TECHNOLOGICAL RELIABILITY OF GRAIN DRYERS OPERATION AND PROCESSES

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Abstract: A mathematical model of the heat transfer during grain drying has been developed. To estimate qualitative parameters of a technological process, the theory of the tolerance control is used. Control criteria for the drying process in rhomb-shaped aggregates have been determined. The obtained results allow increasing the technological reliability of grain dryers operation.

Keywords: grain post-harvest care, technological reliability, probability, optimization.

Introduction

The flow line limiting section of grain post-harvest care is a dryer; the efficiency of its operation determines the pace of harvest work fulfillment and the quality of grain-harvesting complex operation as a whole. When analyzing the operating regimes of grain dryers, the effect of control parameters on various criteria of efficiency is evaluated. A control action should not out the internal temperature field formed by the heat-carrier θ_c beyond the set level θ_s. Another criterion for the drying process optimization is ensuring a minimum deviation of the grain moisture from the standard value at the dryer outlet. The non-uniformity of the material at the dryer outlet determines the time spread t of a grain stay in the drying unit by this index and is characterized by the function of distribution in dependence to t. These criteria are agricultural and engineering tolerances for the grain drying technological process execution.

Background

The main condition for the optimum drying process control lies in the need to identify factors affecting the specified process and determining the heat-mass exchange and hydrodynamic characteristics of drying. In order to ensure the stability of controlled parameters of the technical equipment quality, it is required to develop an adequate mathematical model which establishes a relationship between these parameters and the factors affecting them.

In order to create a complete theoretical picture of processes which proceed in a dryer, it is necessary to formalize the corresponding regularities. The number of factors, which are taken into account, also determines the number of connections which allow for obtaining a closed system of kinetic equations.

The technological process under consideration is stationary and is characterized by three-dimensionality of fields of velocities, temperature, pressure, grain humidity and air humidity. Since drying is carried in the volume with fixed geometric parameters, the material shrinkage, which takes place during the gradual removal of the osmotic moisture from grains, has a significant effect on the technological process.

A complete system of equations characterizing the external heat-mass exchange (heat-mass exchange in the flowing around stream) and the internal heat-mass exchange (heat-mass exchange in the solid phase), during grain drying, includes:

- equations of flow dynamics (Navier–Stokes equations):

$$\rho_r\left(\frac{\partial\vec{v}}{\partial\tau}+\vec{v}\Delta\vec{v}\right)=q\rho_r-\nabla\rho+\mu_r\nabla^2\vec{v} \qquad (12)$$

$$\frac{\partial\rho r}{\partial\tau}+\nabla(\rho_r\vec{v})=0 \qquad (13)$$

- an equation characterizing the energy of the air flow in the filling channels:

$$\rho_r C\rho_r \left(\frac{\partial tr}{\partial\tau}+\vec{v}\Delta tr\right)=\lambda_r\nabla^2 tr \qquad (14)$$

- an equation taking into account diffusion of water vapors in the air:

$$\frac{\partial\rho v}{\partial\tau}+\vec{v}\Delta\rho_v=D\cdot\nabla^2\rho_v \qquad (15)$$

- an equation of the heat conductivity for a filling layer:

$$\rho_T C\,\rho_T\frac{\partial tT}{\partial\tau}= \lambda_T\nabla^2 t_T+\varepsilon\frac{\partial U}{\partial\tau}\rho_d r \qquad (16)$$

- an equation characterizing the moisture conductivity of a filling layer:

$$\frac{\partial U}{\partial\tau}=\alpha_n\left(\nabla^2 U+\delta\nabla^2 t_T\right) \qquad (17)$$

Accepted designations are as follows: $\rho\rho_r$ is the moist air density; ρ_V is the vapor density; $\vec{v}$ is the vector characterizing the air flow rate; τ is the time; $\vec{q}$ is the vector characterizing the acceleration of the gravity; p is the gas pressure; μ_r is the factor characterizing the air dynamic viscosity; Cρ_r is the moist air heat capacity; λ_r is the air thermal conductivity; D is the factor characterizing water vapor diffusion in the air; t_T is the temperature of the grain weighed portion; ρ_T is the density of the grain weighed portion; ρ_d is the density of the absolutely dry grain; r is latent heat of vaporization; ε is the phase transformation criterion; α_n is the factor characterizing the moisture conductivity; δ is the factor characterizing the thermal moisture conductivity; ∇ is the Hamiltonian operator; ∇^2 is the Laplace operator.

The following functions were accepted as criteria for assessment of the grain dryer operation quality, characterizing:

- deviation of the heat-carrier temperature in the dryer from the set value, i.e.

$$m(t) = m\{\theta_c, \theta_3\} \qquad (18)$$

- deviation of the grain moisture content at the dryer outlet from the standard value, i.e.

$$b(t) = b\{W_c, W_k\} \qquad (19)$$

Results

In order to determine probabilistic characteristics of overranges and build the area of admissible values of O, let us represent equations (18) and (19) in the form of a two-dimensional vector process:

$$K(t) = \{m(t), b(t), t\epsilon T\} \qquad (20)$$

Components of this equation are continuous and differentiable random functions of time b(t) and m(t), tϵ [t_0, t_0 +T]. Values of the vector K(t) vary on the real axis, i.e. K(t) ϵ ($-\infty,\infty$).

The geometric interpretation of the tolerance problem - lies in the following. The plane (b, m) is the phase space; components b(t) and m(t) of the two-dimensional random process are viewed as coordinates of some point of the phase space. Changes in values of the two-dimensional vector process K(t) are described by the motion of a point with coordinates of b(t) and m(t) in the phase space.

Borders of the area of O admissible values are determined from the condition: m(t) ϵ [$-\theta, \theta$], b(t) ϵ [$-W, W$].

Overrange of the two-dimensional process K(t) trajectory beyond the limits of the O area are the consequence of the overrange of the function b(t) beyond the limits ± W, provided that the second function m(t) remains within the borders [$-\Theta, \Theta$]. The mechanism of the function m(t) overrange beyond the limits of ± Θ is similar, provided that the function b(t) remains within the borders of [-W, W]. The average number of overranges of the two-dimensional random process under consideration from the set area is determined by the following equation:

$$N_{k(t)}(O, T) = [N_w^+(W,T) + N_w^-(-W,T)] \cdot P\{m(t) \epsilon [-\Theta, \Theta]\} + [N_o^+(\Theta,T) + N_o^-(-\Theta,T)] \cdot P\{b(t) \epsilon [-W, W]\} \quad (21)$$

Here $N^{\pm}(\pm W,T)$ is the number of positive or negative overranges of the one-dimensional process b(t) beyond the border (± W) on the interval [t_o, t_o+T];

$N^{\pm}(\pm\Theta ,T)$ is the number of overranges (positive or negative) of the one-dimensional process m(t) beyond the border (± Θ) on the interval [t_o, t_o+T].

If the trajectory of the two-dimensional process K(t) does not overrange the area of O limits, then the following conditions are fulfilled:

b(t) ϵ [$-W, W$];

m(t) ϵ [$-\theta, \theta$] (22)

The average value of the relative stay duration of the vector process K(t) in the area of admissible values is calculated according to the following equation:

$T_{k(t)}(O) = P\{k(t) \epsilon O = P\{b(t) \epsilon [-W, W], m(t) \epsilon [-\theta, \theta]$ (23)

Conclusions

The mathematical model of the drying process in rhomb-shaped aggregates and formulation of the numerical algorithm for calculating the temperature field and the moisture field for the grain by the volume of the dryer allow representing this algorithm in a computer program and carrying out a series of calculations. The information, obtained in such way, is the basis for developing a calculation procedure and substantiation of the parameters of grain dryers.

References

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