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## INTENSIFICATION OF THE PRODUCTION OF DIETARY PRODUCTS BASED ON CITRUS SECONDARY MATERIAL RESOURCES

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**Abstract.** The article is devoted to the problem of intensifying the production of dietary products, specifically candied fruits, by utilizing secondary material resources from citrus processing. Citrus peels are a rich source of vitamins, pectin, and minerals, yet they are often discarded as waste. The research focuses on developing a highly efficient technological scheme for processing mandarin peels into low-calorie dietary candied fruits. The proposed innovation involves replacing traditional energy-intensive thermal processes, such as water blanching and convective drying, with advanced electrophysical treatment in the field of infrared (IR) radiation. Additionally, to enhance the dietary value and reduce the energy content of the final product, traditional sugar is replaced with the low-calorie sweetener aspartame. During the study, the spectral-optical properties of mandarin peels were analyzed to select the most effective IR generators, specifically NIK–220-1000. Experimental research established the optimal parameters for IR blanching: an irradiation density of 0.35-0.40 kW/m<sup>2</sup>, a distance of 20 cm, and a process duration of 50-53 seconds, resulting in a residual moisture content of 73-75%. For the drying stage, the optimal conditions were found to be an irradiation density of 0.35-0.40 kW/m<sup>2</sup> and a duration of 25-27 minutes at a temperature of 100–105°C, achieving a final moisture level of 21–23%. The results demonstrate that the use of infrared energy intensifies the production process by more than five times compared to conventional methods. Furthermore, the quality of the finished product improved significantly, showing better preservation of ascorbic acid and superior organoleptic characteristics. The resulting dietary candied fruits have a low energy value of only 11.5 kcal per 100g, making them suitable for specialized nutrition. The study confirms that implementing IR technologies in the processing of citrus secondary resources is an effective way to improve production efficiency, save energy, and create functional food products with high biological value

**Keywords:** candied fruit, secondary material resources, drying, blanching.

### Introduction. Formulation of the problem

Among the many fruit crops, citrus fruits are especially popular. The fruits contain useful biologically active substances, have a pleasant aroma, taste, carbohydrates, pectin substances, organic acids, minerals and vitamins (B1, B2, C, D, E, P), a high concentration of minerals, which determines their dietary, medicinal value. preventive, dietary, cost. The chemical composition of citrus fruits (peels) is also rich in chemical composition and is the best additive in confectionery products, a good material for the production of candied fruit, and for the preparation of alcoholic aromatic drinks. The highest quality essential oils are obtained from citrus peels and are successfully used in perfume production [1-4]

Practice has shown that expanding the use of secondary material resources and increasing their level ensures savings in raw materials, heat and energy. The

negative impact of waste on the environment is reduced, the raw material base is expanded, which allows for efficient production and significantly increases the economic efficiency and competitiveness of the enterprise [2, 5-8].

### Research materials and methods

Experiments were carried out according to a previously compiled program and method (on the basis of the of Akaki Tsereteli State University - Faculty of Agriculture, Kutaisi).

The purpose of this work is to intensify the production of low-calorie, dietary and biologically active products based on citrus (mandarin) secondary material resources.

The traditional technological cycle of candied fruit production includes: washing raw materials, removing the skin, cutting the skin, holding in brine, washing in

running water, thermal treatment - boiling, soaking in sugar syrup, drying, sorting, packaging [2, 6].

In the technological scheme for the production of dietary candied mandarin from the peel of raw materials, we propose: instead of thermal processes, blanching (in water  $t=100^{\circ}\text{C}$ ) and convective drying (process temperature  $t=120^{\circ}\text{C}$ ), blanching and drying with infrared rays, instead of adding sugar - in the technological scheme we select low-calorie "saccharin" (aspartame).

Infrared energy was chosen as the energy source. It is known that infrared rays significantly intensify technological processes, simplify technological equipment, improve working conditions, eliminate environmental pollution, etc. [9-12].

The specific effect of infrared rays during the thermal treatment of materials of plant and animal origin beneficially changes their structure and the direction of molecular chains, resulting in an increase in the quality of the products, they become suitable for storage for a long time without any chemical additives [13-17].

Due to these positive properties, their use in production is more appropriate (table 1). To study the process of thermal treatment of mandarin secondary material resources, a special methodology was developed, the main factors influencing the process and their relationship were determined (type of generators; type of irradiation; irradiation density  $P \text{ kw/m}^2$ ; distance between the material under study and infrared ray generators  $N \text{ cm}$ ; Material thickness  $\delta \text{ cm}$ ; duration of thermal irradiation  $\tau \text{ min}$ ; final residual moisture content of the semifinished product  $W\%$ ).

Infrared irradiation measurements were performed using a thermoelectric device (DTP0924ROP50-50JO). The process temperature was measured with a mercury thermometer and an infrared thermometer (RaytekMini-TempMT6). The residual moisture in the material was determined with a moisture meter (ECV-4V). Carbohydrates were determined by analytical method, fats in citrus were determined by the Randall method, proteins were determined by the Kjeldahl method, mineral substances were determined using the dry ashing method, ascorbic acid was determined by the titrimetric method, the number of calories was determined by a calorimeter device.

The analytical material was subjected to physical and chemical research, which included: assessment of carbohydrates, fats, proteins, minerals, ascorbic acid, and calorie content.

Carbohydrates were quantified by an analytical method - Sugar was extracted from the material by 3-fold extraction with 80 % ethyl alcohol at  $80^{\circ}\text{C}$  temperature. The alcoholic extracts were combined and

evaporated under vacuum at a temperature not exceeding  $40^{\circ}\text{C}$ , diluted with water and filtered, the filtrate was additionally treated with copper oxide hydrate ( $\text{CuSO}_4+\text{NaOH}$ ). The precipitate that formed was filtered off. Reducing sugars were determined in the filtrate using one of the chemical methods - using Fehling solutions. To determine the total amount of sugar, an inversion was carried out - heating a sugar solution with 0,1 N. solution of hydrochloric acid, cooled and neutralization was carried out.

One way to determine fat in raw materials and finished products is solvent extraction. We used the Randall analytical extraction method, which is an improved method. Hydrolysis was carried out in the presence of hydrochloric acid for an hour at a temperature of  $170^{\circ}\text{C}$ . The hydrolyzed sample was then filtered into glass crucibles and washed with warm deionized water to remove residual hydrochloric-acid, extractions were carried out on a SER 148 instrument.

Proteins in raw materials were determined using the Kjeldahl method. The essence of the method is the sequential implementation of three operations, namely: mineralization; distillation; titration. The method is based on calculating the mass fraction of nitrogen, since its content is a constant value.

Mineral substances were determined using the "dry" ashing method. The simple combustion method is based on heating organic matter at a high temperature with access to air. Dry ashing was carried out in porcelain crucibles. Small samples (3 g) were taken for the study; the heating temperature reached  $300-400^{\circ}\text{C}$ . The mineral content was calculated using the standard formula.

Ascorbic acid was determined by titrimetric method. Titrimetric analysis is based on the precise measurement of the volume of a reagent with a precisely known concentration (sodium 2,6 - dichlorophenolindophenolate) consumed in the reaction with the substance being determined (titrated). Primary standard solutions were prepared by dissolving an accurate weighed portion of the substance (primary standard) in a certain volume of solvent (in a measuring cup). The titration process was repeated three times (with differences in results not exceeding  $\pm 0,10 \text{ ml}$ ). The content of ascorbic acid was calculated using the standard formula.

The number of calories was determined by a device - the Easyover MC2 calorimeter.

Control quality of dry fruits and vegetables includes organoleptic assessment of production. Organoleptic analysis is a physiological process in which the role of a measuring instrument is played by human senses - sight, smell, touch, taste and hearing.

**Table 1 – Main characteristics of infrared generators NIK-220-1000**

Normal voltage, w	Energy consumption, w	Temperature, $^{\circ}\text{K}$	Average working hours, h	Quartz tube diameter, mm	Emitter diameter, mm
220	1040	2550	5000	370	10

The reliability of the results of organoleptic tests depends on the ability of the evaluator to perceive this or that property of the product, the physiological and psychological state of the evaluator, the conditions in which the product is tested and many other factors, while the rules of evaluation play an important role.

For organoleptic assessment, we had a bright, large, clean and isolated storage room. Temperature was 18-20 °C, relative humidity 74–75 %.

We started the organoleptic evaluation with an external inspection of the semi-finished product, then determined the color and hardness, and finally evaluated the smell, taste and consistency.

When organoleptic evaluation of the quality of food production, they determine how much the individual organoleptic indicator of the product meets the requirements of the corresponding control material or standards.

A scoring system was used for organoleptic assessment. In the case of the best quality, the maximum number of buckles was taken into account for each indicator. In case of any deviations, the buckle was reduced accordingly. It is known that fruit production is evaluated on a 10 - point system.

When organoleptically assessing the quality of semi-finished products, great attention was paid to visual properties, color, appearance and shape. When determining the color of the product, we often used color standards.

We tested the product in conditions of good lighting. Odor was determined using an olfactory analyzer. Human olfactory organs are so well developed that he can detect even the smallest amount of aromatic and foreign smelling substances in the product. Before the study, we heated the semi-finished product to 40°C, since the olfactory organs perceive volatile aromatic substances better at a higher temperature. We limited the smell not only on the surface of the material, but also in deep layers. If the product has an unpleasant aftertaste, it is not suitable for consumption and we usually do not conduct a tasting of such a product.

When checking the quality of food production, we used the terms - smell, aroma and bouquet. When we talk about smell, we mean any sensation perceived by the organ of smell. Aroma is an attractive smell of a substance that causes a pleasant sensation. Bouquet is the smell resulting from the ripening of a product.

Taste is the most important organoleptic characteristic of a food product. Definition of taste and smell are closely related to each other. Therefore, we studied them at the same time. There are four main tastes: sweet, bitter, sour and salty. When evaluating the quality of production, we evaluated the combination of these four main flavors [6, 18, 19].

During the control of the appearance of the semi-finished product, they removed the product from the packaging material and determined:

- How much mass is obtained in terms of homogeneity of sizes, elasticity and fragility;

- Does the raw material correspond to standard norms for taste and aromatic properties;
- Does the product have another uncharacteristic smell and taste;
- Are there any metallic impurities in the mass.

### **Results of the research and their discussion**

It is established that the spectral-optical properties of food products and infrared generators are individual. Therefore, it is necessary to select infrared generators during thermal processing of materials taking into account the spectral-optical characteristics of the processed products - by correlation. Only in this case it is possible to achieve high efficiency of heat treatment of materials [20].

The spectral-optical properties of moist materials and products are determined by the dimensions and physical-chemical properties of the materials (composition, surface condition, ability to scatter rays, density, porosity, etc.). It is established that for heat treatment of materials, including drying processes, infrared rays with a wavelength of 0,77-15 μm should be used, because 80-90% of the radiated energy falls in this area of the spectrum, it is also similar to the 1-1,1 μm wave energy of long infrared rays [20, 21].

Wet materials are divided into four main groups: weak, medium, strong, and very strong emissive materials. Most food products, including mandarin peel, belong to the first three groups of materials. When studying their spectral-optical properties, we took into account all optical characteristics (transmittance, reflection, absorption) and used the spectrophotometric method for the complex determination of these properties in a wide range, taking into account the scattering of radiant energy [6].

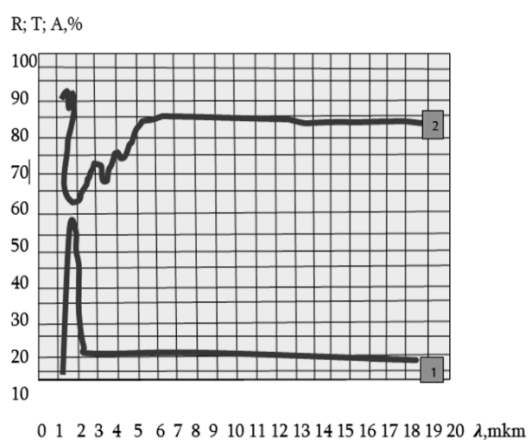
When drying food products, increasing the thickness of the layer, the ability to absorb radiation energy increases and reaches a maximum, while the values of reflection and transmittance decrease. For example: layers of food products with a thickness of 30 mm and more almost completely absorb the irradiated infrared radiation energy, which was confirmed by the study of the spectral-optical properties of the secondary material resource of mandarin (mandarin peel) and the analysis of the constructed curve (fig. 1).

It was determined that the raw material we have chosen has a high reflectivity in the infrared spectrum of 0,7-1,35 μm wavelength. The maximum reflectance for a 30 mm thick layer is 70–72 %, for a 40 mm thick layer 62–63 %, and for a 60 mm thick layer 45–48 %.

The reflectivity and transmittance for the selected material are similar to those in the infrared spectrum. For a 30 mm thick layer, the maximum transmittance in the 0,7–1,35 μm wavelength is 37–40 %, for a 40 mm thick layer it is 22–24 %, and for 60 mm it is equal to 0 in the entire specified interval of the spectrum.

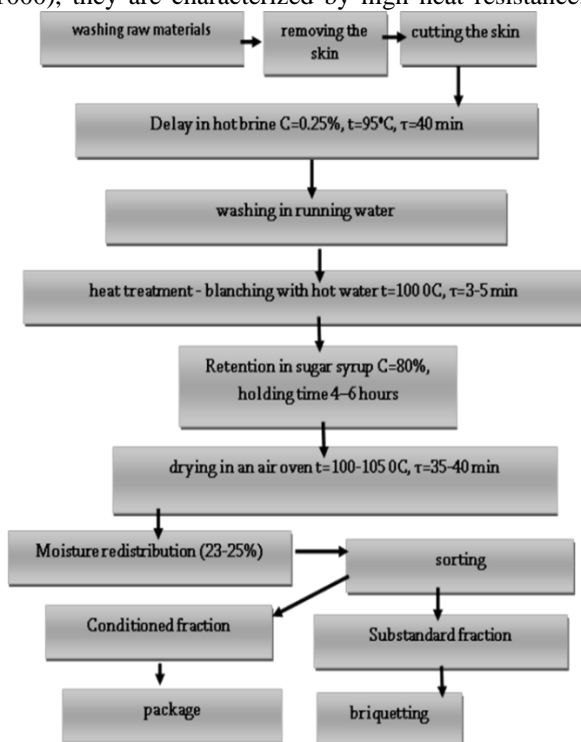
The absorption capacity of the secondary material resource of mandarin - mandarin skin for a thin layer in the wavelength range of 0,7–1,35 μm is insignificant,

and with increasing layer thickness it increases and reaches the maximum (90–95%) for a layer with a thickness of 60 mm.



**Fig. 1 Optical capacity curves of tangerine secondary material resource - mandarin skin**  
 1. Reflectivity-A, 2. Absorption-R, 3. Transmittance  
 $T=0$

Preliminary experiments have shown that low-power mirror electric lamps ZC cannot provide intense and effective heating of the material. Therefore, they are inappropriate. As for the quartz and quartz-halogen tubular type heat emitters (NIK-220-1000 and KG-220-1000), they are characterized by high heat resistance,



**Fig. 2. Technological scheme for the production of candied mandarin fruits using existing technology**

reliability and long-term operation, with the convenience of installation in the camera.

A high concentration of infrared radiation (40 w/cm<sup>2</sup> and more) is achieved in these generators. The surface temperature of the quartz tube is 400–450°C, in the area of the electrodes – 1300°C. The main advantage of quartz and quartz-halogen tube lamps is non-inertia [22].

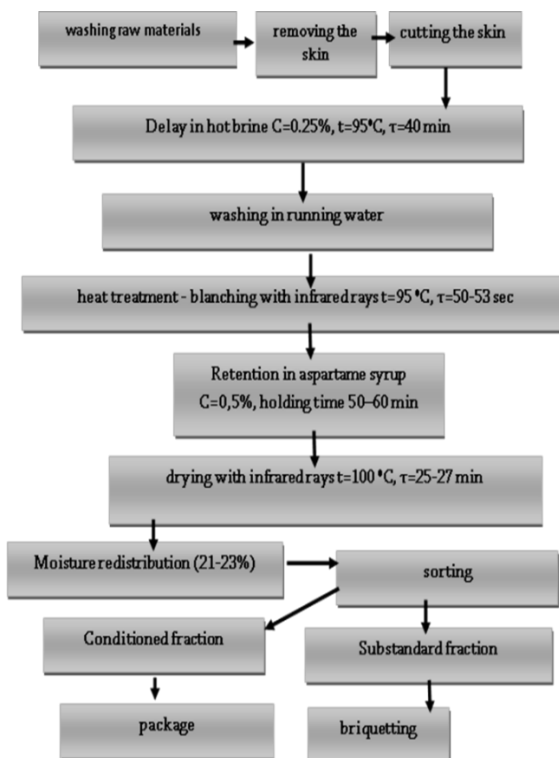
In order to concentrate the energy in the desired direction, it is recommended to use reflectors with the generators, which will increase the intensity of the radiation flow and increase the efficiency of the energy field.

The technological scheme for the production of candied mandarin fruits using existing technology is as follows (fig. 2).

Our proposed technological scheme for the production of dietary candied fruit using infrared energy is as follows (fig. 3).

Based on the methodology, the following materials were chosen for research: peel of citrus raw materials - mandarin.

For the purpose of heat treatment, the raw materials were introduced pre-heated in a laboratory chamber equipped with infrared generators (NIK–220-1000) and evenly distributed onto a metal mesh. The temperature in the drying camera was maintained by selectively switching on the infrared generators and by regulating the air flow supplied to the camera.



**Fig.3. Our proposed technological scheme for the production of dietary candied fruit**

The process of blanching and drying was considered complete after monitoring visual and organoleptic inspection and residual moisture content of the material (blanching – 73-75 %, drying – 21–23 %).

To conduct the experiment, we took the material under study, placed it in a preheated chamber and carried out the blanching process with infrared irradiation; the optimal process temperature was taken to be  $t=95-98^{\circ}\text{C}$ . The blanching process was considered complete after monitoring visual and organoleptic inspection and residual moisture content of the material (73–75 %).

To determine the parameters of the drying mode, the optimal process temperature was  $T=100-105^{\circ}\text{C}$ . The drying process was accepted as complete after monitoring visual and organoleptic inspection and residual moisture content of the material (23–25 %).

Options for optimal modes for blanching mandarin secondary material resources by infrared irradiation are given in table 2, 3, 4. Options for optimal modes for drying mandarin secondary material resources by infrared irradiation are given in tables 5, 6, 7.

**Table 2 Experimentation options**

Variants	Ray radiation density, P, kw/m <sup>2</sup>	Distance between generators and material, H cm	Material layer thickness, $\delta$ cm	Process duration, $\tau$ , sec	Process temperature T, °C	Residual moisture content of the material W, %
I	0,25±0,05	10±2	5	117-120	95-98	73-75
II	0,35±0,05	10±2	7	115-118	95-98	73-75
III	0,45±0,05	10±2	9	114-116	95-98	73-75

**Table 3 – Experimentation options**

Variants	Ray radiation density, P, kw/m <sup>2</sup>	Distance between generators and material, H cm	Material layer thickness, $\delta$ cm	Process duration, $\tau$ , sec	Process temperature T, °C	Residual moisture content of the material W, %
I	0,25±0,05	15±2	5	77- 79	95-98	73-75
II	0,35±0,05	15±2	7	76 - 78	95-98	73-75
III	0,45±0,05	15±2	9	73 - 75	95-98	73-75

**Table 4– Experimentation options**

Variants	Ray radiation density, P, kw/m <sup>2</sup>	Distance between generators and material, H cm	Material layer thickness, $\delta$ cm	Process duration, $\tau$ , sec	Process temperature T, °C	Residual moisture content of the material W, %
I	0,25±0,05	20±2	5	55 -57	95-98	73-75
II	0,35±0,05	20±2	7	54 -55	95-98	73-75
III	<b>0,45±0,05</b>	<b>20±2</b>	<b>9</b>	<b>50 -53</b>	<b>95-98</b>	<b>73-75</b>

**Table 5 – Experimentation options**

Variants	Ray radiation density, P, kw/m <sup>2</sup>	Distance between generators and material, H cm	Material layer thickness, $\delta$ cm	Process duration, $\tau$ , sec	Process temperature T, °C	Residual moisture content of the material W, %
I	0,25±0,05	10±2	5	52- 55	100-105	21-23
II	0,35±0,05	10±2	7	49- 50	100-105	21-23
III	0,45±0,05	10±2	9	46- 48	100-105	21-23

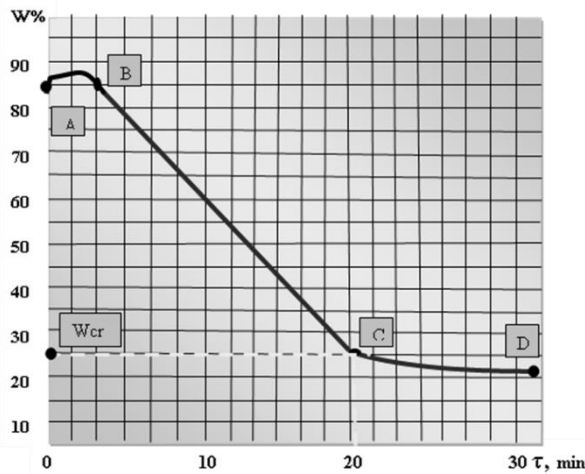
**Table 6 – Experimentation options**

Variants	Ray radiation density, P, kw/m <sup>2</sup>	Distance between generators and material, H cm	Material layer thickness, $\delta$ cm	Process duration, $\tau$ , sec	Process temperature T, °C	Residual moisture content of the material W, %
I	0,25±0,05	15±2	5	44 - 48	100-105	21-23
II	0,35±0,05	15±2	7	42 - 45	100-105	21-23
III	0,45±0,05	15±2	9	37 - 39	100-105	21-23

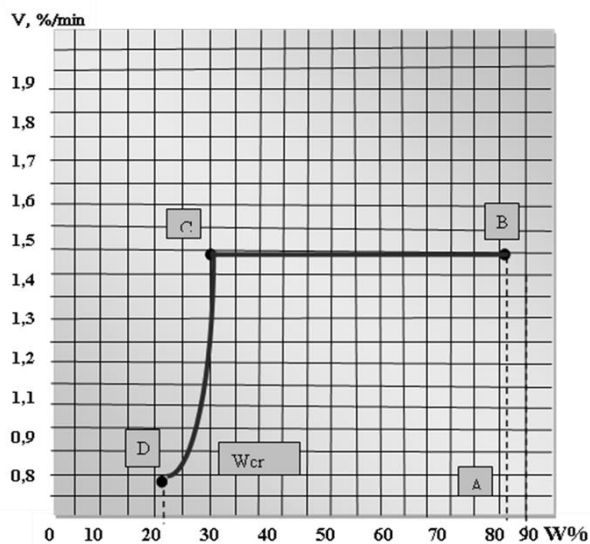
**Table 7 – Experimentation options**

Variants	Ray radiation density, P, kw/m <sup>2</sup>	Distance between generators and material, H cm	Material layer thickness, $\delta$ cm	Process duration, $\tau$ , sec	Process temperature T, °C	Residual moisture content of the material W, %
I	0,25±0,05	20±2	5	34 -37	100-105	21-23
II	0,35±0,05	20±2	7	29 -32	100-105	21-23
III	<b>0,45±0,05</b>	<b>20±2</b>	<b>9</b>	<b>25 -27</b>	<b>100-105</b>	<b>21-23</b>

It turned out that in the field of infrared rays, the kinetics of the drying process of mandarin secondary material resources is characterized by certain, peculiar properties, which is confirmed by a joint analysis of experimental curves built on optimal modes (fig. 4, 5).



**Fig. 4** Drying curves of mandarin secondary material resources in the field of infrared rays



**Fig. 5** Drying speed curves of mandarin secondary material resources in the field of infrared rays

The indicated curves show that the drying process of mandarin secondary material resources consists of three periods:

1. The period of heating the material with increasing drying rate (AB). At this time, the material heats up and surface moisture evaporates. The drying speed reaches a maximum of  $U_{max} = 1,5\%/min$ ; The temperature of the material increases ( $t = 95-100^\circ C$ ); This process lasts a relatively short time ( $\tau = 2,5$  min)

2. Period of constant drying rate of citrus secondary material resources (BC). During this period, free moisture is removed from the material. The drying speed is constant and does not depend on the moisture

content of the material, unless the drying conditions change. The end of free moisture corresponds to the critical humidity of citrus secondary material resources ( $W_{cr} = 24-26\%$ ). This drying period lasts  $\tau = 14-15$  minutes;

3. The period of falling drying speed of citrus secondary material resources (CD). During this period, the drying process depends on diffusion into the material, its structure, physical and chemical properties, moisture content and its form of connection with the material, temperature, etc. During drying in the specified period, part of the bound moisture is removed from citrus secondary material resources. The drying speed is constantly decreasing  $U_{max} = 0,25\%/sec$ ; Humidity of citrus secondary material resources is  $W_2 = 21\%$ ; The temperature of the material constantly increases and reaches the ambient temperature ( $T_{amb} = 100-105^\circ C$ ) temperature of citrus secondary material resources ( $t = 95-100^\circ C$ ); The duration of the process is  $\tau = 7-8$  minutes.

In general, over three periods, mandarin secondary material resources are dried from the initial humidity to the required norm  $W = 62-63\%$ .

Experiments have shown that in order to uniformly redistribute moisture in the dried material, a holding process of 15-20 minutes is necessary.

The influence of different values of the specific load (material layer thickness) of conveyors on the drying process and quality indicators of the semi-finished product under infrared irradiation of the processed material (secondary material resources of mandarin) is shown in table 8.

The physicochemical parameters of the analytical semi-finished product (candied fruit) are given in table 9.

The control material of candied fruits was produced according to the current technological scheme, including: washing of raw materials, removal of the skin, retention in brine ( $C = 0,25\%$ ,  $t = 95^\circ C$ ,  $\tau = 40$  min), washing, blanching with hot water  $t = 100^\circ C$ ,  $\tau = 3-5$  minutes, delay in sugar syrup  $C = 80\%$ , exposure 4-6 hours, drying in an air oven  $t = 100-105^\circ C$ ,  $\tau = 35-40$  min), sorting, packaging.

Comparison of organoleptic indicators of control and analytical materials are given in table 10.

In order to provide a machine-hardware system for the processes of drying and blanching of mandarin secondary material resources by infrared irradiation, based on a generalization of experimental and theoretical data, the main geometric parameters of a blanching-drying machine operating on infrared energy were calculated, the energy balance was determined, the main geometric parameters were clarified, constructive diagrams have been created.

At the same time, modern production requirements were taken into account and the machine was designed for productivity  $G = 100$  kg/h (fig. 6).

**Table 8 – The influence of different values of the specific load (material layer thickness) of conveyors on the drying process and quality indicators of the semi-finished product under infrared irradiation of the processed material (secondary material resources of Mandarin)**

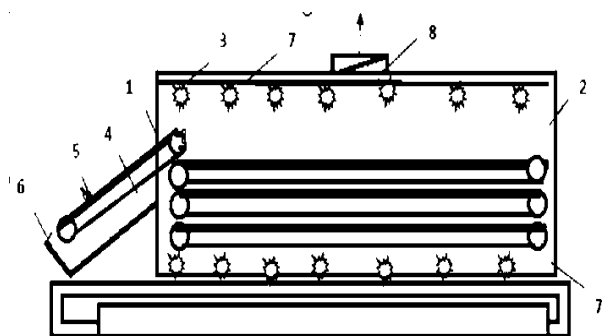
variants	Ray radiation density, P, kw/m <sup>2</sup>	Material layer thickness, δ cm	Distance between generators and material, H cm	Residual moisture content of the material W, %	Mass of normally dried material, %	Weight of underdry material, %	Mass of overdried material, %	Tasting score, point		
								colour	flavour	appearance
I	0,25	5	20	21-23	88,3	10,4	1,3	4,65	4,85	4,70
II	0,35	5	20	21-23	89,5	9,3	1,2	4,65	4,85	4,70
III	0,45	5	20	21-23	90,2	8,4	1,4	4,65	4,85	4,70
I	0,25	7	20	21-23	92,0	7,2	0,8	4,65	4,85	4,70
II	0,35	7	20	21-23	93,5	6,4	1,1	4,65	4,85	4,70
III	0,45	7	20	21-23	95,3	3,5	1,2	4,70	4,90	4,75
I	0,25	9	20	21-23	95,1	3,0	0,9	4,70	4,95	4,75
II	0,35	9	20	21-23	96,5	2,3	1,2	4,70	4,95	4,75
III	0,45	9	20	21-23	98,2	1,1	0,7	4,75	4,95	4,75

**Table 9 Physical-chemical parameters of analytical semi-finished product - candied fruit (% , dry matter)**

Carbohydrates, g	Fats, gr	Proteins, gr	Minerals, mg	Ascorbic acid, %, mg	Calories, kcal
2,9	0,07	0,34	0,15	0,5	11,5

**Table 10 Organoleptic characteristics of the control and analytical semi-finished product**

variants	Tasting score, point		
	colour	flavour	appearance
control	4,25	4,30	4,25
analytical	4,75	4,95	4,75



**Fig. 6. Scheme of a blanching-drying machine for mandarin secondary material resources using infrared energy**

Operating principle of the machine: three working mesh conveyors and one external mesh conveyor (2) are installed in a heat-insulated metal drying chamber (1). The material is fed to the conveyor (2) by an elevator (4), on which a layer leveling mechanism (5) is installed. The processes of blanching and drying mandarin secondary material resources are carried out on all conveyors. To reduce energy losses, aluminum

reflectors (7) are installed on the inner surface of the drying chamber. The processed mass is discharged through a semi-closed opening at the front of the machine.

Process regulation is carried out by adjusting the speed of the working conveyor. Differentiated inclusion of infrared generators in the electrical network.

Based on the calculated material and heat balances, the required power of infrared generators for a blanching-drying machine was determined: Blanching mode Total heat consumption in the machine

$$Q = Q_1 + Q_2 + Q_3 \text{ kJ/h.}$$

here  $Q_1$  - heat consumption for heating raw materials in the process of blanching mandarin secondary material resources by infrared irradiation, kJ/h;

$Q_2$  - heat consumption for moisture evaporation during blanching of mandarin secondary material resources by infrared irradiation, kJ/h;

$Q_3$  - heat loss to the environment during the process of blanching mandarin secondary material resources by infrared irradiation, kJ/h.

$$Q_1 = G \cdot c \cdot (t_2 - t_1) = 100 \cdot 3,43(90 - 20) = 5\,145 \text{ (6,7 kw/h)}$$

here  $G$  - machine productivity,  $G = 100 \text{ kg/h}$ ;  $c$  - specific heat capacity of the material,  $\text{kJ/kg } ^\circ\text{C}$ ;  $t_1$  - initial material temperature,  $t_1 = 20 \text{ } ^\circ\text{C}$ ;  $t_2$  - temperature of material exiting the machine,  $t_2 = 90 \text{ } ^\circ\text{C}$ .

$$Q_2 = w \cdot r = 41 \cdot 2\,350 = 96\,350 \text{ (26,7 kw/h)}$$

here  $w$  - mass of moisture evaporated from the material,  $\text{kg/h}$ ;

$r$  - latent heat of evaporation of water,  $\text{kJ/kg}$ .

$$W = G(w_1 - w_2)/(100 - w_2) = 100(84 - 73)/(100 - 73) = 41 \text{ kg/h}$$

here  $w_1$  – initial moisture content of the material,  $w_1 = 82 - 84 \%$ ;

$w_2$  – final moisture content of the material,  $w_2 = 73 - 75 \%$ .

After the blanching process is completed, as a result of cooling the material, partial self-evaporation of moisture occurs.

$$W^1 = c(G - W)(t_2 - t_1) / r = 3,43(100 - 41)(90 - 24) = 5,7 \text{ kg/h}$$

$$Q_{\text{autoevaporation}} = W^1 \cdot r = 5,7 \cdot 2350 = 13395 \text{ (3,7 kw/h)}$$

$$Q_3 = Q_{\text{camera}} + Q_{\text{air}} = 3,6 \cdot \alpha \cdot F(t_{\text{wall}} - t_0) + L(I_2 - I_0) = 3,6 \cdot 12,12 \cdot 30(55 - 22) + 300(100 - 50) = 59505 \text{ (16,5 kw/h)}$$

here  $\alpha$  - heat transfer coefficient from the outer surface of the camera to the environment.

$$\alpha = 9,74 + 0,07(t_{\text{wall}} - t_0) = 9,74 + 0,07(55 - 21) = 12,12 \text{ kw/m}^2 \text{ } ^\circ\text{C}.$$

$t_0$  – environmental temperature,  $t_0 = 20 - 22 \text{ } ^\circ\text{C}$ ;

$t_{\text{wall}}$  - the average temperature of the outer surface of the camera wall,  $t_{\text{wall}} = 50 - 60 \text{ } ^\circ\text{C}$ ;

$F$  - the area of the outer surface of the camera,  $F = 30 \text{ m}^2$ ;

$L$  – the mass of air which enters the chamber in an unorganized manner and provides a steam outlet,  $L = 300 \text{ kg/h}$ ;  $I_0$  and  $I_2$  – Specific enthalpies of ambient air and air at the exit from the drying chamber, respectively,  $I_0 = 50 \text{ kJ/h}$ ,  $I_2 = 100 \text{ kJ/h}$ .

Therefore, the total theoretical power of infrared generators:

$$P_{\text{teor}} = 50 \text{ kw/h}, P_{\text{real}} = P / \eta = 50 / 0,95 = 53 \text{ kw/h}.$$

#### Drying mode.

Total heat consumption in the machine

$$Q = Q_1 + Q_2 + Q_3 \text{ kJ/h},$$

here  $Q_1$  - heat consumption for heating the raw materials in the process of drying mandarin secondary material resources by infrared radiation, kJ/h;

$Q_2$  - heat consumption for evaporation in the process of drying mandarin secondary material resources by infrared irradiation, kJ/h;

$Q_3$  - heat loss to the environment during the drying of mandarin secondary material resources by infrared irradiation, kJ/h.

$$Q_1 = G \times c (t_1 - t_2) = 100 \times 3,43(105 - 20) = 29155 \text{ (8 kw/h)}$$

here  $G$  - machine productivity,  $G = 100 \text{ kg/h}$ ;

$c$  - specific heat capacity of the material,  $c = 3.43 \text{ kJ/kg } ^\circ\text{C}$ ;

$t_1$  – initial material temperature,  $t_1 = 20 \text{ } ^\circ\text{C}$ ;

$t_2$  - temperature of the material leaving the machine,  $t_2 = 105 \text{ } ^\circ\text{C}$ .

$$Q_2 = w \times r = 65 \times 2350 = 152750 \text{ kJ/h (42.4 kw/h)}.$$

here  $w$  – mass of moisture evaporated from the material,  $\text{kg/h}$ ;

$r$  – latent heat of evaporation of water,  $\text{kJ/kg}$ .

$$W = G(w_1 - w_2) / (100 - w_2) = 100(73 - 23) / (100 - 23) = 65 \text{ kg/h}$$

here  $w_1$  – initial moisture content of the material,  $w_1 = 72 - 74 \%$ ;

$w_2$  – final moisture content of the material,  $w_2 = 21 - 23 \%$ .

After the drying process is completed, as a result of cooling the material, partial self-evaporation of moisture occurs.

$$W^1 = c(G - W)(t_2 - t_1) / r = 3.43(100 - 65)(105 - 24) / 2350 = 4.14 \text{ kg/h}$$

$$Q_{\text{autoevaporation}} = W^1 \times r = 4.14 \times 2350 = 9730 \text{ (2.7 kw)}$$

$$Q_3 = Q_{\text{camera}} + Q_{\text{air}} = 3.6 \cdot \alpha \cdot F(t_{\text{wall}} - t_0) + L(I_2 - I_0) = 3.6 \cdot 12.12 \cdot 30(55 - 22) + 300(100 - 50) = 58196 \text{ (16.2 kw/h)}$$

here  $\alpha$  - coefficient of heat transfer from the external surface of the chamber to the environment.

$$a = 9.74 + 0.07(t_{\text{wall}} - t_0) = 9.74 + 0.07(55 - 21) = 12.12 \text{ kw/m}^2 \text{ } ^\circ\text{C}.$$

$t_0$  – environmental temperature,  $t_0 = 20 - 22 \text{ } ^\circ\text{C}$ ;

$t_{\text{wall}}$  - the average temperature of the outer surface of the camera wall,  $t_{\text{wall}} = 50 - 60 \text{ } ^\circ\text{C}$ ;

$F$  - the area of the outer surface of the camera,  $F = 30 \text{ m}^2$ ;

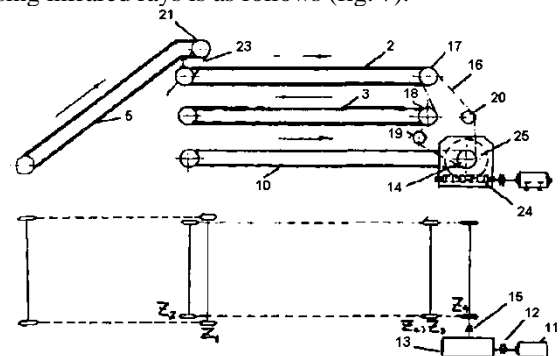
$L$  – the mass of air which enters the chamber in an unorganized manner and provides a steam outlet,  $L = 300 \text{ kg/h}$ ;

$I_0$  and  $I_2$  – Specific enthalpies of ambient air and air at the exit from the drying chamber, respectively,  $I_0 = 50 \text{ kJ/h}$ ,  $I_2 = 100 \text{ kJ/h}$ .

Therefore, the total theoretical power of infrared generators:  $P_{\text{teor}} = 66.6 \text{ kw/h}$ ,  $P_{\text{real}} = P / \eta = 70 \text{ kw/h}$ .

The main geometric parameters of the blanching-drying machine for recycled mandarin raw materials using infrared rays are: total working surface area of the conveyors  $F = 6 \text{ m}^2$ ; Total length of conveyors  $l = 6 \text{ m}$ ; conveyor width  $B = 1 \text{ m}$ ; machine length  $L = 4 \text{ m}$ ; machine height  $H = 2 \text{ m}$ ; speed of movement of working conveyors of the blanching process  $V = 5 - 6 \text{ m/min}$ ; The speed of movement of the working conveyors of the drying process is  $V = 0.24 - 0.25 \text{ m/min}$ .

The kinematic scheme of a blanching-drying machine for mandarin secondary material resources using infrared rays is as follows (fig. 7).



**Fig. 7. Kinematic scheme of a blanching-drying machine for secondary material resources of mandarin with infrared energy.** 2, 3 - working conveyors; 5 - feed conveyor; 10 - output conveyor; 11 - electric motor; 12 - clutch; 13 - worm gearbox; 14 - drive star; 15 - 16 - chain drive; 17, 18, 19, 20 - chain tension stars; 21, 22 - stars located on the shaft; 23 - chain drive

From the electric motor 11 (type - three-phase asynchronous 4A-112M8), coupling 12 (MUVP - flexible tubular finger gear), worm gear 13 and drive star (Z4) 14, the output shaft of the conveyor 10 (D 10),

which is connected to the worm gear, is driven transmission with a simple coupling pipe 15. Z4 with a chain drive 16 drives the working conveyors 2; 3 stars on drum shafts (D2; D3) (Z2; Z3) 17; 18. 19; 20 – represent chain tension stars (Z5; Z6). As for the conveyor for supplying raw materials 5, it moves by a star (Z1) 21, placed on the shaft of the drum (D5) of the working conveyor by a star (Z2) 22, placed on the shaft of the drum (D2) 2 with a chain drive 23.

### Conclusion

A new technological scheme for the production of candied mandarin fruits has been developed;

The main factors influencing the processes have been identified - blanching, curing, in the field of infrared rays and their relationship (type of generators; type of irradiation; Irradiation density  $P$  kw/m<sup>2</sup>; distance between the material under study and infrared rays generators  $N$  cm; Material thickness  $\delta$  cm; Duration thermal irradiation  $\tau$  min; final residual moisture content of the semi-finished product  $W\%$ );

Considering spectral-optical characteristics:

1. By increasing the thickness of the raw material layer, the ability to absorb infrared energy increases and reaches a maximum (90–95%), while the reflectance and transmittance decrease;

2. In a well-organized chamber, on the basis of multiple reflection, transmission and absorption of rays, the materials absorb all the irradiated infrared energy;

3. Changing the position of raw materials on the conveyor and mutual mixing will allow us to increase the thickness of the material layer to 90-100 mm, which will naturally increase the productivity and economic effect of the machine.

4. Quartz and quartz-halogen tube-type heat emitters (NIK–220-1000 and KG–220-1000) are characterized by high heat resistance, reliability and long-term working ability, ease of installation in the chamber, a high concentration of infrared radiation (40 w/cm<sup>2</sup> and more) is achieved in the generators. Their use in production is more appropriate.

Mathematical planning and optimization reports showed that in order to carry out the blanching and drying processes of mandarin secondary material resources in optimal conditions, the following values of the operating factors should be observed in the natural scale:

a) Blanching mode - irradiation density  $P=0,44$  kw/m<sup>2</sup>; Distance between infrared generators and material  $H=18,35$  cm; Process duration  $\tau=54$  sec. At this time, we obtain the desired value of the optimization parameter:  $T=97^{\circ}\text{C}$ ;

b) Drying mode - irradiation density  $P=0,44$  kw/m<sup>2</sup>; Distance between infrared generators and material  $H=18,35$  cm; Process duration  $\tau=26,3$  min. At

this time, we obtain the desired value of the optimization parameter:  $T=105^{\circ}\text{C}$ .

As a result of research, modes for blanching mandarin secondary material resources in the field of identified rays were established, namely: with continuous irradiation: type of generators – NIK–220-1000; type of irradiation - bilateral; Irradiation density  $P=0,35-0,40$  kw/m<sup>2</sup>; distance between the material under study and the identified ray generators  $H=20$  cm; Material thickness  $\delta=9$  cm; Duration of thermal irradiation  $\tau=50-53$  sec ( $95-98^{\circ}\text{C}$ ); residual moisture content of the semi-finished product is 73-75%;

As a result of research, modes for drying mandarin secondary material resources in the field of identified rays have been established, namely: with continuous irradiation: type of irradiation - two-sided; Irradiation density  $P=0,35-0,40$  kw/m<sup>2</sup>; distance between the material under study and the generators  $H=20$  cm; Material thickness  $\delta=9$  cm; Duration of thermal irradiation  $\tau=25-27$  min ( $100-105^{\circ}\text{C}$ ); residual moisture content of the semi-finished product is 21-23 %;

The organoleptic evaluation of the materials of the control and analysis semi-finished products showed that the analysis material is superior to the corresponding indicators of the control material in terms of color, taste indicators and external appearance, especially the external appearance is worth noting, which is very sharp in color and close to the initial color of the mandarin raw material;

In order to provide a machine-hardware system for the processes of drying and blanching of mandarin secondary material resources by identified irradiation, based on a generalization of experimental and theoretical data, the main geometric parameters of a blanching-drying machine operating on identified energy were calculated, the energy balance was determined, the main geometric parameters were clarified, constructive diagrams have been created.

Based on the calculated material and heat balances, the required power of infrared generators for a blanching-drying machine was determined (Blanching mode –  $P_{\text{theor}} = 50$  kw/h,  $P_{\text{real}} = 53$  kw/h, Drying mode -  $P_{\text{theor}} = 66,6$  kw/h,  $P_{\text{real}} = 70$  kw/h.).

Thermal treatment of mandarin secondary material resources in the field of IR rays is feasible and promising. The intensity of the process increases 5 times or more compared to the existing method, the quality of the product improves (0,5-0,6 points); the technological process, technological equipment, etc. are simplified.

### CONTRIBUTION

The author carried out the research, data analysis, preparation of the manuscript material and is responsible for any potential plagiarism. Huge thanks to the administration of the Akaki Tsereteli State University for support and financial support.

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