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Theoretical Basis Of Cascade Dryer Aerodynamics And Evaluation Of Variable Parameters

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Abstract: This article discusses the theoretical foundations of the aerodynamics of a cascade dryer used in the industrial drying of wheat grain and the physical and mathematical models of the heat and mass transfer processes occurring in it. The efficiency of the dryer is evaluated depending on the air flow rate, temperature, partial pressure, and moisture properties of the grain being dried. The study analyzed the effects of parameters such as the drying agent motion mode, resistance coefficients in the grain layer, mass transfer coefficient hm, and evaporation coefficient ϕs. Also, the relationships between the saturation pressure of water vapor on the grain surface psat(Ts), air humidity Yxavo, and air density ρn.u were developed. The results obtained serve to determine the optimal technological modes that allow for energy-efficient drying of wheat while maintaining quality indicators.

Keywords: Wheat drying, cascade dryer, aerodynamics, moisture exchange, mass transfer coefficient, evaporation coefficient, psat(Ts), partial pressure, air density, drying agent, heat-mass transfer process.

INTRODUCTION:

The grain drying process is one of the most important stages in the storage of agricultural products. Prolonged storage of wheat grain at high humidity leads to microbiological deterioration, self-heating, deterioration of quality, and storage losses. Therefore, improving technologies for fast, uniform, and energy-efficient drying of grain is one of the priority tasks of modern agrotechnical areas.

There are several types of wheat grain drying in the industry; These are contact, convective, and radiation (under the influence of sunlight). Among the drying methods, one of the most widely used energy-efficient methods is the convective method, which mainly uses drying drums. Drying drums can reduce the moisture content of wheat grain to 15-14%. Since drying drums also have a number of disadvantages, we first came to the conclusion that a cascade dryer is the most acceptable solution.

METHODS

Cascade dryers are high-performance designs based on the free fall of grain layer by layer and repeated exposure to the flow of drying agent. In such dryers, the aerodynamic properties of the air flow, the trajectory of grain movement, the density of the layer and the heat and mass exchange between the compartments determine the drying efficiency. In particular, the correct assessment of the parameters of the mass exchange coefficient hm, air density ρn.u, evaporation coefficient ϕs and the partial pressure of water vapor on the grain surface Ts forms the scientific basis of the drying process.

In this regard, in this work, theoretical justification of the aerodynamics of a cascade dryer was carried out, the interaction between air and grain during the drying process was modeled, and the main technological parameters affecting the efficiency of the dryer were comprehensively evaluated. The results of the study allow us to reduce energy consumption, optimize drying time, and select effective drying modes while maintaining grain quality.

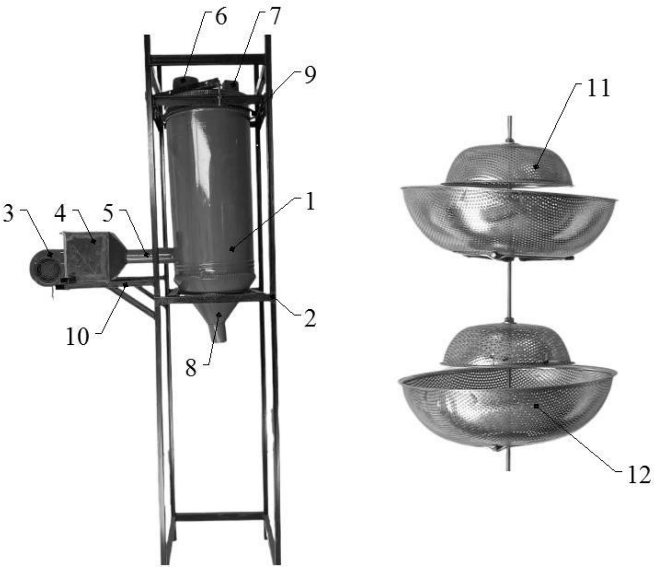
Theoretical calculations for the physical model of the device resulted in the following Ergun equation for cascade dryers;

$$\Delta P=\left[\sum_{i=1}^{N}\left(\frac{\mu}{\frac{d_p^2}{150}\frac{\varepsilon^3}{(1-\varepsilon)^2}}+\rho\frac{1.75}{d_p}\frac{(1-\varepsilon)^2}{\varepsilon^3}\right)+\zeta_{p.t}\frac{1}{2\alpha}+\sqrt[4]{\frac{\mu}{w\cdot\rho_h\sqrt{\frac{V_c}{0,785\cdot w}}}}\cdot\frac{l}{d}+\zeta_m+\zeta_k\right]\frac{\upsilon^2}{2} \qquad (1.1)$$

To verify the above-recommended equation (1.1) and theoretically calculate the total aerodynamic resistance of the device, a physical model of the cascade dryer was prepared based on the analysis performed using the MatLab program and the specified parameters, and the total variable parameters of the device were determined.

RESULTS AND DISCUSSION

Figure 1 shows an overview of the physical model of the cascade dryer, and Table 1 shows the overall dimensions of the device and the measurement values of selected auxiliary devices.



1- Cascade vertical dryer body; 2- Support frame; 3- Fan; 4- Cooler; 5- Hot air flow distribution pipe with a slide; 6- Drying material inlet pipe; 7- Heat agent outlet pipe; 8- Dried material outlet pipe; 9- Ring fastener; 10- Fan and cooler mounting frame; 11- Small cascade nozzle; 12- Large cascade nozzle.

Figure 1. Physical model view of cascade dryer.

Table 1. Overall dimensions of the physical model of the device and measurement values of the selected auxiliary devices

№	Name	Symbol	Value
The main dimensions of the device			
1	Device diameter	mm	400
2	Device height	mm	1300
3	Small cascade diameter	mm	250
4	Large cascade diameter	mm	400
5	Product inlet pipe diameter	mm	60
6	Product outlet pipe diameter	mm	60
7	Heating agent inlet pipe diameter	mm	80
8	Heating agent outlet pipe diameter	mm	100
Values of selected auxiliary devices			
1	Fan power	kW	0,3
2	Coloriferous power	kW	2

3	Rheostat power	kW	0,002
4	Dispenser capacity	kW	0,15
5	Electric regulator	kW	0,1

According to it, the variable parameters are a centrifugal type ventilator (efficiency Q_{max} = 420÷540 m^3/h; electric power N_{dv} = 0.24 kW; rotation frequency n = 2800 rpm), a Pitot-Prandl tube (7.18) (50 and 100 mm in size), a metal pipe with a diameter of D = 60 mm, L = 1200 mm, which determines the speed of the dusty gas, and two Pitot-Prandl tubes with an internal diameter of 7 mm, which determine the static and dynamic pressures in the pipe (the Pitot-Prandl tube was selected in accordance with the diameter of the gas outlet of the ventilator according to the requirements for determining the gas speed, efficiency and pressure St). In addition, in order to compare the results obtained, an electronic meter for determining gas velocity ANEMOMETER VA06–TROTEC (Measurement range 1.1m/s ÷ 50m/s, error coefficient 0.2%, when the gas velocity exceeds 50 m/s, the error coefficient is 5%). To control the velocity of the heat agent, a gate valve was installed on the gas outlet pipe of the heater, forming an angle of 0^o; 30^o; 45^o; 60^o; 90 ^{o}.

Theoretical calculation of the drag coefficient and aerodynamic resistance of the working bodies of the cascade dryer.

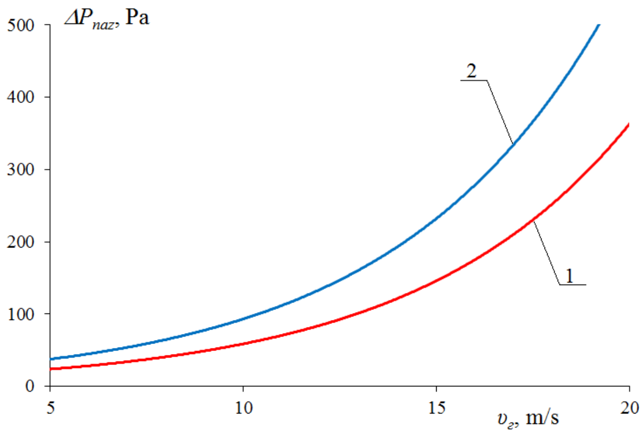
Initially, the theoretically determinable parameters were calculated based on the data given in Table 1 and the device was fully calibrated. After that, the resistance coefficients affecting the air flow in the working bodies of the device were determined. Taking into account the large number of interdependencies of the variable parameters, the resistance coefficients in the air speed range of 5÷20 m/s (with an intermediate increase of 5 m/s) were calculated based on the recommended equations for the lower and upper ranges of the variable parameters. Table 2 presents the determined values of the calculation results.

Table 2. Values of the coefficient of resistance determined based on the variable parameters of the cascade dryer

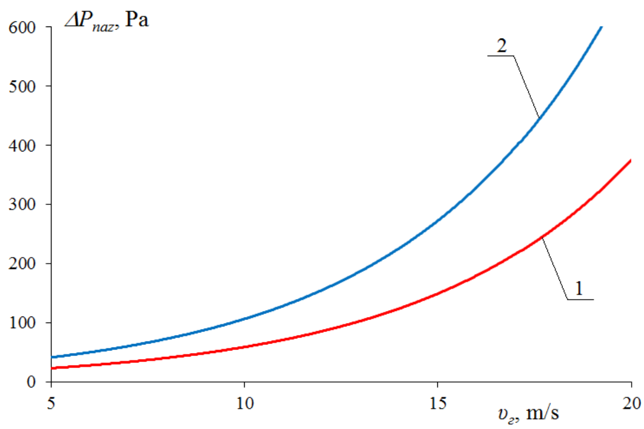
№	Cylinder body diameter, m	Cylinder body height, m	Angle of inclination of a small cascade nozzle, degree value	Large cascade nozzle bevel angle, degree value	Heat agent velocity, m/s	The resistance coefficient is arbitrary	The coefficient of resistance is the apparatus when the material being dried falls
Results obtained in the lower range of variable parameters when the performance is 0.06 kg/s							
1	0,8	1,3	0,16	0,17	5	1,16	1,3
2					10	1,18	1,32
3					15	1,18	1,34
4					20	1,17	1,32
Results obtained in the upper range of variable parameters when the productivity is 0.06 kg/s							
1	0,8	1,3	0,16	0,17	5	1,89	2,15
2					10	1,9	2,16
3					15	1,85	2,15
4					20	1,87	2,15
Results obtained in the lower range of variable parameters when the performance is 0.065 kg/s							
1	0,8	1,3	0,16	0,17	5	1,2	1,49
2					10	1,19	1,48
3					15	1,21	1,49
4					20	1,21	1,5
Results obtained in the upper range of variable parameters when the productivity is 0.065 kg/s							
1	0,8	1,3	0,16	0,17	5	2,1	2,41
2					10	2,2	2,4

3					**15**	**2,21**	**2,37**
4					**20**	**2,21**	**2,38**
Results obtained in the lower range of variable parameters when the performance is 0.07 kg/s							
1	**0,8**	**1,3**	**0,16**	**0,17**	**5**	**1,47**	**1,73**
2					**10**	**1,48**	**1,72**
3					**15**	**1,46**	**1,76**
4					**20**	**1,47**	**1,75**
Results obtained in the upper range of variable parameters when the productivity is 0.07 kg/s							
1	**0,8**	**1,3**	**0,16**	**0,17**	**5**	**2,37**	**2,68**
2					**10**	**2,37**	**2,66**
3					**15**	**2,38**	**2,68**
4					**20**	**2,36**	**2,67**

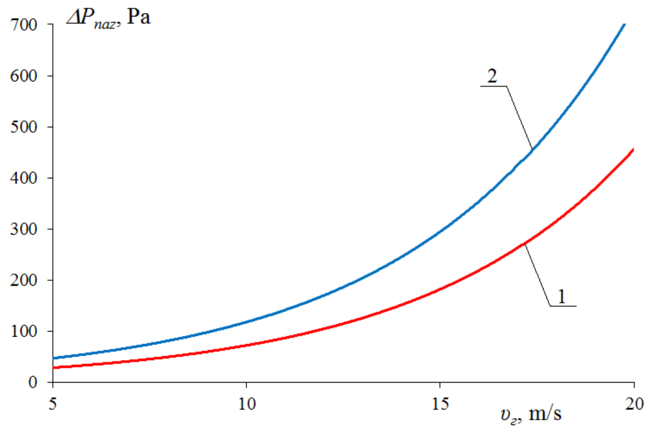
Based on the resistance coefficients obtained in the calculation results, the aerodynamic resistance of the device was theoretically calculated. The results are presented graphically in Figures 2, 3, and 4.



1- When the productivity of the device is 0.06 kg/s and the number of cascades is 4 pieces; 2- When the productivity of the device is 0.06 kg/s and the number of cascades is 8 pieces;
Figure 2. Graph of change of aerodynamic resistance ΔP_{naz} depending on gas velocity v_r



1- When the productivity of the device is 0.065 kg/s and the number of cascades is 4 pieces; 2- When the productivity of the device is 0.065 kg/s and the number of cascades is 8 pieces;
Figure 3. Graph of change of aerodynamic resistance ΔP_{naz} depending on gas velocity v_r



1- When the productivity of the device is 0.07 kg/s and the number of cascades is 4 pieces; 2- When the productivity of the device is 0.07 kg/s and the number of cascades is 8 pieces;

Figure 4. Graph of change of aerodynamic resistance ΔP_{naz} depending on gas velocity v_r.

The graphical relationships obtained using the results of calculations based on equation (1.1) show that with an increase in the numerical value of the parameters changing in the device, the aerodynamic resistance generated in the working bodies of the device also increases according to the law.

CONCLUSION

It can be concluded that the recommended equation (1.1) was found to be a suitable option for determining the aerodynamic resistance of the device in the process under investigation. The error coefficient of equation (1.1) given on the basis of mathematical processing of the results did not exceed 4.2%. These values are important in experimental studies of the device.

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