UDC 661.152
DOI: 10.15587/2706-5448.2021.241142
Article type «Reports on Research Projects»

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DETERMINATION OF GRANULE (PRILL) MOVEMENT MODES IN THE PRILLING TOWER FOR MINERAL FERTILIZER PRODUCTION

The object of research is the mode of movement of the granules of mineral fertilizers obtained in the towers. The subject of research is the effect of the physical and chemical properties of granules, their size and initial hydrodynamic parameters on the speed of movement of the granules in the tower. The fertilizer industry is characterized by high requirements for the production of mineral fertilizers, which makes it promising to use granulation plants of large unit capacity, tower production. The resulting product must have a stable physical and chemical composition, be monodisperse with a spherical shape of granules, which allows long-term storage in bulk without the use of auxiliary equipment and meet international quality standards. The main granulation equipment that is used in the tower production of mineral fertilizers is spray type granulation equipment. In such towers, there is a likelihood of crossing pellet flares, getting pellets into the walls of the pelletizing tower and adhesion of the melt on this surface in industrial conditions, which leads to negative consequences. Therefore, the determination of the modes of motion of granules is still important. Methods of mathematical modeling of the movement of granules under different conditions were used in the work. Numerical methods were used to solve the equations of differential equations. As a result, an equation was obtained to determine the speed components along the x and y axes. The calculation of the horizontal speed of the granule and the determination of the time of its movement in the working area of the prilling tower makes it possible to determine the length of the granule path in this direction, to determine the diameter of the spray torch of the granules. Provides information on preventing the ingress of granules into the walls of the prilling tower and adhesion of the melt on this surface in industrial conditions, which leads to negative consequences. The magnitude of the speed, especially for the vertical component, changes its value several times over time due to a change in the mode of motion of the granules when moving from the granulator down the tower. This indicates the need to also take into account the change in the value of the resistance coefficient over time. When deriving the equations, simplifications were used, and the motion of a solid granule was considered. However, a drop begins to move from the granulator (disperser), which then crystallizes into a granule. Comparing the obtained results, allowing to predict by calculation the behavior of the spray plume of granules, with the initial ones obtained in industrial conditions, it is possible to conclude that the error of the equations obtained is 10.5 %. Therefore, work on improving the obtained equations describing the mode of motion (speed) of the granules will be continued.

Keywords: *granulation, rotating vibrating granulator, monodispersity, ammonium nitrate, drag coefficient, nitrogen fertilizers.*

Received date: 08.04.2021
Accepted date: 31.05.2021
Published date: 18.10.2021

How to cite

Skydanenko, M., Sklabinskyi V., Nadhem, Al-K. M., Nichvolodin, K. (2021). Determination of granule (prill) movement modes in the prilling tower for mineral fertilizer production. Technology Audit and Production Reserves, 5 (3 (61)), 6–9. doi: http://doi.org/10.15587/2706-5448.2021.241142

1. Introduction

The fertilizer industry, in particular, is characterized by high requirements for production volumes (about 200 million tons per year), which makes it relevant to use granulation plants of large unit capacity [1].

The main granulation equipment that is used in the tower production of mineral fertilizers (urea, ammonium nitrate) is spray granulation equipment [2, 3]. This is due to the fact that such granulators form droplets from the mineral fertilizer melt directly, either by mechanical action on the film and the melt jet, or by the action of pressure pulsations on the melt jet. There are also designs of granulators, where the formation of droplets is achieved through the interaction of a film or jet, moves at high speed, with an air flow [4]. As a result of this interaction, the jets break up into droplets. But the latter type of granulation equipment is used less and less. This is due to the polydisperse composition of the droplets, and then, as a result of crystallization, and granules obtained in such equipment [5].

Recently, vibration equipment [6] has become more and more widespread, which is explained by the rather clear monodisperse composition of the granules obtained and low rates of emission of product dust together with the exhaust air [5]. In addition to these advantages, vibrating granulators allow, even during industrial operation, to change the dispersed composition of the granules by changing the frequency and amplitude of forced vibration vibrations imposed on the melt jet.

Separately, in a number of vibrating granulators, there are rotating vibrating granulators (RVG), with the help of which it becomes possible, by changing the number of revolutions of the granulator basket, to change the distance at which the pellet torch is sprayed from the granulator axis. This is of particular relevance at the present time, when the demand for mineral fertilizers is increasing significantly and producers of mineral fertilizers are improving old and building new towers of large diameter. In such large towers, there is a need to spray a large area of the tower with drops of melt. Some manufacturers install several static granulators for this purpose at the top of the prilling tower. But in this case, there is a likelihood of intersection of pellet torches of two neighboring granulators, which leads to very negative consequences. The previously existing methods for calculating the size of the torch did not take into account a number of factors affecting the movement of drops and granules, therefore, they no longer meet modern requirements.

Such negative consequences are solved by installing one RVG in the upper part of the tower, the axis of which coincides with the axis of the prilling tower. But in this case, the question of the correct calculation of the diameter of the spray of the melt onto droplets with the formation of granules and its dependence on the number of revolutions of the RVG basket and the height of the melt level in the granulator becomes relevant. This, in turn, affects the intensification of heat transfer in the tower, and, as a consequence, the mode of its operation and the quality of the finished granular product [7].

Thus, *the object of research* is the mode of movement of the granules of mineral fertilizers obtained in the towers. *The subject of the research* is the influence of the physicochemical properties of granules, their size and initial hydrodynamic parameters on the mode of motion (speed) of the granules in the tower. And *the purpose of the work* is to obtain mathematical dependencies that describe the components of the speed and will make it possible to predict the modes of movement of the granules, and, as a result, improve the quality of the granules of mineral fertilizers.

2. Methods of research

To solve these problems, a number of theoretical and experimental studies were carried out at the Department of Chemical Engineering of Sumy State University (SSU, Ukraine) to develop an engineering technique for calculating the speed of granules. The conditions for the movement of the granules for which the calculation method is suitable are as follows: the granules are formed in the RVG and move in the working space of the prilling tower.

The well-known equations of droplets or solid particles in an air (gas) flow [8] were taken as the basis for theoretical studies:

$$m\vec{a} = \sum_{i=1}^{n} \vec{F}_i, \tag{1}$$

where m – the mass of the granule (drop); a – the acceleration of the movement of the granule (drop); F – the force.

Taking into account the symmetry of the movement of drops around the axis of the tower, and the mathematical record of the resultant of all forces applied to the granule, as the action of the resistance force from the air and the force of gravity, let's obtain from equation (1) the following system of equations:

$$\begin{cases} \dfrac{d}{d\tau} W_x(\tau) = -\dfrac{\xi S \rho_{air}\left(W_x(\tau)+V_x\right)^2}{2m}, \\ \dfrac{d}{d\tau} = W_y(\tau) = g - \dfrac{\xi S \rho_{air}\left(W_y(\tau)+V_y\right)^2}{2m}, \end{cases} \tag{2}$$

where τ – the time of movement of the granule; $W_x(\tau)$ – the horizontal component of the speed of movement of the granule; $W_y(\tau)$ – the vertical component of the speed of movement of the granule; ξ – coefficient of resistance of the medium; S – the area of the midsection; ρ_{air} – the air density; V_y – the vertical component of air speed; V_x – the horizontal component of air speed; m – the mass of the granule.

The location and direction of the coordinate axes is shown in Fig. 1, which also indicates the direction of movement of the granules and schematically shows how the granules are distributed over the cross section of the tower. And also indicated the direction of movement of the main flow of air in contact with the granules and affects their movement.

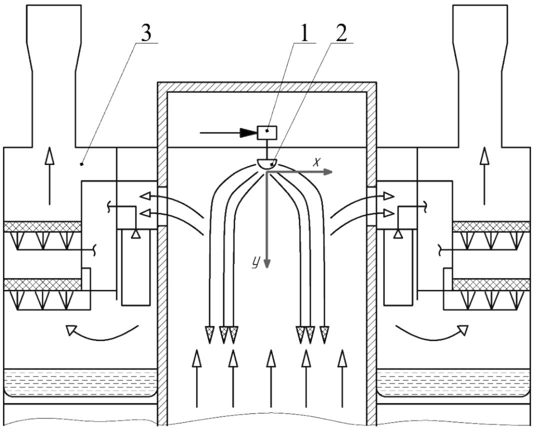

Fig. 1. Location of the granulator in the prilling tower: 1 – granulator (RVG); 2 – granulator basket; 3 – separation of exhaust air cleaning

Let's take into account the value of the mass of the granule, its diameter, the area of the midsection intersection and the fact that in the horizontal direction in the working area of the prilling tower there is practically no horizontal air movement, the system of equations (2) takes the form:

$$\begin{cases} \dfrac{d}{d\tau}W_x(\tau)=-\dfrac{3}{4}\dfrac{\xi\rho_{air}\left(W_x(\tau)+V_x\right)^2}{d_g\rho_g}, \\ \dfrac{d}{d\tau}=W_y(\tau)=9.81-\dfrac{3}{4}\dfrac{\xi\rho_{air}\left(W_y(\tau)+V_y\right)^2}{d_g\rho_g}, \end{cases} \qquad (3)$$

where d_g – the diameter of the granule; ρ_g – the density of the granule.

The initial speed of the granule depends on the initial speed of the drops, from which the granule is then formed, and the angle of inclination to the horizon α of the hole from which the drop follows. If the melt load on the granulator, the number of holes in the basket and their diameter are known, it is possible to determine the initial speed of the granule W_0 and the components of the speed along the coordinate axes W_{x0} and W_{y0} at the initial moment of time at $\tau=0$.

Using these values as initial conditions, a solution to the first equation of system (3) was obtained in the form:

$$W_x(\tau)=-\frac{3\tau\xi\rho_{air}W_{x0}V_x+3\tau\xi\rho_{air}V_x^2-4d_g\rho_gW_{x0}}{3\tau\xi\rho_{air}W_{x0}+3\tau\xi\rho_{air}V_x+4d_g\rho_g}, \qquad (4)$$

and the solution of the second equation of system (3):

$$\begin{multline} W_y(\tau)=-\frac{1}{1635\xi\rho_{air}}\Bigg(\Bigg(5\xi\rho_{air}\sqrt{327}V_y-327\,\mathrm{tg}\Bigg(\frac{1}{6540d_g\rho_g}\Bigg(\Bigg(981\tau\sqrt{\xi\rho_{air}d_g\rho_g}+ \\ +20d_g\rho_g\,\mathrm{arctg}\Bigg(\frac{5}{327}\frac{\xi\rho_{air}\left(W_{y0}+V_y\right)\sqrt{327}}{\sqrt{\xi\rho_{air}d_g\rho_g}}\Bigg)\sqrt{327}\Bigg)\sqrt{327}\Bigg)\Bigg)\sqrt{\xi\rho_{air}d_g\rho_g}\Bigg)\sqrt{327}\Bigg). \qquad (5) \end{multline}$$

Using the obtained equations (4) and (5), it is possible to determine the influence of the physical properties of the granules and the air in which they move on the change in the speed of their movement to reach the bottom of the tower.

3. Research results and discussion

The obtained calculated dependencies were used to determine the speed of motion of ammonium nitrate granules in an industrial rectangular (6.8×6.0 m) prilling tower 42 m high and a melt load of 32 t/h.

In this case, it was taken into account that the rotation speed of the granulator basket was taken into account when determining the initial speed of the granules by creating additional pressure due to the rotation of the RVG basket. The design parameters and dimensions of the pellet flame correspond to the geometry of this industrial tower.

An example of a calculation is shown in Fig. 2, which shows the graphical dependences of the horizontal and vertical components of the speed of the granules until they reach the bottom of the prilling tower.

Analyzing the obtained dependences, the following conclusions can be drawn.

First, the values of the horizontal and vertical speed differ significantly from each other. Therefore, the Reynolds coefficients characterizing the modes of air flow around the granules depend on these numbers and have different values. According to the recommendations of the authors of various studies [9–11], they are described by various mathematical formulas, which must be taken into account in such calculations.

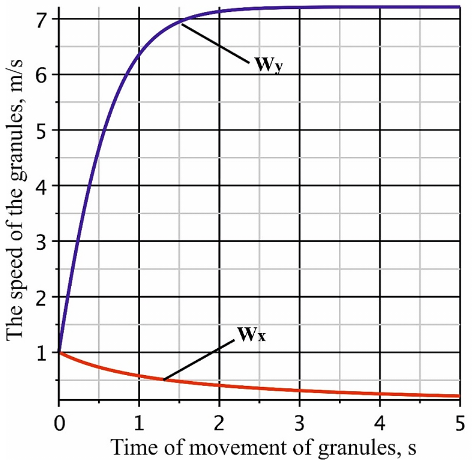

Fig. 2. Graphical representation of changes in the magnitude of the horizontal and vertical components of the speed of granules during their movement from the granulator to the bottom of the prilling tower: W_x – horizontal speed; W_y – vertical speed

Secondly, the calculation of the horizontal speed of the granule and the determination of the time of its movement in the working area of the prilling tower makes it possible to determine the length of the granule path in this direction, to determine the diameter of the spray torch of the granules.

It also provides information to prevent the ingress of granules into the walls of the prilling tower and the adhesion of the melt on this surface in industrial conditions, which leads to negative consequences.

Thirdly, the magnitude of the speed, especially for the vertical component, changes its value several times over time due to a change in the mode of motion of the granules when moving from the granulator down the tower. This indicates the need to also take into account the change in the value of the resistance coefficient over time. When deriving the equations, simplifications were used, the motion of a solid granule was considered. However, a drop begins to move from the granulator (disperser), which then crystallizes into a granule. The studies presented in this article apply to the hydrodynamics of mineral fertilizer granules (ammonium nitrate and urea) obtained by the tower method. The diameter of the granules is 1–5 mm. The diameter of the towers is 6–20 m and the speed of the ascending air inside the tower should not exceed 2 m/s. The developed mathematical model assumes that the granules do not touch while moving in the tower. Therefore, the work on improving the obtained equations describing the mode of motion (speed) of the granules will be continued.

4. Conclusions

A theoretical set of studies was carried out with the subsequent development of a methodology for a theoretical method for calculating the speed of movement of granules in the working space of a prilling tower. In a prilling tower (6.8×6.0 m) and 42 m high, a 2 mm granule overcomes this distance in 5 seconds. In the first 2 seconds, the vertical component of the speed increases to 7 m/s, and then becomes stable. The horizontal component of the speed in the first 3 seconds decreases almost to 0. Comparing the results obtained, which allow one to predict the behavior of the spray of granules by calculation, with the results obtained in industrial conditions [8], wit is possible to conclude that the error of the equations obtained is 8.5 %.

Based on the selection of the operating conditions of the granulator (the height of the melt in the granulator, the pressure on the surface of the melt in the basket of the granulator, the rotation speed of this basket and its geometric dimensions), recommendations have been developed for determining the geometric and technological parameters of its operation. This will allow to achieve stable operation of the granulator in a specific industrial prilling tower to achieve optimal results and obtain a high-quality granular product.

Acknowledgement

The work was carried out by order of the Ministry of Education and Science of Ukraine within the framework of research projects:

– «Creation of new granular materials for nuclear fuel and catalysts in an active hydrodynamic medium» (GDR No. 0120U102036);

– «Fulfillment of the tasks of the long-term plan for the development of the scientific direction «Technical Sciences» of Sumy State University» (DR No. 0121U112684).

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