

OPTIMIZATION OF IMMOVABLE MATERIAL LAYER AT DRYING

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Summary. The article represents a mathematical model of drying of immovable layer of plant material, that enables optimization of the height of a layer loaded into the drier.

Key words: immovable thick layer, elementary thin layer, drying agent, drying coefficient, step-by-step method of drying calculation.

INTRODUCTION

The problem of convection drying of agricultural material in an immovable thick layer lies in the choice of its rational height that assures maximum utilization of a drying agent. Insufficient height results in irreversible energy loss, and its increase leads to humidification of the upper layers having a negative effect [Selenko 1998].

Another reason for negative effect (over-drying of material in some zones) is its non-uniform distribution in the dryer and non-uniformity of material. [Ostapchuk *et al.* 1988]. That is why majority of investigations on cost reduction of agricultural material drying is connected with preparation of material before loading into the dryer. The preparation includes: elimination of impurities from main material, change of shape and sizes of material that can significantly improve a number of efficient parameters of technological process.

INVESTIGATION ANALYSIS

The theoretical description of agricultural material convection drying is done through heat and mass exchange equations. Such method is complicated and laborious. Besides, it is hard to apply the obtained results in engineering calculation of drier units and improvement of drying methods [Selenko 1998].

As shown by investigation results, moisture is changing according to complicated laws: $W = f(W_n, \tau, t)$. That is why the regression equations are used in engineering practices.

To analyze practical tasks, the general characteristics of drying, speed and temperature curves are performed. After analysis of the curves, the equation of kinetics drying is obtained [Lykov 1968]:

$$-\frac{dW}{d\tau} = K(W - W_k), \quad (1)$$

where:

$\frac{dW}{d\tau}$ – drying speed;

K – drying coefficient, depending on properties of agricultural materials and drying mode, min^{-1} ;

W_k – finale material moister, %.

In its turn, drying coefficient K is directly proportional to drying speed and reciprocally proportional to initial material moisture W_n . It is determined by the relative drying coefficient χ , like line slope ratio $K = \chi N$.

$$\chi = \frac{1,8}{W_n}. \quad (2)$$

Purpose of investigations. To investigate theoretically and propose a method for defining the optimal size of immovable material layer at drying taking into account technological factors of the process.

INVESTIGATION RESULTS

It is problematic to obtain an analytical solution of differential equations, describing heat and mass exchange in a material layer, under condition of non-steady drying process. In order to solve such applications, it is worth using a simplified mechanism for analysis of heat and mass exchange between the material for drying and the drying agent [Okun *et al.* 1984].

Analytically, the method can be represented by a system of differential equations. Equation (3) represents energy conservation law in drying, equation (4) – material conservation law, (5), (6) – heat and mass exchange law between material and drying agent.

$$\frac{\partial t}{\partial \tau} + 3600 \cdot V \cdot \frac{\partial t}{\partial x} = -\frac{\gamma_m C_m}{\gamma_{ca} C_{ca}} \cdot \frac{\partial \theta}{\varepsilon \cdot \partial \tau} - \frac{\gamma_m \cdot r'}{\gamma_{ca} C_{ca} \varepsilon} \cdot \frac{\partial W}{\partial \tau} \cdot \frac{1}{100}, \quad (3)$$

$$\frac{\partial W}{\partial \tau} = -\frac{\gamma_{ca} \cdot \varepsilon}{\gamma_m} \left(\frac{\partial d}{\partial \tau} + 3600 \cdot V \cdot \frac{\partial d}{\partial x} \right), \quad (4)$$

$$\frac{\partial t}{\partial \tau} + 3600 \cdot V \cdot \frac{\partial t}{\partial x} = -\frac{\alpha_q \cdot \gamma_m}{\gamma_{ca} \cdot C_{ca} \cdot \varepsilon} (t - \theta), \quad (5)$$

$$\frac{\partial W}{\partial \tau} = -K(W - W_p), \quad (6)$$

where:

- t – drying agent temperature, °C ;
- d – moisture ratio of drying agent , g/kg;
- W – material moisture, %;
- θ – material temperature, °C ;
- V – drying agent speed, m/s;
- C_m, C_{ca} – heat capacity of material and drying agent, kilojoules/kg;
- ε – material layer porosity;
- r' – heat of water evaporation, kilojoules/kg;
- α_q – heat emission coefficient, kilocalorie/kg·h;
- γ_m – material bulk weight, kg/m³;
- γ_{ca} – air specific gravity (drying agent), kg/m³;
- K – drying coefficient;
- W_p – material moisture equilibrium, %;
- x – spatial value, m;
- τ – time, hours.

The step-by-step method of immovable material drying is based on the following assumptions: moisture in the material has a liquid state, heat and mass is exchanged only between the drying agent and material being dried, thermal gradient in the material is not significant, heat between the drying agent and material is exchanged convectively.

Main point of the step-by-step calculation in a thick layer is successive calculation of thin layer drying process, the changes of moisture and temperature of which can be ignored. Thin layer drying during the period $\Delta \tau$, when the drying speed does not significantly change, can be described by a system of algebraic equations [Okun *et al.* 1984].

$$\Delta t = -\frac{\gamma_m \cdot C_m \cdot \delta}{3600 \cdot V \cdot \gamma_{ca} \cdot C_{ca}} \cdot \frac{\Delta \theta}{\Delta \tau} - \frac{\gamma_m \cdot \delta}{3600 \cdot V \cdot \gamma_{ca} \cdot C_{ca}} \cdot \frac{\Delta W}{\Delta \tau} \cdot \frac{r'}{100}, \quad (7)$$

$$\Delta d = -\frac{10 \cdot \gamma_m \cdot \delta}{3600 \cdot V \cdot \gamma_{ca}} \cdot \frac{\Delta W}{\Delta \tau}, \quad (8)$$

$$\Delta t = -\frac{\alpha_q \cdot \gamma_m \cdot \delta}{3600 \cdot V \cdot \gamma_{ca} C_{ca}} (\theta - t), \quad (9)$$

$$\Delta W = -K(W - W_p) \Delta \tau, \quad (10)$$

where:

δ – thickness of thin layer, m.

Precision of thick layer drying calculations by means of step-by-step method depends, first of all, on data validity of thin layer drying according to equations (7), (8), (9), (10). In its turn, it is dependant on correct choice of period $\Delta \tau$, size of elementary thin layer δ and a number of thermal characteristics, used in equations.

Capability of modern computer machinery and rational calculation algorithms enable to reduce magnitude δ to the seed thickness (for calculation of seed material) and $\Delta \tau \leq 1$ s, increasing precision of drying process calculation.

Material and drying agent temperature are connected with correlation:

$$\theta = \frac{t_{i-1} + t_i}{2}, \quad (11)$$

where:

t_{i-1}, t_i – temperature of the drying agent at the entry to i ;

i – layer and at exit, °C.

The biggest impact on calculation of plant material drying process comes from drying coefficient K and drying speed N . The coefficient is a function of a number of parameters. That is why, normally, it is the observed value, depending on the material being dried, drying agent parameters and drying conditions. However, for the materials of „gel” types, including porous colloid materials, according to [Ostapchuk *et al.* 1988], the following equation can be used:

$$\alpha_q (t - \theta) = \frac{N \rho_m R_v}{100}, \quad (12)$$

where:

N – drying speed, %/hour;

ρ_m – dry material thickness, kg/m³;

R_v – ratio of drying material body to its surface.

Thus, the defined relations and initial conditions, namely drying agent parameters t , d and material W , θ at initial time $\tau = 0$ enable formulating of a calculation model of drying process of the plant material layer. For i thin layer within $(j-1)\Delta\tau - j \cdot \Delta\tau$ period, the drying agent parameters are defined as:

$$t_{i,j} = (1-A)t_{i-1,j} + A \cdot \theta_{i,j-1} - B \cdot K(W_{i,j-1} - W_p) \Delta \tau, \quad (13)$$

$$d_{i,j} = d_{i-1,j} + \frac{K}{10.2} (W_{i,j-1} - W_p), \quad (14)$$

and material parameters at temporal value $j \cdot \Delta\tau$:

$$W_{i,j} = W_{i,j-1} - K(W_{i,j-1} - W_p)\Delta\tau, \quad (15)$$

$$\theta_{i,j} = \frac{t_{i-1,j} + t_{i,j}}{2}, \quad (16)$$

where:

$$A = \frac{C_M}{102C_{ca}\Delta\tau + 0,5C_M}, \quad B = \frac{0,01r'}{102C_{ca}\Delta\tau + 0,5C_M}.$$

Moisture equilibrium of seed and plant material for relevant parameters of the drying agent can be defined according to the Henderson formula:

$$W_p = \left(\frac{\ln|1-\varphi|}{5,74 \cdot 10^{-6}(t+273)} \right)^{0,435}, \quad (17)$$

where:

φ – drying agent moisture, %

$$\varphi = \frac{745d}{(622+d) \cdot 10^{0,622+7,5/238+t}}.$$

The represented model enables calculating drying process both in a thin and thick material layer.

Besides, the calculation data obtained characterize drying process enabling optimization of layer height under condition of maximally efficient utilization of the drying agent potential.

CONCLUSIONS

Represented mathematical model of drying process of immovable thick layer enables optimizing height of material being loaded into the drier. Such a method for calculation of the drying process enables maximal efficient utilization of drying agent potential and reduces the cost of agricultural material processing operations.

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