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Dynamics of interfacial interaction between components during mixing

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Abstract. The effect of mechanical action on the mixing and whipping of a mixture of components contributes to the establishment of a three-dimensional sponge-mesh continuous structure of the gluten framework, as it determines the elastic and elastic properties of the medium and is relevant in the dispersion of gas in a liquid. The purpose of the work was to establish the relationship between the gas retention capacity of the medium and the energy consumed for the hydration of the components. The experiments performed the task of determining the gas retention capacity of the medium with variable parameters of the height of the liquid phase from the intensity of mixing, the time of the transient processes of the formation of the full volume of the gas-liquid medium, the time of the transient process of the dispersed gas phase. The difference in levels before the gas phase generation and the stirring mode determines the value of gas retention capacity. Therefore, it was concluded that it is expedient to completely destabilise the steady-state regimes by changing the modes of action of the working body in the flow system. An additional impact on the system is the change of hydrodynamic regimes due to the unstable dynamics of the dispersed gas phase generation. The generation of this phase means the presence of energy costs for the interfacial surface establishment, which must be considered in the overall energy balance. In addition, a part of the gas phase, which existed and continues to exist in the new regime after mixing, enters the

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transient regime. Therefore, the most effective mixing occurs in case of compliance with the shifted mode of dosing components in a suspended state and the mechanical impact of the working body. Considering the tasks and conditions for mixing the dough, the requirements for the design of the mixer are determined, and it is established that the supply of components should last at least 45 seconds. During this period, there is hydration and a reduction in energy consumption. Such an approach intensifies mass transfer and biochemical processes under conditions of thermodynamic equilibrium with appropriate desorption bonds of the dissolved part of the gas phase and liquid, which covers a new method of mixing and allows further use in the design calculations of working chambers

Keywords: mixing, solid, liquid and gaseous phase, change of concentrations, thermodynamics, hydration, stripping

Introduction

The initial conditions of the mixing process are compliance with the recipe of the components. Mixing and whipping of semi-finished products for bakery and confectionery products have their defined stages (Chernenkova *et al.*, 2019; Stadnyk *et al.*, 2021a). The processes of mixing, whipping and foaming are essentially the same and consist in dispersing gas in a liquid. Such a system mainly contains gas bubbles in the whipped mass. They are separated by a thin film of liquid. Schematically, the foam structure can be represented as a packing of gas bubbles with thin films of the main highly dispersed filler (Stadnyk *et al.*, 2021b).

The biopolymers involved in the establishment of such systems include proteins, starches, pentosans, and shell parts. In the process of mixing the components of the emulsion (brew), complex colloidal, physicochemical and biochemical transformations occur under the influence of water and enzyme systems. Colloidal processes are the most active. As a result of water absorption, proteins, starches and pentosans increase in volume, and sugars, minerals, water-soluble substances and vitamins are transferred to the solution. In the wheat dough establishment, the primary role belongs to proteins, which absorb double the amount of water compared to their weight. Osmotically bound moisture in them is 75%, and absorption bound – 25%. It is due to osmotically bound moisture that the protein molecule loosens and increases in volume (Danyliuk *et al.*, 2017).

During the mixing and beating of the mixture of components, swollen, water-insoluble protein substances (gluten proteins) increase in volume due to mechanical action and form a three-dimensional sponge-mesh continuous structure (Lisovska *et al.*, 2017). It is called the gluten framework. It is this that determines the elastic and resilient properties of the material. The framework consists of starch grains, insoluble pentosans, and particles of grain shells. The hydration processes of the environment components occur at different speeds and depend on the water temperature. The maximum swelling of proteins occurs at a temperature of 30°C with water absorption of 2.0...2.5 g/g. At higher temperatures, the swelling of proteins is limited. Water absorption of starch is 0.3...0.4 g/g of water per dry matter. Pentosans absorb water osmotically and form viscous solutions, resulting in a significant increase in moisture absorption capacity and consistency (Stadnyk *et al.*, 2019; Nakov & Ivanova, 2020).

It is considered that the absorbed and bound water between the components is distributed as follows, in %: whole starch grains – 26.4; damaged starch grains – 19.1; gluten proteins – 31.2; pentosans – 23.4 (Kolyanovska *et al.*, 2019).

There are three phases produced by mixing flour with water: solid, liquid and gaseous. *The solid phase* is established by insoluble proteins that establish the gluten framework and ensure its stretchability and elasticity. *The liquid phase* is a viscous solution consisting of adsorbed flour and water components. *The gaseous phase* is established as a result of the saturation of the dough with air balls during mixing and partially by adding air with flour, water, eggs, milk protein, sodium caseinate, etc. It is considered that the gas phase is close to 10% in the total volume of the medium (Mushtruk *et al.*, 2020).

Research analysis

A significant amount of substances in the environment, changes in concentrations, interactions between them and microorganisms, the presence of stimulants, etc. result in relative instability of the system. Under such conditions, there are areas in which the impact of individual factors is assessed. However, adverse effects should be programmed, for example, by osmotic pressures, impacts of factors, deterioration of product quality, etc. While the effect of temperature can be traced, there is no definitive opinion on physical pressure (Palamarchuk *et al.*, 2020; Sukhenko *et al.*, 2019). However, the provisions of thermodynamics closely relate the parameters of pressure and temperature, for example, in the gas laws, the Mendeleev-Clyperon equation, Henry's law, etc. From the standpoint of technical availability, adiabatic or polytropic processes are of interest in influencing fermentable masses (Osipenko *et al.*, 2019; Savenkova *et al.*, 2019). Due to the compression of the establishing mixture on the surface of the chamber, the temperature of the gas phase partially increases. Evidently, before the system is compressed, the temperatures of the gas phase and the vapour coincide. However, after compression, the ratio of temperatures is obtained:

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

in the adiabatic process and polytropic process,

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

where T_1 and T_2 are the initial and final temperatures of the gas phase, respectively; P_1 and P_2 – respectively, the initial and final pressure; k and m – adiabatic and polytropic indices.

The energy input into the system under such conditions [6] is equal to:

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

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

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

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

$$c_н = kp, \quad (4)$$

where k – Henry's constant.

This indicator considers how the proportionality factor affects the temperature and physical and chemical properties of the system components. Increasing temperature decreases solubility $c_н$ (Fig. 1).

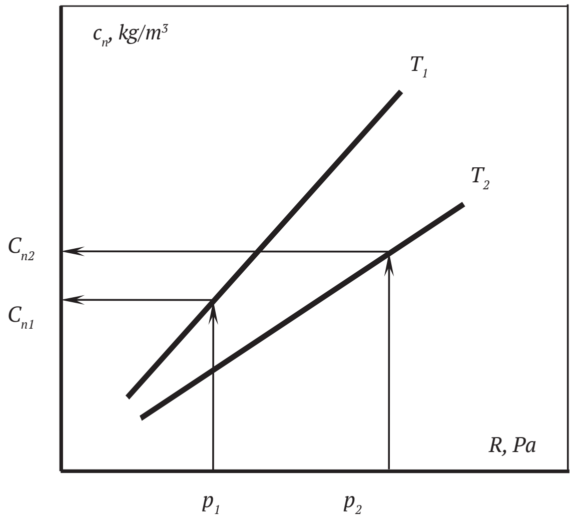

Figure 1. Diagram of the dependence between the parameters C_n and R according to Henry's law

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

$$\pi = CRT, \quad (5)$$

where π – osmotic pressure of the solution, kPa; C – its molar volume concentration (molarity), kmol/l; R=8.314 J/(mol·K) – universal gas constant.

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

$$C = \frac{n}{V}, \quad (6)$$

and the amount of substance is equal to its mass *m* divided by the molar mass *M*. Therefore it follows:

$$C = \frac{m}{MV} \quad (7)$$

and the Van Hoff equation:

$$\pi V = \frac{mRT}{M};$$

$$\pi = \frac{mRT}{MV} \quad (8)$$

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

Thus, the secondary consequence of pressure changes in the system is the change in the temperature of the dispersed gas phase, the introduction of additional energy into the system, and the change in osmotic pressure. The primary consequence of the pressure change in the medium is the active mixing of the mixture of components. Its course occurs under conditions of volumetric stress due to compression or expansion of the gas phase. Therewith, it is significant that under such conditions there is an interaction between local zones, the centres of which are gas caverns. The emergence of the latter in the physical essence corresponds to the phenomenon of breaking the continuity of the medium based on the transformation of the chemical energy of the compounds of the medium into the mechanical potential and, therewith, the kinetic energy of change of shape and size.

The transient process of active gas generation affects the growth of the overall dimensions of the massive medium and its volume. However, the speed of such changes is quite limited. Changes in the volume of the medium occur in a potential field of gravitational forces, which are overcome by the driving factor of the potential energy of the generated gas phase under the intensive establishment of alternating pulses of the acting forces (Shishkin *et al.*, 2020; Pyvovarov *et al.*, 2021).

The course of such processes can be quite fleeting. Therewith, the two processes are combined, since the fermentation of sugars in the medium is added to the pulse mixing. The consequence of this combination is the intensification of mass exchange and biochemical processes. Others will be manifestations of energy impulses in conditions of sharp pressure drops. The difference in pressures means the transition of the system to new parameters of thermodynamic equilibrium with a rapid increase in the gas retention capacity of the system through the expansion of the gas phase with a corresponding increase in its amount. This fact is caused by the desorption of the dissolved part of the gas phase. Evidently, such a transition process concerns both the gas phase and the liquid phase, since the increase in the volume of the gas phase determines the increase in the volume of the gas-liquid mixture and the movement of the liquid phase. The dynamics of the latter is accompanied by the emergence of inertia forces and, accordingly, an increase in pressure in terms of its general and programmed reduction.

The movement of the liquid phase as a result of the establishment of the dispersed gas phase is performed by the vertical working chamber. The established gas-liquid system in dynamics with elastic solid systems with distributed masses results in a conclusion about their equivalence and the possibility of applying Rayleigh's principle for determining the reduced mass of the liquid phase. The availability of data on the masses of the system being studied and force actions on it means the possibility of using the Lagrange-Delambert principle in its modelling. The definition of the driving factor is associated with the dynamics of changes in speed and pressure. Their reactions to the pulsed energy disturbance will coincide since the generators of mechanical impact for pressure reduction are the gas phase itself.

The purpose of the research is to establish the correlation between the gas retention capacity of the medium and the energy spent on the hydration of the components.

Materials and Methods

The research was performed to determine the gas retention capacity of the medium with variable parameters of the height of the liquid phase $h_{p.\phi}$. from the intensity of mixing, the time of the transient processes of the development of the total volume of the gas-liquid medium, the time of the transient process of the dispersed gas phase.

The difference in levels before the gas phase is established and in the mixing (aeration) mode determines the value of gas retention capacity. The beginning and end of the transition processes (obtaining a homogeneous mass) were recorded visually. The change in the height of the liquid phase was accompanied by a similar cycle of changes in the exposure parameters.

Results

The change Δh in the height of the swollen gas-liquid layer compared to the height of the liquid layer meant that it allowed determining the value of gas retention capacity:

$$u_{г.р.с.} = \Delta h f, \quad (9)$$

where f – cross-sectional area of the working chamber. For the inner diameter of the chamber d=0.15 m have f=0.0177 m^2.

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

Table 1. *Results of determination of hydrodynamic parameters of the system with air*

Height of liquid phase $h_{р.ф.}$ = 0.2 m						
Rotameter reading countdown	0.0	10.0	15.0	18.0	20.0	27.0
Mix height, m	0.14	0.15	0.17	0.18	0.19	0.195
Retention 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 growth of gas retention capacity in the system with intensive mixing of components, which affects the increase of gas flow on aeration and height of the liquid phase. Therewith, the effect of the transient process is recorded, according to which the stabilisation of the gas phase velocity occurs at a height of 0.15...0.2 m above the plane of its injection into the liquid. A graphical interpretation of the results of tabular data is presented in Fig. 2.

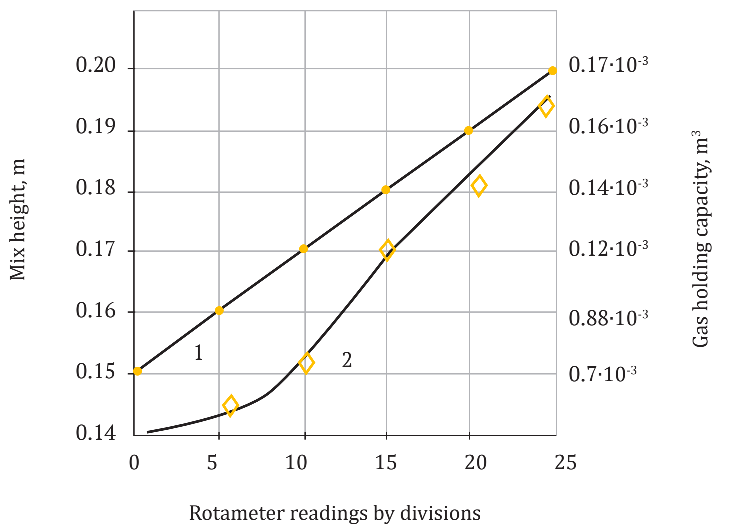

Figure 2. Dependence of the height of the liquid-air mixture (1) and its gas retention capacity (2) on the rotameter readings at a liquid layer height of 0.2 m

Transient processes in mixing systems can occur in modes of a sharp increase in gas retention capacity or a decrease in planned conditions.

Transient processes in the conditions of introduction of liquid flows include those that correspond to the appearance of a dispersed gas phase in the full volume of the medium. Therewith, at the moment of establishment and exit of the gas phase from the medium, the level of gas retention capacity is the highest with subsequent active decrease and transition to the steady state. To explain such a course of processes can be explained by the establishment of circulation circuits in the working chamber at this moment and the increase due to this absolute velocity of the gas phase.

In addition, the transition process corresponds to the termination of the intensive action of the working body on the gas phase generation. If it is performed by a sharp decrease in the flow, it results in the mass floating of the dispersed gas phase.

The observed difference in the velocity of air masses is explained by the physical properties of the gas and the interaction of its dispersed masses with the liquid. Evidently, at the stages of the surfacing of the arrays, there is a restructuring of circulation flows in the remnants of the gas-liquid phase and, therewith, the entire system, which is represented by a combination of liquid and gas-liquid phases (Fig. 3).

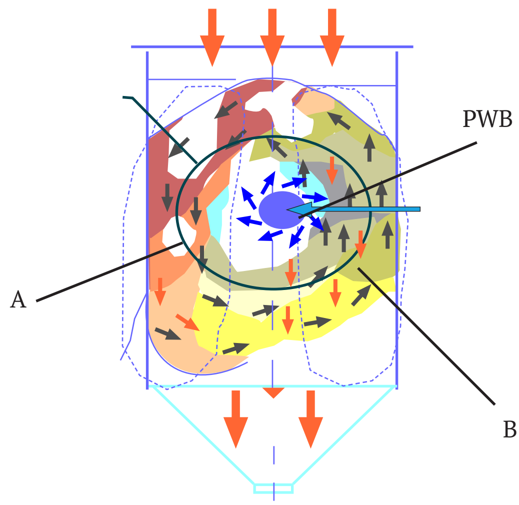

Figure 3. Scheme of movement of mixed components in the working chamber: A – circulation circuit of movement of components; B – the action of forces on components; PWB – plate working body

In such an interaction, the liquid phase moves and the energy potential decreases. Due to the transience of this stage, note its relatively small impact on the technological process and the lack of external energy flow, since the course of events occurs due to the potential and kinetic energy of the system at the beginning of the stage.

In connection with the latter and the part of the experiments that concerned the determination of gas retention capacity, it was concluded that it is advisable to completely destabilise the steady-state regimes by changing the modes of action of the working body in the flow system.

Notably, this component of A_{hyd} hydration has not been previously explored. Its value was accepted in the appropriate parameters. Therefore, in this case, the energy spent on hydration of the components will be considered by the system of equations:

$$\begin{cases} \Delta U = A_{\text{заг}} + q \\ Q_{\text{гід}} = \frac{BC_T \Delta t_{\text{гід}}}{M} \end{cases} \quad (10)$$

where ΔU – change in internal energy; Q_{hyd} – the amount of heat provided by hydration J; Δt_{hyd} – temperature increase due to hydration; q – the amount of heat provided to the system, J; A_{gen} – work performed by the system, J; M – amount of flour in dough, kg; B – the amount of processing dough, kg; C_T – specific heat capacity of dough, kJ/kg.

During the whipping of the mixture, where there is no work for plasticisation, it was assumed:

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

Considering that the author of the mixing process [9] believes that:

$$C_T = \frac{C_M M + W}{B} \quad (12)$$

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

Then:

$$\begin{cases} A_{\text{гід}} = \frac{BC_T \cdot \Delta t_{\text{гіл}}}{M} \\ A_{\text{гід}} = \Delta U - g \end{cases} \quad (13)$$

Change of internal energy :

$$\Delta U = \frac{(C_{\text{м}} M + W) \cdot \Delta t_{\text{гіл}}}{M} \quad (14)$$

Solution (10) :

$$A_{\text{ГД}} = \frac{\Delta t}{M}(CM + B) \quad (15)$$

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 the cycle of energy changes in the growth of the gas dispersed mass, i.e., the component of the mixing stage, are taken. Maximum crushing of gas bubbles in the generating mixture at a uniform level of activity of the surface of the plate working body contributes to the emergence of thin-walled fine uniform porosity of products. The crushing of gas bubbles is one of the main factors affecting the shape stability of the semi-finished product. It is further transformed into other qualitative indicators. Therewith, it is necessary to ensure minimal energy consumption to establish a homogeneous mixture with a fairly uniform distribution of the concentration of solid components (flour) in the liquid phase throughout the mixed volume.

The achieved uniform state of the mixture is unstable. Aeration of the mixture increases the speed of metabolic processes, which generally affects its oxygen saturation. The saturation of the mixture with oxygen results in an intensive oxidation catalysis process. Some of the bubbles are in the form of an emulsion of gas in the liquid phase of the mixture, and the other is in the swollen proteins of the mixture in the form of gas bubbles. Increasing the absorption of water volume activates the action of enzymes, which generally determines the processes of swelling and peptisation of proteins and dilution of the mixture.

Considering this, the change in the volume of the establishing 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 interacting working body with them was determined [1]:

$$A_з = \frac{t_2 - t_1}{n\tau}(m_m c_m - m_м c_м) \qquad (16)$$

Considering the Mendeleev-Clyperon law for an ideal gas [8] and the equations of the theory [1] and the defined hydrothermal reaction, the following is obtained:

$$\begin{cases} \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \\ A_{заг} = A_3 + A_{гід} = \frac{t_2 - t_1}{n\tau}(m_m c_m - m_м c_м) + \frac{\Delta t}{M}(C_б M + B) \end{cases} \qquad (17)$$

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

An additional impact on the system is the change of hydrodynamic regimes due to the unstable dynamics of the dispersed gas phase generation. The surface of the gas-liquid flow is determined through a combination of physical and chemical properties of the medium and the speed of flow of the surface of the working body. The established gas-liquid circuits are frequently chaotic, which results in disturbances of thermal circulation. Therewith, the levels of such violations can be quite deep with changes in areas in the contours of the working chamber.

Thus, hydrodynamic modes in the working chamber are determined by three reasons. The first of them concerns the generated flows of surface contours during the interaction in suspension of the dosing yeast suspension and dosing flour. The second – is the establishment of flows of surface contours under the rotational action of the plate working body. The third reason concerns the establishment of flows with the participation of the gas phase and gravitational action on the flows that rapidly drain down the walls of the cylindrical working chamber.

Evidently, each of these reasons is characterised 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 the dispersed gas phase, and the rate of establishment of the latter is significant, which in turn depends on the speed of whipping and the establishment of the foam frame. A specific level of generalisation in the latter case can be represented by the retention capacity of the medium in the gas phase. The gas retention capacity of the medium depends on the change in the height of the liquid phase in the working chamber of the machine, the intensity of aeration, the time of the transient processes of the establishment of the full volume of the gas-liquid medium, the time of the transient process of the dispersed gas phase. Gas characteristics are presented in Table 2.

Table 2. *Physical parameters of air*

Gas	Molecular weight	Specific mass, kg/m³	Gas steel, J/(kg·K)
Air	28.96	1.293	287

The change Δh in the height of the swollen gas-liquid layer compared to the height of the liquid layer meant that it allowed determining the value of gas retention capacity:

$$u_{г.р.с.} = \Delta h f. \qquad (18)$$

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

Accordingly, the volume of the expanded

gas-liquid layer for each zone of the working chamber will be:

$$V = \pi \int_{h_1}^{h_2} y^2 dx \quad (19)$$

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

Considering that the level of the central part of the dough is on average 20...30 mm higher than that of the walls of the working chamber and considering the conical part of it, the volume of the generated mixture before unloading will be determined:

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

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

It is essential that the change in pressure ΔP does not vary with the coordinate of the selected point in the working chamber. The volume of the generated medium depends on the size of the retention capacity and the location of the corresponding layers. Evidently, the generated phase is in the form of arrays of dispersed bubbles, the total volume of which is calculated using the Mendeleev-Clyperon equation:

$$V_{num.} = \frac{m_{O_2}}{P_{(\kappa)}} RT . \quad (21)$$

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

$$P_{(\kappa)} = P_0 + mgh . \quad (22)$$

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

$$V_{num.} = \frac{m_{O_2}}{P_0 + mgh} RT , \quad (23)$$

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

This generation of the dispersed gas phase means the presence of energy costs for the establishment of the interfacial surface, which should be considered in the overall energy balance. Therewith, it is necessary to name one more feature. A part of the gas phase, which existed and continues to exist in the new regime after mixing, enters the transient regime. Existence is inevitable as the new bubble nucleated in the medium is instantly acted upon by the Archimedean force regardless of the state of the liquid phase. In this regard, the relative movement of the gas phase begins with increasing speed to the value at which the resistance force of the medium becomes equal to the Archimedean force. Therefore, it is necessary to perform a technological operation with the generated environment for a specific period (10...20 seconds) – unloading of the semi-finished product.

Conclusions

The volume of the mixture changes the most at the end of the mixing stage at the maximum mass (according to the recipe), i.e. in the generated mixture and the percentage of the gas phase is 13.6%. Therefore, powdered solids and liquids are most effectively mixed on the surface of the phase contact, while it is necessary to observe the shifted mode of dosing the components in suspension and the mechanical impact of the working body. Considering the tasks and conditions for mixing the dough, the requirements for the design of the mixer are determined, therewith, it is established that the supply of components should last at least 45 seconds. During this period, there is hydration and a reduction in energy consumption.

References

[1] Chernenkova, A., Leonova, S., Chernykh, V., & Chernenkov, E. (2019). Influence of biologically active raw materials on rheological properties of flour confectionery products. *Acta Biologica Szegediensis*, 63(2), 195-205.

[2] Stadnyk, I., Sokolenko, A., Piddubnuy, V., Vasylkivsky, K., Chahaida, A., & Fedoriv, V. (2021). Justification of thermodynamic efficiency of the new air heat pump in the system of redistribution of energy resources at the enterprise. *Potravinarstvo Slovak Journal of Food Sciences*, 15, 680-693.

[3] Stadnyk, I., Piddubnyi, V., Beyko, L., Dobrotvor, I., Sabadosh, G., & Hushtan, T. (2021). Formation of heat and mass transfer bonds when mixing components in a suspended state. *Potravinarstvo Slovak Journal of Food Sciences*, 15, 810-823.

[4] Danyliuk, O., Atamanyuk, V., Gumnytsky, Y., & Bachyk, M. (2017). Investigation of the regularities of the process of periodic dissolution of polydisperse benzoic acid particles during pneumatic mixing. *Integrated Technologies and Energy Saving*, 36-40.

[5] Lisovska, T., Stadnik, I., Piddubnyi, V., & Chorna, N. (2020). Effect of extruded corn flour on the stabilization of biscuit dough for the production of gluten-free biscuit. *Ukrainian Food Journal*, 9(1), 159-175.

[6] Stadnyk, I., Pankiv, J., Havrylko, R., & Karpyk, H. (2019). Researching of the concentration distribution of soluble layers when mixed in the weight condition. *Potravinarstvo Slovak Journal of Food Sciences*, 13(1), 581-592.

[7] Nakov, G., & Ivanova, N. (2020). The effect of different methods for production of crackers on their physical and sensory characteristics. *Technologica Acta-Scientific Professional Journal of Chemistry and Technology*, 13(1), 41-45.

[8] Kolyanovska, L., Palamarchuk, I., Sukhenko, Y., Mussabekova, A., Bissarinov, B., Popiel, P., Mushtruk, M., Sukhenkko, V., Vasuliev, V., Semko, T., & Tyshchenko, L. (2019). *Mathematical modeling of the extraction process of oil-containing raw materials with pulsed intensification of heat of mass transfer*. Retrieved from https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11045/110450X/Mathematical-modeling-of-the-extraction-process-of-oil-containing-raw/10.1117/12.2522354.full?SSO=1.

[9] Mushtruk, M., Gudzenko, M., Palamarchuk, I., Vasyliv, V., Slobodyanyuk, N., Kuts, A., Nychyk, O., Salavor, O., & Bober, A. (2020). Mathematical modeling of the oil extrusion process with pre-grinding of raw materials in a twin-screw extruder. *Potravinarstvo Slovak Journal of Food Sciences*, 14, 937-944.

[10] Palamarchuk, I., Mushtruk, M., Sukhenko, V., Dudchenko, V., Korets, L., Litvinenko, A., Deviatko, O., Ulianko, S., & Slobodyanyuk, N. (2020). Modelling of the process of vybromechanical activation of plant raw material hydrolysis for pectin extraction. *Potravinarstvo Slovak Journal of Food Sciences*, 14, 239-246.

[11] Sukhenko, Y., Mushtruk, M., Vasyliv, V., Sukhenko, V., & Dudchenko, V. (2019). Production of pumpkin pectin paste. In *Proceedings of the 2nd international conference on design, simulation, manufacturing: The innovation exchange* (pp. 805-812). Lutsk: DSMIE

[12] Osipenko, E.Y., Denisovich, Y.Y., Gavrilova, G.A., & Vodolagina, E.Y. (2019). The use of bioactive components of plant raw materials from the far eastern region for flour confectionery production. *AIMS Agriculture and Food*, 4(1), 73-87.

[13] Savenkova, T.V., Soldatova, E.A., Misteneva, S.Y., & Taleysnik, M.A. (2019). Technological properties of flour and their effect on quality indicators of sugar cookies. *Food Systems*, 2(2). 13-19.

[14] Shishkin, A., Sadygova, M., Belova, M., & Kirillova, T. (2020). Mathematical model of resource-saving production technology of baked goods with amaranth flour. *Journal of Engineering Studies and Research*, 26(3), 195-203.

[15] Pyvovarov, P., Cheremskaya, T., Kolesnikova, M., Iurchenko, S., & Andrieieva, S. (2021). Study of properties of wheat germins and meals and their use in the production of dietary hardtacks. *Science Rise*, 4, 39-47.

Динаміка міжфазової взаємодії між компонентами при перемішуванні

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Анотація. Вплив механічної дії на змішування та збивання суміші компонентів сприяє утворенню тривимірної губчасто-сітчастої неперервної структури клейковинного каркасу, бо саме він визначає еластичні та пружні властивості середовища і є актуальним у диспергуванні газу в рідині. Метою роботи було встановлення взаємозв'язку газоутримувальної здатності середовища та енергії, затрачуваної на гідратацію компонентів. Дослідами виконувалося 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 визначає значення газоутримувальної здатності. Тому прийшли 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 цієї фази означає присутність енергетичних витрат на утворення міжфазної поверхні, що повинно враховуватися в загальному енергетичному балансі. Також частина газової фази, що існувала і 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 і умови проведення змішування опари, визначені вимоги до конструкції змішувача, а також встановлено, що подача компонентів має тривати не менше 45 с. За цей період відбувається гідратація та зменшення споживання енергоресурсів. Такий підхід інтенсифікує масообмінні і біохімічні процеси в умовах термодинамічної рівноваги при відповідних зв'язках десорбції розчиненої частини газової фази та рідини, що розкриває новий спосіб перемішування та дозволяє в подальшому використовувати при конструктивних розрахунках робочих камер

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