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Research of a machine with a belt conveyor for drying grain

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Abstract. Currently, grain drying technology is imperfect. Therefore, the development and scientific substantiation of energy-saving, environmentally friendly installations for drying grain that meet the requirements of modern Russian agrarian production is an urgent and important scientific and technical task that is essential for the development of the country. To solve this problem, we have developed a contact-type installation with a belt conveyor. For an objective assessment of the research object, the specific energy consumption per 1 kg of evaporated moisture $q_{уд}$, kJ/kg of moisture was taken as an optimization criterion. The study of the installation in the drying mode was carried out on oat grain. After processing the results of the experiments, a new equation was obtained. This is a regression equation in natural and coded values of independent factors. The regression equation characterizes the influence of independent factors on the optimization criterion. Having solved the regression equation, it was found that the minimum specific energy consumption for drying grain is 4388 kJ/kg of moisture. This value is achieved at an average temperature of the conveyor belt $t_{гр}$ = 60 °C and the residence time of grain in the installation $\tau_{об}$ = 40 s. In this case, the convergence of theoretical and experimentally obtained research results was at least 95%. The decrease in grain moisture during the heating cycle in the developed installation is 2 ... 2.5%, which corresponds to agrotechnical requirements. Thus, as a result of theoretical and experimental studies of the developed installation, it was revealed that with optimal values of independent factors, the specific energy consumption is 4388 kJ/kg of moisture, which is 1.5 times less compared to serial grain dryers, in particular, with the SZ- 1.

1 Introduction

In the food and processing industry, it is of paramount importance to reduce losses and improve the quality of products at all stages of their processing and storage.

Agricultural enterprises, farms, personal subsidiary plots spend significant funds on food processing in third-party organizations, which reduces the profitability of production [1]. During long-term storage of wet grain, pests - beetles, mites, microorganisms - are introduced into it [2]. As a result of their vital activity, pests eat grain, pollute it with waste products, which reduces the quality of grain. To improve the quality, germination properties, as well

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as to be able to store grain for a long time, it must be dried, while its moisture content is brought to 13 ... 14% [3].

At present, grain drying technology and machinery are imperfect. The existing means of mechanization have a high cost, which can exceed 1.5 million rubles, as well as high energy costs, which can exceed 6 MJ / kg of moisture. Grain dryers used in industry can leave up to 45 % of grain wet, they do not meet environmental requirements and have a high weight - over 1500 kg·h/t. In addition, serial installations use heated air as a heat carrier. In such grain dryers, the air is heated by burning liquid fuels in a furnace [4]. However, this is associated with high energy consumption, as well as environmental pollution. When 1 liter of liquid fuel is burned in large quantities, toxic substances are formed: nitrogen oxides, hydrocarbons, carbon monoxide, soot and others. For example, during operation of the SP-50 dryer in 1 hour, up to 14 kg of carbon monoxide, 4.5 kg of hydrocarbons, 20.4 kg of nitrogen oxides, 18 kg of sulfur oxides, 2 kg of soot are emitted into the environment. Therefore, the development of a new method of drying grain and technical devices for its implementation, which ensure the required quality of the finished product with minimum energy consumption is an urgent task.

2 The study objects and research methods

To improve the quality of grain drying, to reduce the specific energy consumption, we have proposed a fundamentally new contact type installation with a belt conveyor (Figure 1). [5].

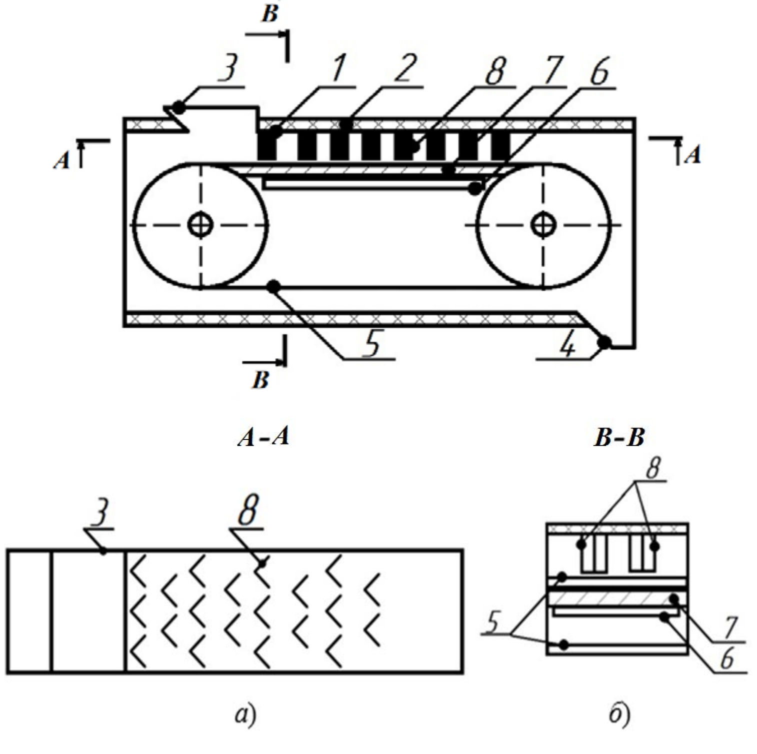

Fig. 1. Scheme of the proposed installation (designations in the text): a) – section along A-A; б) – section along B-B.

The grain drying unit consists of a rectangular casing 1 covered with a layer of heat-insulating material 2, a loading hopper 3, an unloading window 4 installed inside the casing 1 with the possibility of rotation of the transporting working body 5, as well as heating elements 6. The transporting working body 5 is made in the form of two drums mounted for rotation parallel to each other and connected by a flexible belt. The flexible tape is made of heat-conducting material. On the lower side of the upper section of the flexible tape, a plate 7 is installed, also made of a heat-conducting material. Heating elements 6 are located on the lower side of the plate 7. On the inner upper side of the casing 1, perpendicular to the upper surface of the flexible tape, there are grain flow dividers 8 made of two rectangular plates. Rectangular plates are installed vertically and interconnected in such a way that they form an acute angle in plan, the apex of which is directed opposite to the direction of movement of the flexible tape. The flow dividers 8 are installed in a staggered manner with a minimum gap between their lower ends and the outer surface of the upper branch of the flexible tape.

The installation works as follows. Include the drive of the transporting working body 5. Then the heating elements are turned on 6. After reaching the required temperature of the flexible belt, grain is fed into the loading hopper 3, from where it is transported by the belt 5 to the unloading window 4. In contact with the heated surface of the flexible belt, the grain also heats up and loses excess moisture. During the movement of the flexible belt, the grain meets the flow dividers 8. By installing the flow dividers 8 in a staggered manner with a minimum gap between their lower ends and the outer surface of the upper branch of the flexible tape, the grain moves along the outer surface of the flow dividers. In this case, the grain is displaced along the width of the flexible belt of the transporting working body 5, mixed, and moisture is removed from the grain in the form of steam. Dry grain is removed from the dryer through the discharge window 4.

As a result of theoretical research, equations were obtained for determining the throughput (1) and power (2) spent on the drive of the conveyor belt.

$$Q = \gamma\psi\upsilon(2h_{\mathrm{rl}} + h_{\mathrm{p}} + (n_{\mathrm{br}} - 1)h_{\mathrm{v}})(l_2 + n_{\mathrm{r}}(l_{\mathrm{v}} + l_{\mathrm{mr}}) + l_3), \quad (1)$$

$$N_P = (1 + k_{N3})(F_R + F_I)(A + 1)\upsilon(l_2 + n_{\mathrm{r}}(l_{\mathrm{v}} + l_{\mathrm{mr}}) + l_3)/l_{\mathrm{mr}}), \quad (2)$$

where: γ - bulk density of grain, kg/m^3; ψ – filling factor of the conveyor belt at different heights of the grain flow dividers; υ – the speed of the belt of the transporting working body, m/s; h_{rl} – distance between the edge of the grain flow divider and the edge of the conveyor belt, m; h_{p} – is the distance between the edges of the grain flow dividers plates, m; n_{br} – number of flow dividers, along with their large number, pcs; h_{v} – distance between the tops of the grain flow dividers, m; l_2 – distance from the loading hopper to the edge of the first row of grain flow dividers, m; n_{r} – number of rows of grain flow dividers, pcs; l_{v} – length of flow dividers plates, m; l_{mr} – distance between adjacent rows of grain flow dividers, m; l_3 – distance from the edge of the plates of the last row of grain flow dividers to the unloading hopper, m; k_{N3} - proportionality coefficient; F_R – the force required to move the grain, N; F_I - force of inertia, at collision of grain with flow dividers, N; A - design factor of the shape of the discharge nozzle.

The contact-type installation with a belt conveyor was developed in accordance with RF patents Nos. 183490, 172219, 172220, 183490, 173411, 172974 (Figure 2).

Fig. 2. Working chamber of a contact type dryer with a belt conveyor, where: 1 - casing frame; 2 - frame of the plant for drying grain; 3 - loading hopper; 4 - unloading branch pipe; 5 - conveyor belt; 6 - conveyor drive

The study of the installation in the drying mode was carried out on oat grain (Figure 3). The developed installation was investigated in laboratory conditions in full compliance with the requirements of GOST (state standard) [6].

Fig. 3. Study of the movement and heating of grain in the proposed installation

The purpose of experimental research is to determine the optimal design parameters and operating modes of the installation, which provide the required quality of grain drying and the minimum specific energy consumption. As an optimization criterion, the specific energy consumption per 1 kg of evaporated moisture was chosen, since it comprehensively evaluates the object under study, and also connects all the acting factors into a mathematical model [7].

To determine the optimization criterion, the following formula was used:

$$q_{sp} = \sum N/(Q(t_v - t_n), \tag{3}$$

where: $\sum N$ – is the total power spent on the drive of the conveyor belt and on the operation of the electric heater, J/s; t_n – grain temperature before drying, °C; t_v – grain temperature after drying, °C.

3 Research results

The limits of variation of independent factors influencing grain drying in the developed installation were chosen as follows: average belt temperature - 40…80 °C, grain heating time in the installation - 20 ... 70 s.

As a result of the research, a new regression equation (4) was obtained, which characterizes the influence of the selected independent factors on the optimization criterion.

$$q_{sp} = 3070{,}23 + 8{,}71t_{gr} + 36{,}28\tau_{ob} - 0{,}03t_{gr}^2 - 0{,}16t_{gr}\tau_{ob} - 0{,}11\tau^2_{ob}, \quad (4)$$

where: q_{sp} - specific energy consumption, kJ/kg moisture; t_{gr}- average temperature of the heating surface, °C; τ_{ob} - grain processing time in the installation, s.

The resulting regression equation was solved using the canonical analysis of a two-dimensional section (Figure 4).

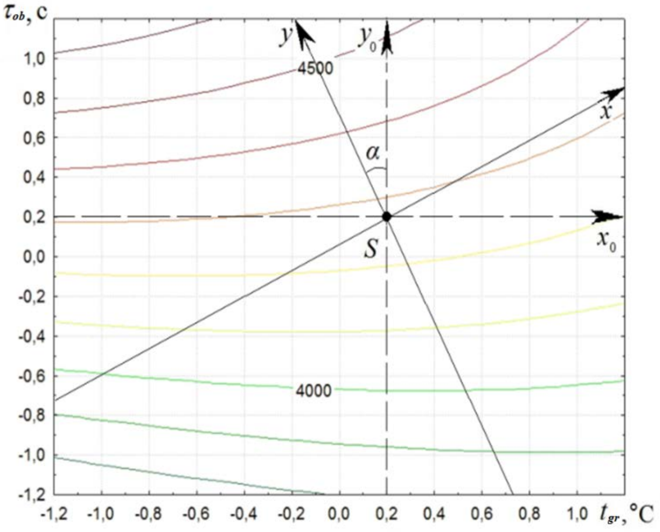

Fig. 4. Two-dimensional section of the response surface, characterizing the effect of t_{gr} and τ_{ob} on q_{sp}

For this, the regression equation was coded and differentiated for each variable. Then the partial derivatives were equated to zero and the roots of the obtained equations (5), (6) were searched.

$$dY/dx_1 = - 39{,}19x_1 – 69{,}54x_2 – 33{,}0112; \quad (5)$$

$$dY/dx_2 = - 69{,}54x_1 – 67{,}66x_2 + 309{,}04; \quad (6)$$

4 Discussion

As a result of the analysis, it was found that the optimal values of independent factors are: the average temperature of the conveyor belt t_{gr} = 60 °C, the residence time of the grain in the installation τ_{ob} = 40 s. Specific energy consumption in this case is q_{sp} = 4388 kJ/kg moisture. The decrease in grain moisture during the heating cycle in the developed installation is 2 ... 2.5 %, which corresponds to agrotechnical requirements. In this case, the throughput of the installation is 400 kg/h, and the convergence of theoretical and experimental research results was at least 95 %.

5 Conclusion

Thus, as a result of theoretical and experimental studies of the developed installation, it was revealed that, with optimal values of independent factors, the specific energy consumption is 4388 kJ/kg of moisture, which is 1.5 times less compared to commercially available grain dryers, in particular, with the installation SZ-1.

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