Forecasting of the Priller Dispersing Modes in the Production of Nitrogen Fertilizers

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***Abstract* – Having performed a comparative analysis of modern nitrogen fertilizers production methods one proved an effective and promising use of prilling systems, as well as identified indicators improving the ecological situation in the enterprise area. Hydrodynamic processes, which take place in the jets, outflowing from the vibration granulator hole, were studied in details.**

Using the analytical method one solved the differential Navier-Stokes equation for liquid outflow conditions and one specified the correlations between process parameters of the vibrator and jet pressure, characterizing their disintegration mode.

Key words – forced perturbations, priller, regular hits, jet disintegration, monodispersity, prilling tower.

I. Introduction

The present work is carried out under the project "Improving the efficiency of granulators and dryers with active hydrodynamic regimes for obtaining the modification and fertilizer encapsulation", state registration 0116U006812.

In modern agriculture worldwide there is a demand for nitrogen fertilizers and it is growing rapidly. In the coming years there are expected active investments and increase of the world production capacity of nitrogen fertilizers manufacturing. IFA Experts estimate that by 2018 the consumption of nitrogen fertilizers will reach 215 million tons of nutrients and in the future it will increase in about 2.5-3% a year [1].

In the world practice, the most common methods of producing nitrogen fertilizer in the chemical industry are prilling in towers and granulation (by layering the melt on the retour particles in a fluidized bed in the drum or plate granulator.) [2]. Prilling method is based on the forced disintegration of the melt jets of mineral fertilizer into droplets outflowing from the dispersive device into the air environment. Thus there takes place the process of spherical drops cooling in free fall, and their crystallization in the counter flow of cooling air.

II. Challenge problem

Forced jet disintegration into droplets is a very complex phenomenon, which has a variety of modes and depends on a number of internal and external factors [3].

The main interest of the contemporary scientists is drawn to the monodisperse mode of the jet disintegration into the main droplets without satellite droplets (small droplets) formation.

As one can see from the analysis of the nitrogen fertilizers production process stages, a great deal of fertilizer is lost with the dust emission of the granulated substance (satellite drops) which comes with the cooling air into the atmosphere. For example, when air flows through the tower in the volume of 300,000 m^3/hour having dust content volume 200-250 mg/Nm^3, the production unit of ammonium nitrate AS-60 emits more than 1500 tons of the products into the atmosphere annually [4].

In addition to the economic aspects associated with the product loss, this problem has an environmental one which is the pollution of air, surface and ground water; nitrites and nitrates accumulation in plants and reservoirs, which all results in a load on the ecosystem. Target of the research is to study the process of unsteady liquid jet efflux from the holes in a thin-walled shell when applying external perturbations, and their effect on the change of the radial and axial velocity component and thus on the formation of the hydrodynamic conditions in the jet, which leads to its disintegration into droplets.

III. Mathematical research

To find the numerical solution of the perturbations spreading mechanism in liquid volume and pressure values changes in the jet outflowing from the perforated bottom hole, one used the known system of equations for description of the unsteady efflux of the viscous fluid from the hole:

$$\begin{cases} \dfrac{\partial \upsilon_r}{\partial \tau} = -\dfrac{1}{\rho}\dfrac{\partial p}{\partial r} + \nu\left[\dfrac{\partial^2 \upsilon_r}{\partial z^2} + \dfrac{\partial}{\partial r}\left(\dfrac{\frac{\partial}{\partial r}(r\cdot\upsilon_r)}{r}\right)\right] \\ \dfrac{\partial \upsilon_z}{\partial \tau} = -\dfrac{1}{\rho}\dfrac{\partial p}{\partial z} + \nu\left[\dfrac{\partial^2 \upsilon_z}{\partial z^2} + \dfrac{1}{r}\dfrac{\partial}{\partial r}\left(r\cdot\dfrac{\partial \upsilon_z}{\partial r}\right)\right] \\ \dfrac{\partial \upsilon_z}{\partial z} + \dfrac{1}{r}\dfrac{\partial}{\partial r}(r\cdot\upsilon_r) = 0 \end{cases} \quad (1)$$

To solve this task one applied methods for solving differential equations of partial derivatives and systems of such equations. Using the method of separation of variables, one obtains a system of equations:

$$\begin{cases} p = -\dfrac{1}{2}\rho C_3^{\,2} r^2 - \dfrac{1}{2}\dfrac{\rho C_2^2}{r^2} + C_9 - 2\rho C_3\left(C_3 z^2 - C_4 z - C_5 z\right) + C_8 \\ \upsilon_r = \dfrac{C_2}{r} + C_3 r \\ \upsilon_z = C_5 + C_6 K + C_7 Y - 2C_3 z + C_4 \end{cases} \quad (2)$$

Where, C_2, $C_3 \ldots C_9$ - equations constants; K, Y - Bessel functions of the first and second kind respectively.

The equation system (2) can not be used in terms of uncertainty of its pressure changes influence on the radial and axial velocity components in course of time. Bessel function in the equation for the velocity axial component determination also makes it difficult to obtain calculated dependencies that can be used for the prior simplified analysis of the liquid jet hydrodynamics and to find definite engineering solutions.

In relation of analysis of the melt jet hydrodynamic parameters, and its outflowing from the holes of the vibration granulator perforated shell, particular interest is in the solution of the equations (1) for the cases of non-stationary efflux, that is, taking into account the changes that occur over time, and it is determined by the presence of a variable.

Using the method of separation of variables (sum) one can solve the equations system (1), and the following solution is obtained:

$$\begin{cases} p = B_{12} + \rho(-B_9 + 4\nu B_8)z + B_{11} + F(\tau) \\ \upsilon_r = \dfrac{B_2}{r} + B_3 r \\ \upsilon_z = B_6 + B_7\ln(r) + B_8 r^2 - 2B_3 z + B_5 + B_9\tau + B_{10} \end{cases} \quad (3)$$

where, B_2, $B_3 \ldots B_{12}$ - equations constants.

One analyzed the obtained system of equations and took some assumptions of the jet efflux physical model and after fulfilling a series of mathematical operations one obtained a solution in the form of the equation for determining the pressure change along the jet flowing out of the priller:

$$p = \rho(-B_9 + 4\nu B_8)z + a\sin(b\tau + c) + d \quad (4)$$

Equation (4) enables to analyze pressure changes in the jet depending on the liquid position relatively to the outlet hole and time. It enables to predict liquid jet disintegration into separate monodisperse droplets of a given size and to choose optimal parameters of the granulator vibratory system operation.

IV. Results

Comparative analysis of the experimental results and theoretical calculation of the equation (4) showed a discrepancy. Having analyzed the results one came to the conclusion that a jet is influenced by a set of perturbations which are caused by uncontrolled outside noise and granulator construction and these factors are difficult to control. Since there are many factors influencing the dependence characteristics and it is difficult to take them into account when fulfilling the theoretical calculation. To obtain the analytical dependence of pressure changes in the jet, taking into account noise, one needs to add the component, considering vibrations which are caused by the external influence (noise), to the received dependence (4). Then the equation (4) becomes:

$$p = \rho(-B_9 + 4\nu B_8)z + a\sin(\omega\tau + c) + d + a_1\sin(\omega_1\tau + c_1) \quad (5)$$

where, a_1 - amplitude, ω_1 - cyclic frequency, c_1 - phase shift of the system vibrations.

Basing on equation (5) one made a graphic chart that shows liquid pressure change along the jet in the process of its outflow from the Priller holes with the parameters that were set during conducting the physical experiment (Fig. 1).

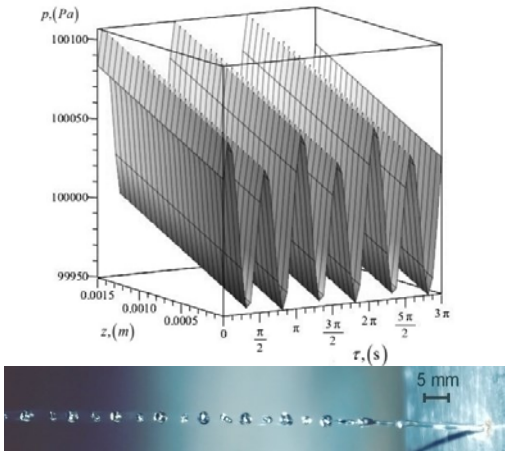

Fig. 1. Polydisperse mode of liquid disintegration

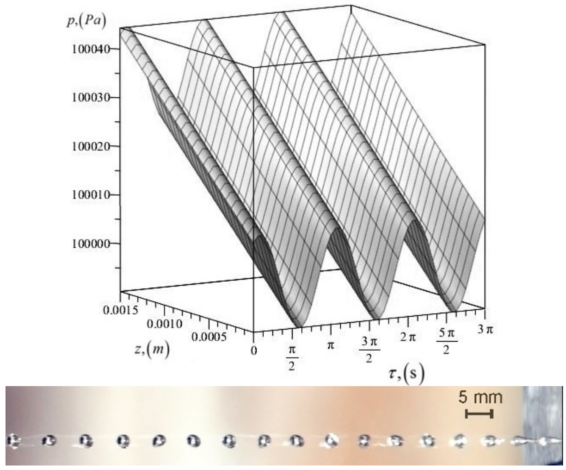

Fig. 2. Monodisprese mode of liquid disintegration

Conclusion

Established regularity of the liquid jets controlled disintegration into droplets and fulfilled research prove the possibility of designing vibration granulators for melt nitrogen fertilizers which enable to obtain prills in the narrow fractional range. Obtained mathematical dependences became the basis of technological and engineering works on developing of the modernized rotating vibration melt granulator.

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