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ADHESION EFFECT ON ENVIRONMENT PROCESS INJECTION

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ABSTRACT

The analytical analysis of roller impact on the medium and its behavior at deformation influences are carried out, ways of choosing an optimal variant of the process for providing the maximum or minimum value of parameters (criterion) are proposed. The physical essence of the equation of energy flows of the intensity of deformation of the mass of the medium, which depends on the method of applying mechanical forces, the degree of its previous dispersion (recipe) and its physical and mechanical properties, is considered. To reveal the essence and understanding of the general research execution, a number of hypotheses for the determination of adhesion are given and a generalized approach to the definition of adhesion is given. The proposed scheme of causal relationships between the medium and roll, divided into three groups, and determine the change in the process of injection dough. The nature of the maximum increase of the forces of interaction of the dough with the high contact of the roller working body in the injection nozzle of the fuming machine is established. Violation of these mutual relations leads to the production of low-quality products and a decrease in the efficiency of the machine. These phenomena are little studied today, and the nature of adhesion requires research. It is noted that the determination of deformation processes during the passage of the process of injection of the medium by roller working bodies plays an important role in calculating the design of molding, roll-over equipment. The deformation in the knot of the injection dough by rolls and the dependence of the work performed on the influence of adhesion on the flow process in the molding machine are revealed. The contact area of the adhesive and the component forming work for overcoming the adhesion and deformation of the environment in determining the criteria that influence the process, according to each particular period of the deformation stage, are substantiated. The obtained data provide an answer to a number of questions about the possibility of regulating the process of the work of agents on the environment.

Keywords: dough; adhesion; adhesive; substrate; forming channel; deformation; stress

INTRODUCTION

Improvement of the technology of pumping, injection, mixing, separation, formation of the environment (non-Newtonian fluids) and the creation of high-performance technological equipment is an actual scientific task. Therefore, the development and calculation of new processes and equipment requires a thorough and comprehensive study of the impact of the most significant physical and mechanical properties of semi-finished baking and confectionery industries. A significant adhesive property of the environment significantly complicates the process and causes additional energy costs. This direction is given insufficient attention; therefore, the physical nature of adhesion is still not fully explored.

Adhesion refers to surface phenomena that arise when contacting heterogeneous bodies. There are different approaches to the definition of adhesion. According to the theory **(Believ, Egorenkov and Pleskachevsky, 1971)**, they can be divided into three groups:

- determination of adhesion as a process (gradual change of state);
- definition of adhesion as properties that characterize the feature of this system;
- definition of adhesion as a state (external and internal circumstances that characterize the state of the system).

Determination of adhesion as a process was given by Rebinder PA: "Adhesion (adhesion) - the appearance of a connection between the surface layers of two heterogeneous (solid or liquid) bodies (phases) that touch each other. A similar definition was given in some other sources **(Berlik and Basik, 1969; Deryagin, 1963; Li, 1979)**. That is, adhesion is interpreted as a process of convergence and removal of bodies from one another.

Often the nature of adhesion is explained by diffusion and electric theory. Adhesion is always the result of the intermolecular interaction of surfaces, different in nature.

According to this theory, with the contact of two bodies due to the Macrobroun motion, there is a rearrangement of the molecules. This occurs in such a way that large particles of molecules approach the contact surface, establish hydrogen bonds with the same molecules or with the polymer groups of the contacting body. This causes an adsorption bond in equilibrium. The influence of pressure and temperature during their increase contributes to the fairly rapid establishment of equilibrium.

In the food industry, there are many processes in which both the forces of friction and adhesion interact simultaneously. These phenomena arise when the relative displacement of the contacting surfaces of two bodies. In studies **Deryagin (1963)** established the connection between the aunt and the adhesion of the expression:

$$P = \mu N + \mu p_0 S_0$$

Where:
μ – actual friction coefficient; S_0 – contact area, m^2; N - normal load, N; p_0 – specific adhesion at the site S_0, Pa; P – external friction force, N.

The author **(Pawel et al., 2016; Stadnyk, Novak and Matenchuk, 2018)** revealed the properties of a dough for the production of bagels, which has elastic, viscous and plastic properties, that is, refers to elastic - visco-plastic bodies. Accordingly **(Gorbatov, 1979; Zimon and Yevtushenko, 1985)** noted that the adhesion of such bodies, as well as the cogenesis of particles, fluids and films, depends on the area of contact of the medium (adhesive) with the rough metal working surface of the machine.

Summarizing the above theories, we can conclude that adhesion is caused by a number of mechanisms that act on the molecular and supramolecular levels and are determined by the properties of these surfaces: physical, chemical or electromagnetic.

By the value that evaluates (determines, measures) adhesion, as a feminogenic phenomenon, a force is adopted that is defined as the force applied perpendicular to the sample, acting on a unit area and sufficient to separate it from the surface:

$$P_a = P/F_0$$

Where:
P – specific power N.m^{-2}; P_a – normal power, N; F_0 – contact area, m^2.

In this case, it is advisable to speak of adhesion strength. When separating structured masses, adhesion strength comes into competition with the cohesive strength of the mass. At tearing away the deformation and flow of the mass itself, determined by the rheological properties of the product itself. That is, it can be adhesive, cohesive and cohesive-adhesive type.

The dependence for the determination of the adhesion force was determined by M. Stefan **(Gorbatov, 1979)**:

$$P = \frac{2\eta R^2}{4\tau_0}\left(\frac{1}{h^2{}_1} - \frac{1}{h^2{}_2}\right), \quad (a)$$

Where:
R – skradius, m; $\boldsymbol{\tau_0}$ – time off (disk difference) from a distance $\mathbf{h_1}$ to $\mathbf{h_2}$, c; $\boldsymbol{\eta}$– fluid viscosity, Pa.s.

If the "adhesion" or the "force of adhesion" is evaluated by dependence (a), then such a process takes place in time, that is, adhesion is evaluated as a process that must be performed for sample discontinuation, and the distance of disc diffusion (h1 and I12) can characterize the phenomenon of cohesiveness.

Finding new ways to reduce adhesion is possible only after studying the physical nature of this phenomenon. Adhesion arises from adsorption of medium molecules (dough) on the surface of the working organ in the thinnest (up to 20 nm) surface layer. At the same time, these molecules are related to the main volume of the medium. Therefore, at all stages of the action of the roller working body on the relative displacement, the environment molecules that are adsorbed on its surface, rotate with it (Figure 1). If the forces of the intermolecular compound in the medium become weaker than the adsorption forces, then the rupture of its mass passes at a distance from the surface of the roll. Such phenomena occur in the period of tightening, compression and rolling of the medium in the formation gap formed between the rotating rolls.

Consequently, adhesion depends on the rheological properties of the medium at the time of the process, the degree of surface treatment of roller working bodies, the thickness of its layer. Investigation of the influence of physical and rheological properties of the environment and the structural features of cylindrical rolls with grooves on improving the quality of products at injection - the problem is relevant and needs to be solved in mathematical dependencies.

Figure 1 Photo of the effect of adhesion on the quality of the dough forming on the surface of an existing roll with straight grooves. Note: 1 – roll; 2 – remnants of the adhering dough after pouring; 3 – bunker with dough.

Analysis of model approximations of medium types.

Processes in the working chamber under the action of rollers occur with different effects on the environment. This process is accompanied by large deformations, which is facilitated by the profile of the roller surface and the design of the working chamber. Special attention in the study of the process of injection of rolls focuses on creating favourable conditions for tightening and compressing the environment.

For roller working valves in the injection nozzle of a fumiving machine, the maximum increase in the forces of the interaction of the dough with the high contact of the roll is characteristic. Violation of these mutual relations leads to the production of low-quality products and a decrease in the efficiency of the machine. These phenomena are little studied today, and the nature of adhesion requires research.

There are several hypotheses to determine adhesion:

- in accordance with Absorption theory Debrajina and Mc-Laren **(Berlik and Basik, 1969)**, adhesion is related to the action of intermolecular forces: physical, van der Waals or chemical, for example, covalent ion .;
- according to electrical theory B. Deryagina **(Deryagin, 1963)** - adhesion is connected with the difference in potentials on the boundary of heterogeneous bodies, that is, with the appearance in the contact area of a kind of electric molecular capacitor, caused by a double electric layer;
- according to the electromechanical theory, adhesion is associated with electromagnetic interaction, that is, with the emission and absorption of electromagnetic waves by atoms and molecules, which can be realized in condensed bodies;
- in accordance with the diffusion theory S. Vosotsky and B. Deryagin's **(Berlik and Basik, 1969)** adhesion is associated with the diffusion of ends of macromolecules through the boundary of the initial contact, resulting in the boundary (finite) case, the interface of the phases may disappear;
- according to the mechanical theory, adhesion contact is formed due to the mechanical adhesion of molecular and supramolecular formations with microniveness of the surface;
- according to the thermodynamic theory, adhesion is associated with a surface tension, which, according to the theory **(Wake, 1982)**, causes the solid-body solid-liquid surface to replace the solid-liquid interface.

In his writings **Zimon and Yevtushenko (1985)** gives preference to intermolecular interaction and partly to the Coulomb force, which determines the primary formation of the relationship between two surfaces. The forces begin to act in direct contact and a certain period after the violation of the contact.

The second group of forces, unlike the first one, manifests itself only when two bodies are contacted. These forces act as a result of primary adhesion and become one of its causes. This group includes chemical bonds, forces of electric and capillary interaction, as well as adsorption and diffusion, which are the result of contact.

With adhesion of liquid and elastic-plastic food masses, a chemical bond may occur.

To a large extent, the adhesion of the food mass depends on the presence of moisture, which can manifest itself as a capillary force.

In the gap between the contacting parts there is a meniscus of fluid. In this case, it seems to charge the particle and the surface. The value of adhesion in this case will be determined by the capillary force:

$$F_K = 4\pi\sigma_{ж}r$$

Where:
$\sigma_{ж}$ - surface tension of a liquid (water), the vapor of which is condensed between the contacting bodies.

In a liquid medium, the adhesion of the parts is less than in the air **(Zimon and Yevtushenko, 1985)**. In this case, there is a disjoint action of the thin layer of the liquid, which is on the surface of the bodies.

Among the components of the viscous medium (dough), the greatest energy of adsorption to metals is water. If it is removed from the surface of the semi-finished product, the adhesion should be reduced. At the same time, the intensity of evaporation of the surface moisture should be very large, so that the resulting thin moss on the surface of the environment prevented the removal of moisture from its volume. Such conditions can be obtained **(Stadnyk et al., 2018)** only at very high velocities - the leakage of the medium under pressure through the opening of the profile channel formed between the rotating rolls. Based on the properties of the viscous medium and the deformation of the rolls, a number of new designs of roller working valves have been proposed **(Derkach, Stadnyk and Stadnyk, 2016)**. Interestingly enough is the detection of the action of the surface of the new working body with screw grooves (Figure 2) on the adhesion properties of the medium.

In the course of the forced flow of the medium layer under the action of roller working bodies, there is a temporary slip on them at a speed. In the future, when the surface layer is squeezed and its slip on the surface of the roll, the medium layer is sealed, and the alignment of the structure takes place. This layer acquires increased gas- and form-retaining ability and penetration of water molecules (diffusion) into it inside with swelling and volume increase.

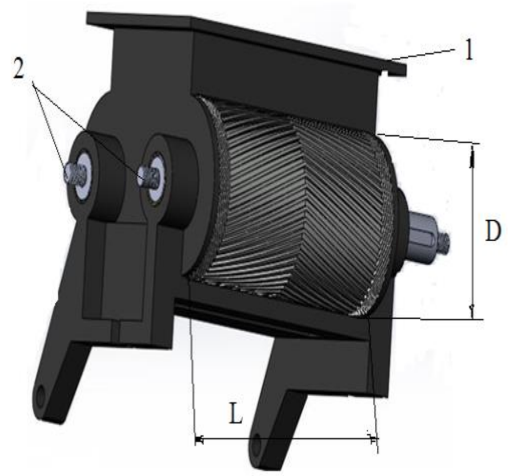

Figure 2 Nominal injection of molding machine. Note: 1 – working chamber; 2 – roller working bodies.

For even sealing and moving the mass of the medium along the surface of the roller working bodies, a gap is established between them, which regulates and smooths the resulting deformation. These deformations depend on the type of environment and requirements for finished products. Therefore, the velocity of the displacement of the medium layer on the surface of the rolls will be practically equal to its velocity. Accordingly, slipping on the surface of the rolls cannot be considered even because the surface has been loose.

Scientific hypothesis

Systems for moving the dough layer between the rollers are important components of the molding machine, which provide the role of its transportation to molding devices. The limited allowable loads of the dough require the creation of specific conditions for the synthesis of systems "roll-dough", forbearing and guiding elements and leading roller working bodies for the use of adhesion forces (measured in H) and friction in the role of forces of forces and forces of resistance. In this regard, in the interest of optimized synthesis, information is needed which relates to the phenomena and characteristics of adhesion, the possibilities of its transformation in kinematic pairs both in the direction of increasing and in the direction of reduction. Varieties of the dough with its features relate to other mechanical parameters and coefficients of friction. At the heart of interactions between rolls and the environment it is seen that they correspond to the laws of friction of Amonton-Coulomb, Euler's ratio, the concept of angle and friction cone, radius and friction wheel, reduced coefficient of friction. In turn, the wording of these concepts and definitions refers to such universally accepted assumptions and concepts of mechanics as the resultant forces of gravity, the resultant distributed forces of normal pressure, the resulting force of adhesion, the center of masses, the geometric center of contact surface, etc. In the technologies of calculations and definitions of the parameters of the systems there are regularities of statics and dynamics and the principles of independence of the forces of activity, of additivity, of Lagrange-Dahmberm.

In search of solving research tasks, simulation was carried out to assess external influences on reactions and responses of local area systems based on mathematical formalizations and with the formulation of computational experiments. The mathematical model of the forces of the adhesion factor of influence, which, unlike the coefficient of friction, acts with a stabilized value is proposed. It is important that this applies to ensure that no hitching is carried out when dragging the dough. Modified theoretical dependencies allowed to carry out the calculation of two-level experiments to create prospects for deepening the possibilities of generation of increased motive factors. Since the angle of coverage α acts as an important variational factor of influence, on the basis of analytical developments a computational experiment was carried out, in which the response function adopted the value of the specified angle. The structure of the dough leads to the need to consider the values of the coefficients of friction. Manifestations of non-isotropy with respect to the orientation of structures take place at the levels of molecular construction in the responses to the value of the coefficients of friction. The corresponding regression equations are obtained.

MATERIAL AND METHODOLOGY

A dough with a moisture content of 33%, for high quality wheat flakes on pressed yeast, was prepared in an opaque manner with a fermentation time of 60 minutes at a temperature of 32 – 33 °C. The quality of the pressed yeast corresponds to the DSTU. Characteristics of wheat flour:
• mass fraction of moisture,% – 14.5;
• the content of raw gluten,% – 28;
• resistance gluten compression on the device IDK-1, per.pril. – 54;
• gluten stretch, cm – 14.

The study of the dough injection process was carried out on the molding machine B-54 of the confectionery factory (Ternopil). It is known from work **(Zimon and Yevtushenko, 1985)** that the adhesion is determined by separating the medium from the surface, measuring the separation effort. In this effort, the adhesion resistance of the medium is calculated. Therefore, the adhesiveness of the Fvd (equal to the ratio of the fracture effort of the Fvd model to the area of the nominal contact Shk) depends on the size of the surface and adhesion, the conditions of contact and the separation of the dough. Adhesion was seen as a process that occurs in time when the surfaces of two heterogeneous bodies come into contact or are violated. For the quantity that quantitatively evaluates the adhesion, the work of the separation (strength) and the unstable process of filling the medium (dough) of the groove surface of the roll at the pressure of the previous loading Pk were used.

At the same time, determination of indicators of physical properties of the dough was carried out. The visco-plastic properties of the dough were determined using a rotating viscometer "Reotest-2" with two coaxial cylinders, using a cylinder S2 and a full range of speeds of rotation of the rotor in aI mode. Tensile displacement τ (Pa) was determined by the formula:

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

Where
α – indicators on the scale of the device;
z – constant, the value of which depends on the cylinders used.

Dynamic viscosity η (Pa.s) was determined by the formula:

$$\eta = \frac{\tau - \tau_0}{\dot{\gamma}}$$

In order to determine the dependences of the shear rate on the shear stress and the dynamic shear stress, the law of the flow of the visco-plastic medium of Shvedov, the Branopolskaya method was used.

The force of pressure on the surface of the plasticizer was determined by registering its displacement using a computer with the integrated program "Power Graph" as a personal recorder, which signals were fed from the built-in resistor as sensors and recorded through the input device with an illustration on the monitor. The program and a guide for its use can be downloaded at www.powergraph.ru (free working version 2.1). Minimum requirements for installing the program: operating system - Windows (98, ME, 2000, XP, Vista); operating memory - 32 MB; free hard disk space – 50 MB. To record signals in the PowerGraph program, you must pre-select the appropriate ADC driver (for example, a Joystick).

RESULTS AND DISCUSSION

Cragelskii noted that in the process of friction of two bodies at different points of contact can simultaneously be five types of fractional connection. These bonds include: cutting, plastic pressing, elastic deformation, adhesion and cohesive destruction. Relying on this theory, most inventors argue that there are two components-adhesive and deformation. Moore proposed the force of friction to determine the equation:

$$P = P_а+P_д+P_к+P_в$$

Where:

$P_а$ і $P_д$ – adhesion and deformation component of frictional forces, N; $P_к$ – cohesive component, taking into account wear on volumetric losses, N; $P_в$ – component of viscous braking in the presence of lubrication, N.

The phenomena of adhesion in the first stages of injection (delay) are explained by the theory of adsorption and diffusion, that is, the adsorption actions (van der Waals forces) on the surface of the roll. Thus, for the proper observance of the injection modes it is necessary to measure and control the adhesion forces. In this case, it is necessary to determine the strength of adhesion, modeling the conditions for the formation of adhesive forces in the working chamber of the machine, considering both the type and condition of the surface, as well as the structural and mechanical properties of the dough.

Consider the process of rolling the medium (dough) between the rollers (Figure 2). When rolling rolls of cylindrical shape, the thickness of the medium is constantly changing in the middle part of the formation, that is, in the zone of clogging. On the output of the rolls - the thickness is the same. All cycles of rolling the curved surface rolls occur without changing the gap of the middle part of the rolls from capture to capture. This allows you to smoothly effect the compression and shift of the dough with the achievement of the entire surface of the formation of the same thickness. Rolls of the same diameter are rotated with the same angular velocity ω, radius R, in length L. The working surface of the rollers is between the gaps h0 and h_1. Where: h_0 – distance between surfaces of rolls in the presence of medium; h_1 – the minimum clearance between the rollers.

When pressed, the dough is compressed, resulting in the thickness of the layer decreases, and its length and width increases. The difference between the incoming h_0 and the final one $h_1$the thickness of the dough layer will be absolute compression:

$$\Delta h = h_0 - h_1 \text{,mm;}$$

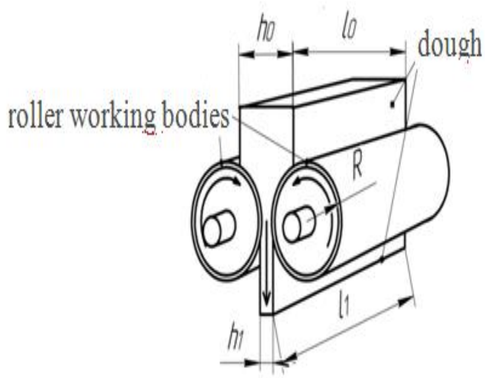

Figure 3 The scheme of rolling the dough.

The difference between the final one$l_1$and the initial one$l_0$the width of the dough layer is the absolute width:

$$\Delta l = l_1 - l_0 \text{, mm;}$$

The value of the deformation of the dough layer during the injection is characterized by the following indicators (coefficients):

relative compression - the ratio of absolute compression to the original thickness of the layer:

$$\varepsilon = \Delta h / h_0, \text{ and } \varepsilon = (\Delta h / h_0) \cdot 100\%$$

compression ratio - the ratio of the input thickness to the final:

$$\varepsilon_K = h_0 / h_1$$

coefficient of stretching of the dough between the rolls - the ratio of the input length of the layer –$l_0$to the original lengthl_1:

$$\zeta = l_1 / l_0$$

Since the volume of the dough when sprayed rolls change, then$h_0 l_0 < h_1 l_1$, where:

$$\zeta = l_1 / l_0 = F_0 / F_1$$

Thus, the length of the layer during rolled rolls increases in proportion to the reduction of its cross-section. The coefficients of compression, stretching and expansion characterize the height, longitudinal and transverse deformation of the dough.

The volume of the dough is limited by the arcs of the capture, the lateral faces of the layer and the plane of entry of the dough between the rolls and its exit, is a deformation zone. On the basis of dependencies, one can establish regularities and calculate the rational parameters of individual operations. That is, thoroughly evaluate the influence of the design parameters of the injection nozzle. These parameters mainly include: working chamber and roller surface; diameter and angle of tightening of the mass of the test; properties of the dough after pumping and forming; specific energy consumption; reliability and duration of the machine's operation.

So, the length of the deformation zone:

$$l = \sqrt{R\Delta h}$$

This zone is constantly in contact with the weight of the dough and, accordingly, the component of adhesion.

Obviously, in some cases, the search for geometric bindings to ensure the specified angles of roll-to-roll coverage can be significantly simplified if the initial synthesis of process equipment is resolved. However, the instability of the values of adhesion and external conditions of operation of roll systems, as well as variations of physical and mechanical parameters dough, lead to the need to search for non-standard approaches to provide the specified kinematic parameters of their displacement. The situation associated with the injection of a dough with limited strength parameters is complicated by significant initial dough masses, peculiarities of feeding and pumping mechanisms, and others like that.

The theory of frictional interaction of the dough with the supporting moving elements of the system was created on the basis of the assumptions about the limited resistance in bending deformations, compression, torsion. The transfer of the dough movement between the rotating rollers is provided by the forces of adhesion and friction that arise between them as a result of their contact. The forces of adhesion, distributed over the arc of coverage, primarily depend on the arcs of coverage, preliminary tightening (tension) and coefficients of friction.

The study of the phenomena of adhesion of the dough with rolls is conditionally divided into two cases: the dough moves along the surface of the cylindrical roll, and when there is no complete relative slip. Both of these occur in systems of transportation and use of viscous materials, the properties of which are limited to the resistance to bending, compression and torsion deformations. Let's dwell in more detail on the relations between the power parameters of the "roll-thistle" system Figure 4. This case corresponds to the system for changing directions in the trajectories of moving the dough or for creating and stabilizing the resistance during displacements and tightness (tensions) at individual sites.

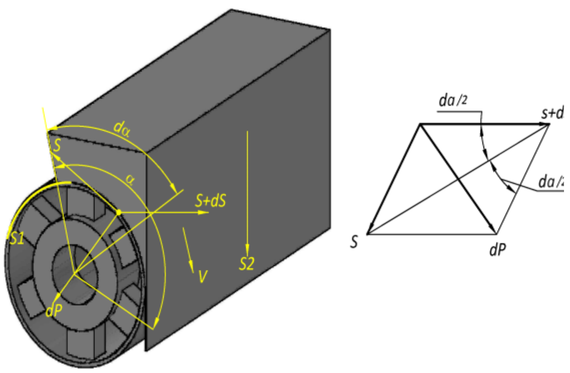

Figure 4 Scheme for extension of determining the force parameters of the roller-dough system.

We accept that a dough on a roll of a given quantity during transportation does not deform, and its speed of slipping V = const. The weight of this dough and its centrifugal force are neglected. If necessary, overcome the strength of adhesion F_{ad} we have:

$$s2 = s1 - F_{ad} \text{ and so}$$
$$F_{ad} = s2 - s1 \quad (1)$$

In the scheme dα and α, respectively, the elementary and full angles of coverage, s and s + ds-tightening (tension) of the dough. Then the elementary force of adhesion dF_{ad} will be:

$$dF_{ad} = (s+ds)-s = ds \text{ and } dFad = fdP \quad (2)$$

Where:
dP – the elemental force of the pressing, which is determined by the known forces s and s + ds.

If you ignore the values of the second order and replace the parallelograms with the diamond with sides s, then

$$dP = 2s\sin d\alpha/2 = 2sd\alpha/2 = sd\alpha \quad (3)$$

Then, considering the equations (2), we have:

$$ds/s = fd\alpha \quad (4)$$

By integrating the left and right parts of the condition (4) in the range from s_1 to s_2 and, respectively, from zero toα, wil have:

$$\int_{s_1}^{s_2} \frac{ds}{s} = \int_0^{\alpha} fd\alpha \ \ln\frac{s_2}{s_1} = f\alpha \quad (5)$$

$$\text{So } s_2 = s_1 e^{\alpha f} \quad (6)$$

Then, taking into account condition (1), write:

$$F_{ad} = s_1(e^{\alpha f} - 1) \quad (7)$$

Force F_{ad} is the greatest force that can be transmitted. The distributed adhesion that acts on the dough is equal to the difference s_1 and s_2, that is:

$$F_{ad} = s_1 - s_2 = s_2(e^{\alpha f} - 1) \quad (8)$$

The value of s_1 must be matched to the allowable load of the dough from the tensile strength and at the same time:

$$[s_1] \leq [\sigma_0] f_0 \quad (9)$$

Where:
$[\sigma_0]$ – permissible stress, Πa; f_0 – the area of its cross-section, m^2.

The condition of the transfer of motion from roll to dough is determined by the size of the angle of coverage $[\alpha]$

$$[\alpha] \geq \frac{\ln \frac{s_1}{s_2}}{f} \geq \frac{\ln \frac{[\sigma_0] f_0}{s_2}}{f} \tag{10}$$

Under the action of rollers, the force of adhesion is partially reduced due to the action of centrifugal forces. Given the last correlation between the power parameters get the form:

$$s_1 = F_{ad} \frac{e^{f\alpha}}{e^{f\alpha}-1} + \frac{qv^2}{g} \tag{11}$$

$$s_2 = \frac{1}{e^{f\alpha}-1} + \frac{qv^2}{g} \tag{12}$$

$$F_{ad} = (s_1 - \frac{qv^2}{g}) \frac{e^{f\alpha}-1}{e^{f\alpha}} \tag{13}$$

Where:
v – velocity, $m.s^{-1}$;
q-is the weight of the flexible element, $kg.m^{-1}$;
g – acceleration of free fall, $m.s^{-2}$.

The given theoretical dependencies in their totality allow to carry out the calculation two-level experiments, which will create prospects for deepening the possibilities of the transfer of motion and in systems with frictional connections with quantitative estimates of the effects of various factors on the original value. The importance of the latter is related to the need to improve and optimize the systems, because even in the presence of mathematical formalization of processes or phenomena in the presence of several factors of influence the direction of finding their optimal relationships remains unknown. Object optimization refers to a set of values of control parameters that ensure the achievement of extremes of the output value and the comparison of the significance of the factors of influence.

The set of mathematical formalizations in the work allows to carry out planning of computational experiments with number of factors from two to four with reception of various functions of the response, using obtained mathematical formulas at the level of algorithms of calculations in direct application or their combinations. In the first approximation, we turn to formula (7), in which the response function is represented by the force of adhesionF_{ad}, and among the factors of influence, let's draw a tension s1 dough, angle of coverageαand the coefficient of friction $f_{тз}$. Landmark when selectin GAvalues 1 should BEAvalues 1 max, which is determined by the cross-sectional area of the test and the permissible stress$[\sigma_0]$in its stretching load and at the same time:

$$s_{1\max} \leq [\sigma] b\delta \tag{14}$$

Where:
b and δ – respectively, the width and thickness of the dough, m.

Due to the fact that there is a two-level experiment, each of the factors acquires two meanings: the upper X and the lower Xin are equal. Since the planning and processing of experiments are performed not with physical but with encoded values, then we define coded changes xi :

$$X_i = \frac{X_i - X_i^0}{h_i} \tag{15}$$

Where:
X_i^0 – the main factor level;
hi – the interval of its variation.

If the quotient space is bounded by the upper X and lower Xin, then the interval is called half the range in which the factor changes:

$$h_i = \frac{1}{2}(X_{ib} - X_{in}) \tag{16}$$

and the main factor level:

$$X_i^0 = \frac{1}{2}(X_{ib} + X_{in}) \tag{17}$$

For a two-level experiment, each factor varies in two levels Xi and Xin, so the coded values of chi will have only two values: -1 and +1.

In accordance with condition (14) we will accept S_{iB} = S1max and S_{iH} = 0,8S_1max. So

$$s_i^0 = \frac{1}{2}(s_{i\max} + 0.8 s_{i\max}) = 0.9 s_{i\max} \tag{18}$$

and the variation interval is:

$$h_i = \frac{1}{2}(s_{i\max} - 0.8 s_{i\max}) = 0.1 s_{i\max} \tag{19}$$

Table 1 Experiment conditions.

Size	Factors		
	S_1,H	**α, rad**	**f**
Code mark factor	X_1	X_2	X_3
The main rye, N.	0.9 $s_{1\max}$ = 2250	2.617	0.3
Variation interval, n	0.1 $s_{1\max}$ = 250	0.523	0.1
Lower level, N	$s_i^0 - h_i = 2000$	2.093	0.2
Upper level, N.	$s_i^0 + h_i = 2500$	3.13	0.4

Table 2 The matrix of planning a three-factor.

Number experience	Factors				Function feedback
	X_0	**X_1**	**X_2**	**X_3**	
1	+	-	-	-	3039
2	+	+	-	-	3799
3	+	--	+	-	3747
4	+	+	+	-	4684
5	+	-	-	+	4619
6	+	+	-	+	3774
7	+	-	+	+	7220
8	+	+	+	+	8777

Accordingly, we will accept:

$$\alpha_i^0 = 150^0 = 2.617 rad$$

$$\alpha_в = \alpha_i^0 + 30^0 = 180^0 = 3.14 rad$$

$$\alpha_н = \alpha_i^0 - 30^0 = 120^0 = 2.093 rad \qquad (20)$$

The basic factor of the coefficient of friction will be adopted f = 0.3, variation interval $f_\alpha^0 = 0.1$.

Sofв = 0.4 and fн = 0.2

The results of factor coding are listed in Table 1. The matrix of planning a three-factor experiment is presented in Table 2. The X_0 column is required to calculate the coefficient b_0. For three factor experiments, the regression equation has eight unknowns and, accordingly, the matrix of planning has eight experiments N.

Matrix of planning in Table 2 is supplemented by a column in which the results of calculations of the response function are entered. To determine the values of s1max we turn to the value of the permissible values of the stresses of the dough. For a yeast dough for strawberries, the allowable stress for stretching is 40 – 50 MPa. We will accept the thickness of the dough δ = 0.125 m, and width b = 0.5 m. Then the cross-sectional area of the film is A = 0.0625 m^2 and per allowable stress for stretching [σ]p 40 MPa.

The next step involves defining the coefficients included in the regression equation. The experimental data array was processed using the application package "Statistica-12" for the computer. The coefficients of the regression equation or approximating function, provided the orthogonality and symmetry of the plan matrix of the planned factor experiment, were determined according to the standard method for known dependencies. The regression equation has the form:

$$y = -5095.9 + 0.29X_1 + 2632.05X_2 + 9130.19X_3$$

At the probability level p = 0.95 and the t-alpha criterion value of 2.365, the following statistics were obtained (Figure 5): the coefficient of multiple determination *D* = 0.842; coefficient of multiple correlation *R* = 0.917; standard deviation of estimation *s* = 0.802; Fisher's *F*-criterion is 7.087. Coefficient *D* is significant with probability *p* = 0.92863.

Graphic representation of the change in the adhesion strength of the dough according to experimental data (Figure 6), that is, the surface of the response of the functional change of the strength of adhesion of the dough as a functional

$$F_{ad} = f(f_T, \alpha)$$

It follows from this that all factors of influence are important in terms of the interests of increasing the tightening of the dough (tension) in contact with the plane, as the driving factor in this case is the adhesion force (condition (7)).

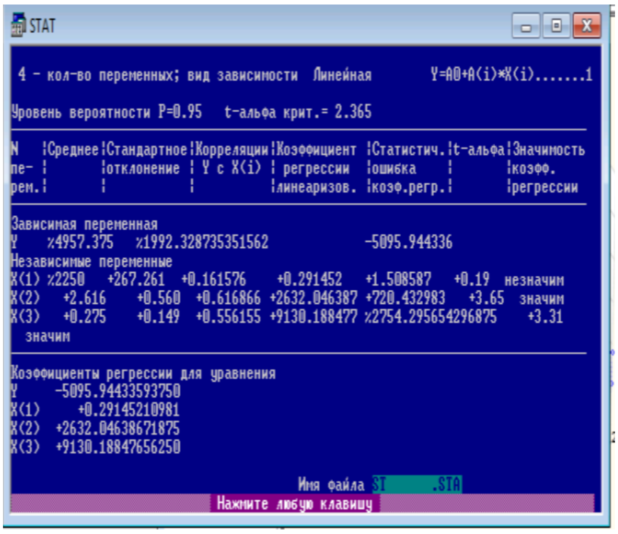

Figure 5 Statistical evaluation.

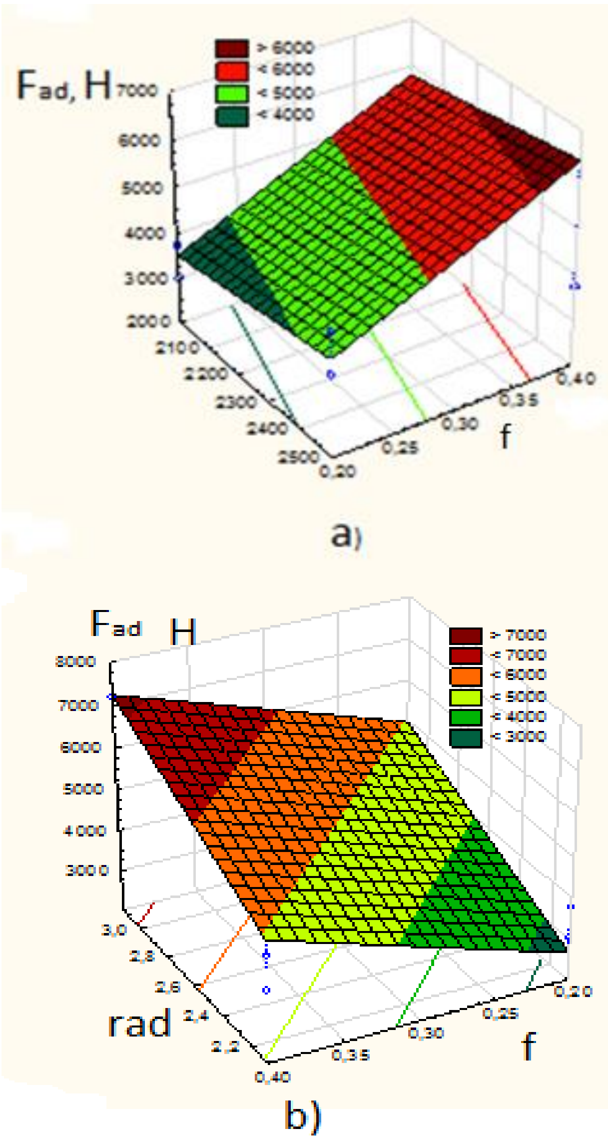

Figure 6 Dependency response graphs. Note: a) y from x_1 and x_2; b) y from x_2 and x_3.

CONCLUSION

The modern theoretical basis for the synthesis of technological machines on the basis of the interaction of working bodies with the environment combines the possibility of considering technological, economic requirements, indicators of high productivity, energy savings, restrictions of dynamic loads, etc. The achievement of the combination of these requirements is largely due to the use of adhesion bonds directly between the working bodies of technological machines and in the production lines. In systems of displacement of a viscous medium (dough) the use of friction working bodies prevails. Energy costs in the displacement systems of the test are related to the work of the driving forces against adhesion and friction and to the creation of flows of kinetic energy of the moving masses. On the basis of the analysis of the peculiarities of the construction of molding machines, mathematical formalization of transient adhesion bonding processes with the achievement of influential modes consisting of two effects on the basis of non-overlapping stages of acceleration of working bodies and in connection with the transfer of forces of inertia to the role of driving forces was proposed.

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