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RESEARCHING OF THE CONCENTRATION DISTRIBUTION OF SOLUBLE LAYERS WHEN MIXED IN THE WEIGHT CONDITION

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ABSTRACT
The analytical and experimental analysis of the processes associated with the formation of structural systems, which includes adsorption, its main paths of formation, patterns of influence on the structure of the environment and its behavior at deformation influences is carried out. The ways of choosing the optimal variant of the adsorption diffusion process for providing the maximum or minimum value of parameters (criterion) are proposed. The physical essence of the relation of the length of the sorbent layer with the time of its protective action (number of bound substance) is considered, which allows to practically characterize the work of the sorbent layer under dynamic conditions. It is noted that the determination of dynamic combined power flow influences during the process of mixing of components plays an important role in the structure formation of the suspension and promotes the construction of calculations for the construction of mixing equipment. The obtained data give an answer a series of questions about the theory of adsorption and diffusion (adsorption actions of van der Walsh forces on surfaces) and the ability to regulate the effect of combined power flows directly affect these process transformations (concentrations). For a illustration and understanding of the general execution of research, depending on the method of applying force, the degree of its previous dispersion and its physical and mechanical properties, a scheme of causal relationships between components and parameters that determine the change in the structure of the components in mixing process on a new discrete machine. The principle of discrete-momentum mixing of components in the weight condition and mechanical influence of the formable working body is considered. Based on the process of mixing the components in the working chamber of the machine, a mathematical model is proposed.

Keywords: dough; injection; thermal conductivity; distribution of heat; heat flux; roll; phase; environment

INTRODUCTION
One of the main direction of rational technical support for the process of mixing components in different industries is machines with working organs of known designs. To date, there is not enough variety of designs of working bodies that perform a technological operation on mixing heterogeneous environment. Many of these machines need to be refined and explored to introduce new developments in manufacture. Particular attention is paid to small, efficient machines with controlled processes occurring in the working chamber. When creating or upgrading small machines for intensive mixing, special attention should be paid to substantiating the technological scheme and the appropriate constructive solution of the decisions taken **(Zvyagin and Vorotnikov, 2004)**. Since the design parameters are interrelated with the process, it significantly influences the possibility of manufacturing such a machine in the conditions of enterprises, technological possibilities of which are aimed at repair and restoration of equipment.

Machines intended to mix components should produce an effect on them in such a way that the raw materials and finished products loss are minimal and the quality of the semi-finished product is high. This leads to the need to ensure the full compliance of process conditions, geometric shapes and structural parameters of the working bodies and structural and mechanical properties of environment.

In his writings **(Zvyagin and Vorotnikov, 2004; Sekundov, 1977)** the author noted that the lag of scientific developments from the needs of practice is explained by an extremely wide range of properties of technological environments, the variety of materials used for their transportation and the difference in the conditions of their exploitation. In addition, the study of the mixing of the viscous medium is associated with a certain complexity due to the need to engage in solving the problems of modern knowledge and methods in various fields of science: physical and chemical mechanics of materials, rigid body physics, metallurgy, etc.

Implementation of the principles of rational mixing requires fundamentally new approaches to the creation of a new generation of technological equipment. The difference between a new machines should be based on a constructive solution of parameters at given physical and chemical properties of a mixture of components. Therefore, the rapid introduction into the industry of technological processes in a weighted condition, due to the fact that when we give the method of conducting the process favorable conditions for its intensification are created. This is due to the increase of the phase contact area, the improvement of mass exchange and heat transfer, the reduction of energy consumption on the impact of hydraulic resistance of the system and the creation of conditions for the transition from the processes of periodic to semi-continuous and continuous.

Analysisoflatestresearches

In the study of the adsorption process in the stationary layer Shylov (**Keltsev, 1984**) introduced the concept of the dynamic activity of the sorbent. He, on the basis of a number of studies, proposed an equation that allows us to practically characterize the work of the sorbent layer under dynamic conditions. This equation links the length of the sorbent layer with the time of its protective action (the amount of bound substance) and has the form:

$$\tau = KL - t_0 \quad (1)$$

Where:
τ – time of protective layer property, min.;
K – protective action coefficient, the value associated with the components dosing rate (fluid) into the interaction system, after the formed region of the gradient and the velocity of its motion, has become constant, min.m^{-1};
L – length of the layer, m;
t_0 – time needed for the formation of the gradient region of theinteracting component concentration velocity in the weight state within the medium, min.

It follows from the equation that the values of K and t_0 are empirical values for the practical characteristics of the interacting systems. The coefficient of protective action of K depends on the sorbent properties, interaction conditions, aerodynamic conditions and physico-chemical parameters of the flour-air mixture. The presence in the equation $\tau 0$ is due to the fact that, owing to the high and constant concentration in the flour, the adsorption property of the initial layer forming the velocity gradient region, is used in a short time and the time of the protective action per unit length of the layer influences less than for the subsequent layer.

In the work of other researchers **(Braginsky, Begachev and Barabash, 1984)** it is shown that the presence in equation (1) t_0 is regular and is a consequence of the short velocity of the adsorption process in dynamic conditions. This leads to the fact that the concentration conditions of any layer and the protective action time are different from the operating conditions of the subsequent layers.

Several of researchers indicate that the formation of the front of mixture does not end when dosed at a sufficiently large length of the layer and that the equation (1) only formally shows the adsorption process in dynamic conditions. However, this equation is the only one that allows us to characterize the system components interaction in dynamic conditions. The adsorption process is heterogeneous and consists of:
- diffusion of droplet molecules between sorbent particles to its outer surface;
- diffusion of droplet molecules inside and active surface of the sorbent;
- sorption on the surface of sorbent pores.

The kinetics of the heterogeneous reaction is determined by the time course of its individual components, and the rate of the heterogeneous process coincides with the speed of the slowest process. Since the adsorption process itself is a purely superficial phenomenon, adsorption is practically instantaneous. Therefore, we can assume that the speed of the adsorption process is determined by the diffusion velocity, it means that it passes mainly in the diffusion region. In the diffusion region, all reactions have the first concentration of the reacting component at constant pressure. The constant of the reaction rate is the diffusion constant. So the expression of the external speed and internal diffusion can be represented by the equation:

$$\frac{da^1}{d\tau} = \beta^1 \left(c_0 - c^1\right)$$

and

$$\frac{da^{11}}{d\tau} = \beta^{11} \left(c^1 - c^{11}\right)$$

in general, the adsorption rate

$$\frac{da}{d\tau} = \beta \left(c_0 - c\right)$$

Where:
β – the mass transfer coefficient of;
C – the mixture concentration, the equilibrium amount of the component that interacts with the unit volume of the adsorbent, kg.m^{-3}.

The value is reversed β, the diffusion resistance is present.

$$\frac{1}{\beta} = R = R_{internal} + R_{external}$$

To date, there is no complete theory describing the adsorption process in dynamic conditions. There are three points of view on the kinetics of the adsorption process. One author considers **(Levich, 1952)**, that the velocity of the adsorption process is determined by the speed of external diffusion, others are derived from representations **(Lykov, 1954)**, that the kinetics of adsorption is determined by the rate of internal diffusion. The third – to the corresponding period, the speed of the process is determined by external diffusion, and then – the speed of internal diffusion of the sorbent component. Consequently, the moment of these changes by different authors is determined differently.

Levich (1952) gave a general method for determining the diffusion flow from the surface. In his theory, the diffusion layer adopts an appropriate and quantitative definition: there is a convective and molecular transfer of matter on the outer boundary of the diffusion layer – one order of magnitude. The change in concentration c in the diffusion layer is determined by the differential equation:

$$D\frac{\partial^2 c}{\partial y^2} = v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} \quad (2)$$

Where:
v_x i v_y projections of fluid velocities.

On the basis of literature data and research analysis, the third point of view most correctly display the essence of the adsorption process in dynamic conditions. Despite the large number of works that display the essence of the adsorption process, to date, in the literature on the adsorption of flour in the liquid phase, there is no rational calculation methodology. Using the methodology it would be possible to use the design of new constructive and technological parameters of the machine, to establish ways to intensify the mixing of components and to select the optimal conditions for conducting the technological process.

Formation of the problem and the purpose of the researching

Modern food technologies are developing in the directions of technological processes intensification, therefore, it was necessary to obtain new experimental data for the qualitative design of modern types of mixing equipment, taking into account the filling of the working chamber, its length or contact area to ensure rapid concentration change.

In his writings **(Lykov, 1954; Strenk, 1971)**notes that the creation of a qualitative mixture is not equivalent to obtaining a uniform concentration of solids particles in the liquid throughout the volume of the apparatus. Often is hard to achieve this, but it is not necessary. The uniform concentration of the suspension in the entire volume of the mixer does not matter, but it is important that all solids are kept in a suspended liquid. Therefore, it is necessary to create a large turbulence of the liquid around the grains in order to reduce the thickness of the laminar layer on the boundary of the liquid – solid.

A typical technological process associated with the formation of structural systems is the process of adsorption. Therefore, new advanced technological methods of interaction of the solid phase with gas, liquid phases in the heavy (boiling) layer and adsorption in the fluid layer (hypersorption) appeared in the food and pharmaceutical industries. The rapid growth of the technique of adsorption requires further researching of the statics and kinetics of the adsorption process for its use in various conditions, especially when mixing the components **(Pawel et al., 2016)**.

The mixing process is considered as a purely mechanical process of mutual penetration (particles of a continuous medium with the same physical properties between particles of a continuous medium and other physical properties) in order to obtain a homogeneous continuous medium with new properties that differ from the properties of the mixed enviroments.

Mixing water and flour is a heterogeneous process. The speed of heterogeneous processes depends on the surface of the interphase contact and on diffusion. The increase in the reaction rate is mainly due to the renewal of matter on the contact surface of the phases, since the diffusion rate is negligible. The heterogeneous reaction consists of several successive stages. For example, the reaction between the liquid and the particles of flour passes through the following stages:

- supply of molecules of any reagent from the solution to the surface of the phase separation;
- adsorption on the surface;
- chemical reaction on the surface;
- desorption of reaction products;
- diffusion of reaction products in the surrounding volume.

The resulting velocity of the entire process is determined by the speed of the last stage – the volume mixing in the working chamber of all components. If this stage is a chemical reaction, mixing is used to align the concentration field. In this case, a large circulation is required. Therefore, the main attention must be paid to the researching of the heterogeneous system structure formation in a mass condition under the influence of mechanical, vibrational, gravitational, hydrodynamic factors. It is necessary to use a combined method of research: theoretical and experimental. On the basis of research, to obtain mathematical models that allow to substantiate the structural, technological parameters and the mechanism of the adsorption process for the design of new mixing machines.

The mechanism of structuring is of fundamental importance for mixing components with given properties. There are several mixing mechanisms. The first one, when the diameter of the formed droplet of the emulsion is up to 20% of the diameter of the center of structure formation. Drops as a heat-carrier, due to adhesive-sorption forces, are fixed on flour particles, and due to their interaction, an intense penetration of the liquid occurs and the formation of a new layer of solid components on the surface of the mixture.

The second option when the diameter of the formed drop is more than 20% of the diameter of the center of structure formation. The solution forms a pellicle on the surface of the flour in the zone of intense heat-mass transfer and, a new layer of the mixture is formed (Figure 1). In case of exceeding the critical value of moisture content, the mixture is destroyed due to the reduction of strength and drains over the walls of the working chamber, or due to the creation of liquid bridges appear agglomerates.

Both methods of mixing are determined by the method of introducing the liquid phase into the apparatus and the hydrodynamic regime of the fluidized bed. To ensure the layered growth of the forming mixture structure forming, the required diameter of the liquid droplets should not exceed 300 μm. So, the presence of a dispersing device that can distribute a heterogeneous liquid phase inside a fluidized bed, and providing a predetermined droplet size, is a prerequisite for mixing the components in the design of a new machine.

The use of a fluidized-bed technique with mechanical stirring allows you to obtain a suspension with a uniform distribution of components throughout the volume of the working chamber of the machine. This multifactorial process with stochastic nature requires complex mathematical modeling **(Neuvazhaev, 2000)**.

Scientific hypothesis

A significant number of transported substances in the environment, changes in their concentrations, the interaction between them and microorganisms, the presence of stimulants, etc., lead to relative instability of the system. Under these conditions, there is an understanding of which direction should assess the effects of individual factors. At first glance, it may seem that in best case should meet the maximum satisfaction or security at the upper levels of the factors of influence. However, the negative effects should also be programmed, for example, by the values of osmotic pressures, double and triple effects of factors, deterioration of quality indicators, etc. Evaluating the effects of changes in concentration (composition of factors), is more difficult. The results of transformations of physical factors determined from this point of view are not enough. If the influence of temperature is carefully observed, then there is no complete point of view relative to the change in the concentration in the layers of the movable components.

The change in the concentration of dissolved flour in the liquid phase of the environment means decreasing of the osmotic pressure and increasing the mass transfer mechanism at the interface between the surfaces of microbial cells and the liquid phase of the environment.Dynamics of changes in the direction of concentration in the three-phase system is possible due to forced mixing. Such effect on the formed environment is one of the most rational, since its manifestations relate to the total volume of the formed medium with the complete exclusion of local zones without their features. The implementation of transient processes based on concentration in three-phase systems is possible due to the successive synthesized gas and solid phases, which have signs of energy-saving technology.

The presence of complete flour interaction at the level of the state of saturation in the liquid phase establishes on their surfaces the separation of the phases of the gas-liquid-solid body and in the liquid film, which causes the main change in concentration, the resistance of the mass transfer, the acceleration of dissolution. Therefore, the speed of the mixing process is not only external, but also corresponds to the essence of the physical and chemical phenomena that occurs when mixing the components. Indeed, the mixing process should be considered as adsorption of flour to moisture with the help of mechanical influences.

Such a conclusion deserves an experimental review and development of proposals for use. A special need for effective flour disintegration technology refers to technologies in which partially exist an intensive aeration process that impedes their productivity and efficiency. However, the peculiarities of phase synthesis in blending machines practically remain aside from these studies. The latter relates to the change in the concentration in the layers of the high-altitude unevenness of the interacting components in the working chamber, the holding capacity and high-altitude gradient of solubility of the flour. It is important that in both these directions should expect to increase the efficiency of technological processes.

The generated impulse energy impacts on the basis of accumulated energy potentials when mixing components in the baking industry should lead to a limitation of material losses. The realization of phenomena of change in concentration in the formed media in the mixing technologies should be considered at the level of the simulation method.

MATERIAL AND METHODOLOGY

The material for research was a liquid aqueous-flour mixture (pre-ferment) with a moisture content of 65 – 75%. The mixture was prepared from high quality wheat flour, and the moisture content of the flour was 13.9 ±0.2%. The tempering temperature was within the range of 24 – 350 °C. The volume of the pre-ferment in all cases was 0.008 m^3, and the density was ρ = 1066 kg.m^{-3}. The required amount of raw material was dosed by mass. The amount of water added in mixing Gv (in mL) was determined by the method **(Drobot, 2010)** (Table 1).

$$G = G_c (W_0 - W_c) / (100 - W_c)$$

Where:
Gc– total weight of flour, gr;
W_0 – moisture content of pre-ferment, %;
Wc – average weighted moisture content of raw materials, %.

The water temperature (t_0 C) of water consumed for mixing the pre-ferment, provided its temperature is 280 °C, was calculated by the formula:

$$t_o = t_n + c_b G_b (t_n - t_b) / c_b G_b + K$$

Where:
To – set temperature, °C.;
c_b – heat capacity of flour, kJ.kg^{-1} K, (c_b =1.257);
G_b– heat capacity of water, 4.19;
t_b – flour temperature, °C.; Gm– amount of water, g;
K – correction factor (in summer 0 – 1, spring and autumn – 2, winter – 3.

Method of work execution

The research process included the mixing of ingredients at different modes: the rotational speed of the shaft, the geometric dimensions of the working body, the distance between the working body and the bottom of the working chamber.

To determine the existence of a functional dependence describing the kinetics of some features of the adsorption process in a weighted state, a researhing was conducted on the physical model (Figure 2) in the TNTU laboratory.

According to the design features of a new mixing machine designed, the free-fall flour is doped into a cylindrical chamber 1 and is wetted downward by a sloping jet of liquid components 6. The jet of liquid components is formed by a pressure device with nine holes in the form of nozzles. The components are supplied from the dispenser of liquid components 4, which is experimentally installed at a certain height so that the prescribed dosage amount is dosed within 1 – 1.5 minutes.

For the control of leakage velocity, duration and quality of liquid components sputtering, the researching of dynamic activity in a curved state on the dispenser of liquid components was performed. The speed was changed from 2 to 3 L.min^{-1}, it corresponded to the speed at which the absorbent layer passed to the suspended state. The supply pressure of the components was controlled by the installation height of the dispenser.

In our experiments, the way of studying the heterogeneity of the distribution of solid particles of flour in the stream was chosen by analyzing the photos obtained on the microscope. Technologies of automated image analysis in the technological process allow to shorten the time and increase the accuracy of product quality control. The processing of digital images is a rather vivid and obvious example of conversion and analysis of measurement data, which are widely used in industrial systems of machine vision.

The light scattering phenomenon is at the basis of optical methods for estimating the size, concentration and structural and morphological features of agglomerates of the disperse phase. The main methods for the investigation of disperse systems using this phenomenon are electronic ultramicroscopy.

For data processing automation, a microscope, a digital camera, which provides image registration at predetermined intervals, image capture devices and digital camera control, is used. Also, software is used to interpret the information received in a convenient way.

Pre-ferment obtained for different mixing modes was examined. The main controlled parameter is the discrete-pulse input of components into the middle of the working chamber, which depends on the design parameters. The mixture was prepared by the developed method – mixing in a weighed condition with the influence of the container working bodies, which created the internal circulatory contour of the components in the chamber. After every 30 seconds of the process, by use the probe, five samples of a mixture of different parts of the volume of the working chamber were selected. Further samples were explored on a microscope.

Figure 3 shows an example of a 600x magnification shot using a biorex Konus-3 microscope and a Sigeta UCMOS 5100 digital camera with a resolution of 5 megapixels in the automatic shooting mode open in the ToupView program area.

The next step is to bring the digital image to the physical units of measurement using a scale based on the digital image of the measuring line with the same magnification factor.

Since the color of the sample is not interesting for further research, to facilitate further transformations, the photo was transformed into shades of gray.

Compared to the results of the visual analysis, while processing a part of the objects is lost. The main problem is the presence of unclosed areas that are not properly processed by the program. Therefore, various combinational lighting options were used to improve the "relief" of the image and the exclusion of "illumination", as well as the multiple use and combination of software filters. In Figure 4 are represented processed micrographs of samples.

The research results are mathematically processed using software packages: Excel, MathCAD.

Statistic analysis

Given the chaotic interaction of the components during their mixing, where the change in concentration occurs between the working plates, in the space of the working chamber and its surface, the task of planning the experiment with the use of a full factor experiment of the second order is drawn up. With two factors, the model of the experiment's function has the form: $y = f(x_1 . x_2)$

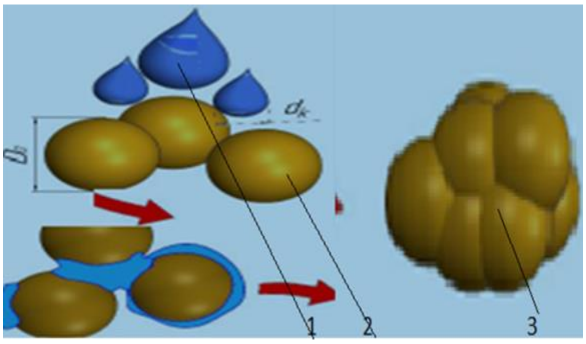

Figure 1 Fixing the drop 1 on the flour particles 2, their interaction, the formation of the mixture 3.

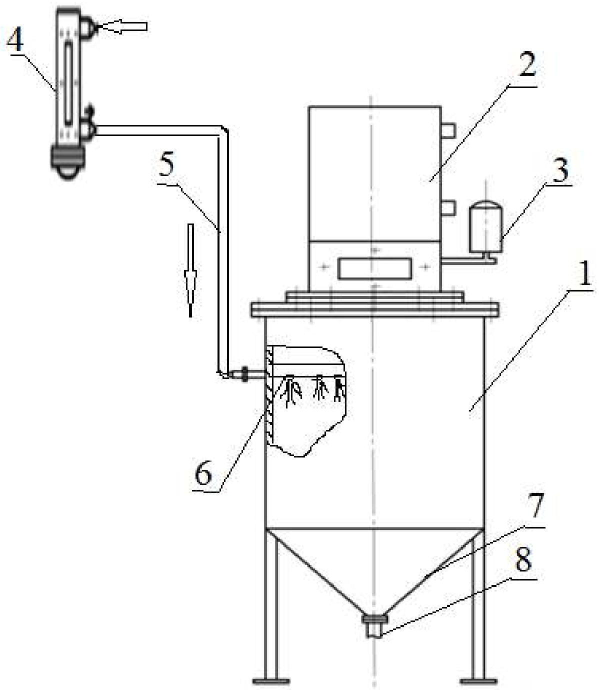

Figure 2 Structural diagram of the physical model of the experimental installation.

Note: cylindrical-conical working chamber – 1. On top mounted vibro-dispenser of loose components 2 with direct current actuator 3; the membrane dispenser 4 is installed to the left and is connected to the spray device 6 installed inside the chamber with mechanical nozzles with the supplied pipeline 5; the cone of the chamber 7 arranges the discharge of the mixture (emulsion) through the pipe 8.

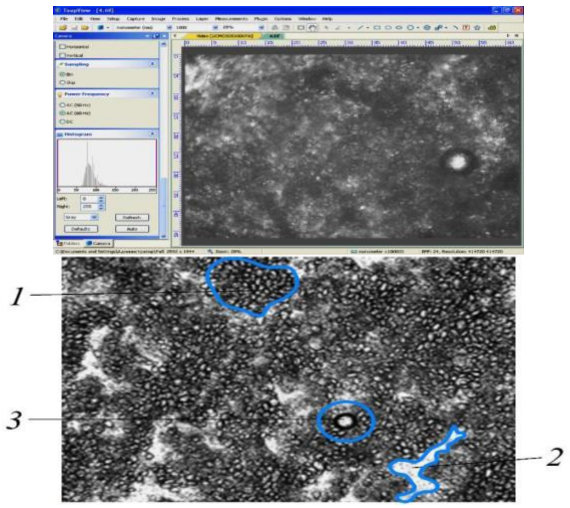

Figure 3 Example of a 600x magnification shot using a biorex Konus-3 microscope and a Sigeta UCMOS 5100 digital camera with a resolution of 5 megapixels.
Note: a) ToupView program work area; b) microscopic sample of pre-ferment: 1 – solid phase; 2 – liquid phase; 3 – air phase.

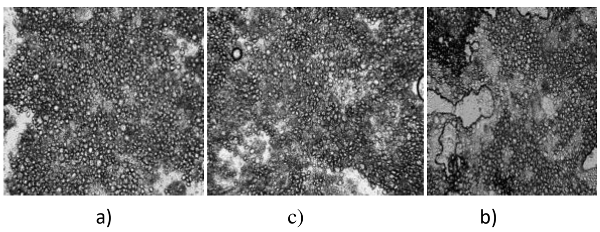

Figure 4 Microphotographs of pre-ferment in different modes.
Note: a) weighted condition; b) surface of cylindrical chamber; c) mixing by a working body.

Table 1 The ratio of the amount of flour and water to the boils of different humidity.

Raw	Amount of raw materials for pre-fermentinmoisture content		
	65%	70%	75%
Flour[g]	2600(40%)	2100(35%)	1800(30%)
Water [mL] (yeast emulsion)	4600 (60%)	3900 (65%)	4200 (30%)
Concentration, [kg.kg^{-1}]	0.666	0.538	0.429

According to the results of the experiment, we obtain a regression equation of the second order.

$$У = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2$$

To conduct experiments a plan with corresponding matrices of experiment planning with the number of experiments and boundaries of factors change has been prepared. The matrix is a list of options taken in this series of experiments. Independent variables were chosen from the analysis of the nature of the effect on the change in concentration. As the optimization parameter, the frequency of rotation of the plate working body and their number on the shaft.Accordingly accepted: y_1 – number of turns of the working body; y_2 – n umber of working bodies. Experiments were conducted on the basis of mathematical planning (Table 3). Determining which factors influence on the change in concentration, determine their level variation and step of variation. The main factors and the equation of variation is given in the Table 2.

Output parameters were:
$У_1$ – change in the concentration of components in the height of their mixing in the gap between the plates. The height of mixing of the mass of components was recorded during the process by the method of visual control on a scale applied to the working camera.
$У_2$ – change in the concentration of components by mixing them in the working chamber. The mixed mass of components was selected by the sampler and recorded by the method (visual inspection according to the photographs).
$У_3$ – change in the concentration of components upon completion of their mixing in the working chamber.

On the basis of experimental data of mixing intensification, mathematical processing was performed using an application StatgraphicsPlus XV.1

According to the data of the dispersion analysis, the influence of the factors of the experiment is statistically significant at the value $p = 5\%$((for example: $p < 0.05$).

Influence of independent variables on output parameter $У_1$. The greatest influence on the change in the concentration in the gap between the plates has the effect of their amount on the shaft (X_2) (p-value for $У_1 = 0.0017$).

Table 4 shows the regression coefficients obtained during the mathematical processing of experimental data.

Using the obtained data of regression coefficients, we make a regression equation for $У_1$

$$У_1 = 0.125556 - 0.0166667X_1 - 0.0266667X_2 + 0.00666667X_1^2 + 0.0X_1X_2 - 0.00333333X_2^2$$

Experimentfailedfor $У_1 = 0.0001111$

Influence of independent variables on output parameter $У_2$. The greatest influence on the concentration change in volume has the influence of rotation frequency of plates on the shaft (X_1) (p-value for $У_2 = 0.0338$).

Table 5 shows the regression coefficients obtained during the mathematical processing of experimental data.

Using the obtained data of regression coefficients, we make a regression equation for $У_2$

$$У_1 = 70.8889 - 0.283333X_1 - 0.633333X_2 - 0.183333X_1^2 - 0.2X_1\,X_2 + 0.266667X_2^2$$

Experimentfailedfor $У_2 = 0.104$

Influence of independent variables on output parameter$У_3$. The greatest influence on the change of concentration in volume has the influence of rotation frequency of plates on the shaft (X_1) (p-value for $У_2 = 0.0001$). Table 6 shows the regression coefficients obtained during the mathematical processing of experimental data.

Using the obtained data of regression coefficients, we make a regression equation for У$_3$

$$У_3 = 83.5556 - 9.0X_1 - 9.83333X_2 + 1.66667X_1^2 + 2.25X_1 X_2 - 1.83333X_2^2$$

Experimentfailedfor У$_3$ = 1.52

The results of the computational experiments allowed to study the kinetics of changes in the concentration of components in the volume of the working chamber. The rational constructive parameters, which contribute to the intensification of the process of mixing the components, are determined.

RESULTS AND DISCUSSION

Distribution of concentrations of soluble layers during mixing

Today there is information about the mechanism of mixing in laminar mode, which proves in the complex movement of the exchange process. In the presence of circular motion of a fluid in a cylindrical working chamber, on the turns of the flow at its transition from the central zone to the reverse, this sharp change in the direction of flow leads to a restructuring of the profile of velocity and the appearance of landslide deformation, which facilitate the mixing of the components. Therefore, the difference between the existing mechanisms of mixing and mixing in a closed profile channel (Figure 5) is considered.

The influence of the physical nature, dispersion, the content of the mixture on the section forming the circulating circuit and the design parameters of the machine at the stage of the mixing process is relevant.

It is also necessary to justify the basic laws of improving the technological requirements and parameters of this process.

Accelerated in the air, a stream of liquid components is found with spray particles of flour during its free fall, partially takes it, hits the walls of the cylindrical chamber and the rotating plate of the working body (Figure 6).

Liquid components, getting on TRO, are sprayed and get an extra speed, which contributes to a greater number of wetted particles of flour. The particles are pressed against each other, mixed, and their speed is lowered at the bottom of the camera. Due to the cylindrical configuration of the working chamber, the jets (emulsions) are automatically lowered, where the surface of the working body acts on them. In this case, the time from the moment of entering the flour and liquid components into the chamber and until they reach the bottom of the chamber is τ1 = 5 – 10 s.

In the first period of time, the adsorption process is heterogeneous, which determines the first and second stages of mixing. We will assume that the process of adsorption is a purely superficial phenomenon that occurs instantaneously. This allows us to assume that the velocity of the adsorption process is determined by the diffusion velocity at constant pressure (atmospheric). Therefore, a number of questions regarding the pre-ferment blending process of free fall in the first stage have not yet been resolved and require further consideration.

When adsorbed in a working chamber, where the kinetics of a heterogeneous reaction is determined by the concentration of components and process conditions, the rate of the adsorption process is determined by the diffusion velocity, that is, the entire process occurs predominantly in the diffusion region, which is divided into two periods. The first period of adsorption – a period characterized by the amount of liquid components that the adsorbent – flour – perceives during time t1 to the contact surface of the working body and the mixing chamber. This plot is shown in Figure 5.

The first period – from the moment of the delivery of ingredients and until the completion of one of them – flour. The liquid components are dosed for 20 – 30 seconds longer. This period can be combined with the submission and termination of the ingestion of doses; then the second period in our case will be very short, but without the necessary effect of adsorption. Structure of flour streams from flour vibrator (VDB), flows of liquid components from the membrane dispenser of liquid components (MDRCs) when rotation of the container's working body, where the speed of the wheel is significantly greater thanthe speed of the mixture of components, in the working chamber of the mixing machinebetween the layers there is mixing not only in the places rotation of the flow, in the longitudinal displacement, in the boundary layer, but also in a significant part of the volume.

The working chamber has consistently connected zones with different mechanisms and level of mixing (Figure 5). The level of deviation of the heterogeneity of the solution of the local concentration C from the average (boundary) is considered that the smaller the value of the heterogeneity, the better the components are mixed. Since mixing occurs at its constant motion (weigth condition, mechanical action of the working body, vibration, gravitation), then it is expedient to apply the mathematical model (2) with the following boundary value problem at the first and second stages with the ideal mixing:

$$\frac{\partial^2 c}{\partial x^2} \cdot D_L - \frac{\partial c}{\partial x} \cdot u = \frac{\partial c}{\partial t} \qquad (3)$$

With the initial conditions:

$$C(x,0) = 0, \; \left.\frac{\partial c}{\partial x}\right|_{x=L} = 0,$$

Where:
c – current concentration of the mixture components in the operating chamber;
t – time;
u – linear flow rate.

The left side of the equation reflects the change in mass concentration in the pseudo-layer over the period of component dosing. The second part reflects a change in the concentration, fixed in time. Consider the scheme of the flow structure in weight mixing (Figure 5).

Based on the obtained data, mathematical calculations were performed to select the optimal function, which most likely reflects the dependence of the change in concentration on time from the mixing method at the first and second mixing stages.

Based on the concepts **(Braginsky, Begachevand Barabash, 1984;Pirogov,Leonovand Shilov, 2008)** of relative mass C and volumetric S concentrations of one of the two components in the solution and their interrelation, taking into account that the radial and longitudinal mixing is insignificant in straight lines of the initial and upstream streams, where the ideal mixing of the components takes place in a curved state and when they move into the working chamber and on the surface of the working body, and the ideal displacement in the process of centrifugal forces with longitudinal mixing, therefore, the process of perfect mixing of the first zone characterizes the dynamics of the concentration of concentrates which limited by time intervals up to 100 s.

The calculation of the change in the ideal mixing concentration in the working chamber volume is carried out by equation:

$$\frac{dS}{dt} = \frac{\upsilon}{V}\left(S' - S\right) \quad (4)$$

Where:

S and S' – current and equilibrium mixture concentration of components in working chamber,
t – time,
υ – volume flow rate,
V – volume of the working chamber.

The left side of the equation reflects the change in volumetric concentration in the pseudosilver for the period of component dosing. The second part reflects a change in the concentration fixed in space (volume) and speed when stirred in a stationary field. Then:

$$-\frac{d\left(S' - S\right)}{dt} = \frac{\upsilon}{V}\left(S' - S\right) \quad (5)$$

$$-\frac{dy}{dt} = w \cdot y; \quad -\int \frac{dy}{y} = \int w \cdot dt;$$

$$-\ln|y| = w \cdot t + C;$$

$$\ln|y| = C - w \cdot t;$$

$$y = e^{C - w \cdot t}, \; S' - S = C_0 \cdot e^{-\frac{\upsilon}{V}t};$$

at $t \to \infty$, $S \to S'$;
at $t = 0$, $S = 0$, $S' = C_0 \cdot 1$;

$$S(t) = S' - S' \cdot e^{-\frac{\upsilon}{V}t}, \; S(t) = S'(1 - e^{-\frac{\upsilon}{V}t}).$$

Initial conditions for the rate of flow of liquid components (ur) and flour (ut) to the mixing cylindrical chamber, kg.s^{-1}:

$$ur := \frac{2.05}{90} \qquad ur = 0.023 \qquad ut := \frac{3.55}{60} \qquad ut = 0.059 \qquad t := 0, 0.1 .. 240$$

Conduct the construction of graphical dependence of the volume velocity of flux changes in a chamber at given parameters:

$$urc(t) = \begin{vmatrix} ur \cdot t \cdot if\, 0 \le t \le 95 \\ 0 \cdot if\, 0 \le t \prec 5 \\ 205 otherwise \end{vmatrix} \qquad utc(t) \begin{vmatrix} ut \cdot t \cdot if\, 0 \le t \prec 60 \\ 355 otherwise \end{vmatrix}$$

$$uc(t) = urc(t) + utc(t)$$

Accordingly, the change in the maximum mass concentration in the volume of the mixture under given conditions:

$$v(t) := \frac{d}{dt}uc(t) \qquad vv := 10 \qquad ss := \frac{ut}{ur + ut} \qquad ss = 0.722$$

Algorithm for calculating the change of current and equilibrium concentration underthe conditions of the process in the working chamber of the machine (Figure 10, Figure 11, Figure13).

A general analysis of mathematical modeling and refined mathematical calculations of the rate of change in concentration shows (Figure 7, FIgure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 15) that at the beginning of the process flour and liquid components interact actively, with time the activity decreases and, starting from 20 s. dosing it turns out differently. The results of the researching (Figure 14) also indicate an intensive acceleration of the process at the initial stage, which confirms the assumption of the effect of mixing activity in the suppressed state with the help of the vibrational action of the VDB. This changes the physico-chemical properties of the components, which is essential for kinetically-controlled processes.

The results of the researching and the analysis of the mathematical models of the process showed that the mass concentration is reached by 90 seconds of mixing. During this period, the first critical value is traced, where the curve has the first shift, which indicates that after 60 s the adsorption of the free surface of the flour ends and the absorption of free and bound flour begins.

Under different conditions of the process, it is observed that the volumetric consumption of raw materials (flour), which we can regulate with the help of a vibrating dispenser, significantly affect the change in concentration. It is also worth noting that the volume of the chamber is important, which can be changed during the research process. Such a change affects the creation of a larger contact, admired by the flow of liquid components.

From the scientific point of view, this is explained by the fact that at the beginning of the process, the adsorption bond is based on the molecular interaction of the flour with liquid components, which are the most strongly bound to the flour and are kept by the molecular force field on the external and internal active surfaces of the flour **(Dolomakin, 2015; Scram, 2003)**. Adsorption moisture on the surface of the flour accelerates the concentration of the first period with the help of vibration action, which after 20 s of the process practically does not affect the intensification, since the formed liquid component layer, which continuously increases with time, these vibrations absorb.

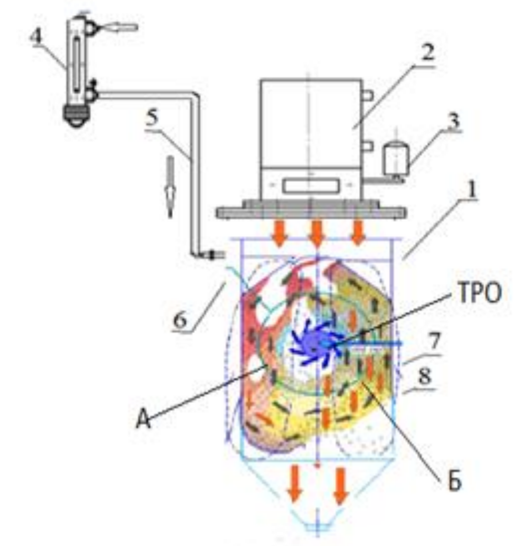

Figure 5 Motion scheme of the mixing components.
Note: A – circulation circuit component movement; B– force influence on the components; TPO–plate working body.

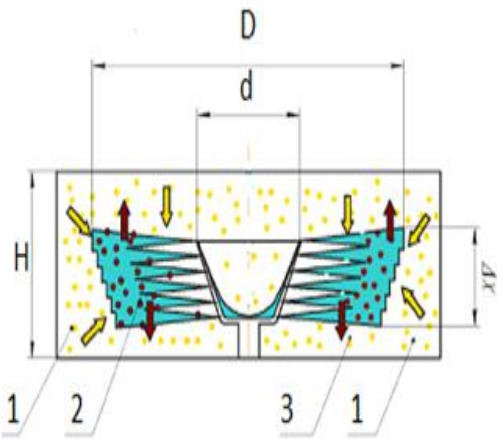

Figure 6 Distribution of components under the influence of the container's working organ.
Note: 1–particles of flour; 2–forming mixture; 3 – air bubbles (occlusion).

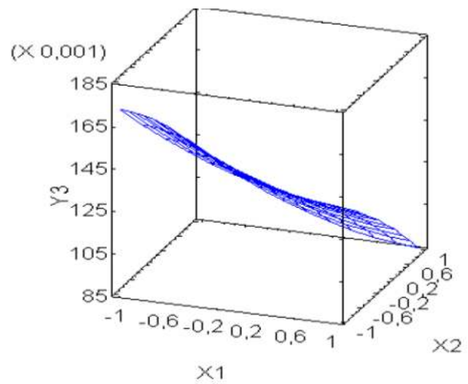

Figure 7 Influence on the change in the concentration of components between rotating plates.

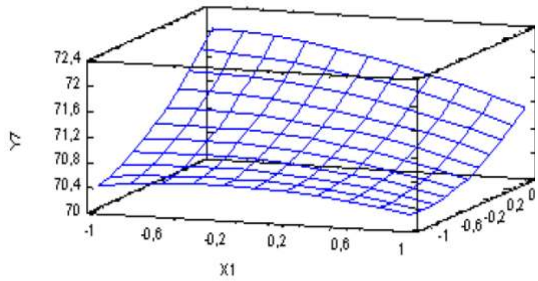

Figure8 Influence on the change in the concentration of components by the frequency of plates rotation.

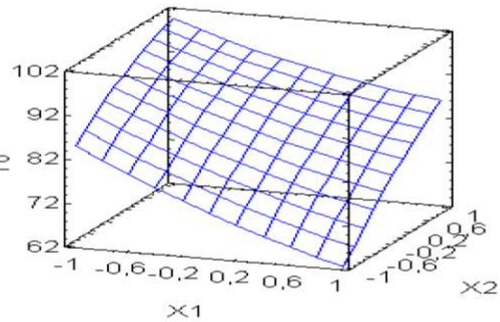

Figure 9 Influence on the change in the concentration of components by the frequency of plates rotation.

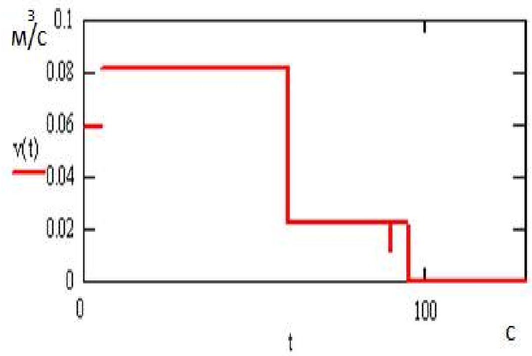

Figure 10 Volume change in flow velocity during its dosing period.

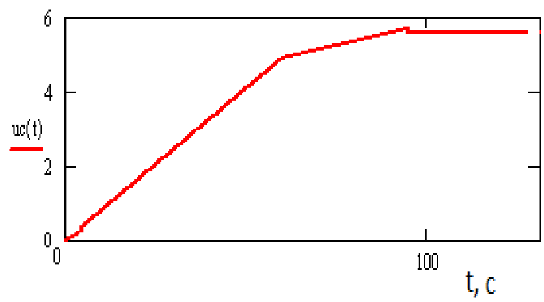

Figure 11 Change of the limiting volume concentration for the period of component dosing.

$$s1(t) := ss \cdot \left(1 - e^{\frac{-v(t)}{vv} \cdot t}\right)$$

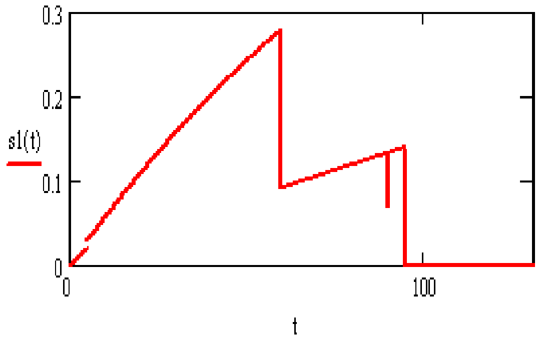

Figure 12 Concentration in the outer transition layer, which varies with time.

$$s2(t) := ss \cdot \left(1 - e^{\frac{-uc(t)}{vv} \cdot t}\right)$$

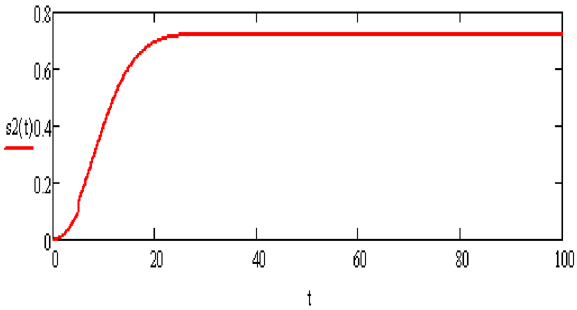

Figure13 Total concentration in the mixture of components.

$$s3(t) := s2(t) - s1(t)$$

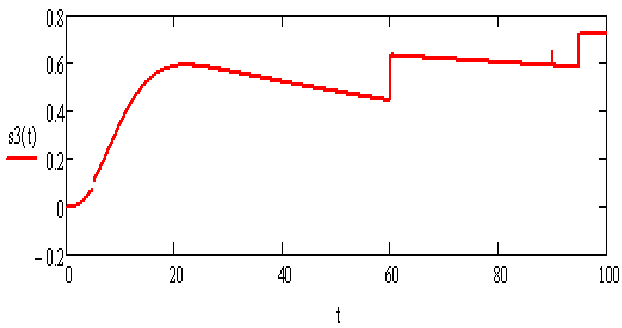

Figure 14 Concentration in the inner layer of components.

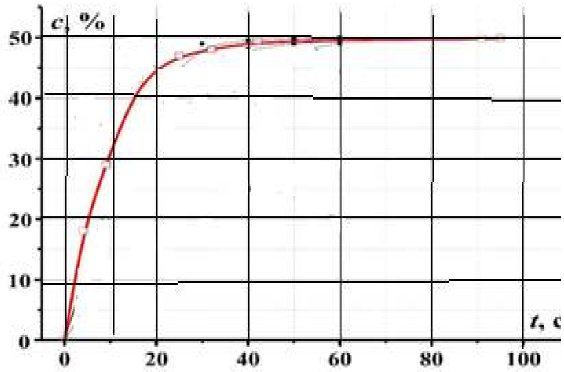

Figure 15 Change in concentration in the pre-ferment when it is formed in various parameters.

It has been experimentally established that the impulses formed by the fluctuations of the dispenser lattice practically do not reach the free surfaces of the container's working body and the working chamber, but fade in the components layers. In this condition, the formation mass concentration increases the contact with the surfaces, reduces periodically the displacement with partial amplitude, but it accelerates the process.

Table 2 Main factors and the equation of variation.

Plan characteristics	**Variable factors**	**Variable factors**
	Number of rotations of the working body X_1, min^{-1}	**Number of working bodiesX_2,pcs**
The main level, $X_1^{(0)}$	90	3
The step of variation	30	1
Lower level $X_1^{(-)}$(-1)	60	2
Upper level, $X_i^{(+)}$(+1)	120	4

Table 3 The experiment plan and its results.

Experiment number	**X_1 min^{-1}**	**X_2 pcs**	**$У_1$ %**	**$У_2$ %**	**$У_3$ %**
1	1	-1	0.17	709.5	85
2	0	-1	0.15	70.4	72.
3	-0	-10	0.14	70.3	62
4	1	0	0.15	70.1	94
5	0	0	0.13	70.8	83
6	-1	0	0.11	70.5	77
7	1	1	0.12	72	100
8	0	1	0.098	72	92
9	-1	1	0.09	71	86

Table 4 Regression coefficients.

Coefficients	**value**
constant	0.125556
A:X_1	-0.0166667
B:X_2	-0.0266667
AA	0.0066667
AB	0.0
BB	-0.00333333

Table 5 Regression coefficients.

Coefficients	**value**
constant	70.8889
A:X_1	-0.283333
B:X_2	0.633333
AA	-0.183333
AB	-0.2
BB	0.266667

Table 6 Regression coefficients.

Coefficients	**value**
constant	83.5556
A:X_1	-9.0
B:X_2	9.83333
AA	1.66667
AB	2.25
BB	-1.83333

CONCLUSION

Based on the results of exrching of sampling at certain time intervals and mathematical calculations, it was established that the maximum water absorption capacity of flour 72.2% is reached after 85 – 90 s while observing the operating modes: the frequency of rotation of the working organ 1.67 s^{-1}, the rate of dosing of liquid components of 0.023 $L.s^{-1}$, flour 0.059 $kg.s^{-1}$. The further process of mixing showed that the absorption of liquid components by surface-active flour slowed down over time due to the fact that the flour, which did not interact with the dosing process, leveled the moisture content.

The leveling of the moisture of various components occurs with the transition to a solution of soluble parts of the flour, which significantly affects the structure and further mechanical properties of the suspension. Therefore, up to 60s during hydration, the flour interacts with moving components, and this process continues with a simultaneous swelling, which does not occur immediately, but eventually.

The rate of formation of consistency is determined by the dosage of liquid components, since this is the main component of the solution and a slight difference in the time of the dosage of components contributes to a uniform, in a short time to ensure the stage of rational parameters of the mixing process. Accordingly, the first stage is performed qualitatively, and the second does not require vigorous mechanical processing, therefore, it is in a state of rest.

Without taking into account this fact, the mechanism of researching will not be complete. The importance and peculiarity of flour dissolution in the context of pseudo-mixing, taking into account vibration action, allows us to determine the size of thechamber, the speed of rotation of the body and the rate of dosing of flour and liquid components in a mass proportion.

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