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# IMPROVEMENT OF A SCRAPER HEAT EXCHANGER FOR PRE-HEATING PLANT-BASED RAW MATERIALS BEFORE CONCENTRATION

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***На підприємствах харчових виробництв під час підігрівання рідких та пастоподібних продуктів широким попитом користуються скребкові теплообмінники, які завдяки високої інтенсивності термообробки дозволяють зберігати початкові властивості сировини, що переробляється. Більшість теплообмінників мають нестабільну стабілізуючою дією: тиск пари – температура, що призводить до псування сировини, в умовах значної енерго- та металоємності. Усунення цих недоліків можливо при використанні в якості нагрівача в вдосконаленому скребковому теплообміннику температуро-стабільного гнучкого плівкового резистивного електронагрівача випромінювального типу. В якості перемішуючого органу теплообмінника запропоновано використовувати шарнірну лопать зі зрізаючої крайкою (з відбивальною гріючою поверхнею) для отримання рівномірного розподілу товщини шару продукту на робочій поверхні й додаткового її підігрівання відбивальною поверхнею лопаті. Теплообмінник має можливість встановлення охолоджуючої оболонки з кільцевими каналами для проходження холодоагенту, яку розміщено на зовнішній поверхні безтермоізоляційного гнучкого електронагрівача. Таке рішення забезпечує можливість охолодження до –15 °С та одночасно виступає в якості додаткової повітряної теплоізоляції при відсутності носія в ній.***

***Визначено рівномірність розподілу теплового потоку на нагрівальній поверхні модельної конструкції вдосконаленого апарата (60,3…60,5 °С) та на відбивальній поверхні шарнірної лопаті зі зрізаючою крайкою (60,0…60,3 °С). Встановлено сумарну товщину шару рідини в залежності від частоти обертання валу запропонованої шарнірної лопаті зі зрізаючою крайкою, яка складає: при 50 хв$^{-1}$ – 2,65 мм, при 350 хв$^{-1}$ – 1,5 мм, в порівнянні зі стандартною шарнірною лопаттю (товщина шару від 5,0 мм до 1,5 мм) за витратою продукту W=50 л/год. Удосконалений скребковий теплообмінник характеризується зменшенням в 1,48 раз питомих витрат енергії (170,4 кДж/кг), затрачуваної на нагрівання одиниці об'єму продукту в порівнянні з підігрівачем з паровою оболонкою – 252,6 кДж/кг. В результаті досліджень підтверджено ефективність використання удосконаленого скребкового теплообмінника та запропоновано його конструкційна схема***

***Ключові слова: підігрівання, скребковий теплообмінник, зрізаюча лопать, теплопідведення, гнучкий плівковий резистивний електронагрівач випромінювального типу***

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## 1. Introduction

In many countries, the development of wellness functional nutrition is one of the main areas of scientific and practical research in the food industry, aimed to provide consumer needs. The rational use of natural raw materials provides a variety of the range of functional nutrition, including infants [1]. Specifically, the quality of baby food ensures the development and formation of the nation's health. The utilization of natural raw materials to produce functional foods predetermines reasonable approaches to the ways of its processing, taking into consideration the starting, phased, and resulting properties [2]. These including the production of juices, jams, concentrated pastes, dried products, and powders with their subsequent use as natural semi-finished products with a high degree of readiness [3, 4]. In particular, there is a widespread tendency to introduce to the formulations of various confectionery and bakery products the natural semi-finished products for enriching the food and biological value [5, 6].

Thermophysical properties of plant-based raw materials largely affect the quality of heat-and-exchange operations, including at heating, pasteurizing, aging, etc. The most influential properties of raw materials include viscosity, crystallization, phase transformations (during extraction), the presence of a more or less heterogeneous structure, as well as stringiness [7]. At the same time, most heat exchanging equipment is obsolete and low resource-efficient, including widely used scraper heat exchangers. Most of them are characterized by difficulties related to stabilizing the vapor pressure in shells and the resulting temperature of the treated raw materials, without their burning and, consequently, damage. Solving these issues requires detailed scientific and practical research into the ways to improve equipment for pre-heating plant raw materials at maximum preservation of their original properties.

One of the directions to address these issues is to determine and ensure the stabilization of temperature parameters in the preliminary heating of raw materials before concentrating at the improved heat exchanger when making high-quality foods of natural origin.

## 2. Literature review and problem statement

The expansion of a range of competitive products from plant raw materials depends on carrying out technological operations based on resource-efficient equipment and providing high quality properties [4]. Thus, work [8] emphasizes the importance of conducting heat-and-exchange processes at the pre-treatment of plant raw materials, which is an important factor of influence on the resulting quality of products received. Improvement of product quality requires constant development and refinement of a generalized matrix for the creation of innovative technological equipment with clearly stabilized heat-mass exchange properties, taking into consideration different physiological properties of raw materials and the ultimate purpose of their use [9, 10].

Paper [11] reports the improved design of a vacuum evaporation machine for the production of high-quality fruit and vegetable paste-like semi-finished products. The advantage of the device is the replacement of the steam component of heating, implying the elimination of metallic pipelines, with clearly stabilized electrical heating. The FFREhRT heater (flexible film resistive electric heater of the radiating type) was implemented in [12], which makes it possible to simultaneously increase the heat exchange surface by heating the agitator. Work [13] noted the effectiveness of eliminating the heating shell with a turbulized heat-carrier in favor of the electric heating of the working chamber of a rotary film apparatus, thereby reducing the machine's metal capacity. Further studies, given in [14], emphasize the effectiveness of improving the heating of the apparatus providing acceptable thermal regimes for the production of high-quality multicomponent natural pastes with maximum preservation of attractive color properties. At the same time, there are partially unsolved issues regarding the uniformity of the distribution of a raw material layer during stirring at the heat-mass-exchange treatment and the possibility to use the above-mentioned equipment in a single hardware-technological complex to achieve resource efficiency in general.

Studies [15, 16] report the results of designing an energy-efficient IR dryer and the influence of its sparing regimes of IR-drying on the color of dried blended powders based on pastes at all stages of production.

The use of drum dryers is characterized by the complexity of control over a change in the mass of raw materials depending on heat removal, which significantly affects the efficiency and quality of the process [17]. Therefore, there is a need to update and find the newest ways to implement the thin-film drying of raw materials taking into consideration the impact of the entire technological process. At the same time, works [15–17] fail to fully disclose the issues of the appropriateness of preliminary operations and the reasonable effects of thermal regimes on the quality obtained, due to peculiarities in the original properties of raw materials being processed. The authors did not fully take into consideration the use of modern heat-mass exchange equipment for the production of quality functional products [18].

The commonly used heat exchangers for the treatment of high-viscous food substances in most cases are characterized by the duration of technological processes, which predetermines the expediency of the development and implementation of generally understandable mechanisms for the optimization of heat-and-mass exchange processes in general [19, 20]. Work [21] reports research into the heat transfer of Newtonian liquids in a scraper heat exchanger depending on the motion speed and properties. At the same time, further investigations are carried out in the direction of increasing heat transfer depending on the design of the cutting blade and the areas of current. In addition, paper [22] describes the velocity profiles for different current areas, velocities, and functions of the flow, forces operating on the surface and blades, leaving out the determination of optimum energy consumption.

Such a solution complicates the process of modeling and substantiation of the optimal geometric dimensions of the machine taking into consideration the structural properties of raw materials, requiring further research in this direction in terms of ensuring the uniform distribution of raw materials. Thus, work [23] gives the isometric fields of suspension movement, establishing the vortex flow from the blades, with the absence of research results that would have ensured the uniformity of the distribution of raw materials depending on rotation velocities.

Study [24] considers a model of the hydrodynamic process and heat transfer in a scraper heat exchanger taking into consideration the action of various forces, based on the derived results of changes in the limits of Reynolds and Nusselt numbers. Work [25] gives a hydrodynamic model of raw material movement taking into consideration alternative data (theoretical-literary) and experimental data, thus emphasizing the considerable effect exerted on the hydrodynamic flow rate model by the properties of the heating surface and the structure of raw materials [26]. This, in turn, makes it possible to confirm the importance of research into hydrodynamic models for the improved scraper heat exchangers aimed to substantiate the rational heat-and-mass exchange parameters and the frequency of blade rotation under conditions of ensuring the uniformity of raw material distribution.

At present, small enterprises that process plant raw materials apply cooking boilers, heaters, etc. for implementing heating processes. Therefore, when comparing the efficiency of the heating process, we chose a vacuum-evaporation plant designed for boiling and warming at simultaneous mixing as the most widespread one in the processing of plant raw materials. Most equipment, applied by canning enterprises, is characterized by high energy- and metal capacity due to the use of intermediate heat carriers, pipeline networks, as well as heat-generating devices, thereby reducing the resource efficiency of production. Such a heat removal technique is poor at stabilizing heat flows, resulting in overheating of a certain volume of raw materials processed. There are also complications to ensure the uniformity of a raw material's layer distribution over the entire surface of the plant, without taking into consideration the design features of mixing devices and the structure of raw materials, disrupting the uniformity of its heating, and reducing the resulting quality. Therefore, further studies should be directed towards resource-saving in the pre-heating process in a scraper heat exchanger while maintaining the uniformity of heating the working surfaces heated by FFREhRT. It is important, in this case, to ensure the uniformity of the distribution of a layer of raw materials under conditions of moving depending on the design features of blades.

## 3. The aim and objectives of the study

The aim of this study is to improve the scraper heat exchanger (SH) for pre-heating plant raw materials before concentrating based on determining the uniformity of temperature distribution and a layer of raw materials.

To accomplish the aim, the following tasks have been set:

– to determine a temperature field under conditions of an altered technique of heat removal and the uniformity of a raw material layer from the hinge blade with a cutting edge at the working surface of the model structure of the scraper heat exchanger;

– to determine the possibility of increasing the efficiency of the scraper heat exchanger by improving the heat removal technique and the design of the hinge blade;

– to offer an improved structure of the scraper heat exchanger.

## 4. Materials, methods of research into the pre-heating of plant raw materials, and an experimental installation

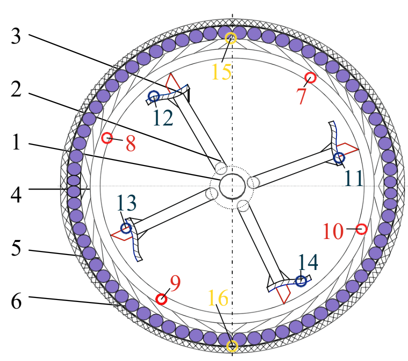
We implemented the structural technological tasks set in this work at the Scientific-Research Center "Innovative biotechnologies and equipment for the production of foods with high wellness properties" of Kharkiv State University of Food and Trade (Ukraine). The study involved the improved model of a scraper heat exchanger in which the working volume was heated by FFREhRT [12]; in this case, a batch heater was used as a comparable structure.

During our experimental and computational studies of the model structure of a scraper heat exchanger (SH) we compiled its detailed description, methods of investigating the pre-heating of plant raw materials. A mixture of puree of the following formulation was used as an example: apple – 60 %; apricot – 30 %; cornel – 10 % with a solids content (DS) of 11 %. Raw materials were heated to a temperature of 65 °C at a variable shaft rotation frequency in the range 25...350 min$^{-1}$, applying different designs of hinge blades. We determined a change in the thickness of a raw material layer on the working surface by a contactless method using the frequency meter CHZ-57 (Ukraine). Automatic control over a temperature field and measurement in real time was carried out by a measuring device made by the company "OVEN" (Ukraine); it was connected to the thermocouples placed in the SH model structure; standard estimation and experimental procedures were used.

## 5. A scraper heat exchanger for pre-heating plant raw materials

### 5. 1. Determining a temperature field and a layer of raw materials on the working surface of the model structure of a scraper heat exchanger

We determined the distribution uniformity of the temperature field induced by FFREhRT using a model structure of the improved SH. Fig. 1 shows the cross-section of the heat exchanger with the sites of thermocouples connected to the multichannel channel device TRM 16. The SH model hosts, on rotational shaft 1, using hinges 2, the blades with a cutting edge and reflective surface 3, which, during the shaft rotation, create a moving layer of the product at the working surface. The working surface is heated by FFREhRT 4; cooling is enabled when using shell 5. The casing of the SH model is equipped with thermal insulation. During our study, the temperature regime was maintained at 60 °C assuming a TRM 16 error of 0.3 °C.

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| | | | |
|---|---|---|---|
| 7 | 60,5 | 12 | 60,0 |
| 8 | 60,3 | 13 | 60,3 |
| 9 | 60,4 | 14 | 60,2 |
| 10 | 60,3 | 15 | 61,1 |
| 11 | 60,1 | 16 | 52,2 |

Fig. 1. Schematic of the cross-section of a model structure of the scraper heat exchanger: 1 – rotary shaft; 2 – hinge connections; 3 – hinged blade with a cutting edge; 4 – flexible film resistive electric heater of the radiating type with an insulation-free surface (FFREhRT); 5 – shell for the refrigerant; 6 – thermal insulating material; location of thermocouples (7–10 – outside of the heating surface in the holes of 2 mm in length; 11–14 – at the reflective surface of the blades; 15 – between the heater and the cooling shell; 16 – outside of the cooling shell)

We acquired data from the thermocouples in the SH model structure in real time using software from 10 thermocouples without loading a product. An analysis of the obtained data confirms the uniformity of the heat flow distribution over the heating surface of the plant, namely the readings from thermocouples 7–10 in the range (60.3... 60.5 °C). The data from thermocouples 11–14 (60.0...60.3 °C), confirm the uniformity of heating on the heated reflective surface of the proposed hinged blade with a cutting edge. Thermocouples 15, 16, producing the measurement data 61.1 °C and 52.2 °C, respectively, characterize slight losses into the environment when the cooling shell is filled with an air medium, which is additional thermal insulation of the device. In this case, the discrepancy between all thermocouples during measurements was within the limits of the error, which confirms the uniformity of the temperature field when applying the modified heat removal technique, namely FFREhRT, and provides the possibility of its further use for the improvement of SH and other thermal devices.

When treating a liquid in SH, the effectiveness of the heating process, in addition to the heat supply technique, is significantly affected by the structure of a stirring device, which forms a movable layer of liquid on the working surface. Given this, it was proposed to compare the basic design of a hinged blade (Fig. 2, *a*) with the suggested hinged blade with a cutting edge (Fig. 2, *b*, position 1) and the reflective heating surface, position 2. When compared, we derived the dependences of the average thickness of the liquid layer δ on the shaft rotation frequency in the model of the improved SH (Fig. 3) while using the blades shown in Fig. 2.

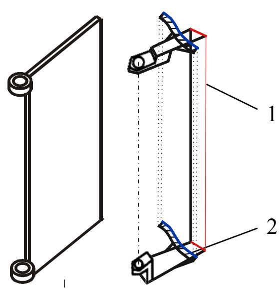


Fig. 2. Schematic: *a* — basic hinged blade; *b* — proposed hinged blade with a cutting edge and a reflective heating surface; 1 — cutting edge; 2 — reflective heating surface

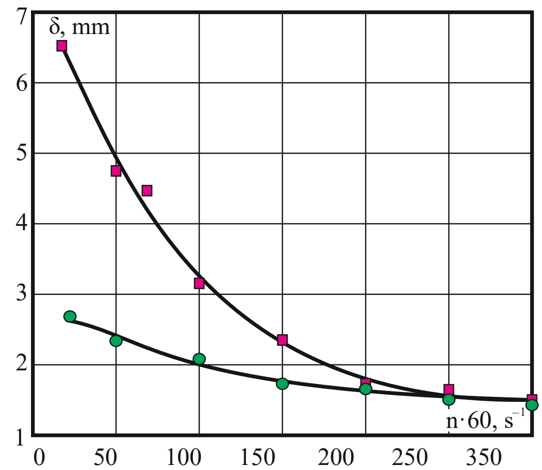


Fig. 3. Dependence of the mean thickness of a layer of liquid δ on shaft rotation frequency *n* (*W*=50 l/h): ■ — hinged blade; ● — hinged blade with a cutting edge

The data obtained indicate that the hinged blade has a total thickness of the layer, which depends on shaft rotation frequency and, at revolutions 50 $min^{-1}$, is 5.0 mm, and at 350 $min^{-1}$ – 1.5 mm, at consumption *W*=50 l/h. For the hinged blade with a cutting edge, the total thickness of the layer is in the range of 2.65...1.45 mm, respectively, thereby ensuring improved efficiency of mixing the uniform layer of raw materials, preventing the formation of soot on the working heated surface.

**5. 2. Determining the efficiency of the improved scraper heat exchanger due to the improved heat removal technique and the design of the hinged blade**

To determine the effectiveness of the improved scraper heater, we compared the characteristics of energy consumption for the pre-warming of the puree-like mixture based on apples, apricots, and cornel, before the concentration Table 1. In our calculations, the input data are the product consumption, the specific heat capacity of raw materials, and of the device's working surface material (stainless steel), as well as the structural parameters of the basic heater and SH (weight, area of the heating surface). The improved SH was compared to the preheater with a steam shell.

Table 1

Comparative characteristics of the improved SH compared with a steam-shell heater

| Energy loss | Heater with a steam shell | scraper heat exchanger (SH) |
|---|---|---|
| Device weight | $m$*=1,259 kg | $m$=32 kg |
| Specific consumption | $q_{sc}=Q_{ta}/m$=126,320.8/500=252.6 kJ/kg | $q_{sc}=Q_{ta}/G$=52,843/0.31=170.4 kJ/kg |
| Specific consumption | $q_{sp}=Q_{ta}/m$=126,320.8/500=252.6 kJ/kg | $q_{sp}=Q_{ta}/G$=52,843/0.31=170.4 kJ/kg |
| Treatment duration | $\tau_{td}=Q/F\cdot k\cdot\Delta t$=97,722/2.2·1,454·77=397 s | $\tau_{st}=L_{ap}/\upsilon_{sk}$=1.0/0.11=9.1 s |
| Heat exchange surface area | $F$*=2.2 $m^2$ | $F=F_{st}+F_{stirrers}$=0.63+0.04=0.67 $m^2$ |
| Device heating | $Q_{dh}=m_1\cdot c_{st}\cdot(t_k-t_n)+m_2\cdot c_{st}\cdot(t_p-t_n)$=670·0.48* *(65–20)+455·0.48·(142–20)=41,116 kJ | $Q_{dh}=m_{SH}\cdot c_{st}\cdot(t_p-t_n)$=32·0.48·(80–20)=921 kJ |
| Product heating | $Q_{ph}=m\cdot c\cdot(t_k-t_n)$=500·3.7·(65–20)=83,250 kJ | $Q_{ph}=G\cdot c\cdot(t_k-t_n)$=0.31·3.7·(65–20)=51.615 kJ/s |
| Total amount | $Q_{ta}$=126,320.8 *kJ* | $Q_{ta}$=52.843 kJ/s |
| Specific metal capacity of the device | $m=M/F$=1,259/2.2=572.2 kg/$m^2$ | $m=M/F$=32/0.67=47.7 kg/$m^2$ |

*Note: *Comparative data on the basic design MZ-2S-241aM are borrowed from ref. [27]*

Comparing the obtained estimation data, it can be concluded that the main indicator of resource efficiency, namely the specific energy consumption on heating a unit of product in SH, is 170.4 kJ/kg (Table 1), compared with the basic device, 252.6 kJ/kg, which characterizes the reduction of consumption by the improved SH by 1.48 times. This ensures the following duration of thermal treatment: SH – 10 s and 7 min in the steam device, respectively, which provides a significant reduction of thermal effect on the raw materials when executing a continuous process involving the use of FFREhRT. The obtained estimation results, the parameters of the uniformity of temperature field distribution from FFREhRT and the uniformity of a raw material layer confirm the efficiency of the proposed solutions for SH improvement.

**5. 3. Design of the improved structure of a scraper heat exchanger**

The obtained results on determining the uniformity of temperature field distribution and a raw material layer distribution, as well as the estimation data, made it possible to propose the improved design of a scraper heat exchanger. SH is intended for the heat-mass exchange treatment of any raw material, in particular, the heating of plant-derived raw materials (Fig. 4); it has vertical operating technological capacity 1. The top of which hosts an electric motor with a worm gear 2, which transmits the adjustable variable of the rotary motion of shaft 3 (rotor) located in the center of capacity 1. Rotor 3 is connected by hinged joints 5 to the hinged blades with a cutting edge 6, which cut the processed raw materials during machine operation. A detailed view of the hinged blade with a cutting edge is shown in Fig. 2, *b*, where 1 is the cutting edge; 2 is the reflective heating surface. Reflective surface 2 is designed to stabilize the hydraulic flow after the nasal flow from the cutting edge and to press a cut layer by reflective surface 2, which is heated additionally by FFREhRT. The coating of surface 2 has non-stick properties for preventing sticking and raw material burning.

The bottom and top parts of technological capacity 1 host inlet branch pipes 7 (for direct feeding of raw material to distributing disk 4) and for discharging it 8. When a raw material passes distributing disk 4, a film is formed, adjusted for thickness (from 2 to 5 mm), which is picked up by the centrifugal force of the hinged blades with a cutting edge 6, ensuring its thermal treatment due to the interaction with the heating surface and discharging it through branch pipe 8.

Capacity 1 is heated by insulation-free FFREhRT 9, by reproducing its geometric shape, providing a clear stabilized heat-and-mass exchange process – warming up. The resulting high-quality technological process makes it possible to replace the technique of the shell heating of SH (by steam or heat carriers) with electrical. It also decreases the machine's metal capacity, heating costs of heat carriers, transportation and maintenance for the implementation of cooling processes at the outer surface of FFREhRT 8. When used as a cooler, SH has thin-walled shell 11, whose inner surface is spiral. The upper and bottom part of shell 11 has branch pipes 12 and 13 nozzles for refrigerant circulation; the outer surface of shell 11 is additionally covered with insulating material 14, which is the plant's casing. It should be noted that during warming shell 11 is without a carrier, only air, which additionally performs the thermal insulating functions during the operation of FFREhRT 9.

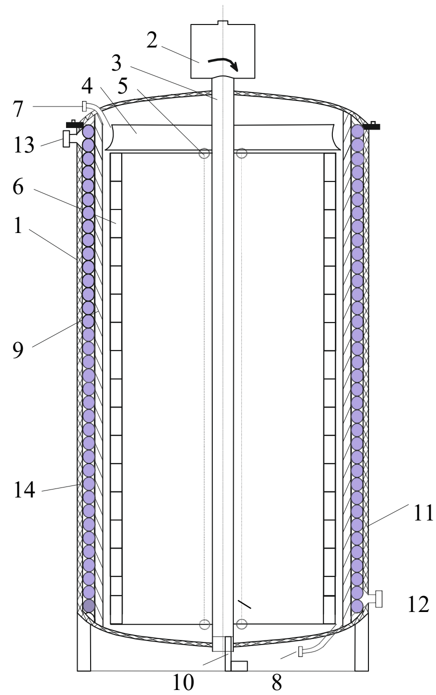


Fig. 4. Diagram of the improved model scraper heat exchanger: 1 – vertical operating technology capacity; 2 – electric motor with a worm gear; 3 – rotary shaft (rotor); 4 – distributing disk; 5 – hinged connections; 6 – hinged blade with a cutting edge; 7 – branch pipe for raw material inlet; 8 – branch pipe for raw material discharge; 9 – flexible film resistive electric heater of the radiating type with an insulation-free surface (FFREhRT); 10 – shaft hoisting mechanism; 11 – shell for a refrigerant; 12, 13 – nozzles for refrigerant circulation; 14 – thermal insulating material

The rotation of the improved stirring device 6 is enabled by an electric drive with worm gear 2. To lift stirring device 6, the bottom part hosts a mechanism for lifting the shaft 10.

The data obtained have made it possible to define the basic technical parameters of the improved SH, which were determined via practical-scientific and design methods for verifying the model structure.

Table 2

Technical parameters of the improved scraper heat exchanger

| Technical parameter | Value |
|---|---|
| Heating surface area, $m^2$ | 0.67 |
| Rotary drive motor power, kW | 1.0 |
| Temperature of the heat-transmitting surface from FFREhRT, °C | to 90 |
| Stirrer rotation frequency, $min^{-1}$ | 50...350 |
| Weight (without load), kg | 32 |

The proposed apparatus is characterized by the design and technological resource efficiency due to the implemented engineering solutions to ensure the replacement of a steam heating system, the elimination of technical networks of heat carrier pipelines. An important feature of the proposed structure of the hinged blade with a cutting edge is the constant trimming of the product layer, which prevents its burning and creates additional warming of the cut layer by a reflective surface for the additional stabilization of a raw material temperature field. In addition, it provides the improvement of operational properties, specifically automation, when using an electric heater with a clear dynamic, as opposed to the vapor supply. Therefore, the minimized temperature effect on raw materials is ensured (heating during 10 s when warming up from 20 to 65 °C).

## 6. Discussion of results of warming plant raw materials in the improved scraper heat exchanger

Implementation of the scraper heat exchanger with non-insulating electric heating by FFREhRT and the proposed design of the hinged blade with a cutting edge, which has a heating reflective surface (Fig. 4), ensures the optimum thickness of a product layer on the working surface in the uniform heating conditions. It is also possible to use the scraper heat exchanger as a cooler (–15 °C, Fig. 1, position 11), provided that the refrigerant is passing through the spiral shell. The shell simultaneously performs the role of insulation when heated. Plant raw materials are heated up to 65 °C, which ensures the maximum preservation of vitamin C, and, consequently, other physical-chemical compounds. The estimation has established a 1.48-time reduction of the specific energy consumption used for heating a unit of product volume (Table 1) when ensuring the duration of thermal treatment for 10 s, compared with the heating parameters in the steam heater (397 s).

Today, there remain issues related to implementing not only low-temperature treatment but also to ensuring the uniform agitation of the flow from blades, focusing on the feasibility of research into this area. Our study has confirmed the uniformity of heat flow distribution over the heating working surface of the apparatus and the reflective heated surface of the hinged blade with a cutting edge (60.0...60.3 °C, Fig. 1, 2, *b*). It was determined that the proposed hinged blade with a cutting edge possesses the total thickness of a liquid layer at a frequency of 50 $min^{-1}$ – 2.65 mm and at 350 $min^{-1}$ – 1.5 mm, compared to a standard hinged blade (a layer thickness is from 5.0 mm 1.5 mm) at product consumption $W$=50 l/h (Fig. 3).

The obtained results confirm the effectiveness of the implemented engineering solutions to solve a scientific and applied task of ensuring the uniformity of the distribution of temperature and a layer of raw materials in the improved scraper heat exchanger for pre-heating plant raw materials before concentrating. The proposed structure demonstrates resource efficiency (Table 1) and insignificant losses into the environment when using a cooling shell when it is filled with an air medium (data from thermocouples 15, 16 – 61.1 °C and 52.3 °C, respectively, Fig. 1).

The improved SH is recommended for the rapid warming of plant raw materials using gentle temperature modes to 65 °C, namely before the concentration, to ensure maximum preservation of their original properties. Violation of any technological parameters will inevitably lead to a decrease in the quality of the products received, as well as reduce the resource efficiency of the equipment.

Further investigations could address investigating the processes of pre-heating plant raw materials and other food mixtures for the formation of generally optimized regimes that would ensure the uniformity of distribution of raw materials and their impact on color changes as one of the factors of preserving product quality in general.

## 7. Conclusions

1. We have confirmed the uniformity of heat flow distribution over a heating surface (in the range of 60.3...60.5 °C) and over the heated reflective surface of the hinged blade with a cutting edge (60.0... 60.3 °C). In addition, the scraper heat exchanger is characterized by insignificant losses into the environment when filling a cooling shell with air medium. We have established the more even distribution of a raw material layer by the proposed hinged blade with a cutting edge, which has the total thickness of the liquid layer, at a frequency of 50 $min^{-1}$, 2.65 mm, and at 350 $min^{-1}$ – 1.5 mm, compared to a standard hinged blade (a layer thickness is from 5.0 mm 1.5 mm) at product consumption $W$=50 l/h. The obtained comparative results concerning the thickness of the raw material layer confirm the greater efficiency of the proposed hinged blade with a cutting edge.

2. The estimation data on the scraper heat exchanger while comparing it to a heater based on steam heating confirm the increase in its resource efficiency, because the specific energy consumption for heating a unit of product volume in SH is 170.4 kJ/kg (Table 1), in comparison with the analog, 252.6 kJ/kg, which characterizes the reduction of costs by the improved SH by 1.48 times. This ensures the rapid warming of a product by the improved SH design, up to 10 s, which would lead to an increase in the quality of the technological process.

3. We have improved the design of the scraper heat exchanger by the non-insulating electric heating by FFREhRT that repeats the geometry of the working surface. The proposed stirring device is the structure of the hinged blade with a cutting edge, which has a heating reflective surface to stabilize the required product layer thickness on the working surface. The scraper heat exchanger could be used as a cooler (–15 °C) provided the refrigerant passes the spiral shell.

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