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Application of Vortex Granulators in Technology of Ammonium Nitrate Obtaining: Main Advantages and Environmental Aspects of Implementation

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Abstract

An article deals with the application of vortex granulators in technology of ammonium nitrate obtaining. The review of the main methods of granulation is carried out. The basic advantages of suspended layer granulators are presented. The basic methods of intensification of heat and mass transfer processes during the granulation in weighted layer granulators are shown. An article presents a short description of the modern vortex type granulation equipment and its main disadvantages. An article describes the problem of waste management in the production of ammonium nitrate. A description of the main methods of waste utilization in production of ammonium nitrate (flue gas and substandard granules of ammonium nitrate) by using vortex granulators is presented. Separate class of weighted layer granulator is the vortex granulators with variable cross-sectional area of the working space. Environmental benefits of such devices are the possibility of classifying the granules in the working volume and internal circulation of small granules. The main advantages of the original constructions of suspended layer vortex granulators are presented. These advantages reduce the amount of small fraction granules and ammonium nitrate dust.

Keywords: Granulation; Vortex granulator; Waste disposal; Classification; Separation

Introduction

The method of granulation process equipment is determined by finished product requirements, properties of raw materials, process peculiarities. The efficiency of the pelletizing process depends on formation of granule mechanism, which is different for different methods and equipment for its implementation [1].

The granulation process is closely connected with changing the state of agglomeration of substance which is granulated. Accordingly, the proposed [2-7] following the general classification of the methods of granulation:

1. Granulation of a mixture of liquid and solid phases agglomeration of powders with subsequent nodulizing of agglomerate with padding between the particles upon withdrawal of the liquid phase;

2. Granulation from a liquid phase by dispersing it into droplets followed by crystallization of solutes during dehydration and cooling of this phase;

3. Granulation from a liquid phase by dispersing it on the surface of particles in fluidized bed;

4. Granulation of solid phase by pressing, followed by crushing of briquettes to granules of desired size.

The analysis of current market of granulated products for the chemical, mining, pharmaceutical and food industries has shown that among these methods of granulation with new (advanced) is part of the granulation in weighted layer [8]. Obtain a granulated product in weighted layer is used by the world famous manufacturers of fertilizers and pharmaceutical products-Urea Casale SA Kahl Group, Stamicarbon, Toyo Engineering Corporation, Changzhou Xianfeng Drying Equipment Company Ltd, Glatt, Uhde Fertilizer Technology, Rottendorf Pharma, etc. [9-15].

The main advantages of using fluidized bed technology in granulating are [16-19]:

1. Intensive mixing of solid phase, resulting in practical equalization of temperatures and volume concentrations in weighted layer;

2. High values of heat transfer coefficient from weighted layer to the heat transfer surfaces (or viceversa);

3. Use of solid particles of small dimensions (of solid phase with a developed specific surface);

4. Relatively small hydraulic resistance;

5. Ease of mechanization and automation.

Review of designs of weighted layer granulators allowed tracing such trends in development of world technology granulation:

1. New constructive solutions applicants mainly are large industrial companies which produce mineral fertilizers, which have a strong reputation in global market. Representatives of academic institutions have smaller lead in this direction;

2. Similar in fact the constructive solutions of intellectually

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protected worldwide well-known industrial companies, not only domestic but also international patents;

3. Essence of the vast majority of security documents is reduced to a constructive improvement of existing pellet mills, and not to a new form of organization of the traffic flows.

All these trends have shown a reduction of scientific component in the development of granulation technologies in weighted layer. The classical weighted layer device has well known methods of calculation and due to design improvement not appears the needs in view of such techniques. The new form of organization of traffic flows requires a thorough theoretical description; this issue is relevant given the information below.

Despite the wide application of weighted layer devices in industry and the variety of designs and techniques to enhance the effectiveness the authors [20-24] noted the following disadvantages:

1. Uneven residence time of particles of the solid phase and solubilizer in weighted layer (equally possible rapid jumping of particles and its stay in layer for longer than the average time);

2. Possibility in some cases an undesirable change of properties of solid particles (abrasion, cracking, adhesion etc.);

3. Necessity of installing powerful probably in exit of gases from the weighted layer, especially in wide granulometric composition of solid phase;

4. Equipment erosion in fluidized bed area, especially significant in the case of particles with high abrasive properties;

5. Limited operating speeds surgical agent limits corresponding to the beginning of the weighing of solid phase and its assignment from the layer;

6. Increased energy costs associated with pumping of solubilizer;

7. Necessity for accurate dosing the liquid phase, which significantly complicates the management of highly productive production;

8. Low stability of weighted layer in a wide range of variation of loads on liquid, solid and gas phases.

Among the variety of methods of intensification of processes of chemical technology flow twisting is one of the most simple and common ways. This is due to the fact that the use of twisted flows leads to improved efficiency of heat-mass transfer and equalization of temperature irregularities and flow stabilization. In granulator the twisting of flow using different devices (swirlers) leads to large-scale impact on all the characteristics of flow field, and consequently heat-mass transfer. This characteristic of the swirling currents of the three-dimensionality of the velocity field and co-measurement of tangential and axial velocity component leads to the formation of three-dimensional pressure field with radial and longitudinal gradient. Due to the presence of transverse components of speed - tangency and radial, convective transfer of momentum, energy and mass is increased and vertical structure of internal swirling flows is changed. Also are connected to such essential in technical applications the properties of swirling flows, expressed in their ability to intensify of heat-mass transfer processes, align local temperature inhomogeneity due to convective mixing.

Literature Review

A world leader of vortex granulation equipment production is Urea Casale Corporation. For urea granulation in weighted layer the Corporation applies vortex device with one or two horizontal rotating swirl [25-29] (Figure 1).

Urea Casale vortex granulator is currently implemented in industry in single unit in Russian Federation.

The described above structure is suitable for high quality coating of organic matter (e.g., seeds), processes for pelletizing. It's characterized by some drawbacks, for example, lack of process of classification of granules, unevenness of film deposition of melt. In addition granulating unit is accompanied by installation of equipment for crushing and scattering, or it is used after granulation tower for growing granules, which leads to additional energy costs [26].

Among industrial designs of weighted layer vortex granulators it is necessary to allocate the devices of BATCH-FB (granulators of periodic action) and CONTI FB (machines of continuous action) Corporation Neuhaus Neotec, technology of Heinen Drying® [30] (Figure 2).

The disadvantage of these devices is its frequency (for devices BATCH-FB) and the presence of rotating parts and Wurster systems in applying the liquid in weighted layer. Such devices according

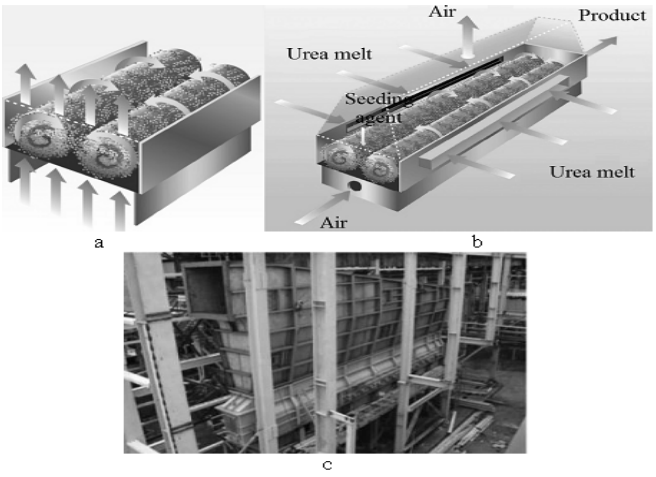


Figure 1: Vortex® granulator: a-principle of operation; b-scheme of flow movement; c-industrial plant in Russian Federation.

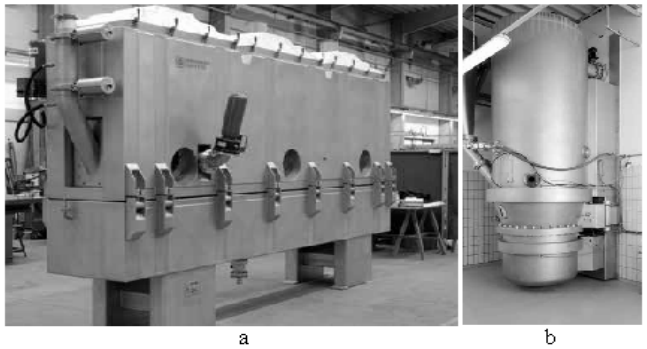


Figure 2: Vortex granulators of Neuhaus Neotec Corporation: a-BATCH-FB; b-CONTI FB.

principle of action similar to vehicles with spouting weighted layer without directional movement srgical agent. In it not are the process of classification of granules is not done, internal circulation of seeding agent for growing it to a marketable fraction is impossible.

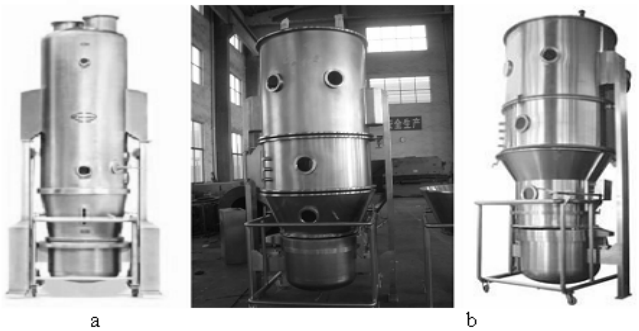
In advertising materials of list of vortex granulators weighted layer (Figure 3) that are produced by Indian [31] and Chinese [32-35] enterprises noted that it "is characterized by the presence of a specialized air dispenser, which provides continuous movement of material, and solves the problem of possible occurrence of channel flow and "blind angle". Other data regarding the mechanisms of creation of vortex motion of gas flow and characteristics of the granulation are do not provide by manufacturers, but the comparative characteristic of structures of Indian and Chinese devises with the handset CONTI FB from Neuhaus Neotec allows set a greater likelihood of copying. The disadvantages of these devices are similar to the disadvantages CONTI FB.

Another variant of apparatus for granulation in weighted layer is granulator of company Changzhou Xiandao Drying Equipemnt [35] based on scheme of Wurster with the Central twist of the gas flow at introduction of solution for granulation (Figure 4). Unlike popular technology top spray in this device out concurrent movement of the gas stream and granules due to lower spraying liquid material is carried.

At the initial stage of formation of granules is carried out orderly movement and form a stable vortex in center tube.

Vortex flows eliminates the problems of possible occurrence of congestive zone. At the same time, the device is suitable for the production of small granules, with the increase of granule size increases the probability of formation of agglomerates and deformation of drops in the vortex flow.

Among other samples of vortex granulators that have not received wide industrial application, it is necessary to allocate the rotary device



a b

Figure 3: Indian (a) and Chinese (b) analogs of vortex granulator CONTI FB (Neuhaus Neotec Corporation).

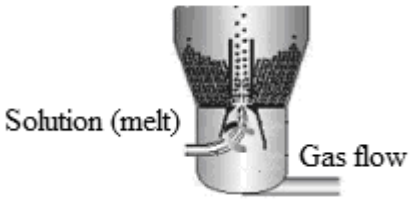


Figure 4: Granulator with Wurster scheme and central twisting of the gas flow.

with weighted layer on a rotating disc [36], multisection box-type device with grooved gas distributor [37], device with lamellar gas distributor [38].

The design of granulators showed that weighted layer technology requires further improvement.

The main factors that negatively affect the quality of granular products is:

1. Possibility of collision and agglomeration of individual droplets;
2. Uneven contact time of dispersed phase with a gas stream;
3. Lack of intense lateral mixing.

A promising direction of development of technology for granular material in weighted layer is creation of vortex granulator-classifier with the internal circulation of seeding agent. In presented work the main future-proof design of these devices. The implementation of these processes in different zones of granulator allows to control the residence time of the granules due to change of hydrodynamic conditions of fluid flow along the height of working space. Also the vortex weighted layer devices, along with machines combined weighted layer, will reduce the presence of stagnant zones and to enhance lateral mixing in the layers.

Developed small-sized devices whirling weighted layer with variable height cross-section of the workspace allow you to solve a number of problems that were described above.

Environmental aspects of the application of vortex granulators

Waste production plants, for example, ammonium nitrate, are [39]:

1. Air, which contains ammonium nitrate dust, nitrogen oxides and ammonia;
2. Fine fraction granules, which cannot be used in agriculture.

The main directions of waste disposal of ammonium nitrate and equipment:

1) Capturing of small fraction and dust with further sending to the preparation of the melt - vortex precipitators [40], the separation stage [41]; 2) Capturing of ammonia to form ammonia water for industrial purposes – vortex heat and mass transfer contact stage [42,43], counter-swirl atomized mass transfer devices [44]; 3) Capturing of small fraction and send it to the rearing - takes place directly in the vortex granulator; 4) Capturing of lower oxides of nitrogen, oxidation of them to the higher oxides, shipping on the production of nitric acid – system "reactor-vortex ejector" [45]; 5) Thermal decomposition of unconditioned ammonium nitrate with the formation of lower oxides of nitrogen, oxidation of them to the higher oxides, shipping to the production of nitric acid – system of "reactor-vortex ejector" [46].

Thus, for waste disposal such methods are used: hydro mechanical, reactionary, mass transfer, combinational.

Granulators with a constant cross-sectional area do not provide the full processes of classification and separation of granules unmarketable fraction in the granulator volume. This is because in the working space of the vortex granulator remain constant with respect to the ascending speed of the gas flow, which corresponds to the working speed pellets (or fractions of pellets in a narrow range). To conduct the process of classification of granules in the apparatus with a constant cross-sectional area is possible in case of gas inlet into the machine multiple threads with the location of the input at different elevations. This

method of classification is quite energy intensive and wide application has not received [47,48].

Much more effective method of classification of the solid phase is the use of devices with variable cross sectional area of the workspace. Thanks to creation in devices fields of the velocity's components of the gas flow along the height of pellet mill is created of different hydrodynamic conditions for the movement of granules. The height of the device there is a distribution of granules in different diameters (provided that the classified granules of the same material) or different mass (in terms of creating granules of porous structure or multi-layered granules) (Figure 5). Small granules leave the working volume of the device, and enter annular space of granulator, and then ejection gas flow is returned to granulation zone (Figure 5). In addition to classification into small and large fractions at the expense of vortex flow thermal separation - in the central layers of the vortex flow temperature is reduced and is increased in peripheral layer.

This allows not only obtaining a product of specified quality, and whiling maintaining the separation and granulation change the terms granules making.

Examples of structures of vortex granulators and its main advantages (patent review of copyright designs)

Vortex granulator with a vibrating spraying of melts (Figure 6a).

Spraying of liquid material in a specified way allows to: Reduce the possibility of contamination of the dispenser; Reduce the frequency of cleaning it 3-5 times; Reduce the number of collisions of individual drops of melt in 2-3 times; Reduce the impact on the cut unevenness of the spray of liquid material; Increase the growth rate of granules marketable fractions.

The formation of the spherical shape is due to the properties of the liquid to break up into uniform drops, if the surface of the jet to create regular oscillations (waves).

The homogeneity of structure of droplets formed from a jet of a fluid material, and the uniformity of the spray pattern achieved by the alignment of the fields' velocity of melt from the holes of perforated surface of sprayer.

Vortex granulator with two-stage contact of granules and heat transfer agent (Figure 6b).

Granulation with zone of secondary contact of small fraction granules with the flow of coolant allows distributing the flow of

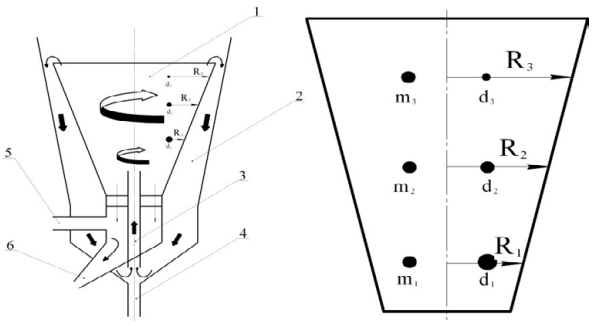


Figure 5: Scheme of the working space of vortex granulator: 1-zone of granulation and classification of granules; 2-zone of internal circulation of seeding agent; 4-zone of internal circulation of seeding agent; 5-heat transfer agent for the formation of vortex weighted layer; 6-output of granules of commodity fraction.

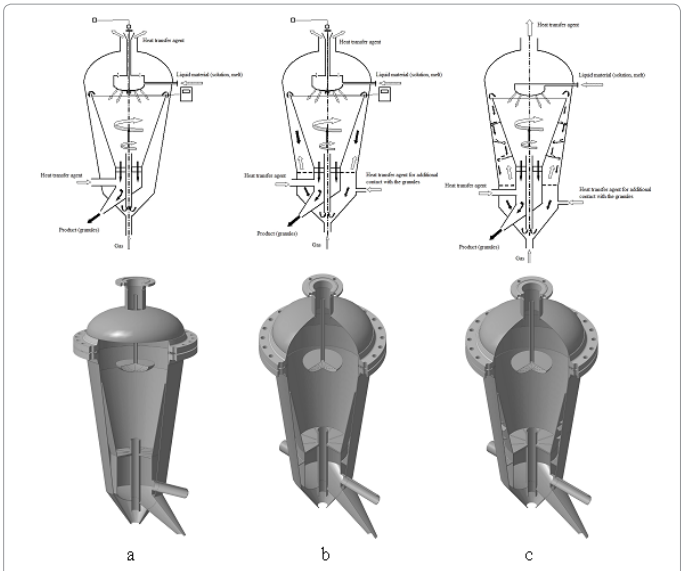


Figure 6: Vortex granulators: a-with a vibrating spraying of melt; b-with two-stage contact of granules and heat transfer agent; c-with multi-zone secondary contact of granules and heat transfer agent.

granules of different fractional composition within a single device.

This is necessary for: Full completion of the crystallization process; Prevent the formation of granules form other than spherical; Reduction of mixing commercial and fine fractions; Increase in the rate of granules growth to commodity fraction; Increasing the degree monodispersity of product.

The formation of a completed crystal structure of granules occurs by increasing the time of contact with heat transfer agent; as a result of upward heat transfer agent flow in zone of secondary contact of crossing time micropose annular cavity device a granule grows. This contributes to the full completion of the crystallization process on the surface of granules to return to first main area, where the spraying of the liquid material. This decreases the influence of the destabilizing factors caused by the inhomogeneity of sizes and shapes of granules.

Vortex granulator with multi-zone secondary contact of granules and heat transfer agent (Figure 6c).

Receiving pellets in weighted layer using a multi-stage zone of secondary contact of granules small fraction of heat transfer agent flow regime in weighted layer allows to increase the residence time of granules small fraction is in contact with heat transfer agent flow. The creation of a one-device weighted layer of different configurations (with a vortex movement of the granules under the action of a counter-whirling axial flow of heat transfer agent and with Pulse-forward trajectory of movement of granules small fraction under the influence of the upward flow of heat transfer agent in secondary area of heat transfer and mass transfer) allows to combine the process granules making with the completion of formation and crystallization of surface and core granule in secondary contact area with heat transfer agent.

The method allows secondary contact between the granules small fraction and heat transfer agent in lower temperature (due to increased residence time of granules small fraction in annular space between the hulls) and mass of heat transfer agent (due to reduced area free-sectional area of annular space between the hulls). Lowering the temperature treatment of granules of small fraction allows to preserve

the integrity of their core and in some cases (in particular, upon receipt of the granules of porous structure) after heat treatment to leave in core of granule air bubbles that contribute to beginning of reaction of detonation of industrial explosives.

Dual-zone vortex granulator (Figure 7).

Granulation in heat transfer agent flow with different movement organization allows to create the most favorable conditions for formation of a high-quality product through a variety of complex forces acting on drop (in upward heat transfer agent flow is gravity and aerodynamic drag drop of the gas stream in the vortex flow of the coolant - gravity, drag force of the drops against gas flow and centrifugal force).

Such constructive decision allows to:

1. Reduce the size of equipment;
2. Reduce energy costs for carrying out process;
3. Increase the degree of monodispersity of product.

Vortex granulator to obtain granules of porous structure with preliminary humidification (Figure 8a).

Humidification of the granules with the liquid material allows

Create a developed porous structure on its surface already within the kernel weighted layer at the initial stage of contact with a vortex flow of high temperature coolant (before granule transfer on surface of fluidized bed); Reduce the possibility of contamination of the walls of the inner cone; Prevent the possibility of collisions of individual drops of liquid material due to the lack of atomization process in the volume of the working space. The uniformity of drying of liquid material on the surface of the pellets and the homogeneity of surface porous structure granules is also achieved by reducing the impact of counter vortex axisymmetric stream of heat transfer agent and uniform distribution of the moistened pellets in weighted layer.

Vortex granulator for obtaining granules of porous structure with preliminary humidification and drying (Figure 8b).

Primary drying of humidified granule upward heat transfer agent flow in this way allows the process of formation of porous surface layer

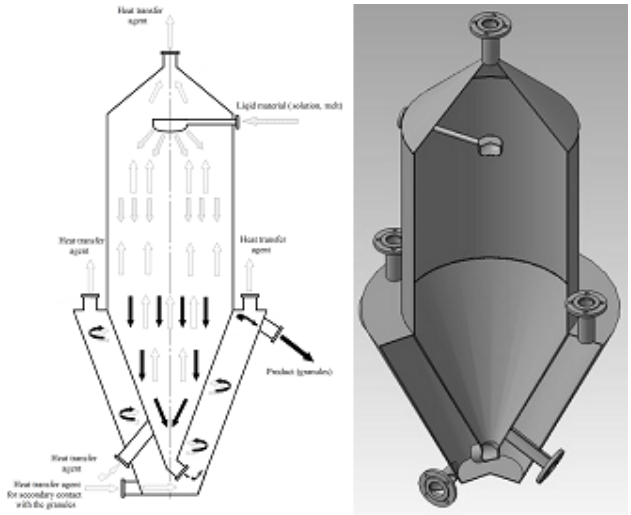


Figure 7: Dual-zone vortex granulator.

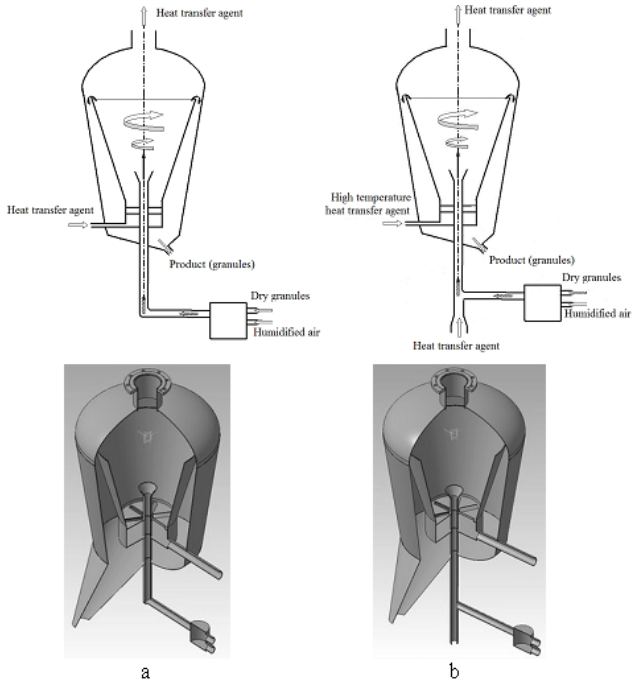


Figure 8: Vortex granulator to obtain granules of porous structure: a-with preliminary humidification; b-with preliminary humidification and drying.

on stage of pneumatic transportation of granules to the working volume of the device after wetting with reduced influence of vortex flow. The use of two stages of contact of heat transfer agent with the granule results in uniform pore formation due to gradual increase in the temperature of the coolant which is in contact with moist pellets. Consequently, a porous surface layer on the pellet passes without a sharp increase in internal stress, which is caused by a sharp temperature differential between the agent for wetting and high-temperature coolant. At the stage of primary drying and moisture removal is performed heating of the surface layer on granule with the gradual formation of a porous film, which further along with the core of the granules takes place to warm up fully on all the cross-section of granules in the vortex flow of high-temperature heat transfer agent.

Vortex granulator with separating device for cleaning gases, which depart (Figure 9).

Method of granulation in vortex weighted layer cleaning waste heat allows you to: To distribute the flows, containing granules of fines and dust for individual degrees within a single device for further processing with different separation mechanisms; To separate the pellets from the fine fraction of the waste heat stream and to return them to the annular space between cylindrical and conical a bicycle working volume of the device, and then in the granulation zone for rearing up to marketable size fraction.

1. Use zone hydraulic filtration from dust with intensively foamed water-gas-air layer with a high specific surface area of phase contact.

The main advantages of the method:

1. For inertial separation of fine granules fraction and creation of a vortex layer water-air layer the energy vortex of the gas flow from the working volume is used;

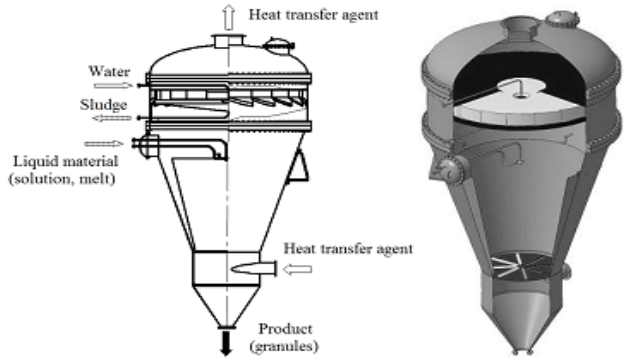


Figure 9: Vortex granulator with separating device for cleaning gases, which depart.

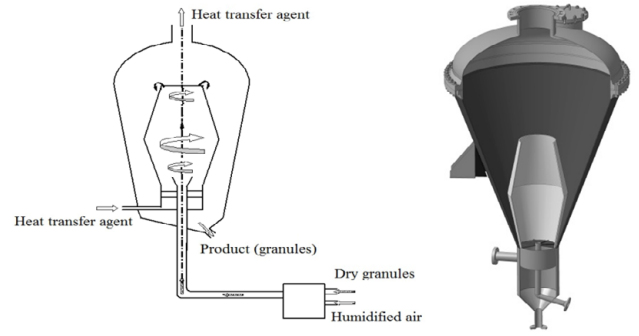


Figure 10: Vortex granulator with rhombic the form of inner cone.

2. Utilization of energy of waste heat;

3. Humidification of the air of industrial premises.

Vortex granulator with rhombic form of inner cone (Figure 10).

The implementation of additional element in rhombic form allows to create conditions for uniform drying of granule and create a porous surface layer without the influence of destabilizing factors: the intersection of trajectories of granules created with the porous surface layer and humidified granule on which the surface layer is being created; the agglomeration of granules with different degree of formation of porous surface layer; the destruction of the porous surface layer and the core of the granules due to long-term contact with the vortex flow of heat transfer agent at the stage where the creation of a porous surface layer and to stabilize the shape of granules is not yet complete; creation of stagnant zones in the workspace of the device.

In addition, for all humidified granules the time of contact with the high temperature flow of heat transfer agent is aligned and minimized [49].

In each part an additional of device for movement humidified granule different hydrodynamic conditions are created.

Conclusions

A brief overview of main methods of granulation is given, the main advantages and disadvantages of granulation methods were analyzed, and prospects of granulation methods further development were outlined.

After the analysis of literary sources concerning the regularities of the process of granulation in weighted layer granulators we identified the prospects for further improvement of this method and the main technological equipment. Based on the analysis of theoretical and experimental materials, we identified deficiencies in hardware design of the apparatus for granulation in weighted layer. As one of passive of intensification of heat and mass transfer processes methods we suggested the use of vortex flows in granulation technology in weighted layer. Examples of application of the vortex apparatus in pelletizing technology. By this time the vortex weighted layer granulators are not widely used in industry due to the lack of reliable methods for their calculation and design. In addition, the existing models of vortex granulators do not allow the processes of classification and separation of granules, do not provide internal circulation seeding agent, at the same time do not perform in its volume several stages of producing granulated product and so on.

According to these theses we can underline the feasibility of a detailed study of regularities of the process of granulation in vortex weighted layer and creation of new forms of organization of traffic flows in vortex granulators and substantiation of possibility of application of vortex granulators as multifunctional devices.

Advantages of suspemded layer vortex granulators:

1. Ability to reduce significantly the dimensions (particularly height) of the workspace;

2. Increasing the residence time of granules in working space of device;

3. Ability to control the movement of granules;

4. Universality (possibility of carrying out the processes of granulation, drying, classification, separation and circulation of seeding agent in volume of a single device);

5. Opportunity to realign and to change design and process parameters if necessary.

Among the tasks that need to be addressed during the modeling stage of process of granulation in vortex devices, we highlight the following:

1. Development of mathematical description of thermodynamics and mass transfer in vortex flows in communication with the fluid dynamics of their motion;

2. Study of process of internal circulation of seeding agent and discharging the granules from the working zone of device;

3. Regularity classification of granules in working space of granulator;

4. The separation mechanisms of small granules;

5. Conditions of deformation of drops and its balance in swirling gas stream;

6. Methods of liquid spraying material and spraying it on seeding agent.

The solution of these problems will allow developing methods of engineering calculation of the vortex type granulator in different production of granulated products from solutions and melts, and through the moistening and heat treatment to obtain granule with porous structure.

References

1. Stahl H (2004) Comparing Different Granulation Techniques. Pharmaceutical Technology Europe 23-33.
2. Litster J, Ennis B (2004) The science and engineering of granulation processes. Springer-Science+Business Media.
3. Parikh D (2009) Handbook of Pharmaceutical Granulation Technology, 3 edition, Informa Healthcare.
4. Stahl H (2010) Comparing Granulation Methods, Hürth: GEA Pharma Systems.
5. Solanki H, Basuri T, Thakkar J, Patel C (2010) Recent advances in granulation technology. International Journal of Pharmaceutical Sciences Review and Research 5: 48-54.
6. Patel P, Telange D, Sharma N (2011) Comparison of Different Granulation Techniques for Lactose Monohydrate. International Journal of Pharmaceutical Sciences and Drug Research 3: 222-225.
7. Agrawal R, Naveen Y (2011) Pharmaceutical Processing: A Review on Wet Granulation Technology. International Journal of Pharmaceutical Frontier Research 1: 65-83.
8. Saikh M (2013) A technical note on granulation technology: a way to optimise granules. International Journal of Pharmaceutical Sciences Review and Research 4: 55-67.
9. Urea Casale S.A. [Electronic resource].
10. Kahl Group [Electronic resource].
11. Stamicarbon [Electronic resource].
12. Toyo Engineering Corporation [Electronic resource].
13. Changzhou Xianfeng Drying Equipment Company Ltd [Electronic resource].
14. Fluid bed technology bringing ideas in motion [Electronic resource].
15. Glatt Innovative Technologies for Granules and Pellets [Electronic resource].
16. Rubino O (1999) Fluid-Bed Technology. Overview and Criteria for Process Selection. Pharmaceutical Technology 23:104-117.
17. Teunou E, Poncelet D (2002) Batch and continuous fluid bed coating: review and state of the art. Journal of Food Engineering 53: 325-340.
18. Guignon B, Duquenoy A, Dumoulin E (2002) Fluid Bed Encapsulation of Particles: Principles and Practice. Drying Technology 20: 419-447.
19. Gadgil P (2009) Survey of fluidization in pharmacy and its advancements: MGV's Pharmacy College.
20. Wen-Ching Yang (2003) Handbook of fluidization and fluid-particle systems: Marcel Dekker, New York, USA.
21. Gidaspow D (1994) Multiphase flow and fluidization: continuum and kinetic theory descriptions with applications: Academic Press, Inc.
22. Kunii D, Levenspiel O (1991) Fluidization engineering: Butterworth-Heinemann.
23. Kwauk M (1992) Fluidization: Idealized and Bubbleless, with Application: Science Press, Ellis Horwood, New York, USA.
24. Gibilaro G (2001) Fluidization-dynamics. The formulation and applications of a predictive theory for the fluidized state: Butterworth-Heinemann.
25. Pat. № 1698393 EP (2006) Process and device for fluidized bed granulation/ Gianfranco Bedetti, Carla Burlando.
26. Zardi F (2011) Vortex granulation: The new route to high-quality solid nitrogen fertilizers. Nitrogen & Syngas conference & exibition.
27. Pat. № 2013/0316078 A1, US (2013) Fluid bed granulation of urea and related apparatus/Gianfranco Bedetti.
28. Pat. № 7955566 B2, US (2011) Fluid bed granulator/Gianfranco Bedetti.
29. Pat. № 2006/094620 A1, WO (2006) Process and device for fluidized bed granulation/Gianfranco Bedetti, Carla Burlando.
30. Fluid bed technology-Bringing ideas in motion (2014) Neuhaus Neotec GmbH.
31. Fluidized Bed Granulation (2014) Umang Pharmatech Pvt. Ltd.
32. Huizhou Pingfang Trading Co. Ltd. [Electronic resource].
33. Changzhou Fengqi Drying Equipment Co. Ltd. [Electronic resource].
34. Yixin Drying Equipment Co. Ltd. [Electronic resource].
35. Changzhou Xianfeng Drying Equipment Co. Ltd.
36. Pat. № 1020040047753 A KR (2004) Device for treating powder particles by rotary flow / Wakamatsu Yoshihiro, Watano Satoru.
37. Pat. № 5695701 US (1997) Apparatus and a process for the preparation of an agglomerated material / Christian Reedtz Funder, Jens Mourits Sorensen, Morten Mohr Hansen.
38. Pat. № 8628276 US (2014) Fluidizing apparatus with swirl-generating means / James Edward Delves, Neil Keith Young, David Oliver Drew.
39. Artyukhov A, Levchenko D, Rossi P (2015) Production of ammonium nitrate in the vortex granulators: recycling of production waste. CLICAP 2015: Congreso Latinoamericano de Ingeniería y Ciencias Aplicadas.
40. Galich R, Yakuba A, Sklabinskyi V, Storozhenko V (2014) Development and Application of Counter Swirling Flow Vortex Dust Collectors. Chemical and Petroleum Engineering 50: 156-161.
41. Artyukhov A, Liaposhchenko O, Sklabinskyi V (2010) Inertial filter separators to clean end gases in vortex granulators. Acta Universitatis Pontica Euxinus I (I): 67-69.
42. Artyukhov A (2014) Optimization of Mass Transfer Separation Elements of Columnar Equipment for Natural Gas Preparation. Chemical and Petroleum Engineering 49: 736-741.
43. Artyukhov A, Liaposhchenko O (2014) Conditions of counterflow motion phases on mass transfer and separation trays for distillation and absorption columns. Journal of Hydrocarbons Mines and Environmental Research 5: 21-27.
44. Sklabinskyi V, Abdullah J, Mohammed N (2011) The characteristics of vortex spray countercurrent mass exchange device. Engineering & Technology Journal 29: 3211-3223.
45. Prokopov M, Levchenko D, Artyukhov A (2014) Investigation of liquid-steam stream compressor. Applied Mechanics and Materials 630: 109-116.
46. Artyukhov A (2013) Computer Simulation of Vortex Flow Hydrodynamics. Journal of Manufacturing and Industrial Engineering 12: 25-29.
47. Artyukhov A, Sklabinskyi V (2015) Theoretical analysis of granules movement hydrodynamics in the vortex granulators of ammonium nitrate and carbamide production. Chemistry and Chemical Technology 9: 175-180.
48. Artyukhov A, Sklabinskyi V (2015) Hydrodynamics of gas flow in small-sized vortex granulators in the production of nitrogen fertilizers. Chemistry & Chemical Technology 9: 337-342.
49. Artyukhov A, Fursa A, Moskalenko K (2015) Classification and separation of granules in vortex granulators. Chemical and Petroleum Engineering 51: 311-318.