Improving the process of kneading yeast dough with cam working elements

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Abstract

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Introduction. It was conducted a study of the process of kneading wheat yeast dough with cam working. The aim is to determine the rational configuration of structural elements for continuous kneading of dough at different levels of frequency of the working elements rotation and the distance between them.

Materials and methods. It was investigated the kneading of wheat yeast dough by cam working elements. Mathematical modeling was performed using the Flow Vision software package based on the simulation of three-dimensional motion of liquids and gases in technical structures, as well as for the visualization of flow curves by computer graphics. Physical modeling was performed via experimental setup with cam kneading elements. The distance between the cams is 2–4–6–8–10 mm, the rotation speed is 20–100 rpm.

Results and discussion. As the rotational speed of the working elements increases from 20 to 100 rpm, the mixing speed increases from 0.1 to 0.6 m/s, the distance between the cams does not affect the mixing in the specified range. The maximum values of pressure reach 16560 Pa for the distance between the cam working elements 2 mm and a speed of 100 rpm, the minimum 555 Pa for the distance between the cam working elements 10 mm and a speed of 20 rpm. In the mixing chamber, the highest-pressure values are formed in the contact zone of the cam working elements with the wall of the mixing chamber and in the contact zone of the two cams. The dependence of the viscosity in the mixing chamber on the speed of rotation of the working element is of a power nature and with increasing speed from 20 to 100 rpm decreases from 1600 to 320 Pa·s. Parts of the mixing chamber in which viscosity values in the range from 320 to 960 Pa·s are achieved are considered to be the most effective during mixing. Reducing the viscosity of the dough involves reducing energy costs during kneading.

Conclusions. To increase the carrying capacity of the cam working elements, improve mixing and reduce heat consumption, it is rational to use cam working elements with a variable pitch and a variable position of the cams at $\alpha = 45^\circ$ or a combined cam working element using a screw auger at the beginning of the working element.

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Introduction

The development of a continuous-action dough-mixing machine is accompanied by the choice of a rational configuration of the working element. Rationalization is realized by analyzing the various configurations of the working element and its effect on the kneading process. Imitation modeling aims to calculate the values of certain characteristics of a process that develop over time, by reproducing the flow of this process on a computer via its mathematical model [1–2].

During projecting of the process of dough mixing, there is a range of issues related to the type of working elements is supposed to be chosen. On the basis of theoretical searches and obtained experimental results, after comparative analysis of working elements, it was decided to simulate the process of kneading yeast wheat dough using cam working elements [3].

Obtaining information about the process of mixing at any point in the mixing tank using simulation modeling and the results of a physical experiment allow to project an effective working element in a high-tech continuous mixing machine [4].

Dough kneading is a complex process that involves creating a homogeneous capillary-porous mass of flour, water, yeast, salt, and other components. The formation of dough during kneading occurs as a result of a number of processes, of which the most important are: physico-mechanical, colloidal and biochemical processes. All these processes occur simultaneously, mutually affecting each other and depend on the duration of kneading, temperature and the amount and quality of raw materials used during kneading the dough [5–6].

The yeast dough is considered as a complex colloidal system, which consists of several continuous and periodic phases. Solids and liquids (gluten and water) in the dough are continuous phases, starch grains and gas formed during fermentation of the dough is a periodic phase. As a result, the physical properties of the dough are characterized by the parameters of solids, liquids, gases, and indices that are caused by the interaction of these phases. This process is carried out by mechanical processing of the dough, and based on the swelling of the starch and protein complex with the formation of elastic-elastic-viscous homogeneous mass containing active-acting microorganisms and ferments [7–8].

The research methodology is based on the information technologies of designing of processes of elastic-viscous-plastic deformation of thixotropic dispersed materials using modern computer technologies [9–10].

Based on the literature analysis, the task for mathematical modeling of the kneading process of the yeast dough with using cam working elements of the selected geometric shape was formed. The speed was in the range from 20 to 100 rpm and the distance between the structural elements for kneading from 2 to 10 mm.

The aim is to determine the rational configuration of cam structural elements for continuous kneading of dough at different levels of frequency of the working elements rotation and the distance between them.

Materials and methods

The object of the study is the process of kneading of yeast dough [20].

The dough is considered as a complex colloidal system consisting of several continuous and periodic phases [19]. Solid and liquid (gluten and water) in the dough are continuous phases, starch grains and gas formed during the fermentation of the dough – the periodic phase. As a result, the physical properties of the dough are characterized by the parameters of solids, liquids and gases and the indicators arising from the interaction of these phases.

This process takes place during machining, and consists in the swelling of starch and protein complex with the formation of elastically elastic viscous homogeneous mass containing active microorganisms and enzymes. The aim of kneading yeast dough is to obtain a homogeneous mass with certain structural and mechanical properties [19].

Theoretical basis of the modeling problem

To determine the exercise of calculating the motion of liquids, it is necessary to formulate and solve a system of differential equations: energy, continuity, motion, change of density and rheological properties. Equation data for non-compressible liquids but cannot adequately describe the process of movement of the yeast dough are used in the literature, as several researchers prove that the dough is compressed due to the significant content of the gas phase [3–4].

The one-dimensional equations (Saint-Venant), which expresses the principle of mass conservation, for cases of steady motion and non-compressible fluid:

$$\frac{\partial vx}{\partial x} + \frac{\partial vy}{\partial y} + \frac{\partial vz}{\partial z} = 0, \quad (1)$$

where, vx , vy , vz – velocity components, m/s.

The equation of motion of a continuous, non-compressible environment is a system of equations and has the form:

$$\begin{cases} \rho \left(\frac{\partial vx}{\partial t} + \frac{vx \partial vx}{\partial x} + \frac{vy \partial vx}{\partial y} + \frac{vz \partial vx}{\partial z} \right) = -\frac{\partial p}{\partial x} + \left(\frac{\partial \sigma x}{\partial x} + \frac{\partial \tau yx}{\partial y} + \frac{\partial \tau zx}{\partial z} \right) + \rho g x \\ \rho \left(\frac{\partial vy}{\partial t} + \frac{vx \partial vy}{\partial x} + \frac{vy \partial vy}{\partial y} + \frac{vz \partial vy}{\partial z} \right) = -\frac{\partial p}{\partial y} + \left(\frac{\partial \tau xy}{\partial x} + \frac{\partial \sigma y}{\partial y} + \frac{\partial \tau zy}{\partial z} \right) + \rho g y \\ \rho \left(\frac{\partial vz}{\partial t} + \frac{vx \partial vz}{\partial x} + \frac{vy \partial vz}{\partial y} + \frac{vz \partial vz}{\partial z} \right) = -\frac{\partial p}{\partial z} + \left(\frac{\partial \tau xz}{\partial x} + \frac{\partial \tau yz}{\partial y} + \frac{\partial \sigma z}{\partial z} \right) + \rho g z \end{cases} \quad (2)$$

where, ρ is the density, kg/m³; t – time, s; p – pressure, Pa; g is the acceleration of free fall, m/s².

Energy equations for non-compressible liquids:

$$\rho c \left(\frac{\partial T}{\partial t} + \frac{vj \partial T}{\partial xj} \right) = \left(\frac{\partial \tau}{\partial xj} \right) \left(\frac{\lambda T}{\partial xj} \right) + \frac{\tau_{ij} \partial v_i}{\partial x_j}, \quad (3)$$

where, c is the specific heat, J/kg; λ – coefficient of thermal conductivity, W/m;

T – temperature, K.

$\tau_{ij} \partial v_i / \partial x_j = F$ – the intensity of the kinetic energy transition into thermal, to the unit of volume. In the Cartesian coordinate system, F is equal to:

$$F = \frac{\tau x \partial vx}{\partial x} + \frac{\tau y \partial vy}{\partial y} + \frac{\tau z \partial vz}{\partial z} + \tau zy \left(\frac{\partial vx}{\partial y} + \frac{\partial vy}{\partial x} \right) + vyz \left(\frac{\partial vy}{\partial z} + \frac{\partial vz}{\partial y} \right) + \tau zx \left(\frac{\partial vz}{\partial x} + \frac{\partial vx}{\partial z} \right) \quad (4)$$

The material density equation describes its dependence on temperature, pressure, humidity, and other factors. In logarithmic coordinates, the dependence of τ on j for many non-Newtonian materials becomes linear for the most part, thus explaining the widespread use of the Ostwald equation:

$$\tau = k \gamma^n, \quad (5)$$

where, τ – the shear stress, Pa; k – the coefficient of consistency; γ – the shear rate, s^{-1} ; n – the fluidity index.

For processes occurring in mixers, it is quite difficult to determine the criteria that includes the velocity of the particles of solution V . It is often used a conditional velocity equal to the velocity at the outside diameter of the working element of the mixer u . The traditional definition of the Reynolds (Re) criterion for flow in pipes is as follows:

$$Re = \frac{V_{av} \cdot d_0 \cdot \rho}{\eta}, \quad (6)$$

where, V_{av} – average speed, m/s; ρ – density, kg/m^3 ; d_0 – the inside diameter, m;
 η – the coefficient of the structured viscosity of the non-Newtonian fluid, Pa·s.

For the case of movement of the blend in the mixer is conditionally taken [5, 7]:

$$V_{av} = \omega \cdot R, \quad (7)$$

where, ω is the angular velocity, rad/s; R – the outer radius of the working element, m.

$$Re = \frac{\omega \cdot R^2 \cdot \rho}{\eta}. \quad (8)$$

The Reynolds criterion calculated by this method is not universal, which determines the nature of the flow of the blend in the mixer, since the nature of the flow also depends on the design of the chamber and the working elements of the mixer, which are not shown in the last formula. This drawback does not make it possible to use the resulting criterion universally to analyze many food processes occurring in mixers, so it is necessary to develop separate formulas for each type of mixer to determine the power consumed for mixing. The Froude criterion (Fr) is the ratio of the inertia forces of the mixable mixture to the gravitational forces. For mixers it can be written as following:

$$Fr = \frac{\omega^2 \cdot R}{g}, \quad (9)$$

where, ω is the angular velocity of rotation of the working element of the mixer, rad/s;

R – the outer radius of the working element, m; g – the acceleration of free fall, m/s^2 .

This criteria takes into account the effect of the vorticity formed on the back of the working element during movement in the yeast dough.

Generalization of the results of the study of the power consumed for mixing non-Newtonian fluids is associated with some difficulties, since the viscosity of such fluids depends on the hydrodynamic regime in the mixer [4], and, accordingly, the angular speed of rotation of the working element and its configuration. The rheological properties must also be taken into account. This can be done using the dimensionless Hedstrom criterion [5]:

$$He = \frac{\tau_0 \cdot R^2 \cdot \rho}{\eta^2}, \quad (10)$$

where, R is the outer radius of the working element, m; ρ – the density of the mixture, kg/m^3 .

The basic definition of the Eulerian criteria in the general case is as follows [6–7]:

$$Eu = \frac{\Delta p}{\rho \cdot V^2} \quad (11)$$

where, Δp – pressure drop, Pa; V is the speed of movement of the mixture, m/s.

The Eulerian criteria is the ratio of the forces that cause the movement of the mixture to the forces of dynamic pressure. For processes occurring in mixers, the pressure drop Δp and velocity V should be replaced by the power consumed for mixing. We obtain the modified Euler criterion or the power criterion K_N :

$$K_N = \frac{N}{\rho \cdot n^2 \cdot R^5}. \quad (12)$$

Thus, taking account mentioned above, the basic criteria equation is describing the motion of a viscous-plastic stirring medium will be as follows:

$$\frac{N}{\rho \cdot n^2 \cdot R^5} = f\left(\frac{\omega \cdot R^2 \cdot \rho}{\eta}, \frac{\omega^2 \cdot R}{g}, \frac{\tau_0 \cdot R^2 \cdot \rho}{\eta^2}\right), \quad (13)$$

also, the obtained equation can be written in the form of a step monomial:

$$K_N = C \cdot Re^m \cdot Fr^n \cdot He^z, \quad (14)$$

where, C is the coefficient; m, n, s are the exponents.

When kneading wheat yeast dough, the role of gravity is quite small, so the value of gravity is neglected. In general, the criteria equation of the mixing power can be written as:

$$K_N = C \cdot Re^m \cdot He^z. \quad (15)$$

Therefore, the considered mathematical models of the movement of wheat yeast dough allow to simulate the process of kneading wheat yeast dough and can be used for simulation in the software complex Flow Vision.

Mathematical modeling the process of kneading the yeast dough

Modeling of the yeast dough kneading process was performed via the Flow Vision software package, which is designed to model the three-dimensional motion of liquids and gases in technical and natural objects, as well as to visualize flow curves by computer graphics.

To simulate the process of kneading the yeast dough by the cam working elements, the software program "Flow Vision" was selected, which is designed to simulate the three-dimensional motion of liquids and gases in technical and natural objects, as well as to visualize curves of currents by computer graphics.

To simulate the process of kneading the wheat yeast dough, an incompressible fluid model was chosen, which describes the flow of a viscous fluid at small and large (turbulent) Reynolds numbers, followed by its visualization [7]. In the model it was used following equations:

Navier-Stokes equation:

$$\frac{\partial V}{\partial t} + \nabla(V \cdot V) = \frac{\partial P}{\rho} + \frac{1}{\rho} \nabla((\mu + \mu_t)(\nabla V + (\nabla)^T)) + (1 - \frac{\rho_{hyd}}{\rho})g; \quad (16)$$

Flow continuity equation:

$$\nabla V = 0, \quad (17)$$

where, V is the velocity vector m/s, P is the pressure Pa, μ_t is the turbulent viscosity Pa's, ρ_{hyd} is the hydrostatic density of kg/m³, g is the vector of gravity m/s².

"The incompressible fluid" simulation model is based on the use of k-ε of the first-level turbulence model [8], which requires to get the formula for turbulent viscosity μ_C

Equation for turbulent viscosity:

$$\mu_C = \mu \rho \frac{k^2}{\varepsilon}; \quad (18)$$

turbulent energy equation k is also included in the model

$$\frac{(\rho k)}{\partial t} + \nabla(\rho V k) = \partial \nabla \left(\left(\mu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right) + \mu_t G - \rho \varepsilon; \quad (19)$$

Turbulent energy dissipation rate equation:

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \nabla(\rho V \varepsilon) = \nabla \left(\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right) + \tilde{N}_1 \frac{\varepsilon}{k} \mu_t G - C_2 \rho \frac{\varepsilon^2}{k}; \quad (20)$$

marked by G expression:

$$G = D_{ij} \frac{\partial v_i}{\partial x_j}; \quad (21)$$

$$D_{ij} = S_{ij} - \frac{2}{3} (\nabla \cdot V + \frac{\rho k}{\mu_t}) \delta_{ij}; \quad (22)$$

$$S_{ij} = \frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}; \quad (23)$$

Parameter values are:

$$\sigma_k = 1; \sigma_z = 1,3; C_\mu = 0,09; C_1 = 1,44; C_2 = 1,92.$$

To load the geometry of the working elements, we use the filter "Element Movement in the Geometry Template", in which we enter the mass of the kneading element, the matrix of inertia, the angular velocity and the primary location. The next step in the simulation is to establish the boundary conditions of the problem, as shown in Figure 1.

Figure 1. Boundary conditions for simulation modeling

At the "Input" border, we set the "Normal Speed" boundary condition; on the border "Cam working element" we establish the "Logarithmic law"; at the Exit boundary we set the Free Exit boundary condition.

The next step of entering the input parameters is to build a grid in the calculation area, which is used to select a uniform grid along the guides x, y, z.

To obtain reliable results, it is necessary to enter the parameters of numerical calculation, which determine the program step by time and take into account the action of gravity.

Several methods were used to visualize the obtained results in the Flow Vision software package: visualization of scalar fields, individual numerical values, velocity vector fields.

Physical modeling of kneading the yeast dough

To compare the results of physical and mathematical modeling, we have developed a kneading machine (Figure 2) that allows us to investigate the process of kneading wheat yeast dough and changing rheological properties, to perform a comparative analysis of different structures of working elements, and based on research to develop effective working elements for kneading yeast dough.

Figure 2. Experimental kneading machines

The procedure for performing physical modeling:

1. Preparation of raw materials and installation, installation of devices.

Yeast dough for the study, prepared for 300 grams of flour, according to the following recipe:

Wheat flour, premium grade 300 g;

Baking yeast, granulated 3 g;

Food salt 4,5 g;

Drinking water 175 ml.

Yeast dough, with a humidity 43%, was prepared in a steamless way from high-grade flour. The duration of fermentation is 30 minutes at a temperature of 33 °C.

2. Pre-mixing the prescription components for 10 s.
3. Loading pre-mixed components into the receiving hopper of the working chamber.
4. Kneading yeast dough and recording data.
5. Determine the mass and humidity of the yeast dough.
6. Determination of structural and mechanical properties of the dough.
7. Determination of the porosity of the finished product.

After the research based on the received data, we build graphics with the dependences of kneading of yeast dough.

Results and discussion

Mathematical modeling of kneading the yeast dough

We conducted studies on the effect of the distance between the cams and the speed of rotation of the working element on the kneading process of yeast dough. The distance between the cam working elements was changed from 2 mm to 10 mm (2–4–6–8–10 mm), the rotation speed was changed in the range from 20 rpm to 100 rpm (20–40–60–80–100 rpm). Simulation modeling of the kneading process was performed in the Flow Vision software package. The simulation results were obtained in the form of graphical images with a color scale of distribution of variables with numerical values (Figures 3, 5, 7).

Figure 3. Visualization of the speed of movement of the dough in the mixing chamber during simulation parametric modeling of the cam working elements in the software complex Flow Vision.

This result is explained by the fact that the cam working elements rotate in the opposite rotation, forcing and accelerating the speed of mixing of the components of the yeast dough [11–12].

Based on the results, after parametric modeling of the kneading process by the cam working elements, a linear dependence of the speed of movement of the dough in the working chamber was obtained (Figure 4).

Figure 4. Variation of mixing speed, depending on the distance between the cams and the speed of rotation of the working element

It has been investigated that with increasing the speed of the working element, the speed of movement of the dough in the mixing chamber increases, under these conditions of the

mixing process the distance between the cam working elements does not affect the speed of mixing.

This result is explained by the fact that the rotational speed of the working element directly affects the mixing speed of the prescription components of the yeast dough, which mix faster with increasing rotational speed despite the distance between the cam working elements in the specified range [11–14].

The change in the mixing speed [$V = \text{m/s}$], depending on the distance between the cams and the speed of rotation of the working element, is determined by the mathematical formula:

$$V = 0,005n + 0,03, \quad (24)$$

Figure 5. Visualization of pressure in the mixing chamber during simulation of parametric modeling of cam working elements in the software complex Flow Vision.

The simulation data on the change in pressure in the mixing chamber were analyzed (Figure 5), which made it possible to obtain the dependence of the pressure on the rotation speed of the working element and the different distance between the cams (Figure 6). It was found that with increasing the speed of the working element, the pressure in the mixing chamber increases. The pressure in the chamber is also affected by the distance between the cam working elements, the smaller the distance, the greater the pressure in the chamber. The maximum pressure values are 16560 PA at a distance between cam working elements of 2 mm and a rotational speed of 100 rpm, a minimum of 555 PA at a distance between cam working elements of 10 mm and a rotation frequency 20 rpm.

In the mixing chamber, the highest pressure values are formed in the contact zone of the cam working elements with the wall of the mixing chamber and in the contact zone of the two cams (Figure 5)

This result is explained by the fact that the cam working elements rotate to meet each other, the highest pressure is observed in the area of engagement of the cam working elements and in the area of contact with the wall of the housing [14–16].

Figure 6. Changing the pressure in the mixing chamber, depending on the distance between the cams and the speed of rotation of the working element.

The change in pressure [$P = \text{Pa}$] in the mixing chamber, depending on the distance between the cams and the speed of rotation of the working element is of a power character and is described by the formula:

$$P = (73 - 6,9S)n^{0,03S + 1,14}, \quad (25)$$

where, S is the distance between the cam working elements, mm; n is the speed of rotation of the working element, rpm.

We obtained the viscosity distribution of the kneading chamber at different rotational speeds and working element distances. The simulation results confirmed the pseudoplastic nature of the test, which is explained by the variable numerical viscosity data of the dough in the kneading chamber (Figure 7). Based on the obtained results, a graph of viscosity change in the mixing chamber was constructed, depending on the distance between the cams and the rotation speed of the working element (Figure 8).

Figure 7. Visualization of the change in viscosity in the mixing chamber during simulation parametric modeling of the cam working elements in the software program Flow Vision

The parts of the kneading chamber that achieve the lowest viscosity are considered to be most effective during mixing. Increasing the rotation speed of the working element leads to an increase in the speed of movement of the dough in the work chamber, which in turn leads to a decrease in the viscosity of the dough and a decrease in energy costs during the kneading process.

This result is explained by the fact that with increasing speed of the working elements decreases the viscosity of the yeast dough, and the change in viscosity is affected by the distance between the cam working elements in the process of kneading the dough [15–17].

Figure 8. Viscosity change in the kneading chamber, depending on the distance between the cams and the rotation speed of the working element

It has been investigated that with increasing rotation speed, the viscosity of the dough [$\eta = \text{Pa} \cdot \text{s}$] decreases in the kneading chamber. The decrease in viscosity is also affected by the reduction of the distance between the cam working elements, as the distance between the cams during the kneading process will decrease the viscosity of the dough.

The mathematically obtained dependence is described as:

$$\eta = (201431 \cdot S^{-1,4})n^{0,09S - 1,4}, \quad (26)$$

where, S is the distance between the cam working elements, mm; n is the speed of rotation of the working element, rpm.

Physical modeling of kneading the yeast dough

Simulation parametric model of the yeast dough kneading process allowed us to study in detail the processes occurring in the dough mixing chamber, the dependence of the flow motion on the design and configuration of the cam working elements, and the rotational speed.

The results of simulation parametric modeling were tested on a physical model (Figure 9).

Figure 9. Comparison of the results of physical and simulation modeling of change of speed [V , m/s] in the mixing chamber at different speed of the cam working element (1 – physical; 2 – simulation)

Comparing the results of physical and simulation modeling of the yeast dough kneading process with the camshafts, and carrying out the mathematical processing of the obtained results, the error is less than 5%, the mathematical model corresponds to adequacy.

On the basis of simulation modeling and experimental studies, the design of the working element for kneading yeast dough in a continuous kneading machine is proposed.

It is rational to use the gap between the cams and the wall of the mixing chamber for cam working elements, this will help during production to compensate for production tolerances and irregularities, compensate for uneven heat distribution and reduce the excessive pressure on the semi-finished product.

Rational parameters of the cam working elements

To increase the carrying capacity of the cam working elements, improve the mixing and reduce the cost of heat (increase the temperature of the dough), rational use of the cam working elements with a variable pitch and a variable position of the cams at $\alpha = 45^\circ$ (Figure 10) or combined cam working element with the use of turns auger (Figure 11) at the beginning of the working element. It is rational to use the selected cam working element profile ($\alpha = 45^\circ$), so that the location of the cam can be changed on the shaft of the working element depending on the needs of the process. Changing the cam pitch also affects the intensity of the kneading process and the duration of the kneading steps.

Figure 10. Cam working element with variable pitch

It is possible to rationalize the process of kneading the dough and reduce the time it takes to stand and ferment due to the intensive mechanical processing of the dough by the working cams, and as a result of obtaining the qualitative characteristics of the bakery products.

It is advisable to knead yeast dough using cam working elements. In the first kneading stage, to ensure the mixing of components and to improve the transport properties, it is advisable to use a cam working element with a pitch of 18 mm and a distance between the cams of 2 mm, the number of doubly located cam 5 pairs with an angle $\alpha = 45^\circ$ or a screw working element (Figure 11) with a pitch of 18 mm is paired with 4 turns of the screw auger on the shaft.

In the second kneading stage, it is advisable to use 2 doubly arranged cam elements with 36 mm increments and 8 mm cam spacings, under these conditions the working volume in the mixing chamber will increase and the mixing chamber pressure will decrease. It is advisable to carry out the plasticization step with a pairwise cam working element with a pitch of 54 mm and a distance between the cams of 4 mm under these conditions, the outlet stabilizes the viscosity of the product.

Figure 11. Combined (cam-screw) working element

In the case of positioning at the beginning of the shaft of the screw element, for the second and third stages on the rest of the shaft, it is advisable to place the cam working element in 18 mm increments and the distance between the cams for 5–8 pairs of cams 2 mm for proper mixing, under these conditions, the pressure is increased, thereby reducing the viscosity and, consequently, the load on the engine, which saves electricity, then 9–12 pairs of cams with the distance 4 mm to plasticize the dough.

Conclusions

The simulated parametric model of the kneading process by cam working elements has been developed that allows to perform design calculations effectively in case rational structural and technological parameters selection. The use of the presented scientific and methodological developments will greatly speed up and economically save the process of creating reliable technological equipment for kneading yeast dough.

Changes in the shear stresses of the yeast dough in the mixing chamber, in the area of engagement of the working elements and close to the contact with the walls of the mixing chamber are studied. The dissipation distribution in the kneading chamber and the temperature change during the kneading process were investigated. At a rotation speed of the working element of 60 rpm, the temperature of the yeast dough rises to 5° C, which is acceptable during kneading of the dough.

Mixing speed, dough viscosity, and mixing chamber pressure were investigated. With increasing rotation speed of the working element, the speed of mixing the dough in the mixing chamber increases. Increasing the rotational speed from 20 rpm to 100 rpm increases the pressure in the kneading chamber and reduces the viscosity of the yeast dough.

Based on the simulation modeling of the yeast dough kneading process, effective working elements for kneading yeast dough in a continuous kneading machine are proposed.

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