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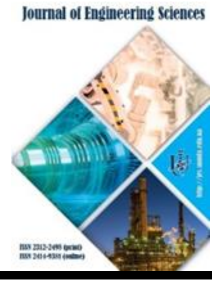

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Rational Choice of a Basket for the Rotational Vibropriller

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Abstract. The use of processing units for the production of mineral fertilizers in the industry in today's market requires improved product quality and increased productivity. As a result, there is a need to change the design of existing units or some structural elements. Rotary vibroprillers, having a relatively simple design, can be of different designs that directly affect the productivity indicators mentioned above. The study considers the influence of the shape of the basket bottom on the quality of the rotational vibroprillers. After using the governing equation of prills motion in the airflow, a program was developed for automatic control of the rotational speed of the priller based on changes in melt loads. It is established that the size of the spray swath can be changed by varying the rotational speed of the priller. There is a tendency to affect the vibropriller performance by controlling the rotational speed and shape of the basket bottom without performance degradation.

Keywords: process innovation, jet flow, droplet formation, oscillations, energy efficiency.

1 Introduction

For calculating the prilling process of mineral fertilizers in prilling towers, it is essential to choose both the number of prillers to be installed in this tower and the shape of the bottom of the prilling basket of these prillers [1].

All these requirements drive by the need for uniform distribution of droplets and subsequently (as the crystallization of the melt occurs) prills in the cross-section of the prilling tower.

Basically, several types of prillers are used to disperse mineral fertilizer melts. These are static vibrating prillers and rotational prillers [2], which have won the favor of mineral fertilizers producers due to the prills' fine dispersion composition. Slightly less, but centrifugal mechanical prillers are also used with vibration on the melt flow.

Static prillers are currently less used in new prilling towers because they have a low flow rate (capacity t/hour) for mineral fertilizer melt, and it is impossible to change the distribution of prills in the cross-section of the prilling tower by varying the flow rate (capacity) of fertilizer melt which is typical for the production process.

Figure 1 shows an example of a basket design used to distribute the fertilizer melt into streams (jets) and inlets to the basket of a static priller.

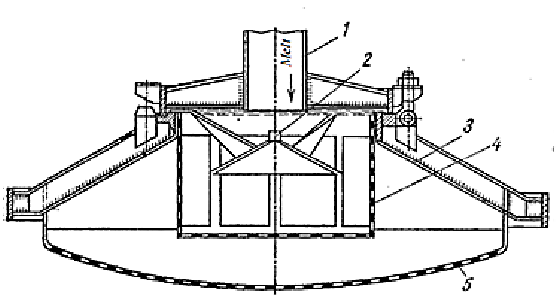


Figure 1 – Static priller: 1 – supply nozzle; 2 – guide cone; 3 – priller casing; 4 – filter screen

Such disadvantages resulting from the melt leakage of the static prillers occurred under the action of hydrostatic pressure, and all the jets of the melt flow nearly at the same speed. This ensures the same conditions for shattering them into droplets only with a constant flow rate of mineral fertilizers [3].

2 Literature Review

In order to make the process of prill formation of high quality, one can use different methods. Thus, in [4], physical modeling of the prill formation process was carried out with the study of the condition of suspension bed formation, which determines the nature of the interaction of the dispersed suspension and the dispersed solid phase. The temperature of prill formation of organic suspensions was experimentally verified, and the operating parameters of the process were determined, and the kinetics of prill growth depending on the dehydration temperature of organic suspensions were studied.

The development of the optimal shape of the working parts of the technological installation can also significantly change the quality of the resulting product. In [5], a mathematical model for estimation of the unsteady concentration of fine particles in the gas flow by time and by the height of the working space of the unit was derived from the description of the physical model of the air separation process for detection the rotating suspended bed and to ensure the loading and unloading of the pneumatic classifier. It was found that the diamond-shaped pneumatic classifier is effective in the separation of prill material, reaching up to 95 % of the target fraction.

The device with inclined perforated boards [6] can provide an active aerodynamic mode. As a result, it is possible to achieve a reduction in the capture of the coarse grade.

The separation or movement of particles and the separation of coarse or fine particles of the fluid flow are critical for ensuring product quality in most industrial processes that involve filtration [7]. The existence of different oscillation modes of droplets depending on the frequencies of the superimposed oscillation is explained in [8] using the proposed model. The study proves this model, and its realization allows us to define analytical dependence for the strain-rate component of droplets.

When designing any machinery, there should be the minimum required set of technical components that provide specific functions [9], and the use of different methods of the hydrodynamic resistance of the operating fluid in rotary machines can increase processing efficiency to obtain finely-dispersed homogeneous mixtures with specific characteristics [10]. Thus, the study [11] confirmed the need for more flexible connections, such as V-belts, in prilling equipment.

As a result of experimentally obtained measurements of the drop of the pressure and velocity of the fluid, it was found that the fluid layer rotates in the vortex chamber and inhibits the vortex flow of the gas phase [12]. It was established [13] that in an air flow with a significant shear effect, the rupture of droplets has certain signs due to stretching and lifting caused by interaction between the deformed droplet and the shear layer.

3 Research Methodology

The above disadvantages were eliminated due to the implementation of rotational vibroprillers, the design of which is shown in Figure 2.

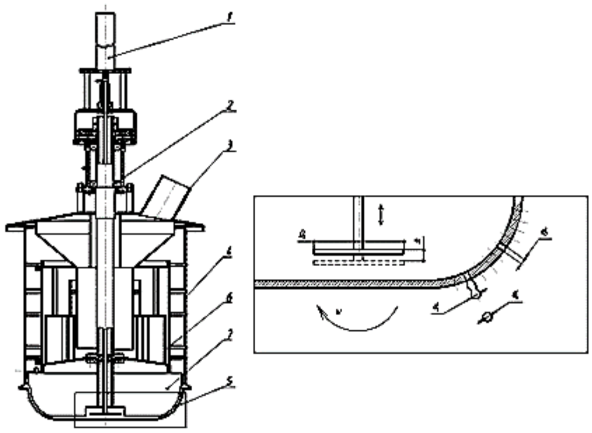


Figure 2 – Rotational vibropriller: 1 – oscillator; 2 – bearing; 3 – inlet nozzle for melt; 4 – cylindrical casing; 5 – perforated bottom (basket); 6 – distributor; 7 – vanes

Rotational vibroprillers (RVP) are characterized by leakage of fertilizer melt under the action of centrifugal force. This force occurs due to the rotation of the perforated basket of the priller [14]. Because of this, it becomes possible to distribute melt droplets on the section of a tower at various distances from its axis, thereby changing the diameter of a dispersion swath of melt.

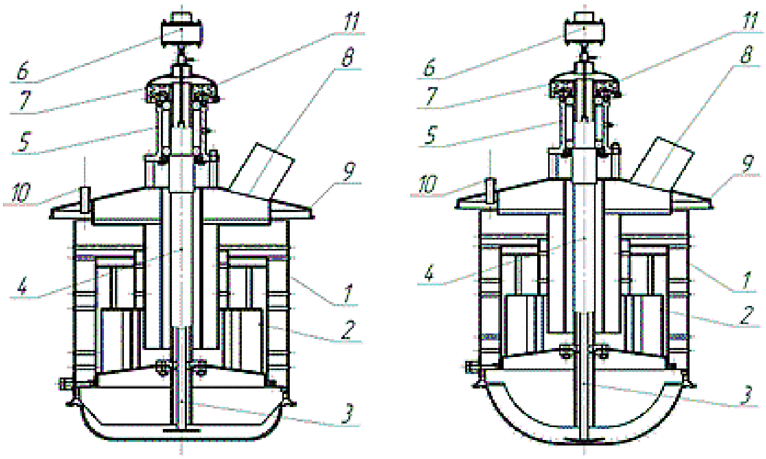
The Chemical Engineering Department of Sumy State University developed and implemented the RVP with baskets of various shapes for dispersing the mineral fertilizer melt.

Figure 3 shows two designs of RVP with spherical and toroidal-shaped basket bottoms.

Based on the results of the commercial introduction of RVP and based on the results of an industry study of the mineral fertilizer producers that used static prillers before replacing them with RVP, a comparative analysis of product quality was conducted. These comparative characteristics are shown in Table 1.

As is evident from Table 1, it is quite reasonable to conclude that RVP has a much better grain-size composition of the product compared to other vibroprillers. For example, the grain size of less than 1 mm, which is the basis of dust emissions into the atmosphere, is less than 1 %.

The shape of the bottom of the RVP basket is essential based on several requirements. First, it provides the distance from the axes of the holes from which the jets of melt flow. This is necessary to eliminate the crossing of the melt jets and to create conditions for additional grinding of the droplets or, conversely, the merging of the droplets into larger ones which significantly impairs the size of prills.



a b

Figure 3 – RVP design: a – toroidal shaped basket bottom; b – spherical shaped basket bottom; 1 – basket with perforated bottom; 2 – distributer; 3 – a rod with spraying element, 4 – shaft; 5 – bearing; 6 – oscillator; 7 – metal cap; 8 – nozzle for melt supply before start-up of the vibropriller; 9 – upper casing half; 10 – nozzle for steam supply before shut-down of the vibropriller; 11 – pulley

Table 1 – Operating data of industrial prillers of different types (production of ammonium nitrate)

Disperser characteristic (spray element)	Diameter of leakage hole, mm	Rotational speed, rpm	Flow rate, t/h	Grain–size composition, %			
				0–1 mm	1–4 mm	2–4 mm	2–3 mm
Priller with spray nozzle	–	–	12	2.2–6.1	80–96	59–63	40–49
Static and acoustic priller	0.85	–	7–18	0.8–1.5	98–99	85–95	80–90
Centrifugal conical priller	–	–	25–70	0.8–2.5	97–99	83–92	75–90
Centrifugal vibrating priller	1.10	35–55	20–100	0.5–1.0	> 99	90–97	> 90

Secondly, the different shape of the bottom allows you to arrange the hole axes for melt jets to flow at different angles to the horizontal plane of the tower. And this also affects the horizontal distance of the prills falling from the axis of the prilling tower.

Taken together, the above factors with an additional factor, such as the rotational speed of the priller basket and, in general, affect the diameter of the melt spray swatch. This is especially important if the tower is rectangular in shape and small in width. In this case, the large diameter of the spray swatch can cause droplets to hit the tower walls, sticking melt on these walls. As a result, it can even lead to the termination of the prilling tower.

4 Results

To develop a theoretical method of calculation and recommendations for selecting the shape of the basket and its rotational speed, the equation of motion of prills in air flow was used:

$$\begin{cases} \frac{d^2x(\tau)}{d\tau^2} = -\frac{3\xi_x\ \rho_{air}\left[\frac{d}{d\tau}x(\tau)+W_x\right]^2}{4\,d_p\rho_p}; \\ \frac{d^2y(\tau)}{d\tau^2} = g-\frac{3\xi_y\ \rho_{air}\left[\frac{d}{d\tau}y(\tau)+W_y\right]^2}{4\,d_p\rho_p}, \end{cases} \qquad (1)$$

where ξ – drag coefficient for prills; x, y – horizontal and vertical axes, respectively; ρ_p, ρ_{air} – density of prills and air, respectively, kg/m^3; d_p – average diameter of prills, m; g – acceleration of gravity, m/s^2.

The corresponding calculation scheme is shown in Figure 4.

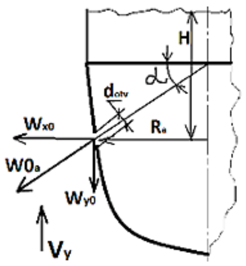


Figure 4 – The scheme of flowing the melt out the basket: H – height, m; R_a – radius on which the leakage occurs, m; α – flow angle of the jet, rad; W_{x0}, W_{y0} – initial values of the horizontal and vertical components of the droplet velocity, respectively, m/s; V_y – air velocity, m/s

Figure 5 shows an example of the calculation result of the radius of the melt spray swath, which corresponds to the horizontal component of the droplet path coming from the largest radius of the basket for ammonium nitrate in the prilling tower of 80 m in height. Signs "x" and "y" (in meters) correspond to the horizontal and vertical distance that the prill passes before it falls at the bottom of the tower.

a b

Figure 5 – Changing the radius of the spray swath for RVP's rotational speed of 180 rpm (a) and 250 rpm (b)

This figure corresponds to the radius of the spray swath.

Considering that an increase in the rotational speed by 70 rpm leads to a significant (almost twofold) increase in the spray swath radius, it is possible to influence the dimensions of the spray swatch by changing the rotational speed of the priller.

5 Conclusions

Based on theoretical and experimental studies in industrial conditions, the program of automatic control of the rotational speed of RVP depending on the change of melt loads in an industrial prilling tower was developed and implemented in the production prototype.

Thus, as a result of an experimental study on model and production prototypes and theoretical calculations, the advantages of RVP over other designs of vibroprillers were substantiated.

A method for determining the diameter of the spray swath of mineral fertilizers to develop recommendations for changing the rotational speed of the prillers in industrial conditions and the shape of the basket provided the desired initial inlet direction of jets and prills into the air stream was developed.

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