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DEVISING A TECHNIQUE AND DESIGNING AN APPARATUS FOR OBTAINING A MULTIFUNCTIONAL PURPOSE FILM FROM INTESTINAL RAW MATERIALS

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The object of research is a technique for making glued intestinal films for multifunctional purposes, which are further strengthened by a stitching apparatus using thermal coagulation.

This paper substantiates the technical and technological solutions for obtaining glued intestinal films that can be used for the manufacture of sausage casings and as a multifunctional material in the food industry.

The technique and apparatus for stitching intestinal raw materials were developed; the structural features of the apparatus and its rational operation modes were determined. The proposed technique involves stitching by thermal coagulation of intestinal films from beef belly, which belong to intestinal and sausage waste. The possibility of stitching intestinal raw materials, different in size, thickness, and species, is achieved, which allows preserving a valuable animal resource and increasing the efficiency of glued intestinal films technology.

The breaking load of the seam obtained by thermal coagulation was investigated and the rational ranges of stitching duration were determined. The breaking load of the seam was defined, which is a series of points that were subjected to thermal coagulation; its nonlinear change with a change in the distance between points was established. It was found that the values of the breaking load of the seam for the range of distance between the points that create it, from 5 to 20 mm, respectively, lie in the range from 17.5 to 15.0 N/m. This satisfies the technological requirements for the strength of the seam of glued intestinal sausage casings.

The influence of the distance between the points that create a seam between the layers of intestinal raw materials on the outflow of the liquid filling fraction for sausages from the sausage casing was established; the height of the liquid fraction, at which the outflow was considered significant, was determined

Keywords: intestinal raw materials, sausage casings, glued intestinal films, beef belly, thermal coagulation, breaking load

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1. Introduction

One of the most important components of the global concept of lean production is the elimination and reduction of residues and waste raw materials [1, 2]. Rational use of natural raw materials in food technology is given close attention, especially effective are solutions for resource saving in the production of meat industry products [3, 4].

Technologies of processing intestines of farm animals in order to obtain universal natural sausage casings and the manufacture of sausages are accompanied by a significant amount of waste and intestinal shortages (about 20 %), due to intensification in animal husbandry, lifetime and technological factors [5]. At the same time, deeper processing of unused residues of substandard intestinal raw materials into restructured food products is not always justified [6]. This is due to the need for significant physicochemical transformations, compared with the direct use of intestines as a natural protective container for minced sausages [7, 8]. From this point of view, the production of glued intestinal sausage casings could significantly and profitably reduce the share of residues and waste raw materials. And the introduction of effective techniques of strong and stable adhesion of segments and strips of intestinal products and their hardware design for the manufacture of bag and sheet film materials for multifunctional purposes is a relevant area of scientific research.

2. Literature review and problem statement

The main disadvantage of glued intestinal films is the insufficient strength of cohesion sutures in a humid environment, as a result of which they delaminate [9].

In [10], the effectiveness of the devised technique for obtaining glued intestinal membranes through the use of substandard raw materials has been proved, thereby reducing the cost of their processing, diversifying the shapes and sizes of shells, and increasing their strength. However, the issue of strengthening the cohesive seam of films remains unresolved since it is proposed to form strength by increasing the layers of intestinal bands and the direction of their location.

Paper [11] reports the results of the study into adhesion of segments of intestinal products using a laser; and [12] – high-frequency current. It is shown that it is possible to obtain sufficient bond strength. In this case, the disadvantage of this technique is the high cost of the equipment used, implementation only for bag segments of intestinal products. The structural features and rational modes of the devices remain unresolved.

Techniques and devices for reinforcing glued intestinal membranes by thermal coagulation and plant tanning have been developed. It was found that an increase in the breaking load value for reinforcing seams obtained by the proposed techniques for films made from pork belly products is achieved, by 4.0–6.0 times [13]. A decrease in the intensity of mass transfer of fried sausages in reinforced glued shells from pork bellies has been proved [14]. Along with this, the parameters of thermal coagulation and tanning for beef and mutton intestinal raw materials remain uncertain, due to differences in chemical composition, morphology, and physicochemical properties of beef, mutton, and pork intestines [15]. The direction and place of application of reinforcing seams does not coincide with cohesion seams but is carried out along a mutual perpendicular intersection in the longitudinal direction. In addition, these technical and technological solutions are intended for the manufacture of bag films, while the production of sheet film materials for multifunctional purposes from intestinal raw materials is more in demand due to their multisegmented applicability in the food industry.

Among known ways to increase the strength of materials of different nature and density, worth attention is such structural and technological techniques as profiling, corrugation, stamping, and adding other formations to the surface [16, 17]. The addition of such stiffeners of various interrupts and shapes in films with collagen structure [18], in the area of cohesive sutures of glued intestinal membranes can be effective in terms of ensuring their given strength.

Thus, devising technical and technological solutions for obtaining glued intestinal films from beef, mutton, and pork raw materials for the manufacture of both sausage casings and multifunctional films could solve the problem.

3. The aim and objectives of the study

The aim of this work is to devise a technique and design an apparatus for stitching intestinal raw materials by thermal coagulation and determine the structural features of this apparatus, as well as the rational modes of its operation. This could make it possible to increase the efficiency of the technology of glued sausage casings and multifunctional films from various types of intestinal raw materials.

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

– to devise a technique for stitching intestinal raw materials and a conceptual solution of the device for its implementation;

– to determine the effect on the strength of the seam between the layers of intestinal raw materials to be connected by thermal coagulation exerted by such parameters as the structural features of working bodies for stitching raw materials, duration of thermal coagulation;

– to determine the requirements for the structural features of the apparatus for stitching intestinal raw materials, based on the characteristic dimensions of the feedstock and filling properties for sausages.

4. The study materials and methods

4. 1. Investigated materials and equipment used in the experiment

The object of our research is a technique for obtaining glued intestinal films for multifunctional purposes, which are further strengthened by a stitching apparatus while using thermal coagulation.

The hypothesis of the study assumes the use of thermal coagulation as a tool for creating a seam between the layers of raw materials, which makes it possible to obtain a multifunctional film of the required size.

The raw materials involved in the research were beef belly products, processed and prepared in accordance with current technological instructions. That is, the raw material was separated beef bellies, which were previously degreased and cleaned of mucous membranes, washed, salted, and stored in the form of a salty product. Raw materials were freed from salt, washed, and kept in water. Before stitching, segments of products, which are bodies close to hollow cylinders, were cut in the longitudinal direction to obtain samples (strips), geometrically close to a rectangle.

To establish the strength of the seam between samples of intestinal membranes, obtained by their stitching using thermal coagulation, the procedure and installation given in [13] were used.

When defining the requirements for the structural features of the apparatus for obtaining sausage casings, there was a need to determine the stitching technique in which the flow of filling for sausages would be absent or small compared to the total weight of the product (<5 %). Raw materials for filling sausages are heterogeneous – they consist of fractions of different fluidity. Based on this, it was assumed that the first fraction of the raw material, which is the most fluid, would flow. That is, if this fraction of filling for sausages does not flow through the seam of the sausage casing, then no outflow for other fractions that have less fluidity would occur. It was using this fraction that studies were conducted on its flow through the seam between samples of the intestinal membranes in the installation shown in Fig. 1.

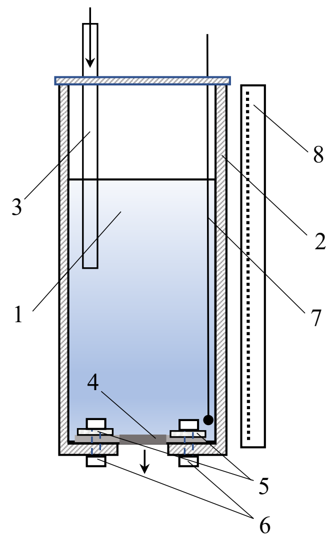

Fig. 1. Diagram of the installation for studying the outflow of the liquid filling fraction for sausages through the seam of the sausage casing: 1 – rectangular cross-sectional capacity; 2 – thermostatic shell; 3 – tube for introducing liquid filling fraction for sausages; 4 – sample of sewn sausage casing (seam is marked with dark gray); 5 – clamping plates; 6 – clamps; 7 – thermocouple; 8 – ruler

The filling fraction for sausages, which has the highest fluidity, was obtained by centrifuging the feedstock preheated to a temperature of 60 °C.

4. 2. Procedures used in the study of raw materials and filling properties for sausages

The procedure for studying the outflow of the filling fraction for sausages, which has the highest fluidity, through the seam of the sewn sausage casing is as follows. The study uses a liquid fraction, which is a heterogeneous substance in composition and, as a result, properties. It should be considered a protein-fat emulsion, the purity of which is highly determined by the technique of separation. The theoretical assessment of the fluidity of such a system has significant difficulties, therefore, the empirical method is used in the study.

The installation for the study is a rectangular section capacity (1 in Fig. 1), in the lower part of which there is a longitudinal slit. The introduction of the liquid fraction separated from the filling for sausages (hereinafter referred to as the liquid fraction) is possible through tube 3, and the outflow through the longitudinal slit in the lower part of the tank. Before introducing the liquid fraction into the container, the slit is tightly closed with a sample of the studied stitched sausage casing 4 using clamping plates 5, parallel to the slit, and clamps 6. A sample of stitched sausage casing is placed so that the seam is directly above the gap. That is, the outflow of the liquid fraction is possible only through this seam.

Next, the container is filled with a liquid fraction to a certain level, which is controlled by ruler 8 through the front wall of the installation, made of organic glass. After that, we visually monitor the presence of leakage of the liquid fraction through the seam of the sausage casing sample 4 for 10...15 min. If leakage is not observed within a specified time, the level of the liquid fraction is discretely increased. If the leakage is registered, then the experiment is completed. In this case, the value of the height of the liquid is recorded along ruler 8, at which this leakage is fixed. The leakage was considered significant when over 10...15 min more than 15 g of liquid fraction flowed through a seam 200 mm long.

Obviously, the fluidity of any fluid through holes of different cross-sections is determined by its rheological properties and, above all, by surface tension and effective viscosity of the liquid. Surface tension and effective viscosity vary with temperature and, as a result, with increasing temperature, fluidity increases. Based on this, the studies were conducted at a temperature of the liquid fraction from 55 to 60 °C.

This temperature range is selected from the following considerations. The liquid filling fraction for sausages is a system close in properties to a protein-fat emulsion. The main part of fat is of animal origin, the melting of which occurs at temperatures less than 60 °C. At the same time, coagulation of proteins, which will reduce the fluidity of the liquid phase due to the formation of coagulated proteins in it, occurs at temperatures higher than 60 °C. Thus, the highest fluidity of the liquid phase will be precisely at the selected temperature range, that is, from 55 to 60 °C. It should be noted that it is rational to study the leakage through the sausage casing of the liquid phase with the highest fluidity since this is what determines the loss of raw materials during filling and subsequent technological operations for the manufacture of sausages.

Taking into account the dependence of the fluidity of the liquid phase on its temperature, the tank of rectangular section 1 was placed in a thermostatic shell 2 (Fig. 1). The walls of the thermostatic shell contain heating elements that make it possible to maintain the temperature of the liquid phase inside the tank in the range from 55 to 60 °C. Temperature control was carried out using thermocouple 7.

The result of the measurement is the dependence of the height of the column or the hydrostatic pressure of the liquid filling phase for sausages, at which the leakage was considered significant, on the characteristic feature of the technique of stitching the sausage casing.

The treatment of the obtained experimental data was carried out using the Mathcad software package, which contains a wide range of procedures for solving statistical analysis problems, namely, interpolation, smoothing, regression and correlation analysis.

5. Determining the structural features and rational operation modes of the apparatus for stitching intestinal raw materials

5. 1. Devising a technique for stitching intestinal raw materials and a conceptual solution of the device for its implementation

The initial requirements for devising a technique of stitching intestinal raw materials and the conceptual solution of the device for its implementation were as follows:

– universality of the apparatus by the size of feedstock: the possibility of using intestinal raw materials of different origin (beef, pork, mutton, etc.) and from different parts of the intestine (small, large intestine, bladder, etc.);

– carrying out in one device operations on stitching natural intestinal raw materials by the technique of thermal coagulation and subsequent drying to the final moisture content (moisture content means the main parameter of the drying process, which is equal to the ratio of the mass of system water of the raw material or product to the mass of solids);

– universality of the products obtained: the possibility of using the resulting products for the production of sausage casings of various sizes and shapes, as well as other glued intestinal films for multifunctional purposes;

– energy and resource efficiency of the device.

Based on the initial requirements for the technique of stitching intestinal raw materials using thermal coagulation, a conceptual implementation of the apparatus is proposed, the general form of which is shown in Fig. 2.

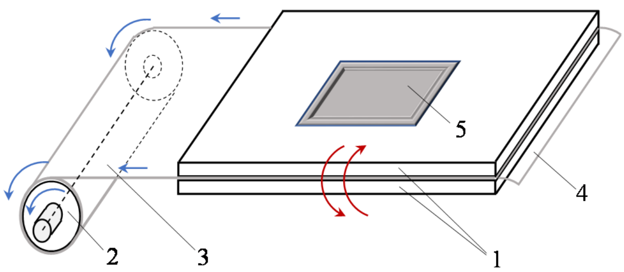

Fig. 2. General view of the conceptual solution of the apparatus for stitching intestinal raw materials using thermal coagulation: 1 — working surfaces for stitching intestinal raw materials; 2 — drum for winding glued intestinal films; 3 — glued intestinal films in the form of a tape; 4 — free end of the tape; 5 — tablet for controlling the mode of operation of work surfaces

The proposed technique for stitching intestinal raw material is as follows (Fig. 2). Samples (strips) of wet intestinal films are spread flat between the working surfaces 1 so that the free ends of the intestinal membranes 4 remain outside the working surfaces. Samples of raw materials are spread flat, that is, one on one, in order to obtain areas that are two layers to be stitched by thermal coagulation.

Next, selecting the appropriate operating modes of surfaces 1 using the control panel 5, they are stitched and dried to the final moisture content. That is, samples of intestinal raw materials between the working surfaces are first stitched by thermal coagulation, and then the working surfaces are heated, and the stitched wet raw materials are dried conductively.

The result is a canvas with a size corresponding to the area of the working surfaces. At the same time, the free ends 4 remain wet. The working surfaces are opened, and the resulting canvas is rolled on drum 2. Wet free ends 4 move in the direction indicated in Fig. 1 by arrows to the edge of the working surface. The presence of wet free ends is due to the convenience of gluing dried raw materials with moisture during their combination before stitching.

The operation of laying samples (strips) of wet intestinal films is repeated, laying them flat on wet free ends and spread flat between each other. The work surfaces are erected; we repeat the operation of stitching and drying. Thus, a tape is obtained, which is a semi-finished product for the production of intestinal membranes of various sizes and shapes and can also be used as a natural sheet film material for multifunctional purposes in the food industry.

The general view of working surfaces for stitching intestinal raw materials in the proposed way is shown in Fig. 3.

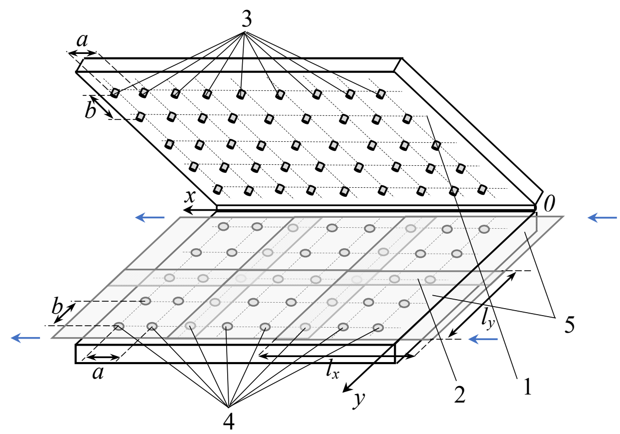

Fig. 3. General view of working surfaces for stitching intestinal raw materials: 1, 2 — upper and lower working surfaces for stitching and drying of intestinal raw materials; 3 — stitching rods; 4 — holes for stitching rods; 5 — samples of intestinal raw materials to be stitched

The working surfaces are two planes. On the upper working plane 1, a rod system 3 is installed, and on the lower plane 2, a hole system 4 is made. Each of the rods coincides with the corresponding hole when closing the lower and upper working surfaces. The rod length and hole depth must meet the following conditions. First, when closing working surfaces, their planes must touch each other. Secondly, when placing wet intestinal raw materials between the planes of the working surfaces and their closing, the rods should not violate the integrity of the wet raw materials due to ruptures.

The function of the rods on the upper working surface is to form a seam between the samples of intestinal films to be stitched and to fix the stitched samples during drying. Since the raw materials are spread flat, this particular zone is subject to stitching. It is possible, in accordance with the characteristic sizes of samples of intestinal films $l_x\, l_y$ (Fig. 3), to heat to the stitching temperature only certain rows of rods, both relative to the Ox axis and relative to the Oy axis. That is, after arranging intestinal raw materials with the appropriate characteristic size, work surfaces are closed, and the appropriate stitching mode is activated. The stitching mode refers to the connection diagram of the rod system horizontally (Ox) and vertically (Oy), their temperature (determined by the properties of intestinal raw materials) and the duration of thermal coagulation.

After that, the heating of the rods with the help of which the stitching was carried out is turned off and the drying mode of the stitched wet raw materials is turned on. For drying, the heating of the planes of the upper and lower working surfaces is switched on. The function of rods and holes is to prevent twisting and reduce wet raw materials during dehydration.

Thus, for the technical implementation of the technique and apparatus for stitching intestinal raw materials, there is a need to establish the following structural features and parameters of the stitching mode:

– the distance between the rods with which the stitching is carried out;

– rod temperature during stitching;

– stitching duration.

5. 2. Investigating the influence of the parameters of the technique for connection by thermal coagulation on the strength of the seam between the layers of intestinal raw materials

Stitching of the intestinal membranes using thermal coagulation is carried out by clamping the layers to be stitched between the working bodies. In [19], the seam between the layers of intestinal raw materials was created with the help of working bodies, which had the form of two continuous plates. The raw material was clamped between plates heated to a temperature of 150...180 °C, for 5...12 s, and a seam in the form of a line was received. The value of the breaking load of the obtained seam between samples of intestinal raw materials for these ranges of thermal coagulation duration and temperature of working bodies is from 12 to 16 N/m. It should be noted that the raw materials for which the study was conducted were pork belly, 30...55 µm thick.

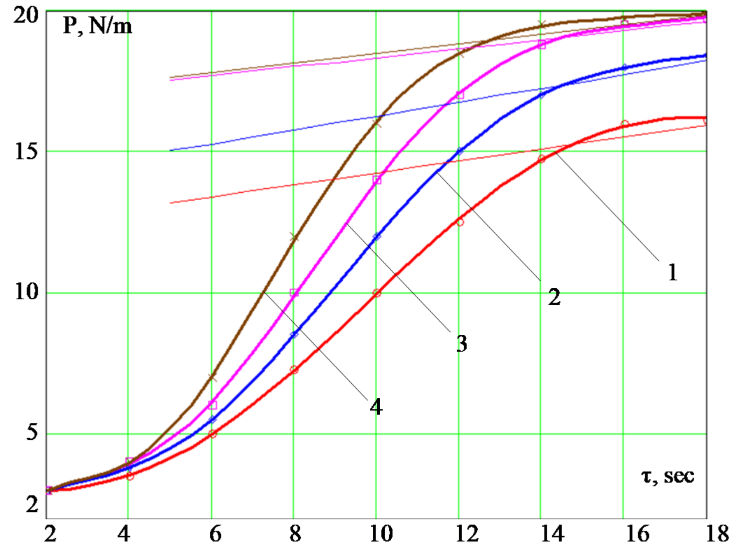

Fig. 4. The value of the breaking load per unit length of the seam between two layers of intestinal films made of beef belly, with different duration of stitching by thermal coagulation at the temperature of the working bodies, °C: 1 – 150; 2 – 160; 3 – 170; 4 – 180

One of the first requirements for the apparatus, in which the stitching of intestinal membranes is implemented, is its versatility in relation to the feedstock. However, the issue of rational temperature of the working bodies and the duration of thermal coagulation remains unresolved. The raw material used in the study and for which there is no information on the rational modes of stitching of its layers by thermal coagulation are beef belly. Beef belly differs from the raw materials studied in [19] in greater thickness. Thus, the thickness of products from different parts of beef intestines used for the production of sausage casings varies from 70...140 µm to 130...230 µm. Obviously, an increase in the thickness of the layers of raw materials to be stitched by thermal coagulation entails an increase in the rational temperature of the working bodies and the duration of stitching. In the study, beef belly was used as raw materials, the thickness of which lies in the range of 70...140 microns.

Determining the rational parameters of stitching at this stage was a two-factor experiment. The first factor is the temperature of the working bodies, the second is the duration of thermal exposure to the layers of raw materials from the working bodies. The criterion for determining the rational values of factors is the value of the breaking load of the obtained seam between the samples to be stitched.

The temperature of the working bodies changed discretely every 10 °C from 150 °C to 180 °C. The duration of clamping the layers of raw materials to be stitched between the working bodies also changed discretely every 2 s from 2 s to 20 s.

The change in breaking load with a change in the duration of stitching of raw material samples at different temperatures of the working bodies is shown in Fig. 4. The load was considered breaking if the seam ruptured under its action. The breaking load was determined per unit seam length. The experimental data were approximated by a polynomial function.

The nature of the change in the breaking load with the change in the stitching duration for different temperatures of the working bodies is the same. There is a monotonous growth of approximation functions, on which three characteristic areas with different inclinations to the abscissa axis can be distinguished.

By increasing the stitching duration from 2 to 6 s, there is a slight increase in the breaking load. Obviously, this increase is due to the adhesion of the layers of raw materials, and not their joint thermal coagulation. With a further increase in the stitching duration, the breaking load increases linearly. This area for different temperatures of the working bodies has a different slope to the abscissa axis: for a temperature of 150 °C, the angle is the smallest, and for a temperature of 180 °C, the largest. In the third section, the angle of inclination of each of the curves decreases again: dependences asymptotically tend to certain values of the breaking load. These asymptotic values of the breaking load are different for each temperature of the working bodies. For a temperature of 150 °C, this value is 16.2 N/m; for a temperature of 160 °C – 18.4 N/m; for 170 °C – 19.7 N/m; for 180 °C – 19.9 N/m.

The approximation to the asymptotic values for each of the curves, respectively, for each temperature value of the working bodies is different. Based on this, the rational duration of stitching should be considered the duration at which the value of the breaking load of the seam is achieved, corresponding to a value close to the asymptotic. A value close to asymptotic means a breaking load value of at least 5 %.

The establishment of a rational stitching duration at each of the temperatures of the working bodies was determined by linear approximation of the finite sections of curves from Fig. 4. The initial data for the linear approximation were arrays of experimental data, where the first point was the value of the breaking load corresponding to the maximum stitching duration. The following points were added according to the correlation coefficient between the experimental data and the obtained linear approximation functions. The addition of each subsequent point to the original data set continued until the correlation coefficient reached 95 %.

The rational ranges of the stitching duration by thermal coagulation, thus defined, at which rational values of the breaking load of the seam between intestinal films made of beef belly are achieved, are equal to:

– for the temperature of working bodies of 150 °C – 15...16 s (rational value of breaking load, 15.4...16 N/m);

– for a temperature of 160 °C – 14...15 s (rational value of breaking load, 17.0...17.7 N/m);

– for 170 °C – 14...15 s (rational value of breaking load, 18.6...19.3 N/m);

– for 180 °C – 12...13 s (rational value of breaking load, 18.8...19.3 N/m).

It should be noted that in [19] it is proved that from the point of view of technological requirements, the strength of the seam of stitched sausage casings should be at least 10 N/m. That is, the properties of the seam obtained from the above rational ranges of the stitching duration by thermal coagulation at a certain temperature of the working bodies meet the technological requirements for glued sausage casings.

Another requirement for the apparatus, which implements the stitching of intestinal films by the technique for thermal coagulation, is its versatility relative to the size of the feedstock. The task that arises in this case is that the seam is located directly at the places of overlapping layers of raw materials, that is, the direction of application of heat coagulation seams should coincide with the direction of cohesion seams.

In general, the shape of the feedstock samples is close to a rectangle with linear dimensions l_x and l_y (as shown in Fig. 3). Therefore, the working bodies should be placed at a distance of no more than l_x–Δl along the Ox axis and l_y–Δl along the Oy axis. Here, Δl is the width of the overlapping between the layers of raw materials. The linear dimensions of intestinal raw material samples can vary in a wide range from 75 to 500 mm. Thus, for the universality of the apparatus regarding the size of the feedstock, the working bodies must be at a distance not exceeding the minimum size of samples of intestinal membranes. In view of this, the use of plates as working bodies for stitching using thermal coagulation is irrational. Since thermal coagulation in the case of stitching samples of raw materials with a linear size larger than the minimum involves not only the overlapping layers but also single layers of raw materials. This leads to a decrease in the strength of the resulting shells, the possibility of the formation of holes due to the burning of raw materials, damage to the appearance of the products.

Thus, the chosen working bodies in the technique proposed in this study are the rod and the hole that coincides with it (respectively 3 and 4 in Fig. 3). The use of such working bodies is due, firstly, to the desire to reduce heat costs from their surface. Secondly, it is possible to use the specified rods for stitching raw materials by thermal coagulation.

When using working bodies in the form of rods and holes, the seam will not be a solid line, as when using plates, but a series of points. Obviously, the breaking load will depend on the distance between the points subjected to thermal coagulation.

Fig. 5 shows the breaking load depending on the distance between the points that create a seam between the layers of the intestinal membranes. The distance between points subjected to thermal coagulation varied discretely through 5 mm from 5 to 25 mm. The temperature of the working bodies was 160 °C, the duration of stitching was 15 s. The first experimental point, for which the abscissa coordinate is zero, corresponds to a seam created between solid plates by a heat coagulation technique. Shown in Fig. 5, the experimental points were approximated for clarity by a polynomial function.

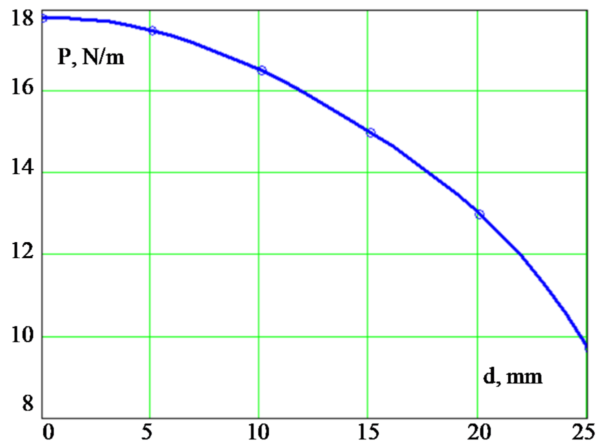

Fig. 5. Breaking load at different distances between points that create a seam between layers of glued intestinal films

The breaking load changes nonlinearly with a change in the distance between points undergoing thermal coagulation and create a seam between the layers of intestinal films. At the same time, the values of the breaking load of the seam for the range of the distance between the points that create it, from 5 to 20 mm, respectively, lie in the range from 17.5 to 15.0 N/m. These values meet the technological requirements for the strength of the seam of stitched sausage casings.

5. 3. Determining the structural features of the device for obtaining a multifunctional film

Under the structural features of the apparatus for stitching intestinal raw materials by the technique for thermal coagulation at this stage of the study should be considered the distance between the rods that create the heat coagulation seam, and the scheme of their heating.

The distance between the rods determines the basic properties of sausage casings: the tensile strength of the casing and the ability to hold the filling for sausages without leakage of its liquid fraction. The strength of the seam depending on the distance between the points forming the seam between the intestinal films is investigated in the previous chapter. The ability of sausage casings to retain filling for sausages without leakage of its liquid fraction was investigated as follows.

Obviously, in glued and additionally stitched sausage casings, the most likely area through which the liquid fraction may leak is the seam. For the case of a seam in the form of a series of points that have undergone thermal coagulation, the issue of leakage through the seam of the liquid filling fraction for sausages requires additional research.

The influence of the distance between the points that create a seam between the layers of intestinal raw materials on the outflow of the liquid filling fraction for sausage products from the sausage casing was investigated. The distance between the points that underwent thermal coagulation and which create a seam between the layers of intestinal raw materials varied discretely through 5 mm from 5 to 25 mm.

Samples of sausage casings were placed in an installation to study the outflow of the liquid filling fraction for sausages through the seam of the sausage casing (Fig. 1). In accordance with the procedure, the height of the liquid fraction was determined, at which its outflow through the seam was considered significant.

The value of the height of the liquid fraction (hydrostatic pressure), at which the outflow was considered significant, for certain values of the distance between the points forming a seam between the layers of intestinal raw materials, is shown in Fig. 6. Our experimental data were approximated by a polynomial function.

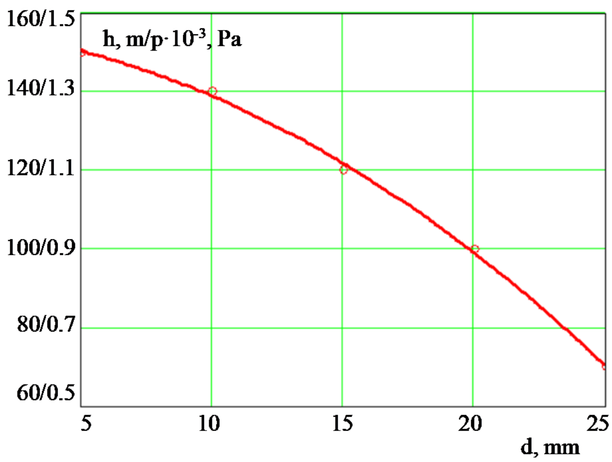

Fig. 6. The value of the height of the liquid fraction (hydrostatic pressure) at which a significant outflow occurred, for different distances between the points forming the sausage casing seam

Obviously, the height value is proportional to the hydrostatic pressure of the liquid, at which fluid flows out through the seam of the sausage casing sample. The values of the corresponding hydrostatic pressure are given through a forward slash in the signatures to the ordinate axis.

The scheme of switching on the rods, with the help of which a seam is created by thermal coagulation, significantly depends on the characteristic geometric dimensions of the feedstock l_x and l_y (Fig. 3). The rod switching circuit means heating to the temperature of thermal coagulation of the corresponding rows both along the *Ox* axis and along the *Oy* axis.

In the study, beef belly is used as a feedstock. The shape of this native raw material is close to rectangular. Its characteristic dimensions lie in the range from 75 to 500 mm. In this case, one of the characteristic dimensions (hereinafter – width) lies in the range from 75 to 100 mm, the other (hereinafter – length) – in the range from 100 to 500 mm.

In accordance with the developed technique, the seam must be formed in the place of the overlapping of the layers of intestinal membranes. That is, the rods with the help of which the heat coagulation seam is created must coincide with this overlapping. Based on this, it should be considered rational to have a limited number of rod switching circuits, with the help of which a seam is created by thermal coagulation. That is, each rod switching circuit should be determined by the size range of the selected raw materials.

The range of characteristic geometric dimensions of feedstock (from 75 to 500 mm) is significantly larger compared to the distances between the rods (from 5 to 25 mm), which are planned to be used for stitching intestinal raw materials. In view of this, preliminary sorting of raw materials into 3 grades with the following ranges of width and length sizes is proposed: I – (75...100)×(350...500) mm; II – (75...100)×(200...350) mm; III – (75...100)×(100...200) mm.

Such sorting makes it possible, in accordance with the variety and taking into account the width of the overlapping (Δl=20 mm), to activate the parallels of the rods, which are placed at distances determined in accordance with the raw material grade along the *Ox* axis and along the *Oy* axis. Thus, along the *Ox* axis, these distances between the rows of rods lie in the range from 65 to 90 mm for all three grades of raw materials. Along the *Oy* axis, the distances between the rows of rods are determined in accordance with the type of intestinal raw materials: I – from 340 to 490 mm; II – from 190 to 340 mm; III – from 90 to 190 mm.

6. Discussion of results of determining the structural features of the apparatus for stitching the intestinal membranes by the technique for thermal coagulation

A technique for stitching intestinal films related to waste due to certain defects and a conceptual solution of the device for its implementation have been developed. This technological advancement makes it possible to obtain a universal tape from intestinal raw materials (Fig. 2). The versatility of the tape is the possibility of further obtaining from it of sausage casings of the desired size both in diameter and length, obtaining curly sausage casings. It is also possible to use it as a natural sheet film material for multifunctional purposes in the food industry.

The designed apparatus (Fig. 3) can be considered universal in terms of geometric dimensions and thickness of the feedstock, its origin. Versatility is achieved by selecting the appropriate rational modes of operation of the device: the temperature and switching on scheme of working bodies for stitching, stitching time, temperature, and drying time. It should be noted that in one device the stitching of intestinal raw materials is carried out, and its drying to the final moisture content.

Beef belly was chosen as the raw material for which the research was conducted. For this raw material, there is no information on rational temperatures and duration of stitching by thermal coagulation.

Investigation of the breaking load of the seam obtained between samples of intestinal membranes at different temperatures of the working bodies and at different duration of the process of thermal coagulation established the rational ranges of values of these factors (Fig. 4). It should be noted that the working bodies were solid plates. It was found that the properties of the seam obtained under the above rational ranges meet the technological requirements for glued intestinal sausage casings. The breaking load of the resulting seam is not less than 10 N/m.

In terms of the breaking load of the seam obtained between samples of intestinal films at certain values of the temperature of the working bodies and the duration of stitching, any of the proposed ranges can be selected. However, from the point of view of energy consumption, the lowest temperature of the working bodies and the shortest duration of thermal coagulation should be chosen, obviously, taking into account the safety margin of the resulting seam.

It should be noted that with an increase in the temperature of the working bodies from 150 °C to 160 °C, that is, by 10 °C, the breaking load of the resulting seam increases by 16 %. At the same time, the duration of the thermal coagulation process decreased by 1 s. With a further increase in temperature by 10 °C (up to 170 °C), the breaking load increases by 11 %, and the duration remains the same. With an increase in the temperature of the working bodies from 170 °C to 180 °C (by 10 °C), the breaking load of the seam increases by only 1 %, and the duration of thermal coagulation decreased by 2 s. Based on this, temperature of the working bodies was 160 °C with the corresponding duration of thermal coagulation of 15...16 s.

However, the working bodies for stitching the intestinal membranes in the developed conceptual solution of the device are rods and corresponding holes. The use of such working bodies makes it possible to reduce energy consumption for heating and reduce heat costs due to convection from their surface compared to the use of solid plates. At the same time, this technical solution avoids such disadvantages of glued intestinal sausage casings, additionally stitched by thermal coagulation, as reducing the strength of the resulting shells, the possibility of forming holes due to burning of raw materials, damage to the appearance of the products.

Obviously, the use of working bodies in the form of rods and holes entails reducing the breaking load of the seam of the resulting sausage casing. Since the seam is not a solid line that has undergone thermal coagulation but a series of points with a certain distance between them. On the other hand, the creation of stiffening bulges in the plane of the cohesion seams of the glued intestinal membranes ensures their greater strength. Based on this, studies have been carried out to find the values of the breaking load of the seam at different distances between the points that form it (Fig. 5). It is determined that with distances between points undergoing thermal coagulation and forming a seam from the range from 5 to 20 mm, the values of the breaking load of the seam (at least 15.0 N/m) meet the technological requirements for its strength. That is, the distance between the rods in the technical implementation of the apparatus for stitching intestinal raw materials in terms of the strength of the resulting seam can be any of the range from 5 to 20 mm.

The limitation of the result obtained can only be the ability of the seam between the stitched intestinal membranes to hold the filling for sausages without leakage of its liquid fraction. This property is also determined by the distance between the points forming the seam and determines the hydrostatic pressure of the liquid filling fraction for sausages, at which its outflow occurs.

Experimentally, the values of the height of the column of the liquid fraction (hydrostatic pressure), at which a significant outflow occurred, were obtained for different distances between the points forming the seam. Our height values lie in the range from 70 to 150 mm.

Traditionally, sausages have a cylindrical shape. In view of this, provided they are technologically processed in a horizontal position, the obtained height values can be considered equal to the diameter of the sausage product. Thus, it is possible, according to the diameter of the sausage casing, to choose the distance between the points that undergo thermal coagulation and form a seam. That is, for a sausage product with a diameter of 140 mm, the distance between the points forming the seam should be no more than 10 mm (Fig. 6), and for a sausage product with a diameter of 100 mm – no more than 20 mm. It should be noted that for a sausage product with a diameter of 70 mm, in terms of the outflow of the liquid filling fraction for sausages, a sufficient distance between the points forming the seam is 25 mm. However, the use of such a distance is not recommended since the breaking load of the obtained seam will be less than 10 N/m, that is, for the strength of the seam of glued and additionally stitched intestinal sausage casings, which meets the technological requirements. Since sausage casings made of beef belly are used for products with a diameter of up to 100 mm, the rational distance between the points forming the seam for such raw materials is 20 mm.

Thus, for the devised technique and apparatus for stitching the intestinal membranes by thermal coagulation, the following recommended modes and parameters of this operation can be formulated:

– working bodies for stitching intestinal raw materials are rods and appropriately placed holes;

– the distances between the rows of rods and holes for beef belly are equal to 20 mm both along the abscissa and along the ordinate axis;

– the temperature of the working bodies (rods), with the help of which a seam is created between the intestinal membranes, is 160 °C;

– the duration of stitching of the intestinal membranes is 15...16 s;

– it is necessary to introduce a preliminary operation of sorting raw materials before stitching. Sorting of raw materials is carried out into 3 grades with the following ranges of sizes, width, and length: I – (75...100)×(350...500) mm; II – (75...100)×(200...350) mm; III – (75...100)×(100...200) mm. Sorting makes it possible to turn on the parallels of rods according to the variety, which are placed at certain distances along the *Ox* axis and along the *Oy* axis. Along the *Ox* axis, the distances between the rod rows lie in the range from 65 to 90 mm for all three grades of raw materials. The distances along the *Oy* axis between the rod rows are determined according to the grade of intestinal raw materials: I – from 340 to 490 mm; II – from 190 to 340 mm; III – from 90 to 190 mm.

The limitation of the study is the use of the technique only for the chosen raw materials, specifically beef belly. In addition, there are no experimental studies on the rational parameters of the drying process of glued and additionally stitched wet intestinal membranes. One of the prospects for further research is to expand the range of intestinal raw materials that can be stitched using the developed technique and apparatus. Another is to obtain rational modes and parameters for drying raw materials.

The disadvantage of our study is that the designed device is a periodic action unit. In this case, the technique requires painstaking human labor, both during sorting and when arranging the intestinal membranes on the work surface. However, the use of automatic devices to perform these operations will obviously be unprofitable due to the insufficiently high cost of the products obtained.

7. Conclusions

1. A technique has been devised for stitching by thermal coagulation of intestinal films from beef belly, which belong to waste due to certain defects; a universal apparatus for its implementation has been designed. It is noted that the

universality of the apparatus is the possibility of stitching with its help of the raw intestinal raw materials, different in geometric size, thickness, species. It is noted that in one apparatus both stitching and drying of raw materials is carried out. The finished product is a universal tape (semi-finished product) – glued intestinal film of multifunctional purpose, from which it is possible to obtain sausage casings of the desired size and shape. It also creates the possibility of its use as a natural sheet film material in the food industry.

2. Our studies of the breaking load of the seam, obtained by the technique of thermal coagulation between solid plates, determined the rational ranges of the stitching duration. For different temperatures of the working bodies, they are equal to: at 150 °C – 15...16 s; at 160 °C – 14...15 s; at 170 °C – 14...15 s; at 180 °C – 12...13 s. The studies of the breaking load of the seam, which is a series of points that have undergone thermal coagulation, established its nonlinear change with a change in the distance between points. It is determined that the values of the breaking load of the seam for the range of distance between the points that create it, from 5 to 20 mm, respectively, lie in the range from 17.5 to 15.0 N/m. It is noted that these values of the breaking load of the seam meet the technological requirements for the strength of the seam of glued and additionally stitched intestinal sausage casings.

3. Our studies of the influence of the distance between the points that create a seam between the layers of intestinal raw materials on the outflow of the liquid filling fraction for sausage products from the sausage casing determined the height of the liquid fraction, at which the outflow was considered significant. It is noted that since the raw material does not have a standard for geometric size, in terms of energy and resource efficiency, it should be sorted before stitching. In view of this, preliminary sorting of raw materials into 3 grades with the following ranges of width and length sizes is proposed: I – (75...100)×(350...500) mm; II – (75...100)×(200...350) mm; III – (75...100)×(100...200) mm. It is noted that sorting makes it possible, in accordance with the variety, to turn on the parallels of rods for thermal coagulation, which are placed at certain distances in the longitudinal and transverse directions. In the longitudinal direction, the distances between the rows of rods lie in the range of 65 to 90 mm for all three grades of raw materials. The distances in the transverse direction between the rows of rods are determined according to the grade of intestinal raw materials: I – from 340 to 490 mm; II – from 190 to 340 mm; III – from 90 to 190 mm.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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All data are available in the main text of the manuscript.

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