potravinárstvo® Slovak Journal of Food Sciences

Potravinarstvo Slovak Journal of Food Sciences
vol. 12, 2018, no. 1, p. 397-404
doi: https://doi.org/10.5219/867
Received: 16 January 2018. Accepted: 2 April 2018.
Available online: 24 April 2018 at www.potravinarstvo.com

ISSN 1337-0960 (online)

GLOBAL RHEOLOGICAL APPROACH TO THE QUALITY OF THE ROLLERS PUMPING OF DOUGH

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ABSTRACT
An analysis was made of the model approximations of three-phase medium and its behavior under deformation impacts in the rollers bulk feed, the lack of reliability of their operation was noticed and regularities and reasonable geometric parameters was determined. The influence of engineering rheology on the medium was considered and on its basis was derived an analytical mechanical model for determining the optimum value of shift deformation in order to ensure reliable operation of the rollers injection mechanism. A new design and method of determining the geometrical parameters of the pumping unit rollers were proposed and the yeast dough state was examined after cyclic action of the rollers.

Keywords: three-phase medium; roller; rheology; shift deformation; dough

INTRODUCTION
Baking and confectionery industry inherent its own specificity and variety of processes. Therefore, the engineering industry produces large range of equipment for its needs, in some cases it is metal-consuming and has complex kinematics. Presence of the rollers moving operating devices that cause mechanical impact on the medium while direct contact whit it is the specific characteristics of forming equipment (FE).

Active efforts are undertaking in Ukraine and abroad on developing a new generation of highly efficient equipment for the abovementioned industry, with the usage of different designs for rollers operating devices. The main requirement for the design of such equipment is to provide feasible designs according to the customer's specifications in a short time, at a low cost and with high reliability. Industrial technology calls for the automated systems development with computer-based programmed control, which will enable prompt respond to the present requirements for durability and quality of machines operation.

The operation mediums of these fields by its composition and nature are very diverse. They can be conventionally divided into gas, liquid, solid and those containing chemicals and surfactants.

Analysis of recent researches and publications
The literature data analysis and researches on enterprises of confectionery industry shows that the quality of the rollers operation depends on the set of parameters that can be divided into the following categories:

- form, kinematics, state and geometrical parameters of the rollers;
- physical-chemical properties of the medium;
- operation conditions: the gap between the rollers, the relative compression force of the medium, the frequency of their rotation;
- features of friction in liquid electroconductive mediums.

A large number of substances in the medium, changes in their concentrations, interactions between microorganisms and presence of the stimulators, etc., lead to the relative instability of the system. Under such conditions, there is an understanding in which way the impact of certain factors should be assessed. At once it may seem that the best case should meet the maximum satisfaction or securing at the upper level impacts. However, negative results must also be programmed, for example, values of osmotic pressure, double and triple impact of factors, production quality indicators decay and so on. Even more difficult is to evaluate the impact of compositional factors. **Gorbatov (1979)**, considers that the impact of temperature can be thoroughly traced, but there is no final point of view relatively physical pressure. However, the provisions of thermodynamics closely links pressure parameters and temperature in the gas laws, Mendeleev-Clapeyron equation, Henry's law and so on **(Naschokin, 1980)**.

Design parameters of rollers affect the structural and mechanical properties of the medium, as there is viscous friction and therefore a temperature changes **(Derkach, Stadnyk and Stadnyk, 2016)**.

Forming machines rotating rollers that operate in technological mediums (dough) with constant impact of adhesion and friction forces can be considered as metal electrodes immersed in an electrolyte. They are charging relative to the solution which leads to the difference of potentials.

As friction is always accompanied by liquid mixing and such impacts as the rollers effect towards the dough is poorly investigated. Therefore, for the correct choice of their characteristics, operating under different temperatures, pressures and also for studding the nature of this process, determining the actual speed of the rheological process is of a great importance.

Analysis of model approximations of medium types

Formed dispersed gas phase consists of several components and is the one that consists of carbon dioxide and partly of the water vapor, spirit and other substances. Yet in this dispersed phase solid phase prevails, so further we will focus on the three-phase system.

Continuous synthesis of carbon dioxide, which takes place in full volume of the medium, is an important feature of the fermentation. This imposes differences in the structure of the medium, composition features of the gas-retaining capacity and, including its quantitative ratio in local areas. Such generation of CO_2 leads to the pronounced nonuniformity of concentration. Obviously, this must be accompanied by the same nonuniformity of energy potential **(Koval, 2016)**.

The assessment of rollers impact can be made on the basis of Archimedes' principle, which demonstration takes place in effecting on dispersed gas-phase. According to mentioned principle becomes possible to determine the total force effect on the medium for certain gas-retaining capacity. Considering though that this motive force accordingly dispersed gas-phase is distributed in dough array. Such feature of force action in full volume of medium with certain assumptions can be interpreted as stress and stressed states analogous. However, unlike the strength of materials concepts of stressed states here we have the feature that the medium is in a dynamic state with the violation of its integrity conditions.

In addition to the mentioned it is necessary to pay attention to another feature of phase interaction. It is known that holding capacity is determined by the value of generated gas flow which depends on the speed of bubbles floating of the gas phase. Absolute and relative speed is recognized at that. Just the relative speed, while the other conditions being, equal characterizes the resistance of bubble movement of the liquid phase in the deformed dough. Since the resistance is determined by the physical-chemical properties of the medium, it means that for each-one relative speed will be stabilized. This shows dependence, which determines the absolute speed of the gas phase:

$$w_{abs} = w_{rel} + w_{liq} ,$$

where w_{liq} – the speed of the gas phase, which it gets in the circulation circuit of the medium created between rollers.

The last depends on the geometry of the supercharger mechanism, the uniformity of flow distribution of the gas phase, transient process organization, disturbances, steady modes, etc. This is the reason to belive that the relative speed of the dispersed gas-phase for each medium is approximately constant under the conditions of bubbles size generalization. Features of physical phenomena’s in gas-liquid systems, which existence is determined by the assumptions on the basis of phenomenological considerations, lead to the conclusion about the energy potential. Since, force effects of dispersed gas-phase on the liquid and the speed of points of the force factors application are known, it enables the ability to define an integral form of the power that corresponds to the kinetic energy of reverse circulation circuit of the medium phase, which is present at the rollers operation.

We give emphasize that under the deformation CO_2 self-generation changes the velocities of fermentation of the sugar-containing raw materials which are limited by microbes natural properties. Therefore fast growth of pressures in such deformation conditions is impossible. This means limited properties of the systems for creating energy impulses. Moreover, the increase in system pressure under other factors being equal leads to the decrease of gas-retaining capacity. At first, due to physical compression of the gas phase and at the second, due to the increasing of gas solubility in accordance with the Henry's law.

Demonstrations of the energy pulses in conditions of pressure sharp decrease will differ. The difference in pressures means the transition of the system to the new parameters of thermodynamic equilibrium. Transient increase of the dough gas-retaining capacity happens due to expansion of the gas phase with its amount appropriate adjunction owning to desorption of the dissolved part of gas phase. Obviously, such transient process pertains not only to the gas phase but definitely liquid one, as the volume increase of the gas phase uniquely determines the growth of the three-phase mixture and phases shift. Its dynamics is accompanied by the inertia and thereafter pressure increase in part of its general and programmed reduction. However, such inertia-dynamic load refers only to gas-liquid mixture in the dough.

Comparison of gas-liquid systems in the dynamics with elastic systems of solids with distributed masses leads to the conclusion of their equivalence and Rayleigh principle applicability for the determination of the reduced mass of liquid phase. The availability of data on the mass of the observable system and of forces that are applied means opportunity to use Lagrange–d'Alembert principle in its modeling. Definition of the driver is related to the dynamics of pressures change.

Comparison of the systems with different technologies of dispersed gas phase formation leads to the conclusion that their response on the energy pulse disturbance will be the same as far as gas phase while pressure decrease is the generators of mechanical impact.

Formulation of the problem

Significant number of components in the medium, changes in their concentrations, interactions between them and microorganisms, the stimulants presence, etc., lead to the relative instability of the system. Under such conditions, there is an understanding in which direction assessment of the impact of certain factors should be made. At once it may seem that the best case must meet the maximum satisfaction or subsistence at all levels of impact factors. However, negative consequences must also be programmed, for example, according to osmotic pressure values, double and triple impact factors, production quality factors deterioration and so on. The impact of composition factors is even more difficult for evaluation.

However, the provisions of thermodynamics link closely pressure and temperature parameters. For instance in terms of technical availability adiabatic or polytropic process have the interest in impact on the fermented dough arrays is given by **Shynkaryk (2014)** and reasoned by **Sokolenko, Ukrainets and Yarovoi (2003)**. Due to the system compression, which is the fermented dough array, the temperature of the gas phase rises. It is clear that before the system compression temperatures of the gas phase and of the dough match. Yet, after compression the following ratio temperature is obtained:

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

for adiabatic process and

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

for polytrophic process where T_1 and T_2 – the initial and final temperature of the gas phase respectively; P_1 and P_2 – the initial and final pressure respectively; k and m – adiabatic and polytropic indices.

The energy introduced into the system at such conditions **(Naschokin, 1980)**, equals

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

M corresponds to the mass of compressible gas; R – gas constant.

Energy introduced in such way should be redistributed between the dispersed gas phase in the dough and overall temperature of the system increases.

One way of changing the free energy is the presence of the surface-active substance (SAS) in medium. High tensile stresses emerge at relevant conditions in layers which are in contact under friction. These stresses will rise while the adsorption of SAS in the technological medium and at some moment can exceed critical, leading to the formation of microcracks. The adsorption of SAS molecules cause disjoining action that contributes to the boost of surfaces deformation of the medium.

Thus, the penetration of the adsorbed substances to the deformed surface layer causes its plastification and softening, facilitates its plastic flow, and sometimes even cause tearing.

Friction in the rotating rollers medium is a pulse oscillation process, resulting in possibility of fluctuation of the deformation effects values.

Problem statement

For machines with rollers operating devices the main functions are: to make the blanks of desired shapes and sizes while ensuring form-retaining ability, dosage accuracy and quality of the products, speed and duration of deformation. For the shape and quality of the products retaining machines with rollers should ensure minimal multiplicity of the masses processing and create required pressure to provide the blanks with desired shape. Rollers surface and processing mass viscosity are of great importance for bulk supply under rollers injection. Operation low reliability of the dough make-up, kneading and moulding machines with rollers caused by poorly developed surface of the rollers, which reduces the effect of their interaction with masses. From the part of operating device significant load effects while rolling out of the mass. This makes highly viscous medium to flow between two parallel surfaces of the rollers which are very close. As a result blank is compacted and partially the product loses its quality.

Based on a thorough analysis of the processes of rollers effect on the medium it has been established that during mass drag in the volume of the injection working chamber, kinetic curve has three typical parts. Each part represents a certain period of time of the process. Dispersed systems flow curve describes the degree of equilibria destruction of the structure outta the intensity of mechanical effects in all possible range of the effective viscosity change $\eta_{ef} = f(\tau)$. Numerous experimental facts confirm that there are areas on the medium flow curves where the dependence $\dot{\gamma}(\tau)$ is linear, which means that plastic viscosity is constant**.** **Machihin (1981)** and **Nikolaev (1976)** considered that a single formula that covers all modes of flow and does not contradict the presence of linear sections on the rheological curve does not exist. There is no formula that at finite values can provide in one range linear dependence, and in another a nonlinear.

For practical purposes there is no need to build a complete flow curve, yet as a rule, limits of typical stress and deformation speed for this process is known beforehand. In general structured dispersed systems cannot be characterized only by effective viscosity value without specifying the shift speed or stress. Any real material has all the rheological properties that varies. Wheat yeast dough, depending on the size of stress, time it is applied, deformation speed may perform flexible-elastic or plastic-viscous properties respectively **(Sokolenko, Ukrainets and Yarovoi, 2003; Guskov, 1970)**.

Complexity of obtaining form of ensuring form-retaining properties of dough and defining of rational processing modes is in close interconnection between the number of factors that effect the rollers reliability and quality of the process and the product. They are:

- presence of mechanical impact on the process by the rollers, that are out of the control measurements;
- usage of the equipment with rollers operating device that constructed without consideration of structural and mechanical properties and specific properties of raw materials (semi-finished products);
- presence of feedbacks between the properties of raw materials and equipment constructive parameters, that takes place under poor control of the process proceeding;
- impossibility to effect the structural and mechanical properties of the medium during the process.

This allows to define their regularities and calculating rational parameters of separate operations. In other words it allows to assess fully the impact of constructive parameters: the working chamber and the surface of the roller under certain angel of mass drag; constructive parameters on the accuracy of the process flow and the dough properties after its flow out the clearance; rate of energy use, reliability and lifetime of machine with the rollers.

Scientific hypothesis

To discuss the parameters of the process of dough injection by the rollers and on their basis develop analytical mechanical model for evaluating the optimum values of deformation shift and geometric parameters of rollers in order to ensure reliable operation of the roller injection mechanism.

MATERIAL AND METHODOLOGY

During the course of the research, flour of the highest grade with 24.0% of gluten with excessively elastic quality (GDI 76 units) was used. The study was carried out as follows. By a commonly defined bagel production technology, a mixture of components with yeast has been prepared. Then dough was made. The resulting array of dough passed the initial stage of fermentation, after which it was divided on two equivalent parts; one corresponded to the experiment, and the other for control. Part of the control remained in the state of digestion, and the experimental sample was placed in the working chamber of the machine and was subjected to the effects of variable pressures in the range from 0.1 to 0.2 MPa with an exposure in time for 30 seconds. The number of cycles was n_{cycle} = 4, 7, 10, and 15. After the formation, a further 5 minutes extraction of the sample was performed, after which the resilience-elastic properties of both parts of the dough were evaluated. The results of the measurements are given in table. This part of the research has led to the conclusion about the positive role of the dispersed gas phase as an internal converter of the dough properties and dough blanks.

Numeric data table 2.5 interpreted in the form of dependency charts P = P (n_{cycle}), L = L (n_{cycle}), values of the parameters given in the table correspond to the average values obtained from ten measurements. The processing of measurements series was carried out according to the following sequence:

- arithmetic mean was determined;
- standard errors of a single measurement was determined;
- maximum possible error Δ of a separate measurement was determined and verification was made in order to ensure that there are no results in measurements that differ from the arithmetic mean for more than the maximum possible error Δ of separate measurements;
- standard errors of the arithmetic mean σ_0 was determined.

The relationship between the specific work consumption depends on the frequency of rotation of the rolls and the step of the ribs, which is described by the dependence:

$$A_{sp} = (157 \cdot S^2 - 151 \cdot S + 22) \cdot n^2 - (585 \cdot S^2 - 579 \cdot S + 83) \cdot n - 22$$

where A_{sp} – specific work; S – step of the ribs; n – frequency of the working body rotation.

The dependence of the specific work serves for the determination of the rational geometric parameters and rotation frequency of the working body, which will provide the quality parameters of the dough mass injection.

Tensile displacement (Pa) was determined by the formula:

$$\tau = z \cdot \alpha,$$

where α – indicators on the device scale; *z* – constant, the value of which depends on the cylinders that are used.

Dynamic viscosity (Pa·s) was determined according to the formula: $\eta = 0{,}1 \cdot (\tau/\gamma)$. For determining the dependences of the shear rate γ on the shear stress τ and the dynamic shear stress, the law of the flow of the viscoplastic medium of Shvedov, the Branopolskaya method was used.

Instruments and equipment

The research of the process of pumping and rolling of the dough was carried out on the molding machine B-58-4 of the confectionery factory (Ternopil) and the physical models were created at the department of Faculty of Engineering of Machines, Structures and Technologies (Ternopil Ivan Puluj National Technical University), it means: elastic properties of the dough were determined using the alveographer of the company «Chopin»; indicators of physical properties of the dough were determined by a rotating viscometer «Reotest-2» with two coaxial cylinders using a cylinder S2 and a full range of rotation speeds of the rotor in «AL» mode; the evaluation of tensility and strength were determined on the device for measuring the tensile dough.

RESULTS AND DISCUSSION

Dough is complex biopolymer in general and its deformation behavior under mechanical effects can be described by conventional models of rheological bodies. Thus to simplify composition of the rheological equations of biotechnological systems mechanical models (spring, sliding coupler, the cylinder with liquid and piston with holes), that emulate the basic properties just ideal bodies (elasticity, plasticity, viscosity) are used. These models can be combined, placing them in parallel, in series, in compound. The model of viscoelasticity with relaxation of the deformations (Maxwell model), viscoplastic body (Shvedov–Bingham model) and some others are the basic rheological models for dough simulation.

General mechanical deformation model of dough injection by the rollers consists of nonlinear-elastic with the elastic modulus $E_1(\sigma)$, which is ensured by the nonlinear elastic elements, the elastic with the elastic modulus E_1, viscosity η_1, which is ensured by the parallel connected linearly elastic and viscous elements. And at the same time with plastic nonlinear elastic modulus $E_2(\sigma)$, viscosity η_2 and F holder, which is ensured by consecutive connected nonlinear elastic and viscous elements with locking element attached to them. The model is mathematically described by the nonlinear rheological differential equation of the second order.

During the dough injection by the rollers when the interaction duration of rollers bodies with them is short so it does not have time to show all the features of highly elastic strain, then its modulus can be presented in the form of elastic bodies with a certain viscosity. Additionally, the deformation in the area of injection is not always proportional to the loading, as this process is influenced by internal and external friction. This is caused by plastic deformation of structural and mechanical properties of the dough and surface structure of the rollers. However, the total deformation of the process remains at current levels. The value of the model total deformation under the load of the rollers can be presented as:

$$\varepsilon = \varepsilon_n + \varepsilon_в \text{ or } \varepsilon = \sigma / E(\sigma) + \sigma t / \eta$$

where $\varepsilon_n \cdot i \cdot \varepsilon_в$ – value of the elastic and viscous deformations; σ – value of the current load (compression), H; t – the rollers operation time, sec; E(σ) та η – complex modulus of the dough elasticity and viscosity.

The viscosity of non-newtonian fluids, which include dough, depends on the speed of deformation under the stress of rollers, related to the structure and its change while flow. In its turn, the dough fluidity depends on its nature and the physical and mechanical properties: concentration, temperature, humidity, acidity, formula. The equation of the flow of the Bingham fluid is acceptable for description of the fluidity dough between the rollers:

$$\theta = \theta_0 + \eta_{pl}\dot{\gamma}$$

Where – θ strain shift; θ_0 – fluidity limit (initial value of the shift stress); η_{pl} – plastic viscosity; $\dot{\gamma}$ – shift speed.

The most credible values of the dough reological parameters obtained on practice needed to calculate dough processing equipment with rollers. Therefore, generalized model of the deformation will be equal to the total deformations occurred in the working chamber of the force unit of the machine B-58-4.

From the Maxwell's, Bingham's, Shvedov mechanical models **(Machihin, 1981)**, and the studies conducted at the place of production the mechanical model, which includes change of the medium (dough) rheology during the process period, proposed for description of dough behavior under rollers action in force unit of the molding machine (Figure 1).

For the period of discreet effect of the rollers on dough, shear stress is constantly changing. The time of deformation forces (torsion, compression, outflow) application is so short that shear stress reached instantly. At first the dough feels viscoelastic deformation (G, η), and then, when stress exceeds the boundary shear stress (BSS), it plastically deformed and starts to flow. When rollers compress the dough partial mixing of media takes place, its partial reverse motion. Therefore, it reveals itself like Bingham's body, combining elasticity, viscosity, plasticity.

Rheological equation of the mechanical model of the dough injection by the rollers may be obtained as follows.

The total deformation of the model of process equals the sum of deformations:

$$d\gamma = d\gamma_з + d\gamma_c + d\gamma_m$$

where $d\gamma_з, d\gamma_c, d\gamma_m$ – deformations of Maxwell's, Bingham's, Shvedov bodies respectively.

Differentiation of the left and right parts of the equation gives: $\frac{d\gamma}{dt} = \frac{d\gamma_з}{dt} + \frac{d\gamma_c + d\gamma_m}{dt}$ (1)

The value $\frac{d\gamma_з}{dt}$ is determined from the equations for viscoelastic relaxing Maxwell's body that corresponds to the consecutively connected models of Hooke and Newton:

$$\frac{d\gamma_з}{dt} = \dot{\gamma} = \frac{\dot{\theta}}{G} + \frac{\theta}{\eta} \quad (2)$$

While time t goes deformation increases and asymptotically approaches to the value $\dot{\gamma} = \frac{\theta - \theta_T}{\eta_{пл}}$.

Therefore, the deformation of the Bingham's body does not develop instantly; there is delay due to the admittable conditions of the fluidity (reverse motion).

Respectively, the value of deformation at the initial flow of dough through the gap between the rollers corresponds Shvedov equation:

$$\dot{\gamma} = \frac{\theta - \theta_T}{\eta_{пл}} + \frac{\dot{\theta}}{G} \quad (3)$$

The universal equation of rheological models of the dough injection by the rollers is**:**

$$\dot{\gamma} = \frac{\dot{\theta}}{G} + \frac{\theta}{\eta} - \frac{\theta - \theta_T}{\eta_{пл}} + \frac{\theta - \theta_T}{\eta_{пл}} + \frac{\dot{\theta}}{G}$$

$$\dot{\gamma} = \frac{\dot{\theta}}{G} + \frac{\theta}{\eta} + \frac{\dot{\theta}}{G}$$

The model (Figure 1) results in instant effect of the rollers on the dough while its injection. We will consider that at the time ṫ = 0 rollers get stress θ_0 and viscous deformation is equal to zero. Therefore, the deformation of the dough will be equal to elastic deformation only:

$$\gamma_0 = \frac{\theta_0}{G}$$

Given deformation does not change in time, so $\gamma = \gamma_0$ and $\dot{\gamma} = 0$. Therefore our equation will look like:

$$\frac{\dot{\theta}}{G} + \frac{\theta}{\eta} + \frac{\dot{\theta}}{G} = 0$$

Integration gives:

$$\frac{\dot{\theta}}{G} + \frac{\theta}{\eta} + \frac{\dot{\theta}}{G} = 0,$$

$$2\frac{\dot{\theta}}{G} + \frac{\theta}{\eta} = 0,$$

$$\frac{2}{G}\frac{d\theta}{dt} = -\frac{\theta}{\eta}; \Big| -\frac{dt}{\theta}$$

$$\frac{2}{G}\frac{d\theta}{\theta}=-\frac{1}{\eta}dt.$$

$$\frac{2}{G}\int\frac{d\theta}{\theta}=-\frac{1}{\eta}\int dt.$$

$$\frac{2}{G}\ln|\theta|=-\frac{1}{\eta}t+c,...\theta(0)=\theta_0$$

$$c=\frac{2}{G}\ln|\theta_0|.$$

Thus,

$$\frac{2}{G}\ln|\theta|=-\frac{1}{\eta}t+\frac{2}{G}\ln|\theta_0|,$$

$$\frac{2}{G}(\ln|\theta|-\ln|\theta_0|)=-\frac{1}{\eta}t,$$

$$\frac{2}{G}(\ln\left|\frac{\theta}{\theta_0}\right|=-\frac{1}{\eta}t,...\left|*\frac{G}{2}\right.$$

$$\ln\left|\frac{\theta}{\theta_0}\right|=-\frac{G}{2\eta}t,$$

$$\frac{\theta}{\theta_0}=e^{-\frac{G}{2\eta}t}.$$

Shear modulus G related with elastic modulus E by dependence $G=\frac{E}{2(1+\mu)}$,

where μ – Poisson's ratio, which is equal to 0.5 in incompressible liquid; E – elastic modulus. The value $\frac{\eta}{G}=T_з$ is a relaxation period. At t = 0, $\theta=\theta_0$ and at t $=T_{rel}=\frac{\eta}{G}$ $\theta=\frac{\theta_0}{e}$, in other words the relaxation period in the dough where the stress drop on e times.

Mechanical rheological model of the dough injection by the rollers and its mathematical formulation is required not only for the objective assessment of the dough consistence in a short process, but to evaluate its behavior at all stages. In this context we will analyze current process according to the rheological model of the dough injection by the rollers.

Geometrical parameters of the rollers medium supply unit determination

The above materials focused by most on biochemical and thermodynamic transformations related to different schemes of dough preparation with its further deformation. Initial conditions of the dough characterized by values of 28 ±2 °C, and 30 ± 2 °C in case of formation. Accurate performance of the kneading while formation is of a great importance. This partially removes carbon dioxide and other fermentation products. While this, the conditions of vital activity of yeast improves, their fermentation activity and elasticity of the medium increases. Kneading is absolutely necessary when processing strong flour and also flour with short jagged gluten.

Mentioned actions for technologies of dough blanks forming are the basis of structural and mechanical properties of elastic or plastic-viscous characteristics of dough. Last affects the stability of blanks shape during maturation and baking and also determines the volume yield of products and quality of crumb structure **(Drobot, 2002)**. Formation of the dough and products indicated properties depends on many factors, mainly on the geometry of the rollers and the ratio of flour polymers, the state of its protein complex and the dough receipt. These stipulate the products output volume and quality of their structure.

As was noted before, the dough by its properties corresponds to elasticity of solid and simultaneously, liquid as to the fluidity (spreading) characteristic. Correlation of these properties is determined by the composition and state of polymers – starch, protein, cellulose, that hydrating with the presence of water and form a colloidal system, and also by the low-molecular compounds of sugars, fats, amino acids, etc. Dough elasticity hinders volume growth, but contributes in keeping accurate form of already made blanks. Dough flexibility causes forming of the foam like structure.

The research using alveograph determined that additional dough treatment by the swaying rollers before its loading

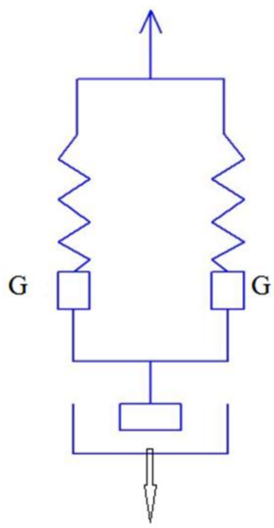

Figure 1 Rheological model of the dough injected by the rollers.

into the working chamber and the operation of the rollers unit itself effects the deformation of the dispersed phase. Under the impact of alternating pressures (compression of the medium) resilience and elasticity of the dough are improved, specific energy consumption on its deformation increases. Thereafter structural and mechanical properties of the dough that depends on the number of processing cycles improves.

The data in Table 1 indicates positive role of the dispersed gas phase as the internal converter of dough properties and also the dough blanks. Numerical data in Table 1 are interpreted in the form of dependences $P = P (n_{cycle})$, $L = L (n_{cycle})$, $P/L = P(n_{cycle})/ L (n_{cycle})$, $S = S(n_{cycle})$ and graphs (Figure 2).

Among the key requirements of the moulding machine with rollers operating devices are system performance conformity, reliability, maintaining of the nominal temperature parameters, medium flow velocity, limited foaming, etc. The rollers geometry selection focuses on some features and extra requests. Thus to the important requirements one can refer minimization of power consumption, the material quantity for rollers manufacturing, reliability of the whole process. Therefore, these factors meet equality in diameter and length of the grooves of the cylindrical roller. In this case it is obvious that the minimum consumption of the material should meet

Table 1 Resilience-elastic properties of the dough with additional mechanical processing.

Number of processing cycles	Resilience, P, mm	Tensility, L, mm	P/L	Alveogram area, S, cm^2	Specific work of the deformation, $W \cdot 10^4$, J
Control (without processing)	85	68	1,25	36.4	238.06
$n_{cycle} = 15$	105	88	1,193	48.4	316.54
$n_{cycle} = 20$	117	99	1,182	66.4	434.3
$n_{cycle} = 25$	133	120	1,108	83.4	545.4
$n_{cycle} = 30$	146	135	1,082	94.2	616.1

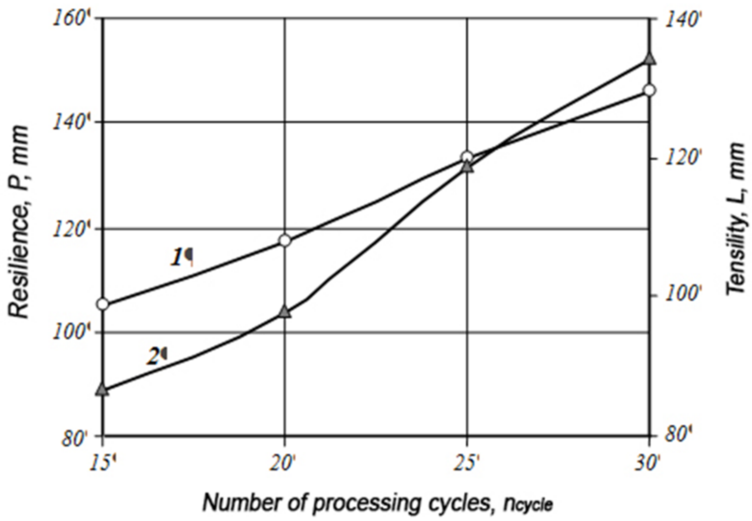

Figure 2 The graph of $P = P (n_{cycle})$ (1) and $L = L (n_{cycle})$, (2) dependences form the number of processing cycles.

Figure 3 New Spiral roller working body design.

the minimum surface area under other equal conditions while the given conditions of quality injection are kept. The mathematical correlations between the surface of the roller S and its volume V, for a cylindrical one:

$$S_в = \pi dl + \frac{\pi d^2}{4};$$

$$V_в = \frac{\pi d^2}{4} l$$

where d and l – diameter and length of the roller respectively.

In case we accept the terms of the surface minimization l = d, then inserting this into the equation and taking into account the usable area of the roller, the equation can be re-written as:

$$S_в = \pi d^2 + \frac{\pi d^2}{2} = 0,35\pi d^2;$$

$$V_в = \pi d^3,$$

Hence the expected conclusion is made that the rollers surface is proportional to the square of its size and the volume – to the cube of the size. Their relation can be defined as:

$$S_в / V_в = 0.35/d.$$

The analysis of the equation makes possible to establish that the specific surface area (surface area that refers to volume) dramatically decreases according to the hyperbola formula which is displayed by the following ratio:

D	0.1	0.15	0.2	0.25
$S_в / V_в$	3.5	2.3	1.75	1.4

CONCLUSION

Thus, increasing of the geometric parameters d eventually could lead to the inability to stabilize the injection, and this will change the structural and mechanical properties of the medium. Our studies confirm earlier determined geometrical parameters of the molding machines rollers with diameters of 160 – 200 mm. In dough make-up units rollers diameter may vary depending on the design of injection chamber, indexing head. Thus, the design parameters affect the structural and mechanical properties of the medium, as there is viscous friction and therefore a temperature changes. This enabled the development of the rollers new design, which will be explored in further studies.

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