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DYNAMICS OF INTERACTION OF COMPONENTS DURING MIXING

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Summary. *The effect of mechanical action on the mixing and whipping of the mixture of components contributes to the formation of a three-dimensional spongy-reticulate continuous structure of the gluten frame, because it determines the elastic and elastic properties of the medium and is relevant in dispersing gas in a liquid. That is why, the objective of the research was to establish the relationship between the gas-holding capacity of the medium and the energy spent on the hydration of the components.*

The research solved the problem of determining the gas-holding capacity of the medium with variable parameters of the height of the liquid phase depending on the intensity of mixing, time of the transient processes of formation of the full volume of the gas-liquid medium, time of the transient process of the output of the dispersed gas phase. The difference in levels before the formation of the gas phase and in the mode of mixing (aeration) determines the value of the gas-holding capacity. In this regard, we came to the conclusion about the expediency of the complete destabilization of the established regimes due to the change in the modes of action of the working body in the flow system. At the same time, one more feature should be mentioned. Part of the gas phase that existed and continues to exist in a new regime after mixing enters the regime of the transition process. Therefore, the most effective mixing occurs in case of compliance with the shifted mode of dosing of components in a suspended state and the mechanical influence of the working body. Considering the problems and conditions for mixing the scam, the requirements for the design of the mixer are determined, and also it is established that feeding of components should last at least 45 seconds. During this period, hydration occurs and energy consumption is reduced. This approach of the formation of pulsed flows of surface contours during the interaction in a suspended state of the dosing components, under the rotating action of the disc-shaped working body and the forces of gravity, creates the conditions for intensification of transferring the mass and biochemical processes under conditions of thermodynamic equilibrium with the corresponding desorption bonds of the dissolved part of the gaseous phase and liquid, which reveals a new method of mixing and allows further use of cylindrical working chambers in structural calculations.

Key words: *mixing, solid, liquid and gaseous phase, concentration change, thermodynamics, hydration, scam.*

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Statement of the problem. The initial condition of mixing process is keeping to the recipe components. Mixing and whipping of semi-finished products for bakery and confectionery production has its defined stages [1, 2]. The processes of stirring, whipping and foaming are essentially the same, and consist in dispersing gas in liquid. Such a system mainly holds gas bubbles in the whipped mass. They are separated from each other by a thin film of liquid. Schematically, the structure of the foam can be imagined as a package of gas bubbles with thin films of the main highly dispersed filler [3].

Biopolymers involved in the formation of such systems include proteins, starch, pentosans, as well as shell parts. In the process of mixing, emulsion components (scum), complex colloidal, physicochemical and biochemical transformations occur under the action of water and enzyme systems. Colloidal processes are the most active. As a result of water

Corresponding author: Ihor Stadnyk; e-mail: igorstadnykk@gmail.com absorption, proteins, starch and pentosans increase in volume, and sugars, mineral and water-soluble substances and vitamins transform into solution. Proteins, which absorb double amount of water compared to their weight, play a primary role in the formation of wheat scum. Osmotically bound moisture in makes 75%, and absorptively bound one is 25%. It is due to the osmotically bound moisture the protein molecule loosens and increases in volume [4].

During stirring and whipping of components mixture due to mechanical action, water-insoluble protein substances (gluten proteins) swell and increase in volume, forming three-dimensional spongy-reticulate whole texture [5]. It is referred to as gluten frame. It determines the elastic and plastic properties of the medium. The framework includes starch grains, insoluble pentosans, particles of grain shells. Processes of medium components hydration occur at different speeds and depend on water temperature. The maximum swelling of proteins takes place at temperature of 30^{O} C with water absorption of 2.0...2.5 g/g. At a higher temperature, the swelling of proteins is limited. The water absorption of starch is 0.3-0.4 g/g of water per dry matter. Pentosans absorb water osmotically and form viscous solutions, which results in significant increase in moisture absorption capacity and strengthening of the consistency [6, 7].

It is considered that the absorbed and bound water is distributed among the components as follows, in %: whole grains of starch – 26.4; damaged starch grains – 19.1; gluten proteins – 31.2; pentosans – 23.4 [8].

Regarding the flour formed by mixing with water, three phases are distinguished: solid, liquid and gaseous. A solid phase is created by insoluble proteins that form the gluten framework and ensure its stretchability and elasticity. A liquid phase is a viscous solution consisting of flour and water bound by adsorption components. A gaseous phase is formed as a result of saturation of the dough with air bubbles during mixing and partial adding of air with flour, water, eggs, milk protein, sodium caseinate, etc. It is thought that in the total volume of the medium, the gas phase is close to 10% [9].

Analysis of available investigations. A significant number of substances in the medium, changes in concentrations, interactions between them and microorganisms, the presence of stimulants, etc., lead to relative instability of the system. Under such conditions, there are directions for evaluating the effects of individual factors. However, negative consequences must also be programmed, for example, according to the values of osmotic pressures, effects of factors, deterioration of products quality indicators, etc. While the temperature influence can be traced, there is no final point of view regarding physical pressure [10, 11]. Though, the laws of thermodynamics closely link pressure and temperature parameters, for example, in the gas laws, the Mendeleev-Clyperon equation, Henry's law, etc. From the point of view of technical availability to influence fermented massifs, adiabatic or polytropic processes are of interest [12, 13]. Because of compression of forming mixture on the chamber surface, the temperature of the gaseous phase partially increases. It is obvious that before the compression of the system, the temperatures of the gaseous phase and the vapor coincide. However, after compression, we obtain the temperature ratio:

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} \tag{1}$$

in both adiabatic and polytropic processes,

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{m}}, \tag{2}$$

where T_1 and T_2 are initial and final temperature of gaseous phases, respectively;
P_1 and P_2 are initial and final temperature pressures, respectively;
k and m – adiabatic and polytropic indicators.

Energy introduced into a system under such conditions [6] equals:

$$E=\frac{MR}{k-1}(T_2-T_1), \tag{3}$$

where M is the mass of the compressed gas;
R is the universal gas constant.

The energy introduced in this way must be redistributed between the dispersed gaseous phase and the vapor, where the overall temperature of the system increases.

According to Henry's law, an increase in partial (and in our case, total) pressure enhances the solubility of gas in the liquid phase of the medium, and an increase in temperature decreases solubility:

$$C_n = kp, \tag{4}$$

where k is Henry's constant.

This indicator takes into account how the proportionality factor affects the temperature and physical and chemical properties of the system components. An increase in temperature decreases solubility C_H (Fig. 1).

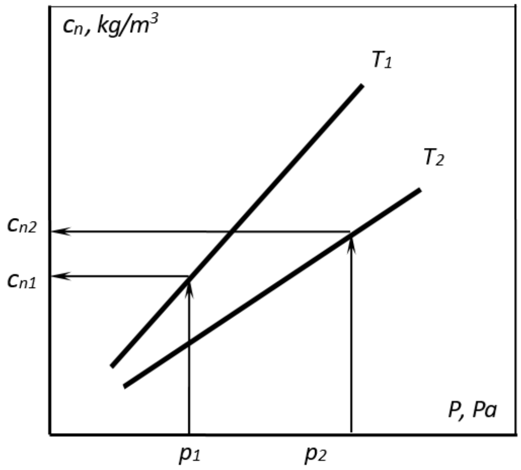

Figure 1. Graph of correlation of parameters c_n and P according to the Henry's law

On the graph, T_1 and T_2 isotherms indicate that theoretically there are options in which the solubility increases, decreases or remains constant with changes in pressure. In addition, the temperature of the medium, according to Vant Hoff law, affects the osmotic pressure of the solution:

$$\pi = CRT, \tag{5}$$

where π is the osmotic pressure of the solution, kPa;

C is its molar volume concentration (molarity), kmol/l;
R = 8.314 J/(mol·K) is the universal gas constant.

The molarity of the solution *C* is the ratio of the amount of dissolved substance *n* to the volume of the solution *V(l)*:

$$C = n/V, \tag{6}$$

and the amount of substance is equal to its mass *m* divided by the molar mass *M*. Hence we have:

$$C = \frac{m}{MV} \tag{7}$$

and Vant Hoff equation:

$$\pi V = \frac{mRT}{M}; \quad \pi = \frac{mRT}{MV}. \tag{8}$$

It follows from the last condition that, in addition to the influence of the temperature *T* of the medium, which can be chosen in a fairly significant range, a more significant influence on the osmotic pressure is achieved due to the destruction of sugars and other organic polymers in the process of fermentation and whipping, since the final results of transformations are alcohol and carbon dioxide and air.

Therefore, a secondary consequence of the change in pressure in the system is change in the temperature of the dispersed gaseous phase, the introduction of additional energy into the system, and change in osmotic pressure. The primary consequence of change in the medium pressure is the active stirring of the mixture of components. It occurs under the conditions of a volumetric stress state due to the compression or expansion of the gaseous phase. Subsequently, it is important that under such conditions there is an interaction between local zones, the centers of which are gas caverns. The emergence of the latter in physical essence corresponds to the phenomenon of discontinuity of the medium based on transformation of chemical energy of the medium bounds into mechanical potential and simultaneously into changes in shape and size.

The transient process of active gas formation affects the growth of overall dimensions of the mass of the medium and its volume. However, the speed of such changes is quite limited. Changes in the volume of the medium occur in the potential field of gravitational forces, which are overcome by the driving factor of the potential energy of the formed gaseous phase during the intensive creation of variable pulses of acting forces [13, 14].

The course of such processes can be quite rapid. Subsequently, there is a combination of two processes, since fermentation of medium sugars is added to pulsed mixing. The consequence of such a combination is intensification of mass exchange and biochemical processes. Other manifestations will be energy pulses in conditions of sharp pressure drops. The difference in pressure means the transition of the system to new parameters of thermodynamic equilibrium with a rapid increase in the gas-holding capacity of the system due to the expansion of the gaseous phase with the corresponding addition of its quantity. This occurs for the reason of desorption of the dissolved part of the gaseous phase. It is obvious that such a transition process applies not only to the gaseous phase, but definitely also to the liquid phase, since the increase in the volume of the gaseous phase clearly determines the increase in the volume of the gas-liquid mixture and the displacement of the liquid phase. The dynamics of the latter is accompanied by the appearance of inertial forces and, accordingly, an increase in pressure in part of the general and programmed decrease.

The liquid phase as an outcome of formation of dispersed gas phase moves vertically in the working chamber. The formed gas-liquid system in dynamics with elastic systems of solid bodies with distributed masses brings to the conclusion of their equivalence and the possibility of applying the Rayleigh principle to determine the reduced mass of the liquid phase. The availabile data on the masses of the studied system and force actions on it means the possibility of using the Lagrange-Delambert principle for its modelling. Determining of the driving force is related to the dynamics of changes in movement speed and pressure. Their reactions to the pulsed energy disturbance will coincide, since the gaseous phase itself is the generator of the mechanical impact due to pressure reduction.

Objectives of the research is to establish the relationship between the gas-holding capacity of the medium and the energy spent on the hydration of the components.

Research materials and methods. The research solved the problem of determining the dependence of gas-holding capacity of the medium with variable parameters of the height of the liquid phase $h_{\text{р.ф.}}$ on the intensity of mixing, time of the transition processes of full volume of gas-liquid medium formation, time of the transition process of the output of the dispersed gaseous phase.

The difference in levels before the formation of gaseous phase and in the mode of mixing (aeration) determines the value of the gas-holding capacity. The beginning and end of transient processes (obtaining of homogeneous mass) was noted visually. The change in the height of the liquid phase was followed similarly to the cycle of changes in the influence parameters.

Presenting of the main material. The change Δh of the height of swollen gas-liquid layer compared to the height of the liquid meant the possibility of determining the value of the gas-holding capacity:

$$u_{g.w.}=\Delta h f, \qquad (9)$$

where f is the cross-sectional area of the working chamber. For the internal diameter of the chamber d = 0.15 m, we have f = 0.0177 m^2.

The results of primary data measurements are given in Table 1.

Table 1

The results of determining the hydrodynamic parameters of the system with air

Height of the liquid phase $h_{l.p.}$ =0.2m						
Counting of the rotameter reading	0.0	10.0	15.0	18.0	20.0	27.0
Height of the mixture, m	0.14	0.15	0.17	0.18	0.19	0.195
Holding capacity, m^3	0.000708	0.000885	0.001239	0.001416	0.001593	0.001682

The analysis of the obtained data leads to the expected conclusion about the increase of the gas-holding capacity in the system with intensive mixing of the components, which influences the increase of the gas flow for aeration and the height of the liquid phase. At the same time, the effect of the transition process, according to which the stabilization of the velocity of the gas phase occurs at a height of 0.15...0.2 m above the plane of its introduction into the liquid phase, is recorded. The graphical interpretation of the table data results is shown in Fig. 2.

Execution of transient processes in mixing systems can occur in the regimes of a sharp increase in the gas-holding capacity or its decrease under planned conditions.

The number of transient processes under the conditions of the introduction of liquid flows movement include those that correspond to the appearance of a dispersed gaseous phase in the full volume of the medium. Meanwhile, at the moment of formation and exit of the gas phase from the medium, the level of gas-holding capacity is the highest, with a subsequent active decrease and transition to a steady state. It is possible to explain such a course of processes by the formation of circulation contours in the working chamber at this moment and an increase in the absolute speed of the gas phase due to this.

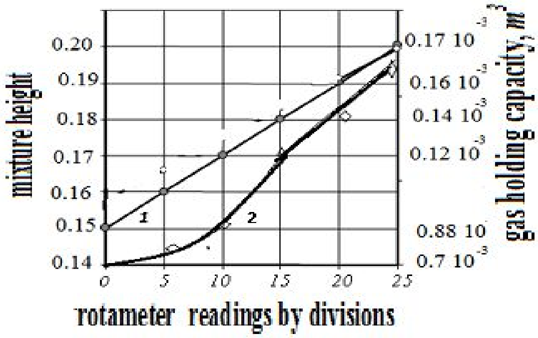

Figure 2. Dependence of the height of the 'liquid-air' mixture (1) and its gas-holding capacity (2) on the readings of the rotameter at a height of the liquid layer of 0.2 m

The transitional process also corresponds to the termination of the intensive action of the working body on the formation of the gaseous phase. If it is carried out by a sharp decrease in the flow, then its result is a mass floating of the dispersed gaseous phase.

The observed difference in the floating rates of air masses is explained by the physical properties of the gas and the interaction of its dispersed masses with the liquid. It is obvious that during the stages of massif floating, there is a reorganization of circulation flows in the remains of the gaseous-liquid phase and at the same time the entire system, which is represented by a combination of liquid and gas-liquid phases (Fig. 3).

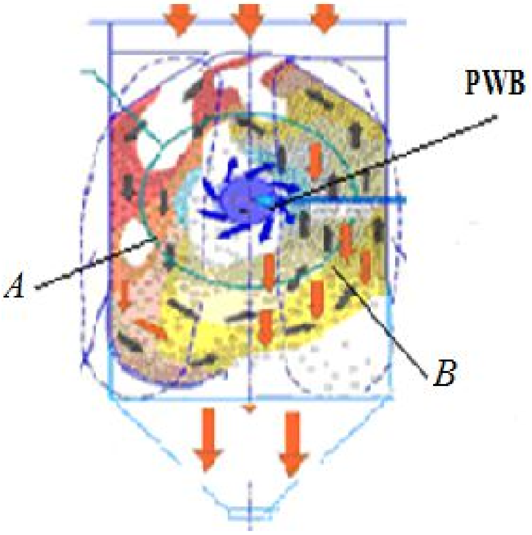

Figure 3. Scheme of the movement of mixed components in the working chamber: A is a circulation contour of the movement of components; B is action of forces on components; DSWB is a disc-shaped working body

In this interaction, the liquid phase moves, the energy potential decreases. In connection with the rapidity of the course of such a stage, we note its relatively small impact on the technological process and the absence of an external energy flow, since the course of events takes place due to the potential and kinetic energy of the system at the beginning of the stage.

Because of the mentioned above and part of the experiments, which concerned the determination of the gas-holding capacity, we came to the conclusion about the expediency of the complete destabilization of the established modes due to the change in the modes of action of the working body in the flow system.

At the same time, it should be taken into account that the hydration component of $A_{гід}$ operation has not been studied before. Its value was taken in the appropriate parameters. Therefore, in our case, the energy spent on the hydration of the components will be considered by the system of equations:

$$\begin{cases} \Delta U = A_{gen} + g \\ Q_{hyd} = \dfrac{BC_T \Delta t_{hyd}}{M} \end{cases}, \qquad (10)$$

where ΔU is the change of internal energy;
$Q_{гід}$ is the amount of heat provided due to the hydration, J;
$\Delta t_{гід}$ is increase in temperature due to hydration;
q is the amount of heat supplied to the system, J;
$A_{заг}$ is work performed by the system, J;
M is the amount of flour in the scum, kg;
B is the amount of processing scum, kg;
C_T is the specific heat capacity of scum, kJ/kg.

During stirring of the mixture, where there is no plasticizing work, it was assumed:

$$A_{gen} = Q_{hyd} \qquad (11)$$

Given that the author of the mixing process [9] consideres that:

$$C_T = \frac{C_m M + W}{B}, \qquad (12)$$

where C_m is the specific heat capacity of flour, kJ/kg;
W is the amount of water (substitutes) according to the recipe of the scum, kg;
M is the amount of flour, kg;
B is the amount of processing scum, kg.

Hence:

$$\begin{cases} A_{hyd} = \dfrac{BC_T \cdot \Delta t_{hyd}}{M} \\ A_{hyd} = \Delta U - g \end{cases} \qquad (13)$$

Change of internal energy:

$$\Delta U = \frac{(C_m M + W) \cdot \Delta t_{hyd}}{M} \qquad (14)$$

Solution (10):

$$A_{hyd} = \frac{\Delta t}{M}\left(CM + B\right) \tag{15}$$

From the analysis of the above about the energy, which can be transferred in various forms through the working body to the medium, the general modes of energy changes cycle in the of ascent of the gas-dispersed array rate increase, i.e., the component of the staged mixing, are taken. The maximum crushing of gas bubbles in the forming mixture at a uniform level of action of the plate-shaped working body surface contributes to the emergence of thin-walled, fine, uniform porosity of the products. Crushing of gas bubbles is one of the main factors affecting the stability of the shape of the semi-finished product. Further, it will be transformed into other quality indicators. At the same time, it is necessary to ensure minimum energy consumption to create a homogeneous mixture with a fairly even distribution throughout the mixed volume of the concentration of solid components (flour) in the liquid phase.

The achieved uniform state of the mixture is unstable. Aeration of the mixture helps increase the rate of exchange processes, which is generally reflected in its oxygen saturation. At the same time, saturation of the mixture with oxygen leads to an intensive process of oxidation catalysis. Part of the bubbles has the form of gas emulsion in the liquid phase of the mixture, and the other is in the swollen proteins of the mixture in the form of gas bubbles. An increase in the absorption of water volume activates the action of enzymes, which generally determines the processes of swelling and peptization of proteins and dilution of the mixture.

An increase in the absorption of water volume activates the action of enzymes, which generally determines the processes of swelling and peptization of proteins and dilution of the mixture.

According to this, the change in the volume of the forming system during mixing in the form of porosity (volume of the gas phase) was predicted. From the energy balance equation, the work spent on heating the structural components and the working body interacting with them was determined [1]:

$$A_з = \frac{t_2 - t_1}{n\tau}\left(m_т c_т - m_м c_м\right) \tag{16}$$

Taking into account the Mendeleev-Clayperon law for an ideal gas [8] and the equation of the theory [1] and the determined hydration, we obtained:

$$\begin{cases} \dfrac{P_1 V_1}{T_1} = \dfrac{P_2 V_2}{T_2} \\ A_{gen} = A_3 + A_{hyd} = \dfrac{t_2 - t_1}{n\tau}\left(m_т c_т - m_м c_м\right) + \dfrac{\Delta t}{M}\left(C\ M + B\right) \end{cases} \tag{17}$$

Assuming that $T_2 = t_2 - t_1$, we transformed the system of equations and determined the volume of the gas phase V_2.

An additional effect on the system is a change in hydrodynamic modes due to unstable dynamics of formation of the dispersed gas phase. The surface of the gas-liquid flow is determined by the combination of physical and chemical properties of the medium and the speed of flow around the surface of the working body. The formed gas-liquid contours are more often chaotic, which also leads to thermal circulation disturbances. At the same time, the levels of such disruptions can be deep enough together with changes in directions in the contours of the working chamber.

Thus, the hydrodynamic modes in the working chamber are determined by three reasons. The first of them refers to the formed flows of surface contours during the interaction in a suspended state of dosing yeast suspension and dosing flour. The second is the formation of streams of surface contours under the rotational action of the disc-shaped working body. The third reason concerns the formation of flows with the participation of the gas phase and the gravitational effect on the flows that rapidly flow through the walls of the cylindrical working chamber.

It is obvious that each of the named reasons is characterized by its driving factors. For the first and second factors, there is a difference in the movement of the medium and temperatures. In the third case, the driving factor is the presence of a dispersed gas phase, and the speed of formation of the latter is important, which in turn depends on the speed of whipping and the formation of a foam frame. A certain level of generalization in the latter case can be represented by the holding capacity of the medium in the gas phase. The gas-holding capacity of the medium depends on the change in the height of the liquid phase $h_{р.ф.}$ in the working chamber of the machine, the intensity of aeration, the time of the transient processes of the formation of the full volume of gas-liquid medium, the time of transient process of the output of the dispersed gas phase. Characteristics of gas are given in Table 2.

Table 2

Physical parameters of air

Gas	*Molecular mass*	*Specific mass, kg/m³*	*Gas constant, J/(kg×K)*
Air	28.96	1.293	287

The change *Δh* of the height of the swollen gas-liquid layer compared to the height of the liquid meant the possibility of determining the value of the gas-holding capacity:

$$u_{g.w.} = \Delta h f, \tag{18}$$

where f is the cross-sectional area of the working chamber.

Respectively, the volume of the swollen gas-liquid layer for each zone of the working chamber will be:

$$V = \pi \int_{h_1}^{h_2} y^2 dx, \tag{19}$$

where y is the radius of the cylindrical chamber, mm;
x – camera height, mm.

Taking into account the fact that the level of the central part of the scam is on average 20...30 mm higher than that of the walls of the working chamber and taking into account its conical parts, the volume for the formed mixture before unloading will be determined:

$$V_{заг} = \pi \int_{h_1}^{h} \left[y_1 + (x - h_1)\mathrm{tg}\alpha\right]^2 dx = \frac{\pi}{3\mathrm{tg}\alpha}\left\{\left[y_1 + (h - h_1)\mathrm{tg}\alpha\right]^3\right\}. \tag{20}$$

The rate of generation of the gas phase is determined by the process technology, and in each cross-section of the cylindrical working chamber of the machine, it is possible to detect signs of the dispersed gas phase. The control system of thermodynamic parameters provides the achievement of the maximum pressure $P_1 = P_{max}$, and from the moment of its achievement, a decrease to a certain value of P_2 is expected. Hence: $\Delta P = P_1 - P_2$.

It is important that the change in pressure *ΔP* does not depend on the coordinate of the selected point in the working chamber. The volume of the formed medium depends on the holding capacity and the location of its corresponding layers. It is obvious that the formed phase is in the form of arrays of dispersed bubbles, the total volume of which is calculated using the Mendeleev-Clyperon equation:

$$V_{sp} = \frac{m_{O_2}}{P_{(k)}} RT \qquad (21)$$

The specific mass of O_2 is known (Table 2) and the final pressure $P_{(к)}$ corresponding to the selected coordinate h is known, then:

$$P_{(к)} = P_0 + mgh. \qquad (22)$$

Therefore, the specific volume of the formed mixing mass according to the recipe with the corresponding air saturation will be:

$$V_{sp} = \frac{m_{O_2}}{P_0 + mgh} RT, \qquad (23)$$

where R and T are the universal gas constant and the absolute temperature of the medium, respectively.

The specified generation of the dispersed gas phase means the waste of energy or the formation of the interphase surface, which must be taken into account in the overall energy balance. At the same time, one more feature should be mentioned. Part of the gas phase that existed and continues to exist in a new regime after mixing enters the regime of the transition process. Existence is inevitable, because the Archimedean force instantly acts on a new bubble in the medium, regardless of the state of the liquid phase. In this connection, the relative movement of the gas phase begins with an increasing speed to the value at which the resistance of the medium becomes equal to the Archimedean force. Therefore, with the created medium, it is necessary to carry out a technological operation for a certain period (10...20 seconds) – unloading of semi-finished product.

Conclusions and perspectives. The volume of the mixture changes the most at the end of the mixing stage at the maximum mass (according to the recipe), that is, in the resulting mixture and the percentage composition of the gaseous phase is 13.6%. Therefore, powder-like solids and liquids are mixed most effectively on the surface of the phase contact, while it is necessary to observe the shifted mode of dosing of the components in a suspended state and the mechanical influence of the working body. In view of the tasks and conditions for mixing the scum, the requirements for the design of the mixer are determined, at the same time it is established that the feeding of components should last at least 45 seconds. During this period, hydration and reduction of energy consumption occurs.

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ДИНАМІКА ВЗАЄМОДІЇ КОМПОНЕНТІВ ПРИ ПЕРЕМІШУВАННІ

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Резюме. *Вплив механічної дії на змішування та збивання суміші компонентів сприяє утворенню тривимірної губчасто-сітчастої неперервної структури клейковинного каркасу, адже саме він визначає еластичні та пружні властивості середовища і є актуаальним у диспергуванні газу в рідині. Тому метою роботи було встановлення взаємозв’язку газоутримувальної здатності середовища та енергії, затрачуваної на гідратацію компонентів. Виконано завдання визначення газоутримувальної здатності середовища зі змінними параметрами висоти рідинної фази від інтенсивності змішування, часу перебігу перехідних процесів формування повного об’єму газорідинного середовища, часу перехідного процесу виходу диспергованої газової фази. Різниця рівнів до утворення газової фази й у режимі перемішування* *(аерації) визначає значення газоутримувальної здатності. У зв'язку з цим, дійшли до висновку про доцільність повної дестабілізації усталених режимів завдяки зміні режимів дії робочого органа в системі потоків. Додатковим впливом на систему є зміна гідродинамічних режимів у зв'язку з несталою динамікою утворення диспергованої газової фази. Генерування диспергованої газової фази означає присутність енергетичних витрат на утворення міжфазної поверхні, що повинно враховуватися в загальному енергетичному балансі. Водночас треба назвати ще одну особливість. Частина газової фази, що існувала й продовжує існувати в новому режимі після змішування, потрапляє в режим перехідного процесу. Тому найефективніше замішування відбувається в разі дотримання зміщеного режиму дозування компонентів у зваженому стані та механічного впливу робочого органу. З огляду на поставлені завдання й умови проведення змішування опари, визначено вимоги до конструкції змішувача, водночас встановлено, що подача компонентів має тривати не менше 45 с. За цей період відбувається гідратація та зменшення споживання енергоресурсів. Такий підхід утворення імпульсних потоків поверхневих контурів під час взаємодії у зваженому стані дозуючих компонентів, за обертової дії тарільчастого робочого органу й сил гравітації, встановлює умови інтенсифікації масообмінних і біохімічних процесів в умовах термодинамічної рівноваги при відповідних зв'язках десорбції розчиненої частини газової фази та рідини. Це розкриває новий спосіб перемішування та дозволяє в подальшому використовувати при конструктивних розрахунках циліндричних робочих камер.*

***Ключові слова**: перемішування, тверда, рідка і газоподібна фаза, зміна концентрацій, термодинаміка, гідратація, опара.*

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