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#### ИССЛЕДОВАНИЕ РЕОЛОГИЧЕСКИХ СВОЙСТВ МАЙОНЕЗНОГО СОУСА С ПОРОШКОМ КОЖУРЫ ВИНОГРАДА

Определены зависимости реологических показателей качества майонезного соуса с порошком кожуры винограда от концентрации комплексного загустителя некрахмальной природы. Установлены оптимальные диапазоны значений концентрации комплексного загустителя, которые позволяют получать

эмульсионный продукт со значениями стойкости эмульсии в соответствии с требованиями нормативной документации. Разработана рецептура майонезного соуса с порошком кожуры винограда и комплексным загустителем некрахмальной природы.

**Ключевые слова:** порошок кожуры винограда, комплексный загуститель, стойкость эмульсии, эффективная вязкость.

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## IMPROVEMENT OF IR EMITTER TO CREATE NON-REFLECTOR DRYER FOR PLANT RAW MATERIALS

Удосконалено ІЧ-випромінювач на основі гнучкого плівкового резистивного електронагрівача випромінювального типу для створення безрефлекторних ІЧ-сушарок рослинної сировини. Це забезпечить зменшення металоемності устаткування, рівномірність розподілу теплових потоків на приймальних поверхнях (сітчастих піддонах із сировиною) та підвищить якість отримуваних сушених напівфабрикатів. Досліджено поглинальну здатність рослинної сировини, що підтверджує ефективність використання вдосконаленого ІЧ-випромінювача.

**Ключові слова:** гнучкий плівковий резистивний електронагрівач, безрефлекторні ІЧ-сушарки рослинної сировини, якість сушених напівфабрикатів.

### 1. Introduction

One of the ways of processing plant raw materials in dried semi-finished products is the use of IR technology [1–3]. IR dryers, which are used today [4], equipped with inertial IR emitters with high temperatures of working surfaces and fixed geometric dimensions and reflector blocks. This increases their metal consumption and does not always ensure a uniform heat flow on the receiving surfaces, which leads to losses of its biologically active substances (BAS) and a change in the color of the dried semi-finished product. Therefore, it is necessary to investigate

in more detail the possibility of using modern low-inertia emitters that do not require the use of reflectors and are capable of ensuring the uniformity of thermal energy at the receivers. So, it is actual to study ways to improve the process of IR drying of semi-finished products from plant raw materials and its instrumental design.

### 2. The object of research and its technological audit

The object of research is an improved flexible film resistive electric heater of emitting type (FFREHET) for

creating a non-reflector IR dryer and vegetable raw material on the example of Antonovka apples.

The disadvantages of using known IR emitters (tubular heating element, quartz lamp, etc.) include metal consumption, inertia, fixed geometric dimensions and high temperature of the working surfaces. This leads to operational complications of drying equipment and significant losses of BAS in the resulting dried semi-finished products. The reasons for this, according to the authors of the study, are the insufficient number of fundamental studies related to the interaction of the spectral properties of the IR emitter and the dried raw materials and doubts about the possibility of using more modern emitters.

In order to confirm the possibility of using the advanced FFREHET for the creation of non-reflector drying equipment, a technological audit was carried out, the purpose of which was to determine the spectral-optical properties of plant raw materials and IR emitters, as well as the properties of the improved heater (FFREHET). The research was carried out at the Department of Processes, Devices and Automation of Food Production, Kharkov State University of Nutrition and Trade (Kharkov, Ukraine). Modern methods and spectral-optical equipment of the Institute of Single Crystals of the National Academy of Sciences of Ukraine (Kharkov, Ukraine) were used, and a vertical cylindrical (VC) IR dryer with a vibrating mechanism and a heat exchanger was designed.

The conducted experimental researches on the object have shown that the improved FFREHET has a low metal consumption. In addition, the emitter is easy to install, has a low inertia, a low temperature of the working surface (45...85 °C), an acceptable length of the IR wave for carrying out the drying processes of plant raw materials. The emitter is capable of following any geometric shape of the working chamber of devices without the use of reflector blocks.

### 3. The aim and objectives of research

*The aim of research* is to intensify the process of IR drying of plant raw materials and its instrumentation using an improved IR emitter. This will ensure a reduction in the metal consumption of equipment, the uniformity in the distribution of heat fluxes on receiving surfaces and the quality of the resulting semi-finished products.

To achieve this aim it is necessary to:

1. Determine the spectral-optical properties of plant raw materials.
2. Determine the properties of the improved FFREHET.
3. Develop non-reflector VC IR-dryer on the basis of FFREHET.

### 4. Research of existing solutions of the problem

The IR dryers used today for the processing of plant raw materials are characterized by the duration of heat treatment, the uneven distribution of heat fluxes on the receiving surfaces. At the same time, a significant number of them are characterized by a lack of energy-saving properties, which leads to an increase in energy consumption, a decrease in the quality of finished semi-finished products and an increase in their prices [1–4].

One of the main directions of increasing the efficiency of production is the conservation of energy resources during drying processes on existing equipment due to its modernization or the creation of fundamentally new equipment.

The main disadvantages of the existing equipment are [4]:

- low uniformity of distribution of heat fluxes from IR emitters due to the complexity of manufacturing reflector blocks of rational form;
- increase of metal intensity of devices due to the use of reflector blocks;
- ignoring the spectral-optical component of the objects «plant raw materials – IR emitter»;
- insignificant energy saving.

These disadvantages belong to the structural and instrumental defects, which affect the quality of drying of plant semi-finished products. Therefore, there is a need to use modern low-metallic IR emitters [5] with a clear dynamics of operation and low temperature of the working surface (Fig. 1). One of the varieties of such IR emitters is FFREHET, which differs in its simplicity of installation, low metal consumption, inertness and simplicity of automation, ease of design of the emitter, low energy consumption and low temperature of the working surface (40...85 °C). For a preliminary determination of FFREHET efficiency, let's compare it with the available IR emitters (Table 1) [5–10].

The analysis of the obtained comparative parameters of IR emitters, given in Table 1, causes the need for detailed studies of the use of FFREHET in the design of modern non-reflector IR dryers. It should be noted that the disadvantage of existing FFREHETs in the conditions of their use in IR dryers is the possibility of getting a vapor-containing component at the junction with the electric grid and low mechanical strength.

It is proposed to improve the FFREHET by spraying a resistive element based on current-conducting nichrome paste on a flexible electrical insulating film with additional coating on top and bottom by layers of a flexible electrical insulating film. Also, FFREHET is provided with drainages for connection to the power grid.

IR drying systems [11] are popular in terms of significant heat and mass transfer. By means of infrared drying, rapid heating can be performed in a short period of time compared to other drying methods. Most dryers of plant raw materials have their disadvantages associated with design parameters (metal consumption, energy consumption). The simplest form of IR dryer is a solar dryer [12], which consisted of a solar air heater and a drying chamber. Using this type of dryer reduces drying time and provides quality products, but its effectiveness depends on the length of a sunny day.

For example, in a combined dryer [13] with electromagnetic emission and hot air, a significant amount of energy is consumed not only for drying the raw materials, but also for heating hot air. Very promising for Ukrainian farms is an industrial dryer [14], located in trucks and providing a significant reduction in costs for the drying process.

Infrared food processing will continue to gain popularity in comparison with conventional treatments, as compared to conventional treatment, it has uniform heating with insignificant duration and minimal loss of quality properties of raw materials, compact equipment design, significant energy and metal efficiency [15].



**Fig. 1.** A photo of the modern IR emitter of the firm «Monocrystal» (Ukraine)

**Table 1**

Comparative characteristics of modern IR emitters in accordance with the specified technical parameters

IR emitter	Technical parameters and repair possibility	Geometric shape, metal consumption and inertia of the IR-emitter
TEH	from 0,5...3 kW, $t_{\max} = 800\text{ }^{\circ}\text{C}$ , Efficiency = 0,95, $\lambda = 3\text{ }\mu\text{m}$ $P_{\text{power}} = 2,2\text{ W/cm}^2$ , $T_w = 10000\text{ hours}$ , Can't be repaired	Fixed geometric shapes and dimensions, high temperature of the working surface, inertia, the need to using reflectors, which leads to an increase in the metal content
Tubular quartz lamp	from 1...2,5 kW, $t_{\max} = 1800\text{ }^{\circ}\text{C}$ , Efficiency = 0,92, $\lambda = 1,3...3\text{ }\mu\text{m}$ , $P_{\text{power}} = 2\text{ W/cm}^2$ , $T_w = 8000\text{ hours}$ , Can't be repaired	Fixed geometric shapes and dimensions, high temperatures of working surfaces, inertia and low metal intensity due to the use of a reflector block
Ceramic electric heater	from 1...2,8 kW, $t_{\max} = 1000\text{ }^{\circ}\text{C}$ , Efficiency = 0,93, $\lambda = 1,2...3\text{ }\mu\text{m}$ , $P_{\text{power}} = 2,1\text{ W/cm}^2$ , $\tau_w = 9000\text{ hours}$ , Can be repaired	Fixed geometric shapes, high temperature of the working surface, inertia, the need for using reflectors and increasing the metal content
Flexible film resistive electric heater of emitting type (FFREHET)	from 0,100...0,480 kW, $t_{\max} = 40...85\text{ }^{\circ}\text{C}$ , Efficiency = 0,98, $\varepsilon = 0,96$ , $\lambda = 3...15\text{ }\mu\text{m}$ , $P_{\text{power}} = 35...85\text{ W/m}^2$ , $T_w = 15000\text{ hours}$ , Can be repaired	Flexible geometric shapes and sufficiently low temperature of the working surfaces provides a low inertia, easy installation and automation, without the use of reflectors

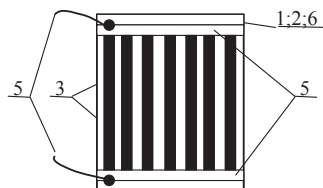
## 5. Methods of research

A study of the effectiveness of the use of the improved FFREHET was carried out on the basis of a pre-designed model of VC IR dryer with a vibrating mechanism and a heat exchanger [16]. To determine the properties of modern infrared emitters, an automatic control system (ACS) was used in real time with the help of the TPM101 monitoring and measuring device (Ukraine) [17].

Determination of the spectral component of the IR emitter interaction with fruit and berry raw materials was carried out with the help of the OME Elman spectrometer (Russia) using the example of apple raw material for the Antonovka variety with an initial moisture content of 86%. During the studies, a silite rod (globar) was used as the source of infrared emission, which actually corresponds to the Planck law for IR emission of an absolutely black body with a relative intensity distribution, and a special tablet is used as the solvent – potassium salt of hydrobromic acid (kBr).

## 6. Research results

Improved FFREHET (Fig. 2) consists of a flexible electrically insulating film 1, on the surface of which is applied to the resistive element through the conductive nichrome paste in the form of series connected rectangular taps 3, which are disposed perpendicularly to the busbars 4 provided by drainages 5 for connection to the electrical network and further covered the top and bottom layers of flexible insulating film 2 and 6. The insulating layers of flexible film 1, 2 and 6 are followed geometric shape of the resistance element and connected by lamination that provides high mechanical and electrical strength.



**Fig. 2.** Schematic diagram of an improved flexible film resistive electric heater of the emitting type 1, 2, 6 – flexible electrical insulating film; 3 – nichrome resistive rectangular bands; 4 – conductive copper busbars; 5 – taps of busbars (4)

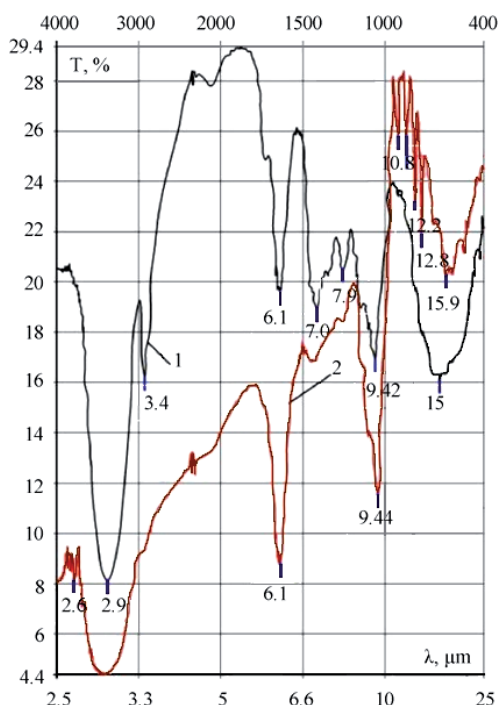
When FFREHET is connected to the electric network with the help of taps 5 connected to busbars 4, current flows into series-connected rectangular taps from a resistive element based on current-conducting nichrome paste 3. Due to the resistance of element (3), the process of uniform emission in significant lengths of infrared waves throughout isothermal surface of the electric heater is carried out. In this case, the resistive element is located on the flexible electrical insulating film 1, which is additionally covered from above and from below by layers 2 and 6 of the same electrical insulating material [18].

Due to this, it is ensured a long period of use of environmentally friendly FFREHET, which does not burn oxygen and is quite suitable for use in dryers for drying plant raw materials. The presence of several electrical insulation layers increases its mechanical strength and electrical safety.

The technical result of the improvement of FFREHET is the increase of electrical safety, reliability, mechanical strength, moisture resistance, as well as the achievement of environmental friendliness in the operation of FFREHET, which contributes to its use in drying non-reflector equipment.

Spectral-optical studies were performed using the OME Elman spectrometer on the basis of the Institute of Single Crystals of the National Academy of Sciences of Ukraine (Kharkov, Ukraine) to determine the efficiency of using an advanced emitter of the FFREHET type for creating drying equipment. The dependences of the transmittance of apple raw materials for the Antonovka variety with an initial humidity of 86%, depending on the change in the length of the IR wave in the spectral region, are obtained (Fig. 3). Apple raw materials, like most vegetable raw materials, have a clearly expressed absorptivity of IR emission in wide ranges of waves provided by a significant content of the liquid component.

As a result, four intense IR regions were clearly defined, namely 2.5...3, 6, 9 and 12...15  $\mu\text{m}$ , which are acceptable for carrying out drying processes (Fig. 3).



**Fig. 3.** Interferogram of the transmission of apple raw materials «Antonovka», obtained with the help of the OME Elman spectrometer: 1 – raw apple; 2 – dried apple

Available IR emitters (tubular electric heaters, tubular quartz lamps, ceramic electric heaters) in accordance with Table 1 have high temperature parameters of working surfaces with a high temperature range and inertia. This makes it difficult to use them for drying plant raw materials [2–6].

Given the analytical data (Table 1), we can conclude that these electric heaters are not able to fully meet the requirements of the drying processes of plant raw materials. Due to high metal consumption, fixed geometric dimensions, high temperature of the working surface, the operation of tubular electric heaters, tubular quartz lamps and ceramic electric heaters does not correspond to design conditions when used in cyclic modes (on/off), which will lead to their failure, in contrast to the parameters of improved FFREHET.

To determine the inertia and dynamics of the known IR emitters, the automatic control system (ACS) was used in real time with the help of the TPM101 monitoring and measuring device [12]. And the preset temperature is 60 °C, which corresponds to the maximum possible temperature parameter during drying of plant raw materials to preserve the BAS [1].

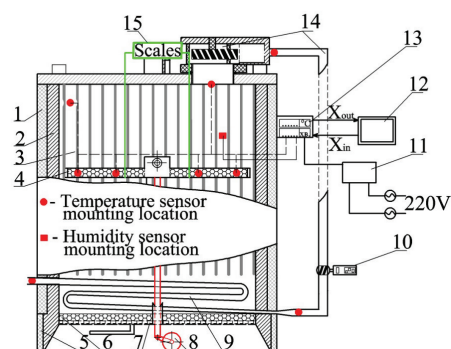
Based on the obtained data, it can draw the following conclusions:

- The tubular electric heater (A) has a considerable inertia at a temperature of 60 °C with a heating duration of  $\tau = 68$  s, and time to the constantly uniform temperature of the working surface (without inertia) is  $\tau' = 96$  s;
- The tubular quartz lamp (B) has a less inertia at a temperature of 60 °C with a heating time  $\tau' = 70$  s, and the time to a constant uniform temperature of the working surface (without inertia) is  $\tau = 100$  s;
- The ceramic heater (C) has a high inertia at a temperature of 60 °C with a heating duration  $\tau = 68$  s,

and the time to the constantly uniform temperature of the working surface (without inertia) is  $\tau' = 94$  s; – FFREHET (D) has a low inertia at a temperature of 60 °C with a heating time  $\tau' = 87$  s, simultaneously corresponds to a constant uniform temperature of the working surface and is characterized by a clear dynamics of operation.

Analysis of the heating modes of IR emitters confirms a clear dynamics of control in a cyclic mode precisely for advanced FFREHET. This will save energy by low metal consumption, a high degree of automation of equipment and the preservation of BAS.

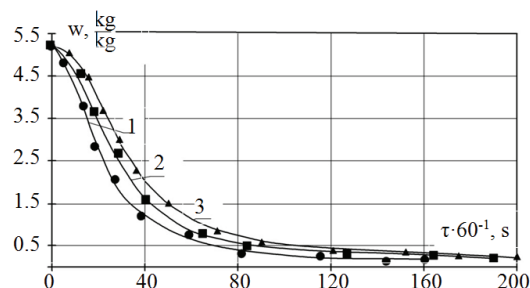
Also, on the basis of the improved FFREHET, an experimental VC IR dryer with a vibrating mechanism and a heat exchanger was developed (Fig. 4).



**Fig. 4.** Schematic diagram of the experimental model of vertical cylindrical IR dryer with a vibrating mechanism and heat exchanger: 1 – working chamber; 2 – heat insulator; 3 – flexible film resistive electric heater of emitting type; 4 – mesh pallet; 5 – supports; 6 – distribution grid; 7 – control valve; 8 – vibrating mechanism; 9 – heat exchanging spiral device; 10 – anemometer; 11 – electricity meter; 12 – personal computer (PC); 13 – measuring controller TPM101; 14 – exhaust fan connected to a thermally insulated pipeline; 15 – scales

The vibration mechanism prevents the plant raw materials sticking together and ensures its mixing during heat treatment, which allows to determine the influence of vibration on the technological process of drying. Heat exchanger enhances the energy efficiency of the process by using the exhaust air to warm the cold air at the entrance to the working chamber of the device.

To confirm the effectiveness of using FFREHET for drying plant raw materials, the known IR emitters were compared using the example of apple raw material Antonovka, using the experimentally obtained kinetics of moisture content in raw materials (Fig. 5).



**Fig. 5.** Kinetics of moisture content of Antonovka apples: 1 – flexible film resistive electric heater of emitting type; 2 – linear quartz lamp; 3 – tubular electric heater

The shortest duration of the thermal process with preservation of the BAS and natural color is observed when using an improved FFREHET and the process duration is  $160 \text{ s}^{-1}$ . A positive trend in the use of improved FFREHET was observed during other experimental studies using carrots, dogwood, chokeberry, pear and spicy-aromatic raw materials. This confirms the previous theoretical and practical conclusions regarding the effectiveness of its application.

## 7. SWOT analysis of research results

*Strengths.* Among the strengths of this research it is necessary to note the results confirming the possibility of using an improved FFREHET to create non-reflector IR dryers for the purpose of obtaining dried semi-finished products of plant origin. Using the proposed development will reduce the metal capacity of devices, provide an effective range of heat treatment of plant raw materials with the preservation of BAS and their high quality.

*Weaknesses.* The main disadvantage of the research is that vacuum deposition of a resistive layer in the production of an improved FFREHET must be carried out in several stages. First, apply a layer on the electrical insulation film with the mounting of the taps on the copper busbars to connect to the electrical network, and then laminate two layers of additional electrical insulation, which provides greater strength of the heater. This leads to an insignificant increase in the cost of emitter manufacturing, but its positive properties eliminate this disadvantage.

*Opportunities.* Additional possibilities that ensure the achievement of the aim of research are the possible external factors associated with the existing drying equipment that is used in the countries of Eastern Europe and Ukraine («Садочок», «Універсал – СД-4», «Уран-70»). In most drying equipment, inertial, metal-intensive IR emitters with high temperatures of working surfaces are used, which are predominantly obsolete physically and morally. Therefore, it is necessary to introduce the developed or improved drying equipment on the basis of fundamentally new or improved IR emitters. This will ensure the efficiency of carrying out technological processes of processing plant raw materials while preserving the BAS, and also reduce the cost of operation of the designed VC IR dryer with a vibrating mechanism and a heat exchange spiral device.

*Threats.* The complexity of implementation of the experimental and practical results of the research is connected with two main factors. The first is the conditions for management of processing plants and farms that operate the designed drying equipment on the basis of an improved FFREHET. In particular, the contribution of additional funds to purchase the necessary equipment and the lack of a guaranteed result from implementation are constraining factors for enterprise managers. At the same time, the position of decision-makers is clear and often justified. After all, improperly selected auxiliary technological equipment and operating parameters may not provide the expected positive result. The second is the market of modern drying equipment, which is offered by world leading companies [19, 20]. At the same time, it should be noted that investing in acquiring new types of facilities is more expedient than upgrading physically obsolete ones.

Thus, SWOT-analysis of research results allows to determine the main areas of activity for the successful implementation of the aim, namely the development of modern refractory IR dryers based on the improved FFREHET. This will ensure an increase in the energy efficiency of drying equipment and a reduction in the costs of metal during their production.

## 8. Conclusions

1. The spectral-optical properties of the Antonovka apple are determined, namely the acceptable IR regions of its absorbing capacity (2, 5...3, 6, 9 and 12...15  $\mu\text{m}$ ). This confirms the effectiveness of using FFREHET during the drying of plant raw materials.

2. It is determined that the FFREHET (D) has a low inertia at a temperature of  $60 \text{ }^\circ\text{C}$  with a heating duration of  $\tau = 87 \text{ s}$ , simultaneously corresponds to a constant uniform temperature of the working surface and is characterized by a clear dynamics of operation.

3. Non-reflector VC IR dryer with a vibrating mechanism and a heat exchanger is developed. Improved FFREHET follows the geometric shape of the working chamber of the device, ensuring a reduction in the geometric dimensions and simplicity of device design. According to experimentally obtained kinetics of moisture content for Antonovka apples, the shortest duration of heat treatment is  $160 \text{ s}^{-1}$  with conservation of BAS and natural color.

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#### УСОВЕРШЕНСТВОВАНИЕ ИК-ИЗЛУЧАТЕЛЯ ДЛЯ СОЗДАНИЯ БЕЗРЕФЛЕКТОРНОЙ СУШИЛКИ РАСТИТЕЛЬНОГО СЫРЬЯ

Усовершенствован ИК-излучатель на основе гибкого пленочного резистивного электронагревателя излучающего типа для создания безрефлекторных ИК-сушилок растительного сырья. Это обеспечит уменьшение металлоемкости оборудования, равномерность распределения тепловых потоков на приемных поверхностях (сетчатых поддонах с сырьем) и повысит качество получаемых сушеных полуфабрикатов. Исследована поглощающая способность растительного сырья для подтверждения эффективности использования усовершенствованного ИК-излучателя.

**Ключевые слова:** гибкий пленочный резистивный электронагреватель, безрефлекторные ИК-сушилки растительного сырья, качество сушеных полуфабрикатов.

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## OPTIMIZATION OF FORMULATION COMPOSITION OF THE CRISP BREAD WITH IMPROVED CONSUMER PROPERTIES

Розглянуто питання оптимізації рецептурного складу зернових хлібців з поліпшеними споживними властивостями. Обґрунтовано оптимальні масові частки порошку розторопші та кухонної солі – 5,27 та 0,92 % відповідно як компонентів цільових продуктів. Доведено, що зернові хлібці з оптимальним складом характеризуються поліпшеними органолептичними, нормованими фізико-хімічними показниками, високою харчовою, біологічною цінністю, є безпечними.

**Ключові слова:** зернові хлібці, спельта, цілнозернові продукти, оптимізація рецептурного складу, комплексний показник якості.

### 1. Introduction

A promising direction in the development of the food industry is the creation of safe and, at the same time, high-grade food and consumer properties. Such products are able to maintain the health of consumers at the proper level, as well as reduce the risks of a number of diseases [1].

The imbalance of modern nutrition, the inability to provide the body with the necessary amount of essential nutrients and biologically active substances (BAS) is a global problem in both developed and developing countries. Unfortunately, in recent years, nutrition quality of the population has significantly worsened and this trend continues. Consequences of such nutrition is a violation of