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DESIGN OF AN APPARATUS FOR LOW-TEMPERATURE PROCESSING OF MEAT DELICACIES

Andrii Zahorulko
Corresponding author
PhD, Associate Professor*
E-mail: zagorulkoAN@hduht.edu.ua
Oleksander Cherevko
Doctor of Technical Sciences, Professor
Department of Processes and Equipment Food and Hospitality-Restaurant Industry named after M. Belaev
Kharkiv State University of Food Technology and Trade
Klochkivska str., 333, Kharkiv, Ukraine, 61051
Aleksey Zagorulko
PhD, Associate Professor*
Marina Yancheva
Doctor of Technical Sciences, Professor, Head of Department
Department of Meat Technology**
Nina Budnyk
PhD, Associate Professor
Department of Food Production
Poltava State Agrarian University
Skovorody str., 1/3, Poltava, Ukraine, 36003
Yuliya Nakonechna
PhD, Associate Professor***
Natalia Oliynyk
PhD, Associate Professor***
Nadia Novgorodska
PhD, Associate Professor
Department of Food Technologies and Microbiology
Vinnytsia National Agrarian University
Sonyachna str., 3, Vinnytsia, Ukraine, 21008
* Department of Equipment and Engineering of Processing and Food Production**
** State Biotechnological University
Alchevskykh str., 44, Kharkiv, Ukraine, 61002
***Department of Technology of Food Production and Restaurant Management
Poltava University of Economics and Trade
Kovalia str., 3, Poltava, Ukraine, 36003

Culinary meat products, in particular, delicacies, account for a significant share of the diet in many countries of the world, predetermining the need to introduce innovative solutions for the production of products of a wide range of use with original taste properties.

A structure of the device for low-temperature processing of meat delicacies involving the heating of the working surface with a flexible film resistive electric heater of radiative type has been developed. Temperature control is carried out with a needle thermocouple. That makes it possible to cool the delicacy to 25...30 °C by autonomous fans during the conversion of secondary thermal energy by Peltier elements. It was established that the low voltage at the temperature of 70...80 °C is 4...6 W, and, at 25...30 °C, it is, respectively, 1.5...3 W. A comparative analysis has been performed of the heat treatment of meat delicacy in the traditional way and in the developed apparatus upon reaching 71...75 °C inside the product.

The temperature for a traditional machine, after 5 minutes of processing, is 15...17 °C at the contact surface and 8 °C at the center. For the model structure, the temperature of the contact surface is 7...8 °C, and 4...5 °C in the center. After 25 minutes of processing in the traditional way, the temperature in the center was 17...18 °C, in the near-wall layers – 60 °C. In the model structure, 8...9 °C, at a temperature of the near-wall layers of 25 °C. The temperature difference from the center to the near-wall layer, depending on the processing time in the traditional way, ranges from 10 to 50 °C, and, in the model apparatus, from 4 to 24 °C. The model device provides a uniform heat supply under conditions of achievement of 71...75 °C in the center of a product with a reduction of specific cost by 2.6 times in comparison with a traditional technique. The ham prepared in the developed apparatus is characterized by uniform coloration, juiciness, and natural original taste

Keywords: meat delicacies, low-temperature processing apparatus, temperature field, secondary energy, Peltier elements

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1. Introduction

Meat products are one of the main food items in many countries around the world, manufactured according to a variety of culinary and industrial technologies using heat and mass exchange equipment. The range of meat delicacies can be presented in a variety of forms, in particular ham, pate, roll, saltison, etc., which are produced using technologies known in the years of our era [1–3]. A significant impact on the technological quality of meat delicacies production is exerted by equipment for heat and mass-exchange processing of products, which must meet modern resource-efficient requirements [4]. This approach requires constant development of food industry processes towards improving existing struc-

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tural and technological solutions to ensure the production of high-quality meat delicacies when using resource-efficient equipment. Achieving resource efficiency in the production of meat delicacies is possible under the conditions of the use of modern heating elements with low energy and metal consumption, regulated temperature influence, ease of maintenance, and ensuring the possibility of using secondary energy.

Therefore, it is a relevant task to design an effective apparatus for low-temperature processing of meat delicacies when using a modern resource-efficient heater of the radiative type, characterized by portability, functionality to ensure the original organoleptic properties of meat delicacies.

2. Literature review and problem statement

Paper [5] reports a study into the heat treatment of meat products at a temperature of 50...65 °C over a long period, characterizing low-temperature culinary processing. That makes it possible to give the meat product a more gentle and better appearance than when cooked at higher temperatures. However, consumers have concerns about the possibility of achieving not only the culinary readiness of the product but also ensuring microbiological safety since heat treatment causes a change in the structure of meat and its components. Denaturation, aggregation, and degradation of connective tissue proteins occur depending on the duration and temperature of heat treatment. However, questions remain about the impact of existing equipment on the quality of heat and mass exchange operations for the production of meat products. Thus, paper [6] reports practical studies aimed at determining the rational conditions for heat treatment of meat raw materials in the temperature range of 51...100 °C when comparing the baking and cooking process in water. The chemical analysis presented in the paper reveals that with an increase in temperature in the center of the sample, due to an intensive decrease in humidity, an increase in the content of fat, ash, proteins, and minerals is ensured. At the same time, the optimum temperature in the center of the pork product is within 71...81 °C. However, the impact of the structural component of the implementation of heat treatment on the resulting quality of the received product due to the highly specialized equipment and the need to implement resource-efficient technologies remains unaddressed.

Work [7] reports a study into the analysis of nutritional value and factors affecting the final quality and safety of the use of traditional meat products. The study results revealed various problems associated with the use of classical technologies and equipment, which, in its design and technological features, is not fully able to ensure the versatility of the production of meat delicacies. Therefore, there is a practical and scientific task to form ways to improve the effective heat and mass exchange equipment. Thus, paper [8] presents comparative studies of the heat treatment of chicken meat in a convective furnace and the technology of sous-vide, followed by a study of the quality obtained. It was found that the use of sous-vide technology at 60 °C lasting for 1 hour is characterized by lower production losses and high rates of tenderness in comparison with samples obtained in a convective furnace. However, the reported results are mostly aimed at determining the technological component leaving the technical component unattended, in terms of the uniformity of heat supply, the degree of juice loss, and the efficiency of the equipment used, in particular the steam bath in the sous-vide technology. For example, work [9] provides a hardware-technological solution aimed at the development of a device for low-temperature processing of meat products by IR radiation in a gentle temperature range of 63...85 °C indicating the received organoleptic properties. However, the structure is characterized by a certain range of products and does not make it possible to produce a wide range of meat culinary products, which, in turn, requires research to minimize the geometric impact on the technological process.

Works [10, 11] describe research aimed at determining the effectiveness of the baking process of meat products compared to sous-vide technology when cooking in a steam bath. That confirms the effectiveness of the sous-vide technology, however, the use of steam baths or cooking in liquids greatly complicates the structural component due to the complexity of the process implementation and temperature control. This, in turn, to some extent affects the resulting quality of the product. Specifically, work [12] investigates the effectiveness of low-temperature processing of meat products with a temperature of up to 85 °C in the steam convector using sonication. The proposed technology reduces the duration of heat treatment but no data are given regarding the efficiency of sonication equipment maintenance. Paper [13] investigates the impact of heat treatment of meat raw materials on the received quality, depending on the heat supply techniques, without taking into consideration the degree of heat supply uniformity. That may be due to the complexity of creating a uniform heat supply in classical devices for heat treatment of meat raw materials, due to the design properties of the working chamber and heat source, for example, heaters, steam, water, etc. The most uniform geometric chambers are spherical and cylindrical, but they require the use of flexible and resource-efficient technologies to ensure the uniformity of the heat flow; in particular, in work [14], uniformity in the cylindrical apparatus is investigated. Uniformity of the cylindrical surface is ensured by modern resource-efficient flexible film resistive electric heater of radiative type (FFREhRT) [15], which has low energy and metal consumption, ease of use, and maintenance. An important component of modern heaters is the introduction of technologies for the use of secondary energy for cooling or the generation of low-voltage power, in particular for exhaust fans due to the properties of Peltier elements [16, 17]. That gives relevance to research into the development of low-temperature equipment for meat delicacies while the practical implementation of modern innovative solutions could ensure the design of fundamentally new equipment with a wide range of use in the food sector and home life. Most existing technological equipment for the production of meat delicacies in the market has some design and technological shortcomings. For example, there are difficulties with heat supply, namely in the case of using a standard device for cooking ham, the capsule with raw materials is partially immersed in water and heated by it [18]. This makes it difficult to control the temperature of the gas or electric heating of the water heat carrier with the submerged capsule, and hence the unevenness of cooking, in particular during the aging of the delicacy to full readiness.

Existing devices cannot use secondary energy to ensure the autonomy of any auxiliary elements, thus allowing us to state some of the main structural and technological tasks to improve the production of meat delicacies, in particular, the apparatus should provide for the following:

– the uniformity of heat treatment of the entire volume of meat delicacy under the conditions of accurately controlled heating;

– the pressing of meat raw materials during heat treatment, followed by cooling of the finished culinary delicacy.

Ensuring these conditions is the creation of an efficient device for low-temperature processing of meat delicacies with resource-efficient properties, portability, and ease of use due to infrared heat treatment. The use of such a device could solve the issue of uniform heat and mass exchange processing of meat raw materials, ensuring the expansion of market assortment due to the production of delicacies with original taste properties.

3. The aim and objectives of the study

The purpose of this work is to design an effective apparatus for the low-temperature processing of meat delicacies through the use of IR heat treatment and the use of secondary energy. This would make it possible to intensify the process of low-temperature treatment of meat raw materials based on modern approaches to the production of high-quality delicacies in various food areas with the expansion of the range.

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

– to design a model structure of the apparatus for low-temperature processing of meat delicacies with a flexible film resistive electric heater of radiative type and Peltier elements for converting secondary heat energy into low-voltage supply voltage of exhaust fans;

– to determine the effectiveness of the designed device and the organoleptic properties of ham compared to the traditional culinary processing technique.

4. The study materials and methods

The experimental and practical research on determining ways to improve the apparatuses of heat treatment of meat products, in particular for the development of a modern apparatus (portable, mobile, and easy to operate) designed for low-temperature processing of meat delicacies was performed at the scientific and educational center “Newest biotechnology and equipment for the production of food products with high wellness properties” at the State Biotechnological University (Ukraine).

To determine the uniformity of a temperature field generated by FFREhRT, pork meat was used in the model structure for the further production of ham. The ham preparation technique involved preliminary rinsing of the raw materials, followed by slicing in sizes of 10×10 mm and 0.5×0.5 mm to obtain a homogeneous dense structure in the formation. NaCl and spices were added to the chopped pork, followed by stirring and maturation in the fridge for 2.0...3.0 hours. Next, the meat raw materials were laid in the shell of the model structure, closed with a lid for further heat treatment (cooking) in natural juice until reaching 71...75 °C in the center of the product. After culinary readiness, we cooled it to 25...30 °C for selling.

Temperature control and regulation were carried out by the eight-channel thermostat “OVEN” (Ukraine) with the help of needle thermocouples.

5. Studying the effectiveness of structural solutions in the apparatus to produce meat delicacies

5. 1. Designing a model structure of the device for low-temperature processing of meat delicacies

The designed model structure of the apparatus for low-temperature processing of meat delicacies (Fig. 1) consists of cylindrical working container 1, which acts as a molding capsule to give the geometric shape of the received product. In the capsule, the formation (pressing) of meat delicacies, made according to any formulation ratio and in the conditions of stuffing raw materials in the shell, is carried out. At the bottom of the machine, centrally distributed spring 2 is connected to disk pressing platform 3.

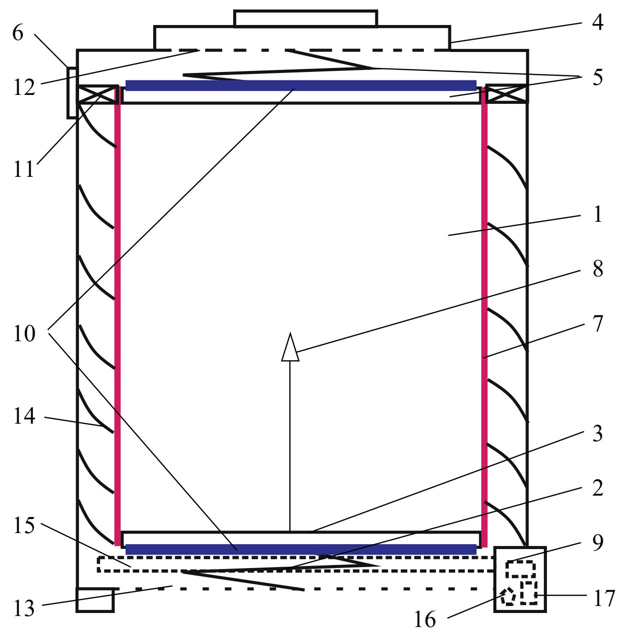

Fig. 1. Schematic of the designed model structure of the apparatus for low-temperature processing of meat delicacies: 1 — cylindrical working container (molding capsule); 2 — spring; 3 — disk pressing platform; 4 — cover with a spring cylindrical surface; 5 — spring loaded cylindrical surface 6 — clamps; 7 — flexible film resistive electric heater of radiative type (FFREhRT); 8 — needle thermocouple; 9 — TPM thermostat; 10 — contact surface of Peltier elements; 11 — exhaust fans; 12, 13 — fresh air intake and drainage holes; 14 — airflow guides; 15 — capacity for technical fluid; 16 — technical fluid drainage nozzle; 17 – control unit

After loading the meat raw materials into capsule 1, it is closed with lid 4 with spring cylindrical surface 5 with the help of latch 6. The working surface is heated by FFREhRT 7, which repeats the cylindrical shape of tank (capsule) 1 and acts as a working surface at the same time. Temperature measurement in the apparatus is carried out with needle thermocouple 8, which is mounted in the center of lower disk pressing platform 3 and connected to thermostat TPM 9, made by “Oven” (Ukraine).

Low-temperature processing of meat raw materials is carried out until reaching 71...75 °C in the center of the product by FFREhRT (7). In this case, the device can further cool the delicacy to 25...30 °C by blowing the outer surface of the working capsule with air coming through holes 12 and is injected with exhaust fans 11. Air movement is carried out according to the screw trajectory around capsule 1 by flow guides 14, followed by the removal of air to the environment through holes 13. Exhaust fans work autonomously after reaching 71...75 °C in the center of the product by the conversion of thermal energy from Peltier elements located at contact surface 10. It was established that the low voltage at the temperature of the contact surface of Peltier elements of 70...80 °C is 4...6 W, and, at a temperature of 25...30 °C, it is, respectively, 1.5...3 W, enabling the autonomous operation of exhaust fans. In the lower part of the apparatus, under disk pressing platform 3, there is technical container 15 for collecting liquid fraction in the case of partial juice removal from the meat product, followed by discharge through nozzle 16. At the bottom of the machine, there is a heat control unit 17 with a built-in thermostat, technical liquid draining nozzle 16, a control unit for Peltier elements and exhaust fans.

5. 2. Determining the effectiveness of the designed apparatus and the organoleptic properties of culinary products

To confirm the effectiveness of the structural and technological decisions taken during the design of the apparatus for low-temperature processing of meat delicacies, one of the main tasks is to ensure uniform distribution of heat flow, and, therefore, the heating of raw materials. Information on the temperature field of the prototypes was recorded with needle thermocouples every 30 minutes; the distance between thermocouples was 20 mm (the diameter of the product is 120 mm). The thermocouples were placed in the transverse section of the product along the axis of diameter. The proposed arrangement of thermocouples (Fig. 2, *a*, pos. 1) made it possible to determine the resulting uniformity of the distribution of heat flow in the prototype, in particular, during the use of the designed model of the apparatus for low-temperature processing of meat delicacies.

To confirm the uniformity of the temperature field in the low-temperature apparatus using the "Oven" software connected to the TPM and 7 needle thermocouples and pre-set temperature at 70 °C. The average total temperature of the experimental space of the device is within ±1 °C, which is a confirmation of the uniformity of temperature control over the volume of the apparatus when using FFREhRT (reading thermocouple numbers is carried out from left to right, according to Fig. 2, *a*).

Experimentally and practically, the process of thermal treatment was investigated, using the example of meat delicacy, ham, prepared in the traditional way (cooking in the volume of water) and processing in the designed apparatus based on FFREhRT. The ham was heated under the conditions of achieving 71...75 °C in the center of the meat product with the measurement of the temperature field by 7 needle thermocouples, located according to the scheme shown in Fig. 2. We obtained temperature distribution curves with the change of time for prototypes made in the traditional way (Fig. 3, *a*) and in the designed model structure of the apparatus for low-temperature processing of meat delicacies (Fig. 3, *b*). It was established that the actual temperature of the prototypes after 5 minutes of processing, for a traditional device, at the contact surface of the product, is 15...17 °C with a temperature in the center equal to 8 °C (Fig. 3, *a*, curve 1). In the model structure, the temperature of the contact surface is 7...8 °C; in the center – 4...5 °C (Fig. 3, *b*, curve 1).

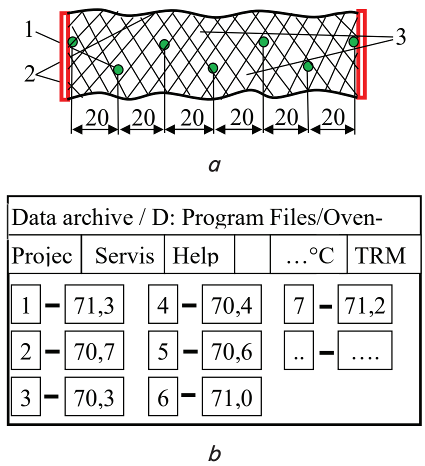

Fig. 2. Experimental and practical determining of the temperature field in the transverse section of the experimental meat delicacy – ham: *a* – layout of thermocouples: 1 – needle thermocouple, 2 – fragment of the working chamber area with the heating surface, 3 – the transverse section of the experimental meat delicacy; *b* – data from needle thermocouples connected to TPM in real time using the software "Oven"

After 25 minutes of processing, the temperature of the sample with the traditional production technique in the center of the product was 17...18 °C (curve 2 in Fig. 3, *a*), and in the model structure – 7...9 °C (curve 2 in Fig. 3, *b*). At the same time, the temperature of the near-wall layers of the ham prototypes using the traditional technique is 60 °C, that is, it actually increased by 4 times, in the model sample, 25 °C, it, respectively, increased by 2.5 times. The temperature curves (3–7 in Fig. 3, *a*) of production in the traditional way are characterized by temperature fluctuations within 2...5 °C with the achievement at the end of the process of the temperature of the near-wall layer of 75 °C. Starting from minute 50 of heat treatment of the sample produced in the traditional way, the predicted alignment and reduction of the difference between the near-wall and central layers is observed (Fig. 3, *a* – curves 3–7).

At the same time, the difference in the temperature of the near-wall layers during heat treatment in the model apparatus (curves: 3–6 in Fig. 3, *b*) is 7...12 °C, between the curves. Temperature curves 7–9 (Fig. 3, *b*) demonstrate uniform temperature fluctuations with the achievement of 71...75 °C. At the end of the process, the temperature field of ham samples is actually the same (Fig. 3, *a*, *b* – curves 7, 9) with a minimum temperature difference of about 8...10 °C. Therefore, we can conclude that the temperature field is uniform as, therefore, the heat treatment of meat delicacies in the model structure of the device for low-temperature processing based on FFREhRT. As a result, high quality of the obtained products is ensured with simultaneous simplification of the heat supply technique and elimination of intermediate heat carriers, in particular cooking in water.

To confirm the effectiveness of the designed apparatus for low-temperature processing of meat delicacies in comparison with the traditional production technique (cooking in water), we have compared the characteristics of heat consumption (Table 1). The initial data for the calculation are the masses of the product, devices, and auxiliary equipment, as well as the starting temperature, and the average one, at the end of heat treatment of the finished product. The calculations were performed without taking into consideration the losses to the environment.

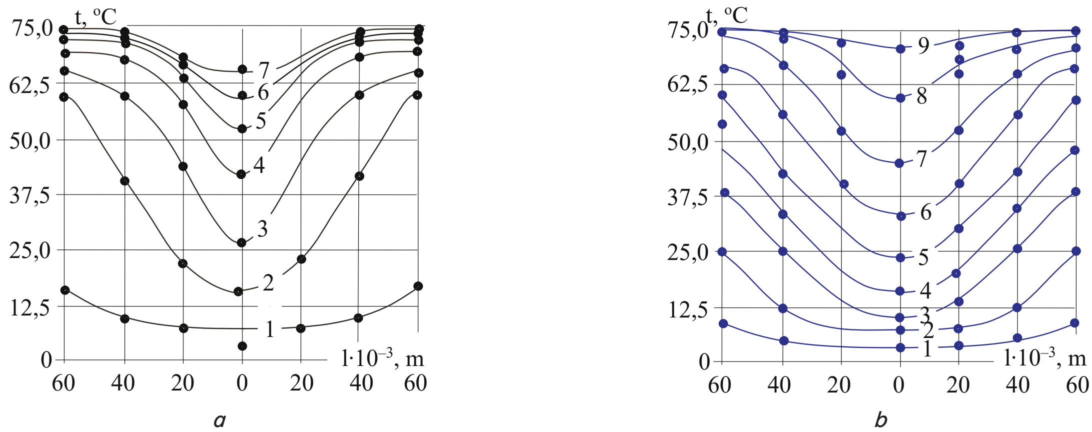

Fig. 3. Temperature distribution of ham prototypes depending on the duration of heating: *a* – in the traditional way; *b* – model apparatus, curves: 1 — 5 min; 2 — 25 min; 3 — 50 min; 4 — 75 min; 5 — 100 min; 6 — 125 min; 7 — 150 min; 8 — 175 min; 9 — 200 min

Table 1

Comparative characteristics of the apparatus for low-temperature processing of meat delicacies compared to the traditional device to produce ham

Indicator	Traditional apparatus for making ham	Apparatus for low-temperature processing of meat delicacies
Apparatus weight	m=0.35 kg	m=0.45 kg
Apparatus heating	$Q_h=m_1c_{raw}(t_2-t_1)$=0.35·0.48(100–20)=13.5 kJ	$Q_h=m_1c_{raw}(t_2-t_1)$=0.45·0.48(68–20)=10.3 kJ
The cost of achieving the culinary readiness of the product	$Q_{pr}=mc(t_5-t_4)$=1.16·3056·(71–15)=198.5 kJ	$Q_{pr}=mc(t_6-t_4)$=1.16·3056·(68–15)=187.8 kJ
Auxiliary equipment heating	$Q_a=mc(t_2-t_7)$=1.5·0.48·(100–25)=54 kJ	–
Heating of water in additional equipment	$Q_w=mc(t_2-t_7)$=3.0·4200·(100–25)=245 kJ	–
Total amount	$Q=Q_h+Q_{pr}+Q_a+Q_w$=13.5+198.5+54+245=511 kJ	$Q=Q_h+Q_{pr}$=10.3+187.8=198.1 kJ
Specific cost	$q_{pr}=Q/m$=511/1.16=440 kJ/kg	$q_{pr}=Q/m$=198.1/1.16=170 kJ/kg

*Note: *Temperature, °C: t_1 – initial for devices; t_2, t_3 – devices at processing; t_4 – initial for products; t_5, t_6 – medium, for a product of culinary readiness; t_7 – initial for auxiliary equipment and heating medium (water)*

We have established by calculation that the specific cost of making ham in the apparatus for low-temperature processing of meat delicacies, compared to the traditional apparatus, is 2.6 times less (Table 1), thereby confirming the effectiveness of the proposed solutions. In addition, an organoleptic evaluation of the ham was carried out by a group of experts from the State Biotechnological University (Table 2).

The organoleptic indicators confirm the effectiveness of the use of the device for low-temperature processing of meat delicacies that ensures uniform coloration and a juicy original taste at the same time.

Further practical application of the reported experimental study could ensure expanding the range of meat delicacies made according to a variety of recipe technologies, with the possibility of introducing a variety of dried products into their composition to give products original taste properties. The resulting products would also be characterized by the juiciness, aroma, and properties of real meat. At the same time, non-compliance with technological and design recommendations when using the apparatus for low-temperature processing based on FFREhRT, in particular, the application of meat without pre-pickling could lead to a change in the resulting organoleptic properties of delicacies.

Our scientific and practical results confirm the expediency of further use of the designed apparatus at hotel and restaurant establishments and at home. The structural and technological advantages of the designed apparatus are resource efficiency, simplification of the heat supply system with the provision of a uniform temperature field due to the use of FFREhRT, the simplicity of design, and mobility.

Table 2

Organoleptic evaluation of ham prototypes

Indicator	Characteristics of the made ham	
	in a traditional way	in the apparatus for low-temperature processing of meat delicacies
Physical appearance	uniform meat substance	uniform meat substance
Taste and aroma	pork taste with natural smell and hard crust of the product	pronounced natural taste and smell of pork with uniform juiciness of the product
Color	the outer surface of the product has a darker section compared to the center of the product	the color of the product throughout the volume has a red-grayish tint
Consistency	the crust has stiffness and less juiciness compared to the center of the product	homogeneous meat consistency with uniform juiciness of the product

6. Discussion of results of meat delicacies production in the designed apparatus

The results of the research confirm the effectiveness of the previously proposed design and technological solutions for the development of an apparatus for low-temperature processing of meat delicacies by IR radiation based on FFREhRT. The innovative solution proposed during the design of the apparatus has made it possible to simplify the heat supply system, eliminate the use of intermediate heat carriers and, in general, reduce energy and metal consumption while ensuring the most uniform temperature field.

The designed model structure of the device for low-temperature processing of meat delicacies makes it possible to press the product in a working capsule, which is heated by a flexible film resistive electric heater of the radiative type that repeats the geometry of the chamber (Fig. 1). The device also has the ability to cool the delicacy to 25...30 °C by blowing the outer surface of the capsule with air from stand-alone fans, powered by the conversion of thermal energy by Peltier elements (Fig. 1, position 10). The low voltage at 70...80 °C is 4...6 W, and, at a temperature of 25...30 °C, it is, respectively, 1.5...3 W. The uniformity of the temperature field in the low-temperature apparatus according to the data from 7 needle thermocouples with a pre-set temperature at the level of 70 °C (Fig. 2, *a*) has been proven. We have performed a comparative analysis of the thermal processing of meat delicacy made in the traditional way (cooking in the volume of water) and in the designed apparatus based on FFREhRT when achieving 71...75 °C in the center of meat product. The temperature after 5 minutes of processing, for a traditional machine, is 15...17 °C at the contact surface; the temperature in the center is 8 °C (Fig. 3, *a*, curve 1). For the model structure, the temperature of the contact surface is 9...10 °C, and in the center – 3...4 °C (Fig. 3, *b*, curve 1). After 25 minutes of processing in the traditional way, the temperature in the center of the product was 17...18 °C, in the near-wall layers – 60 °C, that is, it actually increased by 4 times. In the model structure, 8...9 °C, with the temperature of the near-wall layers of 25 °C, with an increase by 2.5 times (Fig. 3, *a, b*, curves 2).

The temperature difference in the prototype from the center to the near-wall layer, depending on the processing time in the traditional way, is from 10 to 50 °C, and in the model apparatus – from 4 to 24 °C (Fig. 3, *a, b*). Such data indicate a more uniform temperature effect in the model apparatus under conditions of reaching 71...75 °C in the center of the product.

Thus, we can conclude that the temperature field is uniform, as well as, therefore, the heat treatment of meat delicacies in the model structure of the device for low-temperature processing based on FFREhRT. The effectiveness of low-temperature processing of meat delicacies has been confirmed by calculating specific costs, which are 2.6 times less compared to the traditional technique (Table 1). The evaluation of the organoleptic indicators of ham also demonstrates better indicators of the low-temperature technique. The products obtained in the designed device are distinguished by the uniform coloration, juiciness, and natural original taste, unlike the traditional one where such high quality is not achieved (Table 2).

The introduction of the innovative design-technological solution, in comparison with analogs, could ensure the intensification of low-temperature processing of meat delicacies, providing a partial solution to the problem of optimizing the relationship between the technological and structural components of the thermal process. That would ensure the expansion of the range of meat delicacies from a variety of raw materials in the designed apparatus for the food industry and at home, providing a modern approach to the implementation of the production of quality delicacies in various areas of nutrition.

The device proposed for practical implementation for low-temperature processing of meat delicacies is easy to use, portable, and effective due to the simplified heat supply system when using FFREhRT, and does not require professional knowledge. It should be noted that the quality of previous operations with meat raw materials, in particular at marinating, largely affects the final quality of the delicacies received. Further research is planned to be carried out in order to maximize tweaking the designed apparatus for the production of a diverse range of meat delicacies. At the same time, it is planned to study the effectiveness of the introduction of dried organic semi-finished products produced using effective technologies [19, 20] to ensure high-quality and original organoleptic properties.

7. Conclusions

1. A model structure of the apparatus for low-temperature processing of meat delicacies has been designed, consisting of a cylindrical capsule for forming the shape of the product. The working surface is heated by a flexible film resistive electric heater of the radiative type that repeats the cylindrical shape of the capsule. Temperature control is executed with a needle thermocouple connected to TPM until reaching 71...75 °C in the center of the product. At the same time, there is the possibility of cooling the delicacy to 25...30 °C by blowing the outer surface of the capsule with air. In this case, exhaust fans work autonomously powered by the secondary thermal energy converted by Peltier elements. It was established that the low voltage at a temperature of 70...80 °C is 4...6 W, and, at a temperature of 25...30 °C, it is, respectively, 1.5...3 W.

2. We have confirmed the uniformity of the temperature field in the low-temperature apparatus using 7 needle thermocouples at a temperature of 70 °C with slight temperature fluctuations within ±1 °C. A comparative analysis of the heat treatment of meat delicacy in the traditional way (cooking in the volume of water) and in the designed apparatus based on FFREhRT upon reaching 71...75 °C in the center of the product. The temperature after 5 minutes of processing, for a traditional machine, is 15...17 °C at the contact surface, and the temperature in the center is 8 °C. For the model structure, the temperature of the contact surface is 9...10 °C; in the center – 3...4 °C. After 25 minutes of processing in the traditional way, the temperature in the center of the product was 17...18 °C, in the near-wall layers – 60 °C, that is, it actually increased by 4 times. In the model structure, 8...9 °C, with the temperature of the near-wall layers of 25 °C, with an increase by 2.5 times.

Consequently, the temperature difference from the center to the near-wall layer, depending on the processing time, in the traditional way, ranges from 10 to 50 °C, and in the model apparatus – from 4 to 24 °C. Thus, a uniform heat supply is provided in the model apparatus under the conditions of reaching 71...75 °C in the center of the product, as well as a reduction of specific costs by 2.6 times, compared to the traditional technique. The ham that was made in the designed apparatus is characterized by uniform color, juiciness, and natural original taste.

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