Більшість конструкцій вакуум-випарних апаратів для концентрування мають проблему стабілізації теплопідведення по всій поверхні теплообміну. Це пояснюється наявністю парової оболонки, що ускладнює рівномірне теплопідведення. Також серед недоліків є відсутність можливості раціонального збільшення поверхні теплообміну, що в свою чергу впливає на тривалість термічної обробки та якість продукції. Із метою усунення основних недоліків вакуум-випарних апаратів запропоновано спосіб теплопідведення зі збільшеною поверхнею обігрівання. Для розв'язання поставлених завдань з удосконалення запропоновано використовувати сучасні гнучки плівкові резистивні електронагрівачі випромінювального типу (ГПРЕнВТ). Вони характеризуються низькою інерційністю, металоємністю, простотою автоматизації та обслуговування. Такий електронагрівач здатен забезпечувати рівномірність теплового потоку та приймати будь-яку геометричну форму теплопередавальної поверхні.

Відповідно до конструктивно-технологічного рішення замість парової оболонки обігрівання пропонується здійснювати теплоізольованим ГПРЕнВТ, який також розташовується у порожнистому просторі вала мішалки та лопатей. Таким чином забезпечується збільшення поверхні теплообміну від 3,7 м^3 до 4,15 м^3, тобто на 12 %.

Виявлено зменшення граничної напруги зсуву зі збільшенням температури: якщо t=10 °C, то θ_0=79 Па; відповідно t=70 °C, θ_0=12 Па. Ефективна в'язкість для t=10 °C становить $\eta_{еф}$=392 Па·с, для t=70 °C $\eta_{еф}$=2 Па·с. У ході апробації модельного зразка ВВаПТ під час концентрування (50…65 °C) визначено швидкість зсуву: 0,5…2,5 с$^{-1}$. Ефективна в'язкість перебуває в межах 2,0…4,5 Па·с. Удосконалений ВВаПТ характеризується скороченням тривалості виходу на стаціонарний режим порівняно з прототипом (МЗС-320) на 29%. Ефективність конструктивно-технічного рішення підтверджується й зменшенням ваги апарата на 35 %, питомої металоємності на 42 %, тривалості обробки на 12 %

Ключові слова: концентрування, органічна продукція, вакуум-випарний апарат, пастоподібний напівфабрикат, гнучкий плівковий резистивний електронагрівач

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IMPROVING A VACUUM-EVAPORATOR WITH ENLARGED HEAT EXCHANGE SURFACE FOR MAKING FRUIT AND VEGETABLE SEMI-FINISHED PRODUCTS

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1. Introduction

Concentrated semi-finished products based on natural organic raw materials constitute a significant share of the food industry market due to their wide application spectrum, in particular, to meet the daily growing demand of population in natural foods. This demand is caused by the rapid deterioration of the ecological state of many countries in the last decades and by the desire to consume high-quality products with the reasonable component: good value for money. This proves the appropriateness of searching for innovative approaches to the intensification of the concentration process through improving the equipment for its implementation [1]. The basis for the production of concentrated semi-finished products is natural, in particular, organic raw materials, which causes the need for its processing directly in the places of growth. This is primarily due to rapid inevitable physical-chemical reactions associated with losses of its initial properties, including natural value, and a decrease in transportation costs [2].

In order to ensure the qualitative characteristics of processed food raw materials, the appropriate technologies are constantly improved, which allows a significant decrease in the duration of processing.

Ensuring the quality of raw materials, processed into food products, needs constant improvement of the appropriate technologies, which allow considerable reduction of the duration of processing. The use of new energy-saving equipment will ensure the preservation of the initial properties of raw materials and will provide the competitive features to the obtained products [3]. The quality of the obtained organic concentrated semi-finished products is directly influenced by the structural-technological component. During the production of high-quality natural concentrated semi-finished products, significant attention should be paid to thermal exchange processes, which are mostly realized in highly productive and metal-intensive equipment. In many cases, structural implementation does not fully provide the appropriate quality of the obtained products due to complex engineering and technical communications and resource efficiency. This necessitates the search for innovative solutions to improve the concentration processes, in particular, by increasing the heat exchange surface area.

The relevant task is to implement the innovative design and technological solutions related to the improvement of the process of concentration of natural raw materials for further production of various food products on its basis. It is possible to solve the problem by improving the basic structures of vacuum-evaporators by increasing a heat transfer surface and changing the way the working chamber is heated. In turn, this will ensure the thermal stabilizing action of the process and resource efficiency regarding a decrease in metal capacity of the equipment, which will allow obtaining the competitive high-quality assortment of concentrated natural semi-finished products.

2. Literature review and problem statement

Paper [4] proves the necessity of expanding the market of high-quality plant products of natural origin. This raw material has a natural content of biologically active substances (BAS) and has original flavor properties. Thus, it can ensure obtaining a competitive product of plant origin for functional purposes and expand its assortment. This concerns the production not only of ready-to-eat food products, but also of concentrated semi-finished products of high readiness degree. The use of concentrated paste-like semi-finished products from fruit and berry raw materials ensures the expansion of the assortment of food products and allows creating the original flavor properties of the obtained products. To implement the above-mentioned, it is necessary to introduce the substantiated technological modes and modern equipment that will ensure maximum preservation of the natural properties of the obtained semi-finished products.

In recent years, more and more attention is paid to the development and implementation of functional products containing vegetable materials. Paper [5] examines the role of trust, health awareness and prices in shaping consumers' intentions to buy functional products. It was established that the shaped intentions of consumers to purchase such products arises in connection with its high quality. This causes the introduction of innovative methods and apparatus solutions in terms of spreading plant semi-finished products during the subsequent production of functional products on their basis.

Paper [6] analyses the efficiency of using various plant semi-finished products during blending into the unified functional semi-finished product of enhanced quality with regard to the necessity of taking into account the properties of each component and of compliance with reasonable technological operations during their processing, since raw materials quickly lose their initial properties. According to data in article [7], most heat and mass exchange processes are implemented on obsolete technological equipment using high temperatures and are resource intensive. The reason for this is high performance, continuity of technological processes, complexity of technical communications, which complicates their maintenance [8]. Paper [9] indicates the need for the production of concentrated berry products to obtain functionally physiological semi-finished products, which will ensure an increase in the level of the consumer's immunity. This necessitates an innovative approach to solving technological and design tasks to improve the production of concentrated semi-finished products for manufacturing functional products.

The concentration of natural semi-finished products is performed in single-case and multi-case vacuum-evaporators, rotary-film apparatus and drying chambers [10]. Most of them have industrial drawbacks: complicated temperature control, existence of thermal ways, and insufficient heat exchange surface due to the need for placing the separation zones. This causes the complexity of technical and technological service, low resource efficiency, competitiveness and quality of the obtained products. Today, to produce concentrated semi-finished products, it is appropriate to use various resource efficient structures of infrared drying chambers [11], the use of which will make it possible to obtain a powdered semi-finished product of high degree of readiness with assigned geometric dimensions and functional properties.

The studies on determining the impact of the quality of obtained products and the use of its consumption were carried out in paper [12]. Article [13] studies sensory determining of the influence of the quality of obtained products on rational consumption efficiency. It was noted that in most cases color is the first factor that influences the choice of a consumer, then flavor and physiological properties. This causes the need for maximum preservation of the original properties of natural raw materials during heat treatment, as well as their rational formulation blending in the composition in order to give an attractive color and artificially enhance physiological properties of natural raw materials. Morally obsolete technological equipment for the production of concentrated high-quality semi-finished products remains the main problem. Ukrainian vacuum-evaporators are characterized by the complex stabilization of thermodynamic parameters: pressure and temperature in the working chamber of the unit. This greatly affects the quality of the obtained products, causing the need to improve the methods for their stabilization to ensure the guaranteed quality of the food mass under conditions of uniform heating. One of the ways to solve this problem is to replace steam shells with modern electrical heating elements that are able to provide a high-quality level of temperature stabilization during concentration and to enhance the operational performance of the obtained equipment.

Paper [14] deals with the issues of the technology of selective energy supply in the concentration of food solutions. Considering the material contained in the paper enabled the authors to create modern low-heat design of the vacuum-evaporator, in which the process can be implemented using the temperatures of up to 35 °C. However, the complexity of maintenance of electromagnetic generators requires the use of the qualified personnel and complicates the operation of the unit. So, the problem of finding innovative modern methods for heating vacuum-evaporators remains unresolved.

The issues related to the influence of the concentration process on chemical, rheological, microstructural and thermal properties of food raw materials, including pear syrup, described in article [15], remain open. The above research results prove the necessity to determine structural and mechanical properties of raw materials during the concentration, since this will ensure a high-quality structural approach to the implementation of heat and mass exchange treatment and will allow the enhancement of the structural component of the process. Thus, the research of the authors [16] determined the behavior of the flow of baby puree based on plants at different temperatures (5... 65 °C), focusing on their time properties in the range of shear rate (5... 200 s^{-1}). In article [17], the effect of pH, temperature and addition of glucose on the rheological behavior of fruit puree from peach, papaya and mango was found. That proves the need to study structural and mechanical characteristics, both in terms of the product quality and for the purpose of reliable calculation of the nodes of the designed unit.

The research into the development of the method for low-temperature concentration of apple juice, including freezing, as described in [18], determines the need for low-temperature treatment of raw materials with clear stabilization of the temperature field. This, in turn, preliminarily proves the appropriateness of the use of modern heating elements with the high-quality temperature control.

Modern solution on the implementation of the concentration process is presented in paper [19]. It is a system of juice concentration with the closed cycle, provided by the liquid dried layer. Barberry juice was used for the research and compared with the usual concentration process. The non-glazed solar collector with the flat plate was used for the purpose of simultaneous regeneration of the drying solution. Experimental evaluation of the designed system was carried out at different flow rate of circulation air. The results showed a decrease in concentration duration from 480 min to 360 min at the flow rate of 0.014 kg/s, a decrease in dehydration efficiency by 40 % and an increase the rate of moisture evaporation by 33 %. This proves the effectiveness of the proposed system, but the issues of modernization of the existing vacuum-evaporators remains unresolved.

Thus, paper [20] provides the results of generalized heat and mass exchange treatment indicating the undesirable formation of the film during boiling. This is due to overheating of surface layers and a rapid change in physical and chemical properties of raw materials, thus of its quality. To prevent this, it is proposed to increase the heat transfer surface by ensuring the heating of a stirring device and increasing the heat transfer surface. This proves the relevance of the research in this direction.

The modern design and technological solution for improving the basic structures of vacuum-evaporators is to increase heat transfer surfaces, which will provide resource efficiency, specifically, a decrease in process duration and structural metal capacity of the unit, enhancement of the competitiveness of obtained high-quality concentrated organic semi-finished products, which can act as additives in the production of new products. In particular, the introduction of concentrated semi-finished products to the formulation composition of confectionery and bakery products can ensure the enhancement of food and biological value [21].

In paper [22], the expediency of processing fruit and berry raw materials into the concentrated semi-finished product with its subsequent introduction to the formulation of food products was analyzed. This solution ensured an increase in the nutritional value of finished products, thereby proving the need to find the ways to improve the concentration process, first of all, due to the structural improvement.

Our analysis has revealed the main problematic components of production of high-quality concentrated semi-finished products. These include the issues related to the stabilization of thermal influence (pressure – temperature), temperature of treatment and deforming forces during stirring raw materials, as well as substantiation of technological modes in general. It is also necessary to take into account the structural and mechanical properties of raw materials, their components and disperse phase in general. Solution of the mentioned structural and technological drawbacks during improving and designing modern equipment will allow ensuring the optimum concentration process with reduced metal capacity, duration of treatment and will improve the operation conditions. The ways to eliminate these shortcomings can be the replacement of a heating steam shell with low-inertia electric heaters, increasing the heat transfer surface, improving the stirring device and ensuring its heating. Improvement of the basic assembly of MZS-320, most often used at canning enterprises in Ukraine, due to an increase in the heat transfer surface will increase resource efficiency of processing raw materials, ensure the proper quality of the obtained semi-finished products and their competitiveness.

3. The aim and objectives of the study

The aim of this research is to improve the vacuum-evaporator by increasing the heat exchange surface for manufacturing food semi-finished products of high degree of readiness with determining the effectiveness of the design and technological solution that was made.

To achieve the aim, the following tasks were set:

– to develop the improved model design of the vacuum-evaporator with the increased heat transfer surface;

– to conduct the experimental and calculation research using the model structure of the vacuum-evaporator with the increased heat transfer surface (VEHS) to prove its effectiveness.

4. Materials, methods to study concentration of organic raw materials, and experimental setup

Implementation of these tasks according to the purpose of the research was carried out at the Scientific and research center "Innovative biotechnologies and equipment for making food products with high wellness properties" of Kharkiv State University of Nutrition and Trade (Ukraine). Experiments were conducted on the developed improved model structure of the VHES. The paper provides a detailed description of the experimental model of the VHES, as well as materials and methods for studying concentration. During this heat and mass exchange process, the standard calculation and experimental procedures with the use of automatic measuring devices of the "OVEN" company (Ukraine) were used.

Rheological properties of the model samples of puree were determined at the rotary viscosimeter "Reotest-2" in the cylindrical measuring device on Cueto.

5. Vacuum-evaporator with increased heat transfer surface to implement heat and mass exchange process

5. 1. Development of the improved model design of the vacuum-evaporator with increased heat transfer surface

To ensure the improvement of the VEHS, the main design and technological drawbacks existing in the Ukrainian market of vacuum-evaporators were preliminarily taken into account, specifically:

– considerable metal and energy capacity of the network of the systems of steam supply, specifically, the existence of a steam shell in the units;

– duration of the technological process of heat and mass exchange treatment under conditions of using the standard heat exchange surface and the design of a stirrer.

To eliminate the above shortcomings, the design and technological solution to increase the heat transfer surface by upgrading the design of a stirrer was proposed. In addition, the replacement of the steam shell with modern electric heaters was foreseen.

To solve the first task of the research, the model of the design of vacuum-evaporator with the increased heat transfer surface (VEHS) with a vertical working technological capacity 1 was improved (Fig. 1). The model is designed for concentration. In order to reduce metal consumption, heating is implemented only by the flexible film resistive electric heater of the radiation type with the thermal insulating outer surface 2 (FFREhRT) [23]. The use of the electric heater does not require an additional use of steam, existence of any heating shells, piping networks and heat generators.

The upper part of the unit is a heat-insulated separation space for condensation and removal of the secondary vapor. The lid of the unit 3 has a standard control and safety armature 4, mounted in the basic assembly of the vacuum-evaporators of the MZS brand, including observation window 5.

The heat exchange surface is increased as a result of the improvement of the design of the stirring device 6 by its heating of the FFREhRT and placement of six flow separators 7. The improvement of stirring the on-wall layer of the raw material on the main surfaces of concentration (the cylindrical wall and the bottom) was provided by springing of loaded ribs 8. In this case, six flow separators provide intensive stirring the internal mass of concentrated raw materials. Heating of the stirring device 6 is powered due to the hollow inner space and contact platform 9 in the upper part of the unit. The proposed design solution allowed obtaining and increasing the useful heat exchange surface by 0.45 m^3.

The VEHS is unloaded by the automatic device 10, mounted in its lower part around the rotating shaft of stirring device 6, which allows automatic opening of the lock shutter 11. This is implemented by the removal of concentrate by guides 12 to further realization of the semi-finished product.

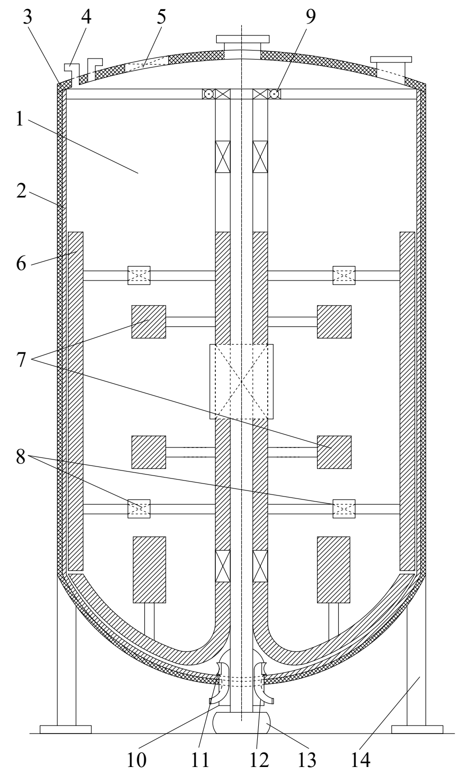

Fig. 1. Diagram of the improved model vacuum- evaporating unit with increased heat exchange surface (VEHS): 1 — vertical working technological capacity; 2 — flexible film resistive electric heater of the radiant type with heat-insulating outer surface (FFREhRT); 3 — unit lid; 4 — control and safety fittings; 5 — observation window; 6 — improved stirring device; 7 — flow separators (6 pcs); 8 — springing ribs; 9 — contact platform of power of the FFREhRT; 10 — unloading automatic device; 11 — automatic lock shutter; 12 — guides for product removal; 13 — electric drive with worm gear; 14 — racks

The improved stirring device 6 is rotated by the electric drive with the worm gear 13. The VEHS is placed on racks 14. The obtained secondary vapor in the process of boiling arrived by the pipeline to the casing-pipe condenser or was used to heat the technical fluid according to the sanitary needs of the line. The principle of the implementation of the technological process in the VEHS is typical of the basic assembly MZS-320, which is distinguished by the heating system with increased heat exchange surface and its decreased duration.

5. 2. Experimental and calculation studies of the model design of the vacuum-evaporator with increased heat exchange surface

At the second stage of the task for testing the improved design of the VHES, the structural-mechanical characteristics of the puree-type semi-finished product, depending on temperature, were determined (Fig. 2), since coordination of the interaction of rheological properties with design features (a stirring device) is an integral part during boiling of plant raw materials. Analysis of the obtained data proves a decrease in boundary shear stress within measurement boundaries with the increase in temperature by six times. If t=10 °C, θ_0=79 Pa; relatively t=70 °C, θ_0=12 Pa. This also allowed determining the dependence of the value of effective viscosity (η_{ef}) on temperature. Thus, for t=10 °C η_{ef}=392 Pa·s, and for t=70 °C η_{ef}=2 Pa·s. It should be noted that an increase in temperature causes significant deterioration of all rheological characteristics of decreasing the indicators of dynamic viscosity of the puree-like semi-finished product.

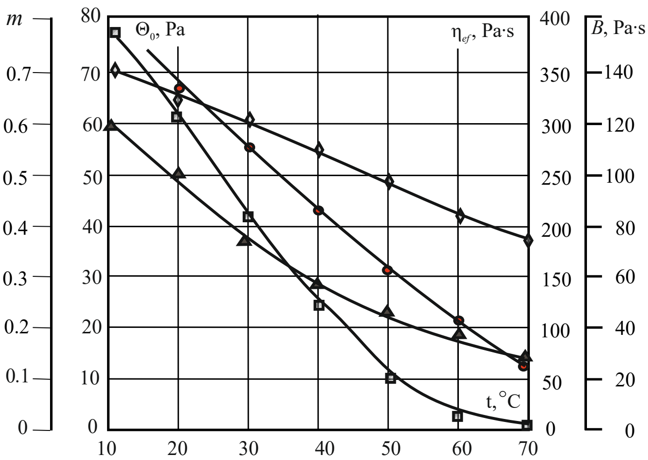

Fig. 2. Dependence of structural-mechanical properties of puree on temperature: ● – boundary shear stress (θ_0); ■ – plastic deformation (η_{ef}); ▲ – effective viscosity at unity value of velocity gradient (B); ♦ – rate of structure ruining (m)

In the course of testing the model sample of the VEHS during concentration (50...65 °C), it was determined that shear rate was 0.5...2.5 s^{-1} and effective viscosity was within 2.0...4.5 Pa·s. Thus, the rheological properties of the puree-like semi-finished product were established according to the pre-selected mode parameters.

To determine the effectiveness of the proposed design and technological solutions in accordance with the second task, kinetics of heating the puree-like semi-finished product in the improved VEHS and the basic structure of MZS-320 was preliminarily established (Fig. 3). The analysis of the presented curves proves the effectiveness of the proposed design and technical solutions in terms of increasing the heat exchange surface. The duration of achieving the stationary mode (52 °C) of the improved VEHS is 575 s, so a decrease in the duration of achieving the stationary mode by 29 % compared to the prototype is ensured. This proves a decrease in the heating duration and, respectively, in the duration of processing the puree-like semi-finished product due to increasing the heat exchange surface.

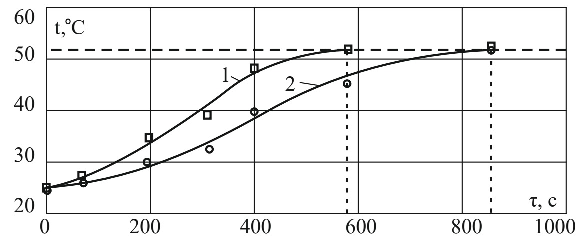

Fig. 3. Kinetics of heating the puree-like semi-finished product: 1 – VEHS; 2 – MZS-320

Due to a decrease in the energy consumption component, the improved VEHS, in addition to resource efficiency, is characterized by environmental friendliness. This is due to a decrease in the volumes of consumption of electricity of thermal power plants, resulting in reduced emissions of CO_2 into the atmosphere.

Table 1 shows the comparative characteristic of the basic structure of the MZS-320 and the improved model prototype VEHS.

Bases on the analysis of data from Table 1, the effectiveness of the proposed structural solution to increase the heat exchange surface and increase resource efficiency in general was proved. This is proved by the decrease in the weight of the unit by 35 %, in specific metal capacity of the unit – by 42 %, in the duration of treatment by 12 %; by an increase in the heat exchange surface by 12 %. According to other design and technical indicators, the improved VEHS also has significant advantages in maintenance and operation. It ensures the solution of the main problem of vacuum-evaporators in terms of stabilization of heat supply on the entire surface of heat exchange. An increase in the heat exchange surface ensures a decrease in the duration of achievement of the stationary mode (heating up to 52 °C within 575 s) and thermal treatment in general (Fig. 3), making it possible to consider indirectly obtaining high-quality concentrates. Boiling within 50...65 °C ensures maximum preservation of vitamin C, and consequently other physical-chemical compounds.

Table 1

Comparative characteristics of improved VEHS compared to the basic structure MZS-320

Power consumption	MZS-320	VEHS
Weight of the unit	m*=1,700 kg	$m=m_{MZS\text{-}320}-m_{shirts}+m_{FFREhRT}$=1,700–620+20=1,100 kg
Specific consumption	$q_{sp}=Q/m$=1,120,798/1,600=700 kJ/kg	$q_{sp}=Q/m$=651,137/1,600=406 kJ/kg
Treatment duration	$\tau=Q/F\cdot k\cdot\Delta t$=1,191,033/3.7·1,454·91=4,065 s	$\tau=Q/F\cdot k\cdot\Delta t$=1,969,245/4.15·1,454·91=3,586 s
Area of heat exchange surface	F*=3.7 m^3	$F=F_{MZS\text{-}320}+F_{stirrers}$=3.7+0.45=4.15 m^3
Unit heating	$Q_{uh}=m_1\cdot c_c\cdot(t_2'-t_1')+m_1\cdot c_c\cdot(t_2''-t_1'')=900\cdot 0.48\times$ $\times(52-25)+620\cdot 0,48\cdot(142+80)=33,452$ kJ	$Q_{uh}=m_1\cdot c_c\cdot(t_2'-t_1')=900\cdot 0.48\cdot(52-25)=11,664$ kJ
Product heating	$Q_{ph}=m\cdot s\cdot(t_k-t_n)$=1,600·3.7·(52–40)=2,552 kJ	$Q_{ph}=m\cdot s\cdot(t_k-t_n)$=1,600·3.7·(52–40)=72,552 kJ
General amount	Q_{ga}=2,053,504 *kJ*	Q_{ga}=2,009,433 kJ
Specific metal capacity of the unit	$m=M/F$=1,700/3.7=459 kg/m^2	$m=M/F$=1,100/4.15=265 kg/m^2

*Note: *Comparative data of basic structure of MZS-320 were taken from literature source [24]*

During the studies, the main technical parameters of the improved VEHS were determined (Table 2).

Table 2

Technical parameters of the improved vacuum-evaporator with increased heat exchange surface

Technical parameter	Value
Volume of technological capacity, m^3	1.0
Power of the rotation drive engine, kW	0.35
Temperature of the heat exchange surface from FFREhRT, °C	up to 150
Rotation rate of the stirrer, min^{-1}	47
Weight (unloaded), kg	1,100

During the experimental and practical studies, the main technical and operational indicators of the improved FFREhRT, which prove the efficiency of its further implementation, were obtained. The result will be the improvement of the design and technological parameters of the existing lines of concentration of natural raw materials. In addition, resource efficiency and uniform impact on the raw material with clear stabilization of the temperature field due to the use of the FFREhRT will be ensured. This, in turn, will provide high quality of the obtained semi-finished product and price and good value for money.

6. Discussion of the obtained results of concentration of organic raw materials in the improved vacuum-evaporator with the increased heat exchange surface

The main problem during manufacturing high-quality concentrates is the use of obsolete technological equipment with complex stabilization of thermodynamic parameters: pressure and temperature in the working chamber of the unit. This largely affects the quality of the obtained products. Today, research into heat exchange during boiling of natural raw materials, specifically, vegetable juice, is going on. The stirring device with steam heating of the heat transfer shell and simultaneous vapor forcing into the stirring device was improved [25]. The drawback of the steam heating system is metal intensity, inertial non-uniformity of heating. The decision to force steam into the lower part of the hollow stirring device is likely to result in a hydro shock due to the steam condensation during heating of vegetable juice. All this greatly complicates the operation and automation of the technological process and the unit in general. One of the ways to solve this problem is to replace the steam shells with a modern electric heater with a high-quality level of temperature stabilization during concentration. The use of the FFREhRT allows eliminating the heating steam shell, the network and the steam generator.

Providing heating of the improved stirring device with six flow separators – FFREhRT – increases the total useful heat exchange surface by 0.45 m^3 (Table 1). An increase in heat exchange surface ensures a decrease in duration of reaching the stationary mode (52 °C – 575 s) by the VEHS and thermal treatment in general (Fig. 3), making it possible to consider indirectly that high-quality concentrates are obtained. Boiling within 50...65 °C provides maximum preservation of vitamin C, and consequently, other physical and chemical compounds.

The issues of the introduction of low-temperature boiling and determining structural and mechanical properties under conditions of stirring remain open today. This caused the need to study structural and mechanical properties during testing the VEHS with an improved stirring device. It was found that in the range of 10...70 °C a decrease in shear stress from 79 to 12 Pa is ensured. In this case, effective viscosity at t=10 °C is η_{ef}=392 Pa·s, at t=70 °C η_{ef}=2 Pa·s (Fig. 2). Comparison of the kinetic curves of heating the puree-like semi-finished product of the improved VEHS with the prototype (MZS-320) proves the reduction of duration of reaching the stationary mode by 29 % (Fig. 3), in particular, efficiency of structural and technical indicators: a decrease in the weight of the unit by 35 %, of specific metal capacity by 42 %, of treatment duration by 12 %. The heat exchange surface increased by 12 % (Table 1).

The main advantage of the design and technological solution is the introduction of modern engineering developments of the intensification of concentration processes. This will lead to the improvement of the technical parameters of vacuum-evaporators, an increase in their competitiveness and a decrease in the cost with the guaranteed quality of obtained products. It should be noted that the effectiveness of the VEHS is obtained through the use of FFREhRT, which in the complex of the implemented design solutions will provide for clear stabilization of thermal influence, simplicity of maintenance and simplification of the automation of boiling process.

Implementation of VEHS is recommended only in the proposed temperature ranges (50... 65 °C) to ensure resource-efficient processing of raw materials into high-quality concentrated semi-finished products of the high level of readiness. It the recommended parameters are not taken into account, it will lead to the inevitable decrease in the quality of obtained products.

In future, it is planned to conduct detailed research into the implementation of the concentration process in the improved unit. The possibility to develop the generalized structure of changes of structural and mechanical properties depending on the kind of raw materials and technological modes will be determined. The impact of the implementation of the proposed solution on the obtained quality of concentrated semi-finished products of high-degree of readiness will be studied by determining the change in color formation of products.

7. Conclusions

1. Heating the technological capacity of the developed model of the design of the vacuum-evaporator with the increased heat exchange surface by the flexible film resistive electric heater of the radiation type with the heat insulating outer surface was proposed. The stirring device is heated in the same way, which ensures an increase in the useful heat exchange surface by 0.45 m^3.

2. The determined structural and mechanical properties prove an increase in boundary shear stress within the measured limits: if t=10 °C, θ_0=79 Pa; respectively t=70 °C, θ_0=12 Pa. Effective viscosity at t=10 °C is η_{ef}=392 Pa·s, at t=70 °C η_{ef}=2 Pa·s. In the course of testing the model sample of the VEHS during concentration (50...65 °C), shear rate was established: 0.5...2.5 s^{-1}. Effective viscosity

ranges within 2.0...4.5 Pa·s. Analysis of the kinetic curves of heating the puree-like semi-finished product reveals that the improved VEHS is characterized by a decrease in duration of achieving the stationary mode by 29 % compared to the prototype (MZS-320). The effectiveness of the design and technical solution is proved by a decrease in the weight of the unit by 35 %, specific metal capacity by 42 %, processing duration by 12 %. The heat exchange surface increased by 12 %.

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