Volume 4, Issue 6, June - 2026 **ISSN(E):** 2938-3773

CALCULATION AND THEORETICAL STUDIES OF HEAT AND MASS TRANSFER PROCESSORS STATE DURING DRYING OF FRUIT PRODUCTS

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Abstract

The article describes current modern and resource-efficient experimental and theoretical research, as well as an analysis of the use of pneumatic structures in rural areas and other sectors of the national economy, information on the principle of converting solar radiation into thermal energy.

Keywords: Drying, temperature, rate, evaporation, product, moisture, heat capacity, thermal conductivity, thermal diffusivity, mass.

Introduction

Drying fruit and vegetable products, including a wide variety of grapes, apricots, apples, plums, melons, onions, and others, involves removing the physical moisture associated with the product. As is well known, grapes, like other food products of plant origin, are colloidal-capillary porous materials.

From the ear depends on the initial, final and equilibrium humidity, thermal stability, physical and chemical composition and heat and mass transfer conditions of the process.

The energy intensity of the drying process and the intensity of heat and mass transfer are determined by the structure of the bond with the framework of a solid. This theory has been the subject of the work of prominent scientists: P.A. Rebinderi, A.V. Likov, M.F. Kozanchiy, A.V. Dukatkin, L.M. Nikitina, M. Polen, A.A. Reze, G.F. Filonenko, A.S. Ginzburg, P.D. Lebedev, M.A. Grishin, and many others.

The founder of the theory of the relationship between moisture and material is P.A. Rebinder, who substantiated the thermodynamic state of moisture in a capillary-root body.

M.A. Grishin points out that the heat of evaporation of capillary-bound moisture is negligible and typically amounts to a few percent of the total heat of evaporation. Physically bound moisture is removed first, followed by capillary water in the micropores. Next, physical-chemically bound moisture, consisting of osmotic water and adsorbed water, is removed.

The fundamental principles of the drying process are characterized by temperature curves, first introduced by A.V. Likov . Figure 1 shows the drying curves of capillary-feathery-colloidal materials; - $W = f(\tau)$change in moisture content over time; change in temperature over time.$t = f(\tau)$ and drying speed

$dW / dt = f(\tau)$.

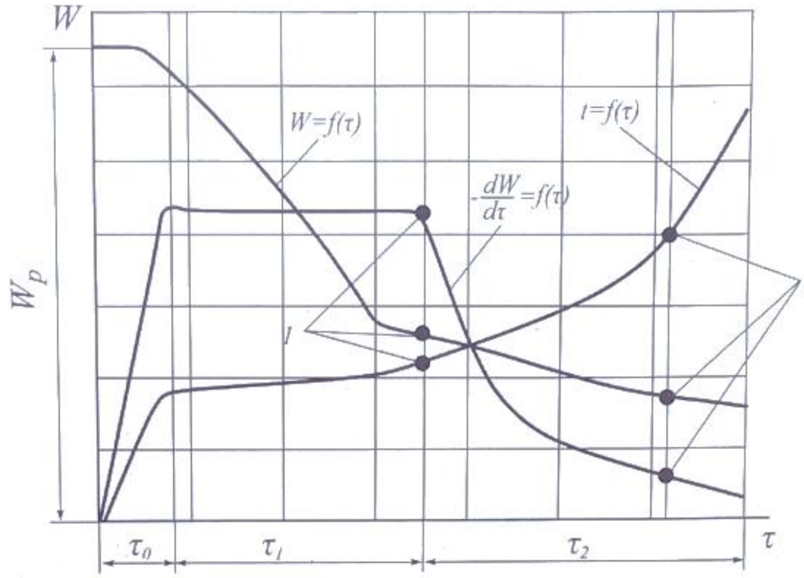

Fig . 1. Drying curves of a capillary porous body

Let's analyze the drying process. Initially, the product heats up quickly, reaching wet-bulb temperature t_M and it is maintained until the end of the first drying period. Starting from W_{kp} , the product temperature increases, and upon reaching W_p , it becomes equal to the coolant temperature.

To analyze the drying process, each of the two periods must be considered separately. The period of constant drying rate is the period of intense moisture evaporation, where the drying rate is constant. For this case, the heat balance equation for convective drying is as follows:

$$dQ = (c_{св}G_{св} + c_{вл}G_{вл})dt + [r + c_{pn}(Q_H - Q_U)]dG_{вл} \quad (1)$$

where dQ is the current value of heat consumption for drying, J/kg;

$c_{св}$ - heat capacity of water, J (kg.K);

G_{sv} - amount of evaporated water, kg/h;

$c_{сл}$ - heat capacity of dried grapes, J/(ka.K);

G_{vl} - quantity of dried grapes, kg/h;

dt - temperature increment, K;

r is the heat of vaporization J/kg: Q_H ,

Q_U .- respectively, the temperature at the beginning and end of drying, K;

dG_{vl} - moisture increment during time dr .

On the other hand, for the amount of heat transferred by convection to the surface of the body over the period dr , we can write

$$dQ = \alpha F(Q_H - Q_U)d\tau \quad (2)$$

where F is the evaporation surface of the berries in the bunches, ^{m2} ;

α - heat transfer coefficient, W/(m2 ^{K}),

If we take into account that in the first period the humidity on the surface of the product is greater than hygroscopic, i.e. the steam is saturated, we can write down.

$$\frac{d_{вл}}{d\tau} = \frac{\alpha F(Q_H - Q_U) - (c_{св}G_{св} + c_{pn}G_{pn})\frac{d\theta}{d\tau}}{\tau} \quad (3)$$

Since in the first period (dθ / dτ) = 0, the drying rate will practically depend only on the product α F (θ_H - Q_U), due to the proportional decrease in F due to shrinkage and changes in the dimensions of the object.

The latter means a reduction in the amount of heat transferred to the product from the heat transfer fluid. Furthermore, a new direction of heat flow emerges—the heating zone deepens and moisture evaporates. Thus, a characteristic feature of the second period is a decrease in the drying rate. Moreover, upon reaching equilibrium moisture content, the temperatures of the heat transfer fluid and the product equalize, and moisture removal decreases to zero.

Drying a product ultimately involves the transfer of moisture from the surface to the surrounding environment and from within the material to its surface. This requires understanding the forces that drive this transfer, which prompts consideration of rational drying methods and techniques that ensure maximum quality preservation with minimal drying costs.

When moisture is transferred externally from the surface of the material, the coolant washes the product in close proximity, forming a boundary layer on the surface. This boundary layer reduces the coolant's velocity, which in turn leads to a temperature gradient and a gradient in the moisture content of the gas. The latter leads to an increase in the partial pressure of the boundary layer relative to the coolant. Thus, phenomena develop in the boundary layer that have varying effects on the drying rate. The rate of moisture evaporation from the product's surface for the first period can then be written as

$$q_n = \alpha_m (p_М - p_n) \frac{760}{B} q (4)$$

where q_m is the rate of moisture evaporation, kg/(m2 * h);

α_m - diffusion coefficient of mass transfer, m^2/s:

r_m, p_n. - partial pressure before and after moisture evaporation, Pa;

B-barometric pressure, Pa,

q - density of melons, kg/ ^{m3} ,

Evaporation of moisture from the surface creates a difference in humidity in the product, which results in the movement of moisture from the inner layers to the surface.

The moisture exchange between the body and the environment is characterized by the Nusselt criterion

$$Nu_m = \frac{\alpha_m}{\lambda_m} l (5)$$

where α_m is the mass transfer coefficient, kg/(m^2 s); is the characteristic size, m; and is the mass conductivity coefficient.

Substituting the value of α_m, in (4), we obtain

$$q_m = \frac{Nu_m \lambda_m}{l} (p_М - p_n) \frac{760}{B} \quad (6)$$

To determine this, Prof. A. V. Nesterenko obtained the following expression []

$$Nu_m = ARe^n Pr_m^{0.33} Gu^{0.135} (\frac{\theta_T}{\theta_П}) \quad (7)$$

where Nu_m - Nusselt mass transfer criterion;

Re is the Reynolds number characterizing the motion mode;

Pr_m is the Prandtl criterion, which characterizes the thermal properties of the material;

Gu – Guhman criterion;

A is the correction factor.

During the period of decreasing drying speed, the intensity of moisture release depends on the difference in moisture concentrations on the surface of the product and the coolant

$q_n = \beta\gamma(W_p - W_n (8)$

Let us consider the phenomenon of heat and matter transfer in their inextricable connection, then the analytical expression of the fundamental law of transfer according to A. V. Lykov can be written

$q_m = -\alpha_m\gamma_0\nabla W (9)$

The concept of the potential conductivity coefficient α_m is common to both heat transfer and moisture movement; the nature of the $\alpha_{m\ dependence}$, depends on the humidity and temperature of the product and is determined by the form of the connection of moisture with the product. If the direction of the gradients of humidity and temperature coincide, then the directions of the corresponding moisture flows also coincide, which together give the total moisture flow, determined by the expression:

$q_m = q_{m_0} + q_{m_\theta} = -\alpha_m\gamma_0\nabla W \ -\alpha_m\gamma_0\delta\nabla W (10)$

To use this moisture flux expression, it is sufficient to know the values of the potential conductivity coefficient α_m and the temperature and heat gradients. Therefore, the product drying time to a given moisture content is determined experimentally. The results are presented as drying curves and drying rates, which require complex experiments and technical means.

Therefore, various scientists have developed analytical methods for determining the drying time.

The advantage of A. V. Lykov's method is that it allows one to calculate the drying time for any moisture content, taking into account the drying regime. For example, for the duration of the first and second drying periods, the process pattern is determined by the relationship:

$$\tau_c = \tau_1 + \tau_c = \frac{W_1 - W_{kp}}{N} - \frac{1}{k}\ln\frac{W_{kp} - W_p}{W_1 - W_p} \quad (11)$$

where W_{kp}, W_p, are the critical and calculated humidity of the product, respectively;

W_1, W_2 - initial and final humidity.

The development of this method allowed V.V. Krasnikov to propose determining the second drying period using the corresponding drying coefficients:

$X_1 = \tan\varphi_1$ and $X_2 = \tan\varphi_1$

$$\tau = \frac{1}{N_\tau}\left(W_1 - W_{kp2}\right) + \frac{2{,}3}{X_1}\lg\frac{W_{kp1} - W_p}{W_{kp2} - W_P} + \frac{2{,}3}{X_2}\lg\frac{W_{kp2} - W_p}{W_2 - W_P} \quad (12)$$

Moreover, they proved that N_τ, - const

The formula for determining the drying time according to O. Krischer is as follows:

$$\tau = \delta^2\rho_0\int_{\omega_1}^{\omega_2}\frac{d\omega}{q_m\delta} \qquad (13)$$

The method of Ryozo Tori and Shinya Hayashi is based on the analysis of heat and mass transfer in the second period and the combined analysis of integral drying curves with temperature and moisture content fields. The calculation of the drying time for the second drying period is as follows.

$$\tau_{II} = \frac{P_1 R_2}{\theta_T - \theta_\Pi}\left\{\left(\frac{1}{\alpha W_{kp_2}} + \frac{R}{\lambda_1}\right)(W_{kp2} - W) - \frac{R}{\lambda_1} W_{kp2} \frac{n}{n+1}\left[1 - \left(\frac{W}{W_{kp2}}\right)^{\frac{n+1}{n}}\right]\right\} \quad (14)$$

Of great interest is the description of drying kinetics proposed by B.S. Sazhin

$$\frac{dW}{d\tau} = -k(A - W)(W - B)(15)$$

Of particular interest here is that the drying process is considered as the transfer of material from one equilibrium state to another, due to a change in the equilibrium conditions.

The solution of equation (15) allows us to determine the drying time using an analytical expression:

$$\tau = \frac{1}{k(A-B)} \ln \frac{(W_{\text{н}} - B)(A - W)}{(B - W_{\text{н}})(W - B)} \quad (16)$$

Considering the complexity of the drying process, due to changes in a number of thermal conductivities, product parameters (heat capacity, thermal conductivity, thermal diffusivity, mass, etc.), the method of G.F. Filonenko was proposed to calculate the drying time, described by the equation

$$\tau = \frac{1}{N_\tau}(W_1 - W_{kp}) + A \int_{W_2}^{W_{kp}} \frac{dW}{(W_2 - W_p)} + \beta(W_{kp} - W_2)(17)$$

Of the methods described above, the most widely used are A. V. Lykov's method using a drying coefficient and G. K. Filonenko's method. However, all of these methods require fairly complex calculations and experiments, while simpler methods for analytically describing drying times, characterized by moisture transfer processes, can be found. Furthermore, these studies allowed for some inconsistency in the conditions of heat and mass transfer when explaining the physical meaning of the phenomena. This can be seen from an analysis of the results of scientific studies applying moisture removal processes in exponential space.

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