying of trajectories of the movement of gas flow depending on value of its velocity components;
– studying of the temperature fields in the working space of the vortex granulator;
– development of algorithm to determine the required staying time of granules in a vortex granulator.

II. Study of hydrodynamic modes of the vortex granulator working

Classification of granules

The mathematical model [1] is the basis for the description of process of granules classification by the sizes.

Granulators with a constant area of cross section don't provide fully processes of classification of granules and separation of non-commodity fraction in volume of the granulator. It is explained that in working space of the vortex granulator the ascending speed of a gas flow keeps conststant, the corresponding working speed of the granule movement (or fractions of granules in the narrow range). It is possible to carry out processes of classification of granules in devices with a constant area of cross section in case of delivering of gas to the device by several streams with an arrangement of places of input on different elevation marks. This way of classification was rather power-intensive and not widely used.

Much more effective method of classification of a disperse phase is using of devices with a variable area of cross section of working space. Thanks to initiation in volume of the device of fields of velocity components of the gas flow movement on height of the granulator it is created various hydrodynamic conditions for the granules movement. On height of the device there is a distribution of granules on diameter (provided that granules from one material) or different weight (in the conditions of creation of granules of porous structure or multilayered granules are classified).

The calculated scheme of working space of the vortex granulator presented on Fig. 1.

values in certain points (or cells) spaces and for certain timepoints. Computer simulation - one of methods of the numerical solution of the equations of hydrodynamics. The ANSYS CFX software product (http://www.ansys.com) is used in this work.

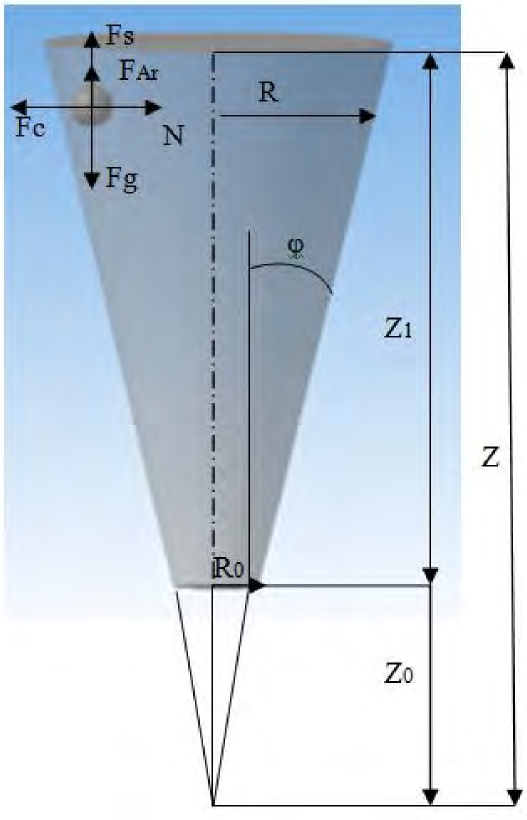

Fig. 1. The calculated scheme of working space of the vortex granulator [1]: Z – general height of a cone; Z_0 – installation height of gas distribution device; Z_1 – height of working space of the granulator; φ – half of a cone expansion angle; R_0 – radius of gas distribution device; R – the radius of the current workspace

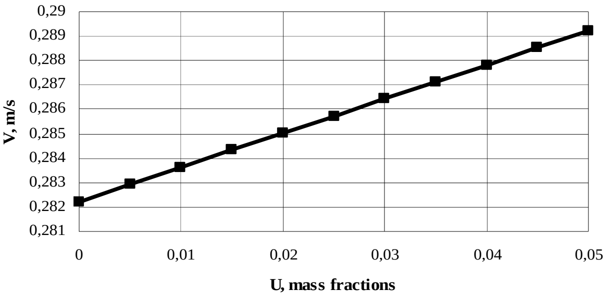

Fig. 2. The dependence of speed of a gas flow which corresponds to "hovering" of a granule from moistness of a granule (granule material – ammonium nitrate, diameter of a granule is 2 mm, temperature of a gas flow is 212 F)

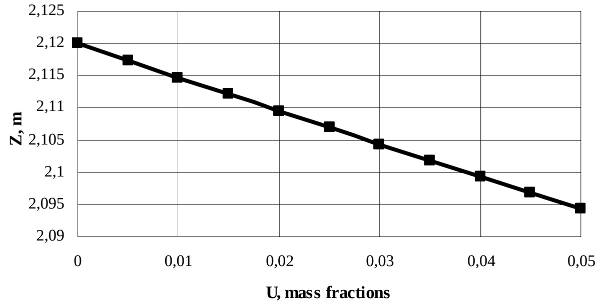

Fig. 3. The dependence of height of an arrangement of a granule on moistness of a granule (granule material – ammonium nitrate, diameter of a granule is 2 mm, temperature of a gas stream is 212 F)

Results of the gas flow rate calculating which corresponds to "hovering" of a humid granule and height of arrangement of a humid granule are presented in Figs. 2 and 3.

The received results allow to design the granulator for providing removal of granules of porous ammonium nitrate from necessary height depending on its moistness (weight).

Trajectories of the movement of gas flow.

At designing of small-sized vortex devices for creation of granules with special characteristics (in particular, porous structure) the special attention is paid to the hydrodynamic modes of the movement of granules in working space of the device under the influence of the twirled gas flow and to determination of their balance conditions [2, 3]. Depending on design features of the vortex device the choice of parameters of a gas stream which will allow a granule to stay necessary amount of time in a working volume of the device is made. Controlling the hydrodynamics of the movement of granules it is necessary to provide them with the set properties without collapse of their structure.

The basis of calculation of hydrodynamic vortex and highly turbulent flows are the classical hydrodynamics equations. Generally these equations are nonlinear and have not strict analytical solution without certain simplifications and assumptions. For implementation of simulation it is possible to solve them in number, finding instead of the continuous decision a discrete set of its values in certain points (or cells) spaces and for certain timepoints.

Computer modeling of hydrodynamics of the movement of a gas stream in the vortex granulator allows to pick up its optimum design of working space already at the initial stage of researches before carrying the experiment out on a natural sample.

The analysis of simularion results which are presented on Fig. 4 showed:

– depending on the value velocity component of the gas stream it has a different configuration with a prevalence of one or other direction of motion;

– zone of the gas stream movement is narrowed with the prevalence of the axial component of the velocity;

– the increase on height of a zone of whirl of a gas stream is observed at the prevalence of the circumferential velocity component;

– movement of a gas stream to a wall of the vortex granulator is carried out more intensively at prevalence of a radial component of the velocity;

– under certain conditions intensity of an initial swirling of a gas stream doesn't influence a trajectory of its movement, and influences only value of total velocity of a gas stream;

– the axial component of speed gradually decreases in process of movement of gas flow on granulator height (it is connected with increase in cross section area of the granulator);

– the circumferential component of velocity is characterized by the maximum value at the exit point of the gas-distributing device;

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

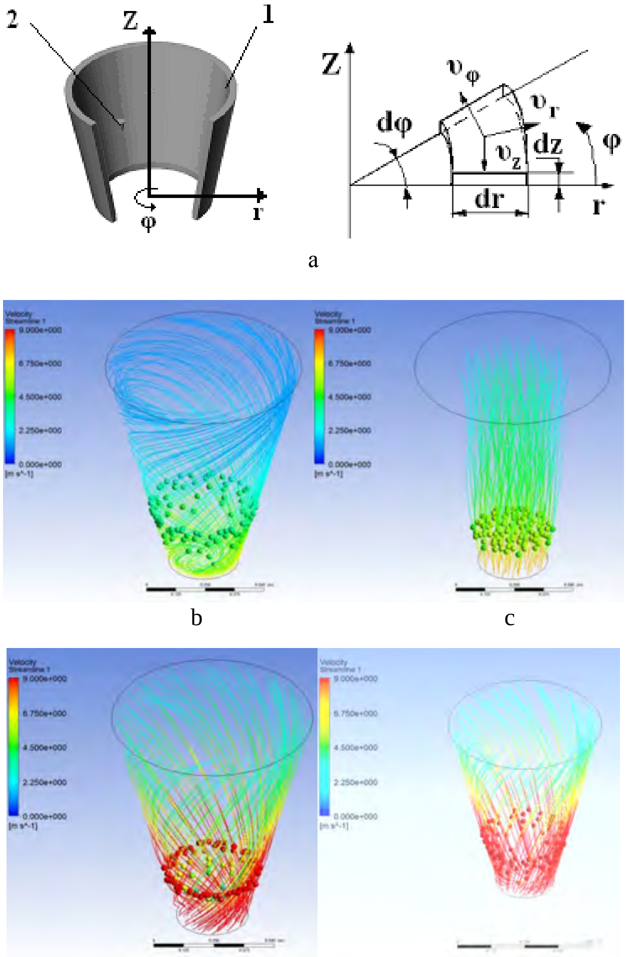

Fig. 4. Trajectories of the gas flow movement in working space of the vortex granulator at different values of components of total velocity: a – directions of components of total velocity (1 – the working space of the granulator; 2 – elementary volume of gas; dr, dφ, dz – elementary gains, Vz, Vr, Vφ, – axial, radial and circumferential velocity components of the gas flow, respectively); b – Vz=1 m/s,Vr=1 m/s, Vφ=8 m/s; c – Vz=8 m/s,Vr=1 m/s, Vφ=1 m/s; d – Vz=8 m/s,Vr=1 m/s, Vφ=8 m/s; e – Vz=8 m/s, Vr=15 m/s ,Vφ=8 m/s

III. Study of hydrodynamic modes of the vortex granulator working

Perspective method of receiving porous ammonium nitrate is the combination of method of heat treatment and moistening of granules in small-size vortex granulators [2]. Considering that each cycle of heat treatment leads to destruction of kernel of granules, the temperature range at which ammonium nitrate tests the minimum quantity of modification transformations is optimum. Temperature range 176-284 F was investigated, there the area of existence of modification of the II ammonium nitrate (183,2-255,2 F) is located. Heat treatment at temperature 284 F gives intensive release of ammonia in the atmosphere, at temperature below 176 F - final moisture content in granules of porous ammonium nitrate is higher than normative value.

Staying time of granules in flow of hot air has to provide removal of moisture to normative value.

Granules can be dried in the device in two ways:

– along with heating of the heat carrier;

– introduction for drying after full heating of the heat carrier and the subsequent heating.

In the first case warming up will be "soft" (gradual warming up of granule increases time of its drying, but protects from destruction of kernel). In the second case intensity of removal of moisture increases (sharp heating allows to reduce the period of warming up of granule, to increase intensity of removal of moisture), but thus destruction of kernel is possible. Selection of optimum thermodynamic operating mode of the granulator will allow to carry out full removal of moisture from granule with preservation of its durability and formation of porous surface layer. The second method of drying was used for research.

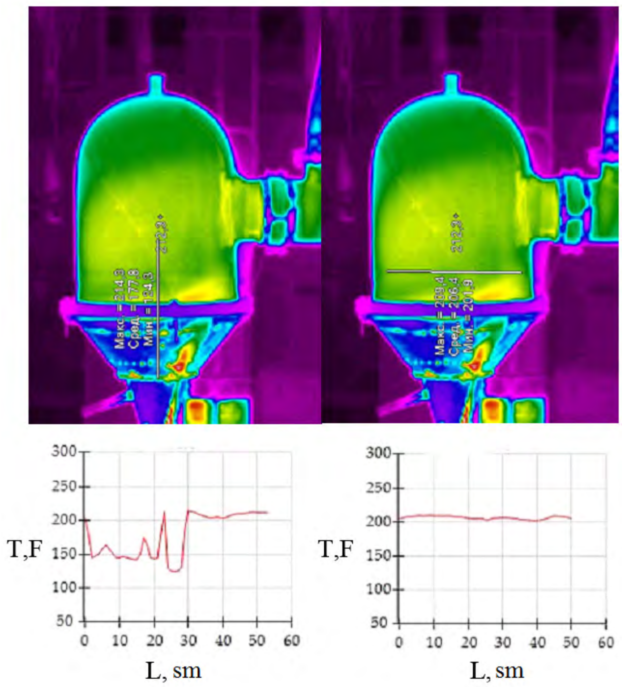

Fig. 5. Temperature field of gas flow in working space of the vortex granulator (operating time of 10 minutes)

The analysis of research results which are presented on Figs. 5-8, has shown that:

– change of temperature profile in working space of the vortex granulator in time is characterized by two extrema (the moment of input of granules in flow of the hot heat carrier and the moment of the beginning of simultaneous heating of granules and the hot heat carrier);

– warming up of working space of the vortex granulator in entering the operating mode is carried out unevenly with characteristic zones of the lowered temperature (eventually warming up becomes uniform);

– after loading of granules temperature in zone of the movement of granules sharply falls, intensity of further warming up of the granulator also decreases.

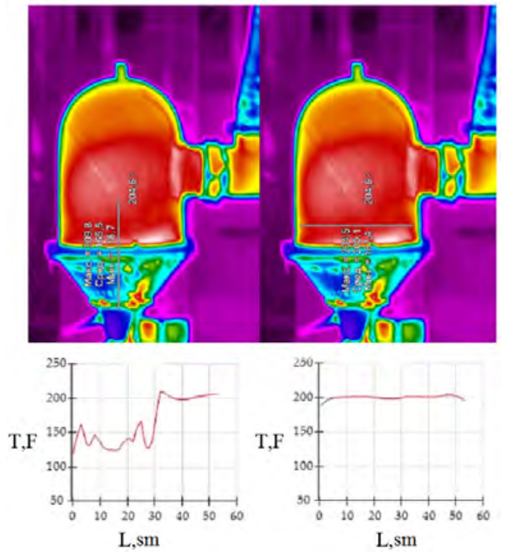

Fig. 6. Temperature field of two-phase flow in working space of the vortex granulator (operating time of 2 minutes from the moment of loading of granules)

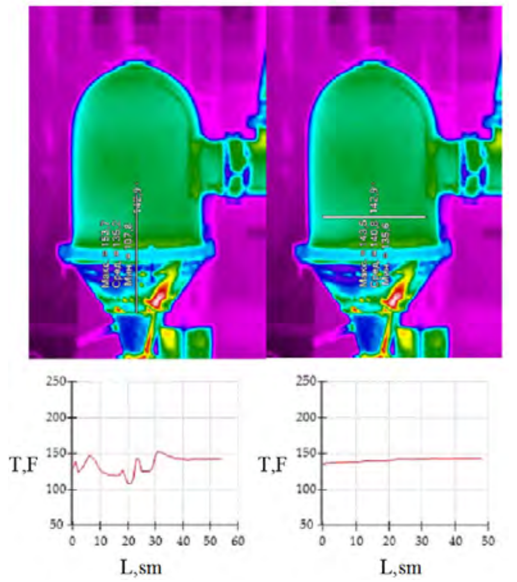

Fig. 7. Temperature field of two-phase flow in working space of the vortex granulator (operating time of 10 minutes from the moment of loading of granules)

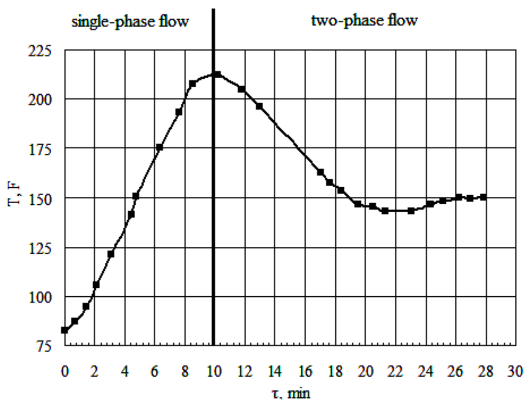

Fig. 8. Dynamics of warming up of working space of vortex granulator

Conclusion

Results of researches which are provided in this material, allow to develop algorithm of calculation of process of receiving porous surface layer on granule of ammonium nitrate. This algorithm is presented on Fig. 9.

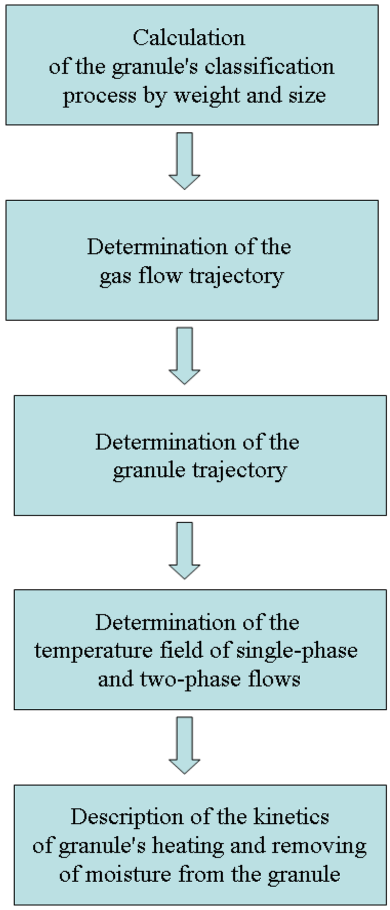

Fig. 9. Algorithm of calculation of process of receiving porous surface layer on granule of ammonium nitrate

The task of future researches – the description of the regularities of warming up of granule and removal of moisture from granules of porous ammonium nitrate in vortex flow of hot air (the last block of algorithm which is presented on Fig. 9).

References

[1] A. E. Artyukhov, A. S. Fursa, K. V. Moskalenko, "Classification and separation of granules in vortex granulators", Chemical and Petroleum Engineering, vol. 51, Nos. 5–6, pp.311-318, Sept. 2015.

[2] A. Artyukhov, V. Sklabinskyi, "Theoretical analysis of granules movement hydrodynamics in the vortex granulators of ammonium nitrate and carbamide production", Chemistry & Chemical Technology, vol.9, No. 2, pp. 175-180, May 2015.

[3] A. Artyukhov, V. Sklabinskyi, "Hydrodynamics of gas flow in small-sized vortex granulators in the production of nitrogen fertilizers", Chemistry & Chemical Technology, vol.9, No. 3, pp. 337-342, Sept. 2015.