INVESTIGATION OF CONVECTIVE-THERMORADIATION DRYING OF PRODUCTS FROM APPLES IN TWO STAGES

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Аннотация: В процессе исследования конвективно-терморадиационной сушки продуктов из яблок опытным путем было встановлено оптимальные параметры сушки. Сырьем для сушки избраны яблоки сорта «Голден Делишес». Подготовка сырья включала мытье, очистку, резку на части и бланширование в сахарном сиропе с добавлением лимонной кислоты и антиоксиданта. С целью интенсификации процесса сушки и получения продукта с высоким содержанием биологически активных веществ была выполнена двухступенчастая сушка с понижением температуры во втором периоде до 55 ° С. Среди представленных на рынке Украины продуктов из яблок были избраны: сушеные яблоки, снеки и цукаты. На примере этих продуктов изучали интенсивность и динамику процесса сушки, так как эти продукты отличаются предварительной подготовкой и начальным содержанием сухих веществ.

Ключевые слова: бланширование, двухступенчастая сушка, сушеные яблоки, снеки, цукаты, коэффициент теплообмена, коэффициент массоотдачи.

Introduction

In Ukraine there is a growing tendency of proper nutrition of the population. Most snacks presented on the market relate to unhealthy food, because they contain butter, preservatives, various flavor boosters and a significant amount of sugar (chocolate bars). Among natural products, consumers prefer nuts (pistachios, peanuts), but their price is higher than average, and not everyone can afford them. Dried apples are in demand, but the monotony of their assortment needs to be expanded. Apples are a common product, but due to the insignificant term of implementation and special storage conditions (temperature, regulated gas environment, relative humidity), there is a need for their processing, that is, the development of an innovative product made from apples.

Materials and Methods

The material for drying is selected autumn variety of apples "Golden Delicious" with high content of initial dry substances and sugar-acid index (more than 8). The pecularity of this variety is the large size of the fetus and the ratio of the seed chamber to the pulp, this particular indicator characterizes the amount of waste. The activity of peroxidase in fresh apples was determined by a photoelectrocolorimeter (FEC). The mass fraction of dry matter was determined by refractometric method; moisture content according to the accelerated Chizhova method; the content of organic acids was determined by titration of alkali (in terms of malic acid), the content of sugars - using the Permanganate method; the content of mineral impurities (ash) - the irrigation of a batch weight; content of pectin substances - with the help of calcium pectates, vitamin C content - potentiometric titration of 2,6-dichlorophenolidophenol.

Results and Discussion

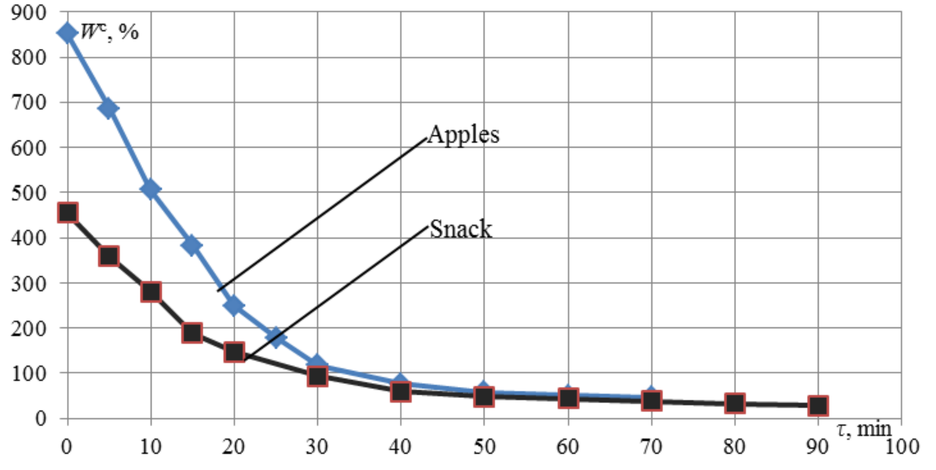
The production of prospective products from apples is characterized by preliminary preparation of raw materials. For the preparation of dried apples, the preliminary preparation consisted of: calibration, inspection, washing, cleaning from inedible parts (peel and seed chamber), cut into pieces of 3-6 mm and blanching in hot water at a temperature of 96-100 ° C, after cooling and drying semi-finished products to a solids content of 85%.

In the production of snacks, the technological scheme is analogous to the production of dried apples until blanching, after which the cut apples with the size of 3-5 mm were blanched in 30% sugar syrup by a ratio of apples and syrup as 1: 2 with the addition of citric acid and antioxidant, and then were cooled during 6 minutes in 30% concentrated sugar syrup at a temperature of 18 ... 20 ° C with addition of 0.1% of citric acid and 0.01% of ascorbic acid. Such an operation is necessary in order that the particles of apples do not lose their shape and absorb a part of sugar with citric acid. This provides an acceptable sugar-acid index of raw materials and a pleasant taste.

In the production of candied fruits, apples also undergo preliminary preparation: sorted, inspected, washed, peeled and seedless apples were cut into slices 15-20 mm thick and 35 mm long. After cutting, they were blanched in hot water (95-98 ° C) for 1 minute, then cooled under cold running water. Then they were boiled in sugar syrup in 3 stages with equal regimens: they were cooked for 30 minutes, then cooled to room temperature, so that the sugar was absorbed into the fruit and in order to avoid parting of apple fuits. The cooking was finished when the solids reached 78% in syrup and 70-72% in fruits. After that, the jam was cooled at room temperature (18-20 ° C) and the fruits were separated from the syrup. The separated fruit were washed off with water and were sent to a dryer to blow the surface of the fruit in order to remove excess moisture for 10 minutes. The next and main technological operation was drying.

Drying of products were carried out upholding following parameters: in the first drying period, where the moisture was removed more intensively, the temperature was 70-75 ° C, and in the second period was 50-55 ° C in order to avoid caramelization of sugars and local browning of the product; the velocity of the coolant in the chamber was 5.5 m/s; specific load - 8.8 kg/m^2; the amount of radiation irradiated by thermoradiation heating elements - 8 kW/m^2, the wavelength of tubular "dark" thermoradiation generators - 2.0-4.0 μm; air heating that was carried out from an external heating element - 2.5 kW/m^2; the distance between the thermoradiation heating elements and the product was 14 cm.

Based on obtained results, drying curves (Fig. 1) were plotted to characterize the change in the moisture content of W^c, with relation to time τ. The figure shows that the heating period for all samples is minimal, and the rate of dehydration was directly proportional to the increase of sugar concentration in products.



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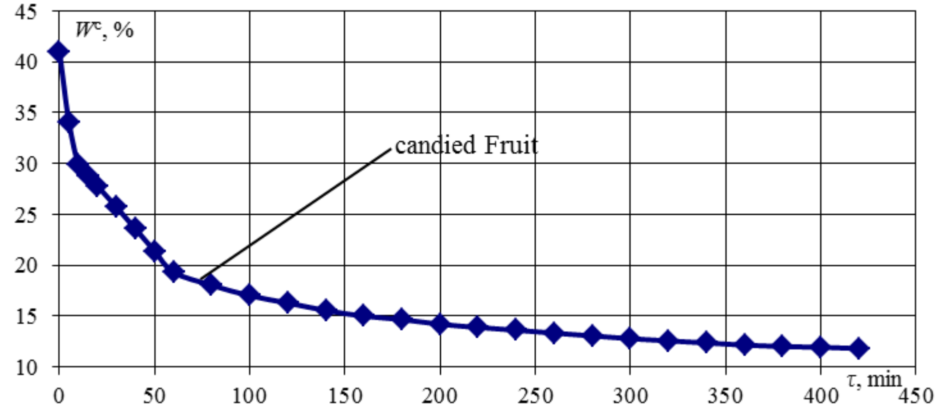

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Fig. 1. *Curves for drying products from apples*

Analyzing *Fig. 1 b*, it shows a rapid removal of moisture for 10 minutes, which is typical for blowing from the semi-finished product in order to remove excess moisture, which remained after the fruit was washed off the sugar syrup.

Approximating the data of the first and second drying periods, we derived the equation of the dependence of the moisture content W^c on the drying time τ (Table 1).

Table 1. *The equation of the moisture content W^c (%) from the drying time τ (min)*

Product:	1 period	2 period
dried apples	$W^c = -30{,}162\tau + 836{,}95$ at $R^2 = 0{,}99$	$W^c = 14611\ \tau^{-1{,}39}$ at при $R^2 = 0{,}99$
snacks	$W^c = -17{,}544\tau + 452{,}56$ at $R^2 = 0{,}99$	$W^c = 3418{,}2\ \tau^{-1{,}07}$ at $R^2 = 0{,}99$
candied fruits	$W^c = -0{,}213\tau + 32{,}04$ at при $R^2 = 1$	$W^c = 55{,}57\ \tau^{-0{,}26}$ at $R^2 = 0{,}99$

where W^c - moisture content,%; τ - time, minutes; R^2 - correlation coefficient.

Based on the drying curves, the obtained dependences of apple products drying rate on moisture content (Fig. 2), allow us to analyze the dynamics of drying variation of samples. In deriving the equation of drying kinetics of the experimental dependences $dW^c/d\tau$ on W^c, it was established that in the first stage the drying rate can be approximately considered constant. And since the second drying period, there has been a growing dependence with a different characteristic of the sugar concentration.

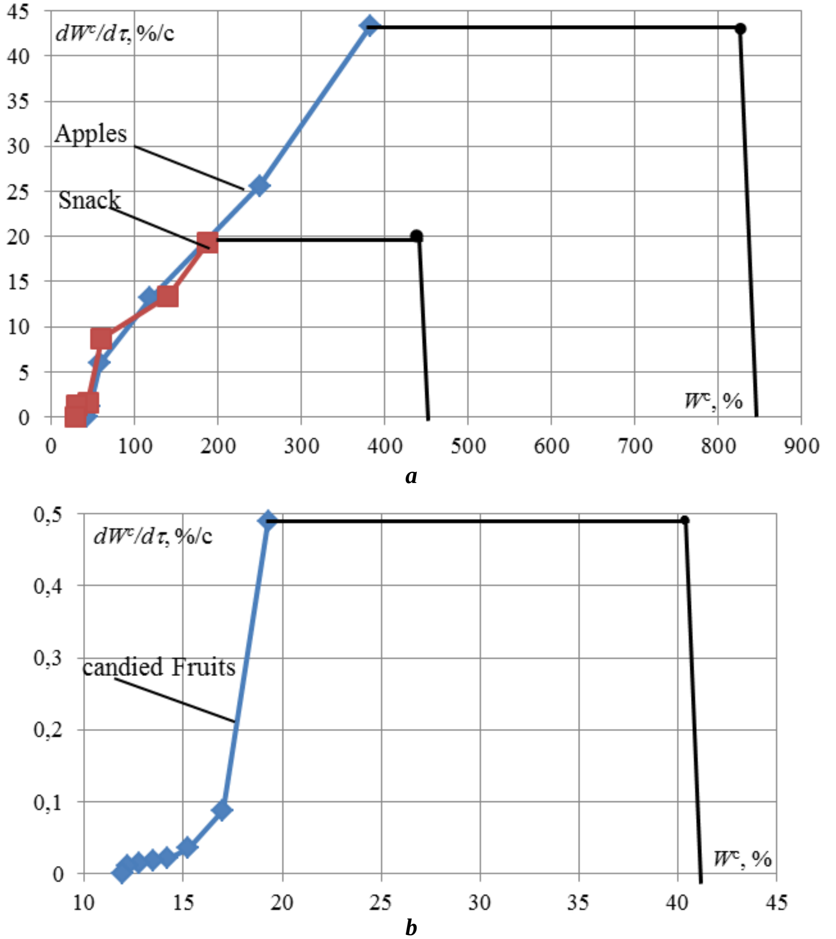


Figure 2. *Curves of apple products drying speed*

Based on the second drying period, the approximation equations of dependences $dW^c/d\tau$ for W^c for each product were derived (Table 2).

Table 2. *Approximation equations for the second drying period*

Product:	Approximation equations
dried apples	$dW/d\tau = 16{,}55\ln(W) - 62{,}87$ at $R^2 = 0{,}98$;
snacks	$dW/d\tau = 8{,}46\ \ln(W) - 28{,}34$ at $R^2 = 0{,}96$;
candied fruits	$dW/d\tau = 0{,}0073\ W^2 - 0{,}2 + 1{,}29$ at $R^2 = 0{,}99$.

Based on the processing of the drying curves and the drying rate curves, the dependences of drying rate coefficients in the first and second periods for all product samples were determined (Fig. 3).

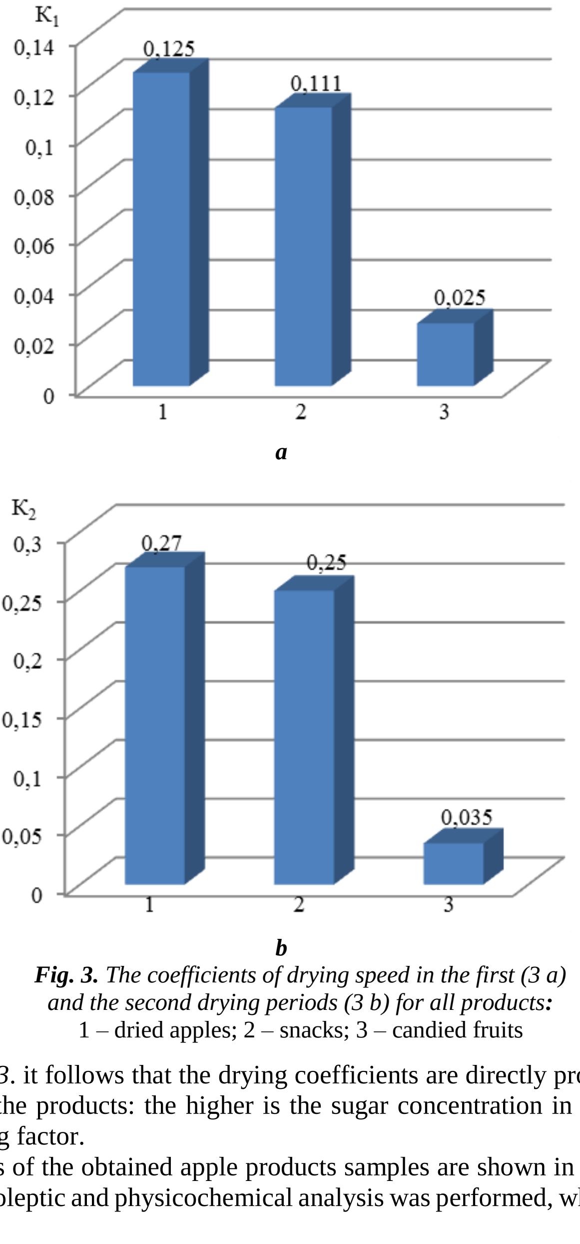
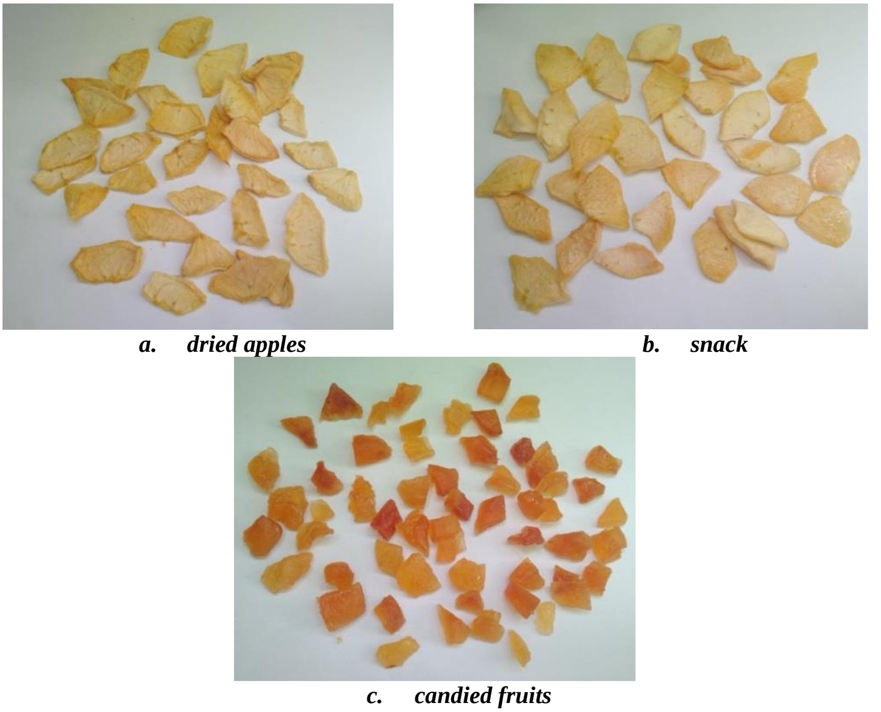


Fig. 3. *The coefficients of drying speed in the first (3 a) and the second drying periods (3 b) for all products:*
1 – dried apples; 2 – snacks; 3 – candied fruits

With *Fig. 3*. it follows that the drying coefficients are directly proportional to the sugar content of the products: the higher is the sugar concentration in the product, the lower is the drying factor.

The photos of the obtained apple products samples are shown in *Fig. 4*. For each product, an organoleptic and physicochemical analysis was performed, which is presented in Tables 3 and 4.



a. dried apples *b. snack*

c. candied fruits

Fig. 4. *Photo of finished samples obtained by drying in two stages*

Table 3. *Organoleptic analysis of products obtained in two-step drying method*

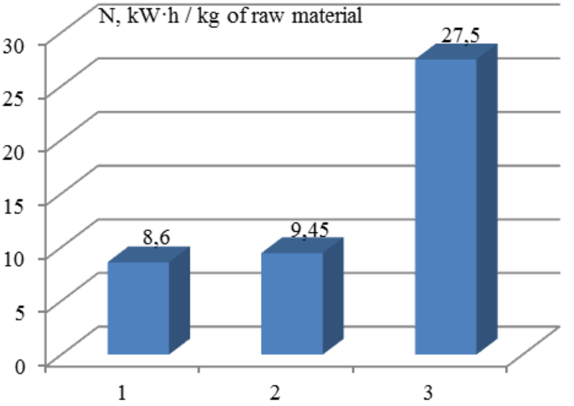
Organoleptic indices	**Dried apples**	**Snacks**	**Candied fruits**
Appearance	parallelepipedal pieces of equal size	parallelepipedal pieces of equal size	equal pieces in the form of cubes
Consistence	Elastic, the product does not stick together during compression	Elastic, the product is glued together when compressed	Dense, elastic, the product can stick together, but when pressed crumbles
Color	Light Brown	Yellow	Brown
Scent	Pleasant, proper for used raw materials	Pleasant, expressed, proper for used raw materials	Pleasant, proper for used raw materials
Taste	Sweet, pleasant, proper for used raw materials	Sour-sweet, pleasant, proper for used raw materials	Sweet, pleasant, proper for used raw materials

Table 4. *Physicochemical analysis of products obtained in two stages drying method*

Indicator	**Product:**		
	dried apples	**snacks**	**candied fruits**
Dry matter of fresh apples,%	12,5		
Dry substances of apples, %	87	84,5	85,5

Indicator	Product:		
	dried apples	snacks	candied fruits
Mono- and bi-sugars, %	65,2	63	76,9
Organic acids, %	2,4	2,3	0,5
Pectin substances, %	4,9	4,1	0,7
Dietary fiber, %	4,2	3,8	0,4
Mineral substances, %	3,7	2,6	0,7
Vitamin C, mg %	2,4	8,3	6,3

Based on the data obtained, the energy costs for all product samples in kW·h in kg of feedstock (Fig. 5 a) and in MJ/kg evaporated moisture (Fig. 5 b) are shown in Fig. 5.



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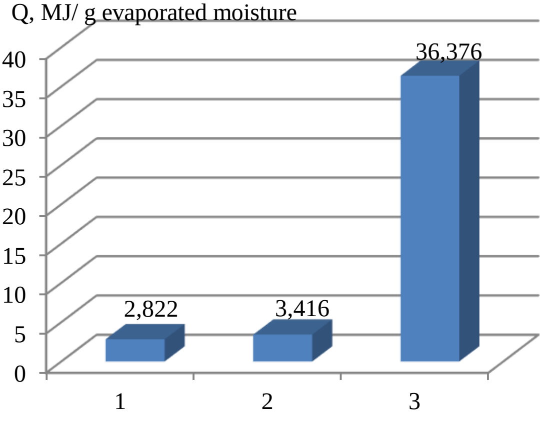

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Fig. 5. *Electricity consumption per 1 kg of feedstock (5a) and 1 kg of evaporated moisture (5 b) for:*
1 – dried apples; 2 – snacks; 3 – candied fruits

Analyzing *Fig. 5* we can conclude that the content of sugars in semi-finished products is of significant importance. The lowest energy costs were 8.6 kW·h / kg (2.82 MJ/kg evaporated moisture) for dried apples, and the largest energy costs for candied fruit were 27.5 kW·h /kg (36.37 MJ/kg evaporated moisture). This phenomenon is explained by the fact that significant concentrations of sugar prevents the removal of moisture from the semi-finished product, keeping it in the product by osmotic and chemical bonds.

In connection with the significant influence of the sugar concentration in the products on the various parameters of the drying process, it is expedient to establish optimum values for it. The amount of heat that is expended on the evaporation of moisture during the apple products drying is presented in Table 5.

Table 5. *The amount of heat that is expended on evaporation of moisture from apple products*

Coolant Temperature t, °C		**Product:**	**Drying Time τ, s**	**Quantity of heat, Q:**		
1 period	**2 period**			**(kW·h)/kg moisture**	**MJ/kg moisture**	**(kW·h)/kg of raw material**
75	55	dried apples	70	846,5	2,82	8,6
		snacks	90	768,5	3,42	9,45
		candied fruits	420	210	36,38	27,5

Internal surface area of a kilogram of dried product for dried apples and snacks, provided that the raw material is cut into parallelepipedal pieces with dimensions of 30 × 3 × 15 mm, is:

$$F = 2 \cdot (a \cdot b + a \cdot h + b \cdot h) \cdot n, \text{ m}^2\text{/kg of feedstock}, \qquad (1)$$

where a, b, h – are the length, width and height of the snack particle, m, respectively; n – is the number of particles per m^2.

External surface area of a kilogram of the dried product for candied fruits, provided that the raw material is cut into pieces in the form of cube with dimensions of 15 × 15 mm, is:

$$F = 6a^2\, n, \text{ m}^2\text{/kg of feedstock}, \qquad (2)$$

where a – is the side of the cube, m^2.

The coefficient of heat transfer is calculated by the formula:

$$\alpha = Q / \Delta t_{cp.} \cdot F, \qquad (3)$$

where $\Delta t_{cp} = t_{п} - t_{cp}$;

t_{cp} – arithmetic-mean air temperature in the drying chamber; t_{n} – is the temperature of the material (in the first drying period it is equal to the temperature of the wet thermometer). The results of the calculations are given in Table 6.

Table 6 *External surface area of a kilogram of dried product and the heat transfer coefficient for products from apples*

Coolant Temperature t, °C		**The Speed of air in the Chamber *w*, *m*/s**	**Product:**	**External surface area of a kilogram of dried product *F*, m²/kg of feedstock**	**Heat transfer coefficient α during drying**
1 period	**2 period**				
75	55	5,5	dried apples	2,633	362,98
			snacks	2,633	398,86
			candied fruits	8,438	362,13

Through studies of drying periods, the speed of the drying process was determined by the state of the environment and the drying conditions, and the total moisture flux was expressed in terms of the volume mass transfer coefficient:

$$J = dW^c/d\tau=\beta(x_г–x) = \beta(x_1–x), \tag{4}$$

where $x_г$ – is the moisture content of air (kg/kg) at the particle boundary, which is considered to be equilibrium; $x_г = x_1$ - moisture content of air at a constant speed (the first period) of drying (kg/kg) was found by a psychrometer. Molar mass of water $M_в = 18$, air $M_п = 29$, relative air humidity φ = 64%. The partial pressure of the saturated water vapor P at the temperature t was found from the tables, and the mole fractions of m from the ratio $m_1 = Pt_1/(1-Pt_1)$, $Pt_1 = Pt/760$. At 21 °C, $Pt_{21} = 18.66 / 760 = 0.025$. The molar fraction at 21 °C $m_2 = Pt_{21}\varphi / (1-Pt_{21}) = 0.016$. The moisture content of air in the first period was found by the formula:

$$x_1 = (M_в/M_n)(m_1/(1–m_1)). \tag{5}$$

Moisture content

$$x = (M_в/M_n)(m_2/(1–m_2)) = 0{,}01. \tag{6}$$

The results of moisture flux determinations $J = dW^c/d\tau$ and the mass transfer coefficient $\beta = J/(x_1-x)$ for each apple product are shown in Table 7.

Table 7. *The moisture flux during drying and the mass transfer coefficient for apple products*

Coolant Temperature t, °C		**The Speed of air in the Chamber *w*, m/s**	**Product:**	**Moisture flow during drying**	**Masstransfer coefficient β, m/s**
1 period	**2 period**				
75	55	5,5	dried apples	43,27	1138,68
			snacks	19,37	509,74
			candied fruits	0,5	98

With the mass-transfer coefficients (Table 7), it is evident that the higher is the sugar content in the product, the worse and slower the moisture is removed.

Conclusions

Food products manufactured in the process of scientific work are suitable for sale in trade networks. Dried apples can be used as raw materials for compotes. Apple snacks, like a quick snack. Candied fruits are offered for industrial processing in the confectionery sphere as fillers for cupcakes, Easter cakes, fancy cakes and pies. The proposed technology of candied fruits can be improved by derging sugar (or powdered sugar) or covering with chocolate glaze and sell in retail trade.

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