RESEARCH ON ENERGY EFFICIENT KINETICS OF DRYING RAW MATERIAL

Jasur Safarov[1*], *Akhtam* Khujakulov[2], *Shakhnoza* Sultanova[3], *Ulugbek* Khujakulov[4], *Sunil* Verma[5]

[1]Tashkent State Technical University, Department technology services, University - 2, Tashkent, 100095, Uzbekistan
[2] Tashkent State Technical University, Department technology services, University - 2, Tashkent, 100095, Uzbekistan
[3]Tashkent State Technical University, Department technology services, University - 2, Tashkent, 100095, Uzbekistan
[4]Tashkent State Technical University, Department technology services, University - 2, Tashkent, 100095, Uzbekistan
[5] Tashkent State Technical University, Department technology services, University - 2, Tashkent, 100095, Uzbekistan

Abstract. In this work, at constant values of the process temperature, the kinetics of drying was considered through the Fick diffusion equation with the corresponding initial and boundary conditions. To describe the process with mathematical expressions, Fick's equation, which expresses the value of moisture content, is reduced to a dimensionless formula. When accepting the boundary conditions of the first kind, the ratio of the moisture diffusion coefficient to the square of the determining size was determined by the least squares method using a special program with subroutines for solving partial differential equations with a sufficient number of exponents in the solution.

1. Introduction

Wet plants to be dried consist of a hard, dry frame, liquid, and a relatively small amount of air and vapor. The process of removing moisture is accompanied by a change in the physical and chemical characteristics of the product, its thermophysical characteristics and structural and mechanical properties. The intensity of heat and mass transfer during the drying process is determined by the form of connection of moisture with the solid frame.

The structure of the dry part of food products has a decisive influence on the formation of a complex material-liquid complex. Cross-linkages between molecules can be formed by both hydrogen bonds and salt bridges or multivalent cations.

However, determining the nature of the interaction of water with individual components of the system and establishing the contribution of each component to the integral value of the binding energy of moisture with the material presents significant difficulties. Among the numerous classifications of the forms of the connection between moisture and the material frame, the classification developed by Acad. P.A.Rebinderomi, based on determining the amount of energy spent on breaking the bond of water with the frame of the material during drying.

The strongest chemically bound moisture can be removed by intense heat treatment or chemical action on the material. An increase in the temperature of the product (before decomposition of the substance) does not violate the chemical bond of moisture in food products. This form of moisture bonding has no effect on the drying process.

A less strong physical and chemical bond is determined by the action of adsorption and osmotic forces. It does not require significant energy consumption to break this connection. The greatest amount of heat is needed to remove a monolayer of adsorbed water molecules, so drying the product to a low moisture content is the most energy-intensive process.

The moisture contained in micro- and macrocapillaries is called mechanically bound. The binding energy of moisture increases with a decrease in the radius of the capillary and an increase in the surface tension of water. The properties of thin films of liquid on the inner surface of capillaries have not been sufficiently studied, therefore, the above said to a greater extent applies to capillaries with a radius of less than $3{,}8*10^{-5}$ mm, in which the values of surface tension and viscosity of water remain the same as for free moisture [1].

P.Duheim's hypothesis about the equality of the binding energy of moisture with the material and the chemical transfer potential was used by L.M. Nikitina [2] when processing a significant amount of sorption and desorption isotherms.

The analysis of isotherms obtained experimentally also makes it possible to identify some areas of moisture content, corresponding to certain forms of moisture-material bond, and the boundaries of the areas cannot be determined unambiguously.

Based on observations of the change in the mass of the material during the drying process, it is possible to construct a drying curve (Fig. 1) in the coordinates: material moisture in mass percent (W) - time in minutes or hours (τ). At the beginning of drying, for a short period of time, the drying line looks like a heating curve of the material (segment AB). Then the first period of constant drying speed begins. During this period, the drying line looks like a straight line. The temperature of the material here takes on a value equal to the temperature of the wet thermometer tm (segment BC). During the first drying period, free moisture is removed. The second period is the removal of bound moisture.

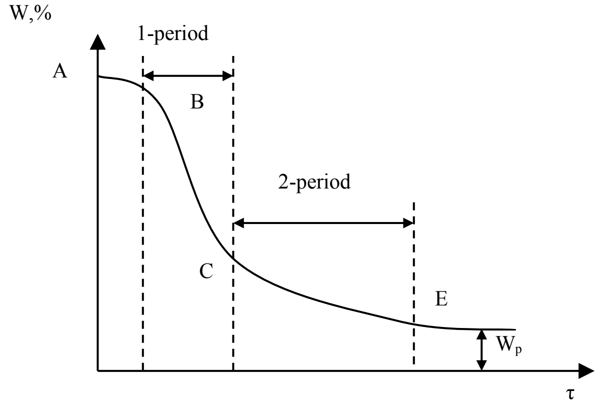


Fig. 1. Drying curve

At point C, corresponding to a certain moisture content of the material, the character of the drying line changes. It becomes a curve asymptotically approaching the value of Wp - equilibrium moisture content under given drying conditions.

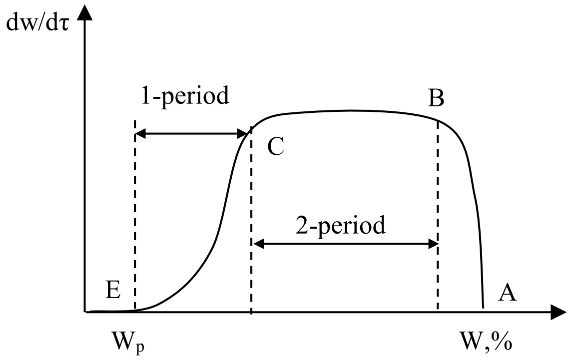


Fig. 2. Curve of drying rate

In the second period, the drying speed decreases continuously. The shape of the drying line depends on the type of connection between moisture and the material and its structure, i.e. on the conditions of movement of moisture inside the product. When equilibrium moisture is reached, moisture removal from the material stops. The temperature of the material is equal to the temperature of the surrounding heat carrier (point E). However, it takes a long time to reach equilibrium moisture content. Based on the drying curves, drying rate curves can be plotted (Fig. 2).

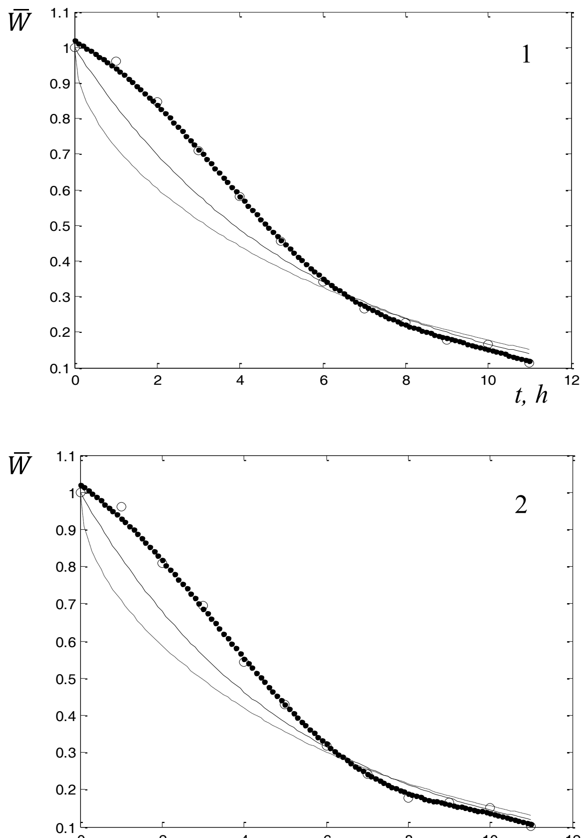
To implement the above, the moisture content in the material is plotted along the abscissa axis, and the drying rate, which is the change in moisture per unit time dw / dτ, along the ordinate. The drying rate for a given moisture content of the material is expressed by the tangent of the slope of the tangent drawn to the point of the drying curve. The shape of the curves of the drying rate in the second period may differ significantly depending on the forms of the connection of moisture with the material.

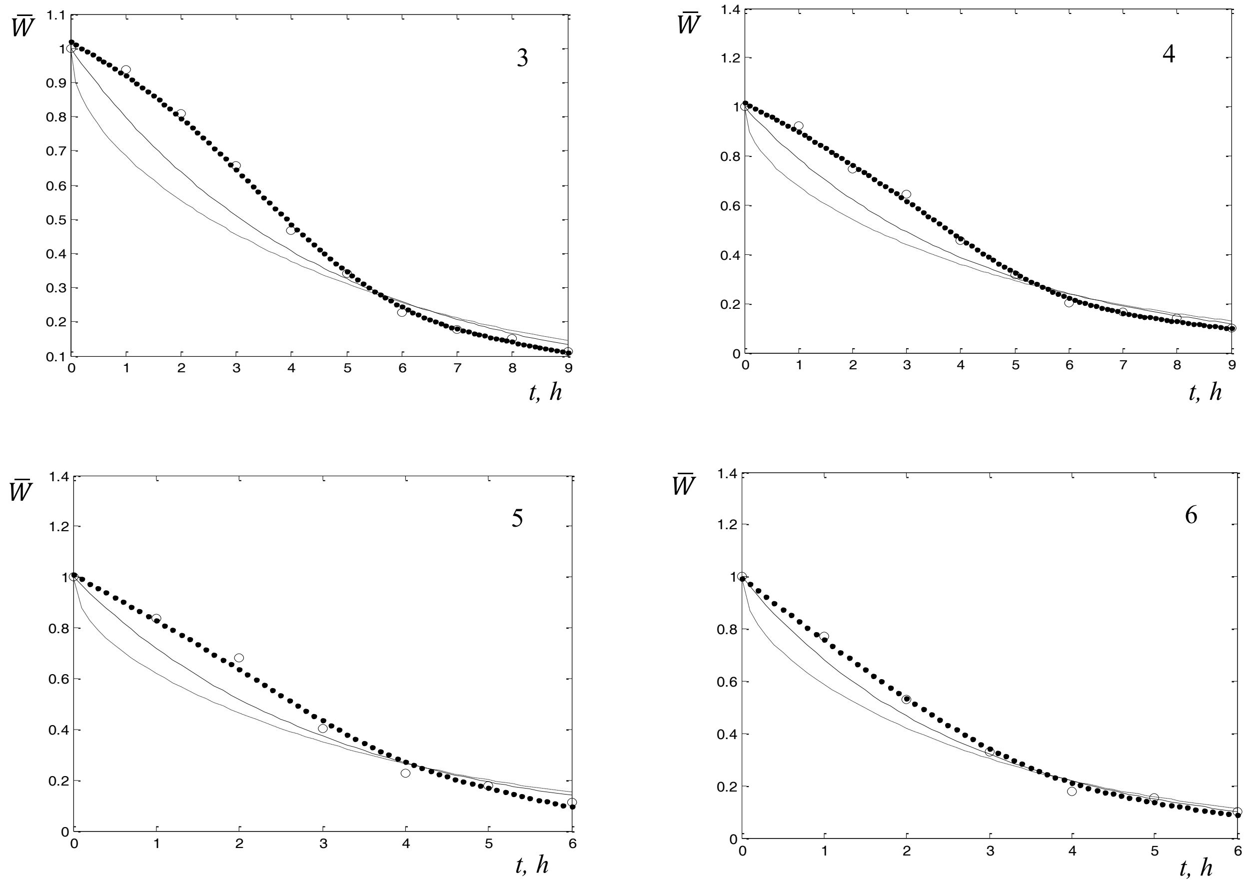
2. Material and methods

The use of automatic control thermostats in the proposed technological installations allows us to consider the drying process isothermal [3-12]. At constant values of the process temperature, the kinetics of drying can be considered through the Fick diffusion equation with the corresponding initial and boundary conditions [13-15]. To describe the process with mathematical expressions, the Fick equation, which expresses the value of moisture content, must be reduced to a dimensionless form using the following formula:

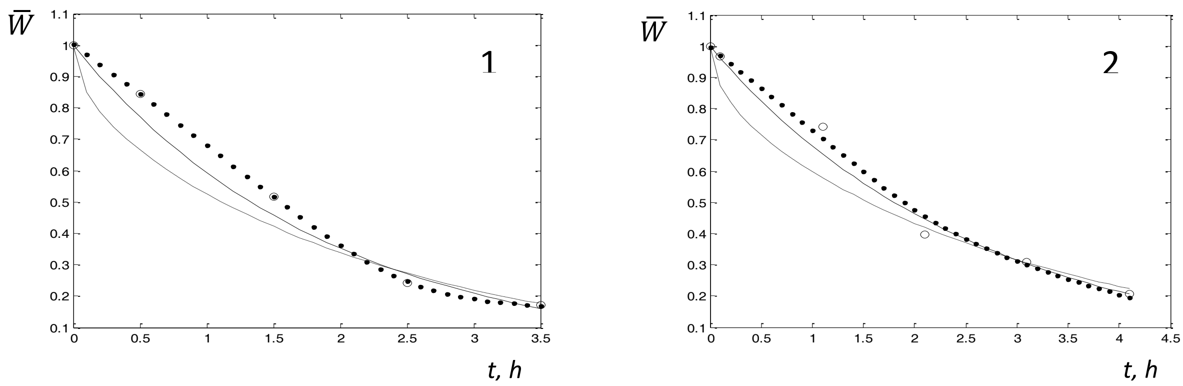
$$\overline{W} = \frac{W - W_p}{W_н - W_p} \quad (1)$$

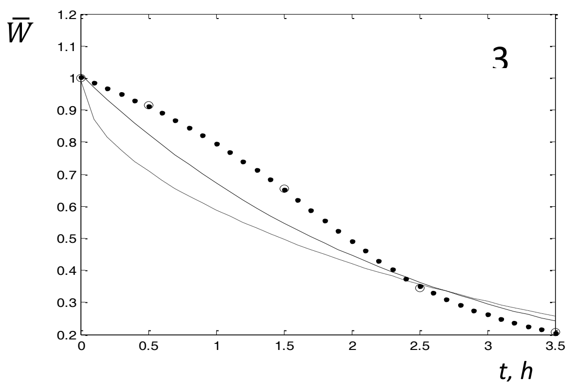
When accepting boundary conditions of the 1st kind, the ratio of the moisture diffusion coefficient to the square of the determining size was determined by the least squares method using a special program with subroutines for solving partial differential equations with a sufficient number of exponents in the solution.





— - Fick's model of the 1st kind; – – – - Fick 3-kind model.
1-curve of drying ginger slices with IR heating; 2-curve of crushed ginger mass drying with IR heating; 3-curve of drying ginger slices in vacuum with IR heating; 4-curve of crushed mass of ginger drying in vacuum with IR heating; 5-curve of drying ginger slices in vacuum with IR heating and vibration; 6-curve of crushed ginger mass drying in vacuum with IR heating and vibration.
Fig. 3. Kinetic patterns of ginger drying





— - Fick's model of the 1st kind; – – – - Fick 3-kind model.
1-vacuum drying with IR heating (drying temperature 50 °C; vacuum -0.8 atm); 2-vacuum drying with IR heating (drying temperature 65 °C; vacuum -0.8 atm); 3-vacuum drying with IR heating (drying temperature 80 °C; vacuum -0.8 atm).
Fig. 4. Kinetic laws of the drying process of rose hips

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3. Results and discussion

Comparison of the calculated and experimental data shows (Fig. 3 dashed line) that it is necessary to take into account the coefficient of mass transfer between phases.

The results of data processing for various drying modes and boundary conditions are shown in table. 1-2 (Fig. 3-4).

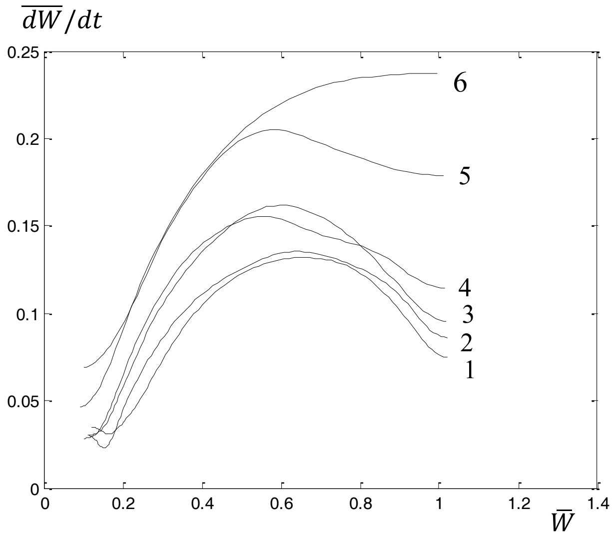
Table 1. Results of processing kinetic data of ginger

Drying mode / Model and drying parameters		1	2	3	4	5	6
Fick's equation with boundary conditions I-gender D/R^2, 1/h		0,0617	0,0668	0,0777	0,0824	0,1129	0,1328
Fick's equation with boundary conditions III-gender	D/R^2	1,410	1,776	1,7193	1,54	2,47	2,11
	Bio	0,133	0,1732	0,1367	0,1622	0,14	0,19

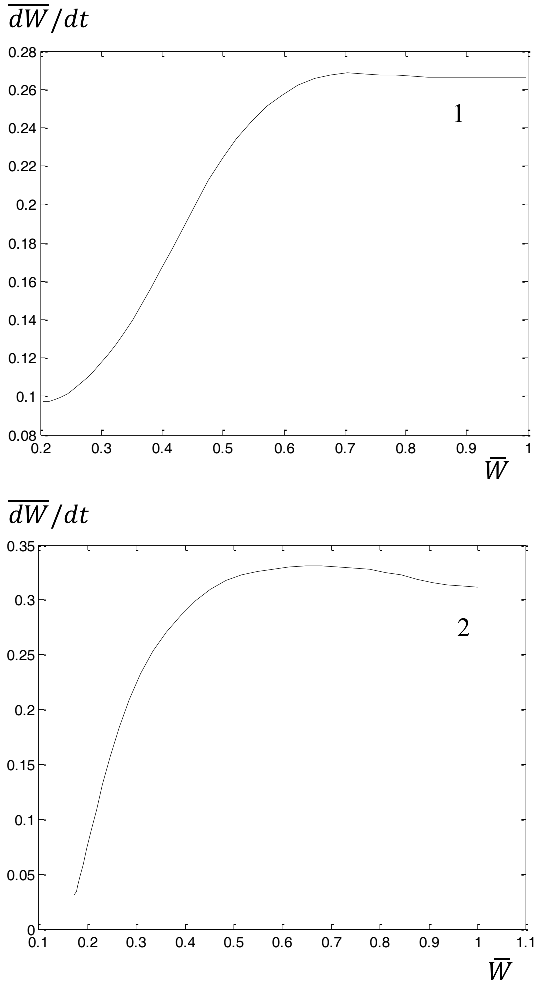
Table 2. Results of processing kinetic data of rose hips

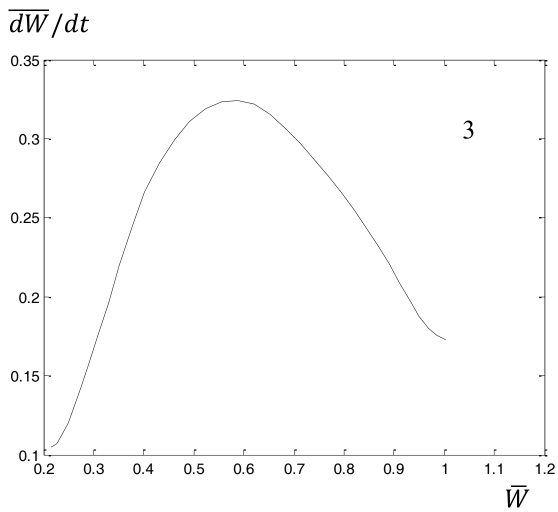
Drying mode / Model and drying parameters		1	2	3
Fick's equation with boundary conditions of the 1st kind D/R^2, 1/h		0,1767	0,1328	0,1098
Fick's equation with boundary conditions of the 3rd kind	D/R^2	3,1663	5,0427	2,2966
	Bio	0,1744	0,0843	0,1537

Let us construct drying curves according to experimental data with pre-leveled spline approximation (Fig. 5-6).



1-curve of drying ginger slices with IR heating; 2-curve of crushed ginger mass drying with IR heating; 3-curve of drying ginger slices in vacuum with IR heating; 4-curve of crushed mass of ginger drying in vacuum with IR heating; 5-curve of drying ginger slices in vacuum with IR heating and vibration; 6-curve of crushed ginger mass drying in vacuum with IR heating and vibration
Fig. 5. Curves of speed of drying ginger





1-vacuum drying with IR heating (drying tempe 50 °C; vacuum -0.8 atm); 2-vacuum drying with IR heating (drying temperature 65 °C; vacuum -0.8 atm); 3-vacuum drying with IR heating (drying temperature 80 °C; vacuum -0.8 atm).

Fig. 6. Curves of the drying rate of rose hips

Conclusion

The performed quantitative formalization of the drying intensity for different drying modes allows us to compare them: in terms of the intensity of both internal diffusion and external mass transfer by arranging in a row indicated in Table 1-2. Based on the Bio criterion, it can be stated that infrared vacuum drying solves the problems associated with limiting internal diffusion of drying. Further improvement of drying in technological and design plans is based on the intensification of external exchange at the boundaries of particles and layers of material.

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