1. Introduction

The constant demand for meat products in many countries of the world stimulates the development of food industry by improving equipment for thermal treatment of various meat raw materials [1]. One of the major tasks of improvement of the heat treatment of meat raw materials is to reduce the technological losses of products' weight at all stages of their production with simultaneous ensuring high quality indicators. This is only possible under condition of using low-temperature treatment of meat raw materials using modern low-power and low metal consumption heating elements, specifically, based of infrared radiation. It is also possible to use various structural elements, particularly
those that turn heat into the supply voltage to ensure the autonomy of the auxiliary apparatus equipment. It should be noted that low-temperature treatment of meat products in the range of 63...85°C makes it possible to obtain high-quality semi-finished meat products even from problem meat with great content of tendons [2].

Therefore, an urgent task is to develop a modern plant for low-temperature treatment of meat products by IR-radiation. This plant must be mobile, portable and ensure high-quality manufacturing of meat products with the original organoleptic properties.

2. Literature review and problem statement

A daily increase in demand for high-quality meat semi-finished products with the original organoleptic properties among the population of many countries in the world causes the development of the meat industry in Ukraine [3, 4]. It is the taste of meat products that is the main indicator of their quality and allows increasing the market consumer demand, which prompts the need for a detailed study of the technological parameters and their impact on the finished product [5]. Therefore, there occurs the need to improve not only the technological process, but also the equipment for its implementation, since in most cases it is energy- and metal-consuming and technologically outdated. In particular, the use of inertial high-temperature heaters with reflector units leads to appearance of non-uniform heat flow. This causes the formation of a crust and degrades the quality of the product, which is inadmissible during low-temperature treatment of most meat products. It is necessary to solve he problem whether it is possible to benefit from using low-temperature thermal energy for apparatus-technological purposes. To solve the existing structural and technological tasks, it is required to apply an innovative approach, developing a plant for low-temperature treatment of meat products by IR-radiation.

In most countries, there is a widespread use of low-temperature treatment of meat raw material, since it ensures obtaining high-quality culinary products with original taste properties [6]. The classic methods for low-temperature treatment of meat raw material include cooling, which has three variants: slow, fast and “shock” [7]. However, in most cases cooling is characterized by high energy consumption, technical difficulty and capital costs of its implementation, in this case, it makes it possible to obtain the product that is ready to use [8, 9]. Today a more modern method of low-temperature treatment of meat products is Sous vide, which is based on cooking food by its vacuuming and keeping in a water bath [10]. However, the technology of Sous vide has not been fully studied in terms of the influence of different technological factors on physical and chemical changes of the treated raw materials [11]. There also occur certain technical difficulties associated with using a water bath and controlling temperature and mode parameters in it. This causes a further search for the ways to improve this technology.

During manufacturing meat products, there are certain temperature dependences that characterize the degree of their culinary readiness and depend on the type of raw materials. After defrosting, raw materials get into the “danger zone”, which is characterized by the temperature range from +5 to + 60 °C. To ensure the safety of meat products, they are subjected to heat treatment. In the range of treatment of 30...45 °C, there occurs fat softening, depending on the type of raw material, as well as the inevitable development of bacteria. Deceleration of the bacteria development and their drying are observed during treatment in the range of 53...58 °C. For example, beef becomes safe for consumption after being approximately for 1.5 hour at the temperature of 55 °C [12].

The basic temperature of meat products treatment is 60 °C, which leads to a change in the color of meat raw material, due to the destruction of proteins of myoglobin. Meat juice loses its coloration with simultaneous maximum destruction of bacteria. The increase in temperature up to 74 °C leads to instant destruction of bacteria and the loss of coloration, and up to 86 °C – causes collagen disintegration and gelatin formation. The temperature above 100°C in most cases is considered not suitable for meat products treatment, because it leads to collagen boiling, the break of intercellular ties and the loss of taste properties. Meat products are considered to be safe if the following temperature is achieved in their center: for pork – 53...65 °C; for poultry – 55...80 °C, for beef (mutton) – 55...83 °C, depending on the structure [12–13].

The ISTOMA stoves for low-temperature treatment of pork are represented in the markets of modern equipment. They are designed for stewing, hot and cold smoking and even storage. According to the design and technological characteristics, they are able to ensure the reduction of losses during heat treatment, incredible taste properties and do not require pipelines [13]. For heat treatment, designers use low-temperature flexible cables that ensure the system of 3D heating instead of high-temperature electric heaters [13]. Reflector panels are used for more uniform thermal radiation in a rectangular chamber, which leads to an increase in metal consumption of the equipment. Vapor and convectomates, even with ultrasonic vibrations, are widely used in addition to these stoves [14]. However, the plants of this design are costly to maintain because of the structural implementation of processes. To some extent, it prevents their wide use, especially in the household. It causes the need for finding innovative solutions to simplify the design and technological process as a result of using more effective radiating elements. It is also appropriate to introduce the autonomy of separate units of the plant with the use of the minimum of automation or entirely without it. This will ensure the ease of maintenance, mobility, ease of use and a decrease in the cost of low-temperature plants.

Among modern energy- and metal-efficient radiating elements, a flexible film resistive electric heater of radiative type (FFREhRT) is most widely used [15]. Taking into consideration the design and technical parameters, presented in paper [16], it is the reasonable solution for the creation of modern low-temperature plants of the reflector-free type.

The autonomy of the structural elements is ensured by a variety of additional elements, such as converters, in which design and technological process and driving energy are applied. During heat treatment, the driving energy is the thermal energy, the conversion of which can later be used to ensure the autonomy of certain structural elements in combination with the plant. Peltier elements are used in most cases for the conversion of thermal energy, for example, into low-voltage of supply, and the simultaneous cooling the external structural surfaces. The advantages of these elements for the conversion of thermal energy into the supply voltage are considered in detail in paper [17], which proves the earlier hypothesis about their effective use.
Most of the existing technology and culinary equipment for low-temperature treatment of meat products is characterized by specific design and technological shortcomings. The basic among them is the use of inertia, energy- and metal-intensive heating elements with reflective units that fully do not provide uniform heat distribution. In this case, only separate plants are autonomous in terms of the use of secondary heat for technological needs. This negatively leads to a decrease in the types of meat products treatment and affects their organoleptic properties. Food industry engineers today are challenged with finding innovative design solutions to carry out low-temperature treatment of meat products. This causes the need for the development of a modern mobile and portable plant for low-temperature treatment of meat products by IR-radiation. Using this equipment, it is possible to process more kinds of meat, thereby expanding culinary products with original taste properties. And its use will be characterized by simplicity and autonomy.

3. The aim and objectives of the study

The aim of this study is to develop a modern mobile and portable resource saving plant for low-temperature treatment of meat products by IR-radiation.

To achieve the set goal, the following tasks were solved:
- to substantiate the possibility of using flexible film resistive electric heater of radiative type and Peltier elements for the development of mobile and portable resource effective plant;
- to develop recommended mode parameters of low-temperature treatment of meat products and to conduct a comparative degustation assessment;
- to establish recommended temperatures of culinary readiness of various meat products (in the center of the product) during low-temperature treatment and to perform comparative degustation assessment.

4. Materials, methods of research into multi-component natural compositions and experimental setup

Experimental-practical research aimed at the development of modern mobile and portable plant for low-temperature treatment of meat products by IR-radiation is conducted at the scientific and educational center “Innovative biotechnologies and equipment for manufacturing food products with high health properties” at Kharkiv State University of Food and Trade (Ukraine). Meat products before treatment are kept in aqueous solutions with spices, or the latter are manually applied to the surface of meat products, kept for some time and loaded to the operation chamber of the plant.

5. Development of a plant for low-temperature treatment of meat products by IR radiation

One of the proofs that the set practical and research aim was achieved is the possibility of using modern energy and resource effective elements based on infrared emitters and Peltier elements that provide heat conversion into low voltage of supply. The results of literary and practical analysis presented in paper [17] prove the possibility and effectiveness of FFREhRT during designing low-temperature infrared plants. This is due to the design and technological properties of FFREhRT, specifically, with its low-temperature and uniform radiative thermal surface. An important characteristic is the possibility of the formation of the working surfaces of the geometrically complex forms without using additional metal structures and reflective surfaces. In this case, FFREhRT has low inertia, energy and metal effectiveness compared to other radiative heating elements.

Thermal energy conversion into low-voltage of supply due to the use of Peltier elements can ensure the autonomous operation of exhaust fans. At the same time, the use of Peltier elements can also provide cooling of the internal space of the plant, thus eliminating the need for insulation of the plant. Introduction of innovative solutions ensured the development of fundamentally new low-temperature plant. This plant is characterized by mobility, portability and practical effectiveness of use in the hotel and restaurant industry and household.

The next stage is the development of the plant for low-temperature treatment of meat products by IR-radiation (Fig. 1), consisting of the operation chamber, that includes two pivotally connected vertical thermally non-insulated semi-spherical halves: hinged 1 and fixed with counterweight 2, pivot 3, rod for meat product fixing 4, needle thermocouple (TPM) 5, connected to the thermoregulating device (measuring temperature regulator with needle thermocouple), FFREhRT 6, absorbing screen (black) 7, Peltier elements 8, exhaust fans 9, technical openings 10 and technical space, connected to cumulative capacity 11.

![Diagram of the developed plant for low-temperature treatment of meat products by IR-radiation](image-url)
this case, FFREhRT 6 is connected to the thermo-regulating plant with needle thermocouple 5 to control thermal treatment of the meat product.

The heat that is formed on the outer part of the FFREhRT 6 is absorbed by black absorbing screen 7. Peltier elements are located at the external side of the screen. They ensure the conversion of the heat, obtained by conductive method from absorbing screen 7, into low voltage of supply (~3...4 W), which is used for the operation of exhaust fans 9, mounted in through openings. During the research, it was discovered that the supply voltage is generated in case of reaching the temperature of a meat product within 30...35 °C. In this case, the temperature on the outer surface of Peltier elements is 10...15 °C. Exhaust fans 9 remove moist air from the operating space of the plant to the thermally non-insulated hinged halves 1, 2. Along with the transformation of voltage, Peltier elements ensure simultaneous cooling of the technical space of the vertical semi-spherical halves (1, 2), thereby eliminating the need for their thermal insulation. Moist air is removed from the operating space of the plant to the thermally non-insulated halves 1 and 2 and is gradually removed to the environment through technical openings 10. Meat juice that is produced during heat treatment is removed through the technical space, connected with cumulative capacity 11, in pivot 3.

As an example, we take the meat product with the addition of organic dried apricots and prunes (Fig. 3) and made its comparative degustation evaluation with the one purchased in trade network “TM Meat Standard” (Table 2).

In order to prove in practice obtaining the uniform distribution of the heat flow from FFREhRT and to ensure uniform heating of meat products, the measuring complex based on a spherical grid with located inside thermocouples was used in the developed plant. In this case, the thermocouples were connected to a personal computer (PC) and the measurement device “TMF”. According to the obtained results, FFREhRT ensures the uniform distribution of the heat flow without formation of a crust on the surface of meat products.

Taking into consideration the data as temperatures of readiness in the center of meat products, preliminary presented in analysis, the study of previously prepared various meat raw materials (pork, poultry, etc.) of the spherical shape with the diameter of 0.1±0.01 m was carried out. After loading them to the operation chamber of the developed plant, they were thermally treated until reaching the temperature of culinary readiness of the product. Specifically, the temperatures from 53 to 85 °C in the center of the product were reached, depending on the type of raw materials. The process of low-temperature treatment on the example of pork fillet; pork for fry; duck breast; mutton tenderloin and other tough beef is shown in Fig. 2.

As the diagram shows, the operating temperature proposed for the plant FFREhRT (90 °C) can be reached in 5 minutes, it is equal to the temperature in the operating chamber. Previously prepared spherical meat products had the initial temperature of 12 °C. It was found that pork fillet reaches 58 °C in the center of the product in 5.2 h; pork for roasts, respectively, reaches 80 °C in 8 h; duck breast meat (80 °C in 6 h); mutton tenderloin (60 °C in 5.5 h); any other tough beef, (80 °C in 6.2 hours). In addition to the studies, presented in the diagram (Fig. 2), other kinds of meat products were studied under conditions of achieving culinary readiness to establish their required safe temperature in the center (Table 1). It should be noted that due to using FFREhRT in the developed plant, the low-temperature treatment of meat products, maximum preservation of their natural properties, juiciness and, first of all, safety are ensured.

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advantages of the plant include, first and foremost, mobility, portability, resource efficiency, reducing the temperature influence on the raw material through the use of FFREhRT. In addition, it is important to ensure the autonomy of operation of exhaust fans through the use of secondary heat, in this case, the necessity to use insulation materials disappears.

Table 1
Temperature of culinary readiness of various meat products (in the center of the product) under condition of their low-temperature treatment in the plant (product diameter is 0.1±0.01 m)

| Type of meat raw material | Temperature of culinary readiness of the product (in the center of the product), °C | Duration of thermal treatment, h |
|---------------------------|----------------------------------------------------------------------------------|-------------------------------|
| Pork (tender meat)        |                                                                                  |                               |
| Meat from ribs            | 53.64                                                                            | 5.0...6.1                     |
| Fillet                    | 52.58                                                                            | 5.0...5.2                     |
| Other                     | 60.80                                                                            | 5.0...8.0                     |
| Pork (tough meat)         |                                                                                  |                               |
| Chop                      | 55.59                                                                            | 5.0...6.5                     |
| Meat for fry              | 60.80                                                                            | 6.0...8.0                     |
| Other                     | 65.80                                                                            | 5...9.5                       |
| Poultry                   |                                                                                  |                               |
| Fillet and chicken breasts| 65.71                                                                            | 4.5...5.0                     |
| Fillet and turkey breasts | 76.80                                                                            | 5.0...5.2                     |
| Fillet and duck breasts   | 75.80                                                                            | 5.6...6.0                     |
| Beef or mutton (tender meat)|                                                                                     |                               |
| Fillet                    | 55.60                                                                            | 5.0                            |
| Tenderloin                | 53.60                                                                            | 5.5                            |
| Chop                      | 55.59                                                                            | 5.0                            |
| Other                     | 62.80                                                                            | 5.0...8.0                     |
| Beef or mutton (tough meat)|                                                                                     |                               |
| Breast                    | 58.60                                                                            | 5.0...6.0                     |
| Other                     | 60.83                                                                            | 6.0...10                      |

Table 2
The results of degustation assessment of meat products

| Sample of meat product | Appearance | Consistency | Taste | Natural color | Smell |
|------------------------|------------|-------------|-------|---------------|-------|
| Meat product obtained in the plant for low-temperature treatment by IR-radiation | 5          | 5           | 5     | 5             | 5     |
| Purchased in a trade network (baked ham) | 5          | 4           | 4     | 4             | 5     |

Fig. 3. Photographs of meat product with the addition of dried organic raw materials, obtained in plant for the low-temperature treatment of meat products by IR-radiation: a — whole meat product; b — meat product that is cut through the center

6. Discussion of results obtained when making meat products in the developed plant

The results of the study prove the design and technological effectiveness of using the plant for low-temperature treatment of meat products by IR-radiation, specifically, ensuring the production of high-quality meat products with high organoleptic properties. The implemented innovative approach during designing the plant made it possible to reduce its energy and metal consumption, to achieve uniform heat flow due to the use of FFREhRT and obtaining low voltage of supply from the Peltier elements as a result of conversion of the secondary heat. The use of these plants is promising due to their mobility and portability.

The proposed plant provides energy efficient sparing low-temperature treatment, which generally provides the best taste properties of meat raw material, such as tenderness and juiciness.

The processes of low-temperature treatment of meat products in the vapor-convectomate by heating the operating chamber with high-temperature heaters were preliminarily studied. However, a certain difficulty of technical maintenance of these plants, the inertia of heating elements, metal consumption and high cost prevent their wide use. That is why we proposed the innovative solution for the development of the plant for low-temperature treatment of meat products by IR-radiation to ensure mobility, portability, and ease of use. The plant will be characterized by reduced price and is recommended to be used in the hospitality industry and the household.

The merit of this study compared to the existing analogues is primarily the creation of the innovative design and technological solution with the intensification of low-temperature treatment of meat products. This will ensure the expansion of the range of models of existing equipment for low-temperature treatment of meat products and increase their assortment due to the fuller use of raw materials. The introduction of the developed plant to the hotel and restaurant industry and households will provide a qualitative approach to low-temperature treatment of meat products at all stages of production of high-quality semi-finished products with the original taste properties.

The use of the plant for low-temperature treatment of meat products by the infrared radiation does not require special expertise. This is due to the fact that the use of FFREhRT with its properties and of Peltier elements provides ease of use, maintenance, autonomy and mobility. Special attention should be paid only to the previous preparations of meat products before their low-temperature treatment, because the quality of the products is affected not only by the characteristics of the plant, but also the raw material selected for the production.

The use of FFREhRT, as well as the possibilities of converting the secondary heat into low voltage of supply by Peltier elements, will generally provide low-temperature treatment of meat products, simplicity and portability of the plant.

Among the restrictions that are possible during these studies, it is possible to point out the necessity of formation of the spherical shape of the meat product in order to ensure uniform heat treatment. The shortcomings of the study include an insignificant change in the shape of meat products during heat treatment.

Subsequently, we are planning to carry out more detailed research to determine and test low-temperature mode pa-
rameters of heat treatment of various meat products in the
designed plant.

7. Conclusions

1. The plant for low-temperature treatment of meat
products by IR-radiation using FFREhRT is characterized
by low inertia, energy efficiency, a simplified circuit of con-
trol of the technological process. It provides a repetition
of the inner semispherical operation chamber of the plant.
The use of Peltier element provides an autonomous operation of
exhaust fans and eliminates the need for heat insulation of
the plant, reducing its metal consumption. Peltier elements
ensure a low voltage of supply if a meat product achieves the
temperature within 35...40°C. In this case, the temperature
on their outer surface is 15...20°C. The plant is resource
effective due to more sparing temperature treatment of meat
products for retaining their original taste properties.

2. The recommended temperatures of culinary readiness
of various meat products (in the center of the product) were
determined under conditions of their low-temperature treat-
ment in the plant. For tender pork, the treatment temperature is
53...80°C with the duration of 5.0...8.0 hours; for tough pork, it
is 55...80°C with the duration of 5.0...9.5 hours; for poultry, it is
65...80°C with the duration of 4.5...6.0 hours; for tender beef, it
is 55...80°C with the duration of 5.0...8.0 hours; for tough beef,
respectively, it is 58...83°C with the duration of 5.0...10.0 hours.
The results of degustation comparison of the meat samples
prove high organoleptic properties of the studied sample.

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