Hydraulic Resistance to Air Flow in Drum Dryers

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Abstract: The article examines the hydraulic resistance during drying of mineral fertilizer at the outlet of a drum dryer. From the analysis of existing designs of nozzles , their operating parameters were analyzed based on multi-stage system analysis based on the MATLAB program, and an improved design scheme for a two-component nozzle was developed. Based on the obtained regression equation, the optimal parameters for the values of the determined criteria were determined: dryer performance, nozzle angle, coolant speed and coolant temperature.

1 INTRODUCTION

Drying materials is one of the most energy-intensive processes in a production line. Using this process is important in determining the quality of the finished product. The cost of thermal drying is 10% of the total cost of the technological process. In this context, it is important to create highly efficient, energy-saving drying modes, as well as regulation and optimization of heat exchange processes in dryers.

It is known from the literature that the drying process depends on the size of the material, humidity, hydrodynamics of movement of the material and the drying agent, parameters of the internal and external environment (Tang, 2003; Romanko & Frolov, 1990; Pavlysh et al., 2013; Koraboev, 2022). The combination of these factors determines the conditions of the drying process. Therefore, various methods and devices are used in industry depending on the physical, chemical and mechanical properties of the material to be dried. The most common is the convective drying method, which is characterized by the simplicity of the design of drum dryers used in this process, high productivity and versatility. Therefore, the trend of using these drying units in various industries is growing, but this type of dryer also has its disadvantages. For example, some complex processes can be mentioned, such as ensuring drying intensity, rational use of the coolant used for drying, optimizing hydrodynamic parameters and minimizing energy costs. Therefore, the issues of determining and justifying the optimal parameters in this type of device are relevant. Many studies have been conducted to determine the optimal parameters of these factors (Tang, 2003). However, the presented data on the hydrodynamics of the dryer and the optimal parameters of heat exchange processes are different and sometimes contradict each other.

It is known that when drying materials in industry, two types of heat exchange are used - contact and convective. However, a large amount of heat is transferred to the dried material through convective heat exchange. The amount of heat transferred by convection to the material to be dried in a drum apparatus is up to 20 times higher than the amount of heat transferred by contact. The intensity of convective heat transfer in the dryer, in turn, directly depends on the opening of the particle surface and the average particle size. The more material is distributed over the drying surface, the greater the area of convective heat exchange. Thus, the efficiency of

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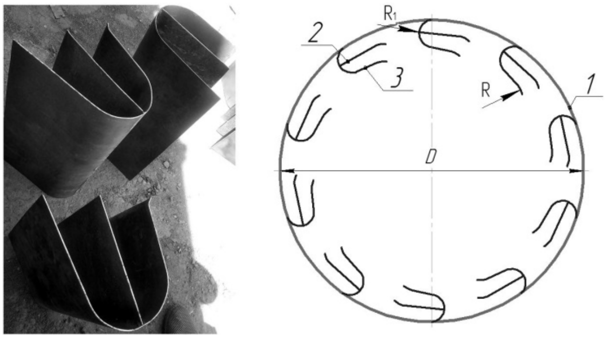


1-drum body; 2-first part of the nozzle; 3-second part of the nozzle

Figure 1: Installation diagram of the proposed nozzle on the drum.

Figure 2: General view of the drum dryer.

drying materials in a drum dryer depends on the surface layer of material falling from the dryer nozzles. In turn, ensuring that the material scatters over the internal section of the drum will depend on the design of the contact element (Romanko & Frolov, 1990; Su et al., 2015).

Although the simplicity, high efficiency and versatility of the design of drum dryers allow them to be widely used in various sectors of the national economy, there are issues such as increasing the intensity of the drying process, reducing hydraulic resistance in the device, rational use of the heating agent and minimizing energy consumption still require research.

2 EXPERIMENTAL PROCEDURE

Based on existing designs of nozzles , their operating parameters were analyzed on the basis of a multi-stage system analysis based on the MATLAB program, and an improved design scheme for a two-component nozzle was developed (Pavlysh et al., 2013) (Figure 1).

Based on system analysis, theoretical studies of the hydrodynamic modes of a drum dryer were carried out, a mathematical model of the drying process was developed, the heat balance of thermal drying of dispersed materials in a drum dryer, methods for calculating heat and mass transfer coefficients and optimizing the drying process (Pavlysh et al., 2013).

In this article, based on the results of theoretical studies, the parameters affecting the intensity of heat transfer at low energy consumption using a two-element nozzle in a drum dryer are experimentally determined, as well as the influence of hydraulic resistance and coolant velocity on the temperature of the material (Aghbashlo et al., 2015; Brammer, 1999; Khoshkava, 2014).

To assess the influence of the nozzle design on the hydrodynamic parameters of the apparatus and heat transfer processes, a laboratory drum dryer was developed and experiments were carried out (Figure 2). The experiments were carried out in two stages (Janowicz et al., 2018; Le Bissonnais, 1989; Sharma et al., 2014).

3 RESEARCH RESULTS

At the first stage, the hydraulic resistance of a drum with a two-section nozzle was studied. For the research, the following limits of variable parameters were selected: nozzle angle inclination R=15; 30 va 45 ^{o} , number of heat exchange zones - 5, number of nozzles in one row - 10 (nozzles are arranged in zones in a checkerboard pattern), Speed of the coolant (air) leaving the heater υ=1.4÷14.2 m/s, Productivity devices Q_{pr}=0.18÷0.46 kg/s, Angle of inclination of the drying drum relative to the plane α = 2.24 degrees (according to technological regulations), rotation speed of the drum dryer was set to n = 2.5; 3; 3.5 and 4 rpm. Tashki x̦ aroat gas va suv tizimi uchun 20 ±2 ^{o} From tanlandi. Namuna materiali siphatida superphosphate mineral ugiti tanlandi. The ambient temperature was 20±2°C. Superphosphate mineral fertilizer [superphosphate regulation] was chosen as the experimental material.

The coefficients of hydraulic resistance of the working bodies influencing the flow of coolant in the dryer were determined experimentally from the difference in the velocities of the inlet and outlet gas in the apparatus and were solved according to the proposed equation (Romanko & Frolov, 1990).

The obtained theoretical and experimental values were compared and correction factors were introduced. Empirical formulas were obtained by the least squares method. The resistance coefficients affecting the coolant flow in a drum dryer with a two-section nozzle are given below.

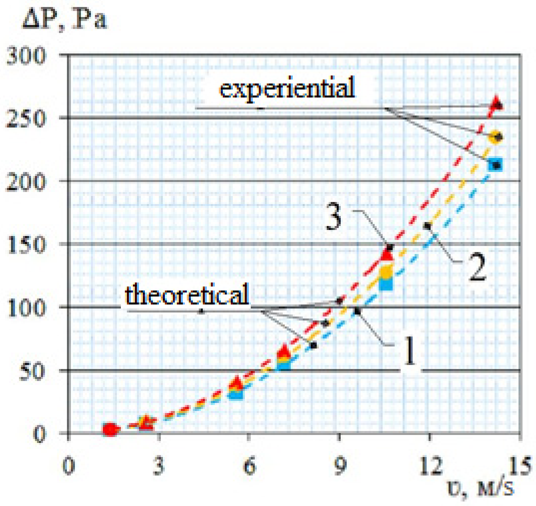
According to the results of experiments at R= 15 ^{o} and at apparatus productivity at 0.02 kg/s, the coefficient is ξ= 3.34, at apparatus productivity at 0.03 kg/s, the coefficient is equal to ξ= 3.52 and at apparatus productivity at 0 .04 kg/s the coefficient is ξ= 3.74. According to the results of experiments at R= 30 ^{o} and at apparatus productivity at 0.02 kg/s, the coefficient is ξ= 4.66, at apparatus productivity at 0.03 kg/s, the coefficient is ξ= 4.81 and at apparatus productivity at 0.04 kg/s coefficient is ξ= 5.07. According to the results of experiments at R= 45 ^{o} and at apparatus productivity at 0.02 kg/s, the coefficient is ξ= 5.91, at apparatus productivity at 0.03 kg/s, the coefficient is ξ= 6.09 and at apparatus productivity at 0.04 kg/s coefficient is ξ= 6.31. The error between theoretical and experimental studies did not exceed 5%.

The total hydraulic resistance of the apparatus was determined experimentally at various values of variable factors. In the experimental determination of hydraulic resistance, an electronic measuring device JM-510 was used, which was compared with the theoretical values determined by equation (4) and plotted on a graph (Figures 3, 4 and 5).

As can be seen from the data presented in Figures 3; 4 and 5 , at a gas speed υ= 1.4÷14.2 m/s at an interval step of 2.65 m/s and at a productivity Q = 0.02 ÷ 0.04 kg/s at an interval step of 0.14 kg /s, with a slope of the bulk part of the nozzle R = 15 o ˒ the minimum value of hydraulic resistance was ΔP = 2.11 Pa, and the maximum value of hydraulic resistance was ΔP = 262.6 Pa. Under similar conditions, with a slope of the bulk part of the nozzle R = 30 ^{o}˒ the minimum value of hydraulic resistance was ΔP = 3.65 Pa, and the maximum value of hydraulic resistance was ΔP = 426.5 Pa. Under similar conditions, with a slope of the bulk part of the nozzle R = 45 ^{o}˒ the minimum value of hydraulic resistance was ΔP = 5.23 Pa, and the maximum value of hydraulic resistance was ΔP = 583.09 Pa. Empirical formulas were obtained to adequately describe the process using the least squares method for the graphical relationships shown in Figures 3-5.

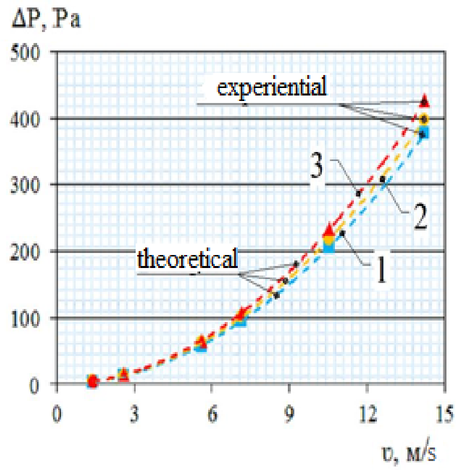
At the second stage, the effect of coolant velocity on the temperature of the material was studied. Experiments were carried out on a laboratory installation to determine the kinetic curves of the drying process of mineral fertilizers. For the research, the following values of variable parameters were selected: drum productivity G_M = 0.02; 0.03; 0.04 kg/s, coolant speed in the drum υ = 1.4÷14.2 m/s and drum speed n = 2.5; 3.0; 3.5; 4.0 rpm

In the experiment, the initial parameters had the following values. The initial moisture content of pre-moistened mineral fertilizers was 20%. The initial temperature of the coolant leaving the heater was set at 100°C. The air temperature at the inlet and outlet of the drum was measured with an ANEMOMETER BA06–TROTEC device. The initial temperature of the material was measured with a TS-4 thermometer. The temperature at which the dried material enters the drum was 21°C. During the experiment, the temperatures of the dried material and the heating agent leaving the drum were measured and are listed in Tables 1–8. During the experiment, samples of dried material were taken and their moisture content was determined. The moisture content of the samples is determined by drying them at 105°C for 3 hours in an oven. The experiment results are shown in Figure 6.



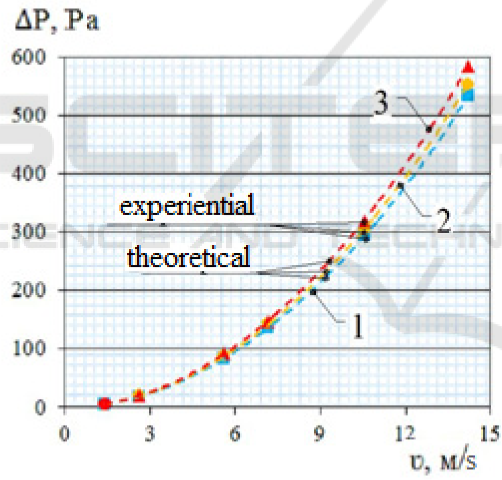
At Q = 0.02 kg /s .

Figure 3: plotted on a graph



At Q = 0.03 kg /s.

Figure 4: plotted on a graph



At Q = 0.04 kg /s.

Figure 5: plotted on a graph

1 - slope of the filling part of the nozzle R = 15 º;
2 - slope of the filling part of the nozzle R = 30 º;
3 - slope of the filling part of the nozzle R = 45 º;

Figures 3-5: Dependence of hydraulic resistance on gas speed.

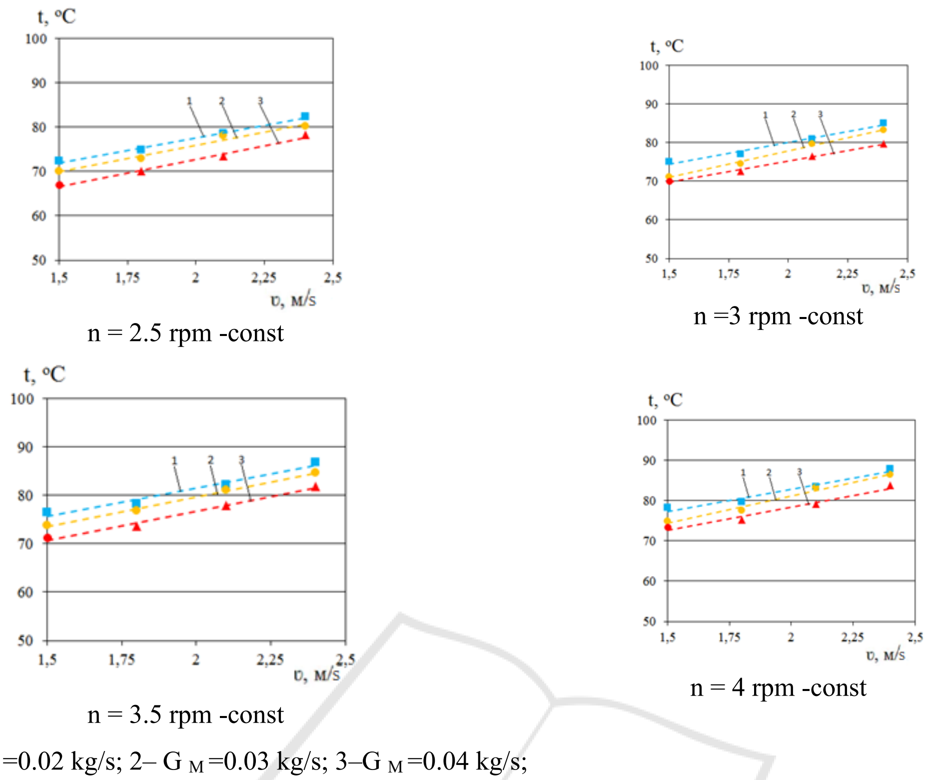


Figure 6: Dependence of coolant velocity on changes in material temperature.

As can be seen from Figure 6, with drum performance GM = 0.02; 0.03; 0.04; 0.05 kg/s, coolant speed in the drum W = 1.5; 1.8; 2.1; 2.4 m/s and at a drum speed of n = 2.5 rpm, the minimum value of the temperature of the dried mineral fertilizer was t_2 = 64.90 C, and the maximum value of the temperature of the dried mineral fertilizer was t_2 = 82.40 C. At a drum speed of n = 3 rpm, the minimum value of the temperature of the dried mineral fertilizer was t_2 = 66.90 C, and the maximum value of the temperature of the dried mineral fertilizer was t_2 = 84.30 C. At the drum speed n = 3.5 rpm, the minimum value of the temperature of the dried mineral fertilizer was t_2 = 68.70 C, and the maximum value of the temperature of the dried mineral fertilizer was t_2 = 86.80 C.

To determine the optimal values, a mathematical planning method was used based on multifactorial experiments. In theoretical studies and multivariate experiments, the second most effective factors are dryer performance (X1), nozzle angle (X2), coolant velocity (X3) and coolant temperature (X4), device hydraulic resistance, product quality and energy consumption. The cooling temperature of the fertilizer (Y1), the granular composition of the material (Y2) and the hydraulic resistance of the drum (Y3) were taken as evaluation criteria for conducting multifactor experiments.

Assuming that the influence of factors on the evaluation criteria will completely cover a second-degree polynomial, experiments were carried out based on the HARTLI-4 design.

To reduce the influence of uncontrollable factors on the evaluation criteria, the sequence of experiments was determined using a 1/17 random number table, and the experiments were repeated 5 times separately.

The arithmetic mean values of the experimental results were chosen. The results of the experiments were processed in the appropriate order, adequately representing the evaluation criteria, were obtained according to the program regression equations of the HARTLI-4 program “PLANEX”, and graphs of the dependence of the variables on the criteria were constructed (Figures 7-8).

Then:

The cooling temperature of the fertilizer in the device is determined by the following regression equation, °C

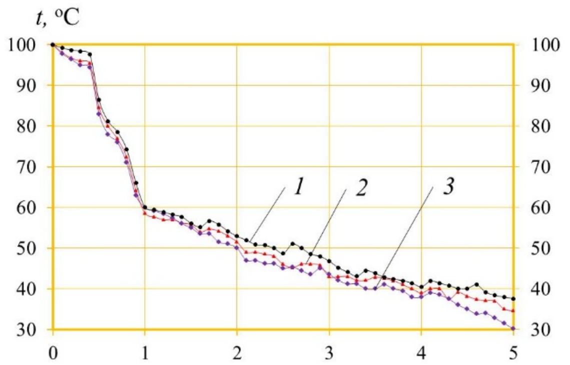


Figure 7: Dependence of fertilizer temperature on variable factors and drum zones.

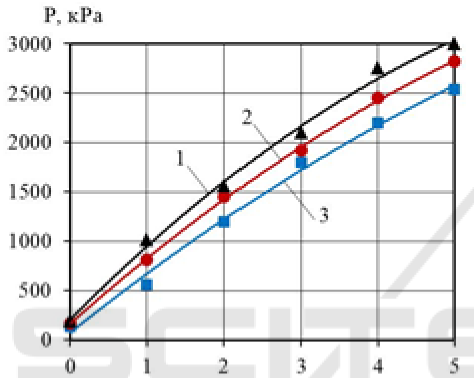


Figure 8: Dependence of hydraulic resistance on variable factors and drum zones

$$Y_1 = + 133.8952 + 35.563 X1 + 0.000 X2 + 154.300 X3 + 18.2967 X4 + 64.683 X1X1 + 45.287 X1X2 - 45.238 X1X3 - 44.679 X1X4 + 62.984 X2X2 - 22.7521 X2X3 - 19.629 X2X4 - 88.350 X3X3 + 45.196 X3X4 - 119.949 X4X4 ; \quad (1)$$

The hydraulic resistance of the drum is determined by the following regression equation, kPa

$$Y = + 1329.121 + 3555.5 X1 + 3620.0 X2 + 1541.13 X3 + 1827.20 X4 + 2556.7 X1X1 + 4520.2 X1X2 – 4521.8 X1X3 – 4457.8 X1X4 + 3879.9 X2X2 – 2274.50 X2X3 – 1937.3 X2X4 – 1728.1 X3X3 + 2117.0 X3X4 – 1088.21 X4X4 ; \quad (2)$$

From the analysis of the obtained regression equations (equations 1 and 2) and graphs (Figures 10-11) it is clear that all factors have a significant impact on the evaluation criteria. In addition, the performance of the device, the angle of inclination of the nozzle, the speed of the coolant and the temperature of the coolant are in a complex relationship with the factors under study.

4 CONCLUSIONS

To determine the factors influencing the processes under study, the hydraulic resistance of the device, and the optimal values of energy consumption, regression equations were solved separately according to specified criteria. In this case, the fertilizer cooling temperature was taken above 30-40 °C, and the hydraulic resistance of the drum was 3.4-4 kPa. This problem was solved on a Pentium IV PC using the Excel program “Search for Solutions”, the optimal values of the variables were obtained in encoded form and the encoded values were converted into natural values. Thus, the optimal parameters for the values of the determined criteria were standardized and amounted to: dryer performance (X1) - 0.39 kg/s, nozzle angle (X2) - 35.6 degrees, coolant speed (X3) - 10.26 m/s and coolant temperature (X4) - 50.4 °C.

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