Розглянуто спосіб зниження розчинності гранул азотних і фосфорних добрив за рахунок нанесення на їх поверхню органічної оболонки. Запропоновано процес капсулювання гранул мінеральних добрив проводити в поличному багатоступеневому апараті зваженого шару з форсунковим розпиленням. Розглянуто вплив конструкції поличних пристроїв на процес укрупнення і унесення гранул. Розроблено математичну модель кінетики гранулювання в поличному багатоступеневому апараті, що враховує зміну щільності розподілу гранул за розмірами на кожному ступені гранулювання

Ключові слова: гранулювання, багатоступеневий апарат зваженого шару, перфорована полка, органічна суспензія, унесення

Рассмотрен способ снижения растворимости гранул азотных и фосфорных удобрений за счет нанесения на их поверхность органической оболочки. Предложено процесс капсулирования гранул минеральных удобрений проводить в полочном многоступенчатом аппарате взвешенного слоя с форсуночным распылением. Рассмотрено влияние конструкции полочных устройств на процесс укрупнения и уноса гранул. Разработана математическая модель кинетики гранулирования в полочном многоступенчатом аппарате, учитывающая изменение плотности распределения гранул по размерам на каждой ступени гранулирования

Ключевые слова: гранулирование, многоступенчатый аппарат взвешенного слоя, перфорированная полка, органическая суспензия, унос

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HYDRODYNAMIC AND KINETIC PROCESSES OF THE MINERAL FERTILIZER GRANULES ENCAPSULATING IN THE MULTISTAGE DEVICE WITH SUSPENDED LAYER

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1. Introduction

Currently the production and rational use of fertilizers are extremely important for agriculture, and before science there is a task to develop environmentally friendly technologies of manufacturing and use of fertilizers. Nitrogen fertilizers (ammonium nitrate, urea) and phosphorus ones (superphosphate, ammophos) dominate in the range of mineral fertilizers used in all edaphic-climatic zones all over the world [1, 2]. They are transformed in the system soil – plant and provide the needs of growing plants in nutrient components. But along with the well-known advantages these fertilizers have significant drawbacks. They are highly soluble and they are quickly washed out from the arable layer, which leads to surface and groundwater contamination. Also, due to inefficient plant nutrition at different stages of growth, nitrite and nitrate accumulate in the main agricultural products.

One of the promising ways of improving the properties of various materials is modification of the starting materials by layering the protective shell (capsule) on their surface. Such coating modifies physical and chemical properties of the substances, improves their quality and extends their functionality; it enables to improve their performance characteristics.

The main purpose of fertilizers encapsulation is to provide slow or controlled release of target components and it increases the efficiency of the produced fertilizers and it enables to reduce the quantity of fertilizers applied into the soil.

Different types of capsules and various methods of their application are developed [3]. However, in most cases, for the obtaining of high-quality protective capsules one requires expensive polymer coatings and further additional processing of raw granules.

Methods of improving fertilizers quality which are not very complicated and which don't require tight and expensive reagents are of great practical interest. At the same time there is rapidly spreading organic production in the EU countries and in the world. Since it is an integrated system of management and food production. This system, first of all, takes into account preservation of the environment, biodiversity level, natural resources and application of high standards and methods of fertilizer production. Organic farming aims to improve public health by the production of high-quality food, soil conservation and environment preservation, as well as the promotion of local and regional production units [4].

Therefore, use of organic waste as a capsule shell is very relevant, because it solves the task of obtaining organic-mineral fertilizers of prolonged action and at the same time it solves the problem of organic waste disposal.

2. Literature review and problem statement

The process of applying organic protective shells on fertilizer granules can be termed as encapsulation and granulation as well, because there takes place a significant increase of the granules size comparing with their initial state [5]. Therefore, for arranging such process one can use standard equipment applied for granulation of fertilizers. However, one should note that organic substance, unlike mineral one, has its own peculiarities, which include the possibility of burning and decomposition at high temperatures, increased ability to stick together, lumping.

In low-tonnage and multi-assortment production, it is rational to use the same device for granulation and encapsulation of dispersed materials in order to reduce the range of the equipment. Organic wastes are very moist suspensions. Fractional composition of such suspensions is very diverse and they contain many colloidal particles, which form a viscous structure. Therefore, fluidized bed apparatus are proposed to minimize costs on processing wet organic substances for encapsulation purpose [6, 7].

The way of obtaining granulation products in the fluidized bed (suspended layer) is used by the world well-known manufacturers of fertilizers and pharmaceutical products: Urea Casale S. A. (Switzerland), Kahl Group (Germany), Stamicarbon (Netherlands), Toyo Engineering Corporation (Japan), Changzhou Xianfeng Drying Equipment Company Ltd (China) Glatt (Germany), Uhde Fertilizer Technology (Netherlands), Rottendorf Pharma (Germany) et al. [8].

The principle of a fluidized bed is used in the apparatus of different designs, operating at different processing modes. However, the processes of granules formation, growth and firming are subject to single analytic laws.

The exact description of the granule growth kinetics is a difficult task, so one uses a number of assumptions to make calculations, as well as empirical and semi-empirical dependences. The main dependences for determining the granule growth rate proposed to date, are based on the theory of uniformly-surface enlargement of particles.

One of the first attempts to describe the dependence of a particle size on the granulation process parameters was made by Grimmet, who offered simple and proper arguments [9]. He proceeded from the assumption that all particles uniformly reach the irrigation zone where the system is stationary and mechanisms of the surface growth are the same for each granule. The disadvantage of this technique is its linear direction and the use of ambiguous and difficult definable value – a total surface of the particles in the layer.

In the paper [10] kinetics of the polymer coating increasing on the surface of the spherical particle is expressed by the differential equation of the form:

$$dW_n = PCd\tau, \tag{1}$$

where dW_n – weight gain of coating on the particle surface, kg; P – consumption of the film-forming solution, which is supplied into the fluidized bed m^3/s; C – polymer concentration in the solution, kg/m^3.

When developing a mathematical model one assumed that all of the particles in a suspended layer are of the same size, on the surface of which a polymer shell of uniform thickness is applied. Increasing of the shell thickness leads to the particle diameter increase and it is expressed by a differential equation:

$$dW_n = \pi d^2 N \rho_a d\frac{d}{2}, \tag{2}$$

where N – number of particles in the fluidized bed; $\pi d^2 N$ – total surface of the particles, m^2; d(d) – growth of the particle diameter, m; ρ_a – film-forming agent density, kg/m^3.

Solving of the system of equations (1) and (2) provides a dependence for determining the coating thickness at any time:

$$\delta = \frac{1}{2} d_0 \left(\sqrt[3]{1 + \frac{PC\rho_P}{M_P \rho_a}\tau} - 1 \right), \tag{3}$$

where ρ_P – density of the particles, kg/m^3; M_P – total mass of the particles, kg.

Equation (3) is “rough”, that is not enough valid. This model sets aside a probability of increasing the shell in a fluidized bed.

In the paper [11] one uses Todes continuity equation which mathematical model has the form:

$$\frac{\partial g}{\partial \tau} + 2 \cdot \left[\Lambda \frac{\partial g}{\partial D} + g \frac{\partial \Lambda}{\partial D} - \frac{3\Lambda g}{D} \right] = -S\psi K g + \phi(D),$$

$$\tau > 0, \quad 0 < D < \infty, \tag{4}$$

where g – function of the granule mass distribution in size, mm^{-1}; τ – time, h; D – current granule diameter, mm; Λ – linear growth rate of the granules, mm/h; S – separator function; ψ – granule formation coefficient, fractions; K – unload constant, h^{-1}; $\phi(D)$ – power function of the new granulation center source (mm·h)$^{-1}$.

To solve the equation (4) empirically one determines granule formation coefficient ψ, linear growth rate of the granules Λ, unload constant K and the function of granule mass distribution in size g.

One suggested the following equation for particle size distribution function:

$$F(D_i; D_{OK}) = 1 - \exp\left\{ -\frac{3 \cdot \left[G_R + (1 - K_{GR}) \cdot G_M \right]}{K_{GR} \cdot G_M} \cdot \ln \frac{D_i}{D_{OK}} \right\}, \tag{5}$$

where K_{GR} – granule formation coefficient; G_M – granulator performance, kg/h; G_R – cycle performance, kg/h; D_i – current diameter, mm; D_{OK} – cycle particle size, mm.

Internal recycle in this case is determined by the value $G_M(1-K_{GR})$. To solve the equation (5) it is necessary to determine by experimental way the K_{GR} value and to know the exact size of the new granulation centers formed during the process.

Disadvantages of the fluidized bed apparatus may include: different time of a particle residence in the apparatus, a need for thorough cleaning of the exhaust air and material entrainment (in particular it is applicable to the suspension components). In addition, a significant drawback is the return of fine particles back in the fluidized bed zone. Because of different residence time of coarse and fine particles in the fluidized bed, their coating with the substance is uneven. The obtained product is non-uniform as to its particle size distribution, which deteriorates its quality. Thorough analyzing of various types of the fluidized bed granulation equipment in chemical [12], food [13] and pharmaceuticals [14] industries showed the urgent need for a new organization of the mutual flow motion, which will enhance monodispersity degree of the finished product.

Among the major techniques of controlling the polydisperse particles residence time in the device one should mark the following:

1. Developing a directed movement of particles using accelerating elements (gas distributors of vortex type) [15]. Gas distributors of vortex type enable to fulfill additional classification and separation of granules [16]. Application of vortex flows for combustion processes [17] as well as reaction apparatus [18], rectification towers [19] provides improved heat and mass transfer characteristics of the process and increased specific productivity. Calculation of the hydrodynamic conditions of the gas flow and granules motion [20] in the devices with vortex accelerating elements proved a high efficiency in controlling particles in the apparatus. Use of vortex flows also aligns the temperature field in the apparatus [21] and enables to increase the intensity of moisture removal from the particle [22]. The authors [23, 24] also noted high stability of a vortex (rotating) fluidized bed in a wide range of loads in the continuous and dispersed phases. In the paper [25] the author noted the ability to manage the suspended layer configuration.
2. Designing of apparatus with variable cross-sectional area applied to the granulation, cooling and dedusting process [26].
3. Application of sectioning (vertical and horizontal) to create different conditions for the particle heightwise (lengthwise) motion in the device.

Promising direction of reducing financial and energy costs on the heat and mass transfer processes in the fluidized bed is application of a multistage countercurrent contact, fluidizing agent and dispersed phase. Therefore, in order to reduce the cost of processing wet materials and increase the uniformity of particle size distribution of the final product one offered to carry out the process of granule coating with organic substance in a multistage shelf apparatus with suspended layer.

Most dependencies for calculating the granule growth rate have a common drawback – focus on the monodisperse layer of granules. However, granulated fertilizers, commercially available, are of a polydisperse composition. Consequently, it is rational to develop a mathematical model, which takes into account the change in distribution density of granules in size during the process of their encapsulation.

3. Purpose and objectives of the research

The purpose of the research is experimental and analytical study of basic laws of the encapsulated granule formation as a result of organic suspensions dehydration in the shelf multistage apparatus with fluidized bed. It will enable to cover the granule surface with organic coating of a given thickness and to predict the optimum particle size of the final product size distribution.

To achieve this purpose it is necessary to solve the following tasks:

– to fulfill the experimental study of hydrodynamics and to determine the design characteristics of the device upper zone (pneumatic classification section);

– to investigate the kinetics of mineral particle enlargement at each granulation stage by coating granule surface with organic substance;

– to develop a mathematical model of the particle encapsulation process in the shelf multistage devices.

4. Experimental research of a mineral fertilizer granule coating with organic substance in a multistage device with suspended layer

To obtain granules with a high content of given size particles it is necessary to carry out granulation and classification processes simultaneously [27], which can be implemented in the shelf multistage apparatus with suspended layer (Fig. 1). A granulator is a box-like structure with a rectangular cross-section with the side ratio of 2:1.

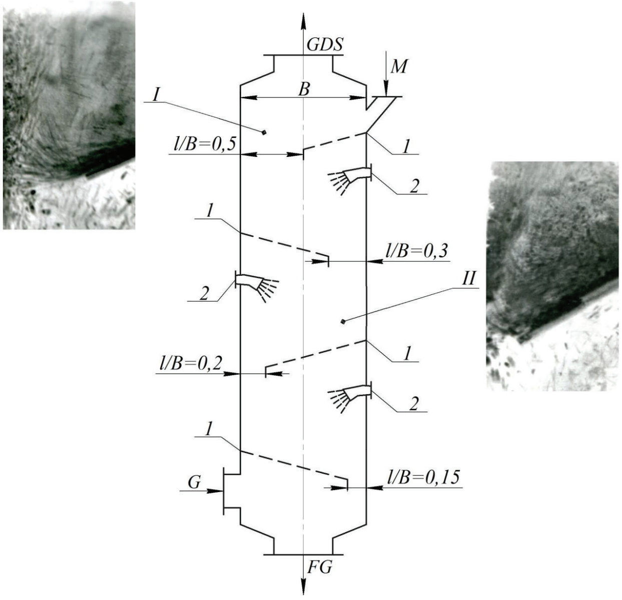

Fig. 1. Multistage granulator with suspended layer: I — classification section; II — granulation section (enlargement of the granules); 1 — perforated shelves; 2 — pneumatic nozzles for spraying the organic substance; M — raw material (mineral fertilizer granules); G — gas; GDS — gas-dispersed substance; FG — finished granules

Operation principle of the apparatus is as follows. The starting fertilizer granules are dosed by the feeder and supplied into the device classification section I where fine particles (less than 1 mm) and crushed granules (fraction 1–1.6 mm) are removed from the material. Now granules free from fine fractions and damaged particles get onto the first stage of the granulation section II, where on the perforated shelf 1 a suspended vortex layer is formed by gas flow introduction into the space between the end of the perforated shell and the apparatus wall. From the top an organic substance is sprayed from a spray nozzle 2.

When introducing the gas flow, which accelerates particle motion in the vortex layer, granule separation takes place: coarser particles enter the layer closer to the end of the perforated shelf 2 and finer ones concentrate on the initial section of the grid. As a result, a residence time of different size particles on a perforated shelf 2 is aligned, which enables to provide uniform coating of the growing granules with organic suspension and, consequently, to increase the homogeneity of the final product size distribution.

As it can be seen from Fig. 1, there are three perforated shelves in the granulation section. Moreover, supplying different amount of suspension on each of them and changing open area of shelves and the distance l between the shelf end and the device wall to create different gas flow rate one can form granules of different size at each shelf contact: finer particles on the upper shelf and coarser granules on the lower one. Lower shelf of the apparatus can also serve as a drying section, where granule drying in the fluidized bed mode takes place.

Experiments were carried out in the apparatus in the form of a vertical channel of rectangular cross section 0.1×0.05 m. Superphosphate granules were used as a starting material. In the first stage of the research it was necessary to obtain the best possible hydrodynamic and design parameters of the pneumatic classification upper section. Inclining shelves were installed in the working volume of the apparatus by the ratio l/B in the range of l/B=1 (free channel) to l/B=0.3. As it can be seen from Fig. 2, entrainment relative value ε has a maximum value for the shelves with the open area of 5 %.

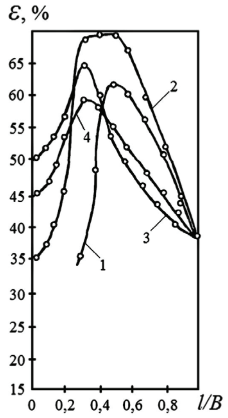

Fig. 2. Influence of the shelf design parameters on the efficiency of removal of the fraction, which is less than 1 mm. Open area of shelves: 1 – 4 – is 0 %, 5 %, 15 % and 30 % respectively. Angle of shelf inclination – 30°. Material – granulated superphosphate. Consumption – 6 kg/(m²·s)

In the granulation section perforated shelves with inclination angle of 30° and open area 15 % are installed. On the first stage the shelf was installed according to the ratio l/B=0.3, on the second one – l/B=0.2 on the third – l/B=0.15 (Fig. 1). These ratios cause gradual reduction of gas flow rate from the upper to the lower stage so that granules which are smaller than a certain size, can not get onto the underlying stage and can be maintained by the gas flow in a suspended state. At the same time, this rate is insufficient to maintain the enlarged granules in suspended state so they get onto the underlying granulation stage. Results of studies on granule enlargement are shown in a histogram of particle size distribution (Fig. 3).

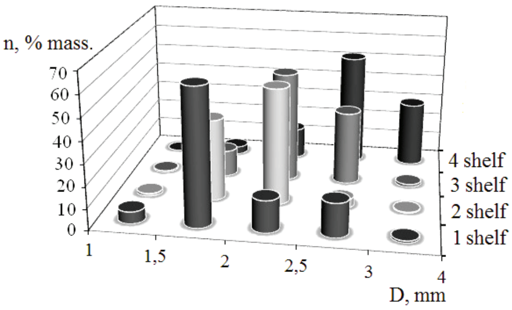

Fig. 3. Histograms of particle size distribution for the granulation process on the separate shelves of the multistage device

As it can be seen from Fig. 3, granules of more or less close-cut fraction are concentrated at each granulation stage of the fluidized bed and the granule size increases from the top shelf to the bottom one.

5. Mathematical model of the granulation kinetics in the shelf multistage device

Classical suspended layer devices, in contrast to multistage devices have well-known calculation methods. The new device design where there is different flow motion needs grounded theoretical description [24].

If one considers the transfer of material flows in the process of granule enlargement on separate stages, under conditions that vary continuously in time, then for the granulation process in three staged apparatus (Fig. 4), one gets the system of equations:

$$\begin{cases} \dfrac{\partial M_1(\tau)}{\partial \tau}\int\limits_0^\infty f_1(D)dD = M_{i-1}\int\limits_0^\infty f_{i-1}(D)dD - M_{i+1}\cdot\theta_{i1}\int\limits_0^\infty f_{i+1}(D)dD, \\ \dfrac{\partial M_2(\tau)}{\partial \tau}\int\limits_0^\infty f_2(D)dD = M_{i-2}\int\limits_0^\infty f_{i-2}(D)dD - M_{i+2}\cdot\theta_{i2}\int\limits_0^\infty f_{i+2}(D)dD, \\ \dfrac{\partial M_3(\tau)}{\partial \tau}\int\limits_0^\infty f_3(D)dD = M_{i-3}\int\limits_0^\infty f_{i-3}(D)dD - M_{i+3}\cdot\theta_{i3}\int\limits_0^\infty f_{i+3}(D)dD, \end{cases} \qquad (6)$$

where M_1, M_2, M_3 – mass of granules on the certain granulation stage kg; τ – time, s; $f_i(D)$ – a function of the granule size distribution in the certain device stage; D – current diameter of the granules, m; θ_i – probability of the granule transition from the upper stage to the lower one.

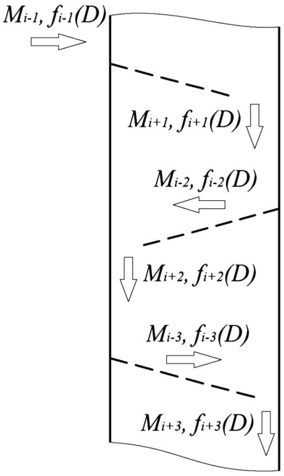

Fig. 4. Calculation diagram of the material movement in the shelf multistage device

Under the matching conditions on the stage boarders the expression looks:

$$M_{i+1} = M_{i-2}, \quad M_{i+2} = M_{i-3};$$

$$f_{i+1}(D) = f_{i-2}(D), \quad f_{i+2}(D) = f_{i-3}(D).$$

Equation (6) shows that granules of the certain granulometric composition get onto each of the stages and leave it after granulation process having more enlarged particles in its composition. The condition for the granule transition from the upper stage onto the lower one is the probability of such transition, as a function of the granule terminal velocity W_1 to the gas flow rate W_2 in the unloading space between the end of the shelf and the device wall:

$$\theta = f\left(\frac{W_1}{W_2}\right). \tag{7}$$

Only granules with the size big enough to overcome the aerodynamic resistance of the gas flow in the unloading space can get onto the lower stage and thus the following condition is observed:

$$\frac{W_1}{W_2} > 1. \tag{8}$$

If the granule size is less than a certain critical value and $W_1 / W_2 < 1$, such granules are weighed with the gas flow, and are carried into the working volume of the same stage for the next granulation process until they reach a critical size and weight sufficient to dip onto the underlying granulation step.

A function of the granule size distribution is expressed as [26]:

$$\frac{\partial f(D)}{\partial \tau} = \operatorname{div}\left(u_T f(D)\right) + \frac{\partial\left(v f(D)\right)}{\partial D} - \frac{\partial f(D)}{\partial G_y}\cdot\frac{dG_y}{d\tau}. \tag{9}$$

Thus, according to the equation (9), the function of changing granule distribution density in size in any local zone of the layer is determined by moving the granules from one point of the apparatus working volume to another one. It takes place because of:

1) forced motion of the particle flow (the first addend takes into account the convective carry out of granules):

$$\operatorname{div}\left(u_T f(D)\right) = \frac{\partial u_{TX} f(D)}{\partial X} + \frac{\partial u_{TY} f(D)}{\partial Y} + \frac{\partial u_{TZ} f(D)}{\partial Z}; \tag{10}$$

2) increase of the granule diameter (the second addend takes into account the rate of granule linear growth);

3) entrainment of fine particles from the layer (third addend).

We neglect the granular composition change by convective transport and entrainment of fine granules due to crashing and attrition. In this case, the equation (9) can be written as:

$$\frac{\partial f(D)}{\partial \tau} = \frac{v\partial\left(f(D)\right)}{\partial D}. \tag{11}$$

For multistage device equation (11) is interpreted as a system of equations of the form:

$$\begin{cases} \dfrac{\partial f_1(D)}{\partial \tau} = \dfrac{v_1 \partial\left(f_1(D)\right)}{\partial D}, \\ \dfrac{\partial f_2(D)}{\partial \tau} = \dfrac{v_2 \partial\left(f_2(D)\right)}{\partial D}, \\ \dfrac{\partial f_3(D)}{\partial \tau} = \dfrac{v_3 \partial\left(f_3(D)\right)}{\partial D}. \end{cases} \tag{12}$$

Laplace transformation is used for the solution of equations (12) in the form of dependencies:

$$D_1 = D_0 + v_1 \cdot \left[\ln f_{i+1}(D) - \ln f_{i-1}(D)\right] \cdot \tau_1; \tag{13}$$

$$D_2 = D_1 + v_2 \cdot \left[\ln f_{i+2}(D) - \ln f_{i-2}(D)\right] \cdot \tau_2; \tag{14}$$

$$D_3 = D_2 + v_3 \cdot \left[\ln f_{i+3}(D) - \ln f_{i-3}(D)\right] \cdot \tau_3. \tag{15}$$

So, values of the granule growth rate at each granulation stage are:

$$v_1 = \frac{dD_1}{d\tau_1} = \frac{D_0 \cdot g_1 \cdot \rho_{GR}}{3 \cdot \rho_S \cdot \sqrt[3]{\left(g_1 \cdot \dfrac{\rho_{GR}}{\rho_S} \cdot \tau_1 + 1\right)^2}}; \tag{16}$$

$$v_2 = \frac{dD_2}{d\tau_2} = \frac{D_1 \cdot g_2 \cdot \rho_{GR}}{3 \cdot \rho_S \cdot \sqrt[3]{\left(g_2 \cdot \dfrac{\rho_{GR}}{\rho_S} \cdot \tau_2 + 1\right)^2}}; \tag{17}$$

$$v_3 = \frac{dD_3}{d\tau_3} = \frac{D_2 \cdot g_3 \cdot \rho_{GR}}{3 \cdot \rho_S \cdot \sqrt[3]{\left(g_3 \cdot \dfrac{\rho_{GR}}{\rho_S} \cdot \tau_3 + 1\right)^2}}, \tag{18}$$

where g_1, g_2, g_3 – specific consumption of the shell material (referred to the mass of the granules) in the certain granulation stage, kg/(kg·s); ρ_{GR} – density of the granule material, kg/m^3; ρ_S – density of the shell material, kg/m^3.

Analysis of the obtained dependences (16)–(18) shows that the granule growth kinetics in the fluidized bed depends on the initial particle size, density and specific consumption of the substance and on the density of the granules themselves.

6. Discussion of the research results of the shelf length influence, and its perforation degree on the granules entrainment process

Naturally-determined increase in fine particles entrainment with decreasing ratio l/B is explained by increase of the flow rate going through the unloading space. Pneumatic classification process of the shelf material with an open area 0 % (solid shelf), and 5 % is more intense than for the shelf with an open area of more than 15 %. This is explained by the fact that at low open area values of the shelf unit gas flow passes predominantly through the unloading space. For larger open area values a significant part of the gas flow goes through the shelf holes, helping to reduce the airflow velocity in the unloading space.

Efficiency of the fine fraction removal (less than 1 mm) in the entrainment, with the ratio l/B=0.5, has a maximum value for the shelf with the open area equal to 5 %. When installing the blind shelf in the working volume of the apparatus (0 % open area), the entire gas flow passes through the unloading space. It causes removal of fine fraction material in this zone. Perforations in the shelf (open area 5 %)

cause a redistribution of the gas flow, directing some part of it through the holes in the shelf. In this case the gas flow rapidly interacts with the material not only in the unloading space, but also on the surface of the shelf. It leads to improving the efficiency of the fine fraction removal from the material by 20 % in the perforated shelf devices, compared to the devices with blind shelves.

A further decrease in efficiency of the fine fraction removal in the entrainment when increasing open area of the inclined shelf to 15 % is caused by enhancement of the gas flow redistribution effect. Gas flow velocity in the unloading space decreases so much that fine fraction removal is insufficient in this zone, as the number of holes eliminates sufficient inter-phase contact. Such decrease in the fine fraction removal efficiency leads to a reduction of costs needed for cleaning the exhaust gas from dust.

In the variation range of the ratio l/B, corresponding to the increase in the entrainment efficiency of the fine fraction, the material is processed in the apparatus in the "gravitational falling layer" mode (Fig. 1, Section I). In this case, energy of the rising gas flow is sufficient to provide effective removal of small particles from a thin layer of material that is weighed on the apparatus wall surface in the unloading zone. A decrease in the ratio of l/B below 0.3 for perforated shelves reduces the removal efficiency of the fine fraction in the entrainment. It is because there is a lack of place for the particle circulation movement in the working volume of the device (Fig. 1, Section II). Gas flow energy is insufficient to remove small components from the material layer in an effective way. However, active influence of the gas flow, which is a part of a suspended layer of the processed material, increases the value of heat and mass transfer coefficients and, consequently, the efficiency of the reviewed processes, including granulation.

7. Conclusions

1. Having fulfilled the experiments one defined the design features of the pneumatic classification section of the multistage device namely for the shelves with open area equal to 5 % which provide maximal efficiency of the fine fraction (up to 1 mm) entrainment.

2. One experimentally studied the kinetics of mineral granules enlargement during their encapsulation with organic substance. It is proved that on each granulation stage granules of a rather narrow-cut fraction are concentrated in the fluidized bed. Moreover, supplying different material quantity on each of the shelves and changing the shelf open area and the gap between the end of the shelf and the apparatus wall, it is possible to form granules of various sizes on each separate stage: from a small (on the top shelf) to larger (on the lower shelf).

3. The resulting model is characterized by a cell structure in which the material is represented as divided into a number of serially connected zones, wherein different granulation modes are implemented.

Gratitude

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