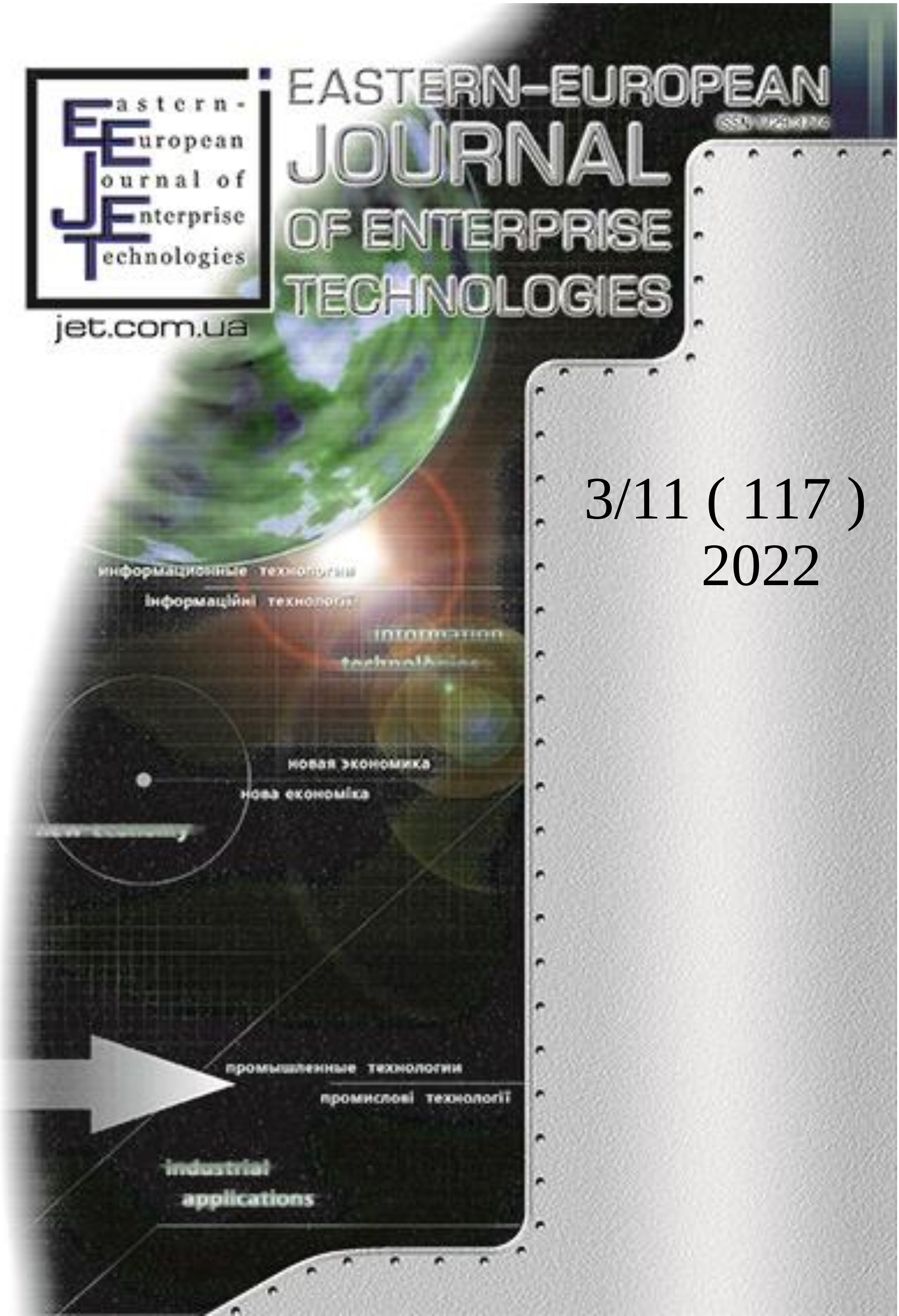
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DEVELOPMENT OF APPARATUS FOR FRYING SEMI-FINISHED MEAT CUT

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A model of the apparatus for frying chopped semi-finished meat products has been designed, which is distinguished by the technique of heat supply by replacing metal-intensive and inertial heaters with inertia-free ones with a uniform distribution of the temperature field by a film resistive electric heater of radiative type. For condensing juice-containing vapors in functionally closed media, plate coil liquid coolers with Peltier elements are used. At the temperature of the heating surfaces of 180 °C, the cold side of the Peltier element provides a coolant temperature of up to 10 °C. The proposed solution could improve the competitiveness of the device, which is explained by the established technical and operational indicators.

The improved device over 300 s provides a temperature in the center of a product of 90 °C, and on surface layers – 130 °C, which characterizes the culinary readiness of meat products. When making samples conventionally, the surface layer warms up to 120 °C, and the central layer – to 72 °C, at the temperature of the contact surface of 160 °C over 180 s with crust formation. In addition, the difference between the opposite layers of the control sample is 85 °C, which confirms the uneven heating during frying in the conventional way, which is explained by the need to use auxiliary operations for turning the product. The heating time to operating temperature was reduced by 88.6 %, specific heat consumption was decreased by 43.0, and productivity by 14.8 %, with full culinary readiness of products, compared with the conventional device.

The increase in the resource efficiency of the apparatus for frying meat products was confirmed, which is achieved by the implementation of the proposed design and hardware solutions to ensure the competitiveness of the apparatus that will make it possible to prepare original meat products

Keywords: frying apparatus, heat supply, chopped semi-finished meat products, film-type electric heater

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1. Introduction

Meat products in many countries account for a significant share of the daily diet of good nutrition, consumed in the form of various products, including semi-finished products brought to the stage of culinary readiness [1]. The available range of meat products such as cutlets, tufts, various rolls, etc. is made in accordance with well-known formulations in compliance with technological operations on a variety of heat and mass exchange equipment [2, 3]. Namely, the use of modern electric heaters will reduce the energy spent on the production of culinary products and simplify the performance of the apparatus for frying chopped semi-finished meat products [4].

Providing equipment with modern operational requirements necessitates the use of innovative engineering trends that will ensure versatility, portability, resource efficiency, and, mainly, the competitiveness of equipment, including the variety of resulting products. It is also necessary to take into consideration the complexity of technological and equipment components in the development of modern resource-efficient equipment, which will ensure the qualitative implementation of technological needs at each stage of equipment production on heat and mass exchangers. In particular, the achievement of resource efficiency in the production of meat culinary products is possible under the conditions of using modern heat carriers that have low inertia, reduced metal consumption, clear dynamics of operation, and the uniformity of heat flow. Another important component is the hardware possibility of using secondary thermal energy for the needs of its own or related equipment and technological complex. Taking into consideration these factors is relevant during the development of resource-efficient low-temperature equipment to produce meat culinary products. Namely, the introduction of modern heating elements and the use of secondary heat will ensure the functionality and competitiveness of the device.

2. Literature review and problem statement

Work [5] emphasizes that meat culinary products, in particular delicacies, occupy a significant part of the diet in many countries. Causing the need for the introduction of innovative solutions to produce products of a wide range of uses with original taste properties. At the same time, most government initiatives in the European countries are aimed at improving nutrition and planetary health, and therefore need to replace previous approaches by taking into consideration modern information technologies [6]. The introduction of modern rational food trends predetermines the use of innovative functional and health technologies and innovative universal equipment for production. In work [7], it is noted that the need to provide health products is actually, so to speak, an automatic quality assessment system, taking into consideration the data obtained, including from consumers and the formation of general assessments. However, in the context of meat consumption, this approach seems inadequate since conflicting evaluative parameters of the product may play a role, in particular, the benefits of a plant-based diet compared to meat. For example, environmental friendliness compared to the taste and compared to health benefits. This, in turn, requires firstly the development of a certain evaluation system, and secondly, ensuring the high quality of meat products obtained using innovative equipment, emphasizing the feasibility of research in this area.

Paper [8] provides data on the potential of using multispectral evaluation technology to control quality during the continuous process of frying minced meat and turkey cut in cubes. The procedure can detect an increase in unwanted agglutination of the roasted product but there is no ability to determine it online, emphasizing the feasibility of using modern equipment. For example, work [9] focuses on the relevance of the production of meat products with original taste properties, causing the need to improve the techniques of processing meat raw materials and equipment for their implementation. In particular, a device for low-temperature processing of meat products with IR radiation is proposed, using a film resistive electric heater of radiative type to ensure the uniformity of heat flow distribution. The device operates in a gentle low-temperature mode but is characterized by a certain range of products, which, in turn, requires further scientific and practical research in the field of development of more rational devices.

Paper [10] investigates the effect of five different cooking methods (cooking, baking in the oven, grilling, frying in a frying pan, and microwave oven) on the physicochemical parameters and organoleptic properties of rabbit meat. Minimal destructive changes in muscle fibers and connective tissue in samples cooked in a frying pan and the greatest destructive effect in that cooked on the grill have been identified. Baking in the oven is found to be the best method of cooking meat since it provides both health benefits and is acceptable to consumers; however, the studies do not consider the effect exerted on the results by the equipment components. This is due to the large range of technological equipment for heat treatment of meat products but it is the hardware effect on the final quality of the product that is the main one that requires detailed research to design innovative equipment. In particular, work [11] investigated the simultaneous heat-and-mass transfer and change in the physical properties of pork meat when deep-fried. Frying in sunflower oil was realized at 90, 100, and 110 °C. It was established that the coefficient of diffusion of moisture had a value from 1.5 to $30.2 \cdot 10^{-9}$ m^2/s while the coefficient of convective heat transfer – was from 187.7 to 226.1 W/m$^2 \cdot$°C. The temperature conductivity remained almost constant throughout the process; on the contrary, specific heat capacity and thermal conductivity decreased with an increase in the duration of frying due to the loss of moisture by meat plates. The density, color, and texture of the crust were influenced by the roasting temperature but the outstanding issues remain related to the influence of the surface type for roasting, causing the relevance of research in this area. Paper [12] investigates the deep-frying of chicken breast fillet without skin and bones (190 °C) with and without dough and breading system for up to 6 minutes (internal 70 °C). Samples without coating demonstrated the splitting of surface muscle fibers when immersed in oil. Over time, the depth of damage increased with the growth of a dense layer of solid crust, as well as the loss of about 1/3 of its weight and changes in organoleptic properties. This is due to heat treatment in the open air; if processing in closed functional containers were implemented, a significant reduction in the above parameters would be ensured, confirming the relevance of research in this area.

Work [13] reports the results of heat exchange when frying minced meat cutlets when in contact with hot plates, under technological conditions for aging products for 4 minutes on the contact surface. The temperature of the raw materials and the heating plate was measured depending on duration, to determine the heat transfer coefficient between the heating plate and the surface of the product. It is established that the heat flow as a function of time depends on the type of heated material and the temperature of the heating plate. However, the cited work did not take into consideration the technique of heat supply and ensuring uniform heating of the meat product from the contact surface to the center and contactless surface; this is due to technological operations of “turning” the product during frying. One of the ways to eliminate the above is to try to ensure uniform heat supply in functionally closed environments, which at the same time could reduce weight losses during heat treatment involving frying in the open environment.

Work [14] states that reducing the loss of meat products during frying is possible by adding natural ingredients to the formulation. For example, oats, which are good for health and well mimic the mechanical and physicochemical characteristics of ground beef (BM); its use (fried cutlets and hamburger cutlets) have high organoleptic properties. Paper [15] reports a technique of production of fruit and vegetable, spicy pastes, which, with further processing, can act as functional and physiological powdered ingredients capable of absorbing liquid, and, in the process of frying, saturate the product with it. Thus, works [16, 17] consider innovative hardware technological solutions for the concentration and final IR drying of pasty concentrates, to produce functional powders of plant origin for meat products. However, there remain unresolved issues related not only to the advantages of using vegetable powders in minced meat but also to the original organoleptic properties received owing to them. This is due to a wide range of studies and, therefore, the relevance of research in this area for the production of competitive health-improving meat culinary products.

An actual component of modern thermal devices is the introduction of energy-saving technologies related to the use of innovative heaters and the possibility of converting secondary thermal energy into a usable component, in particular Peltier elements [18]. Thus, work [19] provides data on the relevance of the use of secondary energy for cooling, or the production of low-voltage power by Peltier elements, confirming the relevance of research into the development of low-temperature equipment for meat products. And the practical implementation of innovative design and technological solutions will ensure the development of competitive equipment with a wide range of use in the food sector and home life, as well as obtaining products with original organoleptic properties.

Unfortunately, most thermal equipment for frying meat products has certain structural and technological disadvantages associated with uneven heat supply, the complexity of heat treatment control, energy and metal capacity. Even frying products in the open environment leads to significant losses in mass and quality, not to mention the use of secondary energy and the degree of resource efficiency. Important tasks in the design of competitive devices for heat treatment of meat products are ensuring the uniformity of the heat flow, maximum preservation of natural organoleptic properties at the production stages, minimization of weight losses, and the use of secondary energy. All this necessitates experimental and practical research to ensure the above advantages, which in turn will allow the expansion of the range of meat products with original taste properties.

3. The aim and objectives of the study

The aim of this work is to design an improved apparatus for frying chopped semi-finished meat products by heating working surfaces for frying with a film resistive electric heater of radiative type, the presence of a cooling platform, and the use of Peltier elements.

To achieve the set aim, the following tasks have been solved:

– to design a model structure of the apparatus for frying chopped semi-finished meat products by heating the working surfaces with a film resistive electric heater of radiative type, the presence of a cooling platform, and the use of Peltier elements;

– to determine via calculation and experimentally the uniformity of a temperature field, to carry out a comparative organoleptic assessment of samples, and to confirm the effectiveness of the proposed design solutions when compared with the classic apparatus for frying semi-finished products.

4. The study materials and methods

At the State Biotechnological University (Ukraine), we considered ways to design a device for frying chopped semi-finished meat products when heating the working surfaces with a film resistive electric heater of radiative type (FREhRT [20]) and a cooling platform with Peltier elements. The proposed engineering and technological solutions in the designed apparatus provide the condensation of the steam-containing component into the product during cooling, due to the formation of functional closed media from the forming cells. And the use of a film resistive electric heater of radiative type will reduce the metal capacity of heating platforms and ensure uniform frying due to conductive-infrared heat supply, under the conditions of maximum contact between the surface of products and the heating plane. That, in turn, will provide the possibility to produce a wide range of meat products under the conditions of using replaceable heating platforms that have a variety of molding cells of products. A comparison of the equipment and technological parameters of the improved apparatus for frying products was performed using the known frying pan SESM-0.2 (Ukraine) [21] applying standard procedures of thermal calculations and based on experimental data using the measuring equipment "OVEN" (Ukraine). To measure the temperature when frying chopped semi-finished meat products, needle thermocouples were used, which were placed on the heating surface between the forming sites (every 2 sites). We determined the temperature at different depths of the product by needle thermocouples (two thermocouples were placed in the surface and intermediate layers, and one – in the central layer, subject to the product thickness of 1.5...2 cm). Measurements at each point in the frying process were carried out at intervals of 60 s. The culinary readiness of products was determined by reaching a temperature inside the samples of 90 °C; the accuracy class of the measuring equipment "OVEN" was ±0.25 %.

The organoleptic properties of prototypes were estimated by an expert board consisting of 5 employees from the State Biotechnological University (Kharkiv, Ukraine), on a 5-point scale.

5. Results of experimental and estimation studies of the apparatus for frying chopped semi-finished meat products

5. 1. Designing an improved model of the apparatus for frying chopped semi-finished meat products

The designed model of the apparatus for frying chopped semi-finished meat products is shown in Fig. 1; it has two platforms 1 with an anti-stick fluoroplastic coating connected unilaterally by hinges 2. The structure of platform 1 on a working surface has forming sites 3, designed for technological placement of culinary meat products during frying. The heating of platforms 1 (from the technical area – opposite to the working area) is carried out by a film resistive electric heater of radiative type 4, which repeats the geometry of platforms 1.

In accordance with the design solution, platforms 1, from the technological (working area), have around the perimeter heat-resistant rubber seals 5, and, from the technical area, below FREhRT 4, have plate coil liquid coolers 6. Coolers 6, in turn, provide faster liquid (water) cooling of the working surface of plates 1 after the culinary readiness of the product. To intensify cooling from 180 °C, between FREhRT 4 and cooler 6, Peltier elements 7 are placed, ensuring the conversion of thermal energy into cooling by lowering the temperature of the incoming liquid.

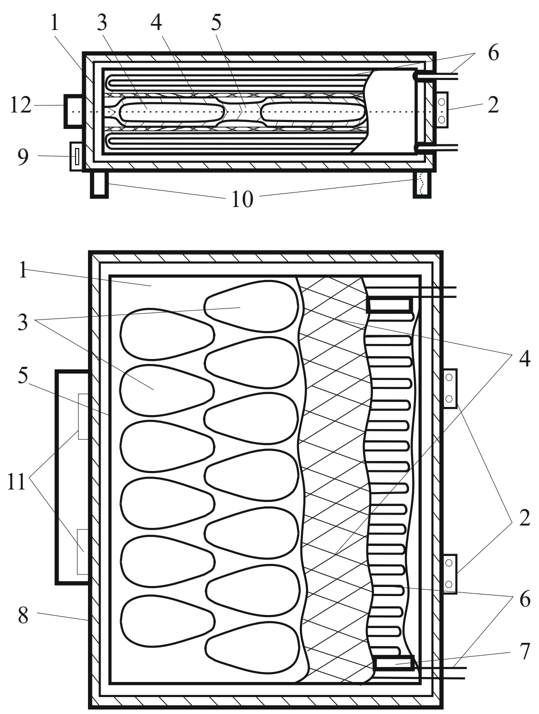

Fig. 1. Diagram of the improved apparatus for frying chopped semi-finished meat products: 1 – platform (2 pcs); 2 – hinge; 3 – forming sites; 4 – film resistive electric heater of radiative type (FREhRT); 5 – heat-resistant rubber seal; 6 – lamellar coil liquid cooler; 7 – Peltier elements; 8 – steel cladding with insulating material; 9 – control panel; 10 – racks (the rear rack has a mechanical height control of 3°); 11 – mechanical retainers; 12 – handle

The outer technical zones of platforms 1 are lined with a steel surface with heat-insulating material; control panel 9 is mounted on the front surface for high-quality control over the frying process. The device is mounted on racks 10; the rear rack has regulators of its height. Changing the height of the rear rack makes it possible to create an angle of inclination of the back surface of the device by 3° to ensure the full draining of the heat carrier from cooler 6.

When closing two platforms 1 with molding sites and heat-resistant rubber seals 5, a functional closed environment is formed. Fixing platforms 1 when frying is carried out by mechanical retainers 11, and the opening of the upper plate for unloading the device is ensured by handle 12.

The work of the apparatus for frying chopped semi-finished meat products is as follows.

On control panel 8, the thermostat by the operator sets the technological required temperature, then connects the device to the power supply network, thereby turning on the film resistive electric heater of radiative type 4. Upon reaching the set temperature, pre-prepared meat products are loaded to the main (lower) platform 1, which has a non-stick fluoroplastic coating and forming sites 3. After that, the second plate is lowered, connected by hinges 2 to the first one, creating a functionally closed environment in the plane of forming sites 3 with the help of mechanical locks 10.

Frying is realized by the conductive-infrared heat supply provided by FREhRT 4 to the working (technological) surface of the platforms subject to the maximum contact between the surface of the products and the heating plane. During frying, the juice-containing component of the meat product is evaporated, forming excessive pressure in the closed functional environment, thereby intensifying the process. And the presence of fluoroplastic non-stick coating of the working surfaces of platforms 1 prevents the adhesion of meat products, making it possible to implement the technological process using fat not as an intermediate heat carrier but as an enricher of the formulation composition of the product.

Upon completion of the meat frying operation, FREhRT 4 is turned off and the liquid cooling (water) is supplied through the plate coil liquid coolers 6, ensuring the cooling of platforms 1 and the condensation of steam in the middle of the product. To intensify cooling, Peltier elements 7 are located between FREhRT 4 and coolers 6, in particular, at a heating surface temperature of platforms 3 of 180 °C, the temperature on the cold side of the element is minus 5 °C. Thus, reducing the temperature of the coolant from 15 °C to 10 °C without electricity consumption for intensification of cooling. It should be noted that the condensation of the juice-containing steam medium in functionally closed containers reduces the loss of mass of products during frying, as is observed with the conventional technique. As well as improve working conditions of technological operators and the impact on the environment in preventing steaming to it. The cooling process is carried out to the recommended temperature, which corresponds to the supply of products to the consumer.

To drain the coolant from coolers 6, they reduce the angle of inclination of the rear racks of the machine by 3°, after 5 minutes, the height of the racks is returned to its previous value and they repeat the process of frying. At the same time, after draining the liquid from coolers 6, an air environment is formed in the middle of them, which acts as an additional heat insulator and additionally prevents heat transfer to the environment.

Unloading of the device is carried out by opening mechanical clamps 10 and lifting the upper platform 1 with the help of handle 11 when fixed in an upright position.

5. 2. Studying the impact of the proposed structural and technological solutions on the effectiveness of the frying process

An experimental and practical comparison of the obtained uniformity of the temperature field when frying chopped semi-finished meat products obtained in the conventional way (control sample) and in the designed apparatus (prototype), shown in Fig. 2, was carried out. At the same time, the obtained results of studying the control samples are characteristic of the 1st stage of frying using the auxiliary stage of turning the sample in 180 s and the total duration of heating the surface is 360 s.

In the process of frying control meat products, there is a significant uneven temperature field in terms of product volume. For example, the surface layer in contact with the heated surface (160 °C) during the operating 180 s warms up to 120 °C, forming a crust, the central layer has – 72 °C. The difference between the opposite layers of the sample is about

85 °C, confirming the uneven heating of the meat sample when frying conventionally, in particular, this is explained by the need to use auxiliary operations to turn the product over on a heating surface. At the same time, it is projected to reduce the temperature of the surface layer of the sample to 50 °C, after the operational turning (180 s), which is explained by the impact in the interaction of the product with the environment.

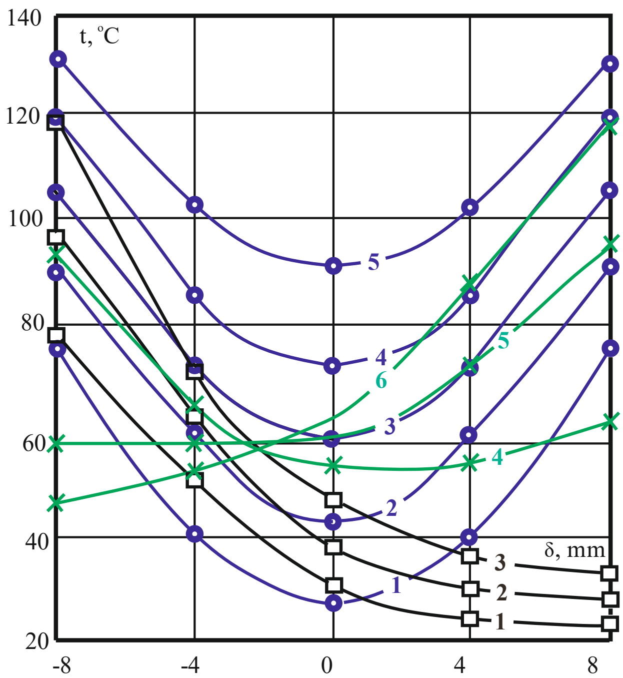

Fig. 2. Temperature field at a distance from the center of experimental chopped semi-finished meat products during frying: in the conventional way, with I operational turning (-□-, where curves 1...3 is the duration of frying (60...180 s), and II operational turning (-×-, where curves 4...6 is the duration of frying (240...360 s); -o- — data obtained in the designed apparatus (curves 1...5 correspond to the duration of frying of 60...300 s)

The temperature of the sample layer after operational turning and when interacting with the heating surface increases to 120 °C – forming a crust. And the temperature of the central layer of the experimental control sample is 67 °C, which does not correspond to the culinary readiness of the product when fried conventionally. At the same time, the temperature difference between the surface layers is 70 °C, and, between the heated layer of the sample and the center of the product – 53 °C.

The operational increase in the duration of frying (more than 360 s) leads to an increase in the thickness of the crust, it is established that in the designed apparatus within 180 s the thickness of the crust of the prototype is formed – 0.65 mm, and after 300 s – 1.05 mm. When frying conventionally for 180 s, a crust with a thickness of 1.35 mm is formed, which partially leads to a deterioration in the organoleptic properties and competitiveness of the products received and is confirmed by the results of a comparative organoleptic assessment (Table 1).

Among the main shortcomings of the control are the deformation of the surface with minor damage, a slightly thicker width with an uneven surface of the product, and a denser consistency, unlike the prototype.

Table 1

Results of comparative organoleptic evaluation of the process of frying semi-finished meat products in a conventional way and the designed apparatus

Indicator	Sample	Sample characteristics	Organoleptic evaluation
Appearance	control	The surface is dark brown, slightly deformed with minor damage	4
	prototype	The surface is brown, not deformed, no damage	5
View in cross-section	control	The color is light brown, the structure is homogeneous, the crust is uneven about 2 mm thick	4
	prototype	The color is light brown, the structure is homogeneous, the crust is a uniform thickness of about 1 mm	5
Smell	control	Strongly expressed, corresponding to this type of culinary products	5
	prototype		
Taste	control	The pronounced taste of raw meat, typical of this type of culinary products	5
	prototype		
Consistency	control	Dense, homogeneous, uncrushed, juicy, products are plastic and hold their shape well	5
	prototype	Gentle, homogeneous, unbreakable, very juicy, products are plastic and hold their shape well	4

At the same time, under the conditions of frying meat products experimentally, there is a significant difference in the temperature field of samples compared with experimental-practical control data. This is due to the contact of the heating surface over the entire surface area of the product, ensuring simultaneous uniform heating up to the center, and therefore an increase in temperature without unilateral overheating.

Over 120...150 s of frying, the temperature of surface layers is 105 °C, ensuring the beginning of the molding of the product's crust, which is ensured by placing a prototype in the form of a cell of frying platforms.

In the initial stages, a slight difference in the rate of heating of prototypes by conventional and proposed ways is predicted, but, for some time, there is a significant intensity of heating. The delay in the first stage of heating the meat product in the experimental apparatus can be explained by placing the sample in the forming sites of the platforms, which prevents steam from entering the environment and creating excess pressure in their volume. Thus, during 300 s, the temperature in the center of the product was 90 °C, under the conditions of non-overheating of surface layers (130 °C), which characterizes the culinary readiness of meat products in the experimental apparatus. The temperature difference of the opposite surface layers of the prototype does not actually differ and, between the surface layer and the central layer, is 40 °C.

When forming on the surface of products of the crust with a sufficiently strong structure characteristic of frying prototypes, or at the last stage of frying the control samples, there was a decrease in weight loss. Our comparison of experimental numerical results characterizes that more significant mass losses during frying occur in prototypes. Mass losses in control samples after 180 seconds (before turning) are 6.0 %, and in experimental 11.3 %, due to the full cone tact of the product with the heating medium, increasing the surface of the mass exchange. With the culinary readiness of the prototype, the weight loss is 2.8...3.0 % lower than that of the control (16.1...16.5 %), which is explained by the presh ence of mechanical obstacles to the removal of steam during frying, as well as a reduction in the duration of the process.

It has been experimentally established that mass losses due to evaporation of moisture are further reduced due to combined cooling, which is unlike natural (outdoors). In particular, intensive cooling of the forming sites and the heating surface as a whole to a temperature of 90 °C ensures the condensation of part of the water vapor in the middle of the products and a decrease in its partial pressure. Forced cooling additionally reduces weight loss by 3.4...3.6 % and is about 13.0 %, that is, 6.3...6.7 % lower than mass losses by control samples. In addition, combined cooling ensures the environmental safety of the process by reducing the release of steam into the production room.

To confirm the effectiveness of the proposed design solution of the apparatus for frying chopped semi-finished meat products, its estimation characteristic is given in comparison with the classic SESM-0.20 frying pan. Comparative calculations of the technical and operational indicators of the device are given in Table 2.

Table 2

Comparative characteristics of the apparatus for frying chopped semi-finished meat products with base SESM-0.20

Indicator	SESM-0.20	Designed apparatus
Voltage	380 V	220 V
The weight of the device	M^*=135 kg	M=6.5 kg
Productivity (by cut meatballs)	$G^*=4.1\cdot10^{-3}$ kg/s	$G=3.49\cdot10^{-3}$ kg/s
Specific heat consumption	$1.1\cdot10^6$ kJ/kg	$0.63\cdot10^6$ kJ/kg
Duration of heating to operating temperature	τ=2,100 s	τ=240 s
Loading surface area	$F^*=0.26$ m^2	$F=0.2$ m^2
Specific metal content of the device	$m=M^*/F^*=519$ kg/m^2	$m=M/F=32.5$ kg/m^2
Efficiency	0.63	0.94
Dimensions, m:		
Length	1.085	0.39
Width	0.87	0.34
Height	0.85	0.18

*Note: *Comparative data on the basic design of SESM-0.20 are taken from [21]*

We have experimentally calculated the technical and operational indicators of the apparatus for frying chopped semi-finished meat products in comparison with the frying pan SESM-0,2, given in Table 1. The data indicate a significant decrease in the overall dimensions and weight of the improved device, which reduces the metal capacity by 93.7 % and significantly affects the reduction in the heating time to the operating temperature, by 88.6 %. The increased surface area of heating of culinary products, the optimal use of water vapor energy, which is removed from the middle of the products, leads to a decrease in the specific heat consumption by 43.0 % and an increase in the efficiency by 49.2 %. The decrease in productivity by 14.8 % is explained by the fact that during frying on SESM-0.2, they are brought only to half-cookability, and in the designed apparatus – to full culinary readiness in 300 s.

6. Discussion of the effectiveness of structural solutions in the designed apparatus for frying chopped semi-finished meat products

The use of a film resistive electric heater of radiative type for heating working surfaces of the device makes it possible to neglect the metal intensity of heaters and ensure uniformity of heat supply under the conditions of maximum contact with forming sites (Fig. 1, pos. 4, and Table 1). To ensure the rapid condensation of juice-containing vapors in functionally closed media, the use of plate coil liquid coolers is proposed (Fig. 1, pos. 6), in addition, Peltier elements 7 are also installed (Fig. 1, pos. 7). This is in combination at the temperature of the heating surfaces (180 °C) and the temf perature on the cold side of the Peltier element of minus 5 °C makes it possible to reduce the temperature of the coolant to 10 °C without additional costs. In this case, the draining of the coolant from the coolers is ensured by reducing the angle of inclination of the rear racks of the device by 3°, and, under the conditions of the drained liquid, the coolers act as an additional air insulating medium.

Due to the change in the technique of heat supply to FREhRT, the dual technical purpose of the cooler and Peltier elements, competitive advantages of the device are ensured in terms of organoleptic indicators (Table 1) and when compared with the basic ones (Table 2). For example, during 300 s, the temperature at the center of the product in the designed apparatus was 90 °C, and flood layers – 130 °C (without overheating), which characterized the culinary readiness of meat products (Fig. 2). When making control samples conventionally, the surface layer in contact with the heated surface (160 °C) during the operating 180 s warmed up to 120 °C – forming a crust, with a temperature of the central layer of 72 °C. The difference between the opposite layers of the control sample is about 85 °C, confirming the uneven heating of the product when frying in the conventional way, which is explained by the need to use auxiliary operations to turn the product over on the heating surface. In the designed apparatus, within 180 s, the thickness of the crust of the prototype is formed – 0.65 mm, and, after 300 s, 1.05 mm, and when frying conventionally, a 1.35 mm thick crust is formed in 180 s. This, in turn, partially leads, taking into consideration the uneven distribution of the temperature field in a conventional way, to a deterioration in the organoleptic properties of fried products (Table 2). In a comparative experimental and calculated way, it was established that the overall dimensions and weight are reduced by 93.7 %; and the duration of heating to operating temperature decreases by 88.6 % (Table 2). An increase in the surface area of heating the product and the use of water vapor energy, which is removed from the middle of the products, leads to a decrease in the specific heat consumption by

43.0 %, an increase in the efficiency by 49.2 %. A decrease in productivity by 14.8 % with full culinary readiness of the meat product. The proposed solutions will increase the efficiency of the frying process with a partial solution to the shortcomings identified during our literary review. In particular, the use of modern film-type heaters will ensure uniformity of heat supply with clear stabilization of the temperature regime and the lack of metal capacity of the heater. The use of forming sites of functional closed media is characterized by a decrease in the weight losses of products during natural cooling by 2.8...3.0 %. Additional weight loss reduction is provided by a combined cooling technique, providing a reduction in weight loss by 6.3...6.7 %, due to the forced condensation of water vapor.

In addition, the use of Peltier elements in the secondary energy apparatus in cooling energy is implemented, intensifying the process of cooling culinary products, and therefore vapor condensation without the use of any additional energy.

The difference between conventional technological and equipment analogs for frying meat products is the use of metal-intensive heating platforms and heating elements that complicate the control of temperature exposure, and, therefore, greatly affect the resulting quality [22]. The main restriction when frying meat products is to ensure uniform heat supply to the entire surface of the product and uniformity of the temperature field, in addition, there are significant losses in the mass of finished products. To solve this design and technological problem of classical frying machines, the use of FREhRT with a uniform distribution of the temperature field, clear temperature stabilization, and reduced metal intensity is proposed. As regards the shortcomings, it is possible to note the need for an appropriate level of qualification of specialists during the operation of the device, which may lead to improper operation and not high-quality manufacturing of products. Further research will be aimed at studying the processes of frying meat culinary products with the addition of powdered natural semi-finished products, which is relevant in view of our literary review. The introduction of semi-finished products in the prescription ratio, in turn, will reduce weight loss at the stages of production, saturate the product with natural juiciness, and give original organoleptic properties.

7. Conclusions

1. An improved model of the apparatus for frying chopped semi-finished meat products has been developed, which is distinguished by the technique of heating working surfaces with a film resistive electric heater of radiative type, the presence of a cooling platform, and the use of Peltier elements. The device makes it possible to ensure the uniformity of heating through the volume of meat products, which leads to the prevention of overheating of individual layers, thereby restraining the development of various physical and chemical changes during long-term high-temperature processing.

2. Experimentally, a significant difference in the temperature field of samples was established in comparison with the control data. It was found that over 300 s the temperature in the center of the experimental product was 90 °C, and the surface layers – 130 °C (without overheating), which characterized the culinary readiness of meat products. This is due to the full contact of the heating surface with the area of products, which ensures their simultaneous uniform heating, and, therefore, an increase in temperature without unilateral overheating. Forming sites provide a decrease in mass losses in products during natural cooling by 2.8...3.0 %, and with a combined cooling technique, a decrease in the mass loss by 6.3...6.7 %, which is due to forced condensation of water vapor. We established a decrease in the specific heat consumption of the designed device by 43.0 % while increasing the efficiency by 49.2 %. Specific metal capacity is less by 93.7 % due to a significant decrease in the dimensional and weight characteristics of the designed model, while the heating time of the roasting surface is more than 8.7 times.

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