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MODELING OF HEAT EXCHANGEMENT IN FLUIDIZED BED WITH MECHANICAL LIQUID DISTRIBUTION

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ABSTRACT

The uniform distribution of mineral and humic substances throughout the volume of granules in the preparation of organo-mineral fertilizers occurs in the layer-shaped mechanism of granulation. To achieve this goal, the introduction of a multicomponent heterogeneous liquid phase into a fluidized bed medium using a mechanical dispersant. The introduction of a liquid phase in the middle of a fluidized bed with the use of a mechanical disperser of conical type with a perforated surface can significantly increase the volume of the irrigation zone with the simultaneous movement of moist granules from the bowl of the dispersant outside, which eliminates the risk of formation of agglomerates and intensifies the renewal of the contact surface phases in the irrigation zone. The proposed mathematical model adequately describes the process of granulation with the use of a mechanical disperser located inside a layer of a granular material in the application of a pulsating mode of fluidization, which significantly intensifies the diffusion-controlled process in the presence of phase transitions.

Keywords: mechanical dispersant, temperature field, inhomogeneous fluidization, distribution.

INTRODUCTION

In many industries, solid composites with well-defined properties and morphology are widely used.

To obtain such products, an intensive heat-mass transfer in multicomponent disperse systems is used in the presence of phase transitions [1].

The influence of the main parameters on the structure and morphology of solid composites under intense heat exchange [1]. The efficiency of such processes is determined by the coefficient of granulation (transformation), which shows the proportion of dry matter entering the apparatus with a liquid phase and form a granular product.

An important factor determining the mechanism of granulation and the economic feasibility of the whole process is the way of introducing a liquid phase into a disperse system.

The different designs of sprayers are used to ensure high values of the granulation coefficient, depending on the rheological properties of the liquid systems [1-3].

The methods of supplying a homogeneous liquid phase by means of different types of nozzles located above or in a layer of granular material [5-6]. However, such a process of granulation is stochastic in which the agglomeration mechanism is more often implemented and is therefore used in the dehydration of monosystems. A similar result is achieved with the use of mechanical high-speed dispersants that are installed over a layer of granular material [6].

The literature [7, 8, 9] presents experimental studies on spray nozzles during drying and granulation of liquid systems in a fluidized bed, in particular the measurement of temperatures at the point of injection of a fluid jet in a layer of granular material [7]. And also the estimation of a disperse system by means of X-ray images or the use of strictly electric probes measurements. [8]. However, these methods provide information at individual points and have a low level of certainty.

In order to provide a layered mechanism of granulation, in some cases, the "Wurster" technology, which consists in the arrangement of a fluidized-bed apparatus of vertical pipes, through which the circulation of granular material is carried out in pneumatic mode, is used [10].

At the bottom of the pipe, a nozzle for spraying only a homogeneous liquid phase is coaxially located. This method has a limit on the specific consumption of liquid phase. Therefore, in order to provide a given liquid phase performance, the number of such systems increases. In real conditions, this complicates the control of the work of individual dispersion units, and for the introduction of heterogeneous systems, this method is generally unacceptable. In addition, in this method of introducing a liquid phase, the local risk of solid particles is significantly increased because the concentration of solid particles in the ascending vertical flow in pneumatic transport mode is minimal (porosity $\varepsilon \geq 0.8$), which, in the absence of mixing intensity, leads to full use of the existing surface of the granular material in the processes of heat-mass transfer. For granulation of heterogeneous systems, this method is unacceptable.

In today's conditions, in response to the challenges associated with the global food crisis, there was a need to create a new generation of organo-mineral fertilizers containing mineral nutrients and stimulants in the given ratios, which determine the agroecological and climatic conditions of the region of their application.

A peculiarity is that the content of humic (stimulating) substances can not exceed 2% of the weight of the granule.

It has been experimentally established that the production of spheroidal granules with a layer structure was achieved by applying a mechanical dispersant of conical type located inside a fluidized bed.

MATERIALS AND METHODS

The experimental installation was consisting of a granulator in the form of a parallelepiped with dimensions AxBxH = 0,3x0,11x1,2 m of stainless steel X18H10T, equipped in the lower part with a slurry-type gas distribution device (GDD), and in the overlayer space with a guide insert.

The height of the stationary layer in the device H0 = 320mm. The initial centers of granulation were spheroidal granules of ammonium sulfate with impurities of humicтsubstances with an equivalent diameter de = 1, 5 mm. In the middle of the volume of the apparatus filled with a layer of granular material is a mechanical dispersant in the form of a perforated cut cone with diameters d1 = 40 mm, d2 = 80 mm and height l = 50 mm with a horizontal axis of rotation. The number of revolutions of the mechanical dispersant varied from 50 to 70 Hz. The mass of the layer in the process of operation was maintained constant by discharging the granular product.

The pressure difference in the layer was measured with a water difmanometer, and the temperature is a computer-information complex with an accuracy of ± 0, 5 °C.

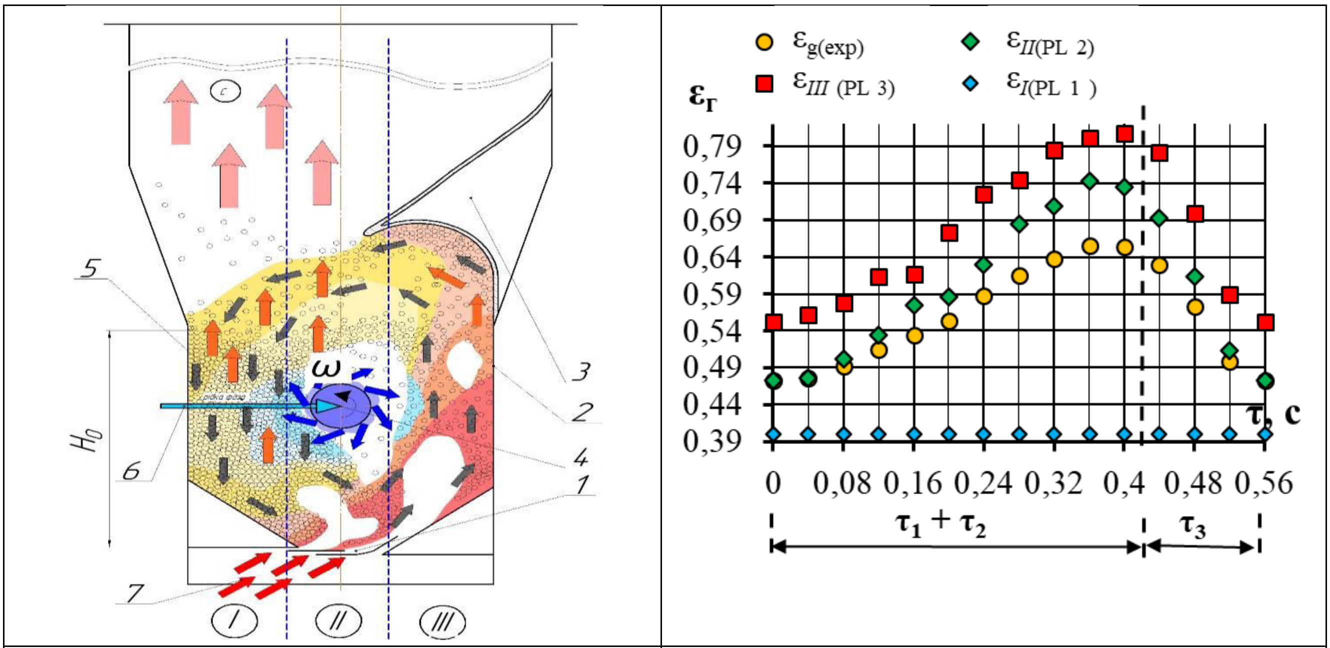
The liquid phase fed to the granulation consisted of 40% (w / w) of aqueous ammonium sulfate solution with impurities of humic substances - 1.5% (w / w) relative to the dry substances.

RESULTS AND DISCUSSIONS

The organization of the process of jet pulsation pseudo-ignition in an autoclaving mode is shown in Figure-1a [11].

The conducted studies [12-14] showed that in the operating mode of jet piston fluidization in the apparatus of Figure-1a, it is possible to allocate 3 zones by hydrodynamic signs.

I - zone of downward motion of a granular material, due to the asymmetric introduction of the coolant (the liquor), the transfer of the granular material occurs due to inertial removal from zone II and III in the upper part of zone I. The layer thickness in this zone is practically constant εI = ε0 = 0.4 the maximum height increases to (1.7 ÷ 2) H0, and the motion of the gas coolant in this zone exclusively in the filtration mode, the dynamics of porosity change is shown in Figure-1b.



a) Inhomogeneous fluidization 1 - fracturing, 2 - granulator chamber, 3 - guide insert, 4 - dispersant, 5 - layer of granular material, 6 - supply of liquid phase, 7 - supply of coolant.	б) Dynamics of porosity change in separate zones of granulator

Figure-1. Inhomogeneous fluidization.

II - boundary zone in which there is a 3D mixing of the granular material due to the movement of gas bubbles and the displacement of a large cluster of granular material into their place, mainly from zone I. In this zone, the porosity changes cyclically εII = 0, 45 → 0, 68 → 0,45. Figure-1b. In the middle of this zone at a height; 0.68H0 from the GDD surface is a mechanical dispersant of conical type.

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III - zone in which there is an active association of gas jets emerging from the gaps of the fracturing and leads to the formation of a gas bubble which at the moment of the beginning of the movement in the vertical direction almost completely fills the intersection of zone III. This leads to the inertial passage of a significant amount of granular material into the superconductor space, when interacting with the insert 4, moves to zone I. Thus, in zone III an active upward movement of the granular material is formed that is characterized by a cyclic change in the porosity εIII = 0, 45 ÷ 0, 75. The dynamics of porosity change in this zone is shown in Figure-1b. The height of the vertical flare gas jet, which is 3 times less than the height of the layer H0 [12, 15]. The apparatus creates a pulsating directional vertical circulation of the granular material counterclockwise.

The pulsation frequency varies depending on 1.5 ≤ de ≤ 4.0 mm, 2.4 ÷ 2.67 Hz [11].

The dispersant rotates in the direction of vertical circulation of the granular material in the apparatus, and the cyclic dynamics of the porosity changes in zones II and III promotes an intensive three-dimensional mixing of the material.

The temperature Determination of field in the disperser zone on the main technological zones will allow to determine the intensity of the heat exchange processes. For measuring the temperatures in the working chamber of the granulator, the conditional planes are located in the middle of the hydrodynamic zones I, II, III in which the tracks of the thermocouples and the plane 4, which pass horizontally through the axis of the disperator rotation, are shown in Figure-2.

PL 1 (X = 50 mm; Y = 0 - 110 mm; Z = 0 ÷ 500 mm)
PL 2 (X = 150 mm; Y = 0 - 110 mm; Z = 0 ÷ 500 mm)
PL 3 (X = 200 mm; Y = 0 - 110 mm; Z = 0 ÷ 500 mm)
PL 4 (X = 0 ÷ 300 mm; Y = 0 - 110 mm; Z = 220 mm)
PL 5 (X = 0 ÷ 300 mm; Y = 0 - 110 mm; Z = 110 mm)

Figure-3 shows the value of the temperature field on the track T3 (X = 100 mm, Z = 220 mm) along the Y axis. This track is on the verge of hydrodynamic zones I (downstream) and middle zone II. In this graph, the configuration of the disperser is given to determine its effect on the temperature field, Figure-3. At a value of 20 ≤ Y ≤ 60 mm, it is characterized by a negative gradient $\frac{dT}{dy} = -0{,}525\frac{grad}{mm}$ minimum temperature of 71 ºC was recorded at Y = 60 mm when the thermocouple was 10 mm from the edge of the dispersant, Figure-3.

If we assume the temperature of the layer at the characteristic point Tc = 95 ºC (X = 250 mm, Y = 70 mm, Z = 220 mm) then the stabilization zone in front of the edge of the dispersant is ΔYz = 25 mm. Thus, in the vicinity of the dispersant, a significant amount of moist granular material is formed closer to the larger diameter of the dispersant.

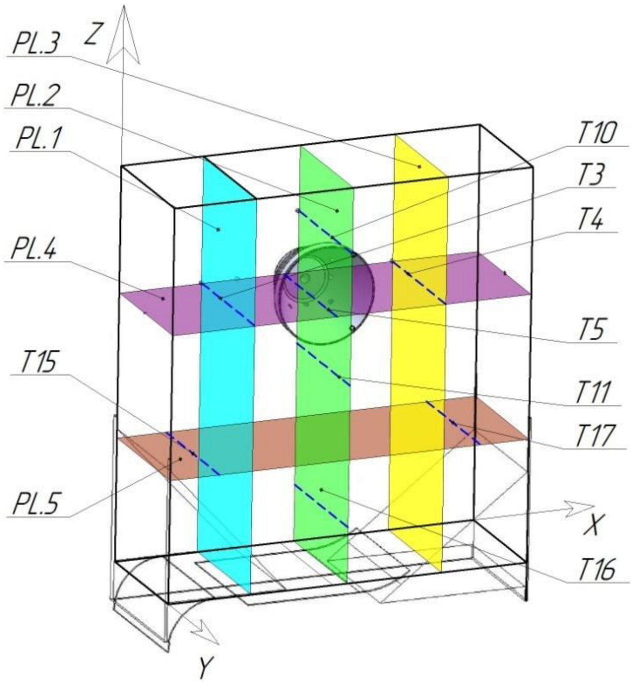

Figure-2. Tracks of thermocouples in the granulator chamber and conditional planes 1,2,3,4 and 5.

The nature of the temperature changes in the trajectory T4, (X = 200 mm, Z = 220 mm) passing on the boundary of zones II and III has a similar character to Figure-3, but the minimum values are greater by 14 ºC and the relaxation zone ΔY4 → 0. This is achieved at the expense of intensive pulsation motion of a gas coolant with a high temperature at a frequency of 1.6 - 2.0 Hz.

Measurement of temperature in the substrate 2 in the middle of zone II on the track T10 with the corridors (X = 150 mm, Z = 270 mm) is shown in Figure-4.

A graceful gradient along the surface of the dispersant at a change of 20 ≤ Y ≤ 70 mm was $\frac{dT}{dy} = -0{,}16\frac{grad}{mm}$ as shown in Figure-4. This Figure is 3.25 less than for the T3 track, indicating the intense displacement of the granular material through the irrigation zone due to the pulsating mode of fluidization. However, the relaxation zone in front of the edge of the dispersant ΔY10 ≥ 40 mm is maximal.

This confirms the assumption that the powerful stream of wet granules from the bowl of the dispersant into zone II above the upper edge of the dispersant.

The measurement of temperatures in the middle zone II of the thermocouple below the disperser track T11 (X = 150 mm, Y = 0 ... 110 mm, Z = 170 mm) is shown in Figure-4.

At 20 ≤ Y ≤ 30 we observe a negative temperature gradient, which is the largest for all disperser located in the vicinity of the disperser, Figure-4. This is due to the instant formation of the sedentary zone of the granular material around the dispersant. Subsequently, due to the intense mixing, the value of the positive temperature gradient at 30 ≤ Y ≤ 50 mm. In this case, the size of the relaxation zone ΔY11 = 40.

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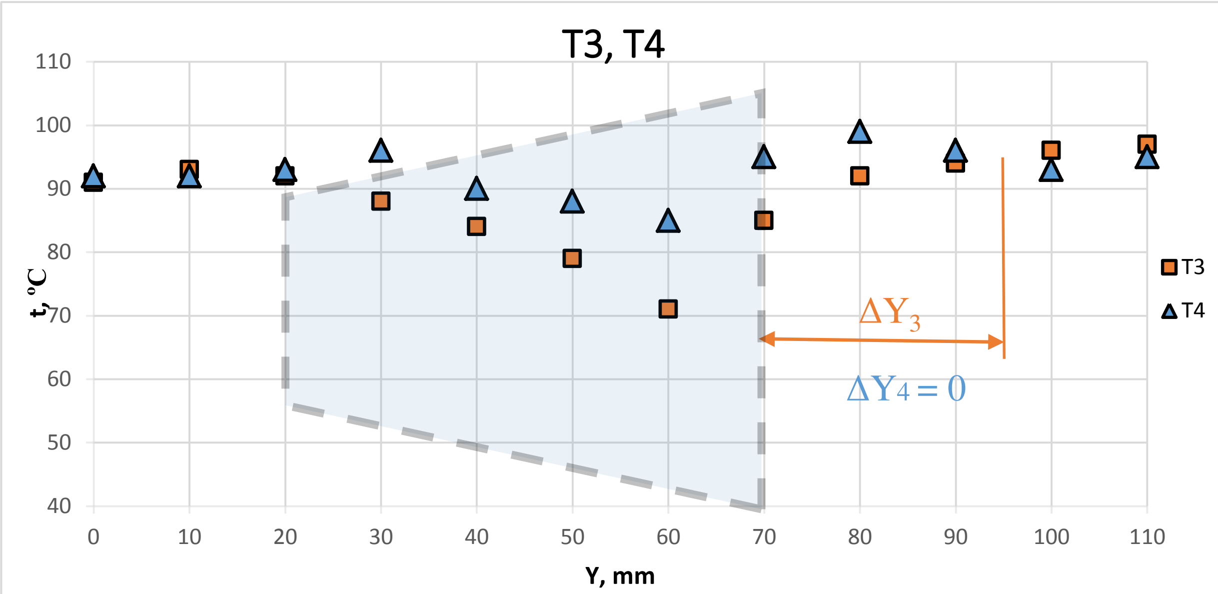

Figure-3. Temperatures in tracks T3, X = 100 mm 0 ≤ Y ≤110 mm, Z = 220 mm, T4, X = 200, 0 ≤ Y ≤110 mm, Z = 220 mm.

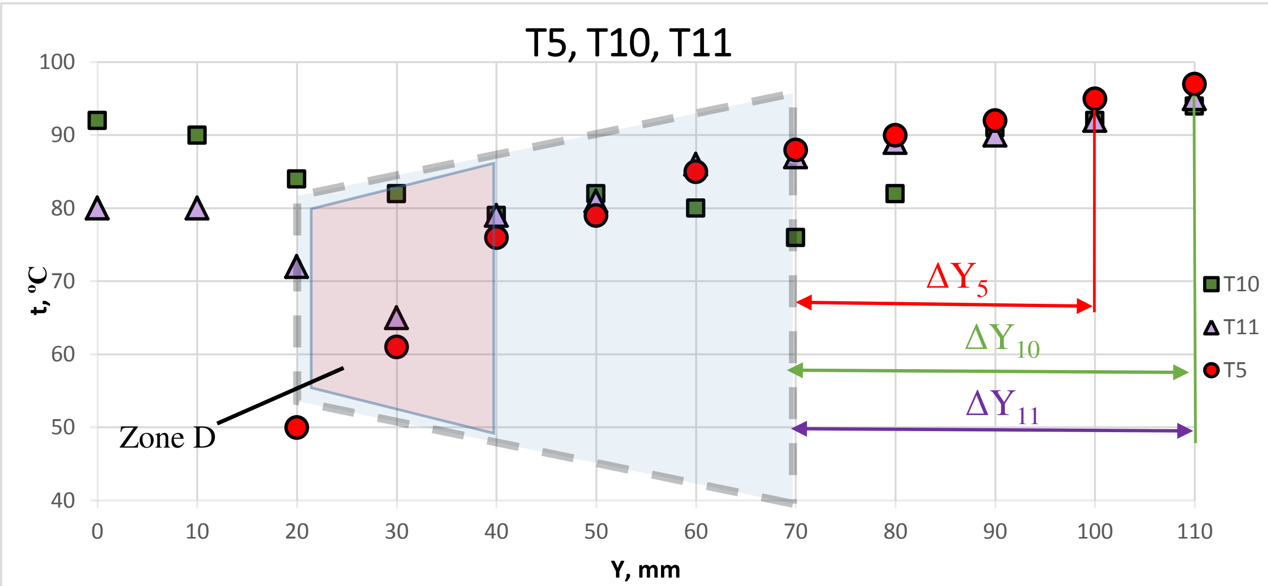

Figure-4. Temperature in tracks T5, X = 150 mm 0 ≤ Y ≤110 mm, Z = 200 mm, T10, X = 150, 0 ≤ Y ≤110 mm, Z = 170 mm T11, X = 150, 0 ≤ Y ≤110 mm, Z = 270 mm

In general, the character of temperature changes measured in tracks above T10 and below the T11 dispersant have opposite temperature gradients, which explains the pulsating hydrodynamic regime.

The analysis of temperature changes in the vicinity of the disperser T3, T4, T10 and T11 shows that the intense removal of the wet granules occurs along the vertical axis above and under the disperser with the relaxation zones ΔY10 = ΔY11 = 40 mm zone II, Figure-4. In the downward area, Figure-3, zone the relaxation ΔY3 = 25 mm, and in the ascending flow ΔY4 → 0. This is achieved by the pulsation mode of fluidization in a self-oscillating mode with a frequency of 1.8 - 2.0 Hz.

Such a configuration of the temperature field in the dispersant zone indicates the presence of an intensive start of moisture of the granules discharged from the bowl of the dispersant almost throughout the perimeter of the conical disperser bowl.

Therefore, the use of mechanical dispersant allows not only to increase the geometric dimensions of the external irrigation zone, but to create a directed flow of moist granules formed in contact with the liquid on the inner surface of the disperser bowl in a horizontal direction. Model of motion of a disperse medium with a mechanical dispersant is shown in Figure-5.

To prevent clogging of tube 2 and the formation of agglomerates in the middle of the disperser bowl, the

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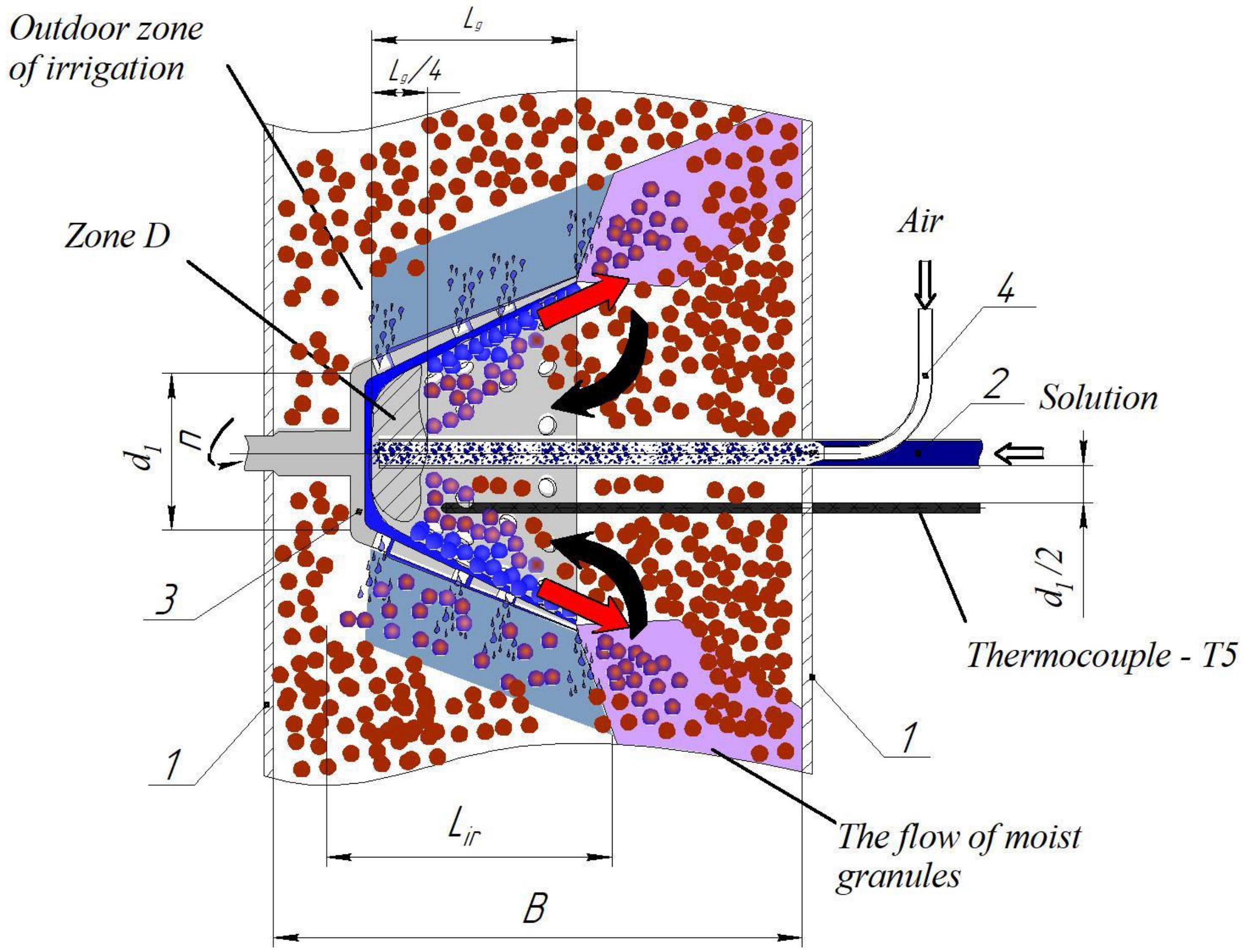
liquid phase is mixed with air 4. When in contact with the bottom in the disperser bowl, the aerosol zone D is formed, from which the solid particles are removed, Figure-5.

The part of liquid through the perforated holes is sprayed on the outside. The second part, which moves along the inner surface of the dispersant, contacts a layer of granules, which, under the influence of centrifugal force, are extensively ejected from the bowl of the dispersant. The heat transfer conditions are determined by the indicators of the thermocouple track T5 which is located below the 10 mm feed tube in the middle of the bowl dispersant in area 2, Figure-5.

The presence of a directed circular motion from the disperser zone confirms the nature of the temperature change in the track, which passes in a vertical plane 10 mm below the axis of rotation T5, Figure-4. Thus, the minimum value of the temperature in the plane of the liquid phase is 50 ºC and at the exit 85 ºC, that is, the gradient is the relaxation zone increased to 95 ºC ΔY5 = 30 mm. Figure-4.

The parameter ΔY_5 indicates a powerful jet of moist particles, which, under the action of centrifugal force, are diverted from the disperser bowl.



1 - the front and rear walls of the apparatus, 2 - the supply line of the liquid phase, 3 - mechanical dispersant, 4 - the tube of air supply.

Figure-5. Model movement of the granular material in the irrigation zone.

Figure-6 shows the results of measuring the temperatures in the horizontal planes located respectively:

T 15 (X = 50 mm, 0 ≤ Y ≤110 mm, Z = 110) PL 5
T 16 (X = 150 mm, 0 ≤ Y ≤110 mm, Z = 90) PL 2
T 17 (X = 250 mm, 0 ≤ Y ≤110 mm, Z = 110) PL 5

So at altitude Z = 110 mm in PL 5, downward movement of zone I, the temperature throughout the depth of the zone 0 ≤ Y ≤ 110 is within 95 ÷ 93 °C T15, Figure-6. The temperature values are measured in the middle zone II is 5 ÷ 10 ºC is higher than in the PL 1 in the range of values 99 ÷ 107 ºC, T16, Figure-6 in which the directional movement of the heated coolant occurs.

The basis of the mathematical model of heat exchange is the authors' equation [14], which is supplemented by the energy consumption for heating the liquid phase, which is on the surface of the granules in the form of a film, and the costs of heating and evaporation of the solvent, as well as taking into account the

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intensification of diffusion controlled processes. Then the equation of thermal balance for gas coolant is written in the form:

$$\varepsilon \cdot \rho \cdot C \cdot \frac{\partial T_g}{\partial t} + V_g \cdot \varepsilon \cdot \rho \cdot \frac{\partial T_g}{\partial x} = \varepsilon \cdot a \cdot \frac{\partial^2 T_g}{\partial y^2} - \alpha \cdot F \cdot (T_g - T_{p+ж}) +$$
$$+ G_p \cdot (1 - x_p) \cdot (r + C_ж \cdot T_{p+ж});$$

For granules:

$$(1-\varepsilon) \cdot \rho \cdot C \cdot \frac{\partial T_{p+ж}}{\partial t} - V_{p+ж} \cdot (1-\varepsilon) \cdot \rho \cdot \frac{\partial T_{p+ж}}{\partial x} =$$
$$= \alpha \cdot F \cdot (T_g - T_{p+ж}) - G_p \cdot (1 - x_p) \cdot (r + C_ж \cdot T_{p+ж}) + G_p \cdot x_p \cdot q;$$

Where:

ε - porosity of a layer (a share of gas)
ρ_g - gas density, kg / m3
ρ_p - density of granules, kg / m3
w_g - gas speed, m / s;
C_p - gas heat capacity, kJ / (kg · K)
λ_g - thermal conductivity of gas, W / (kg · K)
F - specific surface of granules in a layer at a given height, m2 / m3

$$F = \frac{6 \cdot (1 - \varepsilon_0)}{d_e}, \quad d_e = \frac{1}{\sum \frac{x_i}{d_i}},$$

d_e - equivalent particle diameter in the layer, mm
x_i - mass fraction of fraction,
d_i - the average size of fraction, mm
G_p - Specific mass load of the layer of the granular material, kg / (c · m ^ 3)
X_p - concentration of dry substances in the solution submitted to the granulator, % (mass)
T_g, T_b - temperature of the coolant at the inlet to the granulator and temperature in the layer, °C
T_g - coolant temperature, K;
C_p - heat capacity of the working solution supplied to the apparatus, J / (kg · grad)
q - effective heat of crystallization, kJ / (kg · grad)
r - specific heat of vaporization, kJ / kg
w_m - speed of motion of solid particles, m / s;
α - coefficient of heat transfer from gas to the surface of the granules, W / (m ^ 2 · K);
a - coefficient of thermal conductivity, m ^ 2 / s

The system (1) was solved by the Euler method for systems of differential equations of the second order using the iterative clarification of the solution of the equation, and the solution coefficients were adjusted accordingly using numerical integration methods to achieve better convergence. To resolve the system (1), an application using the Borland Delphi environment was created using the Math module.

The calculation results are shown in Figure-7 and show convergence with an average error of 1%.

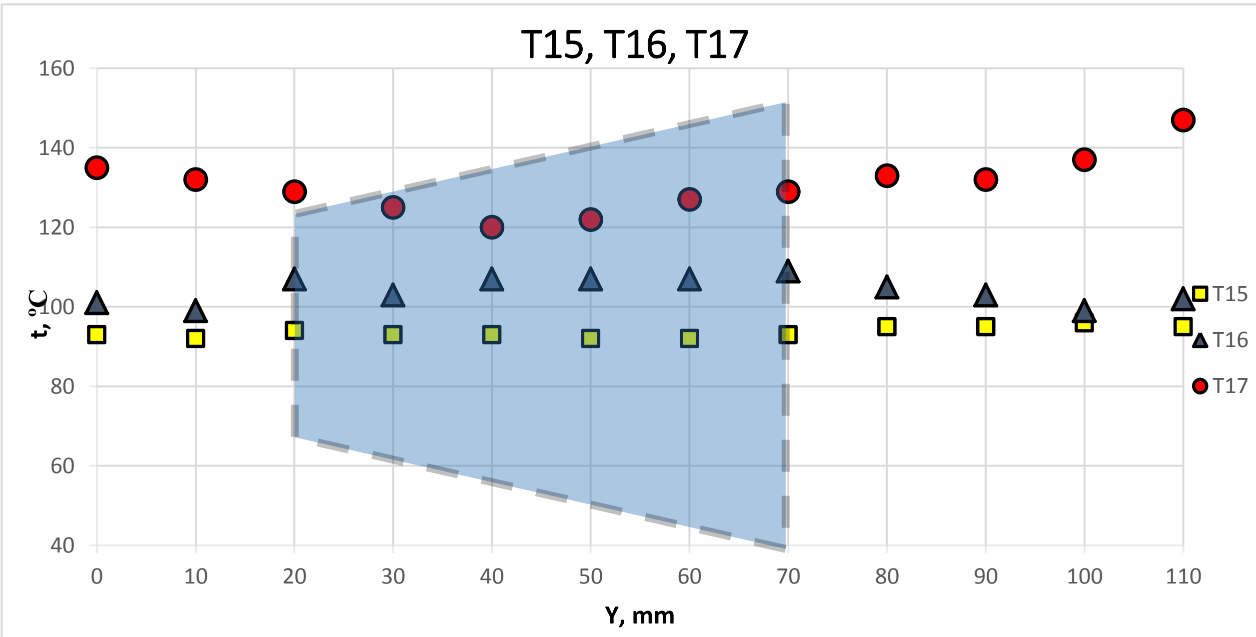

Figure-6. Temperatures in tracks T15, X = 50 mm 0 ≤ Y ≤110 mm, Z = 110 mm, T16, X = 150, 0 ≤ Y ≤110 mm, Z = 90 mm. T17, X = 250, 0 ≤ Y ≤110 mm, Z = 110 mm.

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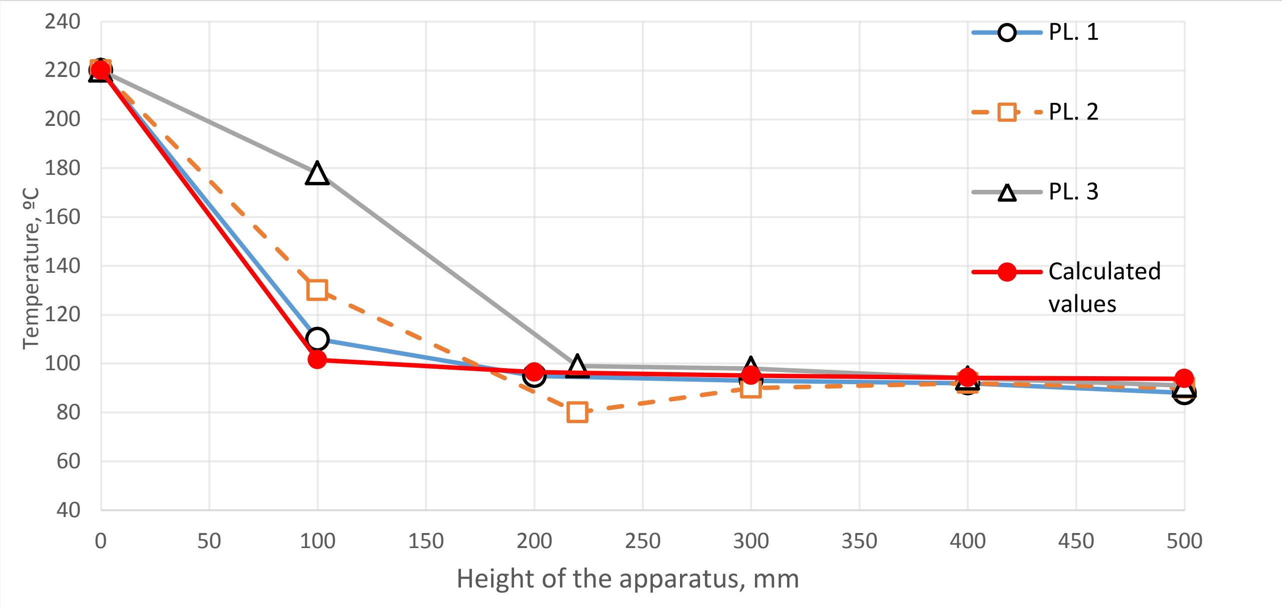

Figure-7. Temperature change by the height of the machine. Estimated and experimental values.

CONCLUSIONS

The proposed mathematical model allows to adequately describe the averaged values of the temperature field during the implementation of the jet-pulsating fluidization in an autoclaving mode with the use of a conical dispersant and to determine the temperature at which a stable process with a layer-shaped granulation mechanism φ = 90% is implemented with a significant increase in the intensity of the diffusion-controlled processes associated with mass crystallization

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