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Determination of Rational Parameters of Pseudomixing by Complex Modelling of Work Processes

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Abstract. The area of improving the quality of the formation of mixtures upon mixing in the food industry is relevant since the improvement of technology and equipment for processing components by various methods, nature, and degree of influence is practically achievable for their improvement. The purpose of this study was to improve the design parameters and increase the efficiency of the mixer by creating conditions that will ensure the optimisation of the dissolution kinetics of a dispersed mixture of flour and liquid components during their pseudo-mixing in a suspended state. This study considered the properties of raw materials based on methods for determining their quality, laboratory methods and tools for conducting research were proposed with the established planning methodology with analysis of the results obtained, and the Flow Vision software package was used in plotting based on the laws of thermodynamics. The experimental data set was processed using a mathematical description of the process of forming the liquid flow and the dispersed flow of flour particles. The study used an incomplete multivariate model of the approximation of the experimental data of the function of three variables in the form of polynomials according to the three-level Box-Behnken plan with 13 experiments performed in 5-fold repetition. Periodic mixers were analysed, and the redistribution and transformation of deformations under optimal mixing modes was considered. The interaction of components and their flow dynamics while minimising energy consumption was established. The authors determined the influence of fluidisation and vibration during the dosing period of the components on the intensification of the interaction of the dispersed phase according to the principle of discrete-pulse energy input, which creates rapid changes in the movement of the components. The functional dependence of the uniformity of the formation of bubbles of the medium on three factors $v_t=f(h, V, v_c)$ was obtained with the verification of the homogeneity of dispersions, the adequacy of the obtained functional dependence and the search for its optimum. The materials considered in this paper represent the practical value of the effective process of uniform distribution of recipe components in the working chamber of the mixer design under study, with the creation of favourable conditions for the formation of the foam structure

Keywords: mixer, mixture, fluidisation, vapour

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Introduction

This study evaluates the component of the technological process of the interaction of components in the working chamber of the machine with the possibility of effective mixture formation based on their redistribution with the creation of local zones.

In the conditions of a market economy, the best process and equipment will be those that optimise technological processes with lower energy and material costs. After all, the property of the interaction of component particles and the amount of surface tension depends in each case on the nature of the phases of the mixing process. The influence of the surface layer of the phase on its total costs is determined by the specific energy. The excess of free energy on the surface of the phase distribution is the main reason for the instability of the liquid consistency of the components (in the form of an emulsion) because according to the principle of thermodynamics, the most stable state of the system corresponds to the minimum value of the surface energy [1; 2]. The uniform concentration of the suspension in the entire volume of the mixer has an effect on the course of the technological process, and therefore, it is an important condition for all particles of a solid body to be in a liquid in a suspended state. Therefore, the need to create large liquid turbulence around the flour to reduce the thickness of the laminar layer at the liquid-solid interface remains relevant today.

For the most part, the equipment for mixing components is chosen considering the specific features of production, the specified productivity, the characteristics of raw materials, the quality indicators of the finished mixture and the economic capabilities of the enterprise. Mechanical mixing in the food industry is widely used due to the simplicity of the design of the working chamber and mixing working bodies. According to the authors [3], working bodies not only serve for mixing, but are devices in the process of homogenisation of non-Newtonian liquids. They have a uniform and intense mass exchange between the solid phase and the liquid.

Technological machines of different designs differ in the degree of impact on components [4]. This effect leads to the production of a final product with different structural and mechanical properties and finished products of different quality. Investigation of the influence of individual mixers on the properties of semifinished products allows searching for the most appropriate designs to determine the optimal mixing modes.

The authors [5] note that currently, when choosing such technological equipment or carrying out modernisation with appropriate parameters, the necessary microstructure of the semifinished product, which allows establishing high-quality contact interaction, is not considered. Therefore, a promising area for mixing a mixture of components is the use of a new generation of equipment, which would increase turbulence and flow circulation while reducing energy consumption and metal consumption.

The development of equipment design for the preparation of liquid water-flour semifinished products, emulsions, suspensions of Ukrainian production is practically absent today, and the existing ones are quite conservative and ineffective. In these machines, the requirements set by modernity are poorly solved. The action of the working

body and the working chamber of the machine is partially absent or unbalanced, and the mixing mode is not regulated, which leads to increased heating of the medium with insufficient aeration [6].

Today, there is a constant search for improving the process. The authors of the studies and researchers are constantly seeking areas for continuous mixing, reducing time, improving the design and ease of maintenance [7]. This is one of the shortcomings of the existing mixers, which is why there was a need for an innovative design of the mixer using vibrating flour dosing and a device for dosing liquid components. The essence is to combine several processes to intensify mixing and then mix components without forming dead zones in the working chamber of the machine.

Scientific research in this area of knowledge opens ways to modernise the existing and develop innovative equipment designs with the necessary parameters. *The purpose of this study* lies in an optimisation of the kinetics of dissolution of a dispersed mixture of flour and liquid components during their mixing in a suspended state.

Literature Review

The problem of dissolving solid particles (flour) today is carried out by mechanical, pneumatic, combined mechanical with vibration, discrete-pulse mixing with a moving or stationary layer of solid and liquid phase [8].

It is known that flour is a high-molecular biopolymer in a crushed (dispersed) state and is a powdered adsorbent [8]. The specific surface area of diverse types of wheat flour ranges within 60...270 m²/kg. Flour, especially from hard varieties of wheat, comprises discrete parts with a size (100...200 µm), and starch granules, e.g., have a size within (5...40 µm) and, usually, can be larger than protein molecules.

The main significance of the interaction of flour with liquid is their flow under conditions of shear deformation. Under the action of working bodies, there is a relationship between the physical and chemical properties of the components and the temperature and force applied. A special section of mechanics – rheology – considers the study of all aspects of medium deformation under the action of applied stresses [9].

The study [10] noted that the formation of a high-quality mixture depends on obtaining a uniform concentration of solid particles in a liquid over the entire volume of the apparatus. Therefore, the mixing process is considered as a purely mechanical process of mutual penetration. The purpose of penetration is aimed at obtaining the most uniform continuous medium. The interaction of particles of a continuous medium with some physical properties between particles of a continuous medium with other physical properties creates new properties that differ from the properties of mixed media [11].

The authors of scientific papers [12; 13] considered models of fluidisation of polydisperse suspensions. Based on the physical essence of the process, a set of equations for modelling a polydisperse system was proposed. In the work based on research, these equations are presented based on grapho-analytical dependencies, but these developed equations do not fully consider the movement of particles.

In the study [14], a mixer containing a cylindrical body with a bottom, a lid, a centrally vertically placed shaft with poppet working bodies is presented. The working cylindrical chamber has mounted brake blades. Thus, the study [15] states that the use of fluidisation and vibration during the dosing of components at the first stage of mixing intensifies the technological process with a dispersed phase. This approach, which is called the principle of discrete-impulse energy input (DIEE), is based on the effective use of the above-mentioned mechanical and other physical effects that occur in a fluidised medium of rapid changes in the movement of components and internal pressure.

The ideology of DIEE implies the presence of many evenly distributed flour particles and bubbles in the formed liquid phase. The behaviour of any individual particle is determined by the influence of the nearest other neighbouring particles. Dynamic characteristics at the local point of the liquid are considered, taking into account the influence of all particles of the dosing components. This leads to the formation within the liquid phase of chaotic, continuously variable in time and space fields of velocities and pressures. The microcurrent in the interphase space has a vortex nature. This creates pressure and velocity fields that resemble the corresponding fields in a turbulent fluid flow [16].

Consequently, the spatiotemporal structure of the flow during pulsed energy input constitutes a factor in the formation of the interface of the phases of concentrated energy dissipation zones. As a result, various powerful factors develop in the boundary layer, which intensify the transfer of heat and mass. All this leads to an increase in the intensification of heat and mass transfer and added mixing.

Apart from hydrodynamics, the kinetics of the process are important components of dissolution. The total dissolution component of the process is determined by the intensity of the kinetics and diffusion stages. They determine and establish the time course of the process with its speed of passage. Clearly, this determines the performance of mixers [17]. The development of mathematical models of process kinetics is based on research in the field of heterogeneous solution [18].

The rate of heterogeneous processes is affected by the size of the interfacial contact surface and diffusion. The authors in [19] note that the increase in the speed of the process occurs mainly due to the renewal of components on the surface of the phase contact, since the diffusion rate is insignificant. Continuing this process of heterogeneous reaction, in the work of the authors [20], the component of several consecutive stages between the liquid phase and flour particles was revealed. The resulting speed of the entire process is determined by the speed of phase interactions.

To facilitate the analysis of the mixing process and the establishment of stage rational parameters, the authors [21; 22] improved the proposed three-stage process model. The essence of the stage model proposed by Professor O.T. Lisovenko, which is also based on the developments of H.D. Cheishner, N. Quendt and other inventors, is discussed in detail in the paper of the authors [23].

An essential component in concentration studies is the speed of movement of a solid flour particle when dissolved in the liquid phase. In the study [24], researchers concluded that the rate of dissolution of a flour particle is proportional to the difference between the concentration of the formed solution and its saturated concentration. Mixing in a fluidised state and using rotating agitators is a process with a crucial influence of hydrodynamics on the state of the medium, product, and productivity [25]. The design parameters of the mixer are actively involved in the formation of the speed of turbulent and convective transfer at the stage of mixture formation. This stage directly affects the efficiency and determines the level of mixing, i.e., the dissolution of solid flour particles to form a homogeneous concentration. When mixing mutually soluble liquids and flour, the mixer design sets the duration of structure formation due to the hydrodynamics of the moving flow [25; 26].

Materials and Methods

Diverse types of flour are used to produce flour products. First-grade flour, yeast, salt, water, and auxiliary raw materials to produce foam were used in the research. Experimental and theoretical studies were carried out based on the Ivan Puliui Ternopil National Technical University. A mixture of first-grade wheat flour with a humidity of $13.9 \pm 0.2\%$, a raw gluten content of 24% and a stretchability of 14 cm was prepared. Water with a temperature of $32\text{--}35^\circ\text{C}$ was used for mixing flour and pressed yeast. The temperature was measured using a TLS thermometer. The dose of the components was measured on an electronic scale with a measurement range of up to 0.1 g. The Benetech GM533A device was used to determine the temperature regimes during the preparation of the steam; quality of dispersion of components and their interaction with flour in a suspended state was used digital camera CANON EOS Wi-Fi 4000D 18-55 DC III (3011C004AA); the quality of the interaction of the components was determined using a My First Lab MFL-06 Duo-scope microscope.

Sampling was carried out according to DSTU 7045: 2009 [27]. Quality control of sourdough was carried out according to generally accepted methods [28]. FlowVision software [29] was used to determine the necessary parameters and operating modes, as well as modelling of the corresponding process. It is based on a finite-volume method for solving hydrodynamic equations based on a rectangular adaptive grid with local grinding. This allowed importing geometry from CAD (computer-aided design system) systems with information exchange with a finite element analysis system.

To conduct the study, the department staff developed and manufactured a new prototype of the mixer (Fig. 1). The basis of the mixing method is the moistening of dust-like flour particles in a suspended state with a jet of liquid under pressure and the interaction of components aimed at the intensity of the influence of heat and mass transfer in the model sourdough composition.

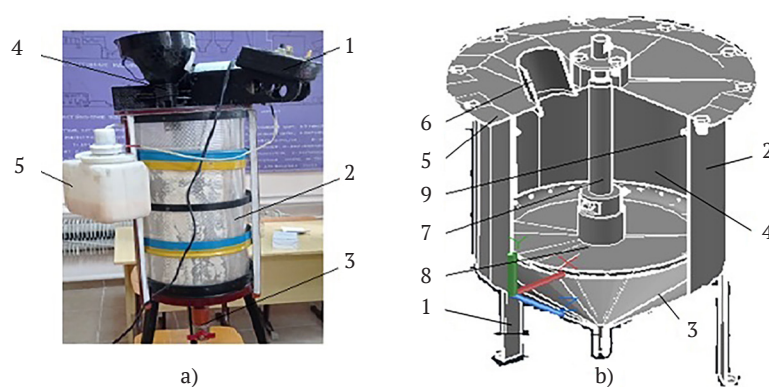


Figure 1. General view of the mixer a): 1 – control panel, 2 – cylindrical working chamber, 3 – nozzle for discharging the paste, 4 – flour vibratory dispenser, 5 – dispenser of liquid components; 3D model b): 1 – body, 2 – cylindrical and 3 – conical parts of the working chamber, 4, 5 – lid with an inlet 6 for flour dispensers, 7 – drive shaft with plate discs, 8, 9 – jet sprayers

The technological process of the stage formation of sourdough is based on the fact that a jet of liquid components accelerated in the air meets with sprayed flour particles in free fall. As a result of such interaction, the resulting mixture partially takes them away, hits the cylindrical wall of the working chamber 4 and the rotating disc-shaped 9 working body. The previously formed liquid mixture of components under the action of gravitational forces falls on the blades (1), is sprayed and receives an added speed. Such conditions contribute to the creation of a large surface of phase contact of wetted flour particles. This actively affects the formation of the mixture with some acceleration, where the speed decreases at the bottom of the chamber. Thanks

to the kneading chamber configuration, the component jets swirl and automatically descend. They accumulate there and constantly receive mechanical action from the rotating kneading body.

To investigate the temperature field and uniformity of the mixture, a scheme for placing thermometers for measuring temperatures in the zone of the suspended state of interaction of metering components was developed. Using T_1 thermometers, temperatures were measured in coordinates $Y=15$ cm, $Z=20$ cm. T_1 was measured in the range of change $X=10$ cm, and T_2 in the range of change $X=10...30$ cm. The layout of temperature measurement zones and the interaction of components is presented in Figure 2.

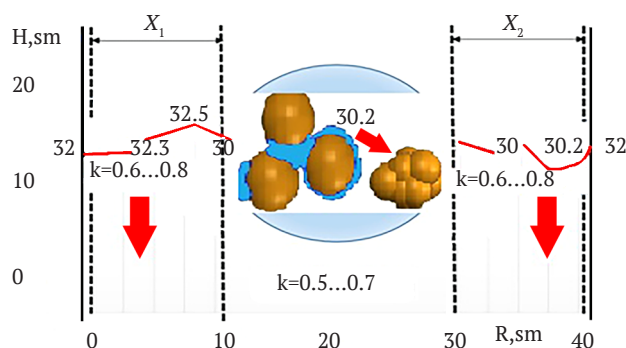


Figure 2. Calculation scheme of the pseudo mixing flow formation process

The study of the mixing process was carried out according to the Box-Behnken plan [30]. This allows getting the maximum amount of objective information about the influence of factors on the mixing process with the least number of experiments, i.e., they provide a regression model in the form of a full quadratic polynomial. Processing of experimental data was carried out using the “Statistica-12” application software package for a computer. The coefficients of the regression equation were determined using the standard method. The best modes were determined by substituting vectors of limited values in the target function under the conditions of sourdough preparation technology on a mixer.

The data of experimental studies were processed using the Microsoft Office software package.

The limit of variation of the factors of the full factorial experiment type $3k$ was used. The homogeneity of variances, the adequacy of the obtained functional dependence and the search for its optimum were checked in the Maple computer mathematics environment [31].

Results and Discussion

Considering the mixing of components during vibration delivery and the outflow of liquid in a suspended state, the final effect of the working bodies on mixing is provided. The working chamber with cylindrical volume 2 (Fig. 1) and

the conical bottom 3 is placed on the frame of the housing 1. The cylindrical chamber, respectively, has a nominal volume for the fluidised bed process and a volume for mixing by working bodies. The level of mixing of liquid sourdough upon dosing components in the suspended state was determined by the height of the resulting mixture. Determining the height h_c of the resulting mixture allows establishing the design parameters of the mixer. Therefore, the height h_c of the resulting mixture was determined according to the following formula:

$$h_c = \frac{4 \sum_{i=1}^n V_k}{\pi D_1^2} \quad (1)$$

where $4 \sum_{i=1}^n V_k$ is the total loaded volume of mixed

components, m^3 ; D_1 is the diameter of the cylindrical part of the working chamber of the mixer, m.

This allowed achieving uniformity during the mixing of sourdough at the established hydrodynamic flows of the forming mixture.

A distinctive feature of hydrodynamics is that within values $0 \leq X \leq 10$ cm, components move with a constant $K=0.8$ (uniformity). In the zone of axial interaction $10 \leq X \leq 30$, 3D surface mixing of components occurs at 30.2°C and at $k=0.7$. And at $30 \leq X \leq 40$, the constant was also $k=0.8$, and the movement of the resulting mixture directed down the chamber wall is created.

Notably, such hydrodynamics of the interaction of components due to the increase in the zone of distribution of the liquid phase and flour ensured a mechanically symmetrical geometric shape of the temperature zone from 32°C to 32.2°C , at 10 mm from the wall of the working chamber. The authors in [32] covered the results of modelling the process of mixing components during the preparation of liquid vapours. The simulation was carried out based on the use of the energy of air and water flows under pressure. The basis of the method of making sourdough is the effect of a liquid jet on a dusty particle of flour in a suspended state. Accordingly, rational values of component feed rates were established, and energy dissipation in the device was investigated.

Therefore, the authors of this paper and the authors of [33; 34] believe that improving the energy efficiency of mixing is possible under the condition of rational parameters of the jet device and technological parameters of the mixing process. This result can be obtained by discrete-pulse dosing of components with the introduction of the ejector design of the nozzle system of the component mixer (jet device). The design of the device (nozzle) [35] is based on creating the maximum phase velocity difference. The resulting phase difference after leaving the nozzle creates conditions for dispersion, since there is a thermodynamic process of converting the potential energy of the flow into kinetic energy, which accompanies an increase in the speed and a decrease in the flow pressure. The level of binding of a small amount of liquid phase active hydrophilic groups of flour particles contributes to the formation of water shells. The interaction of the liquid phase with flour occurs not only on its surface, but also in volume. The process proceeds with the release and absorption of heat (exothermically). The amount of liquid phase retained by about 30% does not lead to a considerable increase in the particle volume (Fig. 2).

This fact is confirmed in studies [36; 37], which describe the method of dissolving components during pneumatic mixing. They established the advantages of pneumatic mixing, which are based on intensive mass transfer between the solid phase and the liquid. The use of compressed air for mixing simplifies the internal design of the device.

Thus, the water-absorbing capacity of flour is affected by its dispersion, i.e., the size of the particles from 0.015 to 0.003 m. Reducing the particle size to 0.012 g contributes to an 8% increase in the specific surface area per unit mass of flour. Therefore, more water can be adsorbed. Thus, the absorption of water by flour particles with small dimensions occurs 45 seconds faster. Hence, experimental studies of the proposed design of the discrete-pulse mixer on the uniformity of the supply of sprayed liquid components and the mass of flour dosed by the vibrodoser on their interaction in a suspended state constitute the area of the conducted research.

The experimental research conducted by the authors [38] determined the parameters of the screw-type conveyor-mixer under which the homogeneity of the mixture is formed (up to 96%). The impact of vibration on the process of movement of the feed mixture and the uniformity of its preparation was also noted.

Therefore, the basis of the method of mixing in a suspended state is the moistening of dust-like particles of flour with a jet of liquid under pressure under the condition of a thermodynamic model of the interaction of components aimed at the intensity of the influence of heat and mass transfer in the model steam composition. All these effects involve improving the kinetic and diffusion effects on the process and establishing the performance of the mixers [39]. Furthermore, of importance is the area of heterogeneous influence during the interaction of flour with liquid components [40].

Notably, the technological process of the preparation stage of the foam is because the jet of liquid components accelerated in the air hits the sprayed flour particles during free fall. Meanwhile, the time of interaction of flour and liquid components in the pre-mixing chamber until they reach the lower part of the chamber is $\tau_l=5-10$ s.

During the interaction of flour with a dispersed jet of the liquid phase, a mostly chaotic process takes place, i.e., their mixing interaction. Thus, in the case under study, under the influence of vibration and mixing in a suspended state by transformations of internal friction forces, the resulting mixture goes into a quasi-equilibrium state.

Therefore, the study considered the mathematical description of the process of forming an extended flow of liquid and a dispersed flow of flour particles, formed by a flour vibrator and a spraying nozzle. The objective function, which characterises the uniformity of the formation of a particle of a mixture of dosing components v_t , is the coefficient of variation [1] of the time t_i of its formation:

$$v_t = \sigma/T, \quad (2)$$

where σ is the mean square deviation of time t_i of formation [13]; T is the mathematical average of time t_i of formation [16].

The studies of the interaction of components at the stage of pseudomixing allow establishing the most influen-

tial controlling factors. The influence of control factors on the target function v_t include:

- the relative height of the medium is formed by the interacting components in the working chamber of the mixer $h=H/D, m$;
- speed of movement of the medium V, s^{-1} ;
- coefficient of variation in the size of the medium bubble, $v_c, \%$.

The coefficient of friction of the formed bubble in the medium was not considered as a controlled factor since the Archimedean repulsive force acts.

The variable influence of the control factors of the objective function is based on the use of factors at 3 levels. The level selection of factors and variation intervals was made based on theoretical justification, the results of earlier experimental studies (Table 1).

Table 1. Variation of the factors of a complete factorial experiment of type $3k$

Indicators	Factors		
	h, mm	V, s^{-1}	$v_c, \%$
Upper level	1.7	10	8
Zero level	1.5	15	5
Lower level	1.3	20	2

To increase the accuracy of response determination and to determine the absence of influence of uncontrollable and unmanageable factors, each experiment was performed in 5-fold repetition. The functional dependence of the uniformity of the formation of medium bubbles on three factors $v_t=f(h, V, v_c)$ was obtained. The limits of variation of the factors of the full factorial experiment of the $3k$ type are presented in Table 1.

Based on this, the obtained empirical model of the complete polynomial of the second degree allows revealing the functional dependence. This dependence characterises the change in the uniformity of the distribution of bubbles in the resulting mixture of sourdough components in the suspended state of the mixer, natural factors:

$$v_t = 423.7 + 193.8 \cdot h_2 + 0.34 \cdot v_{c2} + 0.04 \cdot V_2 - 563.6 \cdot h - 6.6 \cdot v_c - 0.7 \cdot V + 4.04 \cdot h \cdot V + 0.03 \cdot V \cdot v_c \quad (3)$$

A comparison of the estimated $F_{CALC}=4.9$ and tabular $F_T=19.3$ of Fisher's criteria allows accepting the hypothesis about the adequacy of the obtained mathematical model (3) with a 95 percent probability.

From the analysis of experimental data and the obtained dependence (3) (Fig. 3), it was established:

- the uniformity of the component feed should be a monotonous and increasing function of the change in the size of the medium bubble;

- for $v_c=3\%$, $h=1.5$ and a change in the dosing speed V from 10 to 13 m/s, the uniformity of interaction decreases from 9.4 to 9.1%, and then increases monotonically;

- the uniformity of the supply of components at $v_c=3\%$ and the convex function of the speed of movement V acquires a value at $h=1.4...1.5$, and at the limits of variation h increases by 10...15%.

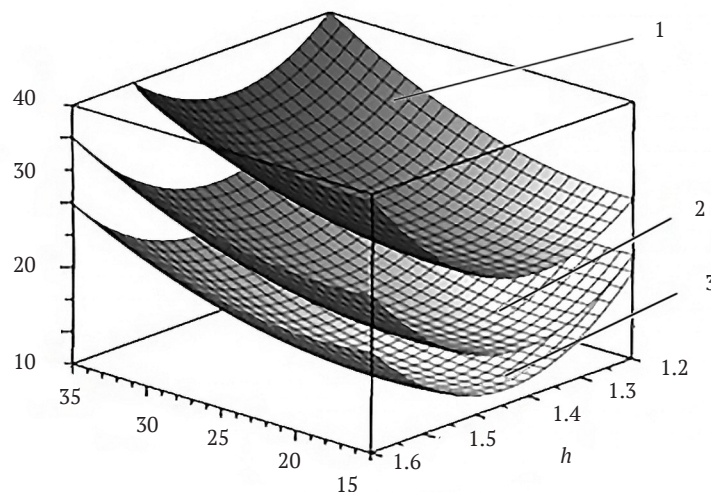


Figure 3. Dependence of the uniformity of the formation of the medium during the dosage of components on the relative height h , the speed of movement V and the coefficient of variation of the droplet sizes, v_c : 1- $v_c=8\%$; 2- $v_c=5\%$; 3- $v_c=2\%$

It is rational for the proposed design of the mixer and the technology of discrete-pulse dosing of components to occur under the uniformity of the supply of components.

Thus, for $v_c=3\%$, the dependence of the uniformity of the dosage of components on the relative height h and the speed of movement V will have the following form:

$$v(v_c=3\%)=193.8 \cdot h^2 + 0.039 \cdot V^2 - 0.264 \cdot h \cdot V - 551.5 \cdot h - 0.62 \cdot V + 406.9 \quad (4)$$

The obtained expression of the differential function of the distribution of the number of particles by the angular scattering of the dosing components allows describing the structure of the dispersed flow formed during mixing in the pseudo-layer.

Nowadays, optimisation of mixing parameters is based on a detailed study of processes. Undoubtedly, at the same time, it is necessary to consider several influencing factors of this system on the viscous medium by choosing analytical methods in the presence of the necessary models, or their development. It is rational to approach the phenomena of rheology together with the postulate of thermodynamics and the transfer of information, precisely because of the energy connections of the processes during mixing. The technological process of using discrete-pulse energy input and the influence of the working body on the flow of a rheologically complex system, considering the design developments of the new mixer and theoretical models, involves the accurate calculation of characteristics aimed at optimising design and technological solutions.

Conclusions

Based on the obtained results of the process of mixing the components in the considered design of the mixer, it was established that the creation of favourable conditions for the formation of the foam structure is ensured by the uniform distribution of recipe components (flour, yeast, water) at a flour supply speed of 2 m/s and a liquid supply speed of 50 m/s.

The proposed mathematical empirical model in the form of a full polynomial of the second degree allows for an

approximate calculation of the uniformity of the formation of the medium, which contributes to the determination of the rational geometric parameters of the mixer in a balanced state. The quality of the formation of the medium (sourdough) in a suspended state for this design of the mixer is ensured by the uniform supply of liquid components and dosing of flour at the set height h from 1.3 to 1.5 cm of the upper part of the working chamber and at the speed of movement of the formed mixture V from 25 to 35 m/s.

The formation of qualitative characteristics of liquid flour masses allows further predicting the process of interaction of fats with the constituent components. The mechanism of the process during kneading is determined by the parameters of this mixer and the quality of the flour. This practical issue of the mixing process cannot be solved analytically because its mechanism is complex. Therefore, the problem was solved in a planned experimental way using process models and mathematical statistics to obtain maximum results.

Undoubtedly, the temperature, humidity of the system, the intensity, and duration of mixing, the amount and composition of introduced fats constitute a study of structure formation, chemical composition, and properties of the physical state of the system under the action of a new mixer. The effect of fat dispersion in the form of droplets or balls, enveloping the flour proteins, prevents the penetration of water into the flour proteins. The design of the mixer allows predicting the reduction of their swelling by trapping air, which leads to a decrease in the density of the medium. Hence, further studies of the discrete-impulse effect on the components are expected to uncover these processes with justified optimisation.

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Визначення раціональних параметрів псевдозмішування шляхом комплексного моделювання робочих процесів

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Анотація. Напрямок підвищення якості утворення сумішей при змішуванні в харчовій промисловості є актуальним, оскільки удосконалення технології й обладнання для здійснення обробки компонентів різними методами, характером та ступенем впливу практично досяжні для їх удосконалення. Мета дослідження – удосконалення конструктивних параметрів та підвищення ефективності роботи змішувача шляхом створення умов, що забезпечить оптимізацію кінетики розчинення дисперсної суміші борошна та рідких компонентів під час їхнього псевдоперемішування у зваженому стані. Розглянуто властивості сировини на методи її визначення якості, запропоновано лабораторні методи та інструменти проведення досліджень при встановленій методиці планування з аналізом отриманих результатів та використано програмний комплекс Flow Vision у побудові графіку на основі законів термодинаміки. Обробку експериментального масиву даних проведено математичним описом процесу формування потоку рідини та дисперсного потоку частинок борошна. Використано неповнофакторну багатовимірну модель апроксимації експериментальних даних функції трьох змінних у вигляді поліномів трирівневим планом Бокса-Бенкіна з 13 дослідями, виконаних у 5-кратній повторності. Проведено аналіз змішувачів періодичної дії, розглянуто перерозподіл і трансформацію деформацій при оптимальних режимах змішування. Встановлено взаємодію компонентів та їх динаміку потоків при мінімізації енерговитрат. Визначено вплив псевдозрідження та вібрації в період дозування компонентів на інтенсифікацію взаємодії дисперсної фази за принципом дискретно-імпульсного введення енергії, що створює швидкі зміни руху компонентів. Отримано функціональну залежність рівномірності утворення бульбашок середовища від трьох факторів $v_c=f(h, V, v_c)$ з перевіркою однорідності дисперсій, адекватності отриманої функціональної залежності та пошук її оптимуму. Розглянуті матеріали статті становлять практичну цінність ефективного процесу рівномірного розподілу рецептурних складових в робочій камері розглянутої конструкції змішувача із створенням сприятливих умов для утворення структури опари

Ключові слова: змішувач, суміш, псевдозрідження, опара