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MODELING AND CALCULATION OF REGIME PARAMETERS OF BATCH DRYERS

The article presents the mathematical model of grain drying materials in circulating batch dryers. Analytical dependences are got for determination of basic regime parameters of process.

Formulation of the problem. The system of technological operations postharvest processing of grain drying belongs to an important place. It gives the opportunity not only to ensure the safety of the harvest and to prevent its damage, but also improve the quality of the product. In recent years, the market of grain-processing technology is increasingly appearing mobile batch dryers foreign manufacturers. Under certain conditions, thanks to the simplicity of the design, maintenance dryers of this type should be used on small farms as a means of preserving the harvest of grains and oilseeds, as well as for drying small batches of various grain material high humidity.

To determine the rational modes of drying grain products of a certain category, you must have robust formulas, allowing to define the necessary parameters for passport appointment indicators [1].

Analysis of recent research and publications. Usually in practice, the construction of dryers [2, 3] calculation of the drying process is reduced to the definition of exposure for a specific drying grain material [3] and a given performance, input and output parameters for calculating the costs of drying agent and the heat flow. This evaporative drying capacity does not always coincide with the possibility of evaporation of the material. But such simple calculations do not allow the analysis and selection of the most appropriate modes of rational drying. Are given in [4] depending only concern a continuous dryers. But in [5] that the drying process in the batch dryer can be represented as a technological scheme of serially connected "elementary" cells in which the process takes place continuously. This approach makes it possible to analyze the periodic drying process to bring to the analysis of a continuous process in a steady state.

The purpose of research. To determine the analytical dependences of the drying process parameters grain material suitable to the operating modes of batch dryers.

Main research results. Following [5], represent heat and mass transfer processes as occurring sequentially in the dryer chamber at a continuous circulation of the grain (Fig. 1). Thus grain is dried by repeated passes through the drying chamber. In this scheme, it is continuous movement of grain is heated and loses moisture. A common way of moving grain: $L = H \cdot n$ (where H — camera height, n — number of passes).

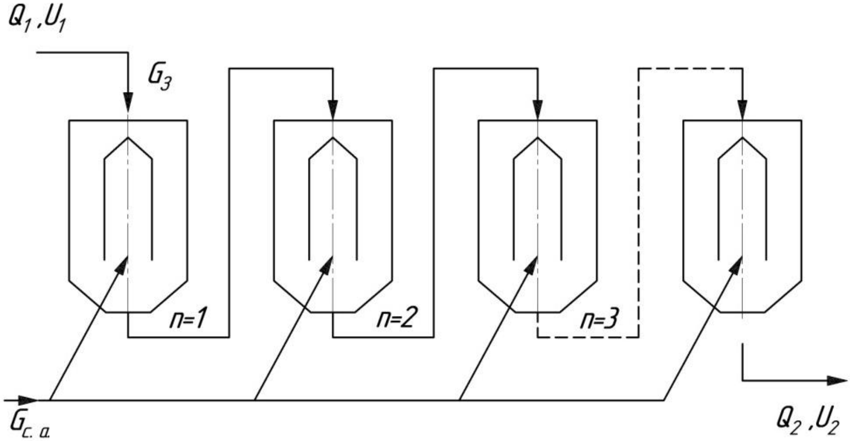

Fig. 1 — Diagram of the process of circulation dryers

Then, the process parameter changes can be considered constant, in which grains of the drying agent and the parameters at each point of the path (path drying) are constant over time.

Assume the following simplifying assumptions:

- speed of moving grain during the same movement;
- heat loss to the environment is not considered, they can be determined by calculating the heat consumption for drying;
- the process of heat transfer occurs by convection, Newton's law, and the removal of moisture from the surface of the grain on the Dalton law;
- internal heat and mass transfer - gradient less, that is, the temperature at the surface and inside the grain is the same;
- the size of the heating surface and remove moisture the same and their difference is taken into account mass transfer coefficient, which is related to the surface of the moisture exchange;
- movement of grain and direct-flow drying agent;

For selected models circulating dryer taking into account the assumptions made on the basis of the analysis of heat and mass balances between the drying agent and the grains are made up the following differential equations:

the equation of conservation of energy for the grain

$$\rho_3(1-m)\cdot c_3\cdot \upsilon_3\cdot \frac{d\theta}{dx}+r_0\cdot \rho_{30}\cdot \frac{dU}{dx}=c_p\cdot m\cdot \upsilon_c\cdot \frac{dt}{dx}, \quad (1)$$

the equation of heat transfer for drying agent (heat balance)

$$\rho_c\cdot c_p\cdot m\cdot \upsilon_c\cdot \frac{dt}{dx}=\alpha\cdot f\cdot(\theta-t), \quad (2)$$

material balance equation for grain

$$-\rho_{30}\cdot \upsilon_3\cdot \frac{dU}{dx}=m\cdot \rho_c\cdot \upsilon_c\cdot \frac{dD}{dx}, \quad (3)$$

mass transfer equation

$$-\rho_{30}\cdot \upsilon_3\cdot \frac{dU}{dx}=f\cdot \beta\cdot [P_3(\theta)-P_\alpha(D)]. \quad (4)$$

In equations (1) - (4) is indicated:

θ, t — temperature and grain drying agent, °C;
U, D — grain moisture content and the drying agent, kg/kg s. r.;
c_3, c_p — specific heat capacity of grain and drying agent, J/kg·°C;
r_0 — specific heat of evaporation, J/kg;
f — specific surface area of the grain, m^2/m^3;
α, β — heat and mass transfer coefficients, respectively, $W/m^2\cdot$°C and $kg/Pa\cdot s\cdot m^2$;
ρ_3, ρ_c — grain density and the density of dry air, kg/m^3;
$P_3(\theta)$, $P_\alpha(D)$ — the partial pressure of water vapor on the heated surface to a temperature *θ* and grain drying agent, Pa;
υ_3, υ_c — moving speed grain and the drying agent, m/s;
ρ_{30} — the density of the bone dry grain, kg/m^3.

Moisture partial pressure dependence of the grain surface area of the saturated vapor pressure at the temperature θ grain can be approximated by a linear relation:

$$P_3(\theta)=a\cdot\theta+c, \quad (5)$$

in the air:

$$P_\alpha(D)=b\cdot D, \quad (6)$$

where a = *4,45; b = 1,14; c = –124* — constant coefficients.

Using the definition of criteria Rebinder [3] $R_b=\frac{cd\theta}{r_0\cdot dU}$, we will do in the equation (1) replacement:

$$-\frac{dU}{dx}=\frac{c}{r_0\cdot R_b}\cdot\frac{d\theta}{dx}. \quad (7)$$

And after appropriate transformations of equations (1) and (2) receive:

$$t=\upsilon_3\cdot B\cdot\frac{d\theta}{dx}, \quad (8)$$

$$\theta = v_c \cdot A \cdot \frac{dt}{dx} + t, \qquad (9)$$

where $A = \frac{\rho_c \cdot c_p \cdot m}{\alpha \cdot f}$ and $B = \frac{\rho_3 \cdot c_3 \cdot (1-m) + \frac{1}{R_b}}{\alpha \cdot f}$.

The system of equations (8) and (9) under the boundary conditions: $x = 0$, $t = t_1$, $\theta = \theta_1$ (where t_1, θ_1 — temperature grain and drying agent in the dryer inlet) we get in the form of:

$$t(x) = t_1 - \frac{\Delta T_1}{k \cdot v_c \cdot A}(1 - e^{-k \cdot x}), \qquad (10)$$

$$\theta(x) = \theta_1 + \frac{\Delta T_1}{k \cdot v_3 \cdot A}(1 - e^{-k \cdot x}), \qquad (11)$$

where $\Delta T_1 = t_1 - \theta_1$ and $k = \frac{v_c \cdot A + v_3 \cdot B}{v_3 \cdot v_c \cdot A \cdot B}$.

Equating equation (3) and (4), taking into account (5) and (6), we obtain:

$$m \cdot \rho_c \cdot v_c \cdot \frac{dD}{dx} = f \cdot \beta \cdot (a \cdot \theta + c - b \cdot D). \qquad (12)$$

Substituting the value of θ with (11) to (12) after the corresponding transformations, we obtain the equation:

$$T_1 \cdot \frac{dD}{dx} + b \cdot D = A_1 + B_1 \cdot e^{-k \cdot x}, \qquad (13)$$

where $B_1 = a \cdot \frac{\Delta T_1}{v_3 \cdot B \cdot k}$, $A_1 = a \cdot \theta_1 + B_1$ and $T_1 = \frac{m \cdot \rho_c \cdot v_c}{\beta \cdot f}$.

The solution of the inhomogeneous differential equation (13) with the boundary conditions: $x = 0$, $D = D_1$, (where D_1, — the moisture content of the drying agent in the dryer inlet) obtained in the form of:

$$D(x) = \left(D_1 - \frac{a \cdot \theta_1 + B_1}{B_1}\right) \cdot e^{-\frac{b}{T_1} \cdot x} + \frac{k \cdot B_1}{k \cdot T_1 + b}\left(e^{-\frac{b}{T_1} \cdot x} - e^{-k \cdot x}\right) + \frac{a \cdot \theta_1 + B_1}{B_1}. \qquad (14)$$

Differentiating equation (14) and substituting the value obtained in equation (3), after transformations we obtain:

$$-T_2 \cdot \frac{dU}{dx} = -A_2 \cdot e^{-\frac{b}{T_1} \cdot x} + B_2 \cdot e^{-k \cdot x}. \qquad (15)$$

Integration of the equations (15) leads to a dependence of the boundary conditions ($x = 0$, $U = U_1$):

$$U(x) = U_1 + \frac{B_2}{T_2 \cdot k}(1 - e^{-k \cdot x}) - \frac{T_1 \cdot B_2}{T_2 \cdot b}\left(1 - e^{-\frac{b}{T_1} \cdot x}\right), \qquad (16)$$

where $A_2 = \frac{b}{T_1} D_1 + \frac{a \cdot \theta_1 + B_1}{B_1} + \frac{b \cdot k \cdot B_1}{(T_1 \cdot k + b) \cdot T_1}$, $B_2 = \frac{k^2 \cdot B_1}{T_1 \cdot k + b}$ and $T_2 = \rho_{30} v_3$.

Thus, the equation (10), (11), (14) and (16) make it possible to determine the operating parameters of the drying process t_2, θ_2, D_2, U_2 at the output of the dryer by substituting $x = L = H \cdot n$ in these equations.

In addition, it is possible to analyze the change in the parameters along the "path of the drying" (Fig. 2) and to determine the most appropriate mode.

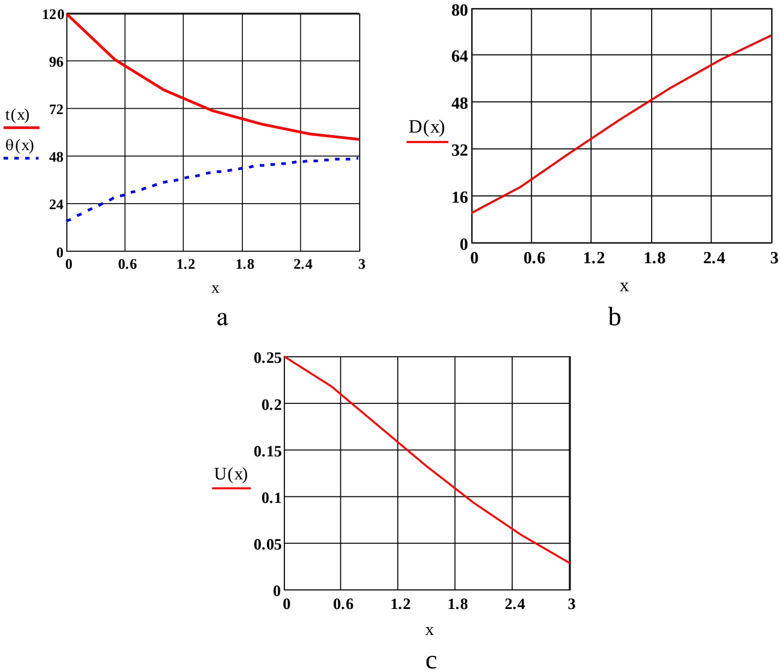

Fig. 2 — Changing grain parameters θ, U and drying agent t, D the number of cycles (the length of the drying tract $x = H_{суш}$)

By varying the speed of movement of the material in each cycle of the circulation can be achieved by isothermal drying mode.

Costs necessary quantity of heat for the drying process can be determined by the formula [6]:

$$q = \frac{c_p(t_1 - t_2)}{(D_2 - D_1)\cdot 10^{-3}}. \qquad (17)$$

Dryer energy efficiency ensured an increase D_2 and a decrease in t_2.

Conclusions. Thus, the proposed mathematical model of the drying process in the batch of grain dryers circulation type and obtained on the basis of its analytical relationships allow us to determine the main parameters of the process and select the best mode of the process.

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