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FEATURES OF HEAT TRANSFER IN THE ENVIRONMENT WHEN IT IS SPRAYED WITH ROTARY ROLLERS

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ABSTRACT
The analytical analysis of roller impact on the medium and its behaviour at deformation influences are carried out, ways of choosing an optimal variant of the process for providing the maximum or minimum value of parameters (criterion) are proposed. The physical essence of the equation of energy flows of the intensity of deformation of the mass of the medium, which depends on the method of applying mechanical forces, the degree of its previous dispersion (recipe) and its physical and mechanical properties, is considered. For a more visual view and understanding of the overall performance of the research, a scheme of causal relationships between the medium and the roll, which determine the temperature change of the dough injection process, is proposed. It is noted that the determination of the influence of the temperature of deformation processes during the passage of the process of injection of the medium by roller working bodies plays an important role for calculations of the design of molding, roll-over equipment. The influence of thermal circulatory chaotic streams is considered, the character of which also leads to violations of the general heat circulation in the medium during the injection. At the same time, the level of such violations may be sufficiently deep with changes in the directions in their contours that influence the process, according to each particular period of the deformation stage in the injection site of the molding machine. Partly revealed methods for determining the change in temperature fluxes in the dough and on the surface of the roll. On the basis of which the change of the energy potential in the interaction of the viscous medium with rotating roller working bodies in the molding machine is considered. An exchange of energy between moving particles is discovered due to collisions of molecules of a more heated part of the body with a greater energy and the transfer of the energy particle to adjacent particles with less energy. It is noted that the definition of temperature fluxes during the process of injection of the medium by roller working bodies plays an important role in calculating the design of molding, roll-over, mixing equipment. The obtained data answer a number of questions about the possibility of thermoregulation of the process of the work of the working bodies into the environment.A set of measures for measuring the temperature during the use of devices was carried out. On the basis of their data, a real temperature change in the roller unit of the molding machine is considered, with a comparative analysis of existing ones with a newly designed design. The change of the energy potential in the interaction of the viscous medium with rotating roller working bodies in the molding machine is considered. An exchange of energy between moving particles is discovered due to collisions of molecules of a more heated part of the body with a greater energy and the transfer of the energy particle to adjacent particles with less energy. It is noted that the definition of temperature fluxes during the process of injection of the medium by roller working bodies plays an important role in calculating the design of molding, roll-over, mixing equipment. The obtained data answer a number of questions about the possibility of thermoregulation of the process of the working bodies into the environment. The essence of formation of temperature fluxes is revealed and the method of their determination in a roller assembly of a molding machine with a comparative analysis of existing ones with a newly designed design is proposed.

Keywords: dough; injection; heat conduction; heat propagation; heat flux; roll; phase; medium

INTRODUCTION
Among the heat processes used in production, the main place is the process of transfer of heat from its sources to the treated material. The exchange of energy between moving particles occurs as a result of their direct collisions. In this case, the molecules of the more heated part of the body, which have more energy, transmit the energy share to adjacent particles with less energy. In gases, the energy transfer is carried out by diffusion of molecules and atoms, in liquids and solid dielectrics, by elastic waves. In metals, the transport of energy is carried out mainly by the diffusion of free electrons.

The generated heat circulation flows are more often chaotic, which also leads to violations of the overall heat circulation in the environment. At the same time, the level of such violations can be sufficiently deep with changes in the directions in its contours. Thus, the hydrodynamic modes in the injection node of the molding machine are determined by the heat flux formed in the dough when it interacts with the surfaces of roller working bodies.

Since all phenomena (processes) **(Drozdziel, 2016)** in nature are described by analogous kinetic equations, they also have a similar nature of the course in time. The speed of any process and, consequently, the rate of transfer of substance after the onset of the action of roller working bodies due to the inertia of the systems changes gradually: first increases to a certain maximum value, holds for this time for this value, and then, as the equilibrium state approaches, gradually slows down to zero (stopping process). Between the environment and the working body there is always an additional higher temperature. There is a difference in temperature potentials $\Delta t = t_1 - t_2$, as a result of which heat passes from a more heated point to a less heated one. The difference in the temperature potentials Δt in the points under consideration is a measure of the deviation of their state from equilibrium between them. This difference causes the heat to move from a heated to a less (colder) point of the space of the medium, which is in the space between the rolls. Thus, this characterizes the difference in the potential of the surface of the roll and the medium itself (dough).

Analysis of model approximations of medium types.

Determination of the temperature fluxes during the process of injection of the medium by roller working bodies plays an important role in calculating the design of molding, roll-over, mixing equipment. However, the research **(Singh et al., 1997)**, the process of compression of the dough between the rolls only the kinetics of its injection, in isolation from the very change in its structure, does not allow to determine the optimal parameters of the process. The change in the physico-chemical properties of the dough under the influence of the working body is considered in the work **(Khamis, 2009)**, but the method for determining the temperature is not shown. In the study of authors **(Bloksma and Niemann, 1975**), the sequence and mechanism of influence of temperature change on the structure at the injection of yeast dough is not completely considered. In their rheological studies, the authors **(Muratova and Smolihina, 2015)** reveal the value of temperature for changing the structure of the environment, but the method of determining the temperature field of the process is absent. More revealingly, the disclosure of temperature effects in the work **(Stadnyk, 2013)**. It led to the modeling of the viscous medium in the gap between the rollers and the temperature distribution was reflected.

Without an explanation of the formation and definition of heat flows in the yeast dough, it is impossible to substantiate optimal regimes and methods of controlling this process. Therefore, in addition to the rational mechanical action of rolls on the environment, it is necessary to maintain an optimal temperature, which should ensure the flow of nutrients to bacterial cells and the required moisture and gas exchange.

Data analysis gives a number of questions about the possibility of thermoregulation of the process of the work of the working bodies into the environment. Therefore, we propose methods for determining the temperature variations in the roller unit of the molding machine in comparison with the new structure **(Stadnyk, 2018)**.

At present, such an estimate is made by the value of the energy coefficient proposed by the well-known scientist V. Kirpichov. This coefficient is defined as the ratio of the amount of heat transmitted through the surface of the heat transfer to the amount of work spent on overcoming the hydraulic resistance when moving the medium. In practice, the energy factor is used in the form of:

$$E = \alpha / N_0$$

Where:

α - coefficient of heat transfer on the surface under given conditions of interaction, W/(m^{2}K); N0 is the energy expended for 1 sec on the movement of the medium, assigned to 1 m^2 surface, W/m2, the corresponding energy is determined by the expression:

$$N = \frac{G\Delta p}{\rho F_b}$$

Where:

G - mass flow rate of the medium, kg.s^{-1}; ΔP - hydraulic resistance of the channel, Pa; ρ - is the density of the medium, kg.m^{-3}; Fv - the working area of the channel, m^2.

Forced convective heat transfer allows you to align the temperature field in the environment (Non-Newtonian fluid) to create the same conditions in any zone of the working chamber. This makes it possible to assert that the temperature at any point over a certain period of time converges, reaching the average temperature of the medium at the beginning and end of the injection process. However, we have established **(Derkach, 2017)**, that when the medium is injected, there is a significant difference - the temperature inside the medium is approaching not the temperature of the roller working body formed on the surface, but to a temperature close to the initial 240.

Consequently, the injection process after a while becomes a character that can be considered practically as a regular mode of thermal conductivity. The extreme temperature to which the temperature is directed in the medium is the temperature at a given injection pressure produced by the action of rotating roller working bodies. It affects the nature of the temperature change and the duration of the stage of the injection discrete mode. Also, the temperature of the surrounding environment is influenced by the temperature field in the middle of the medium.

In fact, these phenomena occur simultaneously and, of course, affect one another. Convection, for example, is often accompanied by thermal radiation and thermal radiation - by heat conduction and convection.

When passing discrete deformation on the environment by rollers, the heat at the boundary section is approximately uniform. The propagation cycle is rather short, and heat loss on radiation and convection is negligible. Therefore, it can be assumed that the side surfaces of the roll are in the adiabatic limit state and that the temperature distribution along the plane parallel to the surface of the friction is uniform. Thus, the temperature in this plane is approximated by one value at the intersection at one-dimensional analysis by finite difference method.

The rolls together with the dough are a multilayer cylindrical wall, which represents only ¼ mutual contact (Figure 1). In this case, the thermal resistance of a multilayered cylindrical wall is equal to the amount of resistance of individual layers. The first layer is the roll wall, and the next layer is the processed medium. This environment can be divided into several layers.

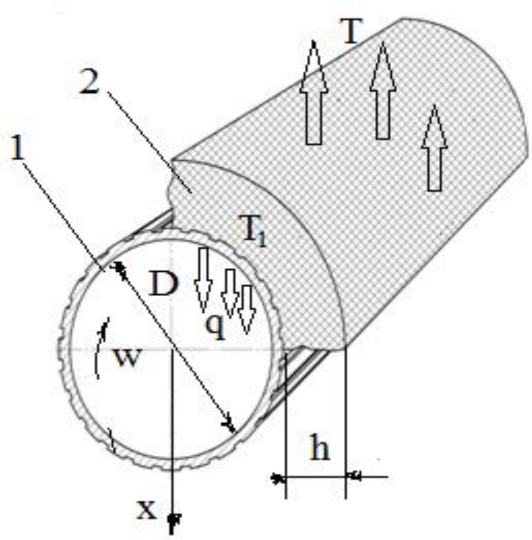

Figure 1 Scheme of impulse friction contact.
Note: 1 - roll working body, mm; 2 - medium (dough); T - constant temperature; T_1 - is the temperature on the surface of the frictional contact.

Scientific hypothesis

At present, scientists have carried out several hypotheses analytically describing the formation and nature of the change in heat transfer, which occured at the dough pieces during deformation. The energy consumption and the process total duration, namely energy level and time of the heat-mass transfer is highly dependent on heat flow movement level. The kinetic energy of deformation characterizes the local heat dynamics, and hence local heat and mass transfer throughout the working volume of the dough. However, the results obtained do not provide a well-founded definition, since the mathematical models that were used are relatively simplified and do not reflect the complexity of the overall heat transfer pattern. Due to the complexity of the solution of such models and the requirment to determine the parameters experimentally, they have not become widespread.

Consequently, the sequence and mechanism of changes formation of heat transfer in the homogeneous structure of the dough, taking into account inherent peculiarities, have been partially studied. Without clarification of the mechanism of formation, that is proceeding in a homogeneous structure during deformation, it is impossible to determine the optimal regimes and methods of control of this process. Analysis of the changes in heat transfer during dough formation and the effect of the working bodies on the finished dough during the formation are absent. Therefore, experimental research methods are more credible. Our research is aimed at overcoming the existing theories and disclosing a new vision of the essence of the formed temperature changes.

Spatial isotropy and temporal unevenness of distribution contribute to the implementation of different heat and mass transfer conditions for each local area of the working volume of the injection unit, and, accordingly, for each individual semi-finished product, which leads to a change in the quality of finished products with the same time of baking. So, due mainly to viscous friction in the dough layers and its partial sliding along the surface of the roller assisted by convection, the transfer of heat into the mass of the dough occurs.

The velocity fields' study of the heat flux was made in order to conduct analytically and practically comparative characteristic of the influence of roller working bodies of different design on the change in the temperature of the dough and to conduct their analysis, by verified statistical methods.

MATERIAL AND METHODOLOGY

Investigation of the process of injection and rollout of the dough was carried out on the molding machine B-54 of the confectionery factory (Ternopil) and physical models, created on the department of OCHT (TNTU named after Ivan Puluj). To determine the heat release on the surface of the friction (the boundary of the roll of the dough), the construction of the reverse heat conduction model is made. By calculation, the temperature of the heating of the dough was determined in the contact area with the rolls and on the basis of the obtained data the axial flow of the flow was determined. Since the temperature gradient in a solid is determined by experimental measurements, then the heat flux can be calculated as the product of the heat conductivity coefficient of the solid on the temperature gradient on the surface. In the inverse of the heat conduction, the method of finite difference is used to estimate the heat flux q (t) at the boundary of the friction section, provided that the known values of the transition temperature on the surface of the roll.

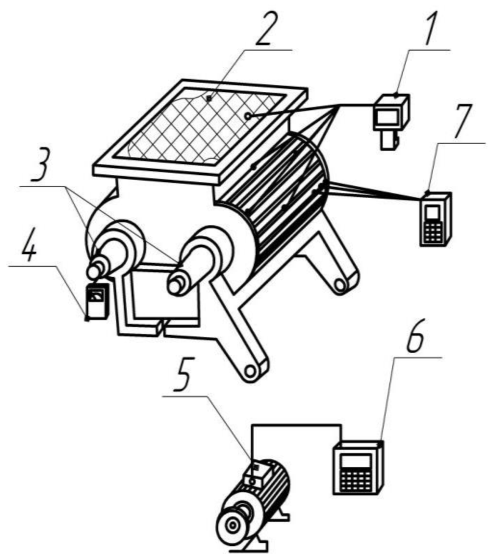

Figure 2 Scheme of injection nozzle for determination of temperature fluxes and power.
Note: 1 - thermal imager; 2 - medium (dough); 3 - roller working bodies; 4 - tachometer; 5 - electric motor; 6 - watt meter; 7 - potentiometer.

Instruments and eguipment

In the work the method of complex determination of the effective thermophysical characteristics of the bubble dough is used and experimentally determine the dependence of the thermal conductivity λ, the volumetric heat capacity cρ, the temperature-conductivity a on the temperature at the stages of its discrete injection of all the mixed mass. Calculations are carried out in the case of injection: the temperature of the environment Tc - 180 °C; the temperature of the test -25 - 280 °C; the thickness of the dough layer on the roll is accepted 20 - 22 mm; average dough velocity - 2.0 $m.s^{-1}$, density ρ = 1165 $kg.m^{-3}$.

Experimental data on determining the heating temperature of the roller working body during the injection process were obtained using thermocouples located in the interaction zone (Figure 2). A hot copper-constantan junction thermocouple with a corresponding graduated table has been used. At complex temperature measurements simultaneously in a few coordinates of the object a battery of differential microthermopares, in which the number of single junctions is six, is used. The cold junction of the battery is common (Figure 3). Hot jumps in batteries are equal to the number of points in the measuring instrument.

The temperature change was fixed by three thermocouples fixed to the surface of the roll, respectively, at a distance of 5; 15 and 25 mm from the end of the roll. The data are used to calculate the heat flux on the viscous friction surface.

Emerging thermo-EDC thermocouples are proportional to the difference in temperature between hot and cold junctions, which is measured by compensating type devices - potentiometers or millivoltmeter. The compensation type device: DC potentiometer PP-63, class 0.05, (Priborpostavka) was used for researches.

Thermocouple calibration: The reliability of the results at temperature measurements with the aid of thermocouples was obtained by preliminary calibration of the produced thermocouples directly under laboratory conditions. The thermocouple calibration consists in determining the potentials of the thermocouples made by the battery and the corresponding indicators of the reference thermometer (Figure 3).

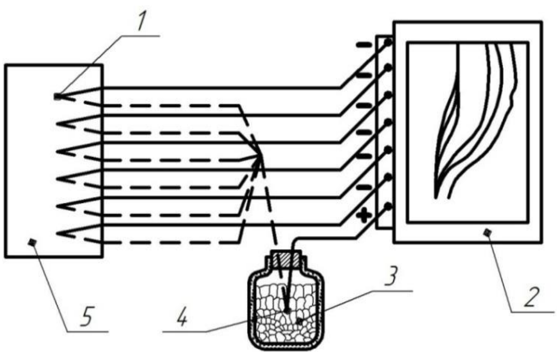

Figure 3 Schematic diagram of the device for measuring temperatures using microtherm battery.
Note: 1 - hot jig, 2 - multipoint electron potentiometer, 3 - Dewar dish, 4 - total cold junction, 5 - investigated object.

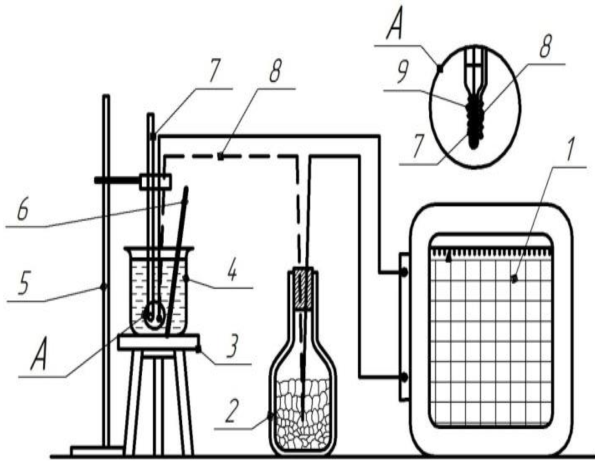

Figure 4 Scheme of installation for calibration of thermocouples.
Note: 1 - measuring self-recording device, 2 - vessel Dewar with ice, 3 - electric heater, 4 - capacity with working fluid, 5 - tripod for fastening the thermometer and thermocouples; 6 - glass rod for mixing; 7 - a mercury thermometer, 8 - a single copper-constantan thermocouple; 9 - a thread for fixing a hot junction thermocouple.

For direct measurement of the heat flow density, that cross-cutting the dough surface, we used the sensor, that was developed by Food Technology Chair of Ternopil Ivan Pul'uj National Technical University which is a several microthermocouple located close to each other. This apparatus uses, the measuring self-recording single-channel device RP-160-00 with a thermoelectric converter, (Priborpostavka) and the technical thermometer of the WT-1 type (Lviv) with a scale from 0 to 100 °C and the precision of 0.1 °C.

Construction of the temperature scale.

After calibrating the thermocouples according to the measurements, a table and the calibration curve of the thermocouple E in millivolts were constructed. E = f (t) is the dependence of the thermo-EDF developed by the thermocouple (in terms of millivoltmeter), on the temperature of its hot junction (in terms of the mercury thermometer).

Metrological analysis of measurable means

Checking the replication of experiments on an experimental installation. When checking the reproduction of pouring penny rolls from the flour of the highest grade of the same lot of grinding and the same baking properties. Initially, they found the average value of yj, then the difference (yj-yj) and the square of the difference $\Delta y_j^2 = |y_j - y_j|^2$ .The results of the measured parameters in the experiments of each series (yj (1), yj (2), yj (3)) of their deviations from the mean values $(y_j - y_j)$, The squares of deviations and dispersion for each series of experiments Si2 were summed up in a table.

The dispersion estimation for each series of experiments uses the formula:

$$S_i^2 = \frac{1}{k-1}\sum_{j-1}^{k}(yj - yj)^2$$

With the number of experiments in the series K = 3:

$$S_i^2 = \frac{1}{2}\sum_{j-1}^{k}(yj - yj)^2$$

Assessment of experiments was carried out according to the Cochran criterion:

$$\text{Gp}=\frac{(S_i^2)max}{\sum_{i=1}^{k} S_i^2}$$

For the temperature of the upper surface of the roll:

$$\text{Gp}=\frac{7}{19.34} = 0.0036$$

The calculated values of the Coherent Gp criterion are compared with the table values for N and F = K-1.

Determination of threshold of sensitivity of measuring devices

Acceptable threshold of sensitivity is given in the parts of the main error of the device (25 - 50%).

Determination of the metrological index

The basis is the rule of three sigms of the metrological index A for the measuring instruments used:

$$A = \frac{3\delta}{\bar{y}_j}$$

Where:

(δ - mean square deviation with repeated measurements,

$$\delta = \sqrt{\frac{\sum_{j=1}^{n}(y_j - \bar{y}_j)^2}{n-1}}$$

$\bar{y}_j$ - average value of the measuring parameter,

$$\bar{y}_j = \frac{\sum_{j=1}^{n} y_j}{n}$$

n - the number of repetitions of measurements.

The condition of sufficient accuracy for experimental studies is the value of A = 0.1:

$$A = \frac{3\sqrt{\frac{\sum_{j=1}^{kn}(y_j-\bar{y}_j)^2}{n-1}}}{\frac{\sum_{j=1}^{n} y_j}{n}}$$

For the investigated parameter / $t_{вк}$ / y_j / 1series calculated value A:

$$A = \frac{3\sqrt{\frac{38.68}{11}}}{16.1} = 0.035$$

Since, for measuring temperature values, the values of the metrological index A do not exceed 0.1, they are sufficiently accurate in measuring instruments.

On the basis of metrological analysis, the mean square error of measurement is determined.

Statisic analysis

For an unbounded plate (roll surface) with an appropriate thickness δ heated by a heat flux of constant density $g_п$ differentiation of non-stationary thermal conductivity is used:

$$\frac{\partial t}{\partial \tau} = a\frac{\partial^2 t}{\partial x^2}$$

with initial conditions t (x.0) = t_0 = const.

Heat transfer by heat conduction occurs due to the energy of the motility transfer:

$$g = -\lambda gradt + \sum_{1}^{n} i_k \gamma_k$$

Where:

g - density of the heat flux is superficial, W/m^2; IC- enthalpy of water or vapor, J.kg^{-1}, carried in the presence of a gradient temperature grad t with intensity (m^2.s^{-1}).$\gamma_к$, k, kg.

Boundary conditions of the second kind:

$$\frac{\partial t(\delta,\tau)}{\partial x} = -\frac{g(t)}{\lambda}.$$

$$\frac{\partial t(0,\tau)}{\partial x} = 0$$

The solution of this equation at given boundary conditions allows us to determine the temperature field t (x, t) and the field of heat fluxes in the plate (surface) of the roll.

The definition of λ was carried out on the basis of a generalized equation which was obtained on the basis of the second kind of regime and the solution of other equations for determining the temperature field:

$$\lambda = h\left[\frac{F(u^{-1}(\Delta t_1^{11} + \Delta t_2^{11}) - u^{-11}(\Delta t_1^{1} + \Delta t_2^{1}))}{u^1 - u^{11}} - R\right]^{-1}$$

Where:

F is the Fourier number, the dimensionless process time F = aτ / δ^2; u - tempo of heating the surface of the test, K / s, u = a / dt; Δt is the temperature difference on the surfaces of the test, K in (1) and (11) in different thermal modes; h - thickness of the dough layer, m; R-ballast thermal resistance, m^2 K / W, equal to h / λ.

In experiments, direct measurements were performed, ie the desired values were obtained directly as a result of the experiment. A number of repeated direct measurements of the same magnitude were processed mathematically, namely, the application of the theory of probabilities and statistical methods. To analyze the errors of the result for a large and small number of measurements, the law of distribution of random mistakes of Student was applied. In order to achieve the specified accuracy, the definition of gross errors used criterion Student.

To plan a physical experiment, the Seidel-Gauss method was used, the completion of which is a multifactor correlation dependence on the basis of the obtained Protoedaconov function. Applying it for processing the results of chemical research allowed to obtain adequate results

$$Y_{\Pi} = \frac{\prod_{i=1}^{k} y_i}{y_{cp}^{k-1}},$$

Where:
y_i - partial functions defined using the least squares method; k - number of factors; y_{cp} - the average value of all the results of the experiment that was taken into account.

The experiments were carried out to the plan with corresponding matrices of planning the experiment with the specified numbers of experiments and the boundaries of the change of factors. As the optimization parameter, the temperature that occurs in the dough during the movement is used. It depends on the input parameters that can be represented in the form:

$$T = f\,(P, L, h),$$

Where:
T - temperature, P - pressure, L - distance between thermocouples, h - thickness of the layer of mass of the dough.

During the planning of experiments to determine the functional change of the dough temperature, a standard symmetric planar matrix of the three-factor experiment was used at three levels of variation of factors for the total number of experiments of one repetition.

$$N = p^k = 3^3 = 27$$

The experiments were performed in a triple repetition for each numbered line of the matrix. The sequence of the first and subsequent experiments was established in accordance with the numbered order of the randomized matrix of the trifactorial experiment. The levels of factor variations and the results of the implementation of the plan matrix, or the experimental array of data obtained during the experiments.

The experimental data array was processed using the computer application package (Statistica-12). The approximating response function, or the optimization parameter, that is dough temperature T, determined experimentally, was calculated with a help of a mathematical model of the complete polynomial of the second power:

$$T = b_0 + b_1x_1 + b_2x_2 + b_{12}x_{12} + b_{11}x_1^2 + b_{22}x_2^2,$$

Where:
x_1, x_2, x_3 - respectively, the coded designation of the dough pressure *P*, the diameter of the rollers *d*, the gap between the rollers h; $b_0, b_1, b_2, b_{12}, b_{11}, b_{22}$ – free term and coefficients of the values of the corresponding factor x_i and their interaction.

At the probability value p = 0.95 and the t-alpha criterion value of 2.053, the following statistics data was obtained. The coefficient of multiple determination D = 0.962; coefficient of multiple correlation R = 0.981; estimate standard deviation s = 0.637; Fisher's F-criterion equal 467.71. Coefficient D is significant with a probability of P = 0.9999.

The evaluation of the reproducibility of the experiments was carried out according to the Cochran‘s criterion with significance level of 5%. The coefficients of the regression or approximation function equation, which is written as $T = f_T(x_1; x_2; x_3)$ under the condition of orthogonality and symmetry of the plan matrix of the planned factor experiment, were determined according to the standard method by known dependencies.

After evaluating the statistical significance of the coefficients of the regression equation according to the - Student criterion and verifying the relevance of the approximation model according to Fisher's F-criterion and the transition from coded indicators of factors to natural, a regression equation is obtained that characterizes the functional change in the dough temperature T depending on the change $200 \leq P \leq 700$ H, $15 \leq h \leq 35$ mm, $155 \leq d \leq 165$ mm.

$$T = 36{,}4 + 4{,}2 \cdot 10^{-3}P - 1{,}7d + 0{,}06h + 2{,}5 10^{-4}Pd - 6{,}8 \cdot 10^{-5}Ph + 8{,}3 \cdot 10^{-3}dh + 5{,}8 \cdot 10^{-6}P^2 + 0{,}01d^2 - 8{,}0 \cdot 10^{-4}h^2$$

The graphic representation of the dough temperature changes according to the experimental data (Figure 5), meaning the response surface of the dough temperature functional change as a function $T = f_T(h; d)$

Measurements of the temperature of the dough in the working chamber, the surface of rolls, the environment were carried out with the use of thermal imaging with the help of the thermal imager Fluke Ti25. The thermal imager manufacturer is "Flukosorpocen" Everett, USA. The software was developed under the software version (PLAST-002).

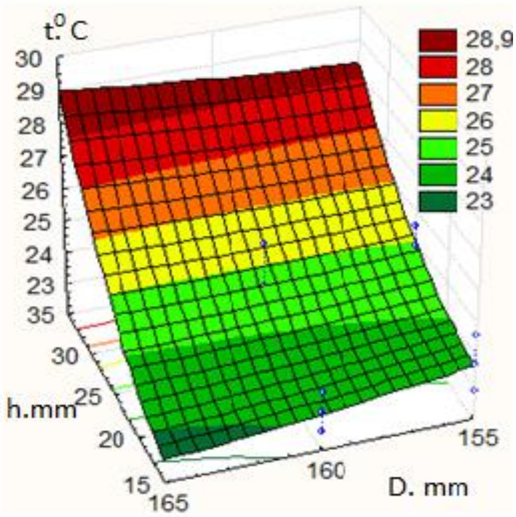

Figure 5 Response surface.

RESULTS AND DISCUSSION

Consider the process of motion of the medium between rotating rolls (Figure 6). After compression of the medium by rolls zone-2, it enters the main zone-3 injection, which, in accordance with Figure 3 can be conventionally divided into three components - the zone of intense heat generation - 111, the transition - 11, and the heat recovery zone - 1. For this part, in most of the constructions of the injection unit, a convective heat regime is implemented that involves the simultaneous transfer of heat by radiation and convection.

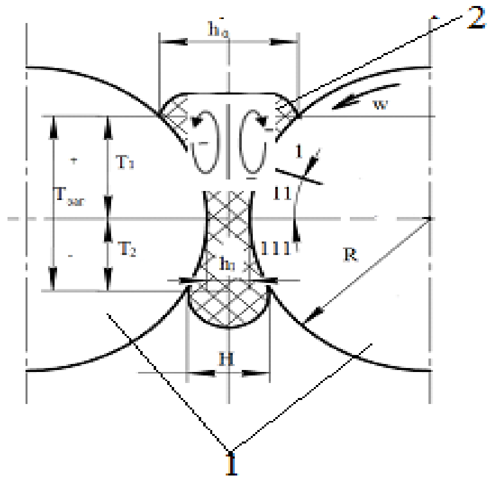

Figure 6 Scheme of temperature distribution at injection.
Note: 1 - rotary rollers; 2 - dough work environment.

The generated thermal circulation flows are more often of a chaotic nature, which also leads to violations of the general heat circulation in the middle case. At the same time, the level of such violations can be sufficiently deep with changes in the directions in the dough contours.

The authors of the works **(Lisovenko, 1983)** note that the change of the dough temperature occurs due to the structural parameters of the working bodies and the working chamber, which create hydrodynamic modes. Created modes determine the intensity of the dough deformation and the expended energy, which is distributed in two directions. The energy expended on the macromolecular structure of the dough gives a positive technological effect, and its expenditures associated with internal friction should be considered beneficial. The expenditures on external friction of the working bodies and the walls of the working chamber, accompanied by the heat output, adversely affect the technological process. In this regard, the mechanical action on the dough should adhere to the investigated limits.

Thus, the hydrodynamic modes in the injection node of the molding machine are determined by two reasons. The first one relates to the heat flux formed on the surfaces of the roll. The second reason concerns the formation of streams involving the gas phase.

The plastic and adhesion strength, form index, and flow index stated in paper **(Obolkina, 2016)** as the dominant factor in the formation of the structure of semifinished products for confectionery products, that must be created taking into account the design features of the equipment. By analogy with the theory of stability of disperse systems, he proposed a theoretical model of aggregative stability of a combined system consisting of semi-finished products with a different structure, taking into account kinematic, hydrodynamic and thermodynamic factors.

Table 1 Empirical coefficients for determining the heat loss in the environment.

Surface type	$\overline{c}$	$\overline{n}$
Vertical	1.4	1.33
Horizontal top	1.7	1.33
Horizontal lower	0.64	1.25

Obviously, each of these reasons is characterized by its driving forces. For the first reason, such a factor is the difference in temperature of the medium and the roll working body of the coolant. In the second case, the motive factor is the presence of the dispersed gas phase. The value of the temperature flux depends on the velocity of the medium and the discreteness of the roller working body, the mass of the yeast wheat dough in the working chamber and the loading hopper, which leads to partial fermentation of sugar in it.

According to **(Shurchkov U., 2013)**, the value of optimal control is referred to the specific energy consumption. It is proved that there is a critical value of velocity and energy consumption. However, in our opinion, false technical decisions are often adopted.

At the same time, a number of researchers **(Kozlov G. F., 1984)** believe that the magnitudes of specific work with varying strength do not give a sufficient view on the technological aspects of the process. As to their and our opinion, the mechanical impact of the working bodies during the deformation with the specific energy consumption – is imperfect.

The method of optimal control of energy load when frictional interaction of friction pairs of dough with rollers under different injection modes allows to set the summed heat to its working surfaces. The management of thermal processes is necessary for the following reasons: to limit the amount of heat accumulated by rollers, in order to reduce the thermal stresses; to lower the surface temperatures in the dough below the permissible ones for it in order to prevent changes in structural and mechanical properties; to provide the work of the injection unit with an acceptable energy load in order to increase the wear and friction properties of the surface layer of the roll; establish the relationship between the rate of change in the temperature of the surface layers and the temperature gradient both on its surface and in thickness.

With the help of a special device that regulates the change of the rheological properties of solid-liquid bodies, Nikolaev investigated the influence of mechanical processing on the structural and mechanical properties of the dough **(Nikolaev B. A., 1976)**. It was found that, with additional mechanical treatment dough viscosity and elastic modulus are reduced.

In mentioned paper, the authors' reveal the reason for dough temperature change, but neither detailed analysis of the phenomena that arise while working bodies operation, nor the methods for identifying these changes are provided.

Consequently, in the investigated medium of the injection unit, the primary energy source is present in the form of chemical energy of hydrocarbons, which must be transformed into carbon dioxide. In this case, the formation of carbon dioxide has a double thermodynamic manifestation, which is accompanied by the release of thermal energy and the formation of a dispersed gas phase CO_2.The heat energy allocated in combination with the thermal energy of viscous friction is realized in a form that can be considered hypothetically as a system for converting thermal energy into mechanical work of partial mixing (reverse motion) of the medium. The mode of circulation is influenced by the structural parameters, the structure of the dough (the presence of gas) and the gravitational field. However, in large volumes of the medium and the discrete action on it, the regime is violated and leads to limited values of efficiency **(Stadnyk, 2018).**

The instability of the value is due to the fact that the temperature in the circulation part of the liquid phase decreases with the increase of the value h_0 (the dough layer in the chamber). The temperature has its greatest value when the dough is released from the gap of rolls. The coefficient of heat transfer from the medium to the wall of the roll depends on the physical and chemical parameters of the medium, the velocity of the rolls, their design parameters; speed upgrade liquid phase in; the rate of renewal of the liquid phase in transverse planes and the area of contact of the liquid phase in the roll gap (compression). The latter should be a complete reaction of the system to change the capacity of the gas phase.

Consequently, taking into account the complexity of the theoretical determination of the value of the convective heat flow $\dot{Q}_k$, the concept of thermal flow from compression of the dough $\dot{Q}_{cm}$, which already includes the value of the specific heat of absorption of the convective heat flow, is used in calculations. Determination of the specific heat of absorption q_A is based on the general laws of this mass transfer process in the injection node.Taking into account all the thermodynamic processes that occur in the environment under the influence of deformation, we have proposed one of the methods for determining the heat fluxes.

Calculation of thermal absorption flow.

The heat flux transferred to or from the liquid phase of the working medium can be calculated by the equation **(Sokolenko, 2012):**

$$Q_A = q_Д \cdot m_A = \frac{q_Д \cdot m_{X1} \cdot (x_к - x_н)}{\mu_X} \quad (3)$$

Where:

$q_Д$ - differential heat of gas dissolution (gas component); $x_к$, $x_н$ – final and initial relative molar particles of the absorbed gas in the liquid phase of the working medium; μ_X - molar mass of liquid; m_A - mass flow of absorbed gas (gas component).

Since there are technological requirements for the porous structure of the bagel, therefore, an equilibrium concentration in the gas phase should be established. Accordingly, this is described by Henry's law **(Sokolenko, 2008):**

$$x_i = \frac{1}{E} \cdot p_i \quad (4)$$

Where:

x_i - molar concentration of the absorbed gas in the dough, which is in the thermodynamic equilibrium with the gas phase, in which the partial pressure of the absorbed component is equal; p_i; E - Henry's constant, determined from the dependence:

$$\ln E = -\frac{q_Д}{R \cdot T} + \text{const} \quad (5)$$

For boundary conditions, for example, under atmospheric pressure, we have:

$$\ln\left(\frac{E}{E_{атм}}\right) = \frac{q_Д}{R} \cdot \left(\frac{1}{T_s} - \frac{1}{T}\right) \quad (6)$$

In the calculation, the final concentration of the absorbed gas in the douth $\overline{x}_к$ can be equal to the concentration at equilibrium. Then, on the basis of the above, the heat flux transferred to or from the dough during the injection process will be:

$$Q_a = \frac{m_x p R \mu}{\frac{1}{T_2} - \frac{1}{T_1}}$$

That is why in the general theory of calculation of the injection site it is necessary to take into account the processes of absorption in the working chamber, which in theory at this time are not described at all. Perhaps this is hampered by the considerable complexity of processes.

In this method of calculating the consumption of absorbed gas, as the operating temperature, can be taken by the average temperature of the gas-liquid phase $t = 0,5 \cdot (t_X + t_Y)$ and pressure $p = 0,5 \cdot (p_{Y1} + p_{Y2})$.

The general heat exchange of the surface of the roller working body with the environment, due to the insignificance of the difference in temperature $T_X - T_{н.с}$, the specific heat flux $\tilde{q}_{н.с}$ can be considered as:

$$q_{н.с} = \frac{c \cdot (T_{cm} - T_{н.с})^n \cdot F_{cm}}{m_{Y1}} \quad (7)$$

Where:

T_{cm} – the temperature of the outer wall of the roll, which does not interact with the medium; F_{cm} – the design surface of the roller working body; c, n – empirical coefficients, are selected according to table. 1 for different types of surfaces.

***Calculation of the temperature of the roll*.**

When calculating the temperature of a roller working organ during all stages (tightening, compression, injection), one can use the heat transfer equation as a plane plate with a two-way heat output **(Derkach,, 2017)**.

$$Vc\rho\delta(\frac{-\partial T}{\partial x})dx = n\alpha(T - T_c)dx$$

Where:

V- the velocity of the roller working body; c - specific heat capacity of the roller working body; ρ - specific gravity of the material of the roller working body; δ is the thickness of the cylindrical wall of the roller working body; x - the distance passed by the roller working body with the environment from the previous stage; n - coefficient, which takes into account the cooling circuit of the roller working body (with two-sided return of heat п=2, and with one-sided-1); α - coefficient of heat transfer; T_c is the ambient temperature (cooler).

After integrating with the temperature of the roller working body at the exit fromthe $T_{вих}$ section, we obtain the equation:

$$T = T_0 + (T_{вих} - T_c)exp(\frac{-nx\alpha}{\rho c K_1 V}) \quad (8)$$

Where:

K_1 is the correction factor characterizing the fraction of the length of the roller working body with the medium (non-Newtonian fluid) on its surface.

To determine the temperature of the medium after the discrete action of the roller working body on it, as well as the cooling temperature at the exit from the gap, the heat conduction problem was used for an unbounded flat wall.

$$\frac{\partial T(x,\tau)}{\partial \tau} = \frac{\lambda}{\rho}\frac{\partial^2 T(x,\tau)}{\partial x^2}$$

Under conditions τ>0; h/2<x<h/2;

$$T(x,0) = f(x)$$
$$\lambda\frac{\partial T(h/2\tau)}{\partial x} = \alpha_в\left[T_0 - T(h/2\tau)\right]$$
$$\lambda\frac{\partial T(h/2\tau)}{\partial x} = \alpha_н\left[T_0 - T(-h/2\tau)\right]$$

Where:

h - the thickness of the media band on the roll working body; $\alpha_в$ and $\alpha_н$- coefficient of heat transfer on the upper (external) and lower (internal) band of themedium; T_0 - ambient temperature (room).

Given that the cooling takes place in seconds in open space before applying to the formation, we use the formula:

$$\alpha = \alpha_a(\frac{T^{0.04}}{29} + 1.2\upsilon^{0.1})$$

Where:

α_a - correction factor; v - velocity of the medium, m.s^{-1}.

The Pep's application fopmly shows the discharge of the current from the roll by the radiation source, the second one - due to the convection.

In the course of the calculation of the current cost of the work of the roller working body as the basic values of the coefficient of capacity of the pipe was used for the weathering of the weathering system - 150 kkal /m^{2}h.°C.

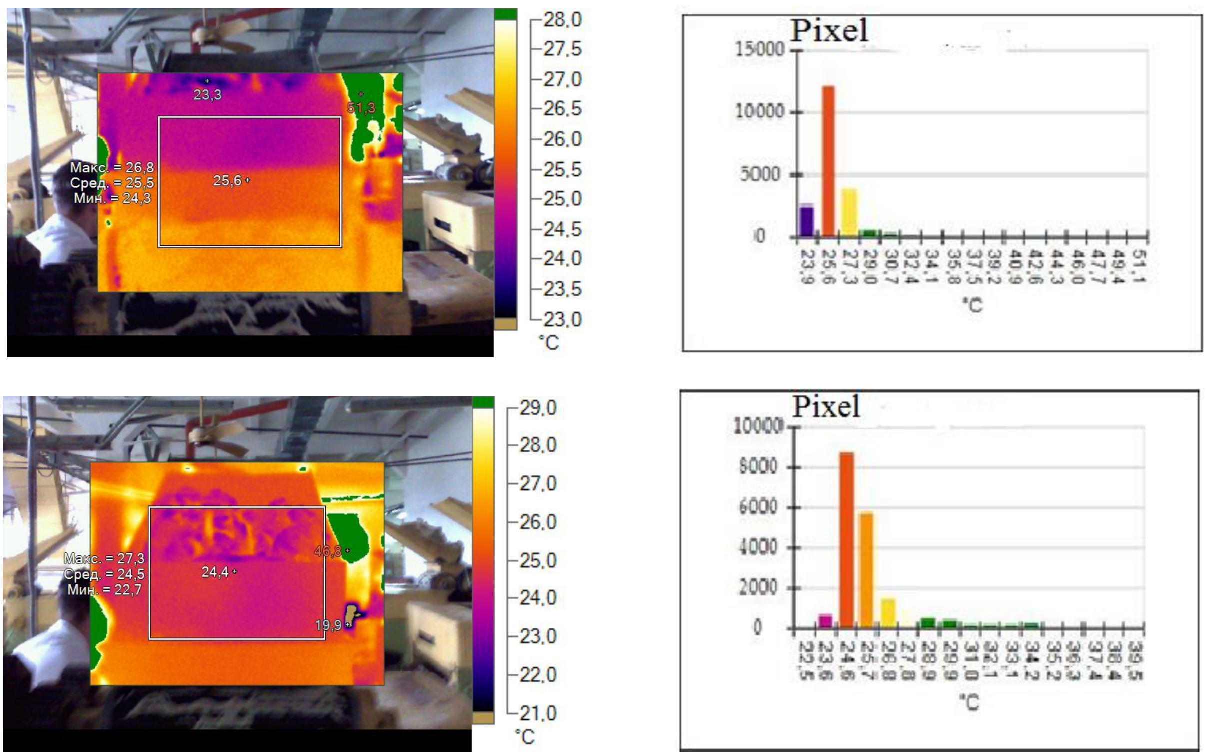

Figure 7 Thermal imaging of the injection unit. Note: a) a new roll construction; b) the existing roll construction.

The K_1 coefficient for the quantifiable value can be determined by comparing the optimal and quantitative data. In a trial, it can be kept by measuring the temperature of the roll working organ at the beginning and end of the discrete process. However, such measurements may not be measurable from the nonobacterial point of the tooth. The only one of the definitions of K_1 is the comparison of the calculated and factual temperature of the roller working body, known in the environment of the known action.

The proposed ways of determining the heat flows are quite complex and limited to the necessary information, since the yeast dough constantly changes over time with its structural and mechanical properties in its deformation. There are other calculation ways to determine the heat fluxes that are based on the processes of heat transfer (convective, heat conduction, radiant, heat transfer), which will be considered in subsequent work. Taking into account the complexity, we give a generalized method of determination.

Determination of the temperature of roll and dough devices.

In determining the coefficients included in equation (8), it is necessary to take into account the fact that at the compression region the value of the temperature pressure at the angle of rotation changes all the time, and the value of the coefficient of heat transfer can be determined rather approximate, since when determining it, it is necessary to take into account the presence of the site, which affects heat transfer. You also need to know the speed of the working environment in the area of rotating rolls. These values can be determined experimentally, but research on this subject has not yet been carried out.

In order to qualitatively evaluate the change in temperature in the dough and heat losses in the environment, which are known to depend on the magnitude of its deformation and biological processes, a thermal imaging of the test facility as a whole was carried out, the results of which are shown in Figure 6. Thermophysical survey was carried out for a number of old and new roller working bodies at given technological modes of work of the molding machine.

The calculations for calculating the temperature of the roller working body from the ground of 08 kp at the injection are shown in the form of cyphilic oxidation in Figure 7.

The shaft working bodies, according to the process, were evacuated by a natural clutch in a quiet air environment in the workshop. Starting from 18 - 27 s the process of compression and injection (curve -1) for the roll of the old cooling design has xapaktype increase in temperature, both external and internal surfaces at 25 - 28˚C. At the same time, curves 2 of the new roll have a more smooth transition of temperatures with a high quality impact on the medium. This process lasts 5s less with coil roll to 260c, when the old - 280s. This phenomenon is due to the prolongation of the viscous flow of the medium and the friction of the surface of the roll. Under new designs, there is no extra heat.

With the corresponding deformation resistance, the temperature calculation is closely related to phase transformations in the medium. Certain thermophysical parameters, such as the thermal conductivity and the coefficient of thermal conductivity α, are determined by the time required for the determination of the temperature.

The change in the temperature of the roller working body in the zone of reflux and cooling (period of idling) was calculated by fopmyl (8). Calculations are carried out in the case of injection: the temperature of the environment Tc – 180˚C; temperature of the mass of the medium – 28˚C; the thickness of the medium layer on the roller working body is adopted – 25 - 35 mm; the average velocity of the medium is 2.0 m / s, the density ρ = 1165kg /m^3. The thermophysical dependencies of properties (bubble dough) on temperature are determined by the formulas λ (w /m^{2}K), c (j / kgK):

$$\lambda = 1.153(0.278 + 0.0045T)$$
$$C = 4167.4(0.58 + 0.0011T)$$

Table 2 shows the thermophysical properties of a dough processed by an old roll, and table 3 new rolls: specific (mass) heat capacity, thermal conductivity, density.

It is clear from the analysis of the tables that the thermophysical properties of the dough under the influence of the deformation of the new roll construction almost remain at one level.

The calculations of temperature are made for two roll structures at given technological pressure of injection (Figure 8).

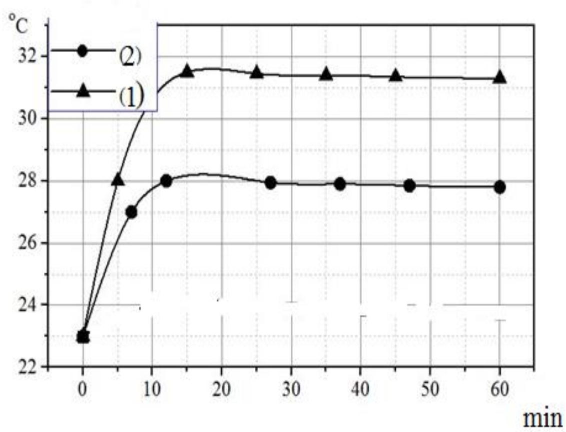

Figure 8. Influence of the stage of the injection process on the temperature of the roller working body.
Note: 1- for the old construction; 2nd for new

In Figure 8 shows dependencies illustrating the thermal efficiency of rolls of the old and new structures after each discrete injection. In the coordinate system, these dependencies have the form of straight lines with almost the same angle of inclination, but different values.

It is possible to note a rather significant difference between the effective accumulation and the return of the resulting temperature by roll when interacting with the medium. Simultaneously from the figure it follows that after the third cycle of injection, the temperatures have the same value. This indicates the stability of the temperature in the subsequent injection of the medium.

Taking into account the mathematical model of the process and experimental data, plotting dependencies

Table 2 The thermophysical properties of wheat dough.

Stage of injection bagel dough	Condition of the dough after the technological process						
	t, ^{0}C	Density ρ, kg/m^3		Heat capacity C, J/(kg^{o}K)		Thermal conductivity λ, W/(m^{o}K)	
	After injection	After injection	After the formation	After injection	After the formation	After injection	After the formation
Mixed up	26.5	1190	1180	0.648	0.680	0.355	0.360
After 60 minutes deformations	28	1160	1153	0.695	0.705	0.362	0.372
After 100 minutes deformations	32	1090	1030	0.708	0.718	0.380	0.4

Table 3 The thermophysical properties of wheat dough when sprayed with a new roll.

Stage of injection bagel dough	Condition of the dough after the technological process						
	t, ^{0}C	Density ρ, kg/m^3		Heat capacity C, J/(kg^{o}K)		Thermal conductivity λ, W/(m^{o}K)	
	After injection	After injection	After the formation	After injection	After the formation	After injection	After the formation
Mixed up	25.5	1190	1188	0.648	0.65	0.355	0.36
After 60 minutes deformations	25.7	1190	1189	0.65	0.65	0.357	0.352
After 100 minutes deformations	26	1179	1189	0.66	0.673	0.36	0.365

T = f (h, P) were constructed at distances between the thermocouples L = const. The graphic image clearly captures the change in temperature in the plane, which varies within the appropriate range for different rolls.

Analyzing the following results of measurements and calculations, one can make the following general rationale for the effect of rotating rolls on the environment:

- the temperature of the working medium in the radial direction increases with the approach to the working roll 4 - 7°C with a difference in at speeds u=(0.4-1) M/C and the relative radius of the medium on the roll and the roll r_2/r_1=1.2; the magnitude of this difference depends on the magnitude of the degree of compression increase;
- the temperature of the working medium at the compression and injection area is practically changed at the angle of rotation of the roll, indicating that it is intensively transported and partly stirred;
- the temperature of the surface of the body of the roll t_{no6} is evenly distributed at the angle of its rotation, with increasing pressure the injection increases linearly and repeats the increase in the temperature at the exit with a difference of about 7°C;
- the temperature of the working medium and the roller surface in the axial direction is evenly distributed in the new designs. In determining the temperature in the axial direction, no changes were found.

CONCLUSION

From the general justified actions of the rotating roller worker on the environment: we can conclude:

- to intensify the injection process possible by ensuring temperature constancy;
- increase of heat transfer surface;
- making rolls from a material having the maximum thermal conductivity;
- intensification of the process of heat conduction through the wall of the roll and heat transfer from the wall of the roll to the inner hollow cylindrical surface;
- increase of heat loss in the environment (return of heat by a roller surface that does not come into contact with the dough).

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