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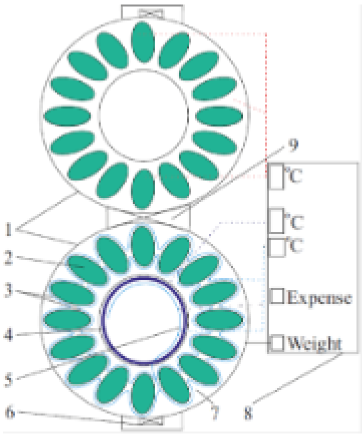

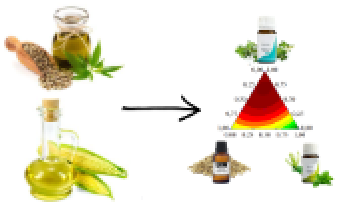

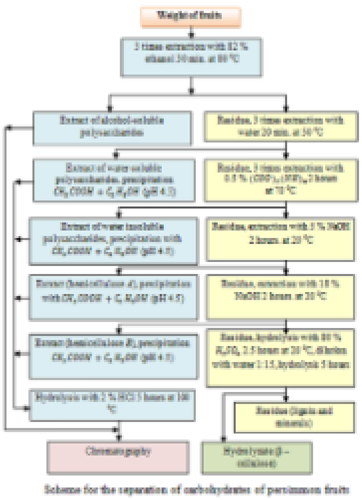

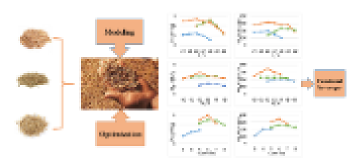


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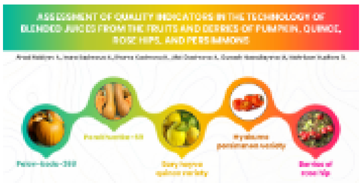

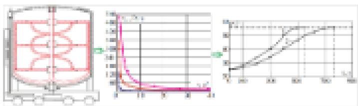

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IMPROVEMENT OF THE VACUUM EVAPORATOR FOR THE PRODUCTION OF PASTE-LIKE SEMI-FINISHED PRODUCTS WITH A HIGH DEGREE OF READINESS

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The object of this study is the process of cooking blended pureed mass based on apple, Jerusalem artichoke, cranberry, and hawthorn in an improved vacuum evaporation apparatus with a unified stirrer for the production of paste-like semi-finished products with a high degree of readiness. Conventional devices for cooking are associated with intermediate heat carriers, significant energy and metal consumption, the difficulty of stabilizing the temperature field under the conditions of a significant duration of the process, which prevents ensuring mobility, resource efficiency, and reducing the quality of resulting products. This led to the improvement of the vacuum evaporator by replacing the steam jacket with a film-like resistive electric heater of the radiating type, with the simultaneous use of a unified stirrer to increase the useful heat exchange surface by 0.6 m^2. This was achieved by heating the internal space of the stirrer with the heater mentioned above, thereby forming the total area of heat exchange up to 2.8 m^2, which is 28 % more than the area of the prototype (2.2 m)^2. The rheological parameters of the resulting fruit and vegetable paste at a boiling temperature of 50...55 °C at a shear rate of 0.8...2.0 s^{-1} were determined, while the effective viscosity was in the range of 5.0...18.0 Pa•s. At the same time, the character of boiling kinetics in the improved vacuum-evaporating apparatus was 30 % lower than the indicator for the basic design MZ-2S-241a.

The improved vacuum-evaporator with a unified stirrer is characterized by reduced specific heat consumption for heating the loaded pureed semi-finished product by 13.8 %. By increasing the heating surface by 28 % and reducing the duration of the temperature load on the product according to experimental data in the device by 29.6 %

Keywords: vacuum evaporation apparatus with a unified stirrer, increased heat exchange surface, blending of fruit and vegetable raw materials

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1. Introduction

Active consumption of concentrated natural (fruit, berry, vegetable, etc.) semi-finished products with a high degree of readiness is associated with changes in the demand for food products characterized by an increased content of physiologically functional ingredients (PFI) [1]. The formation of an incentive for rational healthy nutrition based on natural ingredients is associated with the rapid deterioration of the ecological situation in recent decades. This has had a negative impact on chronic and lifelong diseases, regardless of the emergence of a pandemic situation. In most cases, the consumption of natural ingredients is carried out in fresh form, however, the complexity of transport logistics, the need for storage during transportation arises, as well as further sale and even consumption, thereby complicating the main com-

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ponent of the competitiveness of the logistics chain [2]. One of the effective managerial ways to increase competitiveness is the resource-efficient processing of natural raw materials at collection sites or in an established logistics center. In particular, in semi-finished products of a high degree of readiness (boiled pasta, condensed milk products, dried products of various fractions, etc.) subject to maximum preservation of properties [3]. Forming the constant development of the processing and production component with the use of innovative equipment and technological solutions, making it possible to obtain natural semi-finished products of a high degree of readiness with a wide range of introduction into the recipes of various food products. This, in turn, ensures resource-efficient processing of plant raw materials, and its introduction into food recipes makes it possible to minimize and even completely abandon synthetic components (flavorings, dyes, etc.). By replacing them with natural ingredients with the simultaneous acquisition of original organoleptic and rheological properties, building a fundamentally new therapeutic, preventive, and health food [4]. However, considerable attention should be paid to resource-efficient heat and mass exchange processing of natural raw materials since it is the temperature and specifics of the implementation of the technological process that are the main factors in preserving the initial properties. Predetermining the urgency of finding resource-efficient solutions for the implementation of heat treatment of plant raw materials, their blending for the purpose of a rational combination of PFI and ensuring the mobility of equipment for obtaining cooked semi-finished products of a high degree of readiness. One of the solutions is the introduction of an improved vacuum evaporation apparatus with a unified stirrer, which will have competitive advantages in contrast to basic designs. It will also make it possible to expand the range of concentrated natural blended semi-finished products of a high degree of readiness, in accordance with the needs of consumers.

2. Literature review and problem statement

In work [5], the question of the feasibility of using natural plant raw materials in the food industry in accordance with the needs of consumer cooperatives on the example of Ukraine is considered. Among the main advantages of natural raw materials is a significant content of useful PFIs, original organoleptic and structural-mechanical features; however, raw materials require fast and high-quality processing taking into account the equipment and technological solutions used. The use of rational solutions will allow for the maximum preservation of the properties of natural raw materials, the expansion of the assortment of semi-finished products of a high degree of readiness and the increase of the nutritional composition of food products based on them, confirming the relevance of research into this area.

Ensuring the implementation of resource-efficient production of competitive semi-finished products with a high degree of readiness of various consistencies (powders, pastes, various dried fractions, etc.), which is in significant demand by consumer cooperatives and is due to the ecological situation and pandemics. For example, work [6] analyzed the competitiveness of functional food products taking into account the influence of the main indicators: price, consumer demand, trust in the received quality, and a person's desire to lead a healthy lifestyle. Analytical analysis of the selected parameters among consumer cooperatives involves the quality of the purchased goods and the level of natural origin. This, in turn, requires today's manufacturers to implement innovative solutions to meet the needs of the population, and therefore the search for resource-efficient mobile solutions for processing complexes is relevant today. So, for example, analytical data on the feasibility of producing multi-component semi-finished products with a high degree of readiness are given in [7] since rational mixing according to the nutrient composition will allow obtaining therapeutic and preventive choices of a wide range of use in the recipes of various food products. In most cases, various mixers are used to obtain homogeneous mixed semi-finished products, one of them was designed in [8]. In addition, the complexity of the production of multi-component semi-finished products is the need to carry out complex studies starting from the change in the content of nutrients to the obtained rheological, organoleptic, and competitive properties, taking into account the equipment and technological base used. Taking into account the results presented in [9], it turns out that a significant amount of plant material is processed under the conditions of heat and mass exchange operations with the use of conventional equipment, which is energy- and metal-intensive. In most cases, it has intermediate heat carriers and is characterized by a significant duration of processing, which leads to the loss of useful nutrients, reducing the purchasing power of the obtained products, and therefore reducing the profitability of production [10]. In particular, work [11] focuses on the expediency of the production of boiled natural blended semi-finished products of a high degree of readiness, for the formation of therapeutic and preventive capacity during consumption. This confirms the expediency of implementing innovative solutions for the production of multi-component semi-finished products while taking into account rheological and organoleptic properties during heat-mass exchange processing. Taking into account the data given in [12], it can be concluded that in most cases the boiling (concentration) of blended natural semi-finished products is implemented in stationary vacuum-evaporating (rotor-film) devices. Different heat carriers are used for intensification of boilers, and devices are improved by moving them, but under conditions of stationary location, significant energy and metal consumption, stabilization of the temperature range is difficult, and therefore there is a need to find further rational solutions. So, for example, in work [13], to form a wider range of use of pre-cooked semi-finished products, they are dried in an IR field at low temperatures (45...60 °C). This, in turn, significantly expands the range of use of the dried semi-finished product under conditions of undemanding further storage during sale. However, in the study, issues related to the search for ways to ensure the mobility of processing complexes, in particular during boiling, which will increase the competitiveness of production, and therefore are a relevant area for research, remain unclear.

In [14], the peculiarities of the implementation of the low-temperature concentration process (up to 35 °C) in a vacuum-evaporating apparatus under the conditions of using electromagnetic generators of a certain frequency are considered. This is one of the solutions to eliminate the component of intermediate heat carriers, however, the use of a certain frequency is a complex technical process and requires special maintenance. In addition, this solution is implemented on a stationary vacuum evaporator, and today there is a need to create mobile evaporators to reduce transport logistics and the ability to process one's own raw materials directly at the collection sites. Therefore, there is a need to design rational mobile vacuum-evaporating devices, as well as to intensify the boiling process by increasing the usable heat exchange surface of the device. In addition, questions related to the determination of rheological changes under cooking conditions depending on the design features of the stirring device, which are presented in [15] on the example of cooking pear puree, remain unsolved. Confirming the relevance of research in this area for the search for innovative solutions. In work [16], the calculation of a rotary-film apparatus with a film-forming element having a reflective surface is given, thereby ensuring a reduction in the duration of concentration to 200 s, and in a conventional evaporator to 3600 s, respectively. However, this blade is effective only in that device and the possibility of using it in vacuum-evaporating devices is impractical. This determines the expediency of further research into the prediction of a unified stirrer for the rationalization of the boiling process in conventional vacuum-evaporating devices. Thus, in particular, in work [17], children's puree was boiled based on natural raw materials (fruit and vegetables) at different boiling temperatures (5...65 °C) and shear speed range (5...200 s^{-1}). However, the influence of the heat transfer coefficient on the formation of rheological properties has not been determined. In [18], the influence of the acidity of vegetable blended puree based on peach, papaya, and mango under conditions of variable cooking temperature on the resulting rheological behavior was investigated. However, the issue related to the influence of the method of heat supply and the possibility of forming the equipment mobility of the boiling process remained unexplained. Thus, work [19] devised a method of low-temperature concentration of apple juice as one of the factors of storage of natural nutrients in a uniform temperature field, confirming the feasibility of using rational sources of heat supply with clear temperature dynamics. This confirms the expediency of a comprehensive study for the formation of a generalized strategy of a rational boiling process for the effective improvement of a mobile-type vacuum-evaporator with an increased heat exchange surface due to a unified stirrer.

Paper [20] presents comparative data on the process of concentration of plant juice from barberry in a closed cycle with the usual boiling process. The data are characterized by a decrease in the duration of concentration from 480 min to 360 min at a flow rate of 0.014 kg/s under the conditions of a decrease in dehydration by 40 % and an increase in moisture evaporation by 33 %. However, the formation of a complete cycle is a certain difficulty, especially under the conditions of the formation of a mobile processing complex, confirming the relevance of research in this area.

In [21], the expediency of processing plant raw materials into a concentrated semi-finished product with its subsequent inclusion in the formulation of food products was analyzed. For example, work [22] proved the effectiveness of using a multi-component natural mixed fruit paste based on apple, cranberry, and hawthorn with a content of 28...30 % DS with subsequent addition to the pastille formulation. It has been established that the optimal percentage of blend added to the pastille recipe is 75 %, which made it possible to obtain original sweet products with curative and preventive properties. Therefore, the production of blended semi-finished products with a high degree of readiness is an urgent task from the point of view of use as an independent product and as a natural filler for food recipes.

Taking into account the above literary review, it is possible to conclude about the need to form a modern structural and technological solution based on the improvement of the basic design of the vacuum evaporation apparatus. Some of the main tasks during improvement are:

– determination of the rheological behavior of blended vegetable semi-finished products as one of the factors for predicting the behavior of the semi-finished product during the cooking process and the interaction of the ingredients with each other to understand the obtained properties of the finished product [23];

– formation of the possibility of ensuring the mobility of the vacuum evaporation apparatus due to the use of modern sources of heat supply with clear dynamics and stabilization of the temperature field to ensure the possibility of placement directly in the places of collection of the raw material base;

– increasing the usable heat exchange surface due to the use of a unified stirrer, the surface of which is also heated, this will reduce the duration of temperature treatment and preserve natural nutrients.

Solving the above-mentioned tasks in practical implementation will allow obtaining high-quality natural mixed semi-finished products of a high degree of readiness with a certain content of dry substances (DS) for further use in recipes of various food products.

Improving the basic design of conventional vacuum evaporators based on MZ-2S-241a by providing mobility with an increased heat exchange surface due to the use of a unified stirrer will make it possible to create a competitive device and solve the efficiency of the processing complex.

3. The aim and objectives of the study

The purpose of this study is to improve the mobile vacuum evaporation apparatus, due to the use of a unified stirrer with a surface that is heated to increase the usable heat exchange surface when boiling paste-like semi-finished products of a high degree of readiness. This will make it possible to reduce the duration of the stay of raw materials in the concentration chamber under conditions of intensive mixing to reduce the temperature effect on physiologically functional properties while preserving them.

To achieve the goal, the following tasks were set:

– to design an improved mobile model structure of a vacuum-evaporating apparatus with a unified stirrer, the surface of which is heated;

– to carry out experimental and practical testing of a model structure of a vacuum-evaporating apparatus with a unified stirrer with a heated surface to determine competitive properties.

4. The study materials and methods

The object of our study is the process of cooking blended pureed mass based on apple, Jerusalem artichoke, cranberry, and hawthorn in the improved vacuum evaporation apparatus with a unified stirrer for the production of paste-like semi-finished products with a high degree of readiness.

The design of a conceptual solution for a structural mobile vacuum evaporation apparatus with a unified stirrer will allow creating a competitive device. With a shortened duration of cooking due to the heating surface of the unified stirrer, thereby reducing the temperature effect on the physiologically functional properties of natural raw materials for the preservation of nutrients.

The purpose of experimental and practical research was implemented at the laboratory of the State Biotechnology University by creating a mobile model structure of a vacuum evaporation apparatus and a unified stirrer with a heated surface to increase the usable heat exchange surface. Verifying the resulting engineering and technological solutions will confirm the probability of ensuring the competitive properties of the device when boiling pasty semi-finished products of a high degree of readiness. Control of technological modes of heat and mass transfer processing was carried out by means of automation made by company "Aries" (Kharkiv, Ukraine) with a detailed description of the principle of operation of the experimental model and the experimental and practical part, the results of which were processed in accordance with standard procedures. The determination of structural and mechanical properties was carried out on a rotary viscometer "Rheotest-2" in a cylindrical measuring device according to Couette. For the experimental and practical approbation of the improved device during the cooking of blended mashed mass, natural raw materials with a significant content of PFI were pre-selected: apple, Jerusalem artichoke, cranberry, and hawthorn in the ratio of 35, 30, 25, 10.

5. Investigating the boiling process in a vacuum evaporation apparatus with a unified stirrer, the surface of which is heated

5. 1. Design of an improved model structure of a vacuum evaporation apparatus with a unified stirrer

The production of semi-finished products with a high degree of readiness, in particular, concentrated pastes, depends on the selected equipment and technological solution under the conditions of creating excess pressure to reduce the temperature effect during heat and mass transfer. This, in turn, makes it possible to reduce the duration of heat treatment, and therefore to preserve the initial chemical, physiologically functional properties, etc. as much as possible. The majority of vacuum evaporators cannot be used in mobile lines of processing complexes of medium and low productivity due to the significant structural energy and metal consumption, the need to use steam generator units, etc. The use of the declared usable heat exchange surface of vacuum-evaporating devices leads to the implementation of a long heat-mass exchange process with subsequent loss of the initial properties of raw materials for cooking, and therefore a decrease in the properties of semi-finished products of a high degree of readiness.

The practical implementation of a mobile vacuum-evaporator without a steam generator and with an increased heat exchange surface to ensure effective mixing of raw materials during boiling under the conditions of reducing the duration of heat treatment will form competitive equipment and technological properties.

Let us consider in more detail the improved mobile model structure of the vacuum evaporation apparatus (Fig. 1), in which the heating of the working chamber 1 for boiling raw materials is carried out by a film-like resistive electric heater of the radiating type 2 (FREHRT [24]) with a heat-insulating surface. This will make it possible to reduce the metal content of conventional structures due to the elimination of steam generating stations, steam networks, including jackets for the intermediate heat carrier, forming the prerequisites for the creation of a mobile device. An artificial increase in the usable area of the heat exchange surface in the model structure is realized through the use of a unified stirrer 3, which rotates counterclockwise under the conditions of an additional heated surface of the FREHRT located inside the structure.

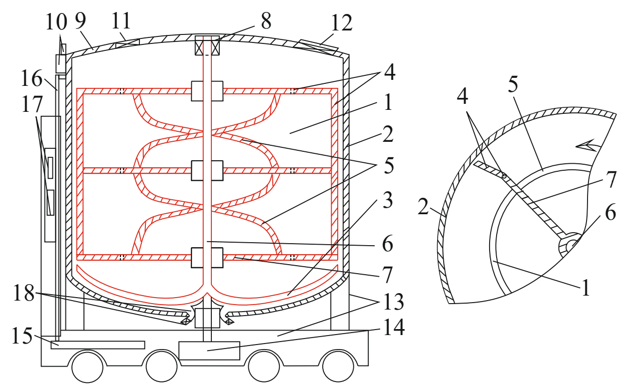

Fig. 1. Scheme of the improved mobile model structure of the vacuum-evaporator with a unified stirrer (where A is a fragment of the working chamber with a unified stirrer): 1 – working chamber; 2 – a film-like resistive electric heater of the radiating type (FREHRT) with a heat-insulating surface; 3 – unified mixer; 4 – the clamping shearing frame is mounted on hinges; 5 – spiral cutting blade; 6 – the main shaft of the unified mixer (3); 7 – transverse jumpers; 8 – brush contact network; 9 – cover; 10 – control and safety fittings; 11 – viewing and servicing window; 12 – nozzle for loading raw materials; 13 – moving platform; 14 – electric drive with a worm gear; 15 – vacuum pump; 16 – flexible highway; 17 – means of automation; 18 – unloading nozzles with automatic means based on the shut-off crane equipment

The unified mixer 3 is a conventional anchor mixer in the lower part, the vertical frame is made in the form of a clamping shearing frame mounted on hinges 4. Mixing of the central layers is realized by a spiral cutting blade 5, connected to the main shaft 6 and transverse jumpers 7. Design feature of the unified stirrer 3 will form the mixing of the entire volume of the raw material being boiled, and the hinged clamping of the cutting frame will ensure the cutting of the raw material from the hot working surface under the condition of intensive mixing of the inner layer. According to preliminary calculations, the use of the proposed unified stirrer 3 will provide an increase in the usable surface of heat exchange by 0.6 m^3. Power supply to FREHRT 2 of the unified mixer 3 is carried out through the brush contact network 8 mounted in the upper part of cover 9, on which the control and safety valve 10 is also mounted. Inspection and maintenance window 11, and a technical nozzle for loading raw materials 12, which will undergo further boiling, respectively to the established technological parameters. Traditionally, for vacuum evaporators, the upper part of the model structure acts as a separation space.

The mobility of the model structure of the vacuum-evaporator with a unified stirrer is ensured by installing it on a moving platform 13. The lower part of which acts as a motor-vacuum compartment due to the installation of an electric drive with a worm gear 14 for a unified stirrer 3 and a vacuum pump 15 with a flexible line 16 to create excess pressure in the working chamber 1. Control and regulation of hardware and technological parameters is carried out by means of automation 16, located in the vertical rack of the moving platform. At the end of the technological process of boiling, unloading of the model structure of the vacuum-evaporating apparatus is realized due to nozzles 18, equipped with automatic means based on the shut-off valve equipment. Pipes 18 have a coupling connection with the main line for further realization of the boiled semi-finished product of a high degree of readiness.

The secondary steam obtained during boiling is used for the technical needs of production, in particular, due to passing through the inner space of the tubular heat exchanger, the liquid was heated for technological needs. The technological process of boiling is typical for conventional designs of vacuum evaporation apparatuses. Including for the MZ-2S-241a basic configuration, the difference is only in mobility, due to the presence of a moving platform, a heating system with an increased heat exchange surface under the conditions of reducing the technological duration of cooking. The low arrangement of the electric drive with a worm gear (Fig. 1, item 14) reduces the weight pressure on the construction of the working chamber of the improved device under the conditions of the simultaneous elimination of the conventional steam jacket with an intermediate heat carrier. Unloading the device due to nozzles with automatic means of closing crane equipment due to its design and conventional technical sealing has no complications for the rotation of the main shaft of the unified mixer. And the structure of the lubrication system of the worm gear prevents overheating of the internal elements under conditions of rational lubrication.

5. 2. Experimental and computational testing of the improved vacuum evaporation apparatus with a unified stirrer

During the experimental and practical studies of the improved design of the vacuum evaporation apparatus, it is necessary to determine the structural and mechanical indicators of the processed fruit and vegetable raw materials. Since the rheological treatment of raw materials has a significant impact on the performance of the apparatus, and the rheological parameters are necessary for the calculation of its main components. Approbation of the improved device was carried out when boiling mashed apples, Jerusalem artichokes, cranberries, and hawthorn in the proportion of 35, 30, 25, 10, respectively.

The dynamic viscosity of the paste made from the specified raw materials was determined depending on the shear rate at different temperature values from 25 °C to 55 °C (Fig. 2). The data indicate a decrease in the dynamic viscosity of the paste as the temperature increases. Viscosity indicators at the beginning of application of the shear force are 525 Pa·s at a temperature of 25 °C; 352 Pa·s at 40 °C; and 133 Pa·s at 55 °C. By the nature of the curves, the paste samples belong to non-Newtonian fluids, and after reaching a shear force of 30 s^{-1}, all samples begin to flow with practically the same indicators. In the operating temperature range of 50...55 °C under conditions of concentration in a vacuum evaporator at a shear rate of 0.8...2.0 s^{-1}, the effective viscosity is in the range of 5.0...18.0 Pa·s.

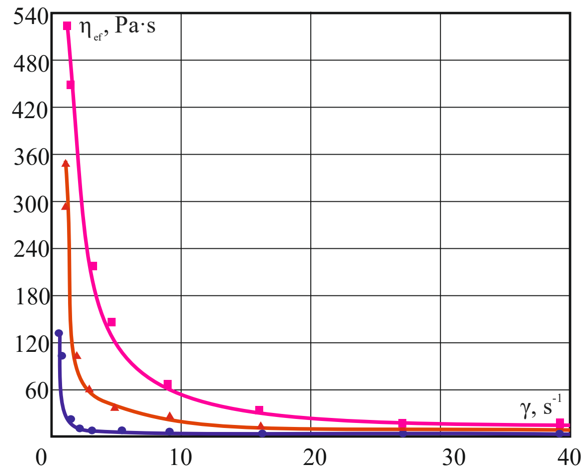

Fig. 2. Structural and mechanical characteristics of fruit and vegetable paste: 30% dry matter: ■ – 25 °C; ▲ – 40 °C; ● – 55 °C

To confirm the effectiveness of the model structure of the vacuum evaporation apparatus, the kinetics of its heating compared to the basic evaporation apparatus MZ-2S-241a were determined (Fig. 3).

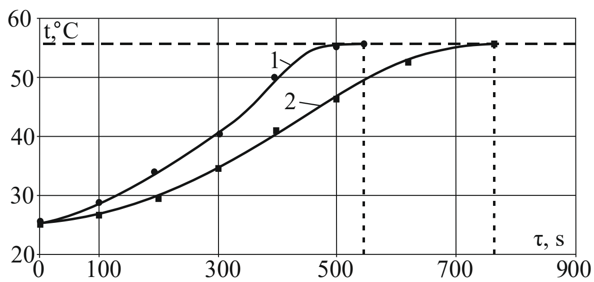

Fig. 3. Kinetics of heating blended puree-like semi-finished product: 1 – improved mobile model structure of a vacuum-evaporating apparatus with a unified stirrer; 2 – MZ-2S-241a

When entering the stationary temperature mode of boiling, the improved device showed a better result of 535 s in contrast to the prototype with an indicator of 760 s. This result is explained by the reduction of the metal capacity of the model sample by eliminating the steam-water jacket and the corresponding shut-off fittings and the design of a unified mixer with additional heating. The total duration of heating is reduced by 26.9 %.

Table 1 gives a comparison of the characteristics of the basic design of the MZ-2S-241a evaporator and the improved mobile model structure of the vacuum evaporator with a unified stirrer. Calculations were carried out without taking into account heat losses to the environment.

Analysis of the data in Table 1 revealed the improvement of the efficiency of the improved model structure of the vacuum-evaporating apparatus with a unified stirrer compared to the given basic design. The improved model is distinguished by a decrease in specific metal capacity by 48 %, while the working surface of heat exchange increases due to additional heating of the stirrer plane by a film heater by 28 %. According to the indicator of specific heat consumption for bringing puree to the boiling temperature under vacuum, there is a decrease of 13.8 %, and the duration of the processing process, according to experimental data, decreased by 29.6 %. Replacing the steam heating device with an electric one in general improves operational performance and makes it possible to simplify the automation system of the evaporation plant. Reducing the processing time using a gentle temperature regime of 54...56 °C will help preserve the nutrient composition of the resulting paste.

improvement of the conventional structure by eliminating the intermediate heat carrier, the possibility of installation on a mobile platform, and increasing the usable heat exchange surface with a unified stirrer. This, in turn, will make it possible to minimize the well-known shortcomings of conventional vacuum evaporation apparatuses, namely the complexity of their location in changing places of collection of the own raw material resource base of European countries [25]. In most cases, this is due to the use of intermediate heat carriers, which in turn characterize the apparatus with high energy and metal consumption, and therefore the difficulty of controlling the temperature range, reducing the quality of the finished semi-finished products. So, for example, in work [26], research was conducted on the boiling of natural raw materials under the conditions of using an improved mixing device into which hot steam was supplied to intensify the process but this is a complex design solution. However, the main disadvantages of the steam system, including other intermediate heat carriers, are the significant metal content and the complexity of maintenance and stabilization of the temperature effect, leading to the search for technical solutions for the elimination of intermediate carriers. Refuse for intermediate heat carriers becomes possible due to the use of electric heat supply sources based on FREHRT, which can also be used to heat the unified mixer. One of the solutions for the use of electric heating in vacuum evaporation apparatuses is given in [27], emphasizing the possibility of effective replacement of intermediate heat carriers, but the issue of the mobility of the apparatus for placement in mobile complexes is not considered.

Table 1

Comparison of characteristics of the improved mobile model structure of the vacuum evaporation apparatus with a unified stirrer with the basic design

Indicator	МЗ-2С-241а	Vacuum evaporation apparatus with a unified stirrer
Weight of the device	m^*=900 kg	$m=m^*-m_{shirts}+m_{GPRenVT}$= =900–320+15=595 kg
The working surface of heat exchange	F^*=2.2 m^2	$F=F^*+F_{stirrers}$=2.2+0.6=2.8 m^2
Processing time	$\tau=Q/F{\cdot}k{\cdot}\Delta t$= =1049112/2.2·1454·87=3769 s	$\tau=Q/F{\cdot}k{\cdot}\Delta t$= =1049328/2.8·1820·87=2366 s
Specific metal capacity	$m=M/F$=900/2.2=409 kg/m^2	$m=M/F$=595/2.8=212.5 kg/m^2
The heat of heating the device	$Q_{ap}=m_1{\cdot}c_c(t_2-t_1)+m_2{\cdot}c_c(t_3-t_1)$= =480·0.48(55–25)+320·0.48(127–25)= =22579 kJ	$Q_{ap}=m_1{\cdot}c_c(t_2-t_1)$= =495·0.48(55–25)=7128 kJ
The heat of heating the product	$Q_{pr.}=m{\cdot}c{\cdot}(t_k-t_n)$=800·3.7·(55–25)= =88 800 kJ	$Q_{pr.}=m{\cdot}c{\cdot}(t_k-t_n)$= =800·3.7·(55–25)=88 800 kJ
The total amount of heat	Q_{total}=111379.2 kJ	Q_{total}=95928 kJ
Specific costs for heating the device and the product	$q_{prod.}=Q/m$=111379.2/800=139.2 kJ	$q_{prod.}=Q/m$= =95928/800=119.9 kJ/kg
Product heating time (from experimental data, Fig. 3)	τ=760 s	τ=535 s

*Note: *Information on the basic design of the MZ-2S-241a is taken from a literary source [25]*

During the research, the technical parameters of the improved structure of the vacuum evaporation apparatus were established (Table 2).

Table 2

Technical characteristics of the improved model of the vacuum-evaporating apparatus with a unified stirrer

Technical characteristics	Indicator
Area of the heating surface, m^2	2.8
Capacity, m^3	0.5
Drive power, kW	2.0
The temperature of the heating surface from FREHRT, °C	to 120
Stirrer rotation frequency, min^{-1}	48
Weight, kg	595

Our practical-experimental studies of the improved model of the vacuum-evaporating apparatus with a unified stirrer confirm the improvement of its operational indicators with positive resource saving. The introduction of the proposed design of the apparatus in lines for the concentration of fruit and vegetable raw materials will contribute to the reduction of the cost price of the obtained products.

6. Discussion of results of improving the mobile vacuum evaporation apparatus with a unified stirrer

A feature of the proposed technique is to ensure the competitive properties of vacuum evaporators due to the

To form the mobility of the vacuum evaporation apparatus, the basic design of MZ-2S-241a (Fig. 1) with a unified stirrer was improved, which makes it possible to increase the heat exchange surface by 0.6 m^2 due to the additional heating of FREHRT (Table 1). The proposed design of the improved device provides a reduction in the duration of reaching the stationary mode when boiling at a temperature of 55 °C to 535 seconds, unlike the basic design of MZ-2S-241a (760 seconds, Fig. 4). This will make it possible to implement the boiling process in a shorter technological time, and therefore preserve natural nutrients during boiling.

To determine the efficiency of the improved vacuum evaporation apparatus with a unified stirrer when boiling fruit and vegetable paste based on apples, Jerusalem artichokes, cranberries, and hawthorn. The nature of the rheological behavior of the blended semi-finished product in the temperature range of 50...55 °C was studied. It was found that at a shear rate of 0.8...2.0 s^{-1}, the effective viscosity is in the range of 5.0...18.0 Pa·s (Fig. 3). By the nature of the curves, the paste samples belong to non-Newtonian fluids, and after reaching a shear force of 30 s^{-1}, all samples begin to flow with practically the same indicators. The analysis of the obtained kinematic curves (Fig. 4) of the heating of the mashed semi-finished product under the conditions of boiling in the improved mobile model structure of the vacuum-evaporating apparatus with a unified stirrer compared to the prototype (MZ-2S-241a) is characterized by a decrease of 29.6 %. In addition, the following competitive structural and technical indicators were obtained, namely: a reduction of the specific heat consumption for heating the device loaded with the product by 13.8 %. The heating surface was increased by 28 %, and the duration of the temperature load on the product in the device was reduced by 29.6 % according to experimental data. In general, reducing the processing time using a gentle temperature regime of 54...56 °C will contribute to preserving the quality of the nutrient composition of the obtained paste (Tables 1, 2).

The practical implementation of the improved mobile design of the vacuum evaporation apparatus with a unified stirrer will ensure the competitiveness of processing complexes in the places of the raw material base under conditions of preservation of natural nutrients. The use of the improved structure will allow the technical transportation of products to be implemented with the help of a moving platform (Fig. 1, item 14) instead of the installation of stationary metal-intensive constructions of difficult-to-operate pumping stations for pumping highly viscous materials. The use of the improved device is recommended in the temperature range of 45...65 °C to ensure rational processing of plant raw materials into high-quality concentrated semi-finished products with a high degree of readiness. One of the limitations during the study of cooking modes of fruit and vegetable blended mass is the stabilization of the temperature of the working surface, which can be achieved by using a unified stirrer, the surface of which is additionally heated. It should be noted that non-compliance with the recommendations will lead to a decrease in the competitiveness of the processing complex as a whole and the purchasing power of consumer cooperatives.

In the future, it is planned to carry out a study on the implementation of the boiling process in the improved apparatus under the conditions of introducing resource-saving technologies based on Peltier elements into its structure.

7. Conclusions

1. It is proposed to improve the mobile design of the vacuum evaporation apparatus by replacing the technique of heating the working capacity with the help of a film-like resistive electric heater of the radiating type. The apparatus uses the structure of a unified stirrer with a heating surface in the previously mentioned technique with a heating surface of 0.6 m^2.

2. Approbation of the improved vacuum evaporation apparatus with a unified stirrer was carried out during the cooking of fruit and vegetable paste based on apples, Jerusalem artichoke, cranberries, and hawthorn. The structural and mechanical parameters of the obtained fruit and vegetable paste were determined in the range of operating conditions at a temperature of 50...55 °C under the conditions of concentration in an improved vacuum-evaporator at a shear rate of 0.8...2.0 s^{-1}, the effective viscosity is in the range of 5.0...18.0 Pa·s. The kinetic characteristics during heating in the improved model structure of the vacuum-evaporating apparatus compared to the basic design MZ-2S-241a were established. The effectiveness of the design improvement was proven due to the improvement of the efficiency of the main indicators compared to the prototype, namely, the specific heat consumption for heating the device loaded with the product was reduced by 13.8 %. The heating surface was increased by 28 %, and the duration of the temperature load on the product in the device was reduced by 29.6 % according to experimental data.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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