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Energy-saving dryer

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Abstract. The urgency of creation of drying installation of contact type with electric heating a thin layer of a grain is formulated and proved. The circuit of installation for drying a grain is offered and her working process is described. Theoretical researches by definition of technological and constructive parameters of installation are resulted. The basic advantages of offered installation to drying a grain are revealed in comparison with existing.

In ensuring the safety of the harvested crop and bringing it to marketable products, the most important place belongs to the means of mechanization of post-harvest processing and storage of grain. Over the past decade, the gross grain harvest has almost halved, the provision of farms with complete means of mechanization has decreased many times. In this regard, the loss of grain reaches 10...20 % of its gross yield. Due to financial difficulties farms do not acquire new equipment, and the industry due to lack of demand produces it in limited quantities. At the same time, the level of profitability of grain production and especially seeds is not less than 40 %. Therefore, in the coming years, we can predict an increase in demand for new equipment for processing and storage of grain.

The creation of promising means of mechanization of grain drying should be based on the following conceptual provisions.

Store and process the harvest should be mainly at the place of its production. As the basic elements of the infrastructure of grain and seed processing enterprises to use different types of storage. To apply a two-step technology involving in the harvest period a minimum amount of work necessary for the preservation of the harvest and post-harvest - bring it to desired conditions. Grain and grain waste to bring to commodity production (flour, cereals, compound feeds, etc.) in grain-producing farms [1].

The creation of modern technology that can provide high-quality drying of grain in a short time is possible only on a scientific basis. Studies of the thermal characteristics of a single grain and a grain layer have shown that the values of the thermal conductivity and thermal diffusivity for a single grain are significantly different from those for a layer of the same grain. It follows from this that for rapid heating of the entire mass of grain, it is necessary to create a drying plant in which each individual grain is heated. This can be done in grain dryers contact type with a movable thin layer of grain.

To solve the tasks set before the heat treatment, on the basis of in-depth study and analysis of the existing means of mechanization, we proposed a plant for drying grain (figure 1) [2]. It consists of a cylindrical casing 1, covered with a layer of heat-insulating

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material 2, a loading hopper 3, a discharge window 4, coaxially installed inside the casing with the possibility of rotating the transporting working body 5, made in the form of a screw, as well as a cooling device including a fan 6 and an air duct 7, connected to the inner cavity of the casing 1 behind the discharge window 4.

The transporting working body 5 receives the drive from the electric motor 8 through the variator 9 by means of transmission 10. The end surface of the casing 1 from the side of the loading hopper 3 has holes 11. On the outer surface of the casing 1 under a layer of insulating material 2 between the loading hopper 3 and the discharge window 4, the heating elements 12 are placed.

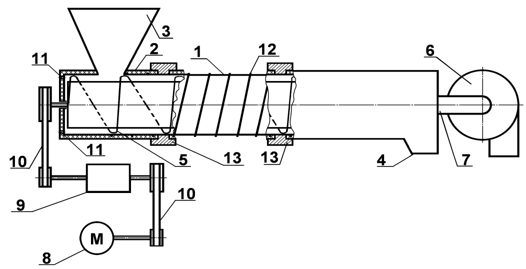

Fig. 1. Grain drying Plant:
1 - casing; 2 - thermal insulation material; 3 - loading hopper; 4 - discharge window; 5 - transporting working body; 6 - fan; 7 - air duct; 8 - electric motor; 9 - variator; 10 - belt transmission; 11 - holes; 12 - heating elements; 13 – rings

The installation works as follows. Includes heating elements 12. After reaching the required temperature of each of the components of the casing 1, the grain is fed to the loading hopper 3, from where it enters the transporting working body 5 and moves it to the unloading window 4. In contact with the heated surface of the casing 1, the grain heats up, loses excess moisture, which in the form of steam is sucked through the perforation 14 of the working body 5 and then through the air duct 7 by the flow of air blown by the fan 6 through the holes 11 in the casing 1. Dry grain is removed from the plant through the discharge window 4. When using the grain of other crops, the heating temperature of the casing 1 is changed with the help of individual heating elements 12, and the rotation frequency of the working body 5 is changed with the help of a variator 9.

The proposed installation can be used in small agricultural enterprises, private households and farms. The dryer does not require large capital investments, it is easy to maintain and operate. The main bearing frame for the screw and its drive is made of an angular isosceles profile № 4. For the screw casing, aluminum alloy sheets D 16 are used, up to $2{,}5\cdot10^{-3}$ m thick, the screw itself is made of St.1...St.4. The heating elements use nichrome wire brands - X25H20, H15N60 diameter cross-section 1...1,6 mm.

The performance of the transporting working body in the form of a screw, as well as the possibility of changing the frequency of its rotation by installing a variator significantly increases the versatility and reliability of the installation, since it can work with the grain of any crops. In addition, the implementation of the composite casing and the supply of each component of the individual heating element allows you to quickly warm up the grain and maintain its temperature within the specified limits.

To determine the cost of heat in the developed installation, set the mass of the removed moisture [3].

The mass of moisture $m_в$, evaporated from the grain is equal to the difference of grain masses before drying - m_1 and after drying - m_2, i.e.

$$m_в = m_1 - m_2 . \tag{1}$$

When drying, the mass m of absolutely dry grain remains unchanged:

$$m = m_1 \frac{100-\omega_1}{100} = m_2 \frac{100-\omega_2}{100} = const\,. \quad (2)$$

Transforming equation (1), we obtain the mass of the removed moisture

$$m_в = m_1 \frac{\omega_1 - \omega_2}{100-\omega_2}\,. \quad (3)$$

Heat consumption Qt is taken proportional to the mass of evaporated moisture, i.e.

$$Q_T = \kappa_T m_в\,, \quad (4)$$

where κ_T - is the proportionality coefficient, MJ/(kg of evaporated moisture).

When drying food grains of cereal crops in grain dryers $\kappa_T \approx 4{,}5...5{,}0$ MJ/(kg of evaporated moisture), while reducing the humidity from 20 to 14 %. For drying seed grain, the coefficient κ_T is more than 2 times, cereals, legumes and rice - 1.5 ... 2 times.

In general, the heat consumption, kJ/kg, for heating the grain

$$Q = \frac{GC}{W_c}(t_1 - t_0)\,, \quad (5)$$

where *G* - is the amount of grain leaving the drying zone, kg / h; *C* - is the heat capacity of the grain at the exit from the drying zone, kJ/(kg ºC); W_c - the amount of evaporated moisture, kg/h; t_0, t_1 - grain temperature, respectively, before and after heating, ºC.

The heat capacity of the grain at the exit from the drying zone is determined from the expression:

$$C = \frac{(100-\omega)C_c + \omega C\omega}{100}\,, \quad (6)$$

where C_c = 1.55 J/(kg ºC), C_ω = 4.19 J/(kg ºC) - is the heat capacity of the dry matter of the grain and water, respectively; ω - grain moisture at the exit from the drying zone, %.

At a low temperature ($t < 0$) heat consumption for heating the grain

$$Q = \frac{G}{W_c}\left(Ct_1 + \frac{100-\omega}{100} C_c t_0 \right) + \frac{G_0}{W_c} \times \\ \times \left[\left(1 - \frac{100-\omega}{100-\omega_0'} \right) \cdot (334 + 2{,}1 t_0) + \frac{\omega_0'}{100} C_\omega t_0 \right], \quad (7)$$

where G_0, G - respectively, the amount of grain entering and leaving the drying zone, kg/h; ω_0, ω_0' - is the initial and critical moisture content of the grain, %, (for practical calculations ω_0' it is assumed to be equal to the limit value of average dryness); 334 -atent heat of ice melting, kJ/kg; 2,1 - the heat capacity of ice, kJ/(kg ºC).

The theoretical amount of heat, J, required to heat the material at a certain temperature drop (t_k - t_n) is proportional to the mass of the material and its heat capacity:

$$Q = mC(t_к - t_н)\,, \quad (8)$$

where *m* - is the mass of the material, kg; *C* - specific heat capacity of the material, J/(kg ºC); $t_к$, $t_н$ - final and initial temperature of heating, ºC, respectively.

The required power of the electric heater, kW, is determined from the expression [4-6]:

$$P = \frac{Q}{3{,}6 \cdot 10^3 t \eta_T}, \tag{9}$$

where t - is the duration of heating, h; $\eta_т$ - thermal efficiency of the installation (for a heat-insulated installation $\eta_т$ = 0,9 ... 0,95, for a non-isolated $\eta_т$ = 0,7...0,8).

For continuous installations:

$$\eta_т = A_п /(A_п + A_а + A_с),$$

where $A_п$ - the useful cost of thermal energy, J; $A_а$ - is the energy loss for heating the structural elements of the installation, J; $A_с$ - energy loss to the environment during heating, j.

$$A_a = C\rho V\left(t_k - t_н\right) \cdot 10^{-3},$$

where ρ - is the bulk density of the material, kg/m^3; V is the volume of the material being dried, m^3.

Loss to the environment at steady state for cylindrical casing of the drying unit:

$$P_ц = \frac{\pi\left(t_в - t_н\right)L}{D\alpha + \frac{1}{2\lambda_1}\ln\frac{D_1}{D_2} + \frac{1}{2\lambda_2}\ln\frac{D_2}{D_1} + \ldots + \frac{1}{2\lambda_n}\ln\frac{D_n}{D_{n-1}} + \frac{1}{D_n\alpha'}}, \tag{10}$$

where α - is the coefficient of heat transfer from the body to the inner surface of the installation casing, for quiet air α = 12, for moving air $\alpha = 4{,}2 + 15\sqrt{V}$, W/ (m^2 ºC); λ_i - is the thermal conductivity coefficient of the corresponding layer of the material being dried (i = 1, 2, 3… n), W/(m ºC); α′ - heat transfer coefficient from the external surface of the casing to the external environment, W/(m^2 ºC); $t_в$ - casing temperature; ºC; $t_н$ - ambient temperature, ºC; D - is the inner diameter of the casing, m; D_i - is the outer diameter of the i - th layer, m; L - is the length of the heated area of the casing, m.

The average temperature t_i of the i - th layer of the cylindrical casing of the drying unit is determined by the following formula:

$$t_i = t_н + \frac{P_ц}{\pi L}\left[\frac{1}{D_n\alpha'} + \frac{1}{2\lambda_n}\ln\frac{D_n}{D_{n-1}} + \frac{1}{2\lambda_{n-1}}\ln\frac{D_{n-1}}{D_{n-2}} + \ldots + \frac{1}{2\lambda_1}\ln\frac{1}{2}\left(1 - \frac{D_i}{D_{i-1}}\right)\right]. \tag{11}$$

The required power P, kW can be determined, knowing - specific energy consumption, kW • h, per unit mass m, or volume V and installation capacity q in units of mass or volume per hour, that is:

$$P = qA',$$

or, knowing the specific heat losses of the heated object ΔP at t = const in kW per calculated area S_{cm}, volume V of the object and excess of the internal temperature of the object above the external θ:

$$P = \Delta P S_{cm}\theta, \text{ or } P = \Delta P V\theta.$$

The minimum thickness of thermal insulation, $\delta_и$, m, is found from the condition of minimum amount of annual costs per 1 m^2 of insulation [7].

For a cylindrical casing of a drying installation, the economically most advantageous value of insulation thickness, m, is determined from the equality:

$$f(D_2) = f_1(D_2),$$

or the corresponding expression:

$$\left(\frac{1}{\alpha D}+\frac{1}{\alpha' D_2}+\frac{1}{2\lambda_c}\ln\frac{D_1}{D}+\frac{1}{2\lambda_u}\ln\frac{D_2}{D_1}\right)^2=\frac{n\theta S_э}{15{,}7\,pS_u D_2^2}\left(\frac{1}{2\lambda_u}-\frac{1}{\alpha' D_2}\right),$$

where $S_э$ - is the annual consumption of electricity, rub.; $S_и$ - the annual consumption of insulation, rub.; α and α' - heat transfer coefficients, W/(m^2 ºC); p - annual deductions for depreciation of thermal insulation,%; θ - is the calculated temperature difference between the heat-generating body and the air over the season, ºC; n - work time per year, h; $\lambda_с$ and $\lambda_и$ - are the thermal conductivity coefficients of the material of the casing and the material of thermal insulation, respectively, W/(ºC m); D - is the inner diameter of the casing, m; D_1 and D_2 - are the inner and outer diameters of the cylindrical layer of thermal insulation, respectively, m.

The proposed installation can be used both independently and as part of technological lines for drying, roasting or sterilizing grain. The use of this installation allows to reduce the specific energy intensity of the grain drying process and improve the quality of the finished product. At the same time, the specific energy consumption of grain drying is reduced to 10,97 Kw • h/t compared to the existing installations of a similar type, and the specific metal consumption is reduced to 800 kg • h/t. This makes it possible, under optimal operating conditions, to save 29,2 rubles per ton of products. The payback period of the drying unit does not exceed 0,92 years.

References

1. Trisvyatsky, LA Technology of receiving, processing, storage of grain and products of its processing / L.A. Trisvyatsky, B.E. Miller. - Moscow: Kolos, 1983. - 351 p.

2. Pat. 2465527 Russian Federation, IPC F26B 17/04 (2006.01). A device for drying grain / V.I. Kurdyumov, A.A. Pavlushin, S.A. Sutyagin; Applicant and patent holder of Ulyanovsk State Agricultural Academy FGOU. - Application No. 2011119459/06, dated May 13, 2011; publ. 10/27/12, Bull. No. 30.

3. Vargas, W.L. Heat conduction in granular materials / W.L. Vargas, J.J. McCarthy // AIChE Journal. – 2001. – № 47. - Pp. 1052-1059.

3. Baum, A.E. Drying grain / A.E. Baum, V.A. Carvers. - M .: Kolos, 1983. - 223 p.

4. Yadollahinia, A.R. Design and fabrication of experimental dryer for studying agricultural products / A.R. Yadollahinia, M. Omid, S. Rafie // Int. J. Agri. Biol. - 2008. - № 10. - Pp. 61-65.

5. Kurdyumov, V.I. Theoretical substantiation of the dynamics of grain drying at the contact method of heat supply / V.I. Kurdyumov, A.A. Pavlushin, G.V. Karpenko // Bulletin of the Ulyanovsk State Agricultural Academy. - 2015. - № 3 (31). - P.125-130.

6. Kurdyumov, V.I. Justification of optimal operation modes of a contact-type grain dryer / V.I. Kurdyumov, A.A. Pavlushin, S.A. Sutyagin // Bulletin of the Ulyanovsk State Agricultural Academy. - 2014. - № 4 (28). - P.160-165.

7. Wang, L.J. Rapid cooling of porous and moisture foods by using vacuum cooling technology / L.J. Wang, D.W. Sun // Trends in Food Science Technology. – 2001. – № 12. - Pp. 174-184.