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# UNIVERSAL MULTIFUNCTIONAL DEVICE FOR HEAT AND MASS EXCHANGE PROCESSES DURING ORGANIC RAW MATERIAL PROCESSING

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***Запропоноване інноваційне конструктивне рішення універсального багатофункціонального апарата, що забезпечує реалізацію максимальної кількості тепломасообмінних процесів. А саме: витримування, підсушування, бланшування, уварювання, розварювання, настоювання, перемішування, розчинення та частково екстрагування. Поєднання цих процесів в єдиному апараті забезпечить його технологічну багатоопераційність, мобільність завдяки розташуванню на рухомій площадці. На ній змонтовано: моторне відділення; центральна опора фіксування робочої технологічної ємності; відділення з паровим генератором та вакуум насосом; технічні магістралі. Для керування основних режимних параметрів: швидкістю обертання валу мішалки; температурою нагрівання; тиском пароведення та вакуумуванням використовується засоби автоматизації. Також встановлена допоміжна технічна висувна піднімальна рейка з обертальним механізмом, призначена для розвантаження та завантаження ємності.***

***Конструктивне рішення багатофункціонального апарату забезпечує використання змінних секційно-модульних елементів. При цьому обігрівання технологічної ємності здійснюється гнучким плівковим резистивним електронагрівачем випромінювального типа, що забезпечує вихід апарату на робочий режим протягом 1,5 хв., простоту обслуговування та зниження його металоємності конструкції.***

***Під час апробації універсального багатофункціонального апарата встановлено, що він забезпечує зменшення тривалості тепломасообмінних процесів. А саме: витримування органічної сировини на 22 %, бланшування на 25 %, екстрагування на 21 %, уварювання на 32 %, підсушування на 13 %, настоювання на 43 % та розчинення дрібнодисперсної фракції на 20 %. Питомі витрати енергії, затрачуваної на нагрівання одиниці продукту, менші на 10 % та 19 % в порівнянні з УПТОДС-150 та казаном КВМ-150 відповідно. Це підтверджує ефективність прийнятого інноваційного рішення при забезпеченні мобільності, енерго- та ресурсоефективності, легкості експлуатації та обслуговування апарата***

***Ключові слова: універсальна обробка, органічна продукція, багатоопераційність, фермерські господарства, ресурсоефективність, гнучкий плівковий резистивний електронагрівач***

## 1. Introduction

The food industry has developed with the introduction of innovative microbiological solutions for production of various products at a minimum input of organic raw materials in Ukraine. However, it does not yet meet the demand of the population of Ukraine and European countries completely, as the needs of population for natural organic food increase daily. The growth of demand for high-quality natural organic raw materials necessitates the search for innovative approaches for intensification of technological heat and mass exchange processes and equipment for implementation [1, 2]. Production of food of such raw material requires a special approach to it immediately after harvesting in a ripe condition. Failure to comply with technological modes, starting from transportation and ending with implementation of final products, will lead to inevitable loss of useful natural properties [3]. Further nutritional value of resulting products depends on structural and technological features of heat and mass exchange processes.

The most common heat and mass exchange processes for processing the natural organic raw materials include: aging, drying, blanching, boiling, and boiling soft, infusion, mixing, dissolution and partially extraction. Each of these processes is special in terms of its implementation. It requires application of high-performance and metal consuming equipment in most cases. However, sometimes such equipment is not able to provide high quality of obtained products and requires complex engineering and technical communications. All the above-mentioned defines a need to find ways to combine heat and mass exchange processes for processing of natural organic raw materials in single modern universal multifunctional equipment.

Therefore, the actual task is a structural solution for the modern energy- and resource-saving universal multifunctional device for the course of heat and mass exchange processes for processing natural organic raw materials. This, in turn, will ensure competitiveness of organic high-quality products and reduce losses of raw materials and resource costs for production, which will greatly increase a range of products of organic origin in a variety of food production.

## 2. Literature review and problem statement

Organic products are in great demand in the markets of European countries. This leads to modernization of existing technological equipment in the process of development of small farm enterprises and hotel and restaurant facilities. The main problem for initial processing of organic raw materials is preliminary heat and mass processing with preservation of useful substances. The equipment used plays an important role in this case. It is single-process equipment in most cases, and this complicates universality of its use greatly. The need for resolution of this issue necessitates an innovative approach to the solution of technological and structural tasks for creation of universal multifunctional equipment for multi-operational purposes [4, 5].

Today, producers use various types of equipment for the course of heat and mass exchange processes for processing of natural raw materials, such as: heaters, blanchers, holders and other devices of periodic and continuous action. In most cases, equipment has high performance. It performs continuous technological processes with complex technical communications and complex service needs [6].

Technological aging operations (in sugar syrup or organic acids of a certain concentration) and blanching of fruits are necessary to increase permeability of the intercellular structure during further processing and mitigation of the tissue structure of plant materials. Paper [6] presents generalized technological and structural methods for conducting the specified operations, but it does not provide possible ways of their practical intensification, because of complexity of forecasting and implementation of heat and mass exchange processes, since we have to determine mode parameters experimentally for each case, in dependence on a type, variety and degree of ripeness and size of fruits, and structural features of equipment used [7]. All these factors determine complexity of observance and stabilization of processes in single-process equipment (tape devices, drum devices and screw devices of continuous action). It is expedient to carry out preliminary experimental and practical research on multioperational modular devices under conditions of use of combined methods of heat transfer based on modern low-metal and non-inertial heating elements to overcome mentioned difficulties.

Drying operation is necessary to prevent excessive bitterness and astringency of certain varieties of organic raw materials. In particular, drying occurs under action of temperature within the limits of 50...60 °C during 30...50 minutes [7]. At processing of organic natural raw materials, producers also use boiling for production of pastes, jams and other products. The purpose of boiling is to soften fruit tissue, to remove moisture and air, to introduce sugar and to destruct microorganisms. The process can occur under atmospheric pressure or under vacuum. Application of vacuum is expedient, due to the desire to reduce boiling temperature, which can exceed 100 °C for products with the sugar content of more than 60 % at atmospheric pressure [8].

Boiling soft operation serves to soften the natural structure of raw materials. It contributes to maintenance of tissue integrity, juiciness, brighter coloration of pulp before wiping for further production of, for example, puree-shaped semifinished products. Work [8] presents the results of the study on its realization by steam supplying to an operation capacity. The authors of this work established that heat losses due to the heat carrier leakage make up 5...95 % on average depending on structural features of a device. Thus, the issue of possible ways to intensify the process and to achieve reduction of energy and metal costs remains unsolved. All mentioned makes us suggest that further scientific and practical research is desirable in the direction of reducing of energy and resource costs.

A base of extraction is mass transfer of substance in order to achieve an equilibrium state between an extractant and concentrated substance or organic solvents. Paper [9] notes that it is necessary to classify extraction objects of extraction for separate equipment during extraction in most cases. And it complicates the process. Authors of the paper propose to use vacuumizing and pseudo-liquefaction, increasing of process temperature, reducing of a size of raw material particles and increasing of a degree of mixing for intensification of the process. But the work does not highlight possibility of application of precisely multioperational energy saving devices, which will significantly increase profitability of an enterprise in production.

Mixing is necessary to provide a homogeneous structure and to dissolve a fine dispersed fraction in the liquid or technological homogeneous mixtures for viscous and liquid food products (mashed potatoes, pastes, etc.), which consist of several components. It takes place in single-process reactors or cooking caldrons.

In the food industry, farms, hotel and restaurant facilities, producers preliminary heat raw materials, including finished products, with direct heat sources (electric current) or various intermediate heat transfer agents. Authors of a paper emphasize once again that duration of heating processes is the most important factor in assessment of energy and resource efficiency of a process, and as a consequence, the obtained quality of processing of plant materials. The reason for this is a need for an experimental determination of mode parameters for each case. However, the problems of rational heat supply and possibility of combination of separate operational tasks in a single structural and technological solution to ensure reduction of resource costs remain unresolved.

Work [12] denotes a need for efficient use of energy resources in the direction of trends in development of food industry and industrialization of many countries, but it does not cover ways of their solution. Because they are complex and they depend on many factors, which are difficult to forecast, in many cases. That is why they have a complex engineering-technological task, which requires experimental and practical testing.

All the above indicates that most of heat and mass exchange processes and existing technological equipment for its implementation have general structural and technological disadvantages. The main ones are single-process operation, power and metal consuming, complexity of technical communications, application, and maintenance. Thus, work [11] emphasizes a need to comply with the European Food Safety Modernization Act. But the issues of effectiveness of approbation of this bill to certain branches of the food industry remain unclear. The reason is a degree of its current innovative development, imperfection of legislation and limits of responsibility in the countries. One of the ways to solve these difficulties is the interest of the governments of the countries in introduction of modern innovative technological solutions for a resource-efficient approach to creation of modern requirements in the food industry for production of high-quality and competitive products. We can achieve this by combination of heat and mass exchange processes in multifunctional universal devices with reduced overall dimensions and simplified operational properties.

Therefore, one of the tasks of the food industry is resource-efficient processing of organic raw materials directly during its collection and further heat processing. This confirms the expediency of the task of combination of these processes in a single design and technology complex, which will ensure the quality of products obtained and an ease of technological service.

## 3. The aim and objectives of the study

The objective of this study is to determine possibilities to provide energy and resource saving effects of the universal multifunctional device (UMD) based on optimization of structural and technological solutions for conducting the heat and mass exchange processes in processing of natural organic raw materials.

We solved the following tasks to achieve the objective:

– to determine basic parameters of heat and mass exchange processes of organic natural raw materials in UMD;

– to design a universal multifunctional device;

– to confirm the energy and resource efficiency of the developed UMD design in comparison with the basic devices according to results of experimental and calculation studies.

## 4. Materials and methods to study the multicomponent natural compositions and the experimental installation

We performed optimization of the proposed structural and technological solutions for the course of heat and mass exchange processes in processing of natural organic raw materials and determination of possibilities of provision of energy and resource preservation at the laboratories of the Kharkiv State University of Power and Trade (Ukraine) on the developed UMD model installation. A paper [13] gives a detailed description of the experimental model of UMD and materials and methods for the study on heat and mass exchange of natural organic raw materials. We used standard calculation and experimental methods with application of automatic measuring devices of «OVEN» company (Ukraine) in the course of heat and mass exchange processes.

## 5. Universal multifunctional device for implementation of heat and mass exchange processes

The main requirements for UMD design were:

– tendency to preserve maximally natural properties of organic raw materials through application of acceptable technological and structural solutions for implementation of technological processes;

– provision of mobility, energy and resource efficiency of equipment characterized by ease of operation and maintenance.

It was necessary to combine maximally all possible heat and mass exchange processes to ensure all mentioned requirements. We could implement these operations in the created device due to development of auxiliary section-modular devices and rational design in the operation area of the device.

UMD-200 universal multifunctional device (Fig. 1) has a horizontally placed internal operation capacity 1. Its heating occurs due to a flexible film resistive electrical heater of the radiating type with heat-insulating outer surface 2 (FFREhRT) [14].

There are the following elements in the internal space of the operation technological capacity 1 according to design features:

– horizontal technical separators 3. They are designed for layer-cutting of liquid and raw material flow in the operation technological capacity 1, especially during heat and mass exchange processes, such as: extraction, infusion, boiling, mixing and dissolution;

– a modular-replaceable head of bubble sprayer 4, which is connected to the technical branch pipe by the automatic fuse of steam line 11;

– a main line of the drainage for technological liquids 5.

According to the design, we should place UMD on mobile platform 6 with stop lockers 7 to ensure its mobility. The platform has the following auxiliary structural elements:

– an engine section with output rotary shaft 10 made on the basis of a worm reduction gearbox, which passes through the nodal junction with the bearing 9, and which is secured to the end by quick coupler 8;

– a stationary central support for fixing operation technological capacity 1 with mechanism 18 for this capacity within the limits of 10...35°;

– automatic fuse of steam line 12 connected to the section of steam generator 13;

– a section for vacuum creation14 with vacuum pipeline 15;

– an auxiliary technical retractable lifting rack with rotational mechanism 16 with its lifting mechanism 20;

– control unit 17, which provides control of the speed of rotation of quick coupler 8 by heating temperature of the technological capacity, vapor pressure and vacuum in the device;

– a linking branch pipe designed to connect flexible vacuum hose 19.

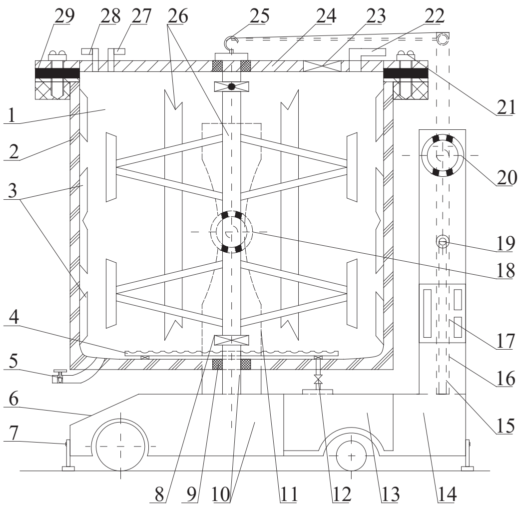


Fig. 1. Diagram of UMD-200 universal multifunctional device: 1 – internal operation technological capacity; 2 – flexible film resistive electrical heater of the radiating type with a heat-insulating outer surface (FFREhRT); 3 – technical separators; 4 – removable head of a bubble sprayer; 5 – drainage tap for technological liquid; 6 – mobile platform; 7 – stop lockers; 8 – quick couplings; 9 – node junction with a bearing; 10 – engine section with an output rotary shaft; 11 – central support for fixing of the operation technological capacity; 12 – automatic fuse of a steam line; 13 – section for a steam generator; 14 – section for vacuum creation; 15 – vacuum pipeline; 16 – auxiliary technical retractable lifting rack with a rotational mechanism; 17 – speed control unit for quick coupler 8, with technological capacity heating temperature, steam pressure and vacuum; 18 – mechanism for inclination of operation technological capacity; 19 – linking branch pipe for flexible vacuum hose; 20 – lifting mechanism of auxiliary technical retractable lifting rail with rotational mechanism 16; 21 – roller bolts; 22 – linking branch pipe of the flexible vacuum hose 19; 23 – hermetic loading hopper; 24 – lid of the operation technological capacity; 25 – hook for lifting the lid; 27 – replaceable modular element in the form of a stirrer; 27 – automatic safety valve; 28 – mechanical pressure relief valve; 29 – rubber seals

We propose to use variable sectional modular elements to implement the maximum amount of heat and mass exchange processes in UMD. Namely: the replaceable modular element in the form of mixer 27 – the perforated one with internal angular separators and the plate one (Fig. 2, *a, b*). Installing of replaceable sectional modular elements in technological capacity 1 is perdormed with the help of quick couplings 8, which provide rotation to intensify processes of preliminary processing.

There is a lid of operation technological capacity 24 attached to technological capacity 1 with the help of roller bolts 21 (4 pcs.). It has rubber seals 29 in places of interaction with technological capacity 1. There are the following design elements on the lid of operation technological reservoir 24: branch pipe 22 for junction of flexible vacuum hose 19, sealed loading hopper 23 intended for filling with a technological fine mixture with its subsequent mixing and dissolution, as well as with process fluids in general.

There is auxiliary hook 25 installed on the lid of operation process capacity 24 for lifting it during replacement of sectional modular elements and unloading of the device. There is automatic safety valve 27 installed on the lid of operation technological capacity 24 to prevent an increase in excess pressure in technological capacity 1. There is a mechanical valve for removal of excess pressure 28 for unvacuumizing of technological capacity 1 manually.

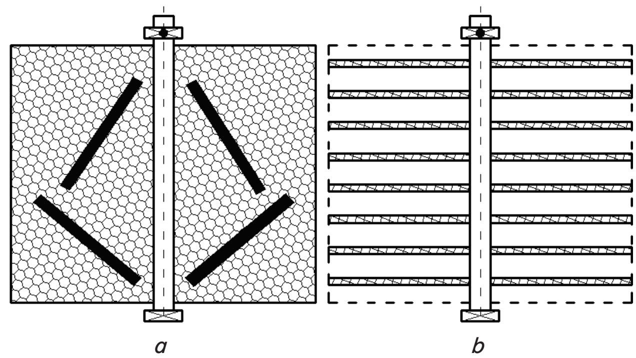


Fig. 2. Replaceable section-modular elements designed specifically for a universal multifunctional device: *a* – perforated one with internal angular separators; *b* – plate one

The use of replaceable sectional modular elements solves the technological task of heat and mass exchange processing of organic natural raw materials. For example, we can use a perforated element with internal angular separators (Fig. 2, *a*) for extraction and blanching. The separators prevent consolidation of raw materials and its gradual movement (mixing) into the section-modular perforated capacity during its rotation. Plate section-modular element (Fig. 2, *b*) serves to dry raw materials in most cases. In this case, we should select diameters of holes according to the type and geometric form of organic raw materials. A specially designed replaceable modular mixing element in the form of a two-level blade is designed for mixing, dissolution of fine dispersed fraction and its infusion.

The replaceable modular element in the form of stirrer 27 serves during aging, infusion, boiling soft in technological acids and liquids and boiling. As well as for mixing and dissolution of fine dispersed fraction in liquid or homogeneous technological mixtures.

UMD has also stop lockers 7 located on the floor of the mobile platform 6 and designed to prevent its movement during operation of the device.

The principles of UMD operation in accordance with the proposed heat and mass exchange processes are as follows. For the processes of aging, blanching, infusion and partially extraction in technological acids, it is necessary to load preliminary prepared natural organic raw materials to the replaceable section-modular perforated element. There are angular separators (Fig. 2, *a*) inside it. Using the auxiliary retractable lifting rail 16 and the quick coupler 8, we should install this element preliminary on the lid of the operation working technological capacity 24 with a hook for lifting it. The rack has rotary mechanism 20. We load this construction to the inner operation technological capacity 1, where the bottom the part couples with quick coupler 8. After fixing of the replaceable section-modular perforated element in the operation capacity of the device, it is necessary to fix the lid of operation technological capacity 24 with roller bolts 21.

Then, an operator sets the required technological parameters using control unit 17, they include:

– a speed of rotation of quick coupler 8, the shaft of which is installed in the hermetic node connection with bearings 9.

The speed of rotation of the coupling actuator varies within 5...15 min$^{-1}$. The worm reduction gearbox installed in engine compartment 10 provides rotation. There is an automatic delay for turning on the worm reduction gearbox until the temperature in the operation capacity reaches 25 °C. This, in turn, ensures energy saving at the heating stage of raw materials;

– temperature of heating. FFREhRT 2 heats the operation surface of UMD. It is capable to provide the maximum temperature of 130 °C;

– vacuum pressure. The developed device is capable of provision of pressure in vacuum creation section 14 within the limits of 13...19 kPa (for boiling and boiling soft processes). The pressure, after its formation, enters the branch pipe of flexible vacuum hose 19, which is connected to branch pipe 22;

– bubbling pressure. The hot steam appears in the section with steam generator 13. After reaching the hot steam pressure in the range of 0.1...0.5 MPa, an automatic fuse of steam line 12 opens and the steam enters the replaceable head of bubbling sprayer 4.

Loading and fixing of the replaceable section-modular perforated element with angular separators (Fig. 2, *a*) occurs in the inner operation technological capacity 1. During the process of aging, blanching, infusion and partially extraction, technological capacity 1 is filled with liquids through hermetic loading hopper 23 according to technological needs by about 50 % of its volume. The hopper is located on the lid of device 24.

An operator holds natural organic materials for a certain period of time and turns off heating, bubbling and devacuumizing of technological capacity 1 with mechanical pressure relief valve 28. Then he disconnects the branch pipe of flexible vacuum hose 19 from vacuumizer 14 and returns the capacity to an angle of 10...35° using the mechanism of inclination of operation technological capacity 18. After that, he opens the drainage tap for the obtained technological liquid, which is connected to the technological pipeline or a certain capacity.

After completion of the drainage of the preliminary treated technological fluid, it is necessary to return capacity 1 to its original geometric position and unscrew roller bolts 21. Then, with the help of auxiliary retractable lifting rail 16 with rotational mechanism 20, an operator should unload inner operation capacity 1. To uncouple the lower quick coupling, first of all, it is necessary to lift the lid of device 24 for 0.01 m and turn it at an angle of 5...10°. After that, it is necessary to unload the section-modular perforated element completely with further technological processing of raw materials.

Application of the replaceable modular element in the form of mixer 27 and the section-modular plate element (Fig. 2, *b*) in other operations for preliminary processing (heat processing) has a similar working principle with differences only in certain features. For example, it is not needed to tilt inner operation technological capacity 1 after completion of processing on the plate elements for drying of organic natural raw materials on plate elements.

We conducted research for determination of basic technological parameters of the preliminary heat processing of organic natural raw materials in UMD under different conditions. Namely: dried (during extraction), powder and liquid (dissolution and mixing) – with subsequent comparison of the obtained results with known technological devices based on KVM-150 [15] and UPTODS-150 [16].

Table 1 shows results of experimental and practical research during testing of the developed UMD in comparison with the analogues. A decrease in duration of heat processing of the proposed processes of the experimental model confirms the results, as this is an indicator of the increase in the efficiency of the proposed constructional and technological solutions. Using the standard methodology of the course of the heat-and-mass exchange process of drying, we determined the effectiveness of application of the developed UMD model on the example of the comparative kinetics graph.

We dried fruits of black chokeberry with the initial moisture content of 78 % to the final moisture content of 25 % (Fig. 3). The analysis of the obtained experimental curves shows the intensity of the process of drying of raw materials in the developed UMD and the reduction of duration of heat processing compared with KVM-150 by 17 % (by placing into the working chamber of the perforated plate shell) and UPTODS-150 by 9.6 %. The increase in the efficiency of UMD in the example of drying occurs, first of all, due to a decrease in duration of going out of the device to the stationary mode, because of the rapid release of FFREhRT at operating temperature compared with the base units.

Table 1

List of generalized heat-and-mass exchange processes with the results of the study

| Name of heat and mass exchange processes | Ratio of temperature of a working surface to duration, °C/s | | |
|---|---|---|---|
| | Traditional boiling caldron KVM-150 | UPTODS -150 | UMD-150 |
| Aging in technological acids | 20...25/1.800 | 20...25/1.550 | 15...20/1.200 |
| Blanching | 105...110/300 | 105...110/240 | 80...85/180 |
| Extraction | 85...90/6.800 | 85...90/3.600 | 75...80/2.850 |
| Aging | 70...75/900 | 70...75/740 | 60...65/500 |
| Drying | 50...55/3600 | 50...55/3450 | 45...50/3.000 |
| Mixing | 47 min$^{-1}$ | 10 min$^{-1}$ | 5...15 min$^{-1}$ |
| Infusion | 25...30/2.000 | 25...30/1.400 | 15...20/800 |
| Dissolution of fine dispersed fraction | 30...40/1.800 | 30...40/900 | 25...30/720 |

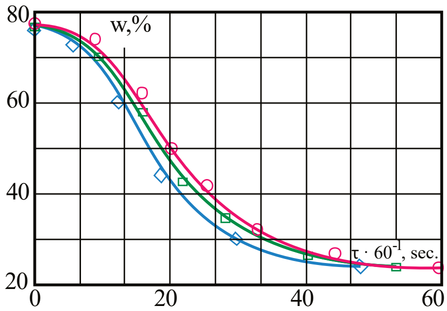


Fig. 3. Kinetics of the process of drying the fruits of black chokeberry: ○ — KVM-150; □ — UPTODS-150; ◊ — UMD-150

The results obtained at comparison with the closest prototype (UPTODS-150, Table 1) confirm the reduction of duration of all proposed heat and mass exchange processes for processing of natural organic raw materials. The temperature influence on raw materials decreased due to vacuumizing of the technological capacity of UMD. For example: duration of aging of organic raw materials in technological acids decreased by 22 %, blanching – by 25 %, extraction – by 21 %, aging – by 32 %, drying – by 13 %, infusion – by 43 %, and dissolution of fine dispersed fraction – by 20 %. The reduction of duration of heat and mass exchange processes in UMD in comparison with the basic apparatus occurs due to the direct interaction of the heater with the working camera, which thereby reduces duration of the device's going out to the stationary mode.

Practical calculation equations of the thermal process confirm the efficiency of the structural and technological solution implemented in the experimental UMD sample in terms of energy and resource preservation in comparison with the traditional devices (we accepted the boiling caldron KVM-150 and UPTODS-150 with steam heating as the basic options), namely:

– calculations of the specific energy consumption of the heat consumed by a unit of the product in devices confirmed the decrease of indicators by 10 % and 19 % compared with UPTODS-150 and KVM-150 caldron, respectively (Table 2), and the specific metal content decreased by half compared with UPTODS-150;

– possibility of reducing of temperature of the heater compared to the steam heating by 15... 25 °C, due to the heater blurring on the outer surface of the working capacity, since, the device goes out to the working temperature of the surface for 1.5 minutes to the set temperature according to the technical properties of FFREhRT;

– standard technological lines for processing of plant raw materials for heat and mass exchange processes are mostly one-process equipment, such as blanchers, extractors, mixers, boiling caldron, etc. The designed UMD provides possibility of multi-operation heat treatment in a single device in accordance with the design and technological implementation; thereby it provides a significant reduction in overall dimensional-weight characteristics of the line.

Significant reduction of energy consumption in the new device has a significant ecological value, since the preferential electricity generation at the thermal power plants reduces consumption of energy and, therefore, reduces emissions of $CO_2$ into the atmosphere.

Based on data in Table 2, we can conclude that the use of electric heating will reduce energy and metal losses and simplify the temperature control in the operating chamber of the device compared in comparison with steam heating.

We determined technical parameters of the developed universal multifunctional device in the study (Table 3).

We obtained generalized technical parameters of the developed UMD in the course of the study. The parameters confirm the effectiveness of the use of UMD in small farms and hotel and restaurant enterprises. It can provide guaranteed increase of technical and operational indicators of existing single-operation equipment in case of its placement on unproductive technological lines with the productivity of 50...200 kg/h UBA compared with existing prototypes (Table 1, 2). First of all, because of multi-operationality, mobility, resource efficiency and decrease in the thermal impact on raw materials by vacuuming of the working capacity and the use of FFREhRT during its processing, energy and metal consumption in general. This, in turn, will provide the high quality of the obtained semi-finished product at the output from UMD.

Table 2

Comparative characteristic of energy losses for heating of liquid during blanching

| Energy losses | KVM-150 | UPTODS-150 | UMD-50 |
|---|---|---|---|
| Heating of the device | $Q_{Heat.}=m_1\cdot c_c\cdot(t_2'-t_1')\cdot m_1\cdot c_c\cdot(t_2''-t_1'')=$ $=145\cdot0.48(143-20)+175\cdot0.48(90-20)=$ $=14{,}440$ kJ | $Q_{Heat.}=m_1\cdot c_c\cdot(t_2'-t_1')\cdot m_1\cdot c_c\cdot(t_2''-t_1'')=$ $=95\cdot0.48\cdot(143-20)+105\cdot0.48\cdot(90-20)=$ $=9{,}136$ kJ | $Q_{Heat.}=m_1\cdot c_c\cdot(t_2'-t_1')=$ $=35\cdot0.48\cdot(90-20)=1{,}176$ kJ |
| Heating of the product | $Q_{pr.}=m\cdot c\cdot(t_k-t_n)=$ $=150\cdot4.19\cdot(90-20)=44{,}089$ kJ | $Q_{pr.}=m\cdot c\cdot(t_k-t_n)=$ $=150\cdot4.19\cdot(90-20)=44{,}089$ kJ | $Q_{pr.}=m\cdot c\cdot(t_k-t_n)=$ $=50\cdot4.19\cdot(90-20)=14{,}696$ kJ |
| To the environment | $Q_{loss}=0.02\cdot Q_{pr}=0.02\cdot44{,}089.5=882$ kJ | $Q_{loss}=0.02\cdot Q_{pr}=0{,}02\cdot44089.5=882$ kJ | $Q_{loss}=0.02\cdot Q_{pr}=$ $=0.02\cdot14{,}696.5=294$ kJ |
| Total amount | $Q=59{,}412$ kJ | $Q=54{,}107$ kJ | $Q=16{,}166$ kJ |
| Specific loss | $q_{sp.loss}=Q/m=59412/150=396$ kJ/kg | $q_{sp.loss}=Q/m=54107.25/150=361$ kJ/kg | $q_{sp.loss}=Q/m=16166.4/50=323$ kJ/kg |
| Specific metal capacity of the device | $m=M/F=390/1.2=325$ kg/m$^2$ | $m=M/F=300/1.2=250$ kg/m$^2$ | $m=M/F=75/0.6=125$ kg/m$^2$ |

Table 3

Technical parameters of the universal multifunctional device

| Technical parameter | Unit of measurement | Value |
|---|---|---|
| The volume of technological capacity | $m^3$ | 0.05...0.2 |
| Power of the rotary drive motor | kW | 0.35 |
| Temperature of the operation surface (FFREhRT) | °C | up to 130 |
| Steam consumption during blanching | kg/h | 15...30 |
| Rotating speed | $min^{-1}$ | 5...15 |
| Weight (without loading) | kg | 75...130 |

## 6. Discussion of results of processing the natural organic raw materials in the developed universal multifunctional device

Experimental and practical results of the research confirm structural and technological efficiency of the use of UMD for heat and mass exchange processes for processing of natural organic raw materials and ensuring of the high quality of raw materials received.

The proposed structural and technological approach to the design of UMD gives us possibility to combine most of heat and mass exchange processes in a single universal device. And this device is mobile, simple and safe for use. It has reduced energy and metal consumption, due to the use of modern FFREhRT and elimination of the heating steam shell. Such a solution is promising, since it reduces inertia and metal intensity of the basic structures of similar devices.

The given technological parameters for the course of the specified heat and mass exchange processes provide reduction of duration and temperature influence. This, in turn, will provide a spare approach to organic natural raw material and maximization of preservation of its original properties.

The advantages of the study in comparison with existing analogues are, first of all, creation of an acceptable structural and technological solution for intensification of heat and mass exchange processes. This will improve technical parameters of the mentioned devices and reduce the cost. Introduction of the proposed device and the recommended mode parameters to the food industry will provide a qualitative approach to raw materials in the early stages of production of high quality semi-finished products with the maximum preserved content of BAS and therapeutic and prophylactic properties. It is possible to use the proposed UMD not only for the processing of seasonal organic raw materials due to the maximum combination of heat and mass exchange processes and convenience of performance. As well as for preparation of emulsions, sauces, condensed milk products, and other semi-finished products and finished products directly in places of sale.

Previously, the authors of paper [16] investigated processes of thermal processing of wild raw materials on UPTODS [16]. Heating of its working chamber occurred due to a steam shell. Such a heating system was characterized by inertia, metal consumption, uneven heating, complexity of operation and automation. The proposed innovative solution in the developed device eliminates these technical deficiencies.

It is necessary to pay special attention to the use of acceptable technological modes during processing of natural organic raw materials in a single universal complex of equipment, because of natural properties of raw materials associated with rapid damage and short shelf life before processing and transportation. That is why we apply blanching, aging, drying and other types of heat and mass exchange processing in processing of organic raw materials in most cases to provide necessary technological properties for further production of high-quality food products. We recommend using the developed design of UMD for the mentioned heat and mass exchange processes within the limits of temperature regulation from 30 to 130 °C during processing of plant raw materials.

In the future, we plan to carry out a detailed study on implementation of heat and mass exchange processes in the proposed devise. We also plan to find ways to improve UMD further to maximize preservation of original natural properties of organic raw materials.

## 7. Conclusions

1. An analysis of literary sources on technological and structural preconditions of heat and mass exchange processes (aging, drying, blanching, boiling, boiling soft, infusion, mixing, dissolution and partially extraction) gave possibility to identify common disadvantages in processing of organic raw materials. There were among them: single-operation, energy and metal capacity, complexity of technical communications, application, maintenance, small amount for small farms and enterprises of hotel and restaurant business. This necessitates a search for innovative, structural solution for multioperational, universal multifunctional equipment. A characteristic feature of it will be: high productivity, mobility, ease of maintenance and high quality of organic semi-finished products obtained.

2. We performed comparison of UMD with the prototype (UPTODS-150) and confirmed the reduction of duration of heat and mass exchange processes during processing of organic raw materials.

Namely: the reduction of duration of maintenance of organic raw materials in technological acids by 22 %, blanching – by 25 %, extraction – by 21 %, boiling – by 32 %, drying – by 13 %, infusion – by 43 %, and dissolution of fine dispersed fraction – by 20 %.

It also provides for the reduction in duration of the temperature effect on raw materials due to vacuumizing of the technological capacity of UMD. Calculations of specific energy consumption of the heat consumed per unit of product in the device confirmed the decrease of indicators by 10 % and 19 % compared with UPTODS-150 and KVM-150 caldron, respectively, and the specific metal content decreased by half compared with UPTODS-150.

3. The use of UMD on technological lines with productivity of 50...200 kg/h will ensure guaranteed increase of technical and operational indicators of existing single-process equipment, due to multi-operationality, mobility, resource efficiency, a decrease of the temperature effect on raw materials, vacuumizing of the operation capacity. Application of use of FFREhRT will provide a significant reduction in energy and metal costs, which will make possible production of high-quality organic semi-finished products in general, in particular at harvesting sites.

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