Original scientific paper
UDC 664.856.047

APPLICATION OF RADIATION INFRARED DRYING METHOD TO REMOVE WATER FROM FRUIT GELS

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Abstract

The traditional method of drying fruit gels involves convective two-stage removal of moisture for 6 - 8 h until the dry matter content in the finished product is 78 - 80%. Quite a long duration of convection drying, and high energy consumption for the process have become a significant obstacle for the production of confectionery marmalade. That's why it is important to find promising methods for drying fruit gels.The aim of the research was to obtain scientific results on the application of infrared radiation drying for fruit gels.

The studies used formulations of fruit gels based on a mixture of plum, and Japanese quince puree using low-methoxylated amidated (LA) pectin and various types of sugars - sucrose, glucose, fructose. To obtain test samples, pectin was mixed with sugar, polydextrose, fruit puree was added and the mixture of ingredients was boiled to a dry matter content of 68%, poured into molds for structure formation. The formed gels were dried in a laboratory installation by infrared radiation.

It is established that depending on the type of sugar included in the recipe, the process modes are changing. For fruit gel with sucrose, the total drying time is 160 min., and it consists of two modes with temperatures of 50 ^{0}C and 70 ^{0}C, respectively. For the sample of fruit gel with glucose, the drying time is 200 min. with temperatures of 40 ^{0}C and 70 ^{0}C, respectively, and for the sample with fructose - 180 min. with temperatures of 40 ^{0}C and 55 ^{0}C, respectively.

According to the method of drying marmalade by infrared radiation, the drying time is reduced by an average of 4 - 5 h compared to the traditional method of convection.

Key words*: Fruit gels, Infrared drying, Glucose, Sucrose, Fructose.*

1. Introduction

Technologies of many types of confectionery products with a gel-like structure include a drying stage. It achieves a dry matter content that is sufficient for further storage of the product without microbiological spoilage. These are the technologies of most products of the lozenge-marmalade group: fruit-berry and fruit-jelly marmalade, protein and fruit lozenges, marshmallows [1, 2, and 3].

The traditional method of drying involves convection two-stage removal of moisture for 8 - 12 h for marshmallows, 10 - 14 h for lozenges, 8 - 14 h for fruit lozenges, and 6 - 8 h for marmalade. Duration of this technological operation and high energy consumption have become a significant obstacle to the production of confectionery factories of fruit jelly and fruit and berry marmalade, the value of the chemical composition of which far exceeds the variety of confectionery products.

Therefore, the question of optimizing the drying process of fruit gels, the search for promising methods of drying is relevant and promising.

At any scale of use of drying technologies, the main task is implementation of a number of technical and economic parameters, such as: minimum possible energy consumption of the process; maximum uniformity of drying; minimum time of an exit on the set humidity, and other characteristics of drying. Today there are a large number of different technologies of drying (dehydration) for food products: natural [4], aeration [5], convection [6], in the fluidized bed [7], infrared [8], in the electromagnetic field of ultrahigh frequencies [9], acoustic [10], sublimation [11], etc. The technology of fruit and berry marmalade has so far used the convection drying method, which is carried out in several stages, and in the dryers create two or three zones with different temperatures [12]. Fruit jelly is dried in chambers, cabinets and tunnel dryers: fruit and berry: 6 - 7 h in two-stage mode (in the first zone - 55 - 58 ^{0}C, in the second: 65 - 70 ^{0}C, and 6.5 - 8 h in three-stage mode: in the first zone - 55 - 57 ^{0}C, in the second - 65 - 70 ^{0}C, and in the third - 50 - 55 ^{0}C. Jelly marmalade type "lemon and orange slices" is dried for 8 - 10 h at a temperature of 35 - 40 ^{0}C. During drying, the product removes about 10% of moisture (from 68 - 72 to 76 - 80%), and on the surface of marmalade forms a thin crystalline crust, which reduces the rate of sorption processes of the product during storage. The main disadvantages of the convection drying method are the significant duration of the process, and, accordingly, quite significant energy costs.

Today, the method of drying by infrared (IR) radiation is interesting for the food industry [13, 14, and 15], which consumes less energy to evaporate 1 liter of water than convection drying. Scientists have proposed to use infrared drying for: paprika [16], okra [17], onion slices [18], spore fungi, *Cordyceps militaris*, and peaches [19], noodles [20], fruit lozenges [21], ginger [22], and other products in order to maximize the preservation of bioactive and aromatic compounds, color and increase the shelf life of the product. However, all studies have shown less time for the drying process compared to convection without loss of product quality.

Process of infrared drying does not involve the use of organic fuel, and infrared rays are characterized by high thermal action. The principle of the infrared method is based on the absorption of infrared rays by moisture inside the product, due to which it is heated and subsequently evaporated. This type of drying has not only high efficiency, but also high efficiency. In our opinion, it can be used to dry fruit gels, which are the basis of many confectionery products. For example, in the technology of fruit jelly marmalade marmalade mass is cast with a dry matter content 68 - 72%, and requires drying to a dry matter content of 80 ± 2%, which will ensure the resistance of marmalade to microbiological spoilage during storage. Convection drying process is quite long and requires significant energy consumption, and drying with infrared radiation will reduce it, thus affecting the cost of finished products.

In addition, infrared drying leads to the destruction of harmful microflora present on the surface of the product and disinfects it before packaging [23]. If in the convection method of drying the transport of energy and moisture is carried out by one carrier - air, then in infrared drying energy is transmitted by radiation, and moisture is carried out by pure steam, in which there are no dust particles. This makes the drying process safer. Manufacturers of modern equipment have proposed ovens with infrared radiation, but in the confectionery industry for drying fruit gels, which are the basis of marmalade, they have not found widespread use, as there is no research to substantiate the modes and parameters of the process.

There are two forms of bound water in fruit gel: colloidal, or adsorption-bound, and capillary. The movement of adsorption-bound moisture in colloidal materials is subject to the laws of diffusion. The internal diffusion of moisture in the fruit gel depends on the humidity gradient and the state of the temperature field of the material during drying. The higher the humidity gradient, the greater the moisture conductivity of the material and the more intense the drying. Movement of moisture in the material is directed from the center to the peripheral layers. As the surface layers dry, the temperature field moves deep into the material. This can cause a significant temperature gradient inside the material and under the action of thermal conductivity can begin to move moisture in the opposite direction: from the outer layers to the inner, which delays the drying process. Therefore, the drying process must be carried out in such a way that the removal of the bulk of moisture occurs before the formation of a crystalline crust on the surface. Otherwise, the prematurely formed crust will interfere with moisture and may partially dissolve in the moisture that enters the surface of the marmalade from the inner layers. The secondary crust is porous and not strong enough [24].

Prescription composition of fruit gels usually contains a significant amount of fruit or berry puree, sugar, starch molasses. Sometimes an additional amount of water-soluble pectin is added to the composition to form a strong gel. The intensity of water migration inside the marmalade increases with increasing sugar content and, conversely, slows down when using a significant amount of molasses or additional amount of gelling agent as a high molecular weight substance with higher water binding capacity.

Hence, the aim of the research was to obtain scientific results on the use of infrared radiation drying for fruit gels as a basis for the production of confectionery.

2. Materials and Methods

The subject of research was fruit gels with sucrose, glucose, fructose in the drying process using the radiation infrared method. The studies used formulations of fruit gels, which included the following raw materials: plum puree, Japanese quince puree, sucrose, glucose, fructose, LA-pectin, and polydextrose. In Table 1 are presented recipes of fruit gels.

Table 1. Working recipes for fruit gels

Name of raw materials	Dry matter content, %	Prescription amount of ingredients, g		
		Sample №1 (sucrose)	Sample №2 (glucose)	Sample №3 (fructose)
Plum puree	10	25	25	25
Japanese quince puree	10	25	25	25
Sucrose	99,85	51	-	-
Glucose	91	-	58,33	-
Fructose	99,97	-	-	56,07
Pectin LMA	90	1,22	1,22	1,22
Polydextrose	96	22	14,58	24,03
Total:	-	124,22	124,13	131,32

This composition of fruit gels was selected in the process of developing a confectionery product with low sugar content [25, 26].

To obtain test samples, pectin was mixed with sugar, polydextrose, fruit puree was added and the mixture was boiled to a dry matter content of 68%, poured into molds and left for 40 min. in the laboratory at a temperature of 20 ± 2 ^{0}C for cooling and structuring. The formed gels in the form of hemispheres (base diameter - 30 mm, height 12 - 14 mm) weighing 15 ± 1 g were removed from the mold and subjected to drying in a laboratory drying unit, which included a unit for automatic control of relative humidity, which were connected infrared emitters with a wavelength in the range of 1.2 - 4 microns and a flux density of 2 - 15 kW/m^2, which was developed by scientists Dubkovets'kym, Malezhyk, Strel'chenko, and Burlakoyu from the National University of Food Technologies of Ukraine [27] (Figure 1). A sample of fruit gel was placed in a drying chamber in a mesh basket, the device was turned on and the temperature values were set with the help of regulators. During the drying process, changes in the mass of the gel samples were noted.

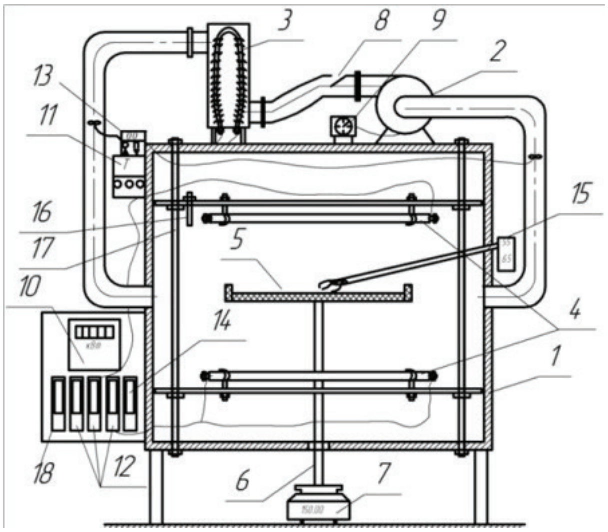

Figure 1. Drying installation
1 - drying chamber; 2 - fan; 3 - heater; 4 - IR generators; 5 - box mesh basket; 6 - a barbell; 7 - analytical scales; 8 - air recirculation gate; 9 - speed variator; 10 - electricity meter; 11 - temperature controller; 12 - automatic switches of the heater, upper and lower infrared generators; 13 - relative humidity regulator; 14 - automatic fan switch; 15 - thermometer with thermocouples; 16 - contact temperature sensor; 17 - adjusting device for the position of the nodes of the IR generators; 18 - relay on and off IR generators

The mass fraction of reducing substances was determined in the dried sample by the accelerated copper-alkaline method [28], which is based on the interaction of reducing sugars contained in the solution of the product sample with copper (II) ion complexed with excess tartaric acid salt.

In order to determine the reducing substances, a portion of the product thoroughly ground in a mortar was dissolved in distilled water at a temperature of 60 - 70 ^{0}C, transferred to a volumetric flask with a volume of 200 or 250 cm^3, cooled, and adjusted to the mark and mixed well (test solution).

Approximate and control titrations were performed for the determinations. Using an approximate titration, pipette 5 cm^3 of Fehling I ($CuSO_4$) and Fehling II (alkaline ferrous salt solution) were added into a 100 cm^3 conical flask, heated to boiling, poured 10 cm^3 of test solution from the burette and boiled for 2 min. At the end of the second minute of boiling, three drops of methylene blue were added and the color of the solution was observed. If the color of the solution did not disappear, then, without ceasing to boil, it was titrated with the test solution until the blue color disappears. After the color of the solution disappeared, the volume of the test solution was determined.

Based on the tentative experiment, a control determination was performed, characterized in that the amount of test solution added to the mixture of Fehling's solutions before boiling was taken in an amount less than 5 cm^3 than the total volume of test solution spent on tentative titration.

The number of milligrams of invert sugar per 100 cm^3 of solution was found according to the volume of test solution used for the approximate titration. The mass fraction of reducing substances, X, %, was calculated by the formula

$$X = V \times n \times K \times m \times 1000,$$

Where: V - volume of the volumetric flask with the solution, cm^3; n - amount of invert sugar in the test solution spent on the control titration, mg; m - portion of the test product sample, g; K - correction factor for Fehlings; 1000 - conversion of mg of invert sugar into grams.

3. Results and Discussion

For each sample of fruit gel, the drying modes were selected individually.

3.1 Drying of the sample with sucrose

Convection drying method, which was taken under control, used a drying temperature of 50 ± 2 ^{0}C, which is used for the first drying period in traditional technological schemes. Humidity in the drying chamber ranged from 3 ± 0.5%. Under this regime, the drying process lasted 30 min., the sample lost 2.2% of moisture, which is a fairly small amount and reached a dry matter content of 70.2%. A total of 756 kJ of energy was used for the process. This drying mode did not provide the required final moisture content of the product (78%), a crust formed on the surface of the products, which prevented the removal of moisture.

Radiation infrared drying method used a two-stage mode, in which the first period maintained the ambient temperature in the chamber 50 ± 1.5 ^{0}C (for 20 - 40 min.), and in the second period increased the temperature to 700 ± 1.5 ^{0}C with in order to intensify the process of moisture. Humidity in the drying chamber ranged from 4 ± 0.5%.

The result of this drying method showed that the process is intensified and generally removes up to 8 ± 0.5% of moisture from the samples. Drying time was 160 ± 10 min., but as a result of such regimes the set final content of dry substances in a product which is necessary for qualitative further storage was not reached. The total energy consumption was 5,940 - 9,036 kJ (depending on the first stage of drying). Based on the data obtained, it was decided to reduce the first stage of drying to 20 min., when the highest intensity of moisture is observed to prevent crust formation on the surface of the product, and the duration of the second stage will depend on reaching the final dry matter content.

As shown by the data obtained (Figure 2), the gel sample was characterized by a fairly uniform moisture, drying lasted 160 min., the gel reached the amount of dry matter 78%, which meets the requirements of state regulations. The total energy loss for the whole process was 9,684 kJ. Thus, based on the results of the drying process, we consider it appropriate to recommend a two-stage mode, according to which the first stage takes place at a temperature of 50 ± 1.5 ^{0}C for 20 - 40 min., the second - at a temperature of 700 ± 1.5 ^{0}C for 120 min.

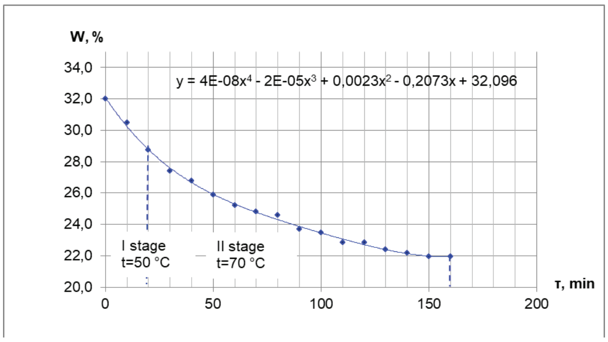

Figure 2. Drying curve of fruit gel on sucrose

3.2 Drying the sample with fructose

In the first stage of research with fructose gels, the recommended drying methods for sucrose gels were used. This method of drying took more than two hours, it was possible to remove a significant amount of moisture from the sample, but the surface layer was more dehydrated. Due to this, a hard crust was formed on the surface, moisture was concentrated in the middle of the product, and the gel was deformed. The total energy consumption for the process was 7,452 - 7,560 kJ. Therefore, fructose gels require lowering the temperature of the first stage of drying, so it was decided to carry out drying in the first stage at a temperature of 400 ^{0}C.

It was found that during the first period there was a systematic removal of moisture (Figure 3). Slowing down of moisture took place after 80 min., which required intensification of the process and increase in temperatures. However, taking into account the negative effect of high temperatures on the sample with fructose, the drying temperature in the second stage was reduced and maintained within 55 ± 2 ^{0}C. Humidity in the environment of the drying chamber fluctuated at the level of $W_{average}$ = 7 - 14%.

By this method it was possible to achieve the required amount of dry matter in the gels, the products have not lost their structural and mechanical properties. The total energy consumption was 7,308 kJ.

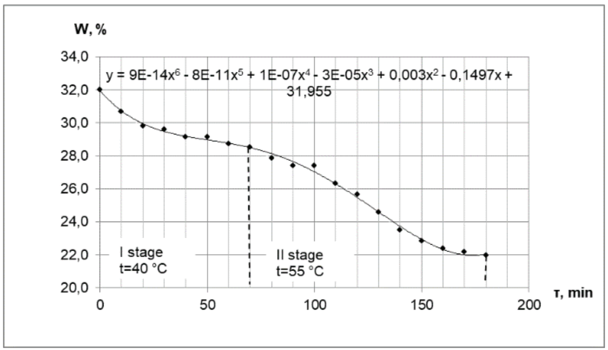

Figure 3. Drying curve of fruit gel on fructose

Thus, when selecting the parameters of drying the gel on fructose by infrared radiation, it was found that the removal of excess moisture from products like the method used for drying products on sucrose is impossible due to the rapid dehydration of surface layers, which prevents the removal of moisture from the middle sample. Therefore, after a series of experiments, it is recommended to carry out the first stage of drying at a temperature of 40 ± 20 ^{0}C for 80 min., the second stage - at a temperature of 55 ± 2 ^{0}C - for 180 min. Under such drying modes, the gels have an elastic structure, without deformation, with a dry matter content of 78%.

3.3 Drying the sample with glucose

As can be seen in Figure 4, for drying the sample with glucose, the first stage was selected as for the sample with fructose and was carried out at a temperature of 40 ± 20 ^{0}C, the second - at a temperature of 70 ^{0}C until complete drying. It was found that the slowing down of water removal at the temperatures of the first period occurs after 40 min from the beginning of drying, which requires an increase in temperature. The second drying period lasts at least 160 min and allows you to remove moisture to the final, required dry matter content. The total drying time of the sample was 200 min, energy consumption for the process - 12,384 kJ. Humidity fluctuated in the first period - 7%, in the second - 5%. Thus, the results of the study showed that the use of infrared drying can be applied to fruit gels.

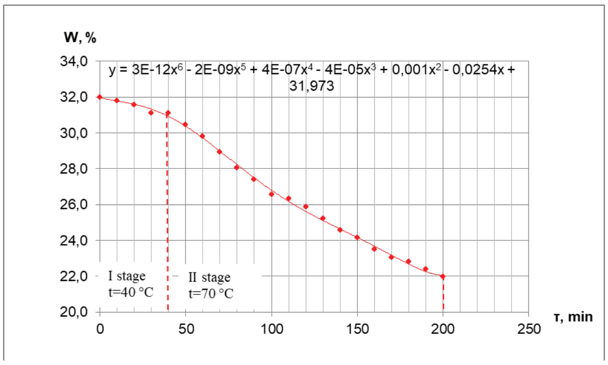

Figure 4. Drying curve of fruit gel on glucose

According to organoleptic parameters, the samples after drying have a good sweetness, satisfactory gelatinous elastic structure, hold their shape, have a crimson-burgundy color, a shiny glossy surface, and do not emit moisture on the surface. Products after drying contain 78% of dry matter, which meets the requirements of current regulations. In the Table 2 presented the results of studies and comparative characteristics of the drying process by infrared.

The table shows that for all samples of fruit gel were selected two-stage drying modes with different parameters of temperature and duration. The first stage for sample №1 (with sucrose) is 20 min. at

Table 2. Recommended drying parameters

Index	Fruit gels		
	with sucrose	with fructose	with glucose
I stage			
Temperature, ^{0}C	50	40	40
Drying time, min	20	70	70
The amount of moisture removed, %	3.28	3.43	0.87
Drying speed, g/min	0.164	0.051	0.021
Energy consumption, kJ	1,404	2,988	1,764
II stage			
Temperature, ^{0}C	70	55	70
Drying time, min	140	110	160
The amount of moisture removed, %	6.77	6.55	9.17
Drying speed, g/min	0.048	0.061	0.057
Energy consumption, kJ	8,856	4,320	10,620
Total drying time, min	160	180	200
Total moisture loss during drying, %	10.05	9.98	10.04
The dry matter content in the samples, %	78		
Total energy consumption, kJ	10,620	7,308	12,384

a temperature of 50 ^{0}C, for samples № 2, 3 (with fructose and glucose, respectively), the temperature is reduced to 40 ^{0}C. The reason for this was that at 50 ^{0}C a crust was formed on fruit and berry marmalade with fructose, which further prevented the removal of moisture. Reducing the temperature by 10 ^{0}C allowed to gradually remove capillary moisture from the sample and avoid the collapse of the housing from the moisture concentrated inside. However, the duration of the first drying period for samples № 2, 3 was extended to 70 and 40 min, respectively. Therefore, drying fruit gels with fructose and glucose requires lower temperatures and more time.

The second stage is characterized by less intense moisture, because colloidal or adsorption-bound water, being strongly bound to pectin macromolecules, is difficult to remove from the gel, as its evaporation process is associated with diffusion and depends on water migration within the sample. Therefore, the second stage is characterized by the intensification of the drying process by increasing the temperature: for samples № 1, 3 - up to 70 ^{0}C, for sample № 3 - up to 55 ^{0}C. Numerous experiments have shown that drying the sample with fructose at a temperature of 70 ^{0}C is impossible. Such samples had an over dried crust, a failed body and moisture inside. The reason for this could be the phenomenon opposite to the removal of moisture: due to the ultra-high temperature for this sample, a significant temperature gradient was formed inside and the moisture began to move from the outer layers to the inner ones. Therefore, the optimum temperature for the second drying stage of the sample with fructose was 55 ^{0}C. The duration of drying in the II stage is: 140 min - for the sample with sucrose, 110 min - with fructose, 160 min - with glucose.

4. Conclusions

- According to the research results, the possibility of using the infrared drying method for fruit gels has been established.
- Depending on the type of sugar included in the recipe, the process modes change. For fruit gel with sucrose, the total drying time is 160 min, it consists of two modes with temperatures of 50 ^{0}C (in the first stage) and 70 ^{0}C in the second. For a sample of fruit gel with glucose, the drying time is 200 min. and also consists of two modes with temperatures of 40 ^{0}C (in the first stage) and 70 ^{0}C in the second. The sample with fructose has a total drying time of 180 min and assumes a temperature not exceeding 40 ^{0}C - in the first stage and 55 ^{0}C - in the second. Such modes allow you to evenly remove from the samples of moisture observed on the drying curves (Figure 2 - 4) and remove approximately the same amount of water.
- Energy consumption for the drying process depends on the time spent on drying the samples and the temperature used in a particular mode. However, using the method of drying marmalade by IR radiation, the drying time is reduced by an average of 5-8 h compared to the traditional method of convection.

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