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SIMULATION OF HYDRODYNAMICS IN GAS DISTRIBUTION DEVICES FOR NON-HOMOGENEOUS MODE OF FLUIDIZATION

An increase in the intensity of diffusion-controlled processes during granulation is provided by apparatuses with non-homogeneous fluidization, the hydrodynamics of which significantly depends on the structural features of the granulator chamber and the gas distributing device (GDD). The main problem is the formation of stagnant zones on the working surface of GDD, which, when supplying a coolant with temperature that exceeds the melting point of granules, leads to the melting of solids and the termination of the process.

In this work, the simulation of hydrodynamics in the granulator chamber was carried out using SolidWorks 2022 SP2 for 4 types of gas distribution devices (GDD) of different configurations with different values of the cross-section coefficient of GDD.

The analysis of the simulation results shows that the most significant influence on the hydrodynamic activity index near the surface of GDD i_{ha} has the cross-section coefficient of GDD φ, since even an insignificant increase in the value of φ from 3.0 to 3.5% leads to a significant decrease in the hydrodynamic activity index i_{ha} by at least 1.4 times for all considered types of GDD. The simulation of hydrodynamics was carried out without taking into account the presence of solid granular material in the granulator chamber and near the surface of GDD plate.

Keywords: *fluidization, granulation, hydrodynamics, gas distribution device, heat transfer, mass transfer, volumetric mixing, jet-pulsating fluidization.*

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Formulation of the problem. The intensification of transfer processes during the dehydration and granulation of liquid multicomponent systems containing components of mineral and organic origin using the fluidization technique significantly depends on the method of interaction of the gas coolant and the granular material. In general, the interaction between the gas coolant and the granular material depends significantly on the design of the gas distribution devices (GDD). However, when supplying a coolant with a temperature exceeding the melting point temperature of thermolabile components, there is a risk of the formation of material melting zones in the presence of stagnant zones on the surface of the gas distribution device (GDD), therefore, the study of methods of supplying the gas coolant through the gas distribution device (GDD) to the fluidized bed during dehydration and granulation processes is relevant.

Analysis of previous studies. A general scientific problem is to ensure a stable granulation process in a fluidized bed with intensive three-dimensional movement with mixing of solid particles at speeds close to the pneumatic transport mode. In the literature, the main attention is paid to the gushing mode of fluidization with a large opening angle of the granulator chamber (*ProCell* technology) [1], application of *Wurster* technology with directed upward movement of the material through the central part of the granulator chamber [2-4] and vortex granulators [5]. However, the application of the proposed technological solutions limits the contact surface of solid particles with the solution in the irrigation zone, also the method of supplying the liquid phase is possible only when using homogeneous systems and makes it impossible to use heterogeneous suspensions. The main disadvantage of hydrodynamic modes when applying the fluidization technologies described in works [1-5] is the absence of a pulsating mode of fluidization, in which the relative velocity is higher and, accordingly, the thickness of the diffusion layer on the surface of the granular material is lower, which increases the efficiency of mass transfer process.

In work [6] a perforated plate with round holes and vertical partitions along the device is used as a gas distributing device (GDD). Vertical partitions divide the apparatus into several zones: zone of material loading, irrigation zone, drying zone and material unloading zone. The rectangular profile of the intersection of the zone between the partitions provokes the emergence of stagnant zones and clogging of the gas distributing device (GDD) at the junctions with the partitions. Another disadvantage is the longitudinal movement of the material. To adjust the moisture content of the final product, it is necessary to change the height of the partition, which complicates the process and requires a complete stop of the apparatus.

At work [7] for the production of nanoagglomerates, a stirrer and vibrating supports are used for mixing. Experimental studies have shown that the use of mechanical mixing of the lower bed of solid material and vibrational mixing of the entire material allows granulation using fluidization in systems with small porosity, namely 0.7÷0.8. The design has moving parts that update the contact surface of the phases and move the medium along the height of the device. Considering the characteristics of the starting material, low reliability of the equipment is obvious for granulation due to high wear and tear of moving parts and seals, as well as the risk of contamination of the material with grease.

By the authors [8] the design with inclined planes that form a plate of triangular section with a central hole for irrigation is presented. The plate is fixed on hinges, which allows it to move under the pressure of the liquefying agent and reduce stagnant zones, but makes it impossible to mix the material (volumatric mixing) due to the absence of pulsation devices. Pulsations are performed in the form of a change in air pressure, which makes it difficult to regulate the process and requires continuous control of the process to minimize the risk of lying down the fluidized bed.

The processes of heat and mass transfer in a fluidized bed during the formation of large gas bubbles were considered in detail in the work [9]. The attempts to increase the effectiveness of diffusion-controlled processes during spray granulation in a fluidized bed are considered in the work [10]. In this paper is proposed the method for improving fluidization of nanoparticles by combining vibration and mixing. At the same time, the quality of fluidization improves significantly, the system enters a fluidized state at a gas velocity that is significantly lower than under normal conditions.

According to the results of studies of the phenomenon of segregation and distribution of the formed agglomerates, which lead to the formation of stagnation zones in the apparatus, in order to reduce the risk of formation of stagnation zones on the working surfaces of gas distributing device (GDD), it is proposed to apply vibrations to the entire apparatus. This leads to an increase in energy consumption and negatively affects the mechanical properties of the room where the industrial equipment is located [10].

Thus, an unsolved part of the scientific problem is the formation of stagnant zones on the working surfaces of gas distribution devices, which in published works propose to be eliminated only with the use of additional elements that require additional energy consumption and reduce the reliability and durability of the equipment without intermediate maintenance of its structural components.

The purpose of the article is the analysis and systematization of data on the effect of the gas distributing device (GDD) design on the granulation process in the conditions of the jet-pulsating mode of fluidization to ensure a high-quality of hydrodynamics mode.

Presentation of the main material. Increasing the efficiency of processes in the production of granulated humic organic-mineral fertilizers can be achieved by applying the fluidized bed technique [11-20]. By the authors [20-30] it is theoretically substantiated and experimentally proven that the intensification of heat and mass transfer processes during the granulation of liquid systems can be achieved by implementing the jet-pulsating mode of fluidization in the self-oscillating mode [20-30] without the use of any mechanical pulsators.

A feature of granulation processes in a fluidized bed is the provision of the necessary phase contact surface for stable kinetics, which determines the height of bed the granular solid particles in the apparatus.

Thus, the mass productivity of the device based on evaporated moisture will be determined as:

$$M = \beta \Delta P^{*}_{mass\ transfere} F_{mass\ transfere} \qquad (1)$$

where β – is the mass transfer coefficient, kg/(m^{2}s); $F_{mass\ transfere}$ – is the surface of the granular material in the fluidized bed, m^2; $\Delta P^{*}_{mass\ transfere}$ – is the partial pressure difference between the moistened surface of the solid granule and the gas coolant, Pa:

$$\Delta P^{*}_{mass\ transfere} = \Delta P^{*}_{saturation\ state} - P^{*}_{apparatus} \qquad (2)$$

where $\Delta P^{*}_{saturation\,state}$ – is pressure of saturation state of gas, Pa; $P^{*}_{apparatus}$ – is the work pressure in apparatus, Pa.

Then the required surface of the particles in the fluidized bed from equation (1) will be determined as:

$$F_{mass\ transfere} = \frac{M}{\beta \Delta P^{*}_{mass\ transfere}} \tag{3}$$

On the other hand, the total surface of the fluidized bed in the apparatus can be calculated using the expression:

$$F_{mass\ transfere} = \frac{6\Delta P_{bed} S_{apparatus}}{D_e \rho_{solids} g} \tag{4}$$

where ΔP_{bed} – is the hydraulic resistance of the fluidized bed of granular solid material in the apparatus, Pa; $S_{apparatus}$ – is the cross-sectional area of the apparatus in zone of the gas distributing device (GDD), m_2; D_e – is the equivalent diameter of the particles in fluidized bed, m; g – acceleration of gravity, m/s^2; ρ_{solids} – is the density of solid particles, kg/m^3.

The hydraulic resistance of the fluidized bed is determined by the expression:

$$\Delta P_{bed} = H_0(1-\varepsilon_0)\rho_{solids} g \tag{5}$$

where H_0 – is the height of the stationary bed of solid particles, m; ε_0 – is the porosity of the fixed bed of solid particles (ε_0= 0.4).

After substituting the expression (5) into equation (4) and solving it with relative to H_0 obtain:

$$H_0 = \frac{F_{mass\ transfere} D_e}{6S_{apparatus}(1-\varepsilon_0)} \tag{6}$$

In work [28] it was established that during experiments on dehydration and granulation of multicomponent liquid systems with a solids content of 40% (wt.) the height of the stationary bed of solid granular material H_0= 0.320 mm. The ratio of the gas jet height in the right slit of gas distributing device (GDD) z_f to the stationary bed height H_0 is:

$$\frac{z_f}{H_0} \approx 0.33 \tag{7}$$

That is, at a height of 0.33 H_0, according to the theory of the movement of a continuous medium through a layer of granular material, a gas bubble will form in the middle of the fluidized bed [28].

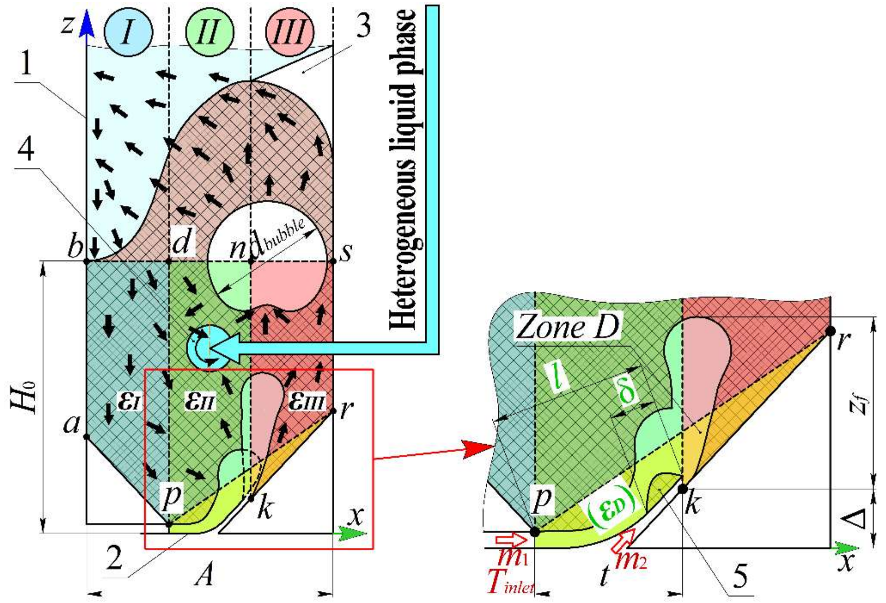
In the works [20-30] the principles of the interaction of the gaseous coolant and solid granular material in the fluidized bed apparatus are formulated, which are aimed at increasing the efficiency of transfer processes during the dehydration and granulation of multicomponent heterogeneous liquid systems with the production of granulated organic-mineral fertilizers with specified properties when using non-homogeneous jet-pulsating fluidization in the self-oscillating mode.

In the dissertation [27] the peculiarity of this hydrodynamic mode is substantiated, which consists in the fact that the liquefaction agent is supplied into the granulator chamber equipped with a gas distribution device (GDD) of slot type 2 (in the lower part) through two slits – points p and k, Fig. 1, in the horizontal (m_1) and vertical (m_2) directions respectively.

The distance between the slits t is determined by the horizontal range of the gas jet h_{hor}, and the shape of the working surface of the gas distributing device (GDD) plate must correspond to its configuration. This necessitates the location of the second slit (point k) at a height Δ relative to the first slit (point p). At the point k, the two jets merge in the self-oscillating mode, which leads to the formation of a combined jet with the height of the breakdown height z_f. Conventional planes drawn through points p and k divide the device camera into three zones of equal width A/3.

To implement this principle by the authors [20-30] for the first time the supplying of a liquefying agent (heat carrier) in mutually perpendicular planes was proposed, Fig. 1. In the left slit, the flow m_1 is supplied perpendicular to the vector of action of gravity force, the jet in the right slit m_2 is supplied almost opposite to the vector of action of gravity. Thus, jet m_1 ensures the movement of solid granular material in the mode of pneumatic transport along the working surface of the gas distributing device (GDD) plate, and jet m_2 – the local gushing mode of fluidization. The kinetic energy of jet m_1 must be sufficient so that at point k it merges with jet m_2 to form at a height $\Delta + z_f$ a gas bubble of intense filling, which is necessary to move a significant volume of solid granular material beyond the initial bed height H_0 [23-28].

Previous studies [15-24] it was established that the height of the stationary bed of solid material H_0 = 0.32 m (determined experimentally during granulation under mass transfer conditions) is three times greater than the breakdown height of the gas jet $z_f/H_0 \leq 0.33$. Therefore, a gas bubble begins to form cyclically at the top of the torch, which, upon exiting the bed of solid material, causes an inertial pulsating emission of granular material into the space above the initial bed of solid material of zones *II* and *III*. After contact with the guiding insert 3, the solid particles move to zone *I*, after which they quickly return to the initial volume of the bed of solid material – this is the end of the cycle.



*1 – granulator chamber; 2 – slit type GDD; 3 – guiding insert; 4 – mechanical disperser;
5 – zone of slowly moving granules*

Fig. 1 – Model of phase interaction in non-homogeneous jet-pulsating mode of fluidization

In the case when the energy of the horizontal jet at a point *p*, Fig. 1, moving over the working surface of the gas distributing device (GDD) will not be enough – a stagnation zone is formed in zone *D*, which has an extremely negative effect on the reliability of the apparatus and, accordingly, on the kinetics of the granulation process. In this regard, it is proposed to determine the quality of hydrodynamics during non-homogeneous fluidization by the value of the porosity in the zone D – $\varepsilon_D \geq [\varepsilon_D] = 0.85$ and the length of the low-motion zone of the material on the gas distributing device (GDD) surface ($\delta \to 0$).

To evaluate the hydrodynamics, the Tagutti method was used, which allows to calculate the function of the loss of the quality of the hydrodynamics [26-28]:

$$L_D = K_1\left(\left[\varepsilon_D\right]-\varepsilon_{D_i}\right)^2 + K_2\left(\frac{[\delta]-\delta_i}{l}\right)^2 \tag{8}$$

where K_1 and K_2 – are weighting factors ($K_1 = 0.3$ and $K_2 = 0.7$); $[\varepsilon_D] = 0.85$ – the specified value of the porosity of the bed of solid material in the zone D; $[\delta] = 0.01l$, m; l – is the chord length of the gas distributing device (GDD) plate, m.

Taking into account the cyclical self-oscillating nature of heterogeneous jet-pulsating mode of fluidization, it is proposed to determine the dynamic quality index of hydrodynamics as the ratio of $\tau_{quality}$ – the time in the cycle during which the value of the quality loss function $L_D \leq 0.1$ is ensured to the total time of the pulsation cycle – τ_{cycle} [26-28]:

$$i_{quality} = \frac{\tau_{quality}}{\tau_{cycle}} \tag{9}$$

The peculiarity of the method is that the porosity of the bed of solid material was determined relative to the initial volume of the bed of solid material *absrkp*, Fig. 2, by zones (*I*, *II* and *III*). It is obvious that at the velocity of the heat carrier in the slits of gas distributing device (GDD), which provides $i_{quality} \to 1.0$, the porosity of the bed of solid material in zones *I*÷*III* will be $\varepsilon_{III(\min)} > \varepsilon_{II(\min)} > \varepsilon_I = \varepsilon_0$, which is related to the peculiarities of the formation of gas jets [26-28].

Thus, at the first stage of the cycle, during the time τ_1, at the height $z_f+\Delta$, a gas bubble is formed, Fig. 2 b, and reaching its critical size. The second stage (τ_2) is the pulsating release of a significant mass of granular material from zones *III* and *II* into the space above the initial bed of solid material and its movement to zone *I*, Fig. 2 c, one or several bubbles, until the residual height of granular material in zone *III* $H_{residual(III)} \leq z_f+\Delta$. Then there is an intensive movement of the bed of solid material of granular material from the space above the initial bed of solid material of zone *I* into the formed voids in zones *II* and *III* and the system returns to the initial state of equilibrium, Fig. 2 a, with countercurrent movement of solid and gas phases (stage 3) – (τ_3). That is, the duration of one cycle of pulsations is, s: $\tau_{cycle} = \tau_1+\tau_2+\tau_3$ [26-28]. This hydrodynamic mode is characterized by a non-linear change in the height of the bed of solid material up to $1.7H_0 \div 2.0H_0$ in zone *I* and the heterogeneity of its porosity (in a fixed volume *absrkp*), which in zone *I* remains constant $\varepsilon_I = \varepsilon_0 = 0.4$ and in zones *II* and *III* can vary cyclically from $\varepsilon_{II(\min)}$ to $\varepsilon_{II(\max)} = 1.5\varepsilon_0$ and from $\varepsilon_{III(\min)}$ to $\varepsilon_{III(\max)} = 2\varepsilon_0$.

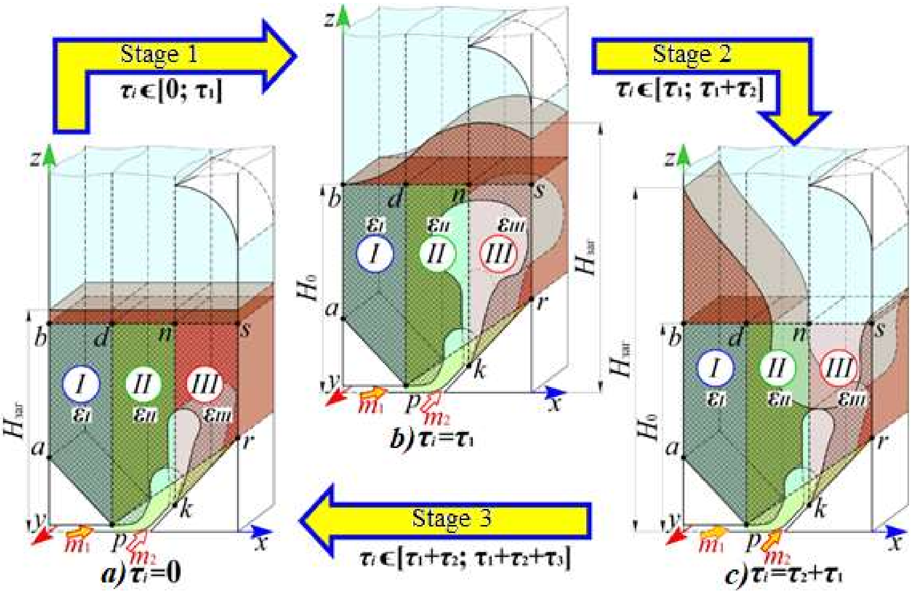
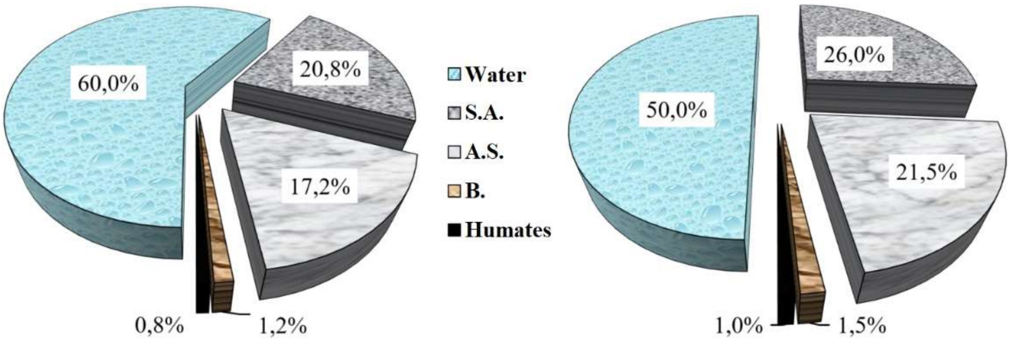


Fig. 2 – Physical model of non-homogeneous jet-pulsating fluidization in self-oscillating mode

From a large number of provided experimental studies of the kinetics of the granulation process of organic-mineral fertilizers [20-30] the results of experiments on the production of organic-mineral fertilizers from the dehydration of aqueous solutions of sunflower ash (S.A.) and ammonium sulfate (A.S.) with admixtures of additional substances, the composition of which are given on Fig. 3 [27, 28].



***a)** experiments 1 and 2 (D1, D2)* ***b)** experiments 3 and 4 (D3, D4)*

Fig. 3 – Composition of the composite liquid phase (wt.%)

During the experiments, a monotonous growth of the equivalent diameter was observed: experiment No.1 – from 1.85 mm to 2.15 mm, experiment No.2 – from 2.46 mm to 2.9 mm, experiment No.3 – from 2.86 mm to

3.58 mm, experiment No.4 – from 3.18 mm to 3.58 mm with an average growth rate of solid granulated material: λ_{D1}=0.182 mm/h, λ_{D2}=0.243 mm/h, λ_{D3}=0.297 mm/h, λ_{D4}=0.301 mm/h, which indicates positive dynamic granulation kinetics.

The temperature of the coolant at the entrance to the granulator was T_{inlet}=180°C, and the bed of solid material temperature was maintained within $T_{bed} = 94 \div 96 \pm 2$°C by feeding the liquid phase into the middle of the fluidized bed using a mechanical disperser. The temperature of the bed of solid material was determined by the physical and chemical properties of the components contained in the working solution, in particular, ammonium sulfate.

Superimposition of the temperature field on the hydrodynamics of non-homogeneous jet-pulsating fluidization in the self-oscillating mode at the third stage of the cycle during a stable granulation process with a coefficient of granulation ψ>95% is shown on Fig. 4 [27, 28].

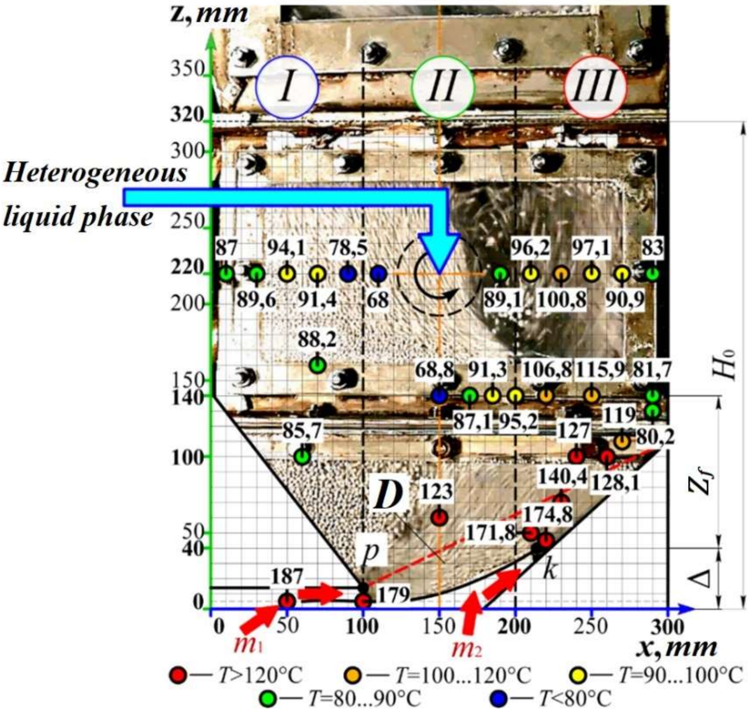


Fig. 4 – Superposition of the temperature field on the hydrodynamics of non-homogeneous jet-pulsating fluidization in the self-oscillating mode at the third stage of the cycle at $D_e \leq 4.0$ mm (x = 250 mm; y = 55 mm; z = 220 mm).

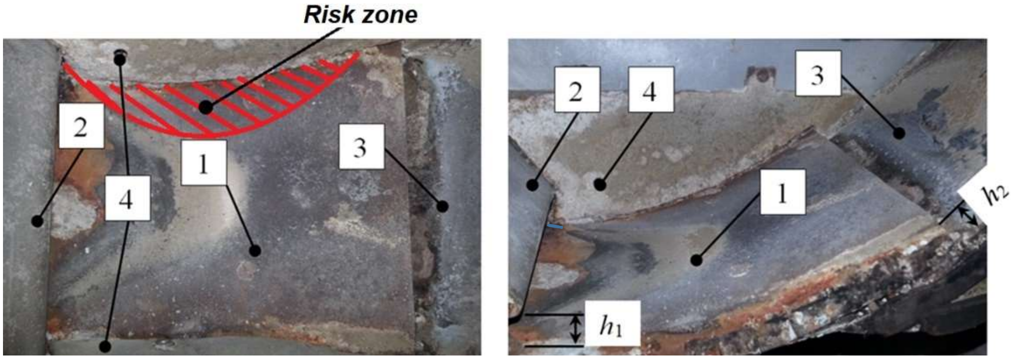
The analysis of the parameters of the temperature field shows that with such a hydrodynamic mode, the temperature of the dispersed solid phase in zone *D* when a horizontal jet m_1 with a temperature of 180°C, Fig. 4, varies from 179ºC to 171.8ºC along the working surface of GDD type 2, which significantly exceeds the melting point of ammonium sulfate and the formation of stagnant zones on the surface of gas distributing device (GDD) will lead to melting of the granules.

At point *k*, a gushing jet m_2 with a temperature of 174.8°C is introduced. The temperature of the combined flows at the end of zone *D*, at a height of 100 mm, decreases to 128 °C, which indicates intensive heat exchange, Fig. 4, due to the active local circulation of solid particles not only in zone *D*, but also in the adjacent area. The same active local circulation of granular material in zones *II* and *III* at a bed of solid material height of 140÷320 mm, in which the irrigation zone is located, is carried out at the expense of a high-temperature coolant. This contributes to the preservation of the driving force for heat and mass exchange. And the global movement of material from zones *II* and *III*, first of all, provides effective renewal of the surface of contact of phases. At the same time, 43÷45% of the mass of the bed of solid material moves beyond the initial bed of solid material into zone *I*, which leads to a twofold increase in the hydrostatic pressure at point *p*, Fig. 4. This will lead to an instant decrease in speed in the right slot and increases the risk of formation of stagnant zones.

As a result, the specific load of the surface of the bed of solid material with moisture was a_f =0.6÷0.7 kg$_{moisture}$/(m^{2}h), which is 1.5 times more than when using the usual bubbling mode – a_f=0.35 kg$_{moisture}$/(m^{2}h) in similar conditions [27, 28].

Thus, the success of the implementation of such an innovative process is determined by the method of introducing the gas coolant into the device, which is implemented by the gas distributing device (GDD) design and significantly affects the kinetics of the dehydration and granulation processes and the reliability of the device as a whole.

On Fig. 5 are given the photographs of the working plate of GDD type 2, which clearly show the limits of action of the active jet of the coolant depending on the volume flow rate of the coolant associated with an increase in the equivalent diameter of the granules in the bed of solid material.



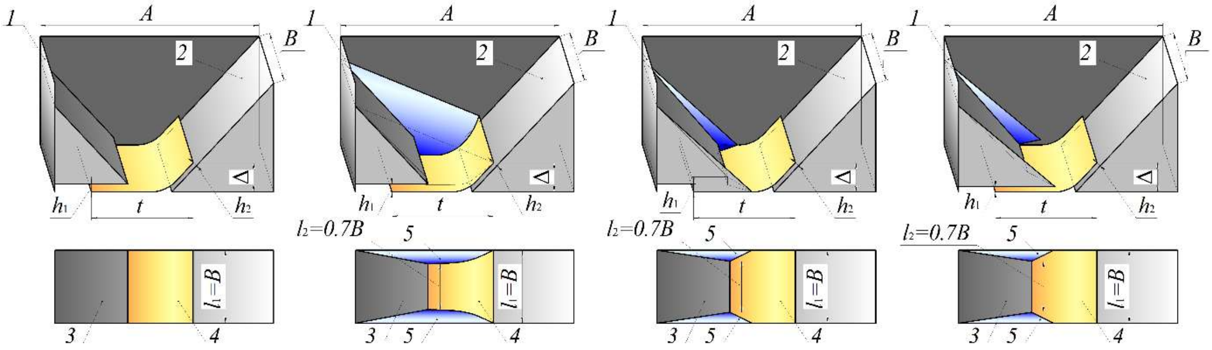
a) *Top view* ***b)*** *Frontal view*

1 – plate; 2, 3 – grates; 4 – narrowing inserts

Fig. 5 – Photo of working surfaces of the GDD type 2 after granulation of organic-mineral fertilizers

The plot of the real velocities of the active jet of the right slit of GDD type 2 resembles the form of a normal distribution. At the same time, stagnant zones may form near the side vertical walls on the surface of the gas distributing device (GDD), which will not allow the temperature of the coolant at the entrance to rise up to 250÷350°C.

Verification of these assumptions was carried out during the simulation modeling of four types of gas distributing devices (GDD), designed to implement a non-homogeneous jet-pulsating hydrodynamics mode of fluidization: GDD types 1 and 2 [28], as well as GDD types 3 and 4, the schematic three-dimensional image of which are shown on Fig. 6.



a) *GDD type 1 (φ1=6%)* ***b)*** *GDD type 2 (φ2=4.9%)* ***c)*** *GDD type 3 (φ3=3%)* ***d)*** *GDD type 4 (φ1=4%)*

1 – device body; 2 – right wedge; 3 – left wedge; 4 –horizontal surface of the working plate of GDD; 5 –narrowing inserts

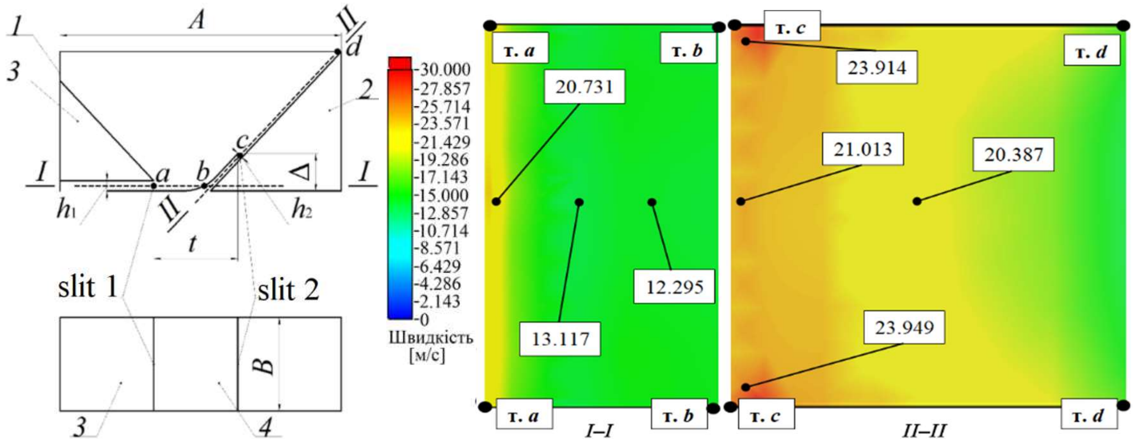
Fig. 6 – Designs of gas distributing devices (GDD)

Determination of the effect of the design features of GDD type 1 and GDD type 2 on the velocity of the gas coolant on the surface of plates 4 and the right wedge 2, Fig. 6, was obtained using the software environment

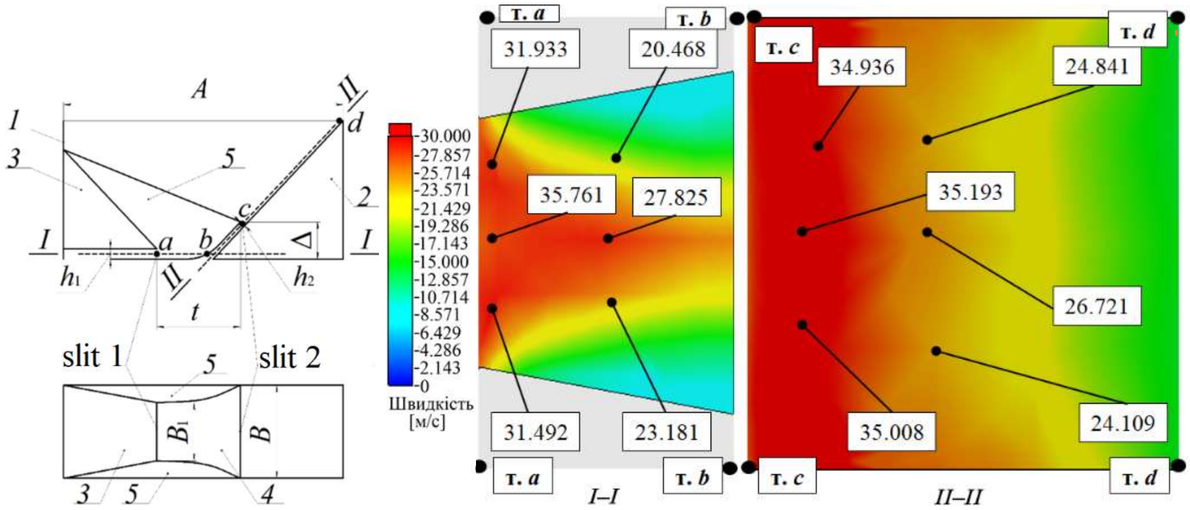
SolidWorks in planes *I–I* along the central axis of slit 1 (0.5h_1), as well as *II–II* along the central axis of slit 2 (0.5h_2), Fig.7.

The result of the simulation is the velocity graphs on the working sections *ab* and *cd*, Fig.7, GDD type 1 and GDD type 2 with cross-section coefficients of 6% and 4.9%, respectively, which indicate that due to the installation of tapered inserts in GDD type 2, a local speed increase of 1.8 times was achieved,Fig. 7 b, compared to GDD type 1,Fig. 7 a.

The analysis of the graphs shows that on the horizontal plate of GDD type 1, the gas velocity does not exceed 13 m/s, which is significantly less than the minimum velocity of 25 m/s,Fig. 7 a. Reducing the cross-section ratio from 6% to 4.9% in GDD type 2 made it possible to increase the gas velocity, while a fairly large zone with a speed of 27 m/s was fixed on the horizontal plate of GDD type 2. Fig. 7 b. That is, the risk of formation of stagnation zones on the horizontal surface of the gas distributing device (GDD) plate is practically eliminated at gas velocities of more than 25 m/s, which is confirmed by the results of the experiment, Fig. 5 [27, 28].



a) GDD type 1 (φ1=6%)



b) GDD type 2 (φ2=4.9%)

Fig. 7 – Plots of liquefying agent velocities on the working surfaces of GDD type 1 and GDD type 2 at V_{sec}=0.03736 m³/s (*SolidWorks*)

The movement of the dispersion along the working surface of the gas distributing device (GDD) in the horizontal direction is considered as pneumatic transport, for which it is recommended that for particles with a size of 2.5 mm and a density of 850 kg/m^3, the gas speed should be twice the removal speed. We assume the first operating speed of 25 m/s, and taking into account the use of a high-temperature coolant, we increase this value to 35 m/s.

To determine the influence of the gas distributing device (GDD) design and the cross-section coefficient on the creation of zones with speeds of at least 25 m/s and 35 m/s on the surface of the working plate, modeling in the environment was applied *SolidWorks* 2022 SP2.

Simulation modeling was carried out for 4 types of gas distributing devices (GDD), Fig.6, when rarefaction – P=4 kPa and volumetric gas flow rate V_{sec}=0.043 m^3/s at different values of the coefficient of the cross-section coefficient of gas distributing device (GDD) φ=3÷4%

Flow simulation results for GDD type 3 and GDD type 4 in planes *I-I* and *II-II*, Fig. 8, given in the form of the velocity field of the gas liquefying agent on Fig. 9 and fig. 10.

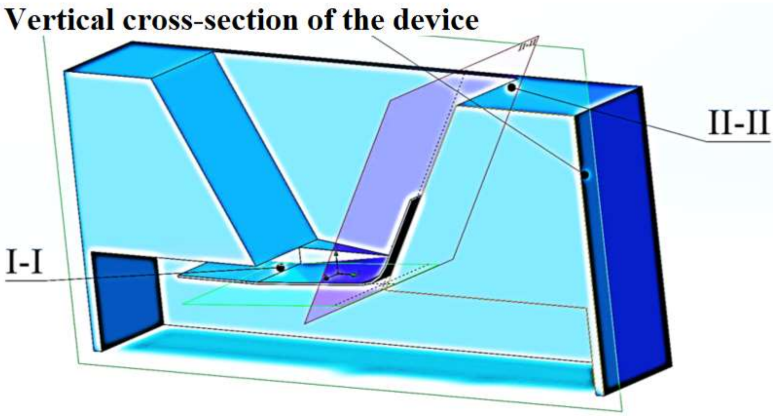
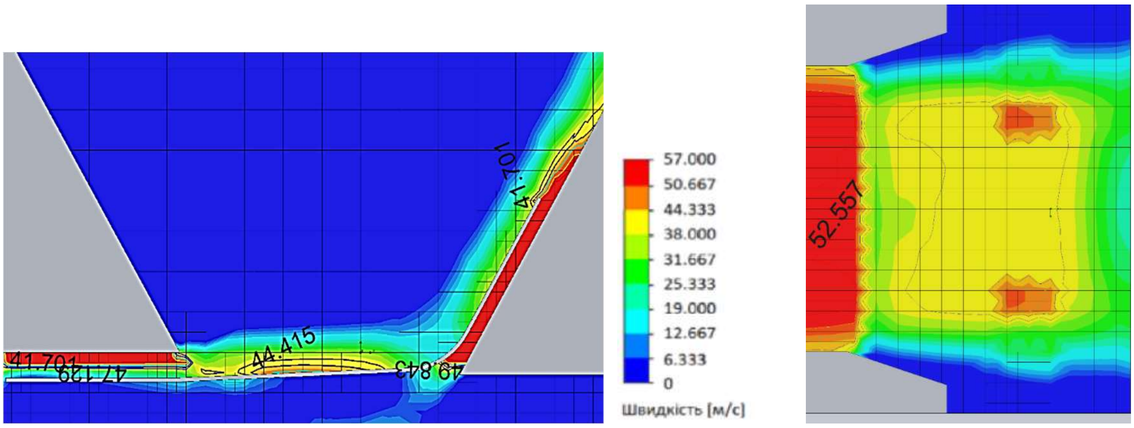
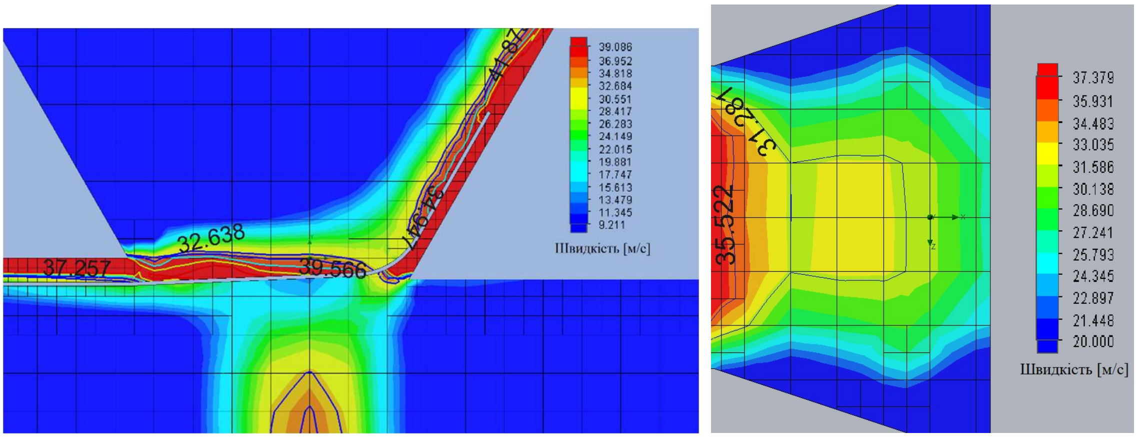


Fig. 8 – Schematic of the arrangement of planes for determining velocity plots in GDD



***a)** vertical cross-sectional plane (II–II, Fig. 8)* ***b)** horizontal cross-sectional plane (I–I, Fig. 8)*

Fig. 9 – Velocity fields for GDD type 3 (P=4 kPa; V_{sec}=0.043 m^3/s; φ = 3%)



***a)** vertical cross-sectional plane (II–II, Fig. 8)* ***b)** horizontal cross-sectional plane (I–I, Fig. 8)*

Fig. 10 – Velocity fields for GDD type 4 (P=4 kPa; V_{sec}=0.043 m^3/s; φ = 3%)

The quality of the hydrodynamic mode on the horizontal surface of the gas distributing device (GDD) was assessed using the index of hydrodynamic activity:

$$i_{ha1} = F_{25}/\ F_{total} \quad (10) \qquad\qquad i_{ha2} = F_{35}/\ F_{total} \quad (11)$$

where F_{25} and F_{35} – the area on the working horizontal plate of gas distributing device (GDD), in which speeds, respectively, are at least 25 m/s and 35 m/s, m^2; F_{total} – is the total area of the horizontal working plate, m^2.

In Table 1 the results of virtual research are presented in the form of the hydrodynamic activity index i_{ha1} – the ratio of the area where the gas velocity exceeds 25 m/s to the total area of the horizontal part of the gas distributing device (GDD) working plate. The area was measured using a dimensional grid as shown on Fig. 8 with an accuracy of 2 mm.

Table 1 – Results of determining the index of hydrodynamic activity i_{ha1}=F_{25}/F_{total}

Type of gas distributing device	φ, %		
	3.0	3.5	4.0
GDD type 1	0.92	0.87	0.67
GDD type 2	0.97	0.9	0.76
GDD type 3	0.96	0.89	0.8
GDD type 4	0.94	0.88	0.77

Similarly, the index of hydrodynamic activity i_2 was determined to determine the part of the surface on which the velocity of the gas coolant is greater than 35 m/s at different values of the cross-section coefficient. The dependence of the index of hydrodynamic activity on the cross-section coefficient of the slits of gas distribution device (GDD) is shown on Fig. 11.

Conclusions. The analysis of the simulation results shows that the most significant effect is on the index of hydrodynamic activity i_{ha2} has a cross-section coefficient φ. At values of cross-section coefficient φ= 3% for GDD type 2, GDD type 3 and GDD type 4 the value of the index of hydrodynamic activity i_{ha2}= 0.89÷0.96.

For GDD type 1 the index of hydrodynamic activity is 2 times smaller. That is, for real conditions, the risk of formation of stagnant zones increases.

An increase in the coefficient of the cross-section φ even up to 3.5% leads to a decrease in the hydrodynamic activity index by 1.4 times for GDD type 2 and GDD type 3. For GDD type 1 and GDD type 4, the decrease is even greater, Fig. 11.

Finally, these results will be verified experimentally during the granulation process on an experimental plant, and can also be used in the design of a slit-type gas distributing device (GDD) for an industrial apparatus. In addition, a decrease in the coefficient of the cross-section will lead to an increase in the hydraulic resistance of the gas distributing device (GDD), and accordingly, the energy consumption. It should also be taken into account that the simulation of hydrodynamics was carried out without taking into account the presence of solid granular material in the granulator chamber and, accordingly, near the surface of the working plate of the gas distributing device (GDD).

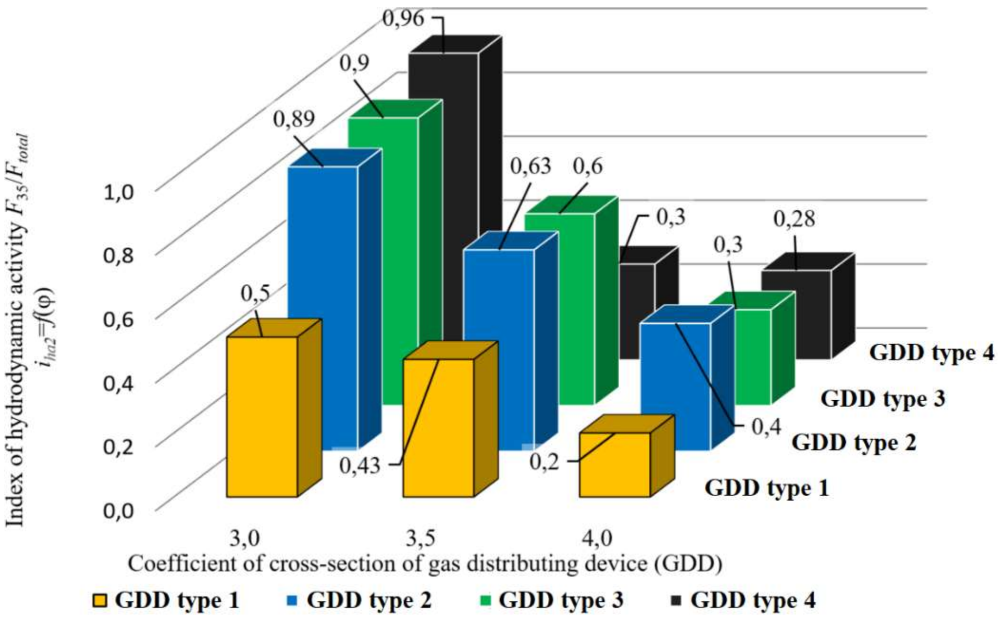


Fig. 11 – Dependence of the hydrodynamic activity index on the GDD cross-section coefficient– $i_{ha2}=f(\varphi)$

Prospects for further research. Thus, the development of an innovative technology of the process of dehydration and granulation in a fluidized bed is impossible without researching the hydrodynamics of flows on the working surfaces of a gas distribution device of the slit type for the implementation of a non-homogeneous jet-pulsating mode of fluidization. Therefore, in the future, it is planned to check the conformity of the results obtained during modeling on a real experimental installation.

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МОДЕЛЮВАННЯ ГІДРОДИНАМІКИ В ГАЗОРОЗПОДІЛЬНИХ ПРИСТРОЯХ ДЛЯ НЕОДНОРІДНОГО ПСЕВДОЗРІДЖЕННЯ

Для реалізації механізму грануляції органо-мінеральних добрив із пошаровою структурою необхідно забезпечити інтенсивну циркуляцію зернистого матеріалу з поступовим проходженням через відповідні технологічні зони апарата: зону інтенсивного теплообміну, зону висхідного потоку, зону зрошення, та зону низхідного руху – релаксації, при ефективність процесу визначається топло- і масообмінних процесів. Підвищення інтенсивності дифузійно-контрольованих процесів при грануляції забезпечується апаратах із неоднорідним псевдозрідженням, гідродинаміка якого суттєво залежить від конструктивних особливостей елементів гранулятора: камери гранулятора та газорозподільного пристрою (ГРП). Невирішеною науковою проблемою є утворення застійних зон на робочій поверхні ГРП, що при підведенні теплоносія, температура якого перевищує температуру плавлення гранул призводить до оплавлення матеріалу та припинення процесу, тому дослідження впливу конструкції ГРП на забезпечення умов якісного неоднорідного псевдозрідження є надзвичайно актуальним.

Метою роботи є аналіз та систематизація даних щодо впливу конструкції газорозподільних пристроїв (ГРП) на процес грануляції в умовах струменево-пульсаційного режиму псевдозрідження для забезпечення якісного гідродинамічного режиму.

Для досягнення поставленої мети у даній роботі проведено моделювання гідродинаміки у камері гранулятора за допомогою Solid SolidWorks 2022 SP2 для 4 типів газорозподільних пристроїв різної конфігурації із різними значеннями коефіцієнта живого перерізу.

Аналіз результатів моделювання показує, що найбільш суттєвий вплив на індекс гідродинамічної активності біля робочої поверхні ГРП i_{ha} має коефіцієнт живого перерізу ГРП φ, оскільки навіть незначене збільшення значення φ від 3.0 до 3.5% призводить до значного зниження індексу гідродинамічної активності i_{ha} мінімум в 1.4 рази для всіх конструкцій ГРП. Однак зменшення коефіцієнта живого перерізу призводить до підвищення гідравлічного опору ГРП, і відповідно енерговитрат тому необхідно також враховувати, що моделювання гідродинаміки проводилось без врахування наявності твердого зернистого матеріалу в камері гранулятора і, відповідно, біля поверхні робочої пластини ГРП. Одержані результати можуть бути використані при проектуванні ГРП щілинного типу для промислового апарата.

Ключові слова: *псевдозрідження, грануляція, гідродинаміка, газорозподільний пристрій, теплообмін, масообмін, об'ємне перемішування, струменево-пульсаційне псевдозрідження.*

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