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ELECTRICAL TREATMENT OF BIOLOGICAL OBJECTS AND FOODSTUFFS

Kinetics of Drying Kernels of Apricot Stones Using a High-Frequency Current

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Abstract—Application of a convective method and a combined method employing a high-frequency current alongside convection for drying kernels of apricot stones is experimentally studied. The drying rate, the drying rate constants, and the duration of the first and second periods are determined. The effect of a high-frequency electromagnetic field on the kinetics of the drying is analyzed.

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The average quantity of secondary products (food wastes) at enterprises of the food-canning industry amounts about 21% of the mass of the processed primary product.

Fruits pits comprise a substantial share of the total volume of the primary product being processed. Their afterproducts possess good qualities and may be regarded as a rather valuable sort of secondary raw material.

Nowadays, air-and-sunshine drying of fruit stones on unequipped open sites is still widely used. For drying kernels of apricot stones, a convective method and a combined method where high-frequency currents (HFC) are used has been proposed. The aim is to intensify the drying process while retaining the biological value of the product, improve the cost effectiveness of the process, and make the process ecologically friendly.

The experimental setup described in [1] was employed for the investigations. Kernels of stones of the "Krasnoshchekii" variety of apricot with an initial moisture content of $U_0 = 146\%$ were dried.

A VNTz-200 mechanic balance was used to register the mass loss. The rate of the air supply to the drying chamber was automatically kept constant at 1.1 m/s. The air parameters were measured before the heat treatment (initial temperature t_0 and relative humidity φ_0) and after the process (t_1).

At the first stage of the work, the kinetics of the convective drying were studied at temperatures of the drying agent of 60, 70, 80, 90, and 100°C. The mass loss was measured over intervals of 5 min, and the drying continued to the equilibrium moisture content of 30% [2].

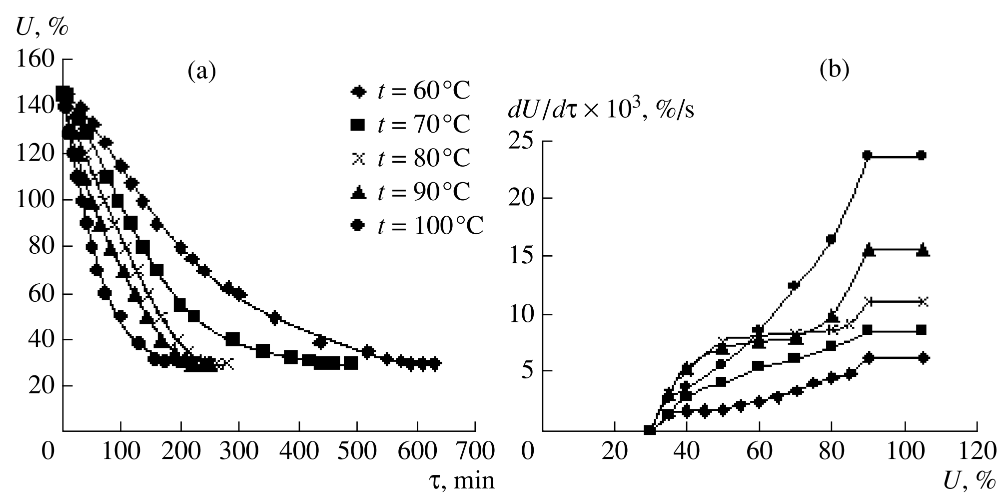

Fig. 1. Drying curve (a) and drying rate curve (b) for kernels of apricot stones using a convective energy supply.

Table 1. Experimental parameters of the kinetics of drying kernels of apricot stones by a convective method

no.	t_1, °C	U_{cr}, %	$\left(\frac{dU}{d\tau}\right)_1 \times 10^3$, %/s	K_1, %/(m^2 s)	$K_2 \times 10^6$, s^{-1}	$\tau_{preheat}$, min	τ_1, min	τ_2, min	τ_{gen}, min
1	60	90	6.46	58.6	1.6	100	240	280	620
2	70	90	8.62	63.5	3.2	89	184	232	505
3	80	95	11.18	65.9	4.0	78	158	169	415
4	90	95	15.74	84.35	4.98	59	122	137	318
5	100	95	23.61	107.1	5.6	35	91	94	220

Figure 1 shows the drying curves $U = f(\tau)$ and the drying rate curves $\left(\frac{dU}{d\tau}\right)_1 = f(U)$ for kernels of apricot stones. As can be seen from the drying curves, the process duration amounted 620 min and 220 min at the temperatures of 60°C and 100°C, respectively; that is, its decrease by a factor of 2.85 was observed.

The curves of the drying rate (Fig. 1b) are typical for colloidal and capillary bodies and involve the range of preheating as well as the first and the second periods of drying [3].

The drying rate was calculated using the experimental data for the first period of drying. Table 1 shows the drying temperature values t_1 (°C), the critical moisture content U_{cr} (%), the drying rate for the first period $\left(\frac{dU}{d\tau}\right)_1$ (10^3) (%/s), the constants of the drying rate for the first period K_1 and for the second period K_2, the preheating time $\tau_{preheat}$, and the drying duration for the first period τ_1 (min) and for the second period τ_2 (min).

At the second stage of the experiment, the effect of the combined action of high-frequency heating, together with the convective method of energy supply, upon the drying kinetics at various regimes of the electromagnetic field $E = 8.75 \times 10^3$ and 1.8×10^4 V/m was studied.

The experimental results are presented in Figs. 2 and 3 as the drying curves and the drying rate curves.

The time of the drying process decreases with the field strength increase for various temperatures. The time of drying to a moisture content of 30% amounted 410 min at a temperature of 60°C and an electromagnetic field strength of 8.75×10^3 V/m, and it was equal 370 min at a strength of 1.8×10^4 V/m; that is, it decreased by 40 min.

The data presented in Fig. 2 demonstrate that the combined action of the high-frequency electromagnetic field and the convective method substantially intensifies the drying process.

Comparison of the dewatering process at the minimal temperature and electromagnetic field strength values ($t = 60$°C and $E = 8.75 \times 10^3$ V/m) with that at the

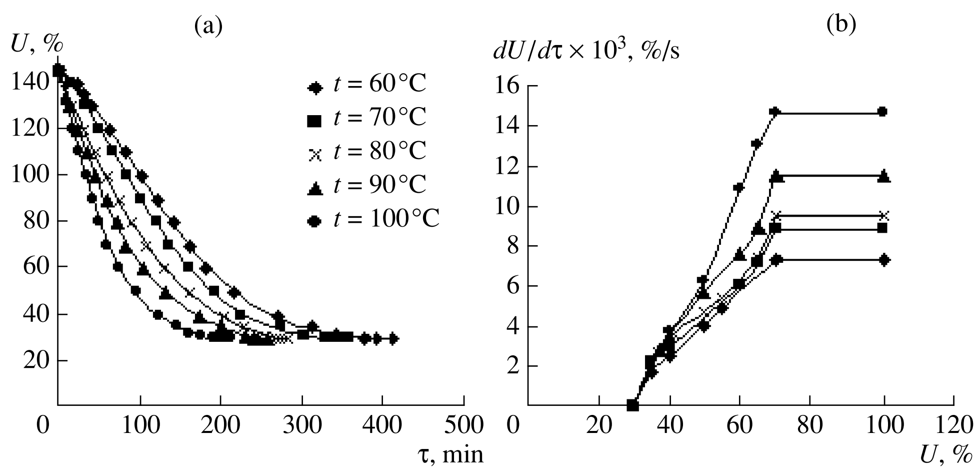

Fig. 2. Drying curve (a) and drying rate curve (b) for kernels of apricot stones using a combined method (convection + HFC); the electromagnetic field strength is $E = 8750$ V/m.

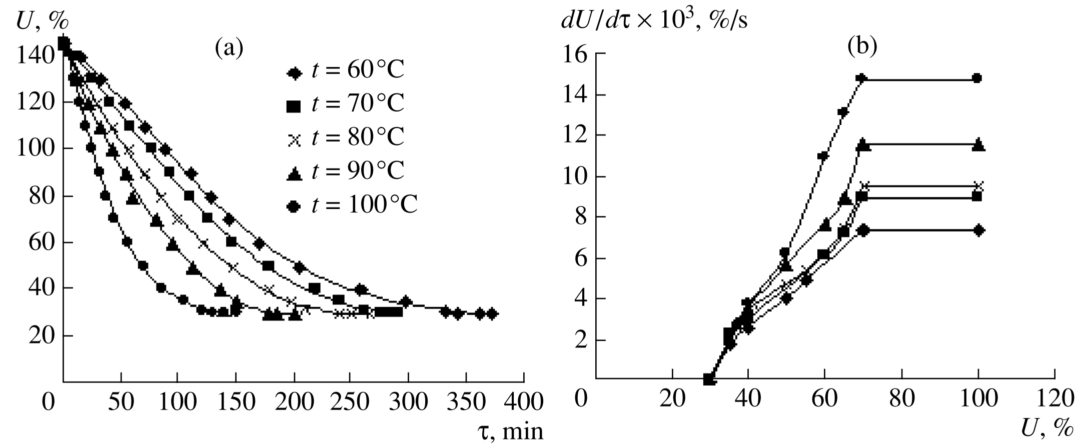

Fig. 3. Drying curve (a) and drying rate curve (b) for kernels of apricot stones using a combined method (convection + HFC); the electromagnetic field strength is $E = 1.8 \times 10^4$ V/m).

maximal temperature and electromagnetic field strength values (t = 100°C and $E = 1.8 \times 10^4$ V/m) shows that the time for drying from 146 to 30% decreases by a factor of 2.8.

The duration of the drying process of the kernels reduces due to the more intensive heat release in the unit volume of the kernels with the field strength increase; therefore, the drying process rate quickly increases to its maximal value when the high-frequency field is used.

At the temperature of the drying agent of 60°C (Fig. 2b) with the electromagnetic field strength $E = 8.75 \times 10^3$ V/m, the maximal rate value increases by 17.8%. The maximal rate of the drying process increases with the temperature increase. When the temperature increases from 60 to 100°C at the same field strength, the drying rate increases by a factor of 2.

The kinetic characteristics of the drying process were calculated both for the convective drying method and for the combined method (convection + HFC) for various values of the field strength and are presented in Table 2.

For the second period, the drying rate constant K_2 at the temperature of 60°C increased by 14.4% with the

Table 2. Experimental parameters of the kinetics of drying kernels of apricot stones by a combined method (convection + HFC)

no.	t_1, °C	U_{cr}, %	$\left(\frac{dU}{d\tau}\right)_1 \times 10^3$, %/s	K_1, %/(m^2 s)	$K_2 \times 10^6$, s^{-1}	$\tau_{preheat}$, min	τ_1, min	τ_2, min	τ_{gen}, min
Electric field strength $E = 8.75 \times 10^3$ V/m									
1	60	70	7.41	67.2	3.53	80	235	85	410
2	70	69	8.93	65.8	4.09	56	223	61	340
3	80	69	9.59	56.6	4.65	28	193	59	280
4	90	70	11.61	62.2	5.86	25	187	48	260
5	100	70	14.72	76.8	6.45	17	165	33	215
Electric field strength $E = 1.8 \times 10^4$ V/m									
1	60	68	8.73	79.2	4.04	45	273	47	365
2	70	72	9.44	69.6	4.37	33	235	31	300
3	80	69	9.61	56.5	4.56	30	185	29	245
4	90	66	11.01	59.0	5.90	17	158	23	198
5	100	72	20.63	93.6	9.55	13	112	20	145

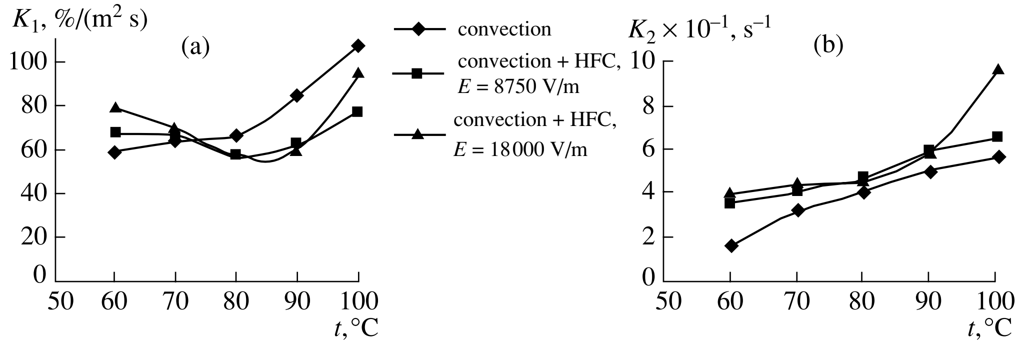

Fig. 4. Dependence of the drying rate constants vs. temperature for various types of energy supply: (a) first period, (b) second period.

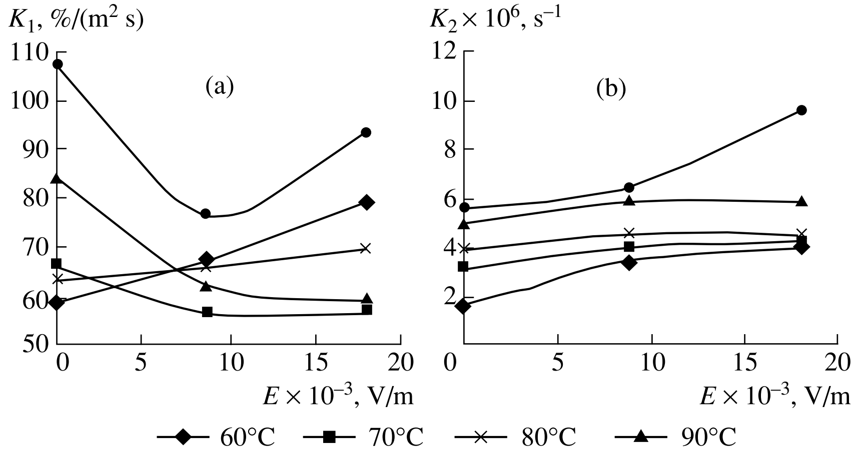

Fig. 5. Dependence of the drying rate constants vs. the electromagnetic field strength for various types of energy supply: (a) first period, (b) second period.

increase in the electromagnetic field strength. The temperature increase from 60 to 100°C and the field strength increase from $E = 8.75 \times 10^3$ to $E = 1.8 \times 10^4$ V/m resulted in an increase in the drying rate constant K_2 from 83 to 136%. These values demonstrate that the HFC exerts a substantial effect upon the drying process (especially in the second period) due to the effect of the HFC on the product structure and the rupture of bonds between the moisture and material. The variation of the drying rate constants is shown in Figs. 4 and 5.

The experimental results lead one to the conclusion that the combined action of HFC together with the convective method of energy supply alters the kinetics of the drying process: in comparison with pure convection, the heating duration of the material decreases from 100 to 13 min (which is more than by a factor of 7) and the duration of the second period of drying decreases by a factor of 14.

Analysis of the dependence of the drying rate constants vs. the temperature demonstrates that the combined action of the electromagnetic field HFC exerts the greater effect upon the internal heat and mass exchange; at that, in the second period, the drying coefficient increases by a factor of 1.83 for $E = 8.75 \times 10^3$ V/m and by a factor of 2.4 for $E = 1.8 \times 10^4$ V/m. This gives evidence of the reciprocal effect of the temperature and the electromagnetic field strength. The curve for $E = 1.8 \times 10^4$ V/m (Fig. 4b) explicitly shows the sinergetic effect of their action.

The results obtained in the experiments on the drying process of kernels of apricot stones with a convective heat supply (Fig. 1) and with the combined action of a convective heat supply and heating with a high-frequency electric field (Figs. 2 and 3) demonstrate that the kernels are a complex organic product. In the course of the heat treatment, the mass loss occurs in the kernels not only due to the moisture removal (typical for the majority of materials) but also due to the biochemical modifications taking place at the high temperatures. Therefore, the applicability of the drying method for such kinds of products as kernels should be justified taking into account these features.

The experiments have shown that the high-frequency heating combined with a convective energy supply is more promising for its application in the dewatering process of kernels of apricot stones if compared with pure convection. The most intensive regime occurs when the drying is performed by the combined action at a temperature of the drying agent of 100°C and with an electromagnetic field strength of $E = 1.8 \times 10^3$ V/m. The drying process is best performed in two steps. At the first stage, a convective energy supply should be used (100°C) down to the critical moisture content in the kernels of 110%. At the second stage, a combined energy supply (convection + HFC) with an electromagnetic field strength of $E = 1.8 \times 10^4$ V/m should be used to obtain an equilibrium moisture content of 30%.

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